MONITORING AND EVALUATION OF THE CHELAN AND GRANT COUNTY PUDs HATCHERY PROGRAMS

2016 ANNUAL REPORT

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TABLE OF CONTENTS

LIST OF APPENDICES

PREFACE

This annual report is the result of coordinated field efforts conducted by Washington Department of Fish and Wildlife (WDFW), the Confederated Tribes and Bands of the Yakama Nation (Yakama Nation), Chelan County Public Utility District (Chelan PUD), the Confederated Tribes of the Colville Reservation (Colville Tribes), the U.S. Fish and Wildlife Service (USFWS), and BioAnalysts, Inc. An extensive amount of work was conducted in 2006 through 2016 to collect the data needed to monitor the effects of the Chelan and Grant County PUD Hatchery Programs. This work was directed and coordinated by the Habitat Conservation Plans (HCP) Hatchery Committees, consisting of the following members: Bill Gale and Matt Cooper, USFWS; Justin Yeager and Craig Busach, National Marine Fisheries Service (NMFS); Catherine Willard and Alene Underwood, Chelan PUD; Tom Scribner and Keely Murdoch, the Yakama Nation; Mike Tonseth, WDFW; Kirk Truscott, Colville Tribes; and Tracy Hillman, BioAnalysts (Chair). This report also includes monitoring efforts funded by Grant County Public Utility District (Grant PUD). Grant PUD helps fund the spring and summer Chinook monitoring programs. Work funded by Grant PUD was directed and coordinated by the Priest Rapids Coordinating Committee (PRCC) Hatchery Sub-Committee, which consists of the same agency and tribal representatives listed for the HCP Hatchery Committee and replaces Chelan PUD representatives with Grant PUD representatives, Todd Pearsons, Peter Graf, and Deanne Pavlik-Kunkel.

The approach to monitoring the hatchery programs was guided by the updated monitoring and evaluation plan for PUD hatchery programs (Hillman et al. 2013). Technical aspects of the updated monitoring and evaluation program were developed by the Hatchery Evaluation Technical Team (HETT), which consisted of the following scientists: Matt Cooper, USFWS; Tracy Hillman, BioAnalysts; Tom Kahler, Douglas PUD; Greg Mackey, Douglas PUD; Andrew Murdoch, WDFW; Keely Murdoch, Yakama Nation; Todd Pearsons, Grant PUD; Mike Tonseth, WDFW; and Catherine Willard, Chelan PUD. The updated plan also directs the analyses of hypotheses developed by the HETT. Most of the analyses outlined in the updated plan will be conducted in the comprehensive reports.

Most of the work reported in this document was funded by Chelan and Grant PUDs. Bonneville Power Administration purchased some of the Passive Integrated Transponder (PIT) tags that were used to mark juvenile Chinook and steelhead captured in tributaries and also helped fund a portion of the screw trap efforts in Nason Creek. We thank Charlie Paulsen for analyzing PIT-tag data for each program. This is the 11th annual report written under the direction of the HCP.

"I often say that when you can measure something and express it in numbers, you know something about it. When you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of science, whatever it may be."

Lord Kelvin

SECTION 1: INTRODUCTION

Chelan and Grant PUDs implement hatchery programs as part of their respective agreements related to the operation of Rocky Reach, Rock Island, Wanapum, and Priest Rapids Hydroelectric Projects. The fish resource management agencies developed the following general goal statements for the hatchery programs, which were adopted by the HCP Hatchery Committees and PRCC Hatchery Sub-Committee (hereafter, Hatchery Committees):

1. *Support the recovery of ESA-listed species by increasing the abundance of the natural adult population, while ensuring appropriate spatial distribution, genetic stock integrity, and adult spawner productivity.*

   Includes the Wenatchee spring Chinook, Wenatchee summer steelhead, and Methow spring Chinook programs.

2. *Increase the abundance of the natural adult population of unlisted plan species, while ensuring appropriate spatial distribution, genetic stock integrity, and adult spawner productivity. In addition, provide harvest opportunities in years when spawning escapement is sufficient to support harvest.*

   Includes the Wenatchee sockeye, Wenatchee summer/fall Chinook, Methow summer/fall Chinook, Okanogan summer/fall Chinook, and Okanogan sockeye programs.

3. *Provide salmon for harvest and increase harvest opportunities, while segregating returning adults from natural tributary spawning populations.*

   Includes the Chelan Falls summer Chinook program.

Following the development of the Hatchery and Genetic Management Plans (HGMPs), artificial propagation programs are now characterized into three categories. The first type, integrated conservation programs, are intended to support or restore natural populations. These programs focus on increasing the natural production of targeted fish populations. A fundamental assumption of this strategy is that adults spawned in the hatchery will produce more adult offspring than if they were left to spawn in the river and ultimately provide a demographic boost to the natural population. The second type, safety-net programs, are extensions of conservation programs, but are intended to function as reserve capacity for conservation programs in years of low returns. The safety-net provides a demographic and genetic reserve for the natural population. That is, in years of abundant returns, they function like segregated programs, and in years of low returns, they can be managed as conservation programs. Lastly, harvest augmentation programs are intended to increase harvest opportunities while limiting interactions with wild-origin counterparts.

Monitoring is needed to determine if the hatchery programs are meeting the intended management objectives of conservation, safety-net, or harvest augmentation programs. Objectives for hatchery programs are generally grouped into three categories of performance indicators:

1. In-Hatchery Indicators: Are the programs meeting the hatchery production objectives?

2. In-Nature Indicators: How do hatchery fish from the programs perform after release?

a. Conservation Programs:
   - How do the programs affect target population abundance and productivity?
   - How do the programs affect target population long-term fitness?

b. Safety-Net Programs:
   - How do the programs affect target population long-term fitness?

c. Harvest Augmentation Programs:
   - Do the programs provide harvest opportunities?

3. Risk Assessment Indicators: Do the programs pose risks to other populations?

The specific objectives identified in the updated monitoring and evaluation plan are as follows:

1. *Determine if conservation programs have increased the number of naturally spawning and naturally produced adults of the target population and if the program has reduced the natural replacement rate (NRR) of the supplemented population.*
2. *Determine if the proportion of hatchery fish on the spawning grounds affects the freshwater productivity of supplemented stocks.*
3. *Determine if the hatchery adult-to-adult survival (i.e., hatchery replacement rate, HRR) is greater than the natural adult-to-adult survival (i.e., natural replacement rate, NRR) and the target hatchery survival rate.*
4. *Determine if the proportion of hatchery-origin spawners (pHOS or PNI) is meeting management target.*
5. *Determine if the run timing, spawn timing, and spawning distribution of both the hatchery component is similar to the natural component of the target population or is meeting program-specific objectives.*
6. *Determine if stray rate of hatchery fish is below the acceptable levels to maintain genetic variation among stocks.*
7. *Determine if genetic diversity, population structure, and effective population size have changed in natural spawning populations as a result of the hatchery program.*
8. *Determine if hatchery programs have caused changes in phenotypic characteristics of natural populations.*
9. *Determine if hatchery fish were released at the programmed size and number.*
10. *Determine if appropriate harvest rates have been applied to conservation, safety-net, and segregated harvest programs to meet the HCP/SSSA goal of providing harvest opportunities while also contributing to population management and minimizing risk to natural populations*

Two additional regional objectives that were not explicit in the goals specified above but were included in the updated monitoring and evaluation plan because they relate to goals and concerns of all artificial production programs include:

11. *Determine if the incidence of disease has increased in the natural and hatchery populations.*
12. *Determine if the release of hatchery fish affects non-target taxa of concern (NTTOC) within acceptable limits.*

Objective 12 was completed using an extensive risk assessment that concluded risks from the PUD hatchery programs were within containment objectives approved by the Hatchery Committees (Mackey et al. 2014; Pearsons et al. 2012).

Objectives in the updated plan have been organized in a hierarchy where productivity indicators are the primary metrics used to assess if conservation and safety-net program goals have been met; harvest rates and effects on non-targeted populations are used for harvest programs. In cases where productivity indicators are not available, or results are equivocal, monitoring indicators may be used to help evaluate the performance of the program. Evaluations of monitoring indicators may not provide sufficiently powerful conclusions on which to base management actions; although they may provide insight as to why a productivity indicator did or did not meet the program goal. Therefore, the relationship between hatchery programs and indicators can be viewed in a chain-of-causation: management actions within the hatchery programs affect the status of monitoring indicators, which in turn influence productivity indicators (Figure 1.1).

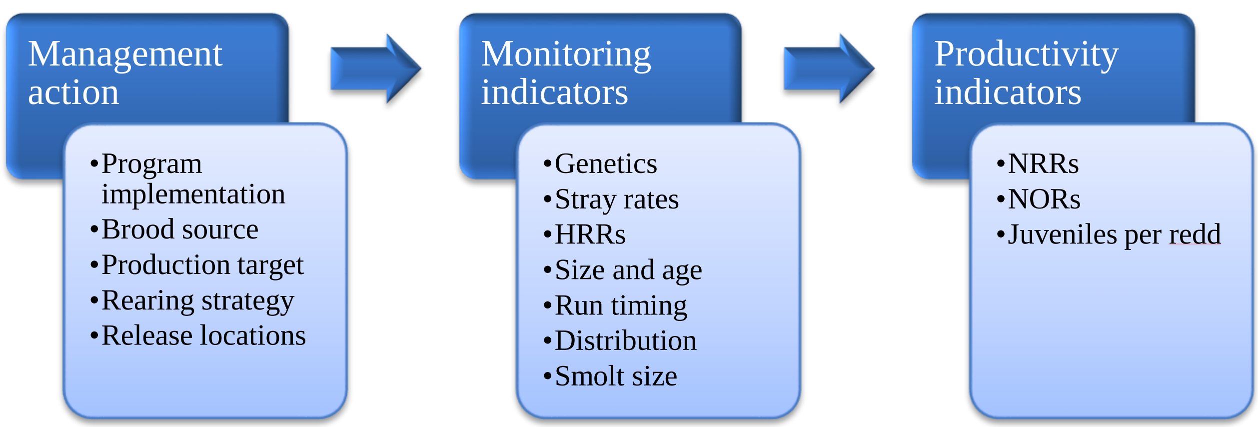

Figure 1.1. Relationship of indicators to the assessment of propagation programs. Management actions affect monitoring indicators, which influence productivity indicators. Monitoring indicators may be used to hypothesize the magnitude of influence on productivity.

Attending each objective is one or more testable hypotheses (see Hillman et al. 2013). Each hypothesis will be tested statistically following the routines identified in the updated monitoring and evaluation plan. Most of these analytical routines will be conducted at the end of five-year monitoring blocks, as outlined in the updated plan.

Both monitoring and productivity indicators will be used to evaluate the success of the hatchery programs. If the statistical power of tests that involve productivity indicators is insufficient to inform sound management decisions, some of the monitoring indicators may be used to guide management. Figure 1.2 shows the categories of indicators associated with each component of monitoring.

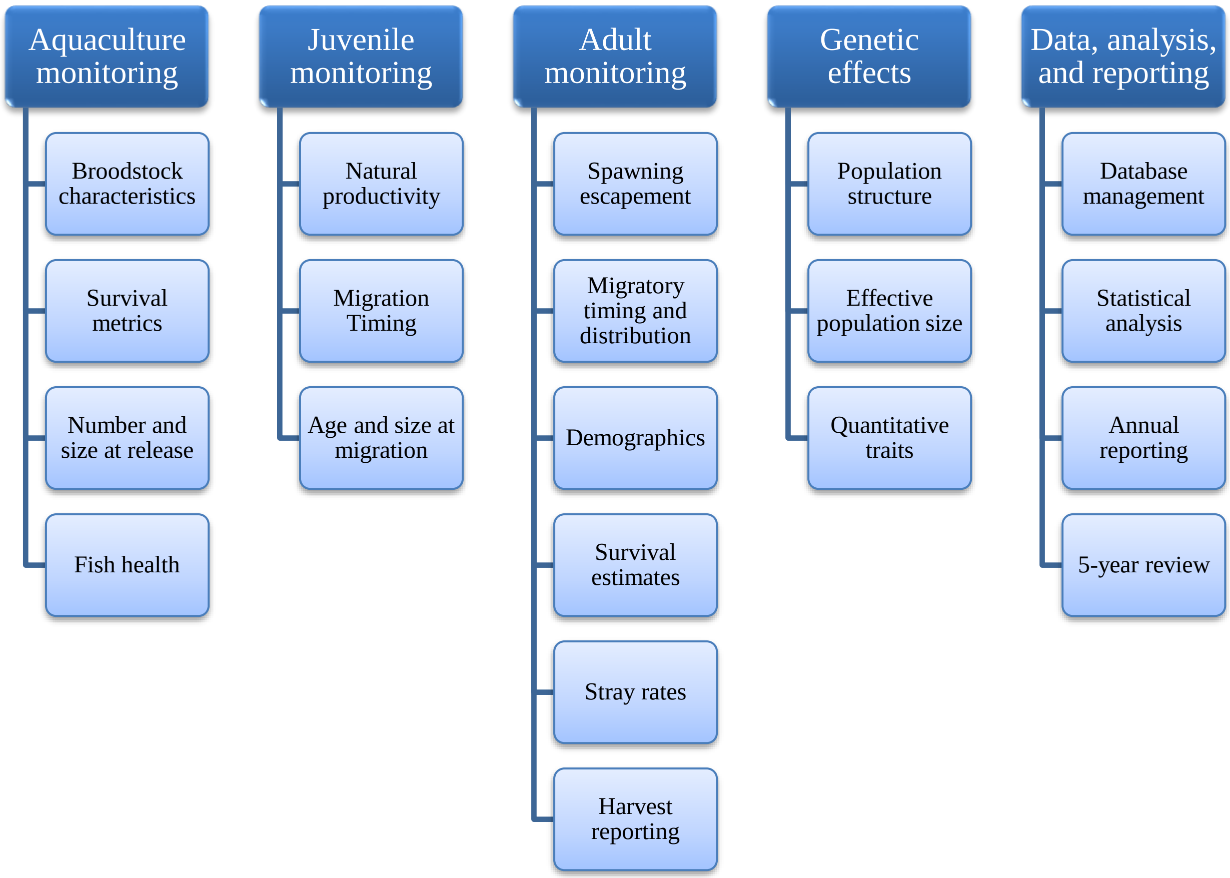

Figure 1.2. Overview of monitoring and evaluation plan categories and components (not including regional objectives).

Throughout each five-year monitoring period, annual reports will be generated that describe the monitoring and evaluation data collected during a specific year. This is the 11th annual report developed under the direction of the Hatchery Committees. The purpose of this report is to describe monitoring activities conducted in 2016. Activities included broodstock collection, collection of life-history information, within hatchery spawning and rearing activities, juvenile monitoring within streams, and redd and carcass surveys. Data from reference areas are not included in this annual report (reference data are in the five-year reports). To the extent currently possible, we have included information collected before 2016.

This report is divided into several sections, each representing a different species, stock, or spawning aggregate (i.e., steelhead, sockeye salmon, spring Chinook salmon, and summer Chinook salmon). For all species, we provide annual broodstock information; hatchery rearing history, release data, and survival estimates; disease information; juvenile migration and productivity estimates; redd counts, distribution, and spawn timing; spawning escapements; and life-history characteristics. For salmon species, we also provide information on carcasses. Brood year 2011 was the final sockeye salmon hatchery release, and beginning in 2013, only natural adult and juvenile sockeye productivity monitoring results are reported. Beginning in 2013, we added a separate section on Nason Creek spring Chinook salmon and in 2014 we added a separate section on White River spring Chinook salmon. The Colville Tribes began conducting monitoring of

Okanogan summer Chinook in 2013; however, we retained the Okanogan summer Chinook section in this report because the PUDs have summer Chinook mitigation obligations in the Okanogan River basin. The Okanogan summer Chinook section includes monitoring information up to the return of brood year 2013 Chinook. Monitoring results for brood years 2013 to present can be found in annual reports prepared by the Colville Tribes to Bonneville Power Administration (BPA). Monitoring results of Grant PUD's fall Chinook salmon mitigation produced at Priest Rapids Hatchery can be found in annual reports written by WDFW and Grant PUD.

Finally, we end each section by addressing compliance issues with ESA/HCP mandates. For each Hatchery Program, WDFW and the PUDs are authorized annual take of ESA-listed spring Chinook and steelhead through Section 10 of the Endangered Species Act (ESA), including:

1. ESA Section 10(a)(1)(A) Permit No. 1395, which authorizes the annual take of adult and juvenile endangered upper Columbia River (UCR) spring Chinook and endangered UCR steelhead associated with implementing artificial propagation programs for the enhancement of UCR steelhead. The authorization includes takes associated with adult broodstock collection, hatchery operations, juvenile fish releases, monitoring and evaluation activities, and management of adult returns related to UCR steelhead artificial propagation programs in the UCR region (NMFS 2003a).
2. ESA Section 10(a)(1)(A) Amended Permit No. 18121, which authorizes the annual take of adult and juvenile endangered UCR spring Chinook and endangered UCR steelhead associated with implementing artificial propagation programs in the Chiwawa River for the enhancement of UCR spring Chinook. The authorization includes takes associated with adult broodstock collection, hatchery operations, juvenile fish releases, and monitoring and evaluation activities supporting UCR spring Chinook artificial propagation programs in the UCR region (NMFS 2003, amended in 2015).
3. ESA Section 10(a)(1)(A) Permit No. 18118, which authorizes the annual take of adult and juvenile endangered UCR spring Chinook and endangered UCR steelhead associated with implementing artificial propagation programs in Nason Creek for the enhancement of UCR spring Chinook. The authorization includes takes associated with adult broodstock collection, hatchery operations, juvenile fish releases, and monitoring and evaluation activities supporting UCR spring Chinook artificial propagation programs in the UCR region (NMFS 2003, amended in 2015).
4. ESA Section 10(a)(1)(A) Permit No. 18119, which authorizes the annual take of adult and juvenile endangered UCR spring Chinook and endangered UCR steelhead associated with implementing artificial propagation programs in the White River for the enhancement of UCR spring Chinook. The authorization includes takes associated with adult broodstock collection, hatchery operations, juvenile fish releases, and monitoring and evaluation activities supporting UCR spring Chinook artificial propagation programs in the UCR region (NMFS 2003, amended in 2015).
5. ESA Section 10(a)(1)(A) Permit No. 1347, which authorizes the annual incidental take of adult and juvenile endangered UCR spring Chinook and endangered UCR steelhead through actions associated with implementing artificial propagation programs for the enhancement of non-listed anadromous fish populations in the UCR. The authorization includes incidental takes associated with adult broodstock collection, hatchery operations, juvenile fish releases, and monitoring and evaluation activities associated with non-listed

summer Chinook, fall Chinook, and sockeye salmon artificial propagation programs in the UCR region (NMFS 2003b).

SECTION 2: SUMMARY OF METHODS

Sampling in 2016 followed the methods and protocols described in Hillman et al. (2013). In this section, we only briefly review the methods and protocols. More detailed information can be found in the updated monitoring and evaluation plan (Hillman et al. 2013).

2.1 Broodstock Collection and Sampling

Methods for collecting broodstock are described in the Annual Broodstock Collection Protocols (WDFW 2016). Generally, broodstock were collected over the migration period (to the extent allowed in ESA-permit provisions) in proportion to their temporal occurrence at collection sites, with in-season adjustments dictated by 2016 run timing and trapping success relative to achieving weekly and annual collection objectives. Pre-season weekly collection objectives are shown in Table 2.1 and assumptions associated with broodstock trapping are provided in Table 2.2.

Table 2.1. Weekly collection objectives for steelhead and Chinook in 2016.

Collection week beginning day	Chiwawa/Nason Spring Chinook[a]		Hatchery Chelan Falls Summer Chinook	Wild Wenatchee Summer Chinook	Wild Methow Summer Chinook	Wenatchee Steelhead	
	Hatchery	Wild				Hatchery	Wild
30 May	6	4					
6 June	10	8					
13 June	16	12					
20 June	24	18					
27 June	24	20		70	12		
4 Jul	20	12	90	46	20	1	1
11 Jul	8	4	80	26	22	1	2
18 Jul			70	36	18	2	3
25 Jul			50	28	10	3	3
1 Aug			40	26	6	3	3
8 Aug			20	20	4	4	4
15 Aug				18	4	4	5
22 Aug					4	4	5
29 Aug					2	6	4
5 Sep					2	7	6
12 Sep					2	7	8
19 Sep						8	8
26 Sep						8	6
3 Oct						8	4
10 Oct						2	2
17 Oct						1	2
24 Oct						1	2
Total	**108**	**150**	**350**	**270**	**106**	**70**	68

[a] Chiwawa NOR spring Chinook (n = up to 80) were collected from the Chiwawa Weir with no specific weekly objectives generated, which is consistent with the Broodstock Collection Protocols. Previously PIT-tagged Chiwawa NOR spring Chinook were also targeted at Tumwater Dam. All Nason Creek spring Chinook were collected at Tumwater Dam from the week of 30 May

through the week of 11 July proportionate to run timing. For 2016, HOR Chiwawa spring Chinook were collected for the Nason spring Chinook safety net program.

Table 2.2. Biological and trapping assumptions associated with collecting broodstock for the Chelan and Grant PUD Hatchery Programs, 2016.[1]

Assumptions	Wenatchee Steelhead	Chiwawa Spring Chinook	Nason Spring Chinook		Wenatchee Summer Chinook	Chelan Falls Summer Chinook	Methow Summer Chinook
			Conservation Program	Safety Net Program			
Production level	247,300 yearling smolts	144,026 yearling smolts	125,000 yearling smolts	98,670 yearling smolts	500,001 yearling smolts	576,000 yearling smolts	200,000 yearling smolts
Broodstock required	138 adults (not to exceed 33% of population)	80 adults (not to exceed 33% of NOR population)	70 adults (not to exceed 33% of population)	72 adults	270 adults (not to exceed 33% of the population)	350 adults	106 adults (not to exceed 33% of the population)
Trapping period	1 July-14 Nov	1 June – 15 July (Tumwater) 13 June-31 July (Chiwawa Weir)	1 June – 15 July	1 June – 15 July	27 June – 15 Sept (Dryden) 15 July- 15 Sept (Tumwater)	1 July – 15 Sep	1 July – 15 Sept
# days/week	5	7 (Tumwater) Not to exceed 15 cumulative trapping days (Chiwawa Weir)	7	7	5 (Dryden) 2 (Tumwater)	7	3
# hours/day	24	24 (Tumwater) 24 up/24 down (Chiwawa Weir)	24	24	24	24	16
Broodstock composition	50% WxW; 50% HxH	100% WxW	100% WxW	100% HxH	100% WxW	100% HxH	100% WxW
Trapping site	Dryden Dam for HxH; Tumwater for WxW. (Tumwater will be used if weekly quota not achieved for WxW (hatchery) at Dryden Dam)	Tumwater Dam and Chiwawa Weir	Tumwater Dam	Tumwater Dam	Dryden Dam (Tumwater will be used if weekly quota not achieved at Dryden Dam)	Chelan River Water Conveyance Canal Trap	Wells Dam east or west ladder

Several biological parameters were measured during broodstock collection at adult collection sites. Those parameters included the date and start and stop time of trapping; number of each species

[1] Throughout this document, "HxH" refers to hatchery-origin by hatchery-origin crosses and "WxW" refers to natural-origin by natural-origin crosses.

collected for broodstock; origin, size, and sex of trapped fish; age from scale analysis; and pre-spawn mortality. For each species, trap efficiency, extraction rate, and trap operation effectiveness were estimated following procedures in Hillman et al. (2013). In addition, a representative sample of most species trapped but not taken for broodstock were sampled for origin, sex, age, and size (stock assessment).

2.2 Within Hatchery Monitoring

Methods for monitoring hatchery activities are described in Hillman et al. (2013). Biological information collected from all spawned adult fish included age at maturity, length at maturity, spawn time, and fecundity of females. In addition, all fish were checked for tags and females were sampled for pathogens.

Throughout the rearing period in the hatchery, fish were sampled for growth, health, and survival. Each month, lengths and weights were collected from a sample of fish and rearing density indices were calculated. In addition, fish were examined monthly for health problems following standard fish health monitoring practices for hatcheries. Various life-stage survivals were estimated for each hatchery stock. These estimates were then compared to the "standard" survival rates identified in Table 2.3 to provide insight as to how well the hatchery operations were performing. Failure to achieve a survival standard could indicate a problem with some part of the hatchery program. However, failure to meet a standard may not be indicative of the overall success of the program to meet the goals identified in Section 1.

Table 2.3. Standard life-stage survival rates for fish reared within the Chelan PUD hatchery programs (from Hillman et al. 2013).

Life stage	Standard survival rate (%)
Collection-to-spawning (females)	90
Collection-to-spawning (males)	85
Unfertilized egg-to-eyed	92
Unfertilized egg-to-ponding	98
30 d after ponding	97
100 d after ponding	93
Ponding-to-release	90
Transport-to-release	95
Unfertilized egg-to-release	81

Nearly all hatchery fish from each stock were marked (adipose fin clip) or tagged (coded-wire tag) in 2016. Different combinations of marks and tags were used depending on the stock. In addition, Chelan PUD personnel PIT tagged 10,207 juvenile WxW Chiwawa spring Chinook and 10,104 juvenile Nason Creek spring Chinook (5,052 WxW and 5,050 HxH); 5,050 Wenatchee WxW steelhead (Circular Ponds), 12,626 Wenatchee WxW and HxH steelhead (Raceway), and 2,525 Wenatchee steelhead (Blackbird Pond); and 10,103 Chelan River summer Chinook, 5,064 Methow (Carlton) summer Chinook, and 20,994 Wenatchee summer Chinook (10,565 Raceway and 10,429 Circular Ponds). PIT tags will be used to estimate migration timing and survival rates (e.g., smolt-to-adult) outside the hatchery.

Lastly, the size and number of fish released were assessed and compared to programmed production levels. The goal of the program is that numbers released and their sizes should fall within 10% of the programmed targets identified in Table 2.4. However, because of constraints due to run size and proportions of wild and hatchery adults, production levels may not be met every year.

Table 2.4. Targets for fish released from the PUD hatchery programs; CV = coefficient of variation.

Hatchery stock	Release targets	Size targets		
		Fork length (CV)	Weight (g)	Fish/pound
Wenatchee Summer Chinook	500,001	163 (9.0)	45.4	18[a]
Methow Summer Chinook	200,000	163 (9.0)	45.4	13-17
Chelan Falls Summer Chinook (yearlings)	576,000	161 (9.0)	45.4	13[b]
Chiwawa Spring Chinook	144,026	155 (9.0)	37.8	18
Nason Spring Chinook	223,670	155 (9.0)	37.8	18
Wenatchee Steelhead	247,300	191 (9.0)	75.6	6

[a] An experimental release size of 30-45 grams (10-15 FPP) was in place for brood years 2012-2014.
[b] An experimental release size of 20-45 grams (10-22 FPP) was in place for brood years 2012-2014.

2.3 Juvenile Sampling

Juvenile sampling within streams included operation of rotary screw traps, snorkel observations, and PIT tagging. Methods for sampling juvenile fish are described in Hillman et al. (2013).

A smolt trap was located on the Wenatchee River near the town of Cashmere at RM 8.3 (Lower Wenatchee Trap), in Nason Creek about 0.6 miles upstream from the mouth, in the White River about 5.8 miles upstream from the mouth, and in the Chiwawa River about 0.4 miles upstream from the mouth (Chiwawa Trap). All traps operated throughout the smolt migration period. The Chiwawa Trap operated between 2 March and 21 November 2016. The Nason Creek Trap operated from 1 March to 30 November in 2016. The White River trap operated from 1 March through 30 November 2016. The Lower Wenatchee Trap operated between 29 January and 26 June 2016. Throughout the trapping period, the traps were briefly inoperable during periods when flows were too high or low, during high water temperatures, during large hatchery releases, and because of heavy debris loads, ice, and mechanical malfunctions.

The following data were collected at each trap site: water temperature, discharge, number and identification of all species captured, degree of smoltification for anadromous fish, presence of marks and tags, size (fork lengths and weights), and scales from smolts. Trap efficiencies at each trap site were estimated by using mark-recapture trials conducted over a wide range of discharges. Linear regression models relating discharge and trap efficiencies were developed to estimate daily trap efficiencies during periods when no mark-recapture trials were conducted. The total number of fish migrating past the trap each day was estimated as the quotient of the daily number of fish captured and the estimated daily trap efficiency. Summing the daily totals resulted in the total emigration estimate.

Snorkel observations were used to estimate the number of juvenile spring Chinook salmon, juvenile rainbow/steelhead, and bull trout within the Chiwawa River basin. The focus of the study was on juvenile spring Chinook salmon. Sampling followed a stratified random design with proportional allocation of sites among strata. Strata were identified based on unique combinations of geology, land type, valley bottom type, stream state condition, and habitat types. A total of 187 randomly selected sites were surveyed during August (Table 2.5). Counts of fish within each sampling site were adjusted based on detection efficiencies, which were related to water temperature. That is, non-linear models that described relationships between water temperatures and detection efficiencies (Hillman et al. 1992) were used to estimate total numbers of fish within sampling sites. These numbers were then converted to densities by dividing total fish numbers by the wetted surface area and water volume of sample sites. Total numbers within a stratum were estimated as the product of fish densities times the total wetted surface or water volume for the stratum. The sum of fish numbers across strata resulted in the total number of fish within the basin. The calculation of total numbers, densities, and degrees of certainty are explained fully in Hillman and Miller (2004).

Table 2.5. Location of strata and numbers of randomly sampled snorkel sites within each stratum that were sampled in the Chiwawa River Basin in 2016.

Reach/stratum	River miles (RM)	Number of randomly selected sites
Chiwawa River		
1	0.0-3.8	11
2	3.8-5.5	5
3	5.5-7.9	8
4	7.9-8.9	6
5	8.9-10.8	5
6	10.8-11.8	6
7	11.8-20.0	29
8	20.0-25.4	24
9	25.4-28.8	11
10	28.8-31.1	21
Phelps Creek		
1	0.0-0.4	1
Chikamin Creek (includes Minnow Creek)		
1	0.0-1.5	12
Rock Creek		
1	0.0-0.7	9
Unnamed stream on USGS map		
1	0.0-0.1	1
Big Meadow Creek		
1	0.0-1.0	13
Alder Creek		
1	0.0-0.1	4
Brush Creek		
1	0.0-0.1	2
Clear Creek		

Reach/stratum	River miles (RM)	Number of randomly selected sites
1	0.0-0.1	2

Working in collaboration with the Comparative Survival Study (CSS) funded by BPA, crews PIT tagged juvenile wild Chinook, wild steelhead, wild sockeye, and in some instances wild coho salmon collected at the smolt traps and collected within the Chiwawa River and Nason Creek using electrofishing techniques. The proposed number of wild spring Chinook and steelhead to be tagged at each location is provided in Table 2.6. The goal of this tagging program is to estimate freshwater juvenile productivity, better understand life-history characteristics, overwinter movement, and survival of salmonids, and to calculate SARs for spring Chinook salmon in the Wenatchee River basin. The PIT tagging effort funded by the PUDs in the Chiwawa River and Nason Creek is specifically directed at addressing uncertainties of estimating abundance using screw traps (e.g., fish passage during times when trapping is not possible).

Table 2.6. Number of wild spring Chinook, steelhead (≥65 mm), and sockeye proposed for PIT tagging at different locations within the Wenatchee River basin, 2016. NT = no sample size target.

Sampling location	Target sample size		
	Wild spring Chinook	Wild steelhead	Wild Sockeye
Chiwawa Trap	2,500-8,000	500-2,000	NT
Nason Creek Trap	2,500-8,000	500-2,000	NT
White River Trap	200-500	NT	NT
Lower Wenatchee Trap	1,000-2,500	50-250	3,000-5,000
Chiwawa Remote Sampling	3,000	NT	NT
Nason Remote Sampling	3,000	NT	NT

Survival rates for various juvenile life-stages were calculated based on estimates of seeding levels (total egg deposition), parr abundance, numbers of emigrants, and smolt abundance. Total egg deposition was estimated as the product of the number of redds counted in the basin times the mean fecundity of female spawners. Fecundity was estimated from females collected for broodstock using an electronic egg counter. Numbers of emigrants and smolts were estimated at trapping sites and numbers of parr were estimated using snorkel observations only in the Chiwawa River basin. Survival estimates could not be calculated for some stocks (e.g., summer Chinook) because specific life-stage abundance estimates were lacking.

2.4 Spawning/Carcass Surveys

Methods for conducting carcass and spawning ground surveys are detailed in Hillman et al. (2013). Information collected during spawning surveys included spawn time, redd distribution, and redd abundance. Data collected during carcass surveys included sex, size (fork length and postorbital-to-hypural length), scales for aging[2], degree of egg voidance, DNA samples, and identification of marks or tags. The sampling goal for carcasses was 20% of the spawning population.

[2] In this report, we use two methods of describing age. One is termed the "European Method." This method has two digits, separated by a period. The first digit represents the number of winters the fish spent in freshwater before migrating to the sea. The second digit indicates the number of winters the fish spent in the ocean. For example, a fish designated as 1.2 spent one winter in freshwater and two in the ocean. A fish designated as 0.3 migrated to the ocean

Steelhead surveys were conducted throughout the mainstem Wenatchee River and downstream from PIT-tag interrogation systems on the Chiwawa River, Nason Creek, and Peshastin Creek. These surveys were conducted during March through June in reaches and index areas described in Table 2.7. Total redd counts in these reaches were estimated by expanding counts within non-index areas by expansion factors developed within index areas.

Table 2.7. Description of reaches and index areas surveyed for steelhead redds in the Wenatchee River basin.

Stream	Code	Reach*	Index/reference area
Wenatchee River	W1	Mouth to Sleepy Hollow Br	River Bend to Sleepy Hollow Br
	W2	Sleepy Hollow Br to L. Cashmere Br	Sleepy Hollow Br to Cashmere Boat Rmp
	W3	L. Cashmere Br to Dryden Dam	Williams Canyon to Dryden Dam
	W5	Peshastin Br to Leavenworth Br	Irrigation Flume to Leavenworth Br
	W6	Leavenworth Br to Icicle Rd Br	Leavenworth Boat Ramp to Icicle Ck
	W7	Icicle Rd Br to Tumwater Dam	Icicle Br to Penstock Br
	W8	Tumwater Dam to Tumwater Br	Island below Swiftwater to Swiftwater CG
	W9	Tumwater Br to Chiwawa R	Tumwater Br to Plain
	W10	Chiwawa R to Lk Wenatchee	Chiwawa Pump St. to Lk Wenatchee
Peshastin Creek	P1	Mouth to PIT Detection Site	Mouth to PIT Detection Site
Chiwawa River	C1	Mouth to Rd 62 Br RM 6.4	Mouth to PIT Detection Site
Nason Creek	N1	Mouth to PIT Detection Site	Mouth to PIT Detection Site

* Reaches 2, 6, 8, 9, and 10 (major spawning areas) are surveyed weekly, while Reaches 1, 3, 5, and 7 (minor survey areas) are surveyed during peak spawning.

Beginning in 2014, adult steelhead escapement estimates in the majority of tributaries in the Wenatchee River basin were generated using mark-recapture techniques based on steelhead PIT tagged at Priest Rapids Dam. Mark-recapture estimates in the tributaries were then added to the estimates based on redd surveys to generate a total spawning escapement to the Wenatchee River basin.

Spring Chinook redd and carcass surveys were conducted during August through September in the Chiwawa River (including Rock and Chikamin creeks), Nason Creek, Icicle Creek, Peshastin Creek (including Ingalls Creek), upper Wenatchee River, Little Wenatchee River, and the White River (including the Napeequa River and Panther Creek). Survey reaches for spring Chinook are described in Table 2.8.

Table 2.8. Description of reaches surveyed for spring Chinook redds and carcasses in the Wenatchee River basin.

Stream	Code	Reach	River mile (RM)
Chiwawa River	C1	Mouth to Grouse Creek	0.0-11.7
	C2	Grouse Creek to Rock Creek	11.7-19.3
	C3	Rock Creek to Schaefer Creek	19.3-22.4

in its first year and spent three winters in the ocean. The other method describes the total age of the fish (egg-to-spawning adult, i.e., gravel-to-gravel), so fish demarcated as 0.3 or 1.2 are considered 4-year-olds, from the same brood.

Stream	Code	Reach	River mile (RM)
	C4	Schaefer Creek to Atkinson Flats	22.4-25.6
	C5	Atkinson Flats to Maple Creek	25.6-27.0
	C6	Maple Creek to Phelps Creek	27.0-30.3
	C7	Phelps Creek to Buck Creek	30.3-31.4
Rock Creek	R1	Mouth to Chiwawa River Road Bridge	0.0-0.5
Chikamin Creek	K1	Mouth to Chiwawa River Road Bridge	0.0-0.5
Nason Creek	N1	Mouth to Kahler Creek Bridge	0.0-3.9
	N2	Kahler Creek Bridge to Hwy 2 Bridge	3.9-8.3
	N3	Hwy 2 Bridge to Lower RR Bridge	8.3-13.2
	N4	Lower RR Bridge to Whitepine Creek	13.2-15.4
Little Wenatchee River	L1	Mouth to Old Fish Weir	0.0-2.7
	L2	Old Fish Weir to Lost Creek	2.7-5.2
	L3	Lost Creek to Rainy Creek	5.2-9.2
	L4	Rainy Creek to Falls	9.2-Falls
White River	H1	Mouth to Sears Creek Bridge	0.0-6.4
	H2	Sears Creek Bridge to Napeequa River	6.4-11.0
	H3	Napeequa River to Grasshopper Meadows	11.0-12.9
	H4	Grasshopper Meadows to Falls	12.9-16.1
Napeequa River	Q1	Mouth to Take Out	0.0-1.0
Panther Creek	T1	Mouth to Boulder Field	0.0-1.0
Wenatchee River	W8	Tumwater Dam to Tumwater Bridge	30.9-35.6
	W9	Tumwater Bridge to Chiwawa River	35.6-48.4
	W10	Chiwawa River to Lake Wenatchee	48.4-54.2
Chiwaukum Creek	U1	Mouth to Metal Bridge	0.0-1.0
Icicle Creek	I1	Mouth to Hatchery	0.0-2.8
	I2	Hatchery to Sleeping Lady	2.8-3.3
	I3	Sleeping Lady to Snow Creek	3.3-3.8
Peshastin Creek	P1	Mouth to Camas Creek	0.0-5.9
	P2	Camas Creek to Mouth of Scotty Creek	5.9-16.3
Ingalls Creek	D1	Mouth to Trailhead	0.0-1.0

The sockeye salmon hatchery program ended after the 2011 brood year. As a result, monitoring activities that focused on evaluating the effects of the supplementation program on the natural population switched to monitoring the abundance and productivity of the natural population (McElhaney et al. 2000). Thus, estimation of spawn time and carcass surveys were discontinued in 2014. Nevertheless, this report retains the results of carcass sampling during the period 1993-2013. Survey reaches in which carcasses and live fish (for area-under-the-curve estimates) were conducted are identified in Table 2.9.

From 2009-2013, mark-recapture methods were used to estimate sockeye spawning escapement within the White River, while area-under-the-curve (AUC) methods were used to estimate spawning escapement within the Little Wenatchee River. Beginning in 2014, mark-recapture methods were used to estimate the spawning escapement of sockeye in both the White River and Little Wenatchee watersheds.

Table 2.9. Description of reaches surveyed for sockeye salmon carcasses and live fish in the Wenatchee River basin during survey years 1993-2013.

Stream	Code	Reach	River mile (RM)
Little Wenatchee River	L1	Mouth to Old Fish Weir	0.0-2.7
	L2	Old Fish Weir to Lost Creek	2.7-5.2
	L3	Lost Creek to Rainy Creek	5.2-9.2
White River	H1	Mouth to Sears Creek Bridge	0.0-6.4
	H2	Sears Creek Bridge to Napeequa River	6.4-11.0
	H3	Napeequa River to Grasshopper Meadows	11.0-12.9
Napeequa River	Q1	Mouth to End	0.0-1.0

Wenatchee summer Chinook redd and carcass surveys were conducted from September through November throughout the entire mainstem Wenatchee River, which was divided into ten reaches (Table 2.10). Surveys were conducted weekly in all reaches. All redds were enumerated during weekly census counts.

Table 2.10. Description of reaches surveyed for summer Chinook redds in the Wenatchee River basin.

Code	Reach	River mile
W1	Mouth to Sleepy Hollow Br	0.0-3.3
W2	Sleepy Hollow Br to L. Cashmere Br	3.3-9.5
W3	L. Cashmere Br to Dryden Dam	9.5-17.8
W4	Dryden Dam to Peshastin Br	17.8-20.0
W5	Peshastin Br to Leavenworth Br	20.0-23.9
W6	Leavenworth Br to Icicle Rd Br	23.9-26.4
W7	Icicle Rd Br to Tumwater Dam	26.4-30.9
W8	Tumwater Dam to Tumwater Br	30.9-35.6
W9	Tumwater Br to Chiwawa River	35.6-47.9
W10	Chiwawa River to Lake Wenatchee	47.9-54.2

Summer Chinook redd and carcass surveys were also conducted in the Methow and Chelan rivers from September through November. Total (map) redd counts were conducted in these rivers. Table 2.11 describes the survey reaches on the Methow River. The Colville Tribes conducted summer Chinook redd and carcass surveys in the Okanogan River basin. Those results are reported in a separate report (annual report to BPA).

Table 2.11. Description of reaches surveyed for summer Chinook redds and carcasses on the Methow, Okanogan, and Similkameen rivers.

Stream	Code	Reach	River mile (RM)
Methow River	M1	Mouth to Methow Bridge	0.0-14.8
	M2	Methow Bridge to Carlton Bridge	14.8-27.2
	M3	Carlton Bridge to Twisp Bridge	27.2-39.6
	M4	Twisp Bridge to MVID	39.6-44.9
	M5	MVID to Winthrop Bridge	44.9-49.8
	M6	Winthrop Bridge to Hatchery Dam	49.8-51.6
Okanogan River	O1	Mouth to Mallot Bridge	0.0-16.9
	O2	Mallot Bridge to Okanogan Bridge	16.9-26.1
	O3	Okanogan Bridge to Omak Bridge	26.1-30.7
	O4	Omak Bridge to Riverside Bridge	30.7-40.7
	O5	Riverside Bridge to Tonasket Bridge	40.7-56.8
	O6	Tonasket Bridge to Zosel Dam	56.8-77.4
Similkameen River	S1	Driscoll Channel to Oroville Bridge	0.0-1.8
	S2	Oroville Bridge to Enloe Dam	1.8-5.7

For summer and spring Chinook, total spawning escapements for each population were estimated as the product of total number of redds times the ratio of fish per redd for a specific stock.[3] Fish per redd ratios were estimated as the ratio of males to females sampled at broodstock collection sites and monitoring sites (e.g., Leavenworth National Fish Hatchery, Dryden Dam, Tumwater Dam, Chiwawa Weir, etc.). For steelhead, spawning escapement was estimated with a combination of PIT-tag-based tributary and redd-based mainstem Wenatchee River estimates. Total spawning escapement for sockeye salmon in the Little Wenatchee and White River watersheds was estimated using mark-recapture methods. Adult sockeye were PIT tagged at Tumwater Dam and Bonneville Dam[4] and detected in the Little Wenatchee and White rivers with stationary PIT-tag interrogation systems.

Derived metrics calculated from carcass surveys, broodstock sampling, stock assessments, and harvest records included proportion of hatchery spawners, stray rates, age-at-maturity, length-at-age, smolt-to-adult survival (SAR), hatchery replacement rates (HRR), harvest rates, and natural replacement rates (NRR). The target HRRs (from Hillman et al. 2013) for different stocks raised in the PUD hatchery programs are provided in Table 2.12. Methods for calculating derived variables are described in Hillman et al. (2013) and in "White Papers" developed by the Hatchery Evaluation Technical Team (HETT) (see Appendices in Hillman et al. 2012). The abundance of hatchery and natural-origin Chinook salmon spawners was based upon the proportion of carcasses by origin that were collected on the spawning grounds.

[3] Expansion factor = (1 + (number of males/number of females)).

[4] Adult sockeye that were tagged at Bonneville Dam and detected at Tumwater Dam were included in the mark-recapture analyses.

Table 2.12. Hatchery replacement rate (HRR) targets for stocks raised in the PUD Hatchery Programs.

Program	Number of broodstock	Smolts released	HRR targets
Chiwawa Spring Chinook	74	144,026	6.7
Nason Creek Spring Chinook	66	125,000	6.7
Wenatchee Summer Chinook	278	500,001	5.7
Methow Summer Chinook	100	200,000	3.0
Wenatchee Steelhead	130	247,300	6.9

Derived data that rely on CWTs (e.g., HRR, SAR, stray rates, etc.) are five or more years behind release information because of the lag time for returning adult fish to enter the fishery and spawning grounds, and the processing of tags. Consequently, complete information on rates and ratios based on CWTs is generally only available for brood years before 2010.

SECTION 3: WENATCHEE STEELHEAD

The goal of summer steelhead supplementation in the Wenatchee Basin is to use artificial production to replace adult production lost because of mortality at Rock Island and Rocky Reach dams, as well as inundation compensation for Rocky Reach Dam, while not reducing the natural production or long-term fitness of steelhead in the basin. The Rock Island Fish Hatchery Complex began operation in 1989 under funding from Chelan PUD. The Complex operated originally through the Rock Island Settlement Agreement, but since 2004 has operated under the Rock Island and Rocky Reach Anadromous Fish Agreement and Habitat Conservation Plans.

Prior to 1998, steelhead eggs were received from Wells Hatchery (adult broodstock were collected at Wells Dam); fish were reared at Eastbank Fish Hatchery and then released into the Wenatchee River. Beginning in 1998, the program changed to collecting broodstock within the Wenatchee Basin. Currently, adult hatchery steelhead are collected from the run-at-large at the right and left-bank traps at Dryden Dam, and at Tumwater Dam if the weekly quotas cannot be achieved at Dryden Dam. Natural-origin (WxW) adult steelhead are collected from the run-at-large at Tumwater and Dryden dams if the weekly quotas cannot be achieved at Dryden Dam.

Before 2012, the goal was to collect up to 208 adult steelhead (50% natural-origin fish and 50% hatchery-origin fish) for the Wenatchee steelhead program. In 2011, the Hatchery Committees reevaluated the amount of hatchery compensation needed to achieve NNI. Based on that evaluation, the goal of the program was revised. The current goal (which began in 2012) is to collect 130 adult steelhead (64 natural-origin and 66 hatchery-origin fish) for a 247,300 smolt program, but the number of broodstock collected cannot exceed 33% of the natural Wenatchee steelhead population. Broodstock collection occurs from about 1 July through 15 November at Dryden and Tumwater dams, with trapping occurring up to 24 hours per day, five days a week. The intent of the current program is to target adults necessary to meet a 50% natural-origin, conservation-oriented program and a 50% hatchery-origin safety-net program.

Before the 2012 brood year, adult steelhead were held and spawned at Wells Fish Hatchery because of unsuitable adult holding temperatures at Eastbank Fish Hatchery. Beginning with the 2012 brood year, adult steelhead holding and spawning have occurred at Eastbank Fish Hatchery with the installation of a water chiller system. Before 2012, juvenile steelhead were reared at a combination of facilities including Eastbank, Chelan, Turtle Rock, Rocky Reach Annex, and Chiwawa facilities. Juvenile steelhead reared in these facilities were trucked to release locations on the Wenatchee River, Chiwawa River, and Nason Creek. A percentage of the fish have also been released volitionally from Blackbird Pond and Rolfing Pond. Beginning in the fall of 2012, the entire Wenatchee steelhead program overwinters at the Chiwawa Acclimation Facility. Some of these fish are transferred to short-term remote acclimation sites (e.g., Blackbird Pond and Rolfing Pond), while others are planted from trucks throughout the Wenatchee, Nason, and Chiwawa basins.

Before 2012, the production goal for the Wenatchee steelhead supplementation program was to release 400,000 yearling smolts into the Wenatchee Basin at six fish per pound. Since 2012, the revised production goal is to release 247,300 smolts (123,650 for conservation and 123,650 for safety net). Targets for fork length and weight are 191 mm (CV = 9.0) and 75.6 g, respectively; the target size at release is six fish per pound. Over 96% of these fish receive CWTs. In addition, since 2006, juvenile steelhead from different parental-cross groups (e.g., WxW, HxW, and HxH) have been PIT tagged annually. No HxW crosses have occurred since brood year 2009.

Beginning in 2010 and consistent with ESA Section 10(a)(1)(A) permit 1395, adult management activities have been conducted to remove excess hatchery-origin steelhead before they spawn in the natural environment. This is accomplished through removal at Tumwater Dam and/or through conservation fisheries. The objective of these activities is to achieve proportion of hatchery-origin spawners (pHOS) and Proportionate Natural Influence (PNI) goals for the Wenatchee steelhead program. Results of adult management activities are submitted to NOAA Fisheries in a separate annual report by 31 August of the year the adult management was concluded.

3.1 Broodstock Sampling

This section focuses on results from sampling 2015 and 2016 brood years of Wenatchee steelhead, which were collected at Dryden and Tumwater dams. The 2015 brood begins the tracking of the life cycle of steelhead released in 2016. The 2016 brood is included because juveniles from this brood are still maintained within the hatchery.

Origin of Broodstock

A total of 136 Wenatchee steelhead from the 2014 return (2015 brood) were collected at Dryden and Tumwater dams (Table 3.1). About 56% of these were natural-origin (adipose fin present and no CWT) fish and the remaining 44% were hatchery-origin (CWT and adipose fin present) adults. Origin was determined by analyzing scales and/or otoliths. The total number of steelhead spawned from the 2015 brood was 110 adults (52.7% natural-origin and 47.3% hatchery-origin).

A total of 132 steelhead were collected from the 2015 return (2016 brood) at Dryden and Tumwater dams; 67 (50.8%) natural-origin (adipose fin present and no CWT) and 66 (45.5%) hatchery-origin (CWT and adipose fin present) adults. A total of 132 steelhead were spawned; 50% were natural-origin fish and 50% were hatchery fish (Table 3.1). Origin was confirmed by sampling scales and/or otoliths.

Table 3.1. Numbers of wild and hatchery steelhead collected for broodstock, numbers that died before spawning, and numbers of steelhead spawned, 1998-2016. Unknown origin fish (i.e., undetermined by scale analysis, no elastomer, no CWT, no fin clips, and no additional hatchery marks) were considered naturally produced. Mortality includes fish killed at spawning and surplus broodstock.

Brood year	Wild steelhead					Hatchery steelhead					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
1998	35	0	0	35	0	43	4	2	37	0	72
1999	58	5	1	52	0	67	1	2	64	0	116
2000	39	2	1	36	0	101	9	12	60	20	96
2001	64	5	8	51	0	114	5	6	103	0	154
2002	99	0	1	96	2	113	1	0	64	48	160
2003	63	10	4	49	0	92	2	0	90	0	139
2004	85	3	0	75	7	132	1	0	61	70	136
2005	95	8	0	87	0	114	7	1	104	2	191
2006	101	5	0	93	3	98	0	0	69	29	162
2007	79	0	2	76	1	97	0	14	58	25	134
2008	104	0	3	77	22	107	0	28	54	25	131

Brood year	Wild steelhead					Hatchery steelhead					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
2009	101	2	0	86	13	107	1	4	73	29	159
2010	106	1	1	96	8	105	2	23	75	5	171
2011	104	8	1	91	4	104	13	2	70	0	161
Average[b]	***81***	***4***	***2***	***71***	***4***	***100***	***3***	***7***	***70***	***18***	***142***
Median	***95***	***3***	***1***	***77***	***2***	***105***	***2***	***2***	***67***	***13***	***147***
2012	63	3	0	59	1	66	0	1	65	0	124
2013	63	8	1	49	5	84	9	7	68	0	117
2014	65	0	1	64	0	70	0	2	68	0	132
2015	76	5	0	58	13	60	0	8	52	0	110
2016	67	0	1	66	0	66	0	0	66	0	132
Average[c]	***67***	***3***	***1***	***59***	***4***	***69***	***2***	***4***	***64***	***0***	***123***
Median	***65***	***3***	***1***	***59***	***1***	***66***	***0***	***2***	***66***	***0***	***124***

[a] Pre-spawn loss represents the number of fish that died during the holding period before spawning. Mortality is the number of fish that were surplused following spawning.
[b] This average and median represent the program before recalculation in 2011.
[c] This average and median represent the current program, which began in 2012.

Age/Length Data

Broodstock ages were determined from examination of scales and/or otoliths. For the 2015 brood year, natural-origin steelhead consisted primarily of 2-salt adults, while hatchery steelhead consisted almost equally of 1 and 2-salt adults (Table 3.2). For the 2016 brood year, natural and hatchery-origin steelhead consisted primarily of 2-salt adults (Table 3.2).

Table 3.2. Percent of hatchery and wild steelhead of different ages (saltwater ages) collected from broodstock, 1998-2016.

Brood year	Origin	Saltwater age		
		1	2	3
1998	Wild	39.4	60.6	0.0
	Hatchery	20.9	79.1	0.0
1999	Wild	50.0	48.3	1.7
	Hatchery	81.8	18.2	0.0
2000	Wild	56.4	43.6	0.0
	Hatchery	67.9	32.1	0.0
2001	Wild	51.7	48.3	0.0
	Hatchery	14.9	85.1	0.0
2002	Wild	55.6	44.4	0.0
	Hatchery	94.6	5.4	0.0
2003	Wild	13.1	85.3	1.6
	Hatchery	29.4	70.6	0.0
2004	Wild	94.8	5.2	0.0
	Hatchery	95.2	4.8	0.0
2005	Wild	22.1	77.9	0.0

Brood year	Origin	Saltwater age		
		1	2	3
	Hatchery	20.5	79.5	0.0
2006	Wild	28.7	71.3	0.0
	Hatchery	60.3	39.7	0.0
2007	Wild	40.3	59.3	0.0
	Hatchery	62.1	37.9	0.0
2008	Wild	65.4	33.7	0.9
	Hatchery	88.8	11.2	0.0
2009	Wild	39.8	57.8	2.4
	Hatchery	23.4	76.6	0.0
2010	Wild	65.2	33.7	1.1
	Hatchery	76.5	23.5	0.0
2011	Wild	27.5	72.5	0.0
	Hatchery	36.0	64.0	0.0
2012	Wild	42.4	52.5	5.1
	Hatchery	40.9	59.1	0.0
2013	Wild	40.7	57.4	1.9
	Hatchery	45.5	54.5	0.0
2014	Wild	47.5	50.8	1.6
	Hatchery	29.4	70.6	0.0
2015	Wild	15.9	82.5	1.6
	Hatchery	47.2	52.7	0.0
2016	Wild	33.8	66.2	0.0
	Hatchery	42.4	57.6	0.0
Average	***Wild***	***43.7***	***55.3***	***0.9***
	Hatchery	***51.5***	***48.5***	***0.0***
Median	***Wild***	***40.7***	***57.4***	***0.0***
	Hatchery	***45.5***	***54.5***	***0.0***

There was little difference between mean lengths of hatchery and natural-origin steelhead in the 2015 and 2016 brood years (Table 3.3). Natural-origin fish were on average 1 to 3 cm larger than hatchery-origin fish of the same age.

Table 3.3. Mean fork length (cm) at age (saltwater ages) of hatchery and wild steelhead collected from broodstock, 1998-2016; N = sample size and SD = 1 standard deviation.

Brood year	Origin	Steelhead fork length (cm)								
		1-Salt			2-Salt			3-Salt		
		Mean	N	SD	Mean	N	SD	Mean	N	SD
1998	Wild	63	15	4	79	20	5	-	0	-
	Hatchery	61	9	4	73	34	4	-	0	-

Brood year	Origin	Steelhead fork length (cm)								
		1-Salt			2-Salt			3-Salt		
		Mean	N	SD	Mean	N	SD	Mean	N	SD
1999	Wild	65	29	5	74	28	5	77	1	-
	Hatchery	62	54	4	73	12	4	-	0	-
2000	Wild	64	22	3	74	17	5	-	0	-
	Hatchery	60	57	3	71	27	4	-	0	-
2001	Wild	61	33	6	77	31	5	-	0	-
	Hatchery	62	17	4	72	97	4	-	0	-
2002	Wild	64	55	4	77	44	4	-	0	-
	Hatchery	63	106	4	73	6	4	-	0	-
2003	Wild	69	8	6	77	52	5	91	1	-
	Hatchery	66	27	4	75	65	4	-	0	-
2004	Wild	63	73	6	78	4	2	-	0	-
	Hatchery	61	59	3	73	3	1	-	0	-
2005	Wild	59	21	4	74	74	5	-	0	-
	Hatchery	59	23	4	72	89	4	-	0	-
2006	Wild	63	27	5	75	67	6	-	0	-
	Hatchery	61	41	4	72	27	5	-	0	-
2007	Wild	64	31	6	76	46	5	-	0	-
	Hatchery	60	60	4	71	36	5	-	0	-
2008	Wild	64	68	4	77	35	4	80	1	-
	Hatchery	60	95	4	72	12	2	-	0	-
2009	Wild	65	33	5	76	48	6	81	2	0
	Hatchery	63	18	4	75	59	5	-	-	-
2010	Wild	64	60	5	74	31	5	76	1	-
	Hatchery	61	53	5	73	23	5	-	-	-
2011	Wild	62	28	5	76	74	5	-	0	-
	Hatchery	60	36	4	74	64	4	-	0	-
2012	Wild	63	25	3	74	31	5	74	3	2
	Hatchery	59	27	3	74	39	4	-	0	-
2013	Wild	61	22	5	77	31	5	74	1	-
	Hatchery	60	35	3	74	42	4	-	0	-
2014	Wild	61	29	4	75	31	4	61	1	-
	Hatchery	60	20	3	72	48	4	-	0	-
2015	Wild	61	10	3	77	52	4	85	1	-
	Hatchery	59	26	3	76	29	5	-	0	-
2016	Wild	62	22	4	74	43	4	-	0	-
	Hatchery	61	28	4	71	38	5	-	0	-
Average	***Wild***	***63***	***32***	***5***	***76***	***40***	***5***	***78***	***1***	***1***

Brood year	Origin	Steelhead fork length (cm)								
		1-Salt			2-Salt			3-Salt		
		Mean	N	SD	Mean	N	SD	Mean	N	SD
	Hatchery	*61*	*42*	*4*	*73*	*39*	*4*	*-*	*0*	*-*

Sex Ratios

Male steelhead in the 2015 brood year made up about 50% of the adults collected, resulting in an overall male to female ratio of 1.00:1.00 (Table 3.4). For the 2016 brood year, males made up about 50.4% of the adults collected, resulting in an overall male to female ratio of 1.02:1.00. On average (1998-2016), the sex ratio is slightly less than the 1:1 ratio assumed in the broodstock protocol (Table 3.4).

Table 3.4. Numbers of male and female wild and hatchery steelhead collected for broodstock, 1998-2016. Ratios of males to females are also provided.

Brood year	Number of wild steelhead			Number of hatchery steelhead			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
1998	13	22	0.59:1.00	15	28	0.54:1.00	0.56:1.00
1999	22	36	0.61:1.00	35	32	1.09:1.00	0.84:1.00
2000	18	21	0.86:1.00	60	41	1.46:1.00	1.26:1.00
2001	38	26	1.46:1.00	40	74	0.54:1.00	0.78:1.00
2002	32	67	0.48:1.00	81	32	2.53:1.00	1.14:1.00
2003	19	44	0.43:1.00	44	48	0.92:1.00	0.68:1.0
2004	43	42	1.02:1.00	90	42	2.14:1.00	1.58:1.00
2005	36	59	0.61:1.00	46	68	0.68:1.00	0.65:1.00
2006	38	63	0.60:1.00	47	51	0.92:1.00	0.75:1.00
2007	36	43	0.84:1.00	49	48	1.02:1.00	0.93:1.00
2008	61	43	1.42:1.00	68	39	1.74:1.00	1.57:1.00
2009	44	57	0.77:1.00	54	53	1.02:1.00	0.89:1.00
2010	49	57	0.86:1.00	62	43	1.44:1.00	1.11:1.00
2011	44	60	0.73:1.00	50	54	0.93:1.00	0.82:1.00
2012	30	33	0.91:1.00	31	35	0.89:1.00	0.90:1.00
2013	33	30	1.10:1.00	38	46	0.83:1.00	0.93:1.00
2014	30	33	0.91:1:00	36	36	1.00:1.00	0.96:1.00
2015	34	42	0.81:1.00	34	26	1.31:1.00	1.00:1.00
2016	34	33	1.03:1.00	33	33	1.00:1.00	1.02:1.00
Total	***654***	***811***	***0.81:1.00***	***913***	***829***	***1.10:1.00***	***0.96:1.00***

Fecundity

Fecundities for Wenatchee steelhead in brood years 2015 and 2016 averaged 5,895 and 5,174 eggs per female, respectively (Table 3.5). Mean fecundity for the 2015 brood year was greater while the 2016 brood year was less than the 5,678 eggs per female assumed in the broodstock protocol.

Table 3.5. Mean fecundity of wild, hatchery, and all female steelhead collected for broodstock, 1998-2016.

Brood year	Mean fecundity		
	Wild	Hatchery	Total
1998	6,202	5,558	5,924
1999	5,691	5,186	5,424
2000	5,858	5,729	5,781
2001	5,951	6,359	6,270
2002	5,776	5,262	5,626
2003	6,561	6,666	6,621
2004	5,118	5,353	5,238
2005	5,545	6,061	5,832
2006	5,688	5,251	5,492
2007	5,840	5,485	5,660
2008	5,693	5,153	5,433
2009	6,199	6,586	6,408
2010	5,458	5,423	5,442
2011	6,276	6,100	6,203
2012	5,309	6,388	5,891
2013	5,749	5,770	5,762
2014	5,831	5,847	5,839
2015	6,220	5,532	5,895
2016	5,392	4,956	5,174
Average	***5,808***	***5,719***	***5,785***
Median	***5,776***	***5,558***	***5,781***

3.2 Hatchery Rearing

Rearing History

Number of eggs taken

From 1998-2011, a total of 493,827 eggs were required to meet the program release goal of 400,000 smolts. This was based on the unfertilized egg-to-release survival standard of 81%. In 2012, the egg take target was reduced to 305,309, which is needed to meet the revised release target of 247,300 smolts. Between 1998 and 2011, the egg take goal was reached 57% of the time (Table 3.6). Since 2011, the target has been reached or exceeded 100% of the time (Table 3.6).

Table 3.6. Numbers of eggs taken from steelhead broodstock, 1998-2016.

Brood year	Number of eggs taken
1998	224,315
1999	303,083
2000	280,872
2001	549,464

Brood year	Number of eggs taken
2002	503,030
2003	532,708
2004	408,538
2005	672,667
2006	546,382
2007	462,662
2008	439,980
2009	633,229
2010	499,499
2011	522,049
Average (1998-2011)	***488,782***
Median (1998-2001)	***501,265***
2012	371,151
2013	339,949
2014	395,453
2015	324,212
2016	341,511
Average (2012-present)	***354,455***
Median (2012-present)	***341,511***

Number of acclimation days

Juvenile WxW steelhead from the Chelan Fish Hatchery and HxH steelhead from the Eastbank Fish Hatchery were transferred to Chiwawa Acclimation Facility in November 2015. In March 2016, about 25,000 HxH steelhead were transferred from the Chiwawa Acclimation Facility to Blackbird Pond near Leavenworth for final acclimation on Wenatchee River water. Fish were acclimated for 23 d at Blackbird Pond before a volitional release was initiated on 20 April. The remainder stayed at the Chiwawa Acclimation Facility until they were volitionally and forced released from the facility during late April to early-May.

Juvenile Wenatchee steelhead at the Chiwawa Acclimation Facility were acclimated and reared on Wenatchee and Chiwawa River water. Before 2012, Wenatchee steelhead were reared on Columbia River water from January through May before being trucked and released into the Wenatchee River basin (Table 3.7).

Table 3.7. Water source and mean acclimation period for Wenatchee steelhead, brood years 1998-2016.

Brood year	Release year	Parental origin	Water source	Number of Days
1998	1999	H x H	Wenatchee/Chiwawa	36
		H x W	Wenatchee/Chiwawa	36
		W x W	Wenatchee/Chiwawa	36
1999	2000	H x H	Wenatchee/Chiwawa	138
		H x W	Wenatchee/Chiwawa	138

Brood year	Release year	Parental origin	Water source	Number of Days
		W x W	Wenatchee/Chiwawa	138
		H x W	Eastbank	0
		W x W	Eastbank	0
2000	2001	H x H	Wenatchee/Chiwawa	122
		H x W	Wenatchee/Chiwawa	122
		H x W	Wenatchee/Chiwawa	122
		W x W	Wenatchee/Chiwawa	122
2001	2002	H x H	Columbia	92
		H x H	Wenatchee/Chiwawa	63
		H x W	Columbia	92
		H x W	Wenatchee/Chiwawa	63
		W x W	Columbia	153
2002	2003	H x H	Columbia	98
		H x W	Columbia	98
		W x W	Columbia	117
2003	2004	H x H	Columbia	88
		H x W	Wenatchee/Chiwawa	84
		W x W	Columbia	148
2004	2005	H x H	Columbia	160
		H x W	Columbia	160
		W x W	Columbia	160
2005	2006	H x H	Columbia	116
		H x W	Columbia	113
		W x W	Columbia	141
2006	2007	Early H x W	Columbia	111
		Late H x W	Columbia	112
		W x W	Columbia	148
2007	2008	Early H x W	Columbia	94-95
		Late H x W	Columbia	91-93
		W x W	Columbia	138
2008	2009	Early H x W	Columbia	120-121
		Early H x W	Columbia/Wenatchee	120-121/28-95
		Late H x W	Columbia	114-115
		W x W	Columbia	152-153
2009	2010	Early H x W	Columbia	93-94
		Early H x W	Columbia/Wenatchee	99-111
		Early H x W	Wenatchee	31-129

Brood year	Release year	Parental origin	Water source	Number of Days
		Late H x W	Columbia	84-87
		W x W	Columbia/Nason	118-120/28
2010	2011	H x H	Wenatchee	188-192
		H x H	Wenatchee	37-87
		H x H	Columbia	181
		W x W	Columbia	148-149
		W x W	Columbia/Nason	113-114/42-101
		W x W	Columbia	148-149
2011	2012	W x W	Wenatchee	160-201
		W x W	Wenatchee	179-188
		W x W	Wenatchee	21-72
		W x W	Nason	56-107
2012	2013	H x H	Wenatchee	168-189
		H x H	Wenatchee	168-225
		W x W	Wenatchee	168-225
		W x W	Wenatchee	168-189
		W x W	Chiwawa	187
2013	2014	H x H	Wenatchee[a]	7-67
		H x H	Wenatchee	168-169
		W x W	Wenatchee	176-197
		W x W	Wenatchee	179-204
2014	2015	H x H	Wenatchee[a]	41-110
		H x H	Wenatchee	161-179
		W x W	Wenatchee	157-172
		W x W	Wenatchee	168-171
2015	2016	H x H	Wenatchee[a]	23-81
		H x H	Wenatchee	156-172
		W x W	Wenatchee	162-178
		W x W	Wenatchee	160-176

[a] Steelhead overwintered in Pond 3 at the Chiwawa Acclimation Facility on Chiwawa River water before they were transferred to Blackbird Pond.

Release Information

Numbers released

In 2011, the HCP Hatchery Committee agreed to reduce the Wenatchee summer steelhead program from 400,000 smolts to 247,300 smolts. Based on this new goal and the number of WxW steelhead present, all HxH steelhead were transferred to the Ringold Fish Hatchery to be included in their production program for the 2012 release.

The release of 2015 brood Wenatchee steelhead achieved 79% of the 247,300 target with about 195,344 smolts released into the Wenatchee and Chiwawa rivers and Nason Creek (Table 3.8). Distribution of juvenile steelhead released in each of the three streams was determined by the mean proportion of steelhead redds in each basin. About 28.2% and 19.3% of the steelhead were released in Nason Creek and the Chiwawa River, respectively. The balance of the program was split between the Wenatchee River downstream from Tumwater Dam (10.9%) and the Wenatchee River upstream from the dam (41.5%).

Table 3.8. Numbers of steelhead smolts released from the hatchery, brood years 1998-2015. Before brood year 2011, the release target for steelhead was 400,000 smolts. Beginning with brood year 2011, the release target is 247,300 smolts.

Brood year	Release year	Number of smolts
1998	1999	172,078
1999	2000	175,701
2000	2001	184,639
2001	2002	335,933
2002	2003	302,060
2003	2004	374,867
2004	2005	294,114
2005	2006	452,184
2006	2007	299,937
2007	2008	306,690
2008	2009	327,143
2009	2010	484,772
2010	2011	354,314
Average (1998-2010)		***312,649***
Median (1998-2010)		***306,690***
2011	2012	206,397
2012	2013	249,004
2013	2014	229,836
2014	2015	264,758
2015	2016	195,344
Average (2011-present)		***229,068***
Median (2011-present)		***229,836***

Numbers marked

Wenatchee hatchery steelhead from the 2015 brood were marked with coded wire tags (CWT) in the snout. About 44.9% of the juveniles released were also adipose fin clipped (Table 9).

Table 3.9. Release location and marking scheme for the 1998-2015 brood Wenatchee steelhead.

Brood year	Release location	Parental origin	Proportion Ad-clip	CWT or VIE color/side	Tag rate	Number released
1998	Chiwawa River	H x H	0.000	Red Left	0.994	52,765
	Chiwawa River	H x W	0.000	Green Left	0.990	37,013
	Chiwawa River	W x W	0.000	Orange Left	0.827	82,300
1999	Wenatchee River	H x H	0.000	Green Left	0.911	45,347
	Wenatchee River	H x W	0.000	Orange Left	0.927	30,713
	Chiwawa River	H x H	0.000	Red Right	0.936	25,622
	Chiwawa River	H x W	0.000	Green Right	0.936	43,379
	Chiwawa River	W x W	0.000	Orange Right	0.936	30,600
2000	Chiwawa River	H x H	0.000	Red Left	0.963	33,417
	Chiwawa River	H x W	0.000	Green Left	0.963	57,716
	Chiwawa River	H x W	0.000	Green Right	0.949	48,029
	Chiwawa River	W x W	0.000	Orange Right	0.949	45,477
2001	Nason Creek	H x W	0.000	Green Right	0.934	75,276
	Nason Creek	W x W	0.000	Orange Right	0.934	48,115
	Chiwawa River	H x W	0.000	Green Left	0.895	92,487
	Chiwawa River	H x H	0.000	Red Left	0.895	120,055
2002	Chiwawa River	H x H	0.000	Red Left	0.920	156,145
	Chiwawa River	H x W	0.000	Green Left	0.928	33,528
	Nason Creek	W x W	0.000	Orange Right	0.928	112,387
2003	Wenatchee River	H x H	0.000	Red Left	0.968	117,663
	Chiwawa River	H x W	0.000	Green Left	0.927	191,796
	Nason Creek	W x W	0.000	Orange Right	0.962	65,408
2004	Wenatchee River	H x H	0.500	Red Left	0.804	39,636
	Chiwawa River	H x W	0.000	Green Left	0.977	153,959
	Nason Creek	W x W	0.000	Pink Right	0.940	100,519
2005	Wenatchee River	H x H	1.000	Red Left	0.983	104,552
	Wenatchee River	H x W	0.616	Green Left	0.979	190,319
	Chiwawa River	H x W	0.616	Green Left	0.979	18,634
	Chiwawa River	W x W	0.000	Pink Right	0.969	14,124
	Nason Creek	W x W	0.000	Pink Right	0.969	124,555
2006	Wenatchee River	H x W (early)	1.000	Green Right	0.918	66,022

Brood year	Release location	Parental origin	Proportion Ad-clip	CWT or VIE color/side	Tag rate	Number released
	Wenatchee River	H x W (late)	0.671	Green Left	0.935	92,176
	Chiwawa River	H x W (late)	0.671	Green Left	0.935	41,240
	Chiwawa River	W x W	0.000	Pink Right	0.945	7,500
	Nason Creek	W x W	0.000	Pink Right	0.945	92,999
2007	Wenatchee River	H x W (early)	0.967	Green Right	0.950	64,310
	Wenatchee River	H x W (late)	0.586	Green Left	0.951	97,549
	Chiwawa River	H x W (late)	0.586	Green Left	0.951	43,011
	Chiwawa River	W x W	0.000	Pink Right	0.952	7,026
	Nason Creek	W x W	0.000	Pink Right	0.952	94,794
2008	Blackbird Pond	HxW (early)	0.917	Green Right	0.910	49,878
	Wenatchee River	H x W (early)	0.917	Green Right	0.910	48,624
	Wenatchee River	H x W (late)	0.595	Green Left	0.908	74,848
	Chiwawa River	H x W (late)	0.595	Green Left	0.908	25,835
	Chiwawa River	W x W	0.000	Pink Right	0.904	25,778
	Nason Creek	W x W	0.000	Pink Right	0.904	102,170
2009	Blackbird Pond	H x W (early)	0.969	Green Right	0.934	50,248
	Wenatchee River	H x W (early)	0.969	Green Right	0.934	105,239
	Wenatchee River	H x W (late)	0.973	Green Left	0.975	27,612
	Wenatchee River	H x W (late)	0.000	Green Left	0.975	45,435
	Chiwawa River	H x W (early)	0.969	Green Right	0.934	23,835
	Chiwawa River	H x W (late)	0.973	Green Left	0.975	33,047
	Chiwawa River	H x W (late)	0.000	Green Left	0.975	54,381
	Nason Creek	W x W	0.000	Pink Right	0.979	145,029
2010	Wenatchee River	H x H	0.994	-	0.984	24,838
	Wenatchee River	H x H	0.994	-	0.984	45,000
	Wenatchee River	H x H	0.994	-	0.984	92,113
	Chiwawa River	W x W	0.000	Pink Right	0.917	81,174
	Nason Creek	W x W	0.000	Pink R/Pink L	0.884	20,000
	Nason Creek	W x W	0.000	Pink Right	0.917	91,189
2011	Wenatchee River	W x W	0.985	CWT	0.953	70,885
	Wenatchee River	W x W	0.985	CWT	0.953	24,992
	Wenatchee River	W x W	0.000	CWT	0.987	25,569

Brood year	Release location	Parental origin	Proportion Ad-clip	CWT or VIE color/side	Tag rate	Number released
	Chiwawa River	W x W	0.985	CWT	0.953	31,050
	Nason Creek	W x W	0.000	CWT	0.989	18,254
	Nason Creek	W x W	0.985	CWT	0.953	36,225
2012	Wenatchee River	W x W	0.000	CWT	0.965	14,824
	Wenatchee River	H x H	1.000	AD/CWT	0.920	9,841
	Wenatchee River	W x W	0.000	CWT	0.965	28,362
	Wenatchee River	H x H	1.000	AD/CWT	0.920	76,695
	Chiwawa River	W x W	0.000	CWT	0.965	12,760
	Chiwawa River	H x H	1.000	AD/CWT	0.920	34,503
	Nason Creek	W x W	0.000	CWT	0.965	43,854
	Nason Creek	W x W	0.000	CWT	0.965	28,165
2013	Wenatchee River	W x W	0.000	CWT	0.963	36,736
	Wenatchee River	H x H	0.998	AD/CWT	0.990	55,055
	Wenatchee River	H x H	0.998	AD/CWT	0.990	25,316
	Chiwawa River	W x W	0.000	CWT	0.963	9,360
	Chiwawa River	H x H	0.998	AD/CWT	0.990	14,040
	Nason Creek	W x W	0.000	CWT	0.963	50,503
	Nason Creek	H x H	0.998	AD/CWT	0.990	38,826
2014	Wenatchee River	W x W	0.000	CWT	0.968	72,345
	Wenatchee River	H x H	0.996	AD/CWT	0.996	58,130
	Wenatchee River	H x H	0.996	AD/CWT	0.996	28,122
	Chiwawa River	W x W	0.000	CWT	0.968	20,443
	Chiwawa River	H x H	0.996	AD/CWT	0.996	14,599
	Nason Creek	W x W	0.000	CWT	0.968	41,188
	Nason Creek	H x H	0.996	AD/CWT	0.996	29,931
2015	Wenatchee River	W x W	0.000	CWT	0.972	52,446
	Wenatchee River	H x H	0.993	AD/CWT	0.980	28,633
	Wenatchee River	H x H	0.993	AD/CWT	0.980	21,386
	Chiwawa River	W x W	0.000	CWT	0.972	20,022
	Chiwawa River	H x H	0.993	AD/CWT	0.980	17,752
	Nason Creek	W x W	0.000	CWT	0.972	35,148
	Nason Creek	H x H	0.993	AD/CWT	0.980	19,957

Numbers PIT tagged

Table 3.10 summarizes the number of hatchery steelhead of different parental origins that have been PIT-tagged and released into the Wenatchee River basin.

Table 3.10. Summary of PIT-tagging activities for Wenatchee hatchery steelhead, brood years 2006-2015.

Brood year	Release location	Parental origin	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
2006	Wenatchee River	H x W (early)	10,036	479	24	9,533
	Wenatchee/Chiwawa rivers	H x W (late)	10,031	922	20	9,089
	Chiwawa River/Nason	W x W	10,019	152	352	9,515
2007	Wenatchee River	H x W (early)	9,852	22	10	9,820
	Wenatchee/Chiwawa rivers	H x W (late)	10,063	73	78	9,912
	Chiwawa River/Nason	W x W	10,038	55	1	9,982
2008	Wenatchee River	H x W (early)	10,101	59	15	10,027
	Wenatchee/Chiwawa rivers	H x W (late)	10,104	106	17	9,981
	Chiwawa River/Nason	W x W	10,101	159	80	9,862
2009	Wenatchee/Chiwawa rivers	H x W (early)	10,114	574	11	9,529
	Wenatchee (Blackbird)	H x W (early)	8,100	0	0	8,100
	Wenatchee/Chiwawa rivers	H x W (late)	10,115	271	11	9,833
	Chiwawa pilot	H x W (early)	10,107	532	103	9,472
	Chiwawa River/Nason	W x W	10,101	38	3	10,060
2010	Wenatchee River	HxH	10,100	624	21	9,455
	Chiwawa River/Nason	WxW	10,100	206	0	9,894
	Wenatchee (Blackbird)	HxH	10,101	235	8	9,858
	Wenatchee River	HxH	10,100	46	28	10,026
2011	Wenatchee/Chiwawa/Nason	WxW (circular)	10,101	139	30	9,932
	Wenatchee/Chiwawa/Nason	WxW (raceway)	20,220	121	35	20,064
2012	Wenatchee/Chiwawa/Nason	WxW (circular)	15,244	176	4	15,064
	Wenatchee/Chiwawa/Nason	HxH (raceway)	10,223	140	13	10,070
2013	Wenatchee/Chiwawa/Nason	WxW	5,100	95	1	5,004
	Wenatchee/Chiwawa/Nason	HxH	10,201	84	12	10,105
2014	Wenatchee/Chiwawa/Nason	WxW	9,051	53	0	8,998
	Wenatchee/Chiwawa/Nason	HxH	10,129	243	76	9,810
2015	Wenatchee/Chiwawa/Nason	WxW	12,101	60	0	12,041
	Wenatchee/Chiwawa/Nason	HxH	11,115	55	0	11,060

2016 Brood Wenatchee WxW Summer Steelhead (Circular Ponds)—A total of 5,050 Wenatchee WxW summer steelhead were PIT tagged at the Chiwawa Acclimation Facility on 23-24 February 2017. These fish were tagged in circular ponds #1 and #3. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 141-149 mm in length and 29-38 g at time of tagging.

2016 Brood Wenatchee HxH and WxW Summer Steelhead (Raceway)—A total of 12,626 Wenatchee HxH and WxW summer steelhead were PIT tagged at the Chiwawa Acclimation Facility on 27 February to 3 March 2017. These fish were tagged in raceway #2. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 129-130 mm in length and 22-26 g at time of tagging.

2016 Brood Wenatchee Summer Steelhead (Blackbird Pond)—A total of 2,525 Wenatchee summer steelhead destined for Blackbird Pond were PIT tagged at the Chiwawa Acclimation Facility on 21-22 February 2017. These fish were tagged in raceway #3. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 133 mm in length and 25 g at time of tagging.

Fish size and condition at release

Except for the Blackbird Pond release, all 2015 brood steelhead were trucked and released as yearling smolts in April and May 2016. The Blackbird Pond group was released volitionally beginning on 20 April. Both WxW and HxH fish did not meet the targets for length, weight, or coefficient of variation (CV) for fork length (Table 3.11). The HxH group was combined with the WxW group in Pond 2 once they were transferred to Chiwawa Acclimation Facility. The HxH fish were larger than the WxW fish at the time of transfer but smaller at the time of release.

Table 3.11. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of steelhead smolts released from the hatchery, brood years 1998-2015. Size targets are provided in the last row of the table.

Brood year	Release year	Parental origin	Fork length (mm)		Mean weight	
			Mean	CV	Grams (g)	Fish/pound
1998	1999	H x H	201	11.1	92.3	5
		H x W	190	12.8	76.9	6
		W x W	173	12.0	55.3	8
1999	2000	H x H	181	8.9	70.6	6
		H x W	187	7.2	75.3	6
		W x W	184	11.3	71.5	6
2000	2001	H x H	218	15.2	122.4	4
		H x W	209	10.6	107.5	4
		W x W	205	10.7	100.9	5
2001	2002	H x H	179	17.4	67.0	7
		H x W	192	15.6	82.8	6
		W x W	206	11.6	102.6	4

Brood year	Release year	Parental origin	Fork length (mm)		Mean weight	
			Mean	CV	Grams (g)	Fish/pound
2002	2003	H x H	194	13.1	83.0	6
		H x W	191	13.0	77.4	6
		W x W	180	19.1	70.3	7
2003	2004	H x H	191	14.4	73.1	6
		H x W	199	12.9	83.9	5
		W x W	200	11.1	90.1	5
2004	2005	H x H	204	11.3	87.2	6
		H x W	202	13.5	71.9	5
		W x W	198	12.4	76.6	6
2005	2006	H x H	215	12.6	116.6	4
		H x W	198	11.8	86.3	5
		W x W	189	15.4	55.3	6
2006	2007	H x H (early)	213	12.1	109.6	4
		H x W (late)	186	11.8	68.3	7
		W x W	178	11.1	58.6	8
2007	2008	H x W (early)	192	17.4	77.1	6
		H x W (late)	179	19.3	63.8	7
		W x W	183	12.3	62.8	7
2008	2009	H x W (early)	184	11.6	68.0	7
		H x W (late)	186	11.6	73.5	6
		W x W	181	13.0	59.7	8
2009	2010	H x W (early)	197	11.3	84.2	5
		H x W (late)	192	11.1	72.7	6
		W x W	190	9.6	70.5	6
2010	2011	H x H	183	14.1	68.9	4
		W x W	188	10.5	68.1	7
2011	2012	H x H	NA	NA	NA	NA
		W x W	156	17.1	45.2	10
2012	2013	H x H / W x W	150	16.1	40.8	11
		H x H / W x W	157	16.4	45.0	10
		W x W	156	18.7	49.0	9
2013	2014	H x H / W x W	157	14.5	49.4	9
		H x H	127	16.2	26.8	17
		W x W	162	20.4	55.8	8
2014	2015	H x H / W x W	152	15.4	40.9	11

Brood year	Release year	Parental origin	Fork length (mm)		Mean weight	
			Mean	CV	Grams (g)	Fish/pound
		H x H	145	13.5	36.6	12
		W x W	162	15.3	50.6	9
2015	2016	H x H / W x W	163	16.1	53.1	9
		H x H	162	9.4	46.1	10
		W x W	180	13.8	70.6	6
Targets			***191***	***9.0***	***75.6***	***6***

Survival Estimates

Overall survival of Wenatchee steelhead (WxW and HxH) from green (unfertilized) egg to release was below the standard set for the program. This is largely because of lower unfertilized egg to eyed egg survival (Table 3.12).

The Wenatchee steelhead program, from its inception, has experienced highly variable fertilization rates. It is unknown at this time what mechanisms may be influencing stock performance at these stages.

Table 3.12. Hatchery life-stage survival rates (%) for steelhead, brood years 1998-2015. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
1998	92.0	100.0	85.5	91.7	99.2	98.8	97.8	99.9	76.7
1999	91.2	100.0	66.9	93.0	95.9	94.9	93.1	99.7	58.0
2000	83.9	96.2	77.6	86.7	99.3	98.9	97.7	99.5	65.7
2001	90.0	100.0	73.0	91.8	99.1	97.8	91.3	99.7	61.1
2002	99.0	100.0	69.2	93.1	95.9	94.4	89.6	89.6	60.0
2003	87.0	96.8	86.3	83.8	97.2	94.8	97.6	85.3	70.4
2004	97.6	98.5	83.4	93.7	97.8	94.1	92.2	99.9	72.0
2005	91.3	95.1	81.3	92.1	95.6	91.8	89.7	99.6	67.2
2006	99.1	95.3	73.2	85.4	95.4	94.6	87.8	98.5	54.9
2007	100.0	100.0	80.3	92.0	95.7	92.7	89.8	99.1	66.3
2008	100.0	100.0	87.1	88.4	99.0	97.4	96.6	99.5	74.4
2009	97.3	100.0	89.0	97.2	96.0	95.2	88.6	96.6	76.6
2010	96.7	100.0	93.8	93.9	91.0	86.2	80.6	96.0	70.9
2011[a]	96.3	94.4	74.2	97.7	96.6	89.5	86.4	98.4	62.7
2012	95.2	98.4	74.7	99.7	97.8	94.0	90.1	98.9	67.1
2013	80.8	97.0	75.0	96.5	97.8	96.6	93.4	99.2	67.6
2014	100.0	100.0	83.3	96.7	95.8	89.9	87.9	98.7	70.8
2015	93.3	98.6	68.5	94.9	96.6	95.8	92.7	97.8	60.3

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
Average	*93.9*	*98.4*	*79.0*	*92.7*	*96.8*	*94.3*	*91.3*	*97.6*	*66.8*
Median	*95.8*	*99.3*	*79.0*	*93.1*	*96.6*	*94.7*	*90.7*	*99.0*	*67.2*
Standard	*90.0*	*85.0*	*92.0*	*98.0*	*97.0*	*93.0*	*90.0*	*95.0*	*81.0*

[a] Survival estimates are only for WxW steelhead.

3.3 Disease Monitoring

Rearing of the 2015 brood Wenatchee summer steelhead was similar to previous years with fish being held on Chelan spring water, Eastbank well water, and Chelan well water before being transferred for overwinter acclimation at the Chiwawa Acclimation Facility. Volitional and force-released fish were released into Nason Creek, Chiwawa River, and the Wenatchee River. The 2015 WxW Wenatchee steelhead had no significant health issues during the rearing period.

3.4 Natural Juvenile Productivity

During 2016, juvenile steelhead were sampled at the Lower Wenatchee, Chiwawa, and Nason Creek traps and counted during snorkel surveys within the Chiwawa River basin. Because the snorkel surveys targeted juvenile Chinook salmon, the entire distribution of juvenile steelhead in the Chiwawa River basin was not surveyed. Therefore, the parr numbers presented below represent a minimum estimate.

Parr Estimates

A total of 16,244 (±14%) age-0 (<100 mm) and 4,031 (±15%) age-1+ (100-200 mm)[5] steelhead/rainbow were estimated in the Chiwawa River basin in August 2016 (Table 3.13 and 3.14). During the survey period 1992-2016, numbers of age-0 and 1+ steelhead/rainbow have ranged from 1,410 to 45,727 and 754 to 22,130, respectively, in the Chiwawa River basin (Table 3.13 and 3.14; Figure 3.1). Numbers of all fish counted in the Chiwawa River basin are reported in Appendix A.

Juvenile steelhead/rainbow were distributed primarily throughout the lower seven reaches of the Chiwawa River (downstream from Rock Creek). Their densities were highest in the lower portions of the river and in tributaries. Age-0 steelhead/rainbow most often used riffle and multiple channel habitats in the Chiwawa River, although they also associated with woody debris in pool and glide habitat. In tributaries, they were generally most abundant in small pools. Those that were observed in riffles selected stations in quiet water behind small and large boulders, or occupied stations in quiet water along the stream margin. In pool and multiple-channel habitats, age-0 steelhead/rainbow used the same kinds of habitat as age-0 Chinook salmon.

Age-1+ steelhead/rainbow most often used pool, riffle, and multiple-channel habitats. Those that used pools were usually in deeper water than subyearling steelhead/rainbow and Chinook salmon. Like age-0 steelhead/rainbow, age-1+ steelhead/rainbow generally selected stations in quiet water behind boulders in riffles, but the two age groups rarely occurred together. Age-1+ steelhead/rainbow used deeper and faster water than did subyearling steelhead/rainbow.

[5] A steelhead/rainbow trout larger than 200 mm (8 in) was considered a resident trout.

Table 3.13. Total numbers of age-0 steelhead/rainbow trout estimated in different steams in the Chiwawa River basin during snorkel surveys in August 1992-2016; NS = not sampled.

Sample Year	Chiwawa River	Phelps Creek	Chikamin Creek	Rock Creek	Unnamed Creek	Big Meadow Creek	Alder Creek	Brush Creek	Clear Creek	Total
1992	4,927	NS	NS	NS	NS	NS	NS	NS	NS	**4,927**
1993	3,463	0	356	185	NS	NS	NS	NS	NS	**4,004**
1994	953	0	256	24	0	177	0	0	0	**1,410**
1995	6,005	0	744	90	0	371	40	107	0	**7,357**
1996	3,244	0	71	40	0	763	127	0	0	**4,245**
1997	6,959	224	84	324	0	1,124	58	50	0	**8,823**
1998	2,972	22	280	96	113	397	18	22	0	**3,921**
1999	5,060	20	253	189	0	255	34	27	0	**5,838**
2000	NS	NS	NS	NS	NS	NS	NS	NS	NS	**NS**
2001	35,759	192	1,449	1,826	0	6,345	156	0	0	**45,727**
2002	12,137	0	2,252	889	0	4,948	277	18	0	**20,521**
2003	9,911	296	996	1,166	96	5,366	73	116	0	**18,020**
2004	8,464	110	583	113	40	957	35	78	0	**10,380**
2005	4,852	120	2,931	477	45	2,973	65	0	0	**11,463**
2006	10,669	21	858	872	34	3,647	73	71	0	**16,245**
2007	8,442	53	2,137	348	11	2,955	65	28	34	**14,073**
2008	9,863	0	2,260	859	0	1,987	57	168	36	**15,230**
2009	13,231	0	1,183	449	0	2,062	170	67	17	**17,179**
2010	17,572	0	2,870	1,478	5	2,843	182	35	33	**25,018**
2011	35,825	0	1,503	804	0	1,066	56	152	40	**39,446**
2012	21,537	0	1,817	1,501	0	2,164	42	54	19	**27,134**
2013	17,889	0	602	816	0	2,189	44	99	43	**21,682**
2014	12,256	21	1,617	1,039	0	1,005	32	56	57	**16,083**
2015	4,532	0	1,989	1,675	0	1,761	170	62	19	**10,208**
2016	10,971	0	1,419	996	0	2,721	50	62	25	**16,244**
Average	***11,146***	***47***	***1,240***	***707***	***16***	***2,185***	***83***	***58***	***15***	***15,216***
Median	***9,164***	***0***	***1,183***	***804***	***0***	***2,025***	***58***	***55***	***0***	***14,652***

Table 3.14. Total numbers of age-1+ steelhead/rainbow trout estimated in different steams in the Chiwawa River basin during snorkel surveys in August 1992-2016; NS = not sampled.

Sample Year	Chiwawa River	Phelps Creek	Chikamin Creek	Rock Creek	Unnamed Creek	Big Meadow Creek	Alder Creek	Brush Creek	Clear Creek	Total
1992	2,533	NS	NS	NS	NS	NS	NS	NS	NS	**2,533**
1993	2,530	0	228	102	NS	NS	NS	NS	NS	**2,860**
1994	4,972	0	476	296	5	107	0	0	0	**5,856**
1995	8,769	0	494	71	0	183	0	0	0	**9,517**
1996	11,381	0	6	27	0	435	0	0	0	**11,849**
1997	6,574	160	0	105	0	66	0	0	0	**6,905**
1998	10,403	0	133	49	0	0	0	0	0	**10,585**

Sample Year	Chiwawa River	Phelps Creek	Chikamin Creek	Rock Creek	Unnamed Creek	Big Meadow Creek	Alder Creek	Brush Creek	Clear Creek	Total
1999	21,779	0	68	201	0	82	0	0	0	**22,130**
2000	NS	NS	NS	NS	NS	NS	NS	NS	NS	**NS**
2001	9,368	16	186	407	0	646	0	0	0	**10,623**
2002	7,200	0	199	165	0	1,526	0	0	0	**9,090**
2003	4,745	362	426	599	0	47	0	0	0	**6,179**
2004	7,700	107	209	0	0	174	0	0	0	**8,190**
2005	4,624	63	957	257	0	287	0	0	0	**6,188**
2006	7,538	76	748	1,186	0	985	0	0	0	**10,533**
2007	6,976	0	945	96	0	431	0	0	0	**8,448**
2008	8,317	0	1,168	298	0	793	0	0	0	**10,576**
2009	4,998	16	320	102	0	167	21	0	5	**5,629**
2010	8,324	32	366	393	0	780	21	0	0	**9,916**
2011	13,329	0	415	470	0	689	0	0	0	**14,903**
2012	7,671	0	285	410	0	210	0	0	0	**8,576**
2013	6,439	0	0	48	0	766	0	0	0	**7,253**
2014	4,568	13	96	211	0	165	0	0	31	**5,084**
2015	614	0	40	100	0	0	0	0	0	**754**
2016	3,418	0	256	40	0	309	0	8	0	**4,031**
Average	***7,282***	***37***	***349***	***245***	***0***	***402***	***2***	***0***	***2***	***8,259***
Median	***7,088***	***0***	***256***	***165***	***0***	***249***	***0***	***0***	***0***	***8,319***

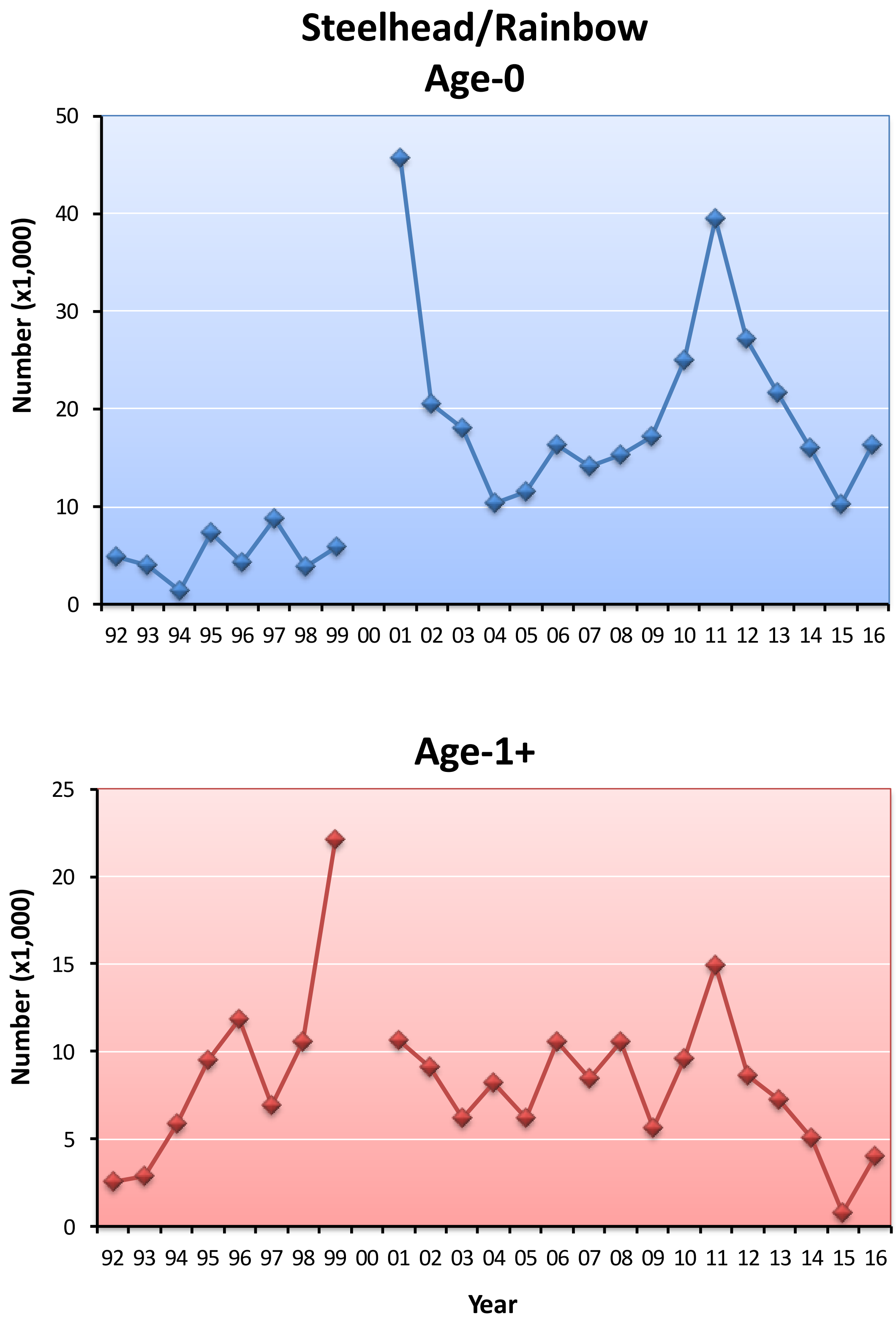

Figure 3.1. Numbers of subyearling and yearling steelhead/rainbow trout within the Chiwawa River basin in August 1992-2016; ND = no data.

Emigrant and Smolt Estimates

Numbers of steelhead smolts and emigrants were estimated at the Chiwawa, Nason, and Lower Wenatchee traps in 2016.

Chiwawa Trap

The Chiwawa Trap operated between 2 March and 21 November 2016. During the trapping period, the trap was inoperable for 72 days due to high or low river discharge, debris, major hatchery releases, and mechanical issues. The trap operated in a single position throughout the sampling season. Monthly captures of all fish collected at the Chiwawa Trap are reported in Appendix B.

A total of 195 wild steelhead/rainbow smolts, 1,518 hatchery smolts, and 1,522 wild parr and fry were captured at the Chiwawa Trap. Most (99%) of the hatchery steelhead were collected in May, while most (75%) of the wild steelhead smolts were captured in April through June (Figure 3.2). Although steelhead/rainbow parr and fry emigrated throughout the sampling period, peaks in emigration were observed in April through June and in October (Figure 3.2). Of the total number of wild steelhead captured, 87% were classified as parr and fry. Three mark-recapture efficiency trials were conducted with a pooled trap efficiency of 8.1%.

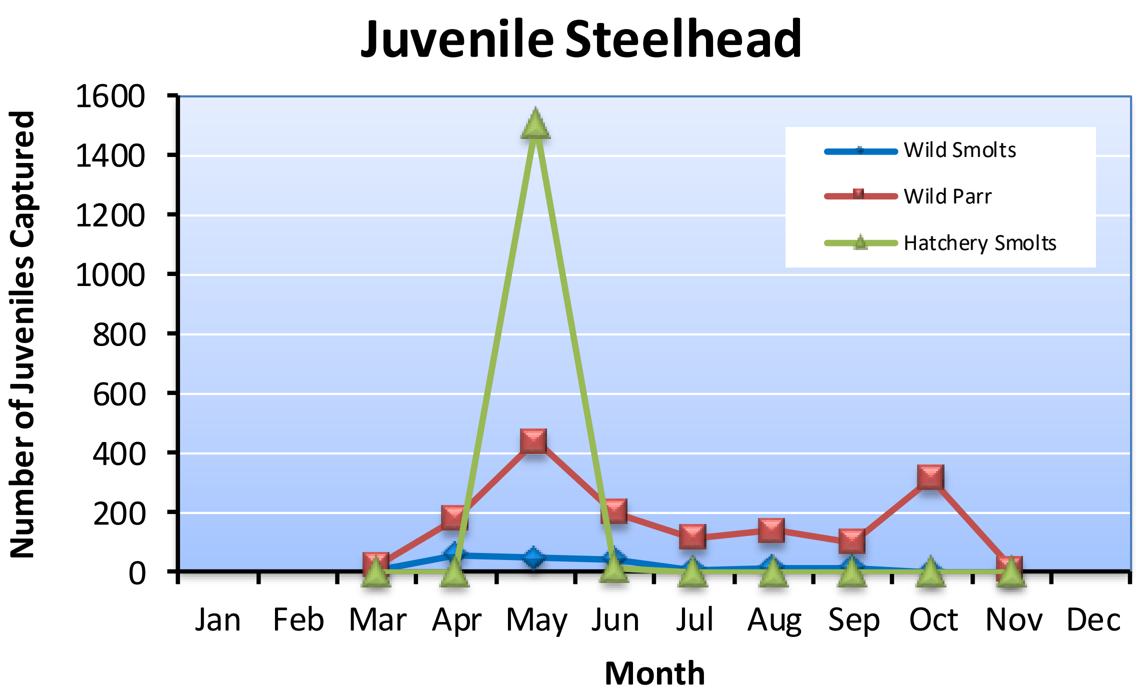

Figure 3.2. Monthly captures of wild smolts, wild parr, and hatchery smolt steelhead/rainbow at the Chiwawa Trap, 2016.

Nason Creek Trap

The Nason Creek Trap operated between 1 March and 30 November 2016. During the nine-month sampling period the trap was inoperable for 62 days because of low discharge and flooding. The trap captured a total of 9 wild steelhead smolts, 98 hatchery steelhead smolts, 663 wild steelhead parr, and 335 wild steelhead fry. The estimated wild steelhead emigration for brood year 2013 was

13,417 (± 9,133). Egg-to-emigrant survival rate for brood year 2012 steelhead was 1.7% and the egg-to-emigrant survival rate for brood year 2012 was 3.0%. Productivity, measured as emigrants-per-redd, was 99.

Lower Wenatchee Trap

The Lower Wenatchee Trap operated between 29 January and 26 June 2016. During that time, the trap was inoperable for 23 days because of too high and low river discharge, debris, elevated river temperatures, large hatchery releases, and mechanical issues. During the sampling period, a total of 329 wild steelhead parr and fry, 88 wild steelhead smolts, and 259 hatchery steelhead were captured at the trap. Because of the low numbers of steelhead encountered at the trap, it was not possible to carry out mark-recapture trials using steelhead. In addition, because there was a poor relationship between trap efficiency and river flow, a pooled estimate was used to derive the number of steelhead emigrants. Using this pooled method, it was estimated that 10,135 (±102,145) steelhead >50 mm FL emigrated out of the Wenatchee during the trapping season. Figure 3.3 shows the monthly captures of all steelhead collected at the Lower Wenatchee Trap. All fish captured in the trap are reported in Appendix B.

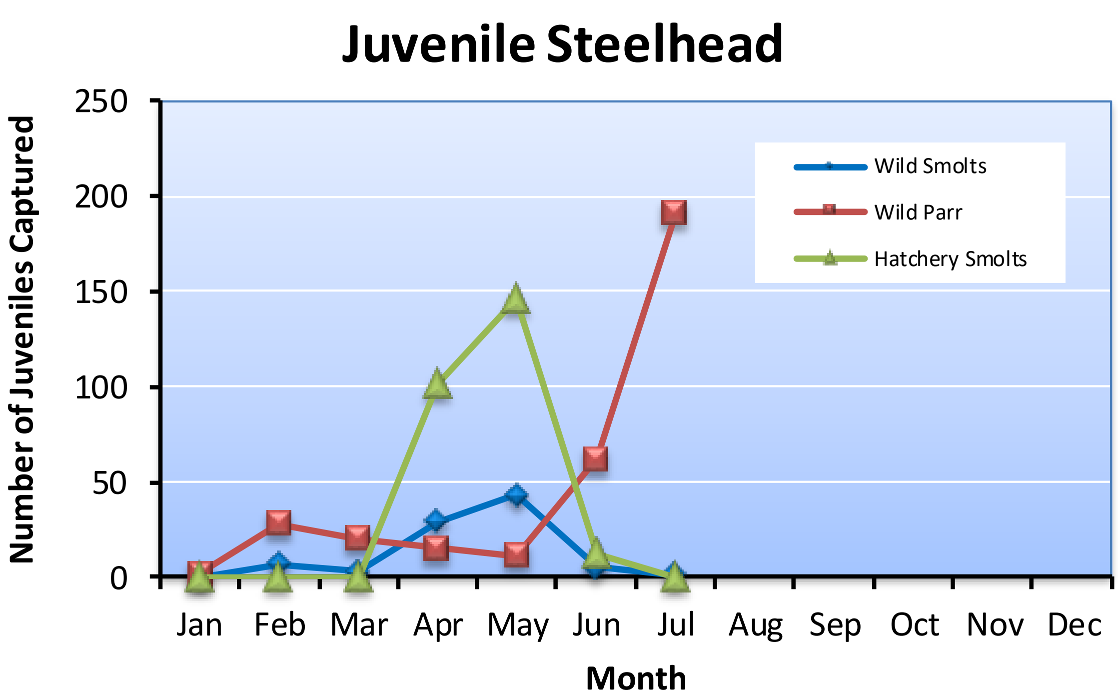

Figure 3.3. Monthly captures of wild smolts, wild parr, and hatchery smolt steelhead/rainbow at the Lower Wenatchee Trap, 2016.

PIT Tagging Activities

As part of the Comparative Survival Study (CSS) and PUD studies, a total of 1,980 juvenile steelhead/rainbow trout (1,979 wild and one hatchery) were PIT tagged and released in 2016 in the Wenatchee River basin (Table 3.15a). Most of these were tagged at the Chiwawa Trap. See Appendix C for a complete list of all fish captured, tagged, lost, and released.

Table 3.15a. Numbers of wild and hatchery steelhead/rainbow trout that were captured, tagged, and released at different locations within the Wenatchee River basin, 2016. Numbers of fish that died or shed tags are also given.

Sampling Location	Species and Life Stage	Number captured	Number of recaptures	Number tagged	Number died	Shed tags	Total tags released	Percent mortality
Chiwawa Trap	Wild Steelhead	1,717	18	1,323	10	10	1,313	0.58
	Hatchery Steelhead	1,518	0	1	0	0	1	0.00
	Total	**3,235**	**18**	**1,324**	**10**	**10**	**1/314**	**0.00**
Nason Creek Trap	Wild Steelhead	1,007	6	531	1	1	530	0.10
	Hatchery Steelhead	98	7	0	0	0	0	0.00
	Total	**1,105**	**13**	**531**	**1**	**1**	**530**	**0.00**
White River Trap	Wild Steelhead	5	0	5	0	0	5	0.00
	Hatchery Steelhead	0	0	0	0	0	0	0.00
	Total	**5**	**0**	**5**	**0**	**0**	**5**	**0.00**
Lower Wenatchee Trap	Wild Steelhead	417	0	131	6	0	131	1.44
	Hatchery Steelhead	259	0	0	1	0	0	0.37
	Total	**676**	**0**	**131**	**7**	**0**	**131**	**0.01**
Total:	**Wild Steelhead**	**3,146**	**24**	**1,990**	**17**	**11**	**1,979**	**0.01**
	Hatchery Steelhead	**1,875**	**7**	**1**	**1**	**0**	**1**	**0.00**
Grand Total:		**5,021**	**31**	**1,991**	**18**	**11**	**1,980**	**0.00**

Numbers of steelhead/rainbow PIT-tagged and released as part of CSS and PUD studies during the period 2006-2016 are shown in Table 3.15b.

Table 3.15b. Summary of the numbers of wild and hatchery steelhead/rainbow trout that were tagged and released at different locations within the Wenatchee River basin, 2006-2016.

Sampling Location	Species and Life Stage	Numbers of PIT-tagged steelhead/rainbow released										
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Chiwawa Trap	Wild Steelhead	1,366	832	1,431	1,127	930	1,012	1,011	1,228	1,186	1,795	1,313
	Hatchery Steelhead	0	3	2	1	2	1	2	0	3	1	1
	Total	**1,366**	**835**	**1,433**	**1,128**	**932**	**1,013**	**1,013**	**1,228**	**1,189**	**1,796**	**1,314**
Chiwawa River (Angling or Electrofish)	Wild Steelhead	33	167	94	35	99	0	0	0	23	0	0
	Hatchery Steelhead	1	47	35	43	64	0	0	0	0	0	0
	Total	**34**	**214**	**129**	**78**	**163**	**0**	**0**	**0**	**23**	**0**	**0**
Upper Wenatchee Trap[1]	Wild Steelhead	21	37	24	46	69	82	70	43	--	--	--
	Hatchery Steelhead	0	0	0	0	0	0	0	0	--	--	--
	Total	**21**	**37**	**24**	**46**	**69**	**82**	**70**	**43**	**--**	**--**	**--**
Nason Creek Trap	Wild Steelhead	1,167	1,335	2,154	753	1,557	805	1,087	1,998	838	383	**530**
	Hatchery Steelhead	0	0	0	0	0	0	538	0	0	0	**0**
	Total	**1,167**	**1,335**	**2,154**	**753**	**1,557**	**805**	**1,625**	**1,998**	**838**	**383**	**530**

Sampling Location	Species and Life Stage	Numbers of PIT-tagged steelhead/rainbow released										
		2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Nason Creek (Angling or Electrofish)	Wild Steelhead	174	452	255	459	318	0	0	0	0	0	0
	Hatchery Steelhead	26	75	87	197	32	0	0	0	0	0	0
	Total	**200**	**527**	**342**	**656**	**350**	**0**	**0**	**0**	**0**	**0**	**0**
White River Trap	Wild Steelhead	0	0	0	12	10	5	5	6	5	6	**5**
	Hatchery Steelhead	0	0	0	0	0	0	0	0	0	0	**0**
	Total	**0**	**0**	**0**	**12**	**10**	**5**	**5**	**6**	**5**	**6**	**5**
Upper Wenatchee (Angling or Electrofish)	Wild Steelhead	413	1,001	21	7	30	--	--	--	--	--	--
	Hatchery Steelhead	2	64	26	23	9	--	--	--	--	--	--
	Total	**415**	**1,065**	**47**	**30**	**39**	**--**	**--**	**--**	**--**	**--**	**--**
Middle Wenatchee (Angling or Electrofish)	Wild Steelhead	0	0	981	867	1,517	0	0	850	--	--	--
	Hatchery Steelhead	0	0	11	5	57	0	0	2	--	--	--
	Total	**0**	**0**	**992**	**872**	**1,574**	**0**	**0**	**852**	**--**	**--**	**--**
Lower Wenatchee (Angling or Electrofish)	Wild Steelhead	0	0	102	69	--	--	--	--	--	--	--
	Hatchery Steelhead	0	0	10	9	--	--	--	--	--	--	--
	Total	**0**	**0**	**112**	**78**	**--**	**--**	**--**	**--**	**--**	**--**	**--**
Peshastin Creek (Angling or Electrofish)	Wild Steelhead	0	0	0	92	307	--	--	--	--	--	--
	Hatchery Steelhead	0	0	0	0	0	--	--	--	--	--	--
	Total	**0**	**0**	**0**	**92**	**307**	**--**	**--**	**--**	**--**	**--**	**--**
Lower Wenatchee Trap	Wild Steelhead	131	461	285	227	465	0	0	613	133	290	131
	Hatchery Steelhead	0	0	0	1	0	0	0	0	4	1	0
	Total	**131**	**461**	**285**	**228**	**465**	**0**	**0**	**613**	**137**	**291**	**131**
Total:	**Wild Steelhead**	**3,305**	**4,285**	**5,347**	**3,694**	**5,302**	**1,904**	**2,173**	**4,738**	**2,185**	**2,474**	**1,979**
	Hatchery Steelhead	**29**	**189**	**171**	**279**	**164**	**1**	**540**	**2**	**7**	**2**	**1**
Grand Total:		**3,334**	**4,474**	**5,518**	**3,973**	**5,466**	**1,905**	**2,713**	**4,740**	**2,192**	**2,476**	**1,980**

[1] 2013 was the last year that the Upper Wenatchee Trap operated.

3.5 Spawning Surveys

Surveys for steelhead redds were conducted during March through early June 2016, in the mainstem Wenatchee River and portions of select tributaries (Chiwawa River, Nason Creek, and Peshastin Creek). Beginning in 2014, adult steelhead escapement estimates in the majority of tributaries in the Wenatchee River basin were generated using mark-recapture techniques based on steelhead PIT tagged at Priest Rapids Dam (BPA funded; see Appendix D and Truscott et al. 2016 for details).

Redd Counts

A total estimate of 126 steelhead redds were counted in the Wenatchee River and the lower portions of select tributaries in 2016 (Table 3.16). Because steelhead escapement estimates in tributaries are based on mark-recapture techniques, there are no or limited redd counts in tributaries beginning in 2014. Additionally, mainstem redd counts since 2014 were expanded based on estimates of observer efficiency (see Appendix D). Thus, evaluation of trends in redd counts is appropriate only before 2014.

Table 3.16. Numbers of steelhead redds estimated within different streams/watersheds within the Wenatchee River basin, 2001-2016; NS = not surveyed. Redd counts from 2004-2013 have been conducted within the same areas and with the same methods. Beginning in 2014, complete redd counts were conducted only within the mainstem Wenatchee River. Therefore, trends in redd counts are only appropriate for the mainstem Wenatchee River from 2004 through 2013.

Survey year	Number of steelhead redds							
	Chiwawa	Nason	Little Wenatchee	White	Wenatchee River[a]	Icicle	Peshastin	Total
2001	25	27	NS	NS	116	19	NS	**187**
2002	80	80	1	0	315	27	NS	**503**
2003	64	121	5	3	248	16	15	**472**
2004	62	127	0	0	151	23	34	**397**
2005	162	412	0	2	459	8	97	**1,140**
2006	19	77	NS	0	191	41	67	**395**
2007	11	78	0	1	46	6	17	**159**
2008	11	88	NS	1	100	37	49	**286**
2009	75	126	0	0	327	102	32	**662**
2010	74	270	4	3	380	120	118	**969**
2011	77	235	2	0	323	180	115	**932**
2012	8	158	0	0	137	47	65	**415**
2013	27	135	NS	NS	200	48	62	**472**
2014	5	0	NS	NS	195[b]	NS	5	**205**
2015	1	1	NS	NS	258[b]	NS	1	**262**
2016	0	0	NS	NS	126[b]	NS	0	**126**

[a] Includes redds in Beaver and Chiwaukum creeks.
[b] Steelhead redd counts in the mainstem Wenatchee River were expanded based on estimated observer efficiency (see Appendix D).

Redd Distribution

Steelhead redds were not evenly distributed among survey reaches on the Wenatchee River in 2016 (Table 3.17). About 91.3% of the spawning in the Wenatchee River occurred upstream from Tumwater Dam (Table 3.17).

Table 3.17. Numbers and percentages of steelhead redds counted within different reaches on the Wenatchee River during March through early June, 2016; CV = coefficient of variation, NA = not available, NS = not surveyed.

Reach	Reach type	Number of redds counted	Expanded redd counts		Percent of redds within stream/watershed
			Estimated	CV	
Wenatchee 1 (W1)	Non-index	0	0	NA	0.0
Wenatchee 2 (W2)	Index	0	0	NA	0.0

Reach	Reach type	Number of redds counted	Expanded redd counts		Percent of redds within stream/watershed
			Estimated	CV	
Wenatchee 3 (W3)	Non-index	0	0	NA	0.0
Wenatchee 4 (W4)	Non-index	0	0	NA	0.0
Wenatchee 5 (W5)	Non-index	0	0	NA	0.0
Wenatchee 6 (W6)	Index	11	11	1.42	8.7
Wenatchee 6 (W6)	Non-index	0	0	NA	0.0
Wenatchee 7 (W7)	NS	NA	NA	NA	NA
Wenatchee 8 (W8)	Index	1	1	0.59	0.8
Wenatchee 9 (W9)	Index	23	26	1.48	20.6
Wenatchee 9 (W9)	Non-index	3	3	0.42	2.4
Wenatchee 10 (W10)	Index	72	82	1.39	65.1
Wenatchee 10 (W10)	Non-index	2	3	0.34	2.4
Total		**112**	**126**	**1.04**	**100.0**

Spawn Timing

Steelhead began spawning during the second week of March in the Wenatchee River. Spawning activity appeared to begin once the mean daily stream temperature reached about 5.5°C and was observed in water temperatures ranging from 3.7-8.8°C. Steelhead spawning peaked during the third week of April in the Wenatchee River (Figure 3.4).

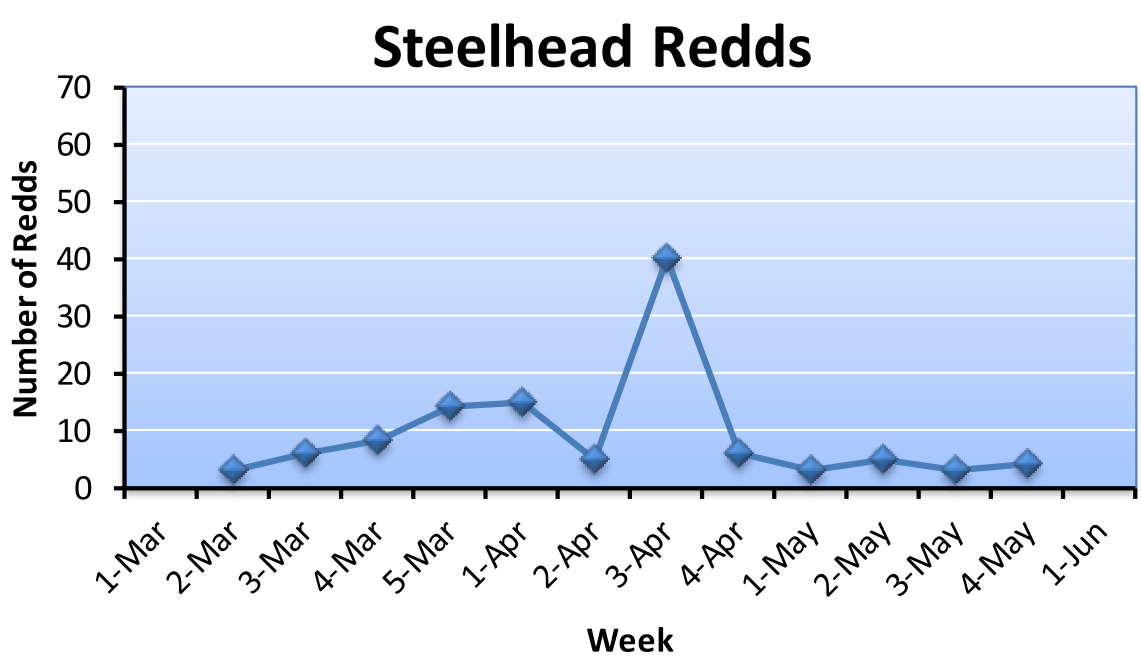

Figure 3.4. Numbers of steelhead redds counted during different weeks on the Wenatchee River, March through early June 2016.

Spawning Escapement

Before 2014, steelhead spawning escapement upstream from Tumwater Dam was calculated as the number of redds (in the Wenatchee River and tributaries upstream from the dam) times the fish per redd ratio (based on sex ratios estimated at Tumwater Dam using video surveillance).[6] Beginning in 2014, escapement in tributaries was estimated using PIT-tag mark-recapture techniques (Truscott et al. 2016; Table 3.18), while observer efficiency expanded redd counts were used to estimate escapement in the mainstem Wenatchee River (Appendix D). Total redd counts were also used to estimate escapement in the lower portions of the main tributaries (downstream from the PIT interrogation sites).

Table 3.18. Spawning escapement estimates for natural-origin and hatchery-origin steelhead within tributaries of the Wenatchee River, brood year 2016. Escapement estimates were based on PIT-tag mark-recapture techniques (Truscott et al. 2016). CV = coefficient of variation and NA = not available.

Tributary	Natural-origin steelhead		Hatchery-origin steelhead	
	Estimate	CV	Estimate	CV
Mission Creek	33	0.38	13	0.69
Peshastin Creek	151	0.19	0	NA
Chumstick Creek	74	0.27	39	0.37
Icicle Creek	72	0.25	18	0.53
Chiwaukum Creek	64	0.36	11	1.00
Chiwawa River	45	0.44	134	0.35
Nason Creek	57	0.39	94	0.32

The estimated fish per redd ratio for steelhead in 2016 was 1.65 (Table 3.19). Multiplying this ratio by the total number of redds estimated in the Wenatchee River upstream from Tumwater Dam resulted in a spawning escapement of 167 steelhead (Table 3.19). Adding this estimate to the mark-recapture estimates of tributary escapement (239 hatchery + 166 wild = 405) indicates that 572 (CV = 0.167) escaped to spawning areas upstream from Tumwater Dam in 2016 (see Appendix D).

Table 3.19. Numbers of steelhead counted at Tumwater Dam, fish/redd estimates (based on male-to-female ratios estimated at Tumwater Dam), numbers of steelhead redds counted upstream from Tumwater Dam, total spawning escapement upstream from Tumwater Dam (estimated as the total number of redds times the fish/redd ratio), and the proportion of the Tumwater Dam count that made up the spawning escapement. Beginning in 2014, escapements include estimates from redd counts in the Wenatchee River and mark-recapture techniques in tributaries.

Survey year	Total count at Tumwater Dam	Fish/redd	Number of redds			Spawning escapement[a]	Proportion of Tumwater count that spawned
			Index area	Non-index area	Total redds		
2001	820	2.08	118	19	137	285	0.35
2002	1,720	2.68	296	179	475	1,273	0.74
2003	1,810	1.60	353	88	441	706	0.39

[6] Expansion factor = (1 + (number of males/number of females)).

Survey year	Total count at Tumwater Dam	Fish/redd	Number of redds			Spawning escapement[a]	Proportion of Tumwater count that spawned
			Index area	Non-index area	Total redds		
2004	1,869	2.21	277	92	369	815	0.44
2005	2,650	1.61	828	136	964	1,552	0.59
2006	1,053	2.05	192	34	226	463	0.44
2007	657	1.94	105	29	134	260	0.40
2008	1,328	2.81	124	35	159	447	0.34
2009	1,781	1.83	284	107	391	716	0.40
2010	2,270	2.33	546	95	641	1,494	0.66
2011	1,130	1.79	427	33	460	823	0.73
2012	1,055	2.00	273	22	295	590	0.56
2013	1,087	1.65	276	9	285	470	0.43
Average[b]	***1,488***	***2.02***	***333***	***59***	***392***	***763***	***0.50***
Median	***1,328***	***2.00***	***277***	***35***	***369***	***706***	***0.44***
2014	865	1.70	124	0	124	839	0.97
2015	1,009	1.78	232	11	243	1,123	1.11
2016	1,017	1.65	120	6	126	572	0.56
Average[c]	***964***	***1.71***	***159***	***6***	***164***	***845***	***0.88***
Median	***1,009***	***1.70***	***124***	***6***	***126***	***839***	***0.97***

[a] Escapement estimates before 2014 were based on expanded redd counts in the Wenatchee River and tributaries; escapement estimates beginning in 2014 were based on expanded redd counts within the Wenatchee River and mark-recapture techniques in tributaries.
[b] The average and median are based on estimates from 2004 to 2013.
[c] The average and median are based on estimates from 2014 to present.

3.6 Life History Monitoring

Life history characteristics of steelhead were assessed by examining fish collected at broodstock collection sites, examining videotape at Tumwater Dam, and by reviewing tagging data and fisheries statistics. Before brood year 2011, some statistics could not be calculated because few steelhead were tagged with CWTs. Since brood year 2011, all steelhead released from the hatchery program have been tagged with CWTs. In addition, about 23,101 of the 2015 brood were PIT tagged. With the placement of remote PIT tag detectors in spawning streams in 2007 and 2008, statistics such as origin on spawning grounds, stray rates, and SARs can be estimated more accurately.

Migration Timing

Sampling at Tumwater Dam indicates that steelhead migrate throughout the year; however, the migration distribution is bimodal, indicating that steelhead migrate past Tumwater Dam in two pulses: one pulse during summer-autumn the year before spawning and another during winter-spring the year of spawning (Figure 3.5). Most steelhead passed Tumwater Dam during July through October and April. The highest proportion of both wild and hatchery fish migrated during October.

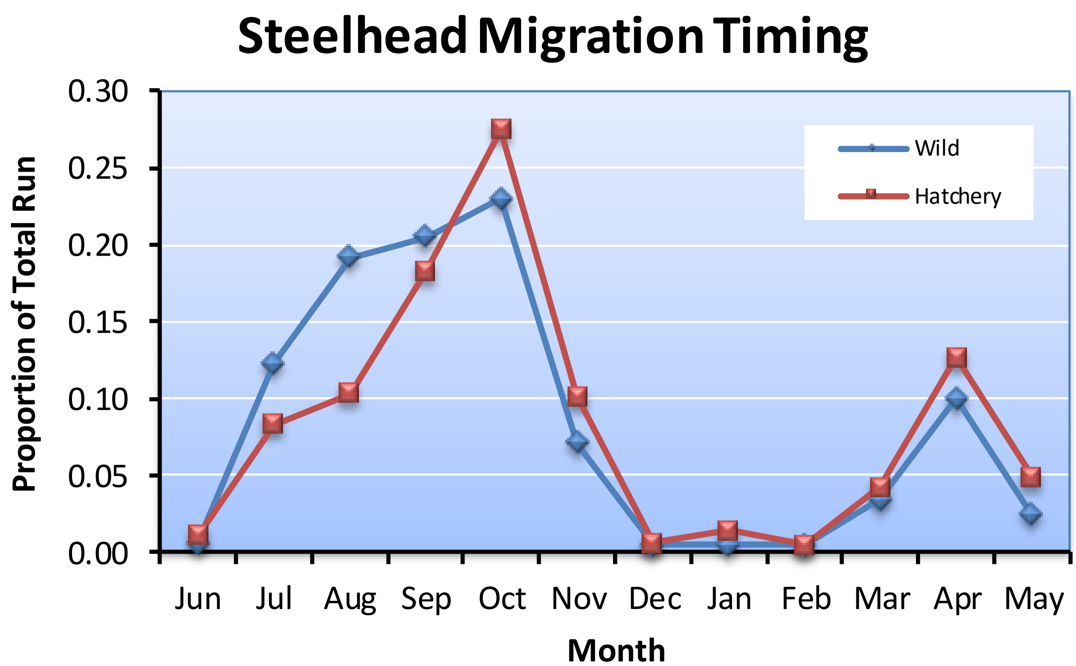

Figure 3.5. Proportion of wild and hatchery steelhead sampled at Tumwater Dam for the combined brood years of 1999-2016.

Because the migration of steelhead is bimodal, we estimated migration statistics separately for each migration pulse (i.e., summer-autumn migration and winter-spring migration). That is, we compared migration statistics for wild and hatchery steelhead passing Tumwater Dam during the summer-autumn period independent of those for the winter-spring migration period. We estimated the week and month that 10%, 50% (median), and 90% of the wild and hatchery steelhead passed Tumwater Dam during the two migration periods. We also estimated the mean weekly and monthly migration timing for wild and hatchery steelhead.

Migration timing of wild and hatchery fish at Tumwater Dam varied depending on the migration season (Table 3.20a and b; Figure 3.5). For the summer-autumn migration period, wild steelhead arrived at the dam about one week earlier than hatchery steelhead. In contrast, there was little difference in migration timing of wild and hatchery steelhead during the winter-spring migration period.

Table 3.20a. The week that 10%, 50% (median), and 90% of the wild and hatchery steelhead passed Tumwater Dam during their summer-autumn migration (June through December) and during their winter-spring migration (January through May), 1999-2016. The average week is also provided for both migration periods. Migration timing is based on video sampling at Tumwater. The presence of eroded fins and/or missing adipose fins was used to distinguish hatchery fish from wild fish during video monitoring at Tumwater Dam. Estimates also include steelhead collected for broodstock.

Spawn year	Origin	Steelhead Migration Time (week)									
		Summer-Autumn Migration (Jun-Dec)					Winter-Spring Migration (Jan-May)				
		10%	50%	90%	Mean	Sample size	10%	50%	90%	Mean	Sample size
1999	Wild	27	32	47	35	81	12	16	17	15	29
	Hatchery	25	31	47	34	47	12	16	18	15	27
2000	Wild	31	36	41	36	238	11	14	18	14	40
	Hatchery	31	34	41	36	194	12	14	16	14	69
2001	Wild	29	34	41	35	391	13	15	17	15	84
	Hatchery	30	38	41	36	227	12	16	17	15	156
2002	Wild	29	39	46	38	810	13	14	17	14	181
	Hatchery	35	42	46	41	610	12	15	18	15	124
2003	Wild	30	33	40	35	731	3	9	16	9	193
	Hatchery	30	35	51	37	372	3	9	15	9	538
2004	Wild	30	40	45	39	644	13	16	18	16	222
	Hatchery	29	40	44	38	677	11	17	19	16	361
2005	Wild	30	39	43	38	986	10	15	17	15	206
	Hatchery	27	38	42	36	1,112	12	16	18	15	377
2006	Wild	29	40	43	39	428	12	15	17	15	191
	Hatchery	29	41	43	39	334	4	13	16	12	181
2007	Wild	30	36	41	35	277	11	17	17	15	108
	Hatchery	29	38	43	36	90	11	17	18	16	214
2008	Wild	30	38	43	38	397	13	15	18	16	123
	Hatchery	33	41	45	40	554	14	18	19	17	311
2009	Wild	30	37	46	37	338	13	15	19	15	87
	Hatchery	29	35	46	36	1,133	13	16	19	16	229
2010	Wild	31	37	45	38	648	11	15	18	15	171
	Hatchery	31	40	45	40	1,207	12	16	19	16	309
2011	Wild	29	36	44	36	797	13	17	19	17	118
	Hatchery	31	39	45	39	991	15	18	19	18	240
2012	Wild	31	34	41	35	642	15	20	20	17	83
	Hatchery	32	39	43	38	715	15	19	19	17	223
2013	Wild	31	36	43	37	755	13	16	18	15	55
	Hatchery	31	42	45	40	1,431	16	17	18	16	210
2014	Wild	29	35	41	35	549	14	18	19	17	57

Spawn year	Origin	Steelhead Migration Time (week)									
		Summer-Autumn Migration (Jun-Dec)					Winter-Spring Migration (Jan-May)				
		10%	50%	90%	Mean	Sample size	10%	50%	90%	Mean	Sample size
	Hatchery	32	40	42	38	511	15	17	19	17	78
2015	Wild	29	38	43	37	714	11	14	17	14	48
	Hatchery	32	39	43	39	928	12	16	17	15	57
2016	Wild	34	41	45	39	610	13	16	19	16	58
	Hatchery	36	41	44	40	692	12	16	19	15	56
Average	***Wild***	***30***	***37***	***43***	***37***	***558***	***12***	***15***	***18***	***15***	***114***
	Hatchery	***31***	***39***	***44***	***38***	***657***	***12***	***16***	***18***	***15***	***209***
Median	***Wild***	***30***	***37***	***43***	***37***	***626***	***13***	***15***	***18***	***15***	***98***
	Hatchery	***31***	***39***	***44***	***38***	***610***	***12***	***16***	***18***	***16***	***214***

Table 3.20b. The month that 10%, 50% (median), and 90% of the wild and hatchery steelhead passed Tumwater Dam during their summer-autumn migration (June through December) and during their winter-spring migration (January through May), 1999-2016. The average month is also provided for both migration periods. Migration timing is based on video sampling at Tumwater. The presence of eroded fins and/or missing adipose fins was used to distinguish hatchery fish from wild fish during video monitoring at Tumwater Dam. Estimates also include steelhead collected for broodstock.

Spawn year	Origin	Steelhead Migration Time (month)									
		Summer-Autumn Migration (Jun-Dec)					Winter-Spring Migration (Jan-May)				
		10%	50%	90%	Mean	Sample size	10%	50%	90%	Mean	Sample size
1999	Wild	7	8	11	8	81	3	4	4	4	29
	Hatchery	6	8	11	8	47	3	4	4	4	27
2000	Wild	8	9	10	9	238	3	4	5	4	40
	Hatchery	8	8	10	9	194	3	4	4	4	69
2001	Wild	7	8	10	8	391	3	4	4	4	84
	Hatchery	7	9	10	9	227	3	4	4	4	156
2002	Wild	7	9	11	9	810	3	4	4	4	181
	Hatchery	9	10	11	10	610	3	4	5	4	124
2003	Wild	7	8	10	8	731	1	3	4	3	193
	Hatchery	7	8	12	9	372	1	3	4	2	538
2004	Wild	7	10	11	9	644	3	4	4	4	222
	Hatchery	7	10	10	9	677	3	4	5	4	361
2005	Wild	7	9	10	9	986	3	4	4	4	206
	Hatchery	7	9	10	9	1,112	3	4	5	4	377
2006	Wild	7	10	10	10	428	3	4	4	4	191
	Hatchery	7	10	10	9	334	1	3	4	3	181
2007	Wild	7	9	10	9	277	3	4	4	4	108
	Hatchery	7	9	10	9	90	3	4	5	4	214

Spawn year	Origin	Steelhead Migration Time (month)									
		Summer-Autumn Migration (Jun-Dec)					Winter-Spring Migration (Jan-May)				
		10%	50%	90%	Mean	Sample size	10%	50%	90%	Mean	Sample size
2008	Wild	7	9	10	9	397	3	4	5	4	123
	Hatchery	8	10	11	10	554	4	4	5	4	311
2009	Wild	7	9	11	9	338	3	4	5	4	87
	Hatchery	7	8	11	9	1,133	3	4	5	4	229
2010	Wild	8	9	11	9	648	3	4	5	4	171
	Hatchery	8	10	11	10	1,207	3	4	5	4	309
2011	Wild	7	9	11	9	797	4	4	5	4	118
	Hatchery	8	9	11	9	991	4	5	5	5	240
2012	Wild	8	8	10	9	642	4	4	5	4	83
	Hatchery	8	9	10	9	715	4	4	5	4	223
2013	Wild	8	9	10	9	755	4	4	5	4	55
	Hatchery	8	10	11	10	1,431	4	4	5	4	210
2014	Wild	7	9	10	9	549	4	4	5	4	57
	Hatchery	8	10	10	9	511	4	4	5	4	78
2015	Wild	7	9	10	9	714	3	4	4	4	48
	Hatchery	8	9	10	9	928	3	4	4	4	57
2016	Wild	8	10	11	9	610	3	4	5	4	58
	Hatchery	9	10	10	10	692	3	4	5	4	56
Average	***Wild***	***7***	***9***	***10***	***9***	***558***	***3***	***4***	***5***	***4***	***114***
	Hatchery	***8***	***9***	***11***	***9***	***657***	***3***	***4***	***5***	***4***	***209***
Median	***Wild***	***7***	***9***	***10***	***9***	***626***	***3***	***4***	***5***	***4***	***98***
	Hatchery	***8***	***9***	***10***	***9***	***644***	***3***	***4***	***5***	***4***	***212***

Age at Maturity

Nearly all steelhead broodstock collected at Tumwater and Dryden dams lived in saltwater 1 to 2 years (saltwater age) (Table 3.21). Very few saltwater age-3 fish returned and those that did were wild fish. On average, there was a difference between the saltwater age at return of wild and hatchery fish. A greater proportion of hatchery fish returned as saltwater age-1 fish than did wild fish. In contrast, a greater number of wild fish returned as saltwater-2 fish than did hatchery fish (Figure 3.6).

Table 3.21. Proportions of wild and hatchery steelhead broodstock of different ages collected at Tumwater and Dryden dams, brood years 1998-2016. Age represents the number of years the fish lived in salt water.

Brood year	Origin	Saltwater age			Sample size
		1	2	3	
1998	Wild	0.39	0.61	0.00	35
	Hatchery	0.21	0.79	0.00	43

Brood year	Origin	Saltwater age			Sample size
		1	2	3	
1999	Wild	0.50	0.48	0.02	58
	Hatchery	0.82	0.18	0.00	67
2000	Wild	0.56	0.44	0.00	39
	Hatchery	0.68	0.32	0.00	101
2001	Wild	0.52	0.48	0.00	64
	Hatchery	0.15	0.85	0.00	114
2002	Wild	0.56	0.44	0.00	99
	Hatchery	0.95	0.05	0.00	113
2003	Wild	0.13	0.85	0.02	63
	Hatchery	0.29	0.71	0.00	92
2004	Wild	0.95	0.05	0.00	85
	Hatchery	0.95	0.05	0.00	132
2005	Wild	0.22	0.78	0.00	95
	Hatchery	0.21	0.79	0.00	114
2006	Wild	0.29	0.71	0.00	101
	Hatchery	0.60	0.40	0.00	98
2007	Wild	0.40	0.59	0.00	79
	Hatchery	0.62	0.38	0.00	97
2008	Wild	0.65	0.34	0.01	104
	Hatchery	0.89	0.11	0.00	107
2009	Wild	0.40	0.58	0.20	83
	Hatchery	0.23	0.77	0.0	77
2010	Wild	0.65	0.34	0.01	92
	Hatchery	0.77	0.23	0.00	98
2011	Wild	0.28	0.73	0.00	102
	Hatchery	0.36	0.64	0.00	100
2012	Wild	0.42	0.53	0.05	59
	Hatchery	0.41	0.59	0.00	66
2013	Wild	0.41	0.57	0.02	54
	Hatchery	0.46	0.55	0.00	77
2014	Wild	0.48	0.51	0.02	61
	Hatchery	0.29	0.71	0.00	68
2015	Wild	0.16	0.83	0.02	63
	Hatchery	0.47	0.53	0.00	55
2016	Wild	0.34	0.66	0.00	65
	Hatchery	0.42	0.58	0.00	66
Average	***Wild***	***0.44***	***0.54***	***0.02***	***75***
	Hatchery	***0.54***	***0.46***	***0.00***	***89***

Brood year	Origin	Saltwater age			Sample size
		1	2	3	
Median	***Wild***	***0.45***	***0.55***	***0.00***	***65***
	Hatchery	***0.48***	***0.52***	***0.00***	***97***

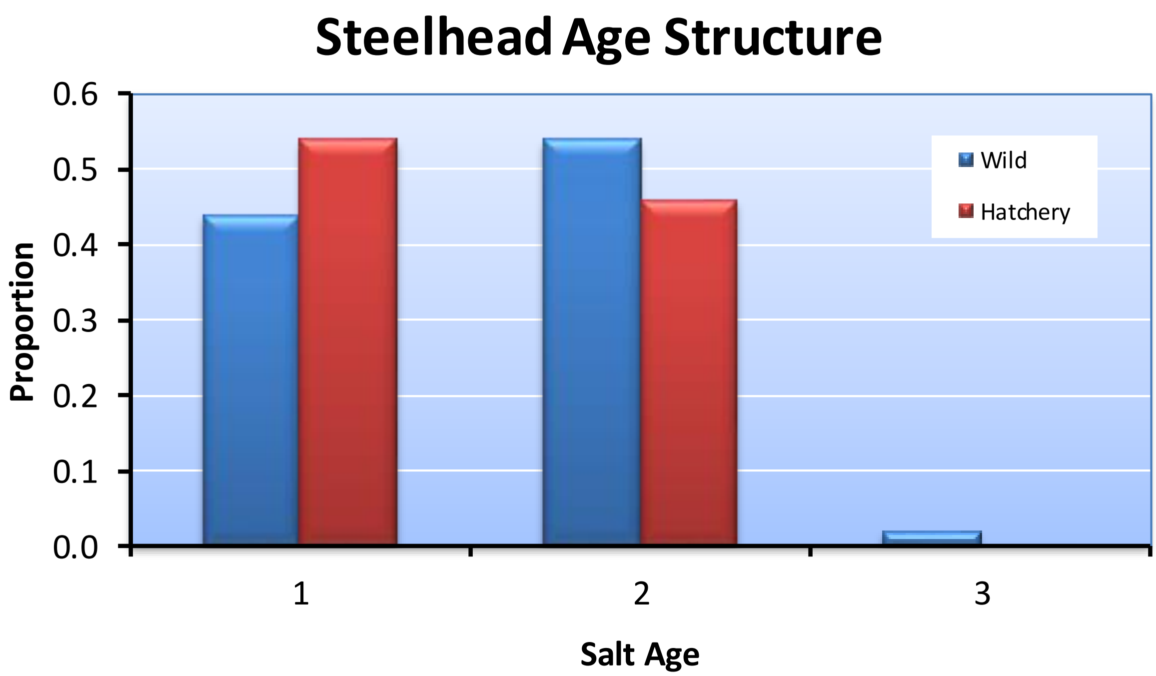

Figure 3.6. Proportions of wild and hatchery steelhead of different saltwater ages sampled at Tumwater Dam for the combined years 1998-2016.

Size at Maturity

On average, hatchery steelhead collected at Tumwater and Dryden dams were about 2 to 3 cm smaller than wild steelhead (Table 3.22).

Table 3.22. Mean fork length (cm) at age (saltwater ages) of hatchery and wild steelhead collected from broodstock, brood years 1998-2016; N = sample size and SD = 1 standard deviation.

Brood year	Origin	Steelhead fork length (cm)								
		1-Salt			2-Salt			3-Salt		
		Mean	N	SD	Mean	N	SD	Mean	N	SD
1998	Wild	63	15	4	79	20	5	-	0	-
	Hatchery	61	9	4	73	34	4	-	0	-
1999	Wild	65	29	5	74	28	5	77	1	-
	Hatchery	62	54	4	73	12	4	-	0	-
2000	Wild	64	22	3	74	17	5	-	0	-

Brood year	Origin	Steelhead fork length (cm)								
		1-Salt			2-Salt			3-Salt		
		Mean	N	SD	Mean	N	SD	Mean	N	SD
	Hatchery	60	57	3	71	27	4	-	0	-
2001	Wild	61	33	6	77	31	5	-	0	-
	Hatchery	62	17	4	72	97	4	-	0	-
2002	Wild	64	55	4	77	44	4	-	0	-
	Hatchery	63	106	4	73	6	4	-	0	-
2003	Wild	69	8	6	77	52	5	91	1	-
	Hatchery	66	27	4	75	65	4	-	0	-
2004	Wild	63	73	6	78	4	2	-	0	-
	Hatchery	61	59	3	73	3	1	-	0	-
2005	Wild	59	21	4	74	74	5	-	0	-
	Hatchery	59	23	4	72	89	4	-	0	-
2006	Wild	63	27	5	75	67	6	-	0	-
	Hatchery	61	41	4	72	27	5	-	0	-
2007	Wild	64	31	6	76	46	5	-	0	-
	Hatchery	60	60	4	71	36	5	-	0	-
2008	Wild	64	68	4	77	35	4	80	2	-
	Hatchery	60	95	4	72	12	2	-	0	-
2009	Wild	65	33	5	76	48	6	81	2	0
	Hatchery	63	18	4	75	59	5	-	0	-
2010	Wild	64	60	5	74	31	5	76	1	-
	Hatchery	61	53	5	73	23	5	-	0	-
2011	Wild	62	28	5	76	74	5	-	0	-
	Hatchery	60	36	4	74	64	4	-	0	-
2012	Wild	63	25	3	74	31	5	74	3	2
	Hatchery	59	27	3	74	39	4	-	0	-
2013	Wild	61	22	5	77	31	5	74	1	-
	Hatchery	60	35	3	74	42	4	-	0	-
2014	Wild	61	29	4	75	31	4	61	1	-
	Hatchery	60	20	3	72	48	4	-	0	-
2015	Wild	61	10	3	77	52	4	85	1	-
	Hatchery	59	26	3	76	29	5	-	0	-
2016	Wild	62	22	4	74	43	4	-	0	-
	Hatchery	61	28	4	71	38	5	-	0	-
Average	***Wild***	***63***	***32***	***5***	***76***	***40***	***5***	***78***	***1***	***1***
	Hatchery	***61***	***42***	***4***	***73***	***39***	***4***	***-***	***0***	***-***
Median	***Wild***	***63***	***28***	***5***	***76***	***35***	***5***	***77***	***0***	***1***
	Hatchery	***61***	***35***	***4***	***73***	***36***	***4***	***-***	***0***	***-***

Contribution to Fisheries

Nearly all harvest on Wenatchee steelhead occurs within the Columbia basin. Harvest rates on steelhead in the Lower Columbia River fisheries (both tribal and non-tribal) are generally less than 5-10% (NMFS 2004). A sport fishery may be opened on Upper Columbia River steelhead when the natural-origin steelhead run is predicted to exceed 1,300 fish at Priest Rapids Dam and the total Upper Columbia River steelhead run is predicted to exceed 9,550 steelhead. To minimize effects on natural-origin steelhead in the tributary fisheries, a three-tiered system as outlined in Permit 1395 is used to determine maximum allowable natural-origin steelhead take during the fishery (Table 3.23a).

Table 3.23a. Three-tiered system for determining natural-origin effects during the recreational fishery on steelhead in tributaries upstream from Rock Island Dam.

Tier	Wenatchee		Methow		Okanogan	
	NOR[1]	Effect[2]	NOR[1]	Effect[2]	NOR[1]	Effect[2]
No Fishery	≤ 599	0%	≤ 499	0%	≤ 119	0%
Tier 1	600	2%	500	2%	120	5%
Tier 2	1700	4%	1600	4%	120	7%
Tier 3	2500	6%	2500	6%	600	10%

[1.] Estimated natural-origin escapement to tributaries.
[2.] Maximum allowable take on natural-origin fish.

WDFW implemented a selective recreational steelhead fishery in the upper Columbia River during fall 2015 through winter 2016 (Table 3.23b). The fishery was conducted as a conservation measure to reduce the proportion of hatchery-origin steelhead on the spawning grounds. There were 56 hatchery steelhead harvested and an additional eight wild steelhead hook-and-release mortalities estimated for the Wenatchee River basin. Over the eight years that the Wenatchee River had a recreational fishery, average harvest has been about 183 hatchery steelhead and 16 wild steelhead hook-and-release mortalities. In the mixed population fishery within the mainstem Columbia from Priest Rapids Dam to Chief Joseph Dam, the average harvest of hatchery steelhead has been 861steelhead with 17 wild hook-and-release mortalities.

Table 3.23b. Harvest and mortality estimates for Upper Columbia steelhead in the Wenatchee and mainstem Columbia River (Priest Rapids Dam to Chief Joseph Dam). Estimated steelhead sport harvest on Wenatchee hatchery steelhead and hook-and-release mortality on wild steelhead (WDFW 2016). The wild steelhead mortality estimate is based on a hook-and-release mortality rate of 5%. Mainstem harvest from Priest Rapids Dam to Chief Joseph Dam is a mixed-population steelhead fishery that may contain fish from the Wenatchee, Entiat, Methow, and Okanogan rivers.

Year	Priest Rapids Escapement			Wenatchee			Mainstem Columbia		
	H	W	Total	H	W	Total	H	W	Total
2006-2007	--	--	--	--	--	--	694	3	697
2007-2008	--	--	--	444	15	459	1,137	13	1,150
2008-2009	14,147	3,232	17,379	--	--	--	921	10	931
2009-2010	29,206	5,682	34,888	251	17	268	1,448	29	1,477
2010-2011	18,710	7,642	26,352	106	12	118	1,412	40	1,452
2011-2012	13,230	4,092	17,322	250	19	269	855	22	877

2012-2013	--	--	--	125	26	151	722	20	744
2013-2014	8,417	4,211	12,628	135	17	152	506	9	515
2014-2015	15,791	5,218	21,009	99	14	113	99	14	113
2015-2016	8,696	2,829	11,525	56	8	64	678	13	690
Average	***15,457***	***4,701***	***20,158***	***183***	***16***	***199***	***861***	***17***	***865***
Median	***14,147***	***4,211***	***17,379***	***130***	***16***	***152***	***855***	***13***	***811***

Origin on Spawning Grounds

With the implementation of PIT-tag mark-recapture techniques in 2014, we can estimate the contribution of natural-origin and hatchery-origin fish on the spawning grounds (Table 3.24). Based on mark-recapture estimates, naturally produced steelhead made up about 60.6% of the escapement in 2016. Importantly, the abundance of hatchery fish in the upper Wenatchee Basin was regulated through surplusing (removal) at Tumwater Dam. A total of 290 hatchery steelhead were surplused at the dam resulting in the passage of 1,025 steelhead over the dam in 2016. Natural-origin steelhead comprised 59.4% (N = 609) of the steelhead that passed the dam.

Table 3.24. Spawning escapement estimates for natural-origin and hatchery-origin steelhead within the Wenatchee River, brood years 2014-2016. Escapement estimates were based on PIT-tag mark-recapture techniques (see Appendix D).

Tributary	Natural-origin steelhead			Hatchery-origin steelhead		
	2014	2015	2016	2014	2015	2016
Mission Creek	94	71	33	31	23	13
Peshastin Creek	226	206	151	6	40	0
Chumstick Creek	78	38	74	7	0	39
Icicle Creek	76	83	72	45	52	18
Chiwaukum Creek	37	48	64	9	12	11
Chiwawa River	142	168	45	103	168	134
Nason Creek	190	237	57	148	68	94
Wenatchee River	340	252	118	251	298	91
Total	***978***	***1,103***	***614***	***545***	***661***	***400***

Straying

Stray rates of Wenatchee steelhead can be estimated by examining the locations where PIT-tagged hatchery steelhead were last detected. PIT tagging of steelhead began with brood year 2005, which allows estimation of stray rates by brood return. These data only provide estimates for brood years 2005 through 2012, because later brood years are still rearing in the ocean. The most recent completed brood year is 2012.

Based on PIT-tag analyses, about 5.1% of brood year 2012 was last detected in streams outside of the Wenatchee River basin. Beginning with brood year 2011, steelhead have been overwinter-acclimated at the Chiwawa Acclimation Facility. This may be the reason for the observed reduction in stray rates since 2011. On average, for brood years 2011 through 2012, about 4% of the hatchery steelhead returns were last detected in streams outside the Wenatchee River basin (Table 3.25).

Steelhead have been detected in the Entiat and Methow rivers as well as in the Deschutes and Tucannon rivers. Several were last detected at Wells Dam. The numbers in Table 3.25 should be considered rough estimates because they are not based on confirmed spawning (only last detections).

Table 3.25. Number and percent of hatchery-origin Wenatchee steelhead that homed to target spawning areas and the target hatchery program, and number and percent that strayed to non-target spawning areas and hatchery programs for brood years 2005-2012. Estimates were based on last detections of PIT-tagged hatchery steelhead. Percent strays should be less than 5%.

Brood Year	Homing				Straying			
	Target streams		Target hatchery*		Non-target stream		Non-target hatchery	
	Number	%	Number	%	Number	%	Number	%
2005	76	73.1	1	1.0	27	26.0	0	0.0
2006	72	61.0	3	2.5	43	36.4	0	0.0
2007	171	60.4	2	0.7	110	38.9	0	0.0
2008	79	86.8	2	2.2	10	11.0	0	0.0
2009	185	83.3	2	0.9	35	15.8	0	0.0
2010	79	80.6	1	1.0	18	18.4	0	0.0
2011	120	87.6	13	9.5	4	2.9	0	0.0
2012	139	89.1	9	5.8	8	5.1	0	0.0
Average	***115***	***76.2***	***4***	***2.7***	***32***	***21.1***	***0***	***0.0***
Median	***100***	***82.0***	***2***	***1.6***	***23***	***17.1***	***0***	***0.0***

* Homing to the target hatchery includes Wenatchee hatchery steelhead that are captured and included as broodstock in the Wenatchee Hatchery program. These hatchery fish are typically collected at Dryden and Tumwater dams.

Genetics

Genetic studies were conducted in 2012 to determine the potential effects of the Wenatchee Supplementation Program on natural-origin summer steelhead in the Wenatchee River basin (Seamons et al. 2012; the entire report is appended as Appendix E). Temporal collections were obtained from hatchery and natural-origin adult summer steelhead captured at Dryden and Tumwater dams during summer and fall of 1997 through 2009 (excepting 2004 and 2005). Natural-origin steelhead consisted of a mixed collection representing all the spawning subpopulations located upstream. Therefore, to determine population substructure within the basin, samples were also taken from juvenile steelhead collected at smolt traps located within the Chiwawa River, Nason Creek, and Peshastin Creek, and from the Entiat River. Samples were also taken from juvenile steelhead collected at the smolt trap in the lower Wenatchee River. These, like natural-origin adult collections, consisted of a mixed collection representing all subpopulations located upstream. A total of 1,468 hatchery-origin and natural-origin adults were processed and 1,542 juvenile steelhead from the Wenatchee and Entiat Rivers were processed for genetic variation with 132 genetic (single nucleotide polymorphism loci; SNPs) markers. Peshastin Creek and the Entiat River served as no-hatchery-outplant controls. Genetic data were interrogated for the presence or absence of spatial and temporal trends in allele frequencies, genetic distances, and effective population size.

Allele Frequencies—Changes to the summer steelhead hatchery supplementation program had no detectable effect on genetic diversity of wild populations. On average, hatchery-origin adults had higher minor allele frequencies (MAF) than natural-origin adults, which may simply reflect the mixed ancestry of hatchery adults. Both hatchery and natural-origin adults had MAF similar to juveniles collected in spawning tributaries and in the Entiat River. There was no temporal trend in allele frequencies or observed heterozygosity in adult or juvenile collections and allele frequencies in control populations were no different than those still receiving hatchery outplants. This suggests that the hatchery program has had little effect on allele frequencies since broodstock sources changed in 1998 from mixed-ancestry broodstock collected in the Columbia River to using broodstock collected in the Wenatchee River.

Genetic Distances—As intended, interbreeding of Wenatchee River hatchery and natural-origin adults reduced the genetic differences between Wells Hatchery adults and Wenatchee River natural-origin adults observed in the first few years after changing the broodstock collection protocol. Although there were detectable genetic differences between hatchery and natural-origin adults, the magnitude of that difference declined over time. Hatchery adults were genetically different from natural-origin adults and juveniles based on pair-wise F_{ST} and principal components analysis, most likely because of the smaller effective population size (N_b) in the hatchery population (see below). Pair-wise F_{ST} estimates and genetic distances between hatchery and natural-origin adults collected the same year declined over time suggesting that the interbreeding of hatchery and natural-origin adults in the hatchery (and presumably in the wild) is slowly homogenizing Wenatchee River summer steelhead. Analyses using brood year were inconclusive because of limitations in the data.

Effective Population Size—Although the effective population size of the Wenatchee River hatchery steelhead program was consistently small, it does not appear to have caused a reduction in the effective population size of wild populations. On average, estimates of N_b were much lower and varied less for hatchery adults than for natural-origin adults and juveniles. Estimates of N_b for hatchery adults declined from the earliest brood years to a stable new low value after broodstock practices were changed in 1998. There was no indication that this had any effect on N_b in natural-origin adults and juveniles; N_b estimates for natural-origin adults and juveniles were, on average, higher and varied considerably over the 1998-2010 period and showed no temporal trend.

It is important to note that no new information will be reported on genetics until the next five-year report (2018).

Proportionate Natural Influence

Another method for assessing the genetic risk of a supplementation program is to determine the influence of the hatchery and natural environments on the adaptation of the composite population. This is estimated by the proportion of natural-origin fish in the hatchery broodstock (pNOB) and the proportion of hatchery-origin fish in the natural spawning escapement (pHOS). We calculated Proportionate Natural Influence (PNI) by iterating Ford’s (2002) equations 5 and 6 to equilibrium, using a heritability of 0.3 and a selection strength of three standard deviations.[7] The larger the PNI value, the greater the strength of selection in the natural environment relative to that of the hatchery

[7] According to authorized annual take permits, PNI is calculated using the PNI approximate equation 11 (HSRG 2009; Appendix A). However, in this report, we used Ford's (2002) equations 5 and 6 with a heritability of 0.3 and a selection strength of three standard deviations to calculate PNI (C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI). This approach is more accurate than using the PNI approximate equation.

environment. For the natural environment to dominate selection, PNI should be greater than 0.50, and important integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004). For the Wenatchee steelhead program, PNI is managed with the goal of achieving a five-year running average of PNI ≥ 0.67 basin-wide. In years when the natural-origin escapement is low (i.e., < 433 fish), the Wenatchee steelhead population will be managed to meet escapement goals rather than PNI.

For brood years 2001-2016, PNI values were less than 0.67 (Table 3.26), suggesting that the hatchery environment has a greater influence on adaptation of Wenatchee steelhead than does the natural environment.

Table 3.26. Proportionate Natural Influence (PNI) values for the Wenatchee steelhead supplementation program for brood years 2001-2016. NOS = number of natural-origin steelhead on the spawning grounds; HOS = number of hatchery-origin steelhead on the spawning grounds; NOB = number of natural-origin steelhead collected for broodstock; and HOB = number of hatchery-origin steelhead included in hatchery broodstock.

Brood year	Spawners[a]			Broodstock			PNI[b]	PNI (5-yr mean)
	NOS	HOS	pHOS	NOB	HOB	pNOB		
2001	158	127	0.45	51	103	0.33	0.45	--
2002	731	542	0.43	96	64	0.60	0.59	--
2003	355	350	0.50	49	90	0.35	0.43	--
2004	371	445	0.55	75	61	0.55	0.51	--
2005	690	862	0.56	87	104	0.46	0.47	0.49
2006	253	210	0.45	93	69	0.57	0.57	0.51
2007	145	115	0.44	76	58	0.57	0.58	0.51
2008	168	279	0.62	77	54	0.59	0.50	0.53
2009	171	545	0.76	86	73	0.54	0.43	0.51
2010	524	970	0.65	96	75	0.56	0.48	0.51
2011	351	472	0.57	91	70	0.57	0.51	0.50
2012	381	209	0.35	59	65	0.48	0.59	0.50
2013	322	148	0.31	49	68	0.42	0.59	0.52
2014	476	363	0.46	64	68	0.48	0.54	0.54
2015	639	484	0.43	58	52	0.53	0.57	0.56
2016	280	324	0.54	66	66	0.50	0.50	0.56
Average	***376***	***403***	***0.52***	***73***	***71***	***0.51***	***0.52***	***0.52***
Median	***353***	***357***	***0.46***	***76***	***68***	***0.54***	***0.51***	***0.51***

[a] The presence of eroded fins or missing adipose fins was used to distinguish hatchery fish from wild fish during video monitoring at Tumwater The PNI estimates are appropriate for steelhead spawning upstream from Tumwater Dam but may not represent PNI for steelhead spawning downstream from Tumwater Dam. Dam. Because not all hatchery fish have eroded fins or missing adipose fins, it is likely we are underestimating WxW hatchery steelhead returns based on video monitoring.

[b] PNI was calculated previously using PNI approximate equation 11 (HSRG 2009; their Appendix A). All PNI values presented here were recalculated by iterating Ford's (2002) equations 5 and 6 to equilibrium using a heritability of 0.3 and a selection strength of three standard deviations. C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI.

Post-Release Survival and Travel Time

We used PIT-tagged fish to estimate survival rates and travel time (arithmetic mean days) of hatchery steelhead from release sites (e.g., Chiwawa River, Nason Creek, and Wenatchee River) to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam (Table 3.27).[8] Over the 12 brood years for which PIT-tagged hatchery fish are available, survival rates from the release sites to McNary Dam ranged from 0.055 to 0.785 (note that survival rates of 0.000 were associated with very small sample sizes); SARs from release to detection at Bonneville Dam ranged from 0.000 to 0.038. Average travel time from the release sites to McNary Dam ranged from 13 to 100 days.

Some of the variation in survival rates and travel time was related to release location, type of release, and rearing scenario. For example, on average, steelhead released in the Chiwawa River appeared to have higher survival rates to McNary Dam than did steelhead released in the lower and upper Wenatchee River or Nason Creek. Within the Chiwawa River, steelhead identified as “movers” had the highest survival rates to McNary Dam, while those identified as “non-screened” had the lowest survival. For steelhead released into Nason Creek and the Wenatchee River, fish released from circulars had higher survival rates than those released from raceways. On average, steelhead released from Blackbird Pond had lower survival rates to McNary Dam than those released from circulars. Based on the available data, SARs varied little among the release locations or rearing scenarios.

Travel time from release to McNary Dam varied among release locations and rearing scenario. In general, steelhead released into the Chiwawa River and Nason Creek appeared to travel more quickly to McNary Dam than did steelhead released into the Wenatchee River. Of those released into the Chiwawa River, steelhead released volitionally from raceways appeared to travel to McNary Dam more quickly than those forced released; although there are few replicates and differences in travel times are small. On average, there appeared to be little differences in travel times for steelhead reared in raceways or circulars that were released into Nason Creek.

Table 3.27. Total number of Wenatchee hatchery summer steelhead released with PIT tags, their survival and travel times (mean days) to McNary Dam, and smolt-to-adult (SAR) ratios for brood years 2005-2015. SARs were estimated to Bonneville Dam. Standard errors are shown in parentheses. NA = not available (i.e., for SARs, not all the adults from the release groups have returned to the Columbia River).

Brood year	Release location[a]	Crosses[b]	Type of release	Rearing scenario[c]	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2003	Chiwawa	HxW	NA	Turtle Rock	29,801	0.755 (0.029)	18.2 (16.7)	0.003 (0.000)
	Nason	WxW	NA	Turtle Rock	34,823	0.648 (0.026)	19.3 (19.6)	0.004 (0.000)
	Wenatchee	HxH	NA	Turtle Rock	30,018	0.767 (0.030)	18.1 (20.6)	0.003 (0.000)
2004	Chiwawa	HxW	NA	Turtle Rock	2,439	0.480 (0.037)	26.9 (59.5)	0.011 (0.002)
	Chiwawa	WxW	NA	Turtle Rock	853	0.485 (0.054)	21.1 (8.8)	0.008 (0.003)
	Nason	WxW	NA	Turtle Rock	8,826	0.412 (0.017)	26.7 (56.1)	0.010 (0.001)
	Wenatchee	HxH	NA	Turtle Rock	9,705	0.621 (0.022)	15.8 (6.3)	0.033 (0.002)

[8] It is important to point out that because of fish size differences among rearing tanks or raceways, fish PIT tagged in one tank or raceway may not represent untagged fish rearing in other tanks or raceways.

Brood year	Release location[a]	Crosses[b]	Type of release	Rearing scenario[c]	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
	Wenatchee	HxW	NA	Turtle Rock	7,379	0.606 (0.029)	19.3 (7.4)	0.013 (0.001)
2005	Chiwawa	HxW	NA	Turtle Rock	3,448	0.540 (0.065)	22.6 (27.2)	0.017 (0.002)
	Chiwawa	WxW	NA	Turtle Rock	717	0.521 (0.128)	22.2 (8.0)	0.013 (0.004)
	Nason	WxW	NA	Turtle Rock	7,306	0.416 (0.031)	21.3 (9.2)	0.009 (0.001)
	Wenatchee	HxH	NA	Turtle Rock	8,610	0.656 (0.057)	20.1 (35.8)	0.017 (0.001)
	Wenatchee	HxW	NA	Turtle Rock	5,021	0.649 (0.074)	20.2 (9.0)	0.014 (0.002)
2006	NA	NA	NA	NA	NA	NA	NA	NA
2007	Chiwawa	HxW	NA	Turtle Rock	2,882	0.520 (0.057)	22.3 (7.9)	0.020 (0.003)
	Chiwawa	WxW	NA	Turtle Rock	785	0.467 (0.069)	18.7 (9.0)	0.038 (0.007)
	Nason	WxW	NA	Turtle Rock	8,060	0.505 (0.030)	22.3 (24.1)	0.030 (0.002)
	Wenatchee	HxW	NA	Turtle Rock	9,047	0.631 (0.041)	18.2 (17.2)	0.038 (0.002)
2008	Chiwawa	HxW L	NA	Turtle Rock	2,008	0.574 (0.080)	20.3 (7.0)	0.006 (0.002)
	Chiwawa	WxW	NA	Turtle Rock	1,457	0.546 (0.090)	31.6 (108.5)	0.010 (0.003)
	Nason	WxW	NA	Turtle Rock	7,951	0.500 (0.037)	21.4 (17.5)	0.014 (0.001)
	Wenatchee	HxW E	NA	Turtle Rock	4,517	0.511 (0.044)	19.5 (7.7)	0.008 (0.001)
	Wenatchee	HxW L	NA	Turtle Rock	6,710	0.545 (0.038)	19.3 (6.8)	0.010 (0.001)
2009	Chiwawa	HxW E	Forced	Turtle Rock	4,874	0.576 (0.076)	24.3 (8.3)	0.012 (0.002)
	Chiwawa	HxW E	Volitional	Chiw. Circ	8,653	0.785 (0.100)	19.4 (26.0)	0.007 (0.001)
	Nason	WxW	Forced	Turtle Rock	8,918	0.504 (0.042)	27.2 (26.6)	0.017 (0.001)
	Wenatchee	HxW E	Forced	Turtle Rock	11,300	0.543 (0.041)	25.8 (54.8)	0.014 (0.001)
	Wenatchee	HxW E	Forced	Turtle Rock	6,681	0.597 (0.063)	28.9 (72.2)	0.013 (0.001)
	Wenatchee	HxW L	Forced	Turtle Rock	4,619	0.478 (0.052)	21.7 (7.6)	0.015 (0.002)
	Wenatchee	HxW E	Volitional	Blackbird	2,184	0.317 (0.054)	NA	0.010 (0.002)
	Wenatchee	WxW	Volitional	Rohlfing	566	0.443 (0.187)	NA	0.014 (0.005)
2010	Chiwawa	WxW	Forced	Turtle Rock	4,226	0.586 (0.057)	24.4 (60.1)	0.009 (0.001)
	Nason	WxW	Forced	Turtle Rock	5,256	0.548 (0.044)	23.5 (53.3)	0.010 (0.001)
	Wenatchee	HxH	Forced	Turtle Rock	8,506	0.583 (0.053)	30.2 (50.1)	0.004 (0.001)
	Wenatchee	HxH	Volitional	Blackbird	9,858	0.629 (0.046)	NA	0.006 (0.001)
	Wenatchee	HxH	Volitional	Chiw. Circ	10,031	0.413 (0.043)	21.6 (66.1)	0.001 (0.000)
2011	Chiwawa	WxW	Volitional	RCY	3,603	0.407 (0.056)	15.1 (8.3)	0.005 (0.001)
	Nason	WxW	Volitional	RCY	4,065	0.334 (0.042)	20.9 (60.9)	0.005 (0.001)
	Wenatchee	WxW	Non-movers	Circular	1,122	0.354 (0.228)	40.6 (89.1)	0.000 (--)

Brood year	Release location[a]	Crosses[b]	Type of release	Rearing scenario[c]	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
	Wenatchee	WxW	Non-movers	RCY	2,395	0.368 (0.084)	22.7 (57.0)	0.004 (0.001)
	Wenatchee	WxW	Volitional	Blackbird	2,099	0.660 (0.016)	NA	0.010 (0.002)
	Wenatchee	WxW	Volitional	Circular	7,206	0.278 (0.043)	31.6 (74.3)	0.006 (0.001)
	Wenatchee	WxW	Volitional	RCY	4,422	0.327 (0.032)	15.2 (25.6)	0.008 (0.001)
	All	WxW	NA	Circular	1,628	0.055 (0.016)	100.4 (151.7)	0.002 (0.001)
	All	WxW	NA	RCY	3,479	0.289 (0.034)	13.6 (8.4)	0.004 (0.001)
2012	Chiwawa	HxH	Volitional	RCY	2,891	0.407 (0.057)	15.2 (7.2)	NA
	Nason	WxW	Forced	Circular	4,271	0.378 (0.065)	25.0 (33.1)	NA
	Nason	WxW	Volitional	Circular	5,404	0.364 (0.048)	24.9 (31.6)	NA
	L Wenatchee	HxH	Forced	RCY	587	0.164 (0.074)	52.2 (114.7)	NA
	U Wenatchee	HxH	Volitional	RCY	2,224	0.573 (0.138)	18.7 (8.4)	NA
	U Wenatchee	HxH	Forced	RCY	1,969	0.603 (0.140)	24.7 (42.5)	NA
	Wenatchee	HxH	Volitional	Blackbird	1,658	0.428 (0.092)	NA	NA
	All	HxH	NA	RCY	769	0.325 (0.163)	97.3 (286.2)	NA
	All	WxW	NA	Circular	5,397	0.327 (0.049)	25.4 (45.0)	NA
2013	Chiwawa	Mixed	Volitional	RCY	1,567	0.354 (0.064)	15.2 (7.0)	NA
	Nason	Mixed	Volitional	RCY	3,796	0.448 (0.115)	20.2 (9.4)	NA
	Nason	Mixed	Volitional	Circ or RCY	308	0.146 (0.053)	17.4 (2.9)	NA
	Nason	WxW	Non-movers	Circular	74	0.000 (-)	0.0 (-)	NA
	Nason	WxW	Volitional	Circular	1,286	0.192 (0.063)	18.4 (6.4)	NA
	L Wenatchee	Mixed	Non-movers	RCY	3,275	0.317 (0.131)	35.3 (69.5)	NA
	U Wenatchee	Mixed	Volitional	RCY	2,862	0.458 (0.081)	16.3 (9.7)	NA
	Wenatchee	HxH	Volitional	Blackbird	819	0.337 (0.128)	NA	NA
	All	HxH	NA	RCY	907	0.000 (--)	36.7 (17.6)	NA
	All	WxW	NA	Circ or RCY	232	0.000 (--)	38.0 (--)	NA
2014	Chiwawa	Mixed	Movers	RCY	793	0.754 (0.497)	27.7 (7.6)	NA
	Chiwawa	Mixed	Non-screen	RCY	915	0.367 (0.236)	25.0 (8.1)	NA
	Nason	Mixed	Movers	RCY	1,553	0.216 (0.084)	28.4 (29.4)	NA
	Nason	Mixed	Non-screen	RCY	1,653	0.076 (0.018)	24.2 (7.1)	NA
	Nason	WxW	Movers	Circular	949	0.244 (0.104)	47.4 (91.0)	NA
	Nason	WxW	Non-screen	Circular	873	0.369 (0.190)	20.8 (6.9)	NA
	L Wenatchee	Mixed	Non-movers	RCY	2,596	0.139 (0.026)	26.4 (59.5)	NA
	U Wenatchee	Mixed	Movers	RCY	2,042	0.278 (0.051)	21.9 (8.2)	NA

Brood year	Release location[a]	Crosses[b]	Type of release	Rearing scenario[c]	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
	U Wenatchee	Mixed	Non-screen	RCY	1,563	0.126 (0.026)	28.7 (8.2)	NA
	U Wenatchee	WxW	Movers	Circular	356	0.278 (0.165)	17.0 (6.5)	NA
	U Wenatchee	WxW	Non-movers	Circular	596	0.381 (0.192)	15.8 (6.8)	NA
	U Wenatchee	WxW	Non-screen	Circular	1,230	0.349 (0.104)	25.8 (57.4)	NA
	Wenatchee	HxH	Volitional	Blackbird	1,814	0.225 (0.055)	NA	NA
	All	Mixed	NA	Circ or RCY	1,884	0.113 (0.030)	41.7 (61.8)	NA
2015	Chiwawa	Mixed	Movers	RCY	4,365	0.423 (0.040)	13.6 (5.7)	NA
	Nason	Mixed	Mixed	RCY	675	0.164 (0.035)	19.8 (8.9)	NA
	Nason	Mixed	Movers	RCY	2,427	0.332 (0.053)	18.6 (6.7)	NA
	Nason	Mixed	Non-screen	RCY	2,123	0.275 (0.056)	20.0 (7.6)	NA
	Nason	WxW	Movers	Circular	1,105	0.412 (0.082)	15.5 (5.3)	NA
	Nason	WxW	Non-screen	Circular	916	0.402 (0.111)	14.9 (5.1)	NA
	L Wenatchee	Mixed	Non-movers	RCY	1,658	0.244 (0.073)	13.0 (6.5)	NA
	U Wenatchee	Mixed	Movers	RCY	2,773	0.341 (0.032)	16.3 (7.9)	NA
	U Wenatchee	Mixed	Non-screen	RCY	1,435	0.469 (0.094)	19.7 (8.9)	NA
	U Wenatchee	WxW	Movers	Circular	1,061	0.555 (0.079)	13.9 (7.3)	NA
	U Wenatchee	WxW	Non-screen	Circular	849	0.355 (0.064)	12.7 (5.5)	NA
	Wenatchee	HxH	Non-screen	Blackbird	2,337	0.364 (0.039)	NA	NA
	All	Mixed	NA	Circ or RCY	1,381	0.167 (0.105)	19.4 (10.8)	NA

[a] All = Chiwawa River, Nason Creek, and the Wenatchee River.
[b] HxH = hatchery by hatchery cross; WxW = wild by wild cross; Mixed = both HxH and WxW crosses; E = early; and L = late.
[c] Circ = circulars; RCY = raceway.

Natural and Hatchery Replacement Rates

Natural replacement rates (NRR) were calculated as the ratio of natural-origin recruits (NOR) to the parent spawning population (spawning escapement). Natural-origin recruits are naturally produced (wild) fish that survive to contribute to harvest (directly or indirectly), to broodstock, and to spawning grounds. We do not account for fish that died in route to the spawning grounds (migration mortality) or died just before spawning (pre-spawn mortality) (see Appendix B in Hillman et al. 2012). For brood years 1998-2012, NRR for summer steelhead in the Wenatchee River basin averaged 0.66 (range, 0.13-3.10) if harvested fish were included in the estimate (Table 3.28).

Hatchery replacement rates (HRR) are the hatchery adult-to-adult returns and were calculated as the ratio of hatchery-origin recruits (HOR) to the parent broodstock collected. These rates should be greater than the NRRs and greater than or equal to 6.9 (the calculated target value in Hillman et al. 2013). The target value of 6.9 includes harvest. In nearly all years, HRRs were greater than NRRs (Table 3.28). HRRs exceeded the estimated target value of 6.9 in 11 of the 15 years.

Table 3.28. Broodstock collected, spawning escapements, natural and hatchery-origin recruits (NOR and HOR), and natural and hatchery replacement rates (NRR and HRR with harvest) for summer steelhead in the Wenatchee River basin, brood years 1998-2012.

Brood year	Broodstock Collected	Spawning Escapement	Harvest included			
			HOR	NOR	HRR	NRR
1998	78	602	148	1,867	1.89	3.10
1999	125	343	1,944	334	15.55	0.97
2000	120	1,030	312	878	2.60	0.85
2001	178	1,655	10,335	1,050	58.06	0.66
2002	162	5,000	1,905	515	11.76	0.13
2003	155	2,598	956	504	6.17	0.27
2004	217	2,949	2,538	728	11.70	0.25
2005	209	3,609	3,106	904	14.86	0.25
2006	199	2,219	1,454	1,007	7.31	0.45
2007	176	880	535	430	3.04	0.49
2008	107	1,835	1,121	714	10.48	0.39
2009	107	1,733	1,024	709	9.57	0.41
2010	105	6,236	3,999	2,237	38.09	0.36
2011	104	3,049	859	2,189	8.26	0.72
2012	129	2,514	1,094	1,420	8.48	0.56
Average	***145***	***2,417***	***2,089***	***1,032***	***13.85***	***0.66***
Median	***129***	***2,219***	***1,121***	***878***	***9.57***	***0.45***

Smolt-to-Adult Survivals

Smolt-to-adult ratios (SARs) are calculated as the number of returning hatchery adults divided by the number of tagged hatchery smolts released. SARs are generally based on CWT returns. However, prior to brood year 2011, Wenatchee steelhead were not extensively tagged with CWTs. Therefore, elastomer-tagged fish were used to estimate SARs from release to capture at Priest Rapids Dam. With the return of brood year 2011, SARs will be based on PIT-tag detections at Bonneville Dam.

SARs (not adjusted for tag loss) for Wenatchee steelhead ranged from 0.0009 to 0.0315 (mean = 0.0093) for brood years 1996-2010 (Table 3.29). For brood years 2011 to present, SARs (to Bonneville Dam) averaged 0.0056 (Table 3.29).

Table 3.29. Smolt-to-adult ratios (SARs) for Wenatchee hatchery steelhead. Estimates for brood years 1996-2010 were based on elastomer tags recaptured at Priest Rapids Dam. SARs were not adjusted for tag loss after release. For brood years 2011 to present, SARs are based on PIT-tag detections to Bonneville Dam.

Brood year	Number of tagged smolts released	SAR
1996	348,693	0.0034
1997	429,422	0.0041

Brood year	Number of tagged smolts released	SAR
1998	172,078	0.0009
1999	175,661	0.0111
2000	184,639	0.0017
2001	335,933	0.0308
2002	302,060	0.0063
2003	374,867	0.0025
2004	294,114	0.0038
2005	452,184	0.0107
2006	258,697	0.0100
2007	306,690	0.0315
2008	327,133	0.0090
2009	484,826	0.0080
2010[a]	192,363	0.0054
Average	***309,291***	***0.0093***
Median	***306,690***	***0.0063***
2011	30,019	0.0057
2012	25,134	0.0055
Average	***27,577***	***0.0056***
Median	***27,577***	***0.0056***

[a] Only 192,363 WxW progeny from brood year 2010 were elastomer tagged; 161,951 HxH steelhead were released.

3.7 ESA/HCP Compliance

Broodstock Collection

Collection of brood year 2015 broodstock for Wenatchee summer steelhead at Dryden and Tumwater dams began on 1 July and ended on 15 October 2014 at Dryden Dam and 10 November 2014 at Tumwater Dam consistent with the collection period identified in the 2014 broodstock collection protocol. The broodstock collection achieved a total collection of 142 steelhead, including 76 natural-origin steelhead (of the 76 fish collected, 58 were spawned and 13 were released back to the river.

About 1,278 steelhead were handled and released (or surplused) at Tumwater and Dryden dams during brood year 2015 Wenatchee steelhead broodstock collection. Most were hatchery-origin fish handled at Tumwater Dam and ultimately surplused to meet the pHOS objective upstream from Tumwater Dam. Fish released at Dryden Dam were released because the weekly quota for hatchery or wild steelhead had been attained, but not for both hatchery and wild fish, or because they were non-target fish (adipose clipped), or they were unidentifiable hatchery-origin steelhead. All steelhead released were allowed to fully recover from the anesthesia and released immediately upstream from the trap sites.

In addition to steelhead encountered at Dryden Dam during steelhead broodstock collection, an estimated 48 spring Chinook salmon were captured and released unharmed immediately upstream from the trap facility. Consistent with ESA Section 10 Permit 1395 impact minimization measures, all ESA species handled were subject of water-to-water transfers.

Hatchery Rearing and Release

The 2015 brood Wenatchee steelhead reared throughout all life stages without significant mortality (defined as >10% population mortality associated with a single event). However, the 2015 brood had poor fertilization to eyed-egg survival (60.3%) combined with somewhat low eyed-egg to ponding survival resulting in an unfertilized-to-release survival of 68.5%, which was considerably less than the program target of 81% (see Section 3.2).

Juvenile rearing occurred at three separate facilities including Eastbank Fish Hatchery, Chelan Fish Hatchery, and the Chiwawa Acclimation Facility. Multiple facilities were used to take advantage of variable water temperatures to manipulate growth of juveniles from different parental crosses. Typically, wild steelhead spawn later than their hatchery cohort and are therefore reared at Chelan Fish Hatchery on warmer water to accelerate their growth so they achieve a size-at-release similar to HxH parental cross progeny reared on cooler water at Eastbank Fish Hatchery. All parental cross groups received final rearing and over-winter acclimation at the Chiwawa Acclimation Facility on Wenatchee River and Chiwawa River surface water before direct release (scatter planting) in the Wenatchee River basin.

The 2015 brood steelhead smolt release in the Wenatchee River basin totaled 195,344 smolts, representing about 79% of the program target of 247,300 smolts identified in the Rocky Reach and Rock Island Dam HCPs and within the maximum 110% allowed in ESA Section 10 Permit 1395. As specified in ESA Section 10 Permit 1395, all steelhead smolts released were externally marked or internally tagged and a representative number were PIT tagged (see Section 3.2).

Hatchery Effluent Monitoring

Per ESA Permits 1196, 1347, 1395, 18118, 18120, and 18121, permit holders shall monitor and report hatchery effluents in compliance with applicable National Pollution Discharge Elimination Systems (NPDES) (EPA 1999) permit limitations. There was no NPDES violations reported at PUD Hatchery facilities during the period 1 January 2016 through 31 December 2016. NPDES monitoring and reporting for Chelan PUD Hatchery Programs during 2016 are provided in Appendix F.

Smolt and Emigrant Trapping

Per ESA Section 10 Permit No. 1395, the permit holders are authorized a direct take of up to 20% of the emigrating steelhead population and a lethal take not to exceed 2% of the fish captured (NMFS 2003). Based on the estimated wild steelhead population (smolt trap expansion) and hatchery juvenile steelhead population estimate (hatchery release data) for the Wenatchee River basin, the reported steelhead encounters during the 2016 emigration complied with take provisions in the Section 10 permit and are detailed in Table 3.30. Additionally, juvenile fish captured at the trap locations were handled consistent with provisions in ESA Section 10 Permit 1395 Section B.

Table 3.30. Estimated take of Upper Columbia River steelhead resulting from juvenile emigration monitoring in the Wenatchee River basin, 2016. NA = not available.

Trap location	Population estimate				Number trapped				Total	Take allowed by Permit
	Wild	Hatchery[a]	Parr	Fry	Wild	Hatchery	Parr	Fry		
Chiwawa Trap										
Population	NA	37,774	NA	NA	195	1,509	1,409	113	3,226	
Encounter rate	NA	NA	NA	NA	NA	0.0399	NA	NA	NA	0.20
Mortality[b]	NA	NA	NA	NA	0	0	9	1	10	
Mortality rate	NA	NA	NA	NA	0.0000	0.0000	0.0064	0.0089	0.0031	0.02
Lower Wenatchee Trap										
Population	NA	195,344	NA	NA	88	256	103	226	673	
Encounter rate	NA	NA	NA	NA	NA	0.0013	NA	NA	NA	0.20
Mortality[b]	NA	NA	NA	NA	0	1	2	4	7	
Mortality rate	NA	NA	NA	NA	0.0000	0.0039	0.0194	0.0177	0.0104	0.02
Wenatchee River Basin Total										
Population	NA	195,344	NA	NA	283	1,765	1,512	339	3,899	
Encounter rate	NA	NA	NA	NA	NA	0.0090	NA	NA	NA	0.20
Mortality[b]	NA	NA	NA	NA	0	1	11	5	17	
Mortality rate	NA	NA	NA	NA	0.0000	0.0006	0.0073	0.0147	0.0044	0.02

[a] 2016 smolt release data for the Wenatchee River basin.

[b] Mortality includes trapping and PIT-tag mortalities.

Spawning Surveys

Steelhead spawning ground surveys were conducted in the Wenatchee River basin during 2016, as authorized by ESA Section 10 Permit No. 1395. Because of the difficulty of quantifying the level of take associated with spawning ground surveys, the Permit does not specify a take level associated with these activities, even though it does authorize implementation of spawning ground surveys. Therefore, no take levels are reported. However, to minimize potential effects to established redds, wading was restricted to the extent practical, and extreme caution was used to avoid established redds when wading was required.

Stock Assessment at Priest Rapids Dam

Upper Columbia River steelhead stock assessment sampling at Priest Rapids Dam (PRD) is authorized through ESA Section 10 Permit No. 1395 (NMFS 2003). Permit authorizations include interception and biological sampling of up to 15% of the Upper Columbia River steelhead passing PRD to determine upriver adult population size, estimate hatchery to wild ratios, determine age-class contribution, and evaluate the need for managing hatchery steelhead consistent with ESA recovery objectives, which include fully seeding spawning habitat with naturally produced Upper Columbia River steelhead supplemented with artificially propagated steelhead (NMFS 2003). The 2014-2015 run-cycle report (BY 2015) for stock assessment sampling at Priest Rapids Dam was compiled under provisions of ESA Section 10 Permit 1395. Data and reporting information are included in Appendix G.

SECTION 4: WENATCHEE SOCKEYE SALMON

The goal of sockeye salmon supplementation in the Wenatchee Basin was to use artificial production to replace adult production lost because of mortality at Rock Island Dam, while not reducing the natural production or long-term fitness of sockeye in the basin. The Rock Island Fish Hatchery Complex began operation in 1989 under funding from Chelan PUD. The Complex operated originally through the Rock Island Settlement Agreement, but since 2004 has operated under the Anadromous Fish Agreement and Habitat Conservation Plans.

Adult sockeye were collected for broodstock from the run-at-large at Tumwater Dam. Beginning in 2011, because of passage delays at Tumwater Dam during trapping operations, sockeye broodstock were collected at Dryden Dam. The goal was to collect up to 260 natural-origin adult sockeye for the program. Broodstock collection occurred from about 7 July through 28 August with trapping occurring no more than 16 hours per day, three days a week at Tumwater Dam and up to seven days per week at the Dryden Dam left and right-bank facilities.

Adult sockeye were held and spawned at Eastbank Fish Hatchery. The fertilized eggs were also incubated at the hatchery. For brood years 1989 through 1998, unfed fry were transferred from the hatchery to Lake Wenatchee net pens. From 1998 to 2011, juvenile sockeye were reared at Eastbank Fish Hatchery until July when they were transferred to the net pens. The initial rearing at Eastbank was to increase growth rates. During most years up through 2005, juvenile sockeye were released from net pens at two different times, August and November. Since 2006, all juvenile sockeye were released in late October.

The production goal for the Wenatchee sockeye supplementation program was to release 200,000 subyearlings into Lake Wenatchee at 20 fish per pound. Targets for fork length and weight were 133 mm (CV = 9.0) and 22.7 g, respectively. Over 90% of these fish were marked with CWTs. In addition, from 2006-2011, about 15,000 juvenile sockeye were PIT tagged annually. Following an evaluation of the supplementation program in 2011, the Hatchery Committees decided to convert the Wenatchee sockeye hatchery program to summer steelhead in 2012. Monitoring occurs annually to track the status of the natural sockeye population.

4.1 Broodstock Sampling

As noted above, the Wenatchee sockeye program was terminated in 2012. Thus, no broodstock have been collected since 2011 and the release of juvenile sockeye into Lake Wenatchee in 2012 (2011 brood) was the last. Therefore, this section presents the history of the program and tracks the juveniles from the 2011 brood that were released as parr into Lake Wenatchee in 2012. Some of these fish began their smolt migrations in 2013.

Origin of Broodstock

Wenatchee sockeye broodstock have not been collected since 2011. Table 4.1 shows the history of the number of broodstock that were collected during the period 1989 to 2011.

Table 4.1. Numbers of wild and hatchery sockeye salmon collected for broodstock, numbers that died before spawning, and numbers of sockeye spawned, 1989-2011. Unknown origin fish (i.e., undetermined by scale analysis, no CWT or fin clips, and no additional hatchery marks) were considered naturally produced. Mortality includes sockeye that died of natural causes typically near the end of spawning and were not needed for the program, surplus sockeye killed at spawning, sockeye that died but were not recovered from the net pens, and sockeye that may have jumped out of the net pens.

Brood year	Wild sockeye					Hatchery sockeye					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
1989	299	93	47	115	44	0	0	0	0	0	115
1990	333	7	7	302	17	0	0	0	0	0	302
1991	357	18	16	199	124	0	0	0	0	0	199
1992	362	18	5	320	19	0	0	0	0	0	320
1993	307	79	21	207	0	0	0	0	0	0	207
1994	329	15	9	236	69	5	0	0	5	0	241
1995	218	5	7	194	12	3	0	0	3	0	197
1996	291	2	0	225	64	20	0	0	0	20	225
1997	283	12	3	192	76	19	0	0	19	0	211
1998	225	37	25	122	41	6	0	0	6	0	128
1999	90	7	1	79	3	60	0	0	60	0	139
2000	256	19	1	170	66	5	0	0	5	0	175
2001	252	27	10	200	15	8	1	0	7	0	207
2002	257	0	1	256	0	0	0	0	0	0	256
2003	261	12	9	198	42	0	0	0	0	0	198
2004	211	13	12	177	9	0	0	0	0	0	177
2005	243	29	12	166	36	0	0	0	0	0	166
2006	260	2	4	214	40	0	0	0	0	0	214
2007	248	15	3	210	20	0	0	0	0	0	210
2008	258	4	11	243	0	2	0	0	2	0	245
2009	258	5	14	239	0	3	0	3	0	0	239
2010	256	3	0	198	55	0	0	0	0	0	198
2011	204	0	8	196	0	0	0	0	0	0	196
Average	***263***	***18***	***10***	***203***	***33***	***6***	***0***	***0***	***5***	***1***	***208***
Median	***258***	***12***	***8***	***199***	***20***	***0***	***0***	***0***	***0***	***0***	***207***

[a] Pre-spawn loss represents the number of fish that died during the holding period before spawning. Mortality is the number of fish that were surplused following spawning.

Age/Length Data

Ages of sockeye were determined from scales and otoliths collected from broodstock and are shown in Table 4.2.

Table 4.2. Percent of hatchery and wild sockeye salmon of different ages (total age) collected from broodstock, 1994-2011.

Return year	Origin	Total age		
		4	5	6
1994	Wild	57.3	41.7	1.0
	Hatchery	40.0	60.0	0.0
1995	Wild	77.3	20.7	2.0
	Hatchery	66.7	33.3	0.0
1996	Wild	65.8	34.2	0.0
	Hatchery	0.0	0.0	0.0
1997	Wild	86.5	13.5	0.0
	Hatchery	57.9	42.1	0.0
1998	Wild	9.9	88.6	1.5
	Hatchery	66.7	33.3	0.0
1999	Wild	21.8	74.7	3.5
	Hatchery	90.0	8.3	1.7
2000	Wild	97.7	2.3	0.0
	Hatchery	100.0	0.0	0.0
2001	Wild	69.9	29.6	0.5
	Hatchery	71.4	28.6	0.0
2002	Wild	31.6	67.6	0.8
	Hatchery	0.0	0.0	0.0
2003	Wild	2.6	90.5	6.9
	Hatchery	0.0	0.0	0.0
2004	Wild	97.5	2.0	0.5
	Hatchery	0.0	0.0	0.0
2005	Wild	74.2	25.8	0.0
	Hatchery	0.0	0.0	0.0
2006	Wild	34.0	65.5	0.5
	Hatchery	0.0	0.0	0.0
2007	Wild	1.9	88.4	9.7
	Hatchery	0.0	0.0	0.0
2008	Wild	95.0	4.0	1.0
	Hatchery	100.0	0.0	0.0
2009	Wild	78.5	21.5	0.0
	Hatchery	100.0	0.0	0.0
2010	Wild	67.4	32.6	0.0
	Hatchery	0.0	0.0	0.0
2011	Wild	53.7	44.3	2.0
	Hatchery	0.0	0.0	0.0

Return year	Origin	Total age		
		4	5	6
Average	***Wild***	***56.8***	***41.5***	***1.7***
	Hatchery	***38.5***	***11.4***	***0.1***
Median	***Wild***	***66.6***	***33.4***	***0.7***
	Hatchery	***20.0***	***0.0***	***0.0***

Lengths and ages of sockeye sampled during the life of the program are provided in Table 4.3.

Table 4.3. Mean fork length (cm) at age (total age) of hatchery and wild sockeye salmon collected for broodstock, 1994-2011; SD = 1 standard deviation.

Return year	Origin	Sockeye fork length (cm)								
		Age-4			Age-5			Age-6		
		Mean	N	SD	Mean	N	SD	Mean	N	SD
1994	Wild	56	125	3	55	91	3	54	2	3
	Hatchery	57	2	1	56	3	1	-	0	-
1995	Wild	51	153	2	55	41	4	54	4	5
	Hatchery	53	2	4	59	1	-	-	0	-
1996	Wild	52	146	4	53	76	3	-	0	-
	Hatchery	-	0	-	-	0	-	-	0	-
1997	Wild	50	166	3	53	26	5	-	0	-
	Hatchery	54	11	4	59	8	2	-	0	-
1998	Wild	51	13	4	55	117	3	53	2	3
	Hatchery	52	4	2	55	2	8	-	0	-
1999	Wild	52	19	4	50	65	4	56	3	1
	Hatchery	50	54	3	56	5	4	56	1	-
2000	Wild	52	167	2	54	4	3	-	0	-
	Hatchery	54	5	1	-	0	-	-	0	-
2001	Wild	54	151	3	56	65	4	58	1	-
	Hatchery	51	5	5	55	2	4	-	0	-
2002	Wild	54	77	2	56	165	4	57	2	0
	Hatchery	-	0	-	-	0	-	-	0	-
2003	Wild	54	5	4	60	172	2	60	13	4
	Hatchery	-	0	-	-	0	-	-	0	-
2004	Wild	53	192	3	56	4	3	63	1	-
	Hatchery	-	0	-	-	0	-	-	0	-
2005	Wild	51	132	3	57	46	4	-	0	-
	Hatchery	-	0	-	-	0	-	-	0	-
2006	Wild	52	70	3	56	135	4	54	2	3
	Hatchery	-	0	-	-	0	-	-	0	-
2007	Wild	57	4	2	58	182	5	58	20	5

Return year	Origin	Sockeye fork length (cm)								
		Age-4			Age-5			Age-6		
		Mean	N	SD	Mean	N	SD	Mean	N	SD
	Hatchery	-	0	-	-	0	-	-	0	-
2008	Wild	52	245	3	52	11	3	62	2	6
	Hatchery	53	2	3	-	-	-	-	-	-
2009	Wild	54	197	3	59	54	4	-	-	-
	Hatchery	54	2	1	-	-	-	-	-	-
2010	Wild	55	130	2	57	63	4	-	-	-
	Hatchery	-	-	-	-	-	-	-	-	-
2011	Wild	55	109	2	59	90	3	61	4	3
	Hatchery	-	-	-	-	-	-	-	-	-
Average	***Wild***	***53***	***116***	***3***	***55***	***78***	***4***	***57***	***3***	***3***
	Hatchery	***53***	***5***	***3***	***57***	***2***	***4***	***56***	***1***	***-***

Sex Ratios

Sex ratios of wild and hatchery sockeye collected during the life of the sockeye hatchery program are presented in Table 4.4.

Table 4.4. Numbers of male and female wild and hatchery sockeye collected for broodstock, 1989-2011. Ratios of males to females are also provided.

Return year	Number of wild sockeye			Number of hatchery sockeye			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
1989	162	137	1.18:1.00	0	0	-	1.18:1.00
1990	177	156	1.13:1.00	0	0	-	1.13:1.00
1991	260	97	2.68:1.00	0	0	-	2.68:1.00
1992	180	182	0.99:1.00	0	0	-	0.99:1.00
1993	130	177	0.73:1.00	0	0	-	0.73:1.00
1994	162	167	0.97:1.00	1	4	0.25:1.00	0.95:1.00
1995	102	116	0.88:1.00	1	2	0.50:1.00	0.87:1.00
1996	150	161	0.93:1.00	0	0	-	0.93:1.00
1997	139	144	0.97:1.00	10	9	1.11:1.00	0.97:1.00
1998	115	110	1.05:1.00	2	4	0.50:1.00	1.03:1.00
1999	22	68	0.32:1.00	37	23	1.61:1.00	0.65:1.00
2000	155	101	1.53:1.00	3	2	1.50:1.00	1.53:1.00
2001	114	138	0.83:1.00	4	4	1.00:1.00	0.83:1.00
2002	128	129	0.99:1.00	0	0	-	0.99:1.00
2003	161	100	1.61:1.00	0	0	-	1.61:1.00
2004	108	103	1.05:1.00	0	0	-	1.05:1.00
2005	130	113	1.15:1.00	0	0	-	1.15:1.00
2006	130	130	1.00:1.00	0	0	-	1.00:1.00

Return year	Number of wild sockeye			Number of hatchery sockeye			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
2007	127	121	1.05:1.00	0	0	-	1.05:1.00
2008	127	131	0.97:1.00	1	1	1.00:1.00	0.97:1.00
2009	133	125	1.06:1.00	0	3	0.00:1.00	1.04:1.00
2010	127	129	0.98:1.00	0	0	-	0.98:1.00
2011	106	98	1.08:1.00	0	0	-	1.08:1.00
Total	***2,074***	***2,017***	***1.03:1.00***	***58***	***48***	***1.21***	***1.03:1.00***

Fecundity

Fecundities of sockeye collected during the life of the hatchery program are presented in Table 4.5.

Table 4.5. Mean fecundity of female sockeye salmon collected for broodstock, 1989-2011. Fecundities were determined from pooled egg lots and were not identified for individual females.

Return year	Mean fecundity
1989	2,344
1990	2,225
1991	2,598
1992	2,341
1993	2,340
1994	2,798
1995	2,295
1996	2,664
1997	2,447
1998	2,813
1999	2,319
2000	2,673
2001	2,960
2002	2,856
2003	3,511
2004	2,505
2005	2,718
2006	2,656
2007	3,115
2008	2,555
2009	2,459
2010	2,782
2011	2,960
Average	***2,649***
Median	***2,656***

4.2 Hatchery Rearing

Rearing History

Number of eggs taken

Numbers of eggs taken from sockeye broodstock during the life of the sockeye hatchery program are shown in Table 4.6.

Table 4.6. Numbers of eggs taken from sockeye broodstock, 1989-2011.

Return year	Number of eggs taken
1989	133,600
1990	326,267
1991	231,254
1992	381,561
1993	231,700
1994	338,562
1995	247,900
1996	314,390
1997	254,459
1998	163,278
1999	190,732
2000	227,234
2001	301,925
2002	356,982
2003	319,470
2004	225,499
2005	211,985
2006	292,136
2007	302,363
2008	316,476
2009	304,963
2010	278,171
2011	290,046
Average	***271,389***
Median	***290,046***

Number of acclimation days

During the life of the program, Wenatchee sockeye were only acclimated on Lake Wenatchee water in net pens. Acclimation days are presented in Table 4.7.

Table 4.7. Water source and mean acclimation period for Wenatchee sockeye, brood years 1989-2011.

Brood year	Release year	Transfer date	Release date	Number of Days	Water source
1989	1990	5-Apr	24-Oct	202	Lake Wenatchee
1990	1991	10-Apr	19-Oct	192	Lake Wenatchee
1991	1992	1-Apr	20-Oct	202	Lake Wenatchee
1992	1993	5-Apr	7-Sep	155	Lake Wenatchee
		5-Apr	26-Oct	204	Lake Wenatchee
1993	1994	5-Apr	1-Sep	149	Lake Wenatchee
		5-Apr	17-Oct	195	Lake Wenatchee
1994	1995	4-Apr	15-Sep	164	Lake Wenatchee
		4-Apr	23-Oct	202	Lake Wenatchee
1995	1996	4-Apr	25-Oct	204	Lake Wenatchee
1996	1997	4-Apr	22-Oct	201	Lake Wenatchee
1997	1998	1-Apr	9-Nov	222	Lake Wenatchee
1998	1999	1-Apr	29-Oct	211	Lake Wenatchee
1999	2000	25-Jul	28-Aug	34	Lake Wenatchee
		26-Jul	1-Nov	98	Lake Wenatchee
2000	2001	2-Jul	27-Aug	56	Lake Wenatchee
		3-Jul	27-Sep	86	Lake Wenatchee
2001	2002	15-Jul	28-Aug	44	Lake Wenatchee
		16-Jul	22-Sep	68	Lake Wenatchee
2002	2003	30-Jun	25-Aug	56	Lake Wenatchee
		1-Jul	22-Oct	113	Lake Wenatchee
2003	2004	6-Jul	25-Aug	50	Lake Wenatchee
		7-Jul	3-Nov	119	Lake Wenatchee
2004	2005	5-Jul	29-Aug	55	Lake Wenatchee
		6-Jul	2-Nov	120	Lake Wenatchee
2005	2006	11-Jul	30-Oct	111	Lake Wenatchee
2006	2007	9-10 Jul	31-Oct	113-114	Lake Wenatchee
2007	2008	7-8 Jul	29-Oct	113-114	Lake Wenatchee
2008	2009	21-Jul	28-Oct	100	Lake Wenatchee
2009	2010	19-20, 23-Jul	27-Oct	97-101	Lake Wenatchee
2010	2011	6, 11-12-Jul	26-Oct	107-113	Lake Wenatchee
2011	2012	9-10-Jul	29-Oct	112-113	Lake Wenatchee

Release Information

Numbers released

Numbers of juvenile sockeye released into Lake Wenatchee during the life of the program are shown in Table 4.8. Coded wire tag marking rates and numbers of PIT-tagged juvenile sockeye released are also shown in Table 4.8.

Table 4.8. Total number of sockeye parr released and numbers of released fish with CWTs and PIT tags for brood years 1989-2011. The release target for sockeye was 200,000 fish.

Brood year	Release year	CWT mark rate	Number of released fish with PIT tags	Number released
1989	1990	Not marked	0	108,400
1990	1991	0.9308	0	270,802
1991	1992	0.8940	0	167,523
1992	1993	0.9240	0	340,597
1993	1994	0.7278	0	190,443
1994	1995	0.8869	0	252,859
1995[a]	1996	1.0000	0	150,808
1996[a]	1997	0.9680	0	284,630
1997[a]	1998	0.9642	0	197,195
1998[a]	1999	0.8713	0	121,344
1999	2000	0.9527	0	167,955
2000	2001	0.9558	0	190,174
2001	2002	0.9911	0	200,938
2002	2003	0.9306	0	315,783
2003	2004	0.9291	0	240,459
2004	2005	0.8995	0	172,923
2005	2006	0.9811	14,859	140,542
2006	2007	0.9735	14,764	225,670
2007	2008	0.9863	14,947	252,133
2008	2009	0.9576	14,858	154,772
2009	2010	0.9847	14,486	227,743
2010	2011	0.9564	5,039	241,918
2011	2012	0.9690	5,074	256,120
Average		***0.9379***	***11,994[b]***	***208,271***
Median		***0.9561***	***14,764[b]***	***197,195***

[a] These groups were only adipose fin clipped.
[b] Average and median are based on brood years 2004 to 2010.

Fish size and condition at release

The size and condition of the juvenile sockeye released into Lake Wenatchee during the life of the program are presented in Table 4.9.

Table 4.9. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of sockeye released, brood years 1989-2011. Size targets are provided in the last row of the table.

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
1989	1990	128	-	18.2	25
1990	1991	131	-	18.9	24
1991	1992	117	3.0	20.6	22
1992	1993	73	6.8	4.2	44
1993	1994	103	-	13.6	40
1994	1995	75	6.1	4.5	38
1995	1996	137	8.2	14.7	30
1996	1997	107	5.6	15.1	30
1997	1998	122	6.1	21.3	21
1998	1999	112	5.4	17.0	27
1999	2000	94	9.5	9.5	48
		134	11.5	31.3	15
2000	2001	123	6.5	22.3	20
		146	8.4	26.0	12
2001	2002	118	7.4	20.7	22
		135	7.3	30.5	15
2002	2003	73	5.6	4.4	104
		118	7.7	13.7	23
		145	9.4	38.6	13
2003	2004	79	4.6	4.8	96
		118	5.9	17.0	26
		158	8.1	44.3	10
2004	2005	116	4.5	17.2	18
		151	7.0	39.3	12
2005	2006	149	7.5	43.7	10
2006	2007	138	10.6	32.4	14
2007	2008	137	9.3	33.0	14
2008	2009	138	9.6	34.6	13

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
2009	2010	143	8.9	35.5	13
2010	2011	132	14.3	30.7	15
2011	2012	142	9.6	35.3	13
Targets		***133***	***9.0***	***22.7***	***20***

Survival Estimates

Life-stage survival estimates for juvenile sockeye during the life of the hatchery program are shown in Table 4.10.

Table 4.10. Hatchery life-stage survival rates (%) for sockeye salmon, brood years 1989-2011. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
1989	41.6	100.0	88.1	63.9	99.2	98.9	98.1	65.2	83.0
1990	96.2	99.4	90.8	96.3	99.9	99.2	98.4	98.4	81.1
1991	91.8	94.1	79.2	94.8	99.8	99.3	96.4	96.4	72.4
1992	91.1	98.8	92.3	98.0	99.9	99.8	98.6	98.8	89.2
1993	57.1	99.2	89.2	98.3	99.6	99.1	93.7	93.8	82.2
1994	89.8	99.2	79.2	96.0	99.5	98.6	98.3	98.2	74.7
1995	97.5	99.1	87.5	95.0	99.0	93.3	73.2	73.2	60.8
1996	99.2	100.0	95.1	98.7	99.7	99.3	96.4	96.5	90.5
1997	92.8	99.3	84.8	97.9	97.9	97.6	95.5	94.9	77.5
1998	75.4	95.5	77.7	98.4	98.6	98.2	97.1	97.2	74.3
1999	92.3	100.0	92.2	97.3	99.6	99.3	98.2	99.7	88.1
2000	84.5	98.1	93.8	97.7	96.7	96.1	91.4	96.8	83.7
2001	75.4	99.2	78.5	97.6	98.0	97.6	86.9	95.1	66.6
2002	100.0	100.0	95.7	97.8	99.6	99.2	94.6	99.8	88.5
2003	91.0	98.1	87.2	96.9	99.0	98.2	94.8	95.5	74.6
2004	88.7	92.6	88.0	93.1	97.9	97.4	93.7	96.1	76.7
2005	98.5	98.5	85.3	94.9	97.8	96.6	95.5	99.2	66.3
2006	95.3	99.1	73.2	85.4	95.4	94.6	87.8	98.5	54.9
2007	88.4	99.2	89.1	98.6	97.0	95.9	94.9	99.0	83.4
2008	97.0	100.0	59.0	88.3	99.1	97.2	93.8	97.4	48.9
2009	95.8	98.3	89.1	94.8	96.9	96.2	88.4	92.3	74.7
2010	99.0	98.0	92.6	98.2	97.5	96.5	95.6	99.6	87.0
2011	100.0	100.0	92.6	100.0	96.8	96.0	95.4	99.7	88.3
Average	***88.6***	***98.5***	***86.1***	***94.7***	***98.5***	***97.6***	***93.8***	***94.8***	***76.8***

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
Median	***92.3***	***99.2***	***88.1***	***97.3***	***99.0***	***97.6***	***95.4***	***97.2***	***77.5***
Standard	***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

4.3 Disease Monitoring

Because the sockeye hatchery program was terminated in 2012, there are no disease-monitoring results.

4.4 Natural Juvenile Productivity

Sockeye smolt abundance was estimated at a rotary screw trap located near the mouth of Lake Wenatchee during the period 1997 to 2011. Because the efficiency of the trap was difficult to assess, the operation was terminated in 2011. In 2012, the trap was relocated downstream near the mouth of the Chiwawa River and operated there for two years. Again, because few marked sockeye smolts were recaptured, the operation was terminated in 2013. Beginning in 2013, smolt abundance has been estimated at the Lower Wenatchee Trap.

Emigrant and Smolt Estimates

The Lower Wenatchee Trap operated between 29 January and 26 July 2016. During that time, the trap was inoperable for 23 days because of high and low river discharge, debris, elevated river temperature, large hatchery releases, and mechanical issues. During the sampling period, a total of 1,346 wild juvenile sockeye were captured at the Lower Wenatchee Trap. A significant relationship between trap efficiency and river discharge was created ($R^2 = 0.52$, $P < 0.043$). Using this model, the number of juvenile sockeye emigrants was estimated at 208,250 (±29,447; 95% CI) during the 2016 trapping season (Table 4.11). Because of high flows coupled with mechanical issues, the trap was not fully operational during peak sockeye emigration. For this reason, the population estimate is considered a minimum. Figure 4.1 shows the monthly captures of sockeye collected at the Lower Wenatchee Trap in 2016. All fish captured in the Lower Wenatchee trap are reported in Appendix B.

Table 4.11. Estimated numbers of wild and hatchery sockeye smolts that emigrated from Lake Wenatchee during run years 1997-2016; NS = no data. Estimates for the run years 1997-2011 were based on sampling at the Upper Wenatchee smolt trap; estimates beginning in 2013 were based on sampling at the Lower Wenatchee smolt trap.

Run year	Numbers of sockeye smolts	
	Wild smolts	Hatchery smolts
1997	55,359	28,828
1998	1,447,259	55,985
1999	1,944,966	112,524
2000	985,490	24,684
2001	39,353	94,046
2002	729,716	121,511

Run year	Numbers of sockeye smolts	
	Wild smolts	Hatchery smolts
2003	5,439,032	140,322
2004	5,771,187	216,023
2005	723,413	122,399
2006	1,266,971	159,500
2007	2,797,313	140,542
2008[a]	549,682	121,843
2009[a]	355,549	119,908
2010[a]	3,958,888	126,326
2011	1,500,730	159,089
2012	ND	ND
2013	873,096 (±95,132)	No program
2014	1,275,027 (±211,615)	No program
2015	1,065,614 (±238,901)	No program
2016	208,250 (±29,447)	No program
Average	***1,630,889***	***116,235***[b]
Median	***1,065,614***	***121.511***[b]

[a] Estimates refined based on PIT tag survival to McNary Dam.
[b] Summary statistics were calculated for years in which hatchery fish were being released (1997-2011).

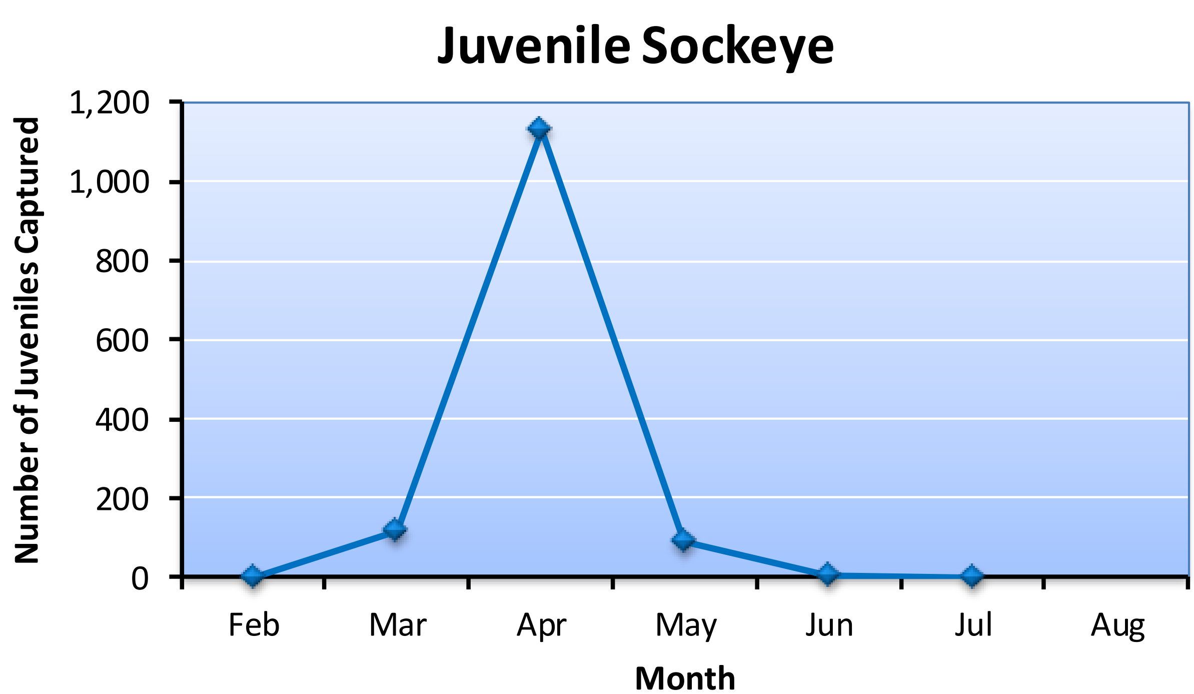

Figure 4.1. Monthly captures of wild sockeye salmon smolts at the Lower Wenatchee Trap, 2016.

Age classes of wild sockeye smolts were determined from a length frequency analysis based on scales collected randomly each year since 1997 (Table 4.12). Each year, a small number of markedly smaller sockeye (<50 mm FL) are collected, and starting with run year 2013, an age-0 class was retroactively assigned based on catch records. For the available run years, most wild sockeye smolts migrated as age 1+ fish. Only in two years (1997 and 2005) did more smolts migrate as age 2+ fish. Relatively few smolts migrated at age 3+.

Table 4.12. Age structure and estimated number of wild sockeye smolts that emigrated from Lake Wenatchee, 1997-2016; ND = no data. Estimates for the run years 1997-2011 were based on sampling at the Upper Wenatchee smolt trap; estimates beginning in 2013 were based on sampling at the Lower Wenatchee smolt trap.

Run year	Proportion of wild smolts				Total wild emigrants
	Age 0	Age 1+	Age 2+	Age 3+	
1997	ND	0.075	0.906	0.019	55,359
1998	ND	0.955	0.037	0.008	1,447,259
1999	ND	0.619	0.381	0.000	1,944,966
2000	ND	0.599	0.400	0.001	985,490
2001	ND	0.943	0.051	0.006	39,353
2002	ND	0.961	0.039	0.000	729,716
2003	ND	0.740	0.026	0.000	5,439,032
2004	ND	0.929	0.071	0.000	5,771,187
2005	ND	0.230	0.748	0.022	723,413
2006	ND	0.994	0.006	0.000	1,266,971
2007	ND	0.996	0.004	0.000	2,797,313
2008	ND	0.804	0.195	0.001	549,682
2009	ND	0.927	0.073	0.000	355,549
2010	ND	0.963	0.036	0.001	3,958,888
2011	ND	0.786	0.214	0.000	1,500,730
2012	ND	ND	ND	ND	ND
2013	0.008	0.919	0.073	0.000	873,096
2014	0.003	0.948	0.049	0.000	1,275,027
2015	0.003	0.777	0.220	0.000	1,065,614
2016	TBD	TBD	TBD	TBD	208,250
Average	***0.467***	***0.787***	***0.196***	***0.003***	***1,630,889***
Median	***0.003***	***0.919***	***0.071***	***0.000***	***1,065,614***

Freshwater Productivity

Egg-smolt survival estimates for wild sockeye salmon are provided in Table 4.13. Estimates of egg deposition were calculated based on the spawner escapement at Tumwater Dam and the sex ratio and fecundity of the broodstock. For the 2012 brood year (a year where brood was not collected), a linear relationship with post-orbital to hypural length as the independent variable was used to calculate average fecundity of sockeye sampled at Tumwater Dam ($r^2 = 0.40$, $P < 0.01$). Smolts for brood years 1995-2009 were based on captures at the Upper Wenatchee Trap. No smolt estimates are available for brood year 2010. Smolt estimates for brood years since 2012 are derived from captures made at the Lower Wenatchee Trap. Egg-smolt survival rates for brood years 1995-2014 have ranged from 0.012 to 0.212 (mean = 0.084).

Table 4.13. Estimated egg deposition (estimated as mean fecundity times estimated number of females), numbers of smolts, and survival rates for wild Wenatchee sockeye salmon, brood years 1995-2014; NA = not available.

Brood year	Number of females	Mean fecundity	Total eggs	Numbers of wild smolts					Egg-smolt survival
				Age 0	Age 1+	Age 2+	Age 3+	Total	
1995	2,136	2,295	4,902,120	NA	4,174	53,549	0	57,723	0.012
1996	3,767	2,664	10,035,288	NA	1,382,133	741,032	985	2,124,150	0.212
1997	5,404	2,447	13,223,588	NA	1,203,934	394,196	236	1,598,366	0.121
1998	2,024	2,813	5,693,512	NA	590,309	2,007	0	592,316	0.104
1999	513	2,319	1,189,647	NA	37,110	28,459	0	65,569	0.055
2000	11,413	2,673	30,506,949	NA	701,257	1,414,148	0	2,115,405	0.069
2001	21,685	2,960	64,187,600	NA	4,024,884	409,754	15,915	4,450,553	0.069
2002	17,226	2,856	49,197,456	NA	5,361,433	541,113	0	5,902,546	0.120
2003	2,158	3,511	7,576,738	NA	166,385	7,602	0	173,987	0.023
2004	15,469	2,505	38,749,845	NA	1,259,369	11,189	275	1,270,833	0.033
2005	5,867	2,718	15,946,506	NA	2,786,123	107,243	0	2,893,366	0.181
2006	2,747	2,656	7,296,032	NA	442,164	25,919	1,507	469,590	0.064
2007	2,001	3,115	6,232,804	NA	329,629	142,916	594	473,139	0.076
2008	11,775	2,555	30,084,691	NA	3,814,226	320,567	NA	4,134,794	0.137
2009	3,939	2,459	9,684,965	NA	1,179,569	NA	0	NA	NA
2010	11,918	2,785	33,190,467	NA	NA[a]	58,497	0	NA	NA
2011	9,722	2,970	28,873,491	NA	816,836[b]	96,902	0	913,738	0.032
2012	14,753	2,745	40,496,573	10,200	1,208,726	234,435	0	1,443,161	0.036
2013	9,477	2,732	25,891,164	3,197	827,982	--	--	--	--
2014	31,203	2,725	85,028,175	625	--	--	--	--	--
Average	***8,105***	***2,725***	***22,261,023***	***4,467***	***1,506,918***	***269,987***	***1,148***	***1,792,280***	***0.084***
Median	***5,867***	***2,718***	***15,946,506***	***3,197***	***1,179,569***	***107,243***	***0***	***1.270,833***	***0.069***

[a] There is no emigrant estimate for trapping during 2012.
[b] Emigrant estimates are derived from captures at the Lower Wenatchee Trap.

Juvenile survival rates for hatchery sockeye salmon are provided in Table 4.14. Release-smolt survival rates for brood years 1995-2009 have ranged from 0.000 to 1.000 (mean = 0.570). Egg-smolt survival rates for the same brood years ranged from 0.000 to 0.710 (mean = 0.294). On average, egg-smolt survival of hatchery sockeye is about three times greater than egg-smolt survival of wild sockeye.

Table 4.14. Juvenile survival rates for hatchery Wenatchee sockeye, brood years 1995-2009.

Brood year	Number of eggs	Number of parr released	Date of release	Estimated number of smolts	Egg-smolt survival	Release-smolt survival
1995	247,900	150,808	10/25/96	28,828	0.116	0.191
1996	314,390	284,630	10/22/97	55,985	0.178	0.197
1997	254,459	197,195	11/9/98	112,524	0.442	0.571
1998	163,278	121,344	10/27/99	24,684	0.151	0.203
1999	190,732	84,466	8/28/00	30,326	0.159	0.359
		83,489	11/1/00	63,720	0.334	0.763
2000	227,234	92,055	8/27/01	30,918	0.136	0.336
		98,119	9/27/01	90,593	0.399	0.923
2001	301,925	96,486	8/28/02	36,484	0.121	0.378
		104,452	9/23/02	103,838	0.344	0.994
2002	356,982	98,509	6/16/03	5,192	0.015	0.053
		104,855	8/25/03	98,412	0.276	0.939
		112,419	10/22/03	112,419	0.315	1.000
2003	319,470	32,755	6/15/04	0	0.000	0.000
		104,879	8/25/04	19,574	0.061	0.187
		102,825	11/3/04	102,825	0.322	1.000
2004	225,499	81,428	8/29/05	159,500	0.707	0.922
		91,495	11/2/05			
2005	211,985	70,386	10/30/06	140,542	0.663	1.000
		70,156	10/30/06			
2006	292,136	225,670	10/31/07	121,843	0.412	0.540
2007	302,363	252,133	10/29/08	119,908	0.397	0.476
2008	316,476	154,772	10/28/09	126,326	0.399	0.813
2009	304,963	227,743	10/27/10	159,089	0.522	0.699

[a] There is no emigrant estimate for the 2010 or 2011 brood years.

PIT Tagging Activities

A total of 1,065 wild juvenile sockeye salmon were PIT tagged and released in 2016 at the Lower Wenatchee Trap. Numbers of wild sockeye salmon PIT-tagged and released as part of the Comparative Survival Study and PUD studies during the period 2006-2016 are shown in Table 4.15. See Appendix C for a complete list of all fish captured, tagged, lost, and released.

Table 4.15. Summary of the numbers of wild sockeye salmon that were tagged and released at the Upper and Lower Wenatchee Traps within the Wenatchee River basin, 2006-2016.

Sampling Location	Numbers of PIT-tagged sockeye salmon released								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Upper Wenatchee Trap	3,165	3,683	10,006	--	--	--	--	--	--
Lower Wenatchee Trap	0	0	0	0	0	0	4,821	3,922	1,065

4.5 Spawning Escapement

The sockeye salmon hatchery program ended after the 2011 brood year. As a result, monitoring activities that focused on evaluating the effects of the supplementation program on the natural population switched to monitoring the abundance and productivity of the natural population. Broadly, the proposed monitoring and evaluation activities cover juvenile and adult life-history stages and provide the data necessary to track or estimate viable salmonid population parameters (VSP); abundance, productivity, spatial structure, and diversity (McElhaney et al. 2000).

From 2009-2013, mark-recapture methods were used to estimate spawning escapement within the White River, while area-under-the-curve (AUC) methods were used to estimate spawning escapement within the Little Wenatchee River. Beginning in 2014, mark-recapture methods were used to estimate the spawning escapement of sockeye in the White River and Little Wenatchee watersheds (see Appendix H for more details).

Mark-Recapture Estimates

Spawning escapement of sockeye salmon in 2016 was estimated using mark-recapture methods. This method relied on PIT tags to estimate sockeye spawning escapement (see Appendix H for more details).

Using mark-recapture methods, the estimated total escapement of sockeye in the Upper Wenatchee River basin in 2016 was 45,068 (Table 4.16). About 85% of the escapement entered the White River watershed (including the Napeequa River).

Table 4.16. Estimated escapement of adult sockeye into the Little Wenatchee and White River watersheds for return years 2009-2016. Escapement was based on recapture of PIT-tagged fish.

Return year	Tumwater Dam count	Recreational harvest	Little Wenatchee escapement	White River escapement	Total spawning escapement
2009	16,034	2,285	576	13,876	14,452
2010	35,821	4,129	2,062	19,542	21,604
2011[a]	18,634	0	2,431	14,582	17,013
2012	66,520	12,107	4,607	23,866	28,473
2013[a]	29,015	6,262	2,426	14,294	16,720
2014	99,898	16,281	4,319	49,021	53,340
2015	51,435	7,916	4,115	20,097	24,212
2016	73,697	14,630	6,747	38,321	45,068
Average	***48,882***	***7,951***	***3,234***	***24,200***	***27,434***
Median	***43,628***	***7,089***	***2,569***	***19,820***	***22,204***

[a] Spawning escapements in 2011 and 2013 were calculated using AUC counts and a regression model.

The spawning escapement of 45,068 Wenatchee sockeye was greater than the overall average of 27,434 (Table 4.17).

Table 4.17. Spawning escapements for sockeye salmon in the Wenatchee River basin for return years 1989-2016; NA = not available and AUC = area under the curve.

Return year	Escapement estimation method	Spawning escapement		
		Little Wenatchee	White	Total
1989	Counts at Tumwater Dam	NA	NA	**21,802**
1990	Counts at Tumwater Dam	NA	NA	**27,325**
1991	Counts at Tumwater Dam	NA	NA	**26,689**
1992	Counts at Tumwater Dam	NA	NA	**16,461**
1993	Counts at Tumwater Dam	NA	NA	**27,726**
1994	Counts at Tumwater Dam	NA	NA	**7,330**
1995	Counts at Tumwater Dam	NA	NA	**3,448**
1996	Counts at Tumwater Dam	NA	NA	**6,573**
1997	Counts at Tumwater Dam	NA	NA	**9,693**
1998	Counts at Tumwater Dam	NA	NA	**4,014**
1999	Counts at Tumwater Dam	NA	NA	**1,025**
2000	Counts at Tumwater Dam	NA	NA	**20,735**
2001	Counts at Tumwater Dam	NA	NA	**29,103**
2002	Counts at Tumwater Dam	NA	NA	**27,565**
2003	Counts at Tumwater Dam	NA	NA	**4,855**
2004	Counts at Tumwater Dam	NA	NA	**27,556**
2005	Counts at Tumwater Dam	NA	NA	**14,011**
2006	AUC	574	5,634	**6,208**
2007	AUC	150	1,720	**1,870**
2008	AUC	3,491	16,757	**20,248**
2009	AUC and Mark-Recap	763	7,004	**7,767**
2010	AUC and Mark-Recap	2,543	19,157	**21,700**
2011	AUC and Mark-Recap	2,431	14,582	**17,013**
2012	AUC and Mark-Recap	4,607	23,866	**28,473**
2013	AUC and Mark-Recap	2,426	14,294	**16,720**
2014	Mark-Recapture	4,391	49,021	**53,340**
2015	Mark-Recapture	4,115	20,097	**24,212**
2016	Mark-Recapture	6,747	38,321	**45,068**
Average		***2,803***	***19,132***	***18,469***
Median		***2,543***	***16,757***	***18,631***

4.6 Carcass Surveys

As described earlier, carcass surveys were not conducted in 2016. The information contained in this section represents carcass data collected before 2014.

Number sampled

Table 4.18 shows the number of carcasses sampled within different survey streams during the period 1993-2013.

Table 4.18. Numbers of sockeye carcasses sampled within different streams/watersheds within the Wenatchee River basin, 1989-2013.

Survey year	Numbers of sockeye carcasses			
	Little Wenatchee	White	Napeequa	Total
1993	90	195	0	**285**
1994	121	165	0	**286**
1995	0	56	0	**56**
1996	43	1,387	3	**1,433**
1997	69	1,425	41	**1,535**
1998	61	524	4	**589**
1999	40	186	0	**226**
2000	821	5,494	0	**6,315**
2001	650	3,127	0	**3,777**
2002	506	7,258	55	**7,819**
2003	86	1,002	14	**1,102**
2004	625	6,960	138	**7,723**
2005	1	7	0	**8**
2006	101	2,158	38	**2,297**
2007	17	363	3	**383**
2008	476	5,132	125	**5,733**
2009	84	3,103	103	**3,290**
2010	217	7,832	70	**8,119**
2011	372	3,322	48	**3,742**
2012	1,309	7,479	31	**8,819**
2013	179	2,996	27	**3,202**
Average	***279***	***2,865***	***33***	***3,178***
Median	***101***	***2,158***	***14***	***2,297***

Carcass Distribution and Origin

Based on the available data (1993-2013), the largest percentage of both wild and hatchery sockeye spawned in Reach 2 on the White River (Table 4.19 and Figure 4.2). However, a greater percentage of wild fish was found in Reach 2 than hatchery fish.

Table 4.19. Numbers of wild and hatchery sockeye carcasses sampled within different reaches in the Wenatchee River basin, 1993-2013. Reach codes are described in Table 2.9.

Survey year	Origin	Numbers of sockeye carcasses					
		Little Wenatchee		White River			Total
		L2	L3	H1	H2	Q1	
1993	Wild	86	0	0	183	0	**269**
	Hatchery	4	0	0	12	0	**16**
1994	Wild	112	0	0	155	0	**267**
	Hatchery	9	0	0	9	0	**18**
1995	Wild	0	0	0	55	0	**55**
	Hatchery	0	0	0	1	0	**1**
1996	Wild	41	0	0	1,299	3	**1,343**
	Hatchery	2	0	0	88	0	**90**
1997	Wild	65	0	0	1,411	40	**1,516**
	Hatchery	4	0	0	11	1	**16**
1998	Wild	61	0	0	515	4	**580**
	Hatchery	0	0	0	9	0	**9**
1999	Wild	30	0	0	164	0	**194**
	Hatchery	10	0	0	22	0	**32**
2000	Wild	694	0	3	5,239	0	**5,936**
	Hatchery	127	0	0	252	0	**379**
2001	Wild	625	0	0	3,063	0	**3,688**
	Hatchery	25	0	0	64	0	**89**
2002	Wild	504	0	0	7,207	55	**7,766**
	Hatchery	2	0	0	51	0	**53**
2003	Wild	81	0	0	993	14	**1,088**
	Hatchery	5	0	0	9	0	**14**
2004	Wild	606	0	0	6,755	166	**7,527**
	Hatchery	19	0	0	205	22	**246**
2005	Wild	201	0	5	2,966	21	**3,193**
	Hatchery	1	0	0	8	0	**9**
2006	Wild	80	0	0	2,112	36	**2,228**
	Hatchery	21	0	0	46	2	**69**
2007	Wild	17	0	0	346	3	**366**
	Hatchery	0	0	0	17	0	**17**
2008	Wild	472	0	0	5,118	124	**5,714**
	Hatchery	4	0	0	14	1	**19**
2009	Wild	80	0	0	3,084	103	**3,267**
	Hatchery	4	0	0	19	0	**23**
2010	Wild	210	0	0	7,711	69	**7,990**
	Hatchery	7	0	0	121	1	**129**
2011	Wild	266	0	0	3,079	43	**3,388**
	Hatchery	106	0	0	243	5	**354**

Survey year	Origin	Numbers of sockeye carcasses					
		Little Wenatchee		White River			Total
		L2	L3	H1	H2	Q1	
2012	Wild	1,270	0	21	7,368	30	**8,689**
	Hatchery	39	0	3	87	1	**130**
2013	Wild	174	0	1	2,936	26	**3,137**
	Hatchery	3	0	0	56	1	**60**
Average	***Wild***	***270***	***0***	***1***	***2,941***	***35***	***3,248***
	Hatchery	***18***	***0***	***0***	***61***	***2***	***81***
Median	***Wild***	***112***	***0***	***0***	***2,936***	***21***	***3,137***
	Hatchery	***4***	***0***	***0***	***22***	***0***	***32***

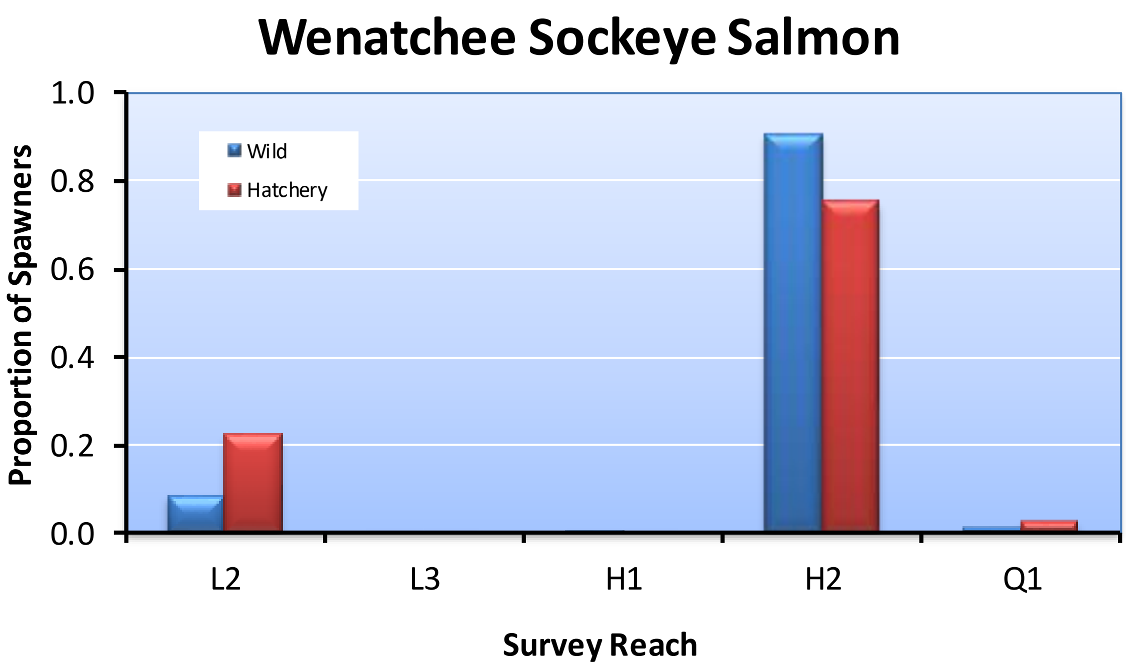

Figure 4.2. Distribution of wild and hatchery produced carcasses in different reaches in the Wenatchee River basin, pooled data from 1993-2013. Reach codes are described in Table 2.9; L = Little Wenatchee, H = White River, and Q = Napeequa River.

4.7 Life History Monitoring

Life history characteristics of Wenatchee sockeye were assessed by examining carcasses on spawning grounds and fish sampled at broodstock collection sites or during stock assessment, and by reviewing tagging data and fisheries statistics.

Migration Timing

There was little difference in migration timing of hatchery and wild sockeye past Tumwater Dam (Table 4.20a and b; Figure 4.3). On average, early in the run, hatchery and wild sockeye arrived at the dam at about the same time. Toward the end of the migration period, hatchery sockeye tended to arrive at the dam slightly later than did wild sockeye. Most hatchery and wild sockeye migrated upstream past Tumwater Dam during July through early August. The peak migration time for both hatchery and wild sockeye was the last two weeks of July (Figure 4.3).

Table 4.20a. The Julian day and date that 10%, 50% (median), and 90% of the wild and hatchery sockeye salmon passed Tumwater Dam, 1998-2016. The average Julian day and date are also provided. Migration timing is based on video sampling at Tumwater. Data for 1998 through 2003 were based on videotapes and broodstock trapping and may not reflect the actual number of hatchery sockeye salmon. All sockeye were visually examined during trapping from 2004 to present.

Survey year	Origin	Sockeye Migration Time (days)								Sample size
		10 Percentile		50 Percentile		90 Percentile		Mean		
		Julian	Date	Julian	Date	Julian	Date	Julian	Date	
1998	Wild	195	14-Jul	201	20-Jul	208	27-Jul	202	21-Jul	4,173
	Hatchery	196	15-Jul	204	23-Jul	220	8-Aug	206	25-Jul	31
1999	Wild	226	14-Aug	233	21-Aug	241	29-Aug	234	22-Aug	908
	Hatchery	228	16-Aug	234	22-Aug	242	30-Aug	235	23-Aug	264
2000	Wild	200	18-Jul	206	24-Jul	213	31-Jul	207	25-Jul	18,390
	Hatchery	199	17-Jul	206	24-Jul	213	31-Jul	206	24-Jul	2,589
2001	Wild	189	8-Jul	194	13-Jul	214	2-Aug	198	17-Jul	32,554
	Hatchery	199	18-Jul	212	31-Jul	240	28-Aug	214	2-Aug	79
2002	Wild	204	23-Jul	208	27-Jul	219	7-Aug	210	29-Jul	27,241
	Hatchery	204	23-Jul	209	28-Jul	222	10-Aug	211	30-Jul	580
2003	Wild	194	13-Jul	200	19-Jul	208	27-Jul	201	20-Jul	4,699
	Hatchery	194	13-Jul	201	20-Jul	211	30-Jul	203	22-Jul	375
2004	Wild	191	9-Jul	196	14-Jul	207	25-Jul	198	16-Jul	31,408
	Hatchery	189	7-Jul	194	12-Jul	203	21-Jul	196	14-Jul	1,758
2005	Wild	192	11-Jul	199	18-Jul	227	15-Aug	204	23-Jul	14,176
	Hatchery	187	6-Jul	200	19-Jul	251	8-Sep	212	31-Jul	42
2006	Wild	201	20-Jul	204	23-Jul	214	2-Aug	206	25-Jul	9,151
	Hatchery	202	21-Jul	219	7-Aug	228	16-Aug	215	3-Aug	507
2007	Wild	201	20-Jul	210	29-Jul	227	15-Aug	213	1-Aug	2,542
	Hatchery	205	24-Jul	213	1-Aug	231	19-Aug	216	4-Aug	65
2008	Wild	200	18-Jul	207	25-Jul	219	6-Aug	208	26-Jul	29,229
	Hatchery	201	19-Jul	206	24-Jul	215	2-Aug	208	26-Jul	103
2009	Wild	198	17-Jul	204	23-Jul	213	1-Aug	206	25-Jul	15,552
	Hatchery	199	18-Jul	205	24-Jul	215	3-Aug	207	26-Jul	534
2010	Wild	199	18-Jul	205	24-Jul	220	8-Aug	208	27-Jul	34,519
	Hatchery	200	19-Jul	215	3-Aug	244	1-Sep	218	6-Aug	1,302
2011	Wild	213	1-Aug	216	4-Aug	224	12-Aug	217	5-Aug	17,680
	Hatchery	213	1-Aug	213	1-Aug	231	19-Aug	216	4-Aug	954
2012[a]	Wild	207	25-Jul	212	30-Jul	216	3-Aug	212	30-Jul	21,246
	Hatchery	207	25-Jul	207	25-Jul	228	15-Aug	213	31-Jul	348

Survey year	Origin	Sockeye Migration Time (days)								Sample size
		10 Percentile		50 Percentile		90 Percentile		Mean		
		Julian	Date	Julian	Date	Julian	Date	Julian	Date	
2013	Wild	196	15-Jul	200	19-Jul	207	26-Jul	201	20-Jul	28,245
	Hatchery	197	16-Jul	201	20-Jul	211	30-Jul	203	22-Jul	770
2014	Wild	194	13-Jul	199	18-Jul	210	29-Jul	201	20-Jul	97,670
	Hatchery	196	15-Jul	201	20-Jul	211	30-Jul	203	22-Jul	2,229
2015	Wild	191	10-Jul	199	18-Jul	215	3-Aug	203	22-Jul	49,628
	Hatchery	181	30-Jun	199	18-Jul	212	31-Jul	200	19-Jul	1,782
2016	Wild	190	8-Jul	196	14-Jul	208	26-Jul	198	16-Jul	73,619
	Hatchery	192	10-Jul	195	13-Jul	207	25-Jul	197	15-Jul	78
Average	***Wild***	***199***		***205***		***216***		***207***		***26,981***
	Hatchery	***199***		***207***		***223***		***209***		***757***
Median	***Wild***	***198***		***204***		***214***		***206***		***21,246***
	Hatchery	***199***		***206***		***220***		***208***		***507***

[a] The origin of sockeye passing Tumwater Dam during 8 through 11 August 2012 was not assessed. The total number of sockeye passing Tumwater Dam in 2012 was 30,617 adults. Thus, about 9,023 adults of unknown origin passed Tumwater Dam in 2012.

Table 4.20b. The week that 10%, 50% (median), and 90% of the wild and hatchery sockeye salmon passed Tumwater Dam, 1998-2016. The average week is also provided. Migration timing is based on video sampling at Tumwater. Data for 1998 through 2003 were based on videotapes and broodstock trapping and may not reflect the actual number of hatchery sockeye salmon. All sockeye were visually examined during trapping from 2004 to present.

Survey year	Origin	Sockeye Migration Time (week)				Sample size
		10 Percentile	50 Percentile	90 Percentile	Mean	
1998	Wild	28	29	30	29	4,173
	Hatchery	28	30	32	30	31
1999	Wild	33	34	35	34	908
	Hatchery	33	34	35	34	264
2000	Wild	29	30	31	30	18,390
	Hatchery	29	30	31	30	2,589
2001	Wild	27	28	31	29	32,554
	Hatchery	29	31	35	31	79
2002	Wild	30	30	32	30	27,241
	Hatchery	30	30	32	31	580
2003	Wild	28	29	30	29	4,699
	Hatchery	28	29	31	29	375
2004	Wild	28	28	28	29	31,408
	Hatchery	27	28	29	28	1,758
2005	Wild	28	29	33	30	14,176
	Hatchery	27	29	36	31	42

Survey year	Origin	Sockeye Migration Time (week)				Sample size
		10 Percentile	50 Percentile	90 Percentile	Mean	
2006	Wild	29	29	31	30	9,151
	Hatchery	29	32	33	31	507
2007	Wild	29	30	33	31	2,542
	Hatchery	30	31	33	31	65
2008	Wild	29	30	32	30	29,229
	Hatchery	29	30	31	30	103
2009	Wild	29	30	31	30	15,552
	Hatchery	29	29	31	30	534
2010	Wild	29	30	32	30	34,519
	Hatchery	29	31	35	32	1,302
2011	Wild	31	31	32	31	17,680
	Hatchery	31	31	33	31	954
2012[a]	Wild	30	31	31	31	21,246
	Hatchery	30	30	33	31	348
2013	Wild	28	29	30	29	28,245
	Hatchery	29	29	31	29	770
2014	Wild	28	29	30	29	97,670
	Hatchery	28	29	29	29	2,229
2015	Wild	28	29	31	30	49,628
	Hatchery	26	29	31	29	1,782
2016	Wild	28	28	30	29	73,619
	Hatchery	28	28	30	29	78
Average	***Wild***	***29***	***30***	***31***	***30***	***26,981***
	Hatchery	***29***	***30***	***32***	***30***	***757***
Median	***Wild***	***29***	***29***	***31***	***30***	***21,246***
	Hatchery	***29***	***30***	***32***	***30***	***507***

[a] The origin of sockeye passing Tumwater Dam during 8 through 11 August 2012 was not assessed. The total number of sockeye passing Tumwater Dam in 2012 was 30,617 adults. Thus, about 9,023 adults of unknown origin passed Tumwater Dam in 2012.

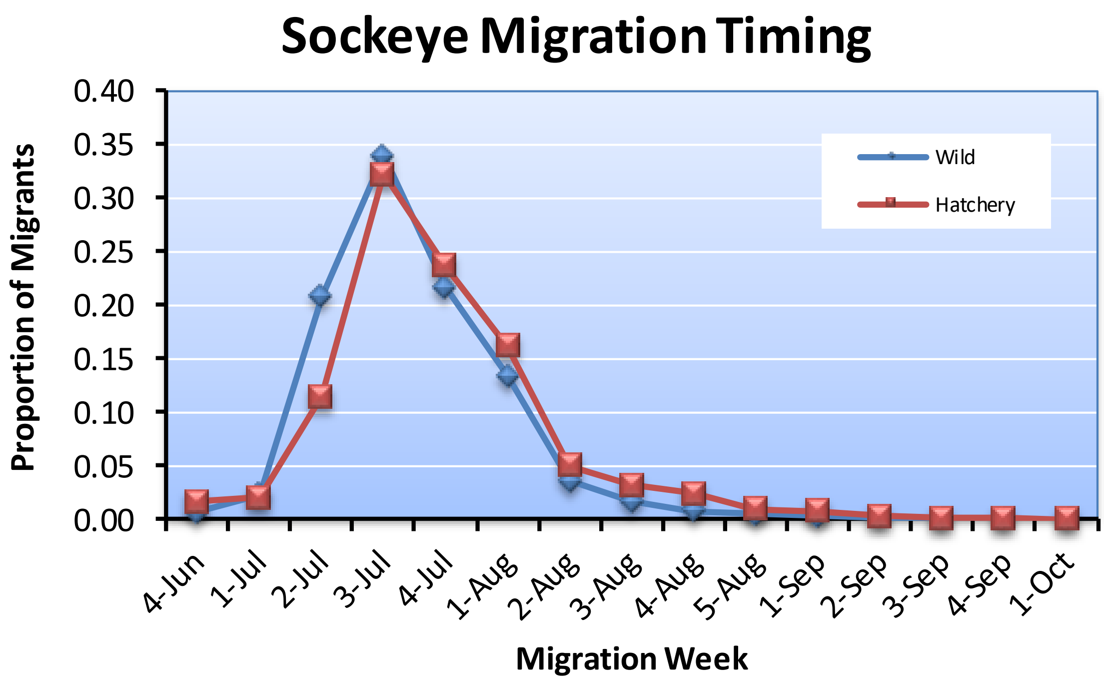

Figure 4.3. Proportion of wild and hatchery sockeye observed (using video) passing Tumwater Dam each week during their migration period late-June through early-October; data were pooled over survey years 1998-2016.

Age at Maturity

Although sample sizes are small, most hatchery sockeye returned as age-4 fish, while most wild sockeye returned as age-4 and 5 fish (Table 4.21; Figure 4.4). Only wild fish have returned at age-6.

Table 4.21. Proportions of wild and hatchery sockeye of different ages (total age) sampled in broodstock (1994-2011), on spawning grounds (1994-2012), and at Tumwater Dam (2013-2016).

Survey year	Origin	Total age						Sample size
		2	3	4	5	6	7	
1994	Wild	0.00	0.00	0.00	0.00	0.00	0.00	0
	Hatchery	0.00	0.00	0.88	0.13	0.00	0.00	16
1995	Wild	0.00	0.00	0.00	0.00	0.00	0.00	0
	Hatchery	0.00	0.00	0.00	1.00	0.00	0.00	1
1996	Wild	0.00	0.00	0.00	0.00	0.00	0.00	0
	Hatchery	0.00	0.00	1.00	0.00	0.00	0.00	82
1997	Wild	0.00	0.00	0.00	0.00	0.00	0.00	0
	Hatchery	0.00	0.00	0.77	0.23	0.00	0.00	13
1998	Wild	0.00	0.08	0.85	0.08	0.00	0.00	26
	Hatchery	0.00	0.00	0.64	0.36	0.00	0.00	11
1999	Wild	0.00	0.00	0.18	0.73	0.10	0.00	113

Survey year	Origin	Total age						Sample size
		2	3	4	5	6	7	
	Hatchery	0.00	0.00	0.65	0.35	0.00	0.00	31
2000	Wild	0.00	0.00	0.00	1.00	0.00	0.00	1
	Hatchery	0.00	0.00	0.98	0.02	0.00	0.00	359
2001	Wild	0.00	0.00	0.76	0.24	0.00	0.00	29
	Hatchery	0.00	0.00	0.75	0.25	0.00	0.00	171
2002	Wild	0.00	0.00	0.20	0.80	0.00	0.00	5
	Hatchery	0.00	0.00	0.29	0.71	0.00	0.00	63
2003	Wild	0.00	0.00	0.00	1.00	0.00	0.00	5
	Hatchery	0.00	0.33	0.67	0.00	0.00	0.00	6
2004	Wild	0.00	0.00	0.00	0.00	0.00	0.00	0
	Hatchery	0.00	0.02	0.93	0.05	0.00	0.00	244
2005	Wild	0.00	0.00	0.00	0.00	0.00	0.00	0
	Hatchery	0.00	0.13	0.75	0.13	0.00	0.00	8
2006	Wild	0.00	0.00	0.34	0.65	0.01	0.00	207
	Hatchery	0.00	0.00	1.00	0.00	0.00	0.00	65
2007	Wild	0.00	0.00	0.02	0.88	0.10	0.00	206
	Hatchery	0.00	0.00	0.35	0.65	0.00	0.00	17
2008	Wild	0.00	0.00	0.95	0.04	0.01	0.00	258
	Hatchery	0.00	0.08	0.92	0.00	0.00	0.00	12
2009	Wild	0.00	0.00	0.79	0.21	0.00	0.00	251
	Hatchery	0.00	0.00	1.00	0.00	0.00	0.00	2
2010	Wild	0.00	0.00	0.67	0.33	0.00	0.00	193
	Hatchery	0.00	0.00	0.98	0.02	0.00	0.00	130
2011	Wild	0.00	0.00	0.63	0.36	0.01	0.00	270
	Hatchery	0.00	0.02	0.96	0.02	0.00	0.00	274
2012	Wild	0.00	0.00	0.92	0.08	0.00	0.00	13
	Hatchery	0.00	0.00	0.96	0.03	0.01	0.00	128
2013	Wild	0.00	0.002	0.56	0.44	0.002	0.00	457
	Hatchery	0.00	0.00	0.50	0.50	0.00	0.00	2
2014	Wild	0.00	0.00	0.88	0.12	0.00	0.00	1,332
	Hatchery	0.00	0.03	0.95	0.02	0.00	0.00	40
2015	Wild	0.00	0.00	0.81	0.19	0.00	0.00	882
	Hatchery	0.00	0.00	1.00	0.00	0.00	0.00	53
2016	Wild	0.00	0.00	0.77	0.23	0.00	0.00	765
	Hatchery	0.00	0.00	0.00	1.00	0.00	0.00	1
Average	***Wild***	***0.00***	***0.00***	***0.72***	***0.27***	***0.01***	***0.00***	***218***
	Hatchery	***0.00***	***0.01***	***0.90***	***0.09***	***0.00***	***0.00***	***75***
Median	***Wild***	***0.00***	***0.00***	***0.75***	***0.25***	***0.00***	***0.00***	***29***

Survey year	Origin	Total age						Sample size
		2	3	4	5	6	7	
	Hatchery	***0.00***	***0.00***	***0.90***	***0.10***	***0.00***	***0.00***	***31***

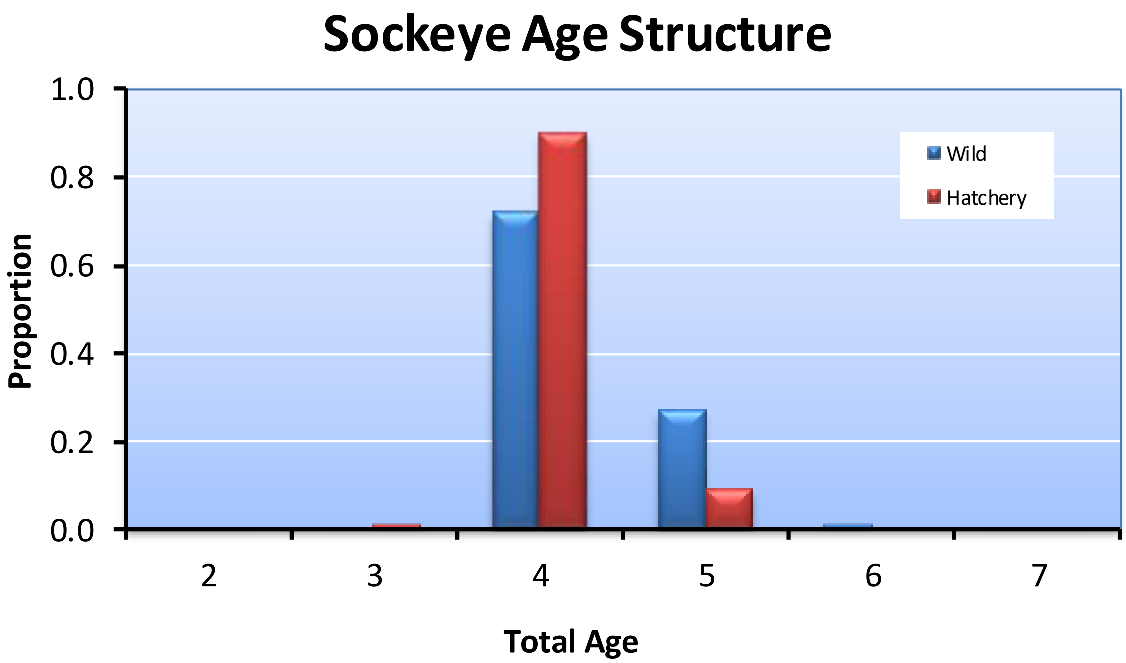

Figure 4.4. Proportions of wild and hatchery sockeye salmon of different total ages sampled at Tumwater Dam and on spawning grounds in the Wenatchee River basin for the combined years 1994-2016.

Size at Maturity

Although sample sizes are small, wild and hatchery sockeye differed in mean length in 2016 (Table 4.22). However, the pooled data indicate that there is little difference in mean sizes of hatchery and wild sockeye salmon sampled in the Wenatchee River basin (Table 4.22). Analyses for the five-year reports will compare sizes of hatchery and wild fish of the same age groups and sex.

Table 4.22. Mean lengths (POH; cm) and variability statistics for wild and hatchery sockeye salmon sampled at Dryden Dam (broodstock) and on spawning grounds in the Wenatchee River basin, 1994-2016; SD = 1 standard deviation. From 2014 to present, data are collected from sockeye sampled at Tumwater Dam.

Survey year	Origin	Sample size	Sockeye length (POH; cm)			
			Mean	SD	Minimum	Maximum
1994	Wild	0	-	-	-	-
	Hatchery	14	42	3	37	47
1995	Wild	0	-	-	-	-
	Hatchery	1	53	-	53	53
1996	Wild	0	-	-	-	-
	Hatchery	5	51	3	49	55

Survey year	Origin	Sample size	Sockeye length (POH; cm)			
			Mean	SD	Minimum	Maximum
1997	Wild	6	40	3	38	45
	Hatchery	17	41	3	37	50
1998	Wild	585	43	3	34	50
	Hatchery	20	43	3	40	51
1999	Wild	99	42	3	36	50
	Hatchery	31	41	3	36	47
2000	Wild	1	48	-	48	48
	Hatchery	377	40	2	30	49
2001	Wild	29	42	2	38	47
	Hatchery	184	43	3	35	51
2002	Wild	5	42	1	40	43
	Hatchery	52	44	3	37	49
2003	Wild	5	44	4	38	47
	Hatchery	13	42	5	30	48
2004	Wild	0	-	-	-	-
	Hatchery	230	40	3	33	49
2005	Wild	0	-	-	-	-
	Hatchery	8	43	9	35	64
2006	Wild	248	45	4	34	52
	Hatchery	17	41	5	31	48
2007	Wild	248	45	3	32	52
	Hatchery	16	41	5	31	48
2008	Wild	261	52	3	44	66
	Hatchery	20	39	3	30	41
2009	Wild	260	43	3	33	53
	Hatchery	22	41	2	36	46
2010	Wild	200	56	3	48	66
	Hatchery	131	41	2	35	45
2011	Wild	277	43	3	35	51
	Hatchery	282	40	3	32	49
2012	Wild	15	40	4	34	48
	Hatchery	130	40	3	31	48
2013	Wild	2	49	3	47	51
	Hatchery	64	50	4	43	65
2014	Wild	1,367	42	2	31	51
	Hatchery	43	41	3	32	45
2015	Wild	920	43	2	37	53
	Hatchery	54	43	2	39	47

Survey year	Origin	Sample size	Sockeye length (POH; cm)			
			Mean	SD	Minimum	Maximum
2016	Wild	798	43	3	36	51
	Hatchery	1	38	-	38	38
Pooled	***Wild***	***5,326***	***43***	***3***	***31***	***66***
	Hatchery	***1,732***	***41***	***3***	***30***	***65***

Contribution to Fisheries

The total number of hatchery and wild sockeye captured in different fisheries is provided in Tables 4.23 and 4.24. Harvest on hatchery-origin sockeye has been less than the harvest on wild sockeye.

Table 4.23. Estimated number and percent (in parentheses) of hatchery-origin Wenatchee sockeye captured in different fisheries, brood years 1989-2010.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational[a] (sport)	
1989	0 (0)	279 (30)	4 (0)	639 (69)	922
1990	0 (0)	23 (100)	0 (0)	0 (0)	23
1991	0 (0)	6 (100)	0 (0)	0 (0)	6
1992	0 (0)	38 (97)	1 (3)	0 (0)	39
1993	0 (0)	4 (100)	0 (0)	0 (0)	4
1994	0 (0)	3 (100)	0 (0)	0 (0)	3
1995	0 (0)	10 (100)	0 (0)	0 (0)	10
1996	0 (0)	62 (82)	9 (12)	5 (7)	76
1997	0 (0)	69 (73)	11 (12)	15 (16)	95
1998	0 (0)	7 (100)	0 (0)	0 (0)	7
1999	0 (0)	3 (20)	0 (0)	12 (80)	15
2000	0 (0)	59 (12)	9 (2)	414 (86)	482
2001	0 (0)	0 (0)	0 (0)	3 (100)	3
2002	0 (0)	16 (100)	0 (0)	0 (0)	16
2003	0 (0)	3 (100)	0 (0)	0 (0)	3
2004	0 (0)	6 (3)	1 (1)	192 (96)	199
2005	3 (2)	61 (41)	7 (5)	79 (53)	150
2006	2 (0)	124 (23)	2 (0)	409 (76)	537
2007	2 (2)	96 (80)	13 (11)	9 (8)	120
2008	0 (0)	96 (19)	12 (2)	400 (79)	508
2009	1 (0)	20 (16)	2 (2)	104 (82)	127
2010	0 (0)	97 (36)	5 (2)	170 (63)	272
Average	***0 (0)***	***49 (61)***	***3 (2)***	***111 (37)***	***164***
Median	***0 (0)***	***22 (77)***	***1 (0)***	***7 (12)***	***58***

[a] Includes the Lake Wenatchee fishery.

Table 4.24. Estimated number and percent (in parentheses) of wild Wenatchee sockeye captured in different fisheries, brood years 1989-2010.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational[a] (sport)	
1989	0 (0)	2,192 (31)	26 (0)	4,838 (69)	7,056
1990	0 (0)	191 (100)	0 (0)	0 (0)	191
1991	0 (0)	293 (99)	2 (1)	0 (0)	295
1992	0 (0)	345 (99)	5 (1)	0 (0)	350
1993	0 (0)	661 (99)	4 (1)	0 (0)	665
1994	0 (0)	146 (100)	0 (0)	0 (0)	146
1995	0 (0)	63 (85)	4 (5)	7 (9)	74
1996	0 (0)	1,553 (56)	247 (9)	993 (36)	2,793
1997	0 (0)	3,060 (54)	376 (6)	2,266 (40)	5,702
1998	0 (0)	937 (98)	7 (1)	10 (1)	954
1999	0 (0)	22 (19)	3 (3)	90 (78)	115
2000	0 (0)	1,188 (19)	165 (3)	4,881 (78)	6,234
2001	0 (0)	827 (100)	1 (0)	0 (0)	828
2002	0 (0)	379 (83)	2 (0)	73 (16)	454
2003	0 (0)	129 (24)	15 (3)	383 (73)	527
2004	0 (0)	1,559 (24)	174 (3)	4,825 (74)	6,558
2005	0 (0)	2,498 (44)	198 (3)	2,996 (53)	5,692
2006	0 (0)	2,844 (52)	135 (2)	2,505 (46)	5,484
2007	0 (0)	1,534 (57)	214 (8)	960 (35)	2,710
2008	0 (0)	5,447 (25)	613 (3)	13,544 (72)	19,206
2009	0 (0)	854 (20)	53 (1)	5,336 (80)	6,664
2010	0 (0)	5,468 (26)	262 (1)	15,603 (73)	21,333
Average	***0 (0)***	***1,463 (60)***	***115 (3)***	***2,694 (38)***	***4,272***
Median	***0 (0)***	***896 (55)***	***21 (2)***	***664 (36)***	***1,823***

[a] Includes the Lake Wenatchee fishery.

Straying

Stray rates were determined by examining CWTs recovered on spawning grounds within and outside the Wenatchee River basin. In addition, PIT tagging of hatchery sockeye, which began with brood year 2005, allows estimation of stray rates by brood return. Targets for strays based on return year (recovery year) outside the Wenatchee River basin should be less than 5%. The target for brood year strays should also be less than 5%.

Based on CWTs and brood year analysis, virtually no hatchery-origin Wenatchee sockeye strayed into non-target spawning areas or hatchery programs before brood year 2006 (Table 4.25). However, sockeye from brood years 2006 and 2007 strayed into the Entiat River and a few into the Methow River (non-target streams) and a non-target hatchery (Umpqua Trap) (Table 4.25).

Stray rates of Wenatchee sockeye from brood year 2006-2010 exceeded the target of 5%. The number of returning hatchery sockeye has decreased since brood year 2008.

Table 4.25. Number and percent of hatchery-origin Wenatchee sockeye that homed to target spawning areas and the target hatchery program, and number and percent that strayed to non-target spawning areas and hatchery programs, by brood years 1990-2010. Hatchery-origin sockeye from brood years 1995-1998 were not tagged because of columnaris disease (NA = not available). Percent stays should be less than 5%.

Brood year	Homing				Straying			
	Target streams		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1990	402	99.5	2	0.5	0	0.0	0	0.0
1991	1	100.0	0	0.0	0	0.0	0	0.0
1992	92	98.9	0	0.0	0	0.0	1	1.1
1993	29	96.7	1	3.3	0	0.0	0	0.0
1994	66	94.3	4	5.7	0	0.0	0	0.0
1995	NA	NA	NA	NA	NA	NA	NA	NA
1996	NA	NA	NA	NA	NA	NA	NA	NA
1997	NA	NA	NA	NA	NA	NA	NA	NA
1998	NA	NA	NA	NA	NA	NA	NA	NA
1999	65	100.0	0	0.0	0	0.0	0	0.0
2000	571	100.0	0	0.0	0	0.0	0	0.0
2001	17	100.0	0	0.0	0	0.0	0	0.0
2002	251	100.0	0	0.0	0	0.0	0	0.0
2003	11	100.0	0	0.0	0	0.0	0	0.0
2004	56	100.0	0	0.0	0	0.0	0	0.0
2005	67	97.1	2	2.9	0	0.0	0	0.0
2006	117	41.9	0	0.0	160	57.3	2	0.7
2007	260	82.0	1	0.3	56	17.7	0	0.0
2008	86	90.5	0	0.0	9	9.5	0	0.0
2009	11	73.3	0	0.0	4	26.7	0	0.0
2010	0	0.0	0	0.0	2	100.0	0	0.0
Average	***124***	***86.7***	***1***	***0.8***	***14***	***12.4***	***0***	***0.1***
Median	***66***	***98.9***	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***

* Homing to the target hatchery includes Wenatchee hatchery sockeye that are captured and included as broodstock in the Wenatchee Hatchery program. These hatchery fish were collected at Tumwater Dam.

Based on PIT-tag analyses, on average, about 11% of the hatchery sockeye returns were last detected in streams outside the Wenatchee River basin (Table 4.26). The numbers in Table 4.26 should be considered rough estimates because they are not based on confirmed spawning (only last detections). Nevertheless, these data do indicate that some hatchery sockeye from the Wenatchee program have strayed into the Entiat and Methow rivers and possibly into the Okanogan system (based on sockeye detected at Wells Dam but not in the Methow River).

Table 4.26. Number and percent of hatchery-origin Wenatchee sockeye that homed to target spawning areas and the target hatchery program, and number and percent that strayed to non-target spawning areas and hatchery programs for brood years 2005-2011. Estimates were based on last detections of PIT-tagged hatchery sockeye. Percent strays should be less than 5%.

Brood Year	Homing				Straying			
	Target streams		Target hatchery*		Non-target stream		Non-target hatchery	
	Number	%	Number	%	Number	%	Number	%
2005	166	92.2	0	0.0	14	7.8	0	0.0
2006	440	94.6	0	0.0	25	5.4	0	0.0
2007	192	95.0	0	0.0	10	5	0	0.0
2008	127	89.4	0	0.0	15	10.6	0	0.0
2009	41	82.0	0	0.0	9	18	0	0.0
2010	53	100.0	0	0.0	0	0.0	0	0.0
2011	65	71.6	0	0.0	25	28.4	0	0.0
Average	***155***	***89.3***	***0***	***0.0***	***14***	***10.7***	***0***	***0.0***
Median	***127***	***92.2***	***0***	***0.0***	***14***	***7.8***	***0***	***0.0***

* Homing to the target hatchery includes Wenatchee hatchery sockeye that are captured and included as broodstock in the Wenatchee Hatchery program. These hatchery fish were collected at Tumwater Dam.

Genetics

Genetic studies were conducted in 2008 to determine the potential effects of the Wenatchee sockeye supplementation program on natural-origin sockeye in the upper Wenatchee River basin (Blankenship et al. 2008; the entire report is appended as Appendix I). Specifically, the objective of the study was to determine if the genetic composition of the Lake Wenatchee sockeye population had been altered by the supplementation program, which was based on the artificial propagation of a small subset of the Wenatchee population. Microsatellite DNA allele frequencies were used to differentiate between temporally replicated collections of natural and hatchery-origin sockeye in the Wenatchee River basin. A total of 13 collections of Wenatchee sockeye were analyzed; eight temporally replicated collections of natural-origin sockeye (N = 786) and five temporally replicated collections of hatchery-origin sockeye (N = 248). Paired natural-hatchery collections were available from return years 2000, 2001, 2004, 2006, and 2007. All collections were taken at Tumwater Dam and consisted of dried scales and fin clips.

Overall, the study showed that allele frequency distributions were consistent over time, regardless of origin, resulting in small, insignificant measures of genetic differentiation among collections. This indicates that there were no year-to-year differences in allele frequencies between natural and hatchery-origin sockeye. In addition, the analyses found no differences between pre- and post-supplementation collections. Thus, it was concluded that the allele frequencies of the broodstock collections equaled the allele frequency of the natural collections.

It is important to note that no new information will be reported on genetics until the next five-year report (2018).

Proportionate Natural Influence

Another method for assessing the genetic risk of a supplementation program is to determine the influence of the hatchery and natural environments on the adaptation of the composite population. This is estimated by the proportion of natural-origin fish in the hatchery broodstock (pNOB) and the proportion of hatchery-origin fish in the natural spawning escapement (pHOS). We calculated Proportionate Natural Influence (PNI) by iterating Ford's (2002) equations 5 and 6 to equilibrium, using a heritability of 0.3 and a selection strength of three standard deviations. The larger the PNI value, the greater the strength of selection in the natural environment relative to that of the hatchery environment. For the natural environment to dominate selection, PNI should be greater than 0.50, and important integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004).

The PNI values for the life of the program (brood years 1989-2011) are shown in Table 4.27. Throughout the program, PNI was consistently greater than 0.67. The hatchery program was terminated in 2012.

Table 4.27. Proportionate Natural Influence (PNI) values for the Wenatchee sockeye supplementation program for brood years 1989-2016. NOS = number of natural-origin sockeye counted at Tumwater Dam; HOS = number of hatchery-origin sockeye counted at Tumwater Dam; NOB = number of natural-origin sockeye collected for broodstock; and HOB = number of hatchery-origin sockeye included in hatchery broodstock. NP = no hatchery program.

Brood year	Escapement[a]			Broodstock			PNI[b]
	NOS	HOS	pHOS	NOB	HOB	pNOB	
1989	21,802	0	0.00	115	0	1.00	1.00
1990	27,325	0	0.00	302	0	1.00	1.00
1991	26,689	0	0.00	199	0	1.00	1.00
1992	16,461	0	0.00	320	0	1.00	1.00
1993	25,064	2,662	0.10	207	0	1.00	0.91
1994	6,934	396	0.05	236	5	0.98	0.95
1995	3,262	186	0.05	194	3	0.98	0.95
1996	6,027	546	0.08	225	0	1.00	0.93
1997	8,376	68	0.01	192	19	0.91	0.99
1998	3,982	32	0.01	122	6	0.95	0.99
1999	961	64	0.06	79	60	0.57	0.91
2000	19,620	1,164	0.06	170	5	0.97	0.94
2001	28,288	815	0.03	200	7	0.97	0.97
2002	27,371	193	0.01	256	0	1.00	0.99
2003	4,797	58	0.01	198	0	1.00	0.99
2004	26,095	1,460	0.05	177	0	1.00	0.95
2005	13,983	28	0.00	166	0	1.00	1.00
2006	9,182	255	0.03	214	0	1.00	0.97
2007	2,320	59	0.02	210	0	1.00	0.98
2008	22,931	92	0.00	243	2	0.99	1.00
2009	13,043	445	0.03	239	0	1.00	0.97

Brood year	Escapement[a]			Broodstock			PNI[b]
	NOS	HOS	pHOS	NOB	HOB	pNOB	
2010	30,357	1,134	0.04	198	0	1.00	0.96
2011	17,490	940	0.05	196	0	1.00	0.95
Average	***15,755***	***461***	***0.03***	***203***	***5***	***0.97***	***0.97***
Median	***16,461***	***186***	***0.03***	***199***	***0***	***1.00***	***0.97***
2012	30,903	502	0.02	NP	NP	NP	NP
2013	22,118	614	0.03	NP	NP	NP	NP
2014	81,804	1,840	0.02	NP	NP	NP	NP
2015	42,132	1,528	0.03	NP	NP	NP	NP
2016	59,008	59	0.00	NP	NP	NP	NP
Average	***47,193***	***909***	***0.02***	***NP***	***NP***	***NP***	***NP***
Median	***42,132***	***614***	***0.02***	***NP***	***NP***	***NP***	***NP***

[a] Proportions of natural-origin and hatchery-origin spawners were determined from reading video tape at Tumwater Dam, adjusted for fish harvested in the Lake Wenatchee recreational fishery.

[b] PNI was calculated previously using PNI approximate equation 11 (HSRG 2009; their Appendix A). All PNI values presented here were recalculated by iterating Ford's (2002) equations 5 and 6 to equilibrium using a heritability of 0.3 and a selection strength of three standard deviations. C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI.

Post-Release Survival and Travel Time

We used PIT-tagged fish to estimate survival rates and travel time (arithmetic mean days) of hatchery sockeye salmon from Lake Wenatchee to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam (Table 4.28).[9] Over the seven brood years for which PIT-tagged hatchery fish were released, survival rates from Lake Wenatchee to McNary Dam ranged from 0.211 to 0.370; SARs from release to detection at Bonneville Dam ranged from 0.005 to 0.044. Average travel time from Lake Wenatchee to McNary Dam ranged from 176 to 202 days.

Table 4.28. Total number of hatchery sockeye parr released with PIT tags, their survival and travel times (mean days) to McNary Dam, and smolt-to-adult (SAR) ratios for brood years 2005-2011. Standard errors are shown in parentheses.

Brood year	Number of sockeye released with PIT tags	Survival to McNary Dam	Travel time[1] to McNary Dam (d)	SAR to Bonneville Dam
2005	14,859	0.334 (0.013)	176.4 (61.9)	0.020 (0.001)
2006	14,764	0.370 (0.030)	202.0 (9.1)	0.044 (0.002)
2007	14,947	0.312 (0.013)	199.9 (8.6)	0.024 (0.001)
2008	14,858	0.307 (0.020)	192.9 (35.7)	0.015 (0.001)
2009	14,486	0.211 (0.015)	194.2 (29.1)	0.005 (0.001)
2010	5,039	0.302 (0.048)	191.7 (26.6)	0.014 (0.002)
2011	5,074	0.318 (0.038)	196.7 (7.3)	0.036 (0.003)

[9] It is important to point out that because of fish size differences among rearing tanks or raceways, fish PIT tagged in one tank or raceway may not represent untagged fish rearing in other tanks or raceways.

[1] Travel time is calculated from the date of release from the net pens in the fall, overwintering in Lake Wenatchee, to spring outmigration.

Natural and Hatchery Replacement Rates

Natural replacement rates (NRR) were calculated as the ratio of natural-origin recruits (NOR) to the parent spawning population. Natural-origin recruits are naturally produced (wild) fish that survive to contribute to harvest (directly or indirectly), to broodstock, and to spawning grounds. We do not account for fish that died in route to the spawning grounds (migration mortality) or died just before spawning (pre-spawn mortality) (see Appendix B in Hillman et al. 2012). We calculated NORs with and without harvest. NORs without harvest include all returning fish that either returned to the basin or were collected as wild broodstock. NORs with harvest include all fish harvested and are based on a brood year harvest rates from the hatchery program. For brood years 1989-2010, NRR in the Wenatchee averaged 1.58 (range, 0.13-5.72) if harvested fish were not included in the estimate and 1.87 (range, 0.14-6.88) if harvested fish were included in the estimate (Table 4.29).

Hatchery replacement rates (HRR) were estimated as hatchery adult-to-adult returns. These rates should be greater than the NRRs and greater than or equal to 5.4 (the calculated target value in Hillman et al. 2013). The target value of 5.4 includes harvest. HRRs exceeded NRRs in 14 or 15 of the 23 years of data depending on if harvest was or was not included in the estimates (Table 4.29). Hatchery replacement rates for Wenatchee sockeye have equaled or exceeded the estimated target value of 5.4 in five of the 23 years (Table 4.29).

Table 4.29. Broodstock collected, spawning escapements, natural and hatchery-origin recruits (NOR and HOR), and natural and hatchery replacement rates (NRR and HRR; with and without harvest) for sockeye salmon in the Wenatchee River basin, 1989-2010.

Brood year	Broodstock Collected	Spawning Escapement	Harvest not included				Harvest included			
			HOR	NOR	HRR	NRR	HOR	NOR	HRR	NRR
1989	255	21,802	2,757	23,616	10.81	1.08	3,680	30,672	14.43	1.41
1990	316	27,325	401	3,509	1.27	0.13	423	3,701	1.34	0.14
1991	233	26,689	95	4,820	0.41	0.18	101	5,116	0.43	0.19
1992	343	16,461	576	5,336	1.68	0.32	615	5,685	1.79	0.35
1993	307	27,726	71	11,151	0.23	0.40	75	11,815	0.24	0.43
1994	265	7,330	47	1,191	0.18	0.16	50	1,337	0.19	0.18
1995	209	3,448	121	840	0.58	0.24	131	913	0.63	0.26
1996	227	6,573	1,351	28,093	5.95	4.27	1,427	30,886	6.29	4.70
1997	226	8,444	739	36,097	3.27	4.27	834	41,798	3.69	4.95
1998	190	4,014	104	16,165	0.55	4.03	111	17,120	0.58	4.27
1999	147	1,025	68	566	0.46	0.55	83	682	0.56	0.67
2000	195	20,784	1,425	29,082	7.31	1.40	1,907	35,316	9.78	1.70
2001	245	29,103	24	17,241	0.10	0.59	28	18,068	0.11	0.62
2002	257	27,564	281	5,752	1.09	0.21	297	6,207	1.16	0.23
2003	219	4,855	32	2,054	0.15	0.42	35	2,590	0.16	0.53
2004	202	27,555	94	23,589	0.47	0.86	293	30,149	1.45	1.09
2005	207	14,011	460	20,793	2.22	1.48	606	26,486	2.93	1.89
2006	220	9,437	1,147	26,966	5.21	2.86	1,682	32,450	7.65	3.44
2007	228	2,379	917	13,619	4.02	5.72	1,037	16,311	4.55	6.88
2008	260	23,023	808	45,020	3.11	1.96	1,314	66,511	5.05	2.50

Brood year	Broodstock Collected	Spawning Escapement	Harvest not included				Harvest included			
			HOR	NOR	HRR	NRR	HOR	NOR	HRR	NRR
2009	261	13,488	344	15,346	1.32	1.14	469	19,704	1.80	1.46
2010	201	31,491	1,748	79,993	8.70	2.54	2,020	101,32 5	10.05	3.22
Average	***237***	***16,115***	***619***	***18,675***	***2.69***	***1.58***	***783***	***22,947***	***3.40***	***1.87***
Median	***228***	***15,236***	***373***	***15,756***	***1.30***	***0.97***	***446***	***17,594***	***1.62***	***1.25***

Juvenile-to-Adult Survivals

When possible, both parr-to-adult ratios (PAR) and smolt-to-adult ratios (SAR) were calculated for hatchery sockeye salmon. Ratios were calculated as the number of hatchery adult recaptures divided by the number of tagged hatchery parr released or the estimated number of smolts emigrating from Lake Wenatchee. Here, survival ratios were based on CWT returns, when available, or on the estimated number of hatchery adults recovered on the spawning grounds, in broodstock, and harvested. For the available brood years, PARs have ranged from 0.0001 to 0.0339 for hatchery sockeye salmon and SARs have ranged from 0.0002 to 0.0255 (Table 4.30).

Table 4.30. Parr-to-adult ratios (PAR) and smolt-to-adult ratios (SAR) for Wenatchee hatchery sockeye salmon, brood years 1990-2010; NA = not available.

Brood year	Number of parr released	Number of smolts	Estimated adult recaptures	PAR	SAR
1989	108,400	NA	3,680	0.0339	NA
1990	270,802	NA	423	0.0016	NA
1991	167,523	NA	101	0.0006	NA
1992	340,597	NA	615	0.0018	NA
1993	190,443	NA	75	0.0004	NA
1994	252,859	NA	50	0.0002	NA
1995	150,808	28,828	131	0.0009	0.0045
1996	284,630	55,985	1,427	0.0050	0.0255
1997	197,195	112,524	834	0.0042	0.0074
1998	121,344	24,684	111	0.0009	0.0045
1999	167,955	94,046	83	0.0005	0.0009
2000	190,174	121,511	1,907	0.0100	0.0157
2001	200,938	140,322	28	0.0001	0.0002
2002	315,783	216,023	297	0.0009	0.0014
2003	240,459	122,399	35	0.0001	0.0003
2004	172,923	159,500	293	0.0017	0.0018
2005	140,542	140,542	606	0.0043	0.0043
2006	225,670	121,843	1,682	0.0075	0.0138
2007	252,133	119,908	1,037	0.0041	0.0086
2008	154,772	126,326	1,314	0.0085	0.0104

Brood year	Number of parr released	Number of smolts	Estimated adult recaptures	PAR	SAR
2009	227,743	159,089	426	0.0019	0.0027
2010	243,260	NA	2,062	0.0085	NA
Average	***209,862***	***116,235***	***783***	***0.0044***	***0.0068***
Median	***199,067***	***121,843***	***425***	***0.0018***	***0.0045***

4.8 ESA/HCP Compliance

Smolt and Emigrant Trapping

ESA-listed spring Chinook and steelhead were encountered during operation of the Lower Wenatchee trap. ESA takes are reported in the steelhead (Section 3.8) and spring Chinook (Section 5.8) sections and will not be repeated here.

Spawning Surveys

Sockeye spawning ground surveys conducted in the Wenatchee River basin during 2016 were consistent with ESA Section 10 Permit No. 1347. Because of the difficulty of quantifying the level of take associated with spawning ground surveys, the Permit does not specify a take level associated with these activities, even though it does authorize implementation of spawning ground surveys. Therefore, no take levels are reported. However, to minimize potential effects to established redds, wading was restricted to the extent practical and extreme caution was used to avoid established redds when wading was required.

SECTION 5: WENATCHEE (CHIWAWA) SPRING CHINOOK

The goal of Chiwawa spring Chinook salmon supplementation is to achieve "No Net Impact" to the productivity of spring Chinook caused by the operation of the Rock Island Hydroelectric Project. The Rock Island Fish Hatchery Complex began operation in 1989 under funding from Chelan PUD. The Complex operated originally through the Rock Island Settlement Agreement, but since 2004 has operated under the Rock Island and Rocky Reach Anadromous Fish Agreement and Habitat Conservation Plans.

Adult spring Chinook are collected for broodstock at the Chiwawa Weir and Tumwater Dam. From 2011 through 2013, all spring Chinook broodstock were collected at the Chiwawa Weir in order to reduce passage delays caused by trapping at Tumwater Dam. Before 2009, the goal was to collect up to 379 adult spring Chinook for the program with natural-origin fish making up not less than 33% of the broodstock. In 2011, the Hatchery Committees reevaluated the amount of hatchery compensation needed to achieve NNI. Based on that evaluation, the goal of the program was revised. The current goal (beginning with brood year 2013) is to collect 74 natural-origin spring Chinook. The number collected cannot exceed 33% of the natural-origin spring Chinook returns to Tumwater. Beginning in 2014, previously PIT-tagged hatchery-origin Chiwawa spring Chinook are collected at Tumwater Dam, while the Chiwawa Weir is used to collect natural-origin brood for the Chiwawa spring Chinook program. Broodstock collection occurs from May through July at Tumwater with trapping occurring up to 24 hours per day, seven days a week and at the Chiwawa Weir with trapping occurring from 15 June to 1 August (not to exceed 15 cumulative trapping days) on a 24-hour-up/24-hour-down schedule consistent with annual broodstock collection protocols.

Adult spring Chinook are spawned and reared at Eastbank Fish Hatchery. Juvenile spring Chinook are transferred from the hatchery to the Chiwawa Acclimation Facility in late September or early October. They are released volitionally from the Chiwawa Acclimation Facility during April the following year.

The production goal for the Chiwawa spring Chinook supplementation program up to brood year 2009 was to release 672,000 yearling smolts into the Chiwawa River at 12 fish per pound. Brood years 2010-2011, and 2012 were transition years to a reduced program of 298,000 smolts and 205,000 smolts, respectively. Beginning with the 2013 brood, the revised production goal is to release 144,026 smolts as part of a conservation program at 18 fish per pound. The Wenatchee spring Chinook safety-net program is now part of the Nason Creek spring Chinook program. Targets for fork length and weight are 155 mm (CV = 9.0) and 37.8 g, respectively. Over 90% of these fish are marked with CWTs. In addition, since 2006, juvenile spring Chinook have been PIT tagged annually.

With issuance of new ESA Section 10 permits in 2013, adult management (i.e., removal of excess hatchery-origin adults at dams, traps, and weirs, and in conservation fisheries) was implemented in 2014 to achieve pHOS and PNI goals for the Wenatchee spring Chinook programs.

Although this section of the report focuses on results from monitoring the Chiwawa spring Chinook program, information on spring Chinook collected throughout the Wenatchee River basin is also provided. Information specific to the Nason Creek spring Chinook conservation program is presented in Section 6 and the White River Captive Broodstock Program is presented in Section 7.

5.1 Broodstock Sampling

This section focuses on results from sampling 2014-2016 Chiwawa spring Chinook broodstock, which were collected at the Chiwawa Weir and at Tumwater Dam, consistent with methods in the broodstock collections protocols (Tonseth 2014, 2015, and 2016). Some information for the 2016 return is not available at this time (e.g., age structure and final origin determination). This information will be provided in the 2017 annual report.

Origin of Broodstock

Natural-origin adults made up between 31.3% and 100.0% of the Chiwawa spring Chinook broodstock for brood years 2014-2016 (Table 5.1). Natural and hatchery-origin adults were collected at Tumwater Dam and the Chiwawa Weir for return year 2016. Broodstock were trapped at Tumwater Dam from end of-May through mid-July 2016, and at the Chiwawa Weir from mid-June through late-July. Hatchery-origin broodstock were collected at Tumwater Dam in 2016 to meet the Nason Creek Safety Net broodstock requirements and to fill potential shortfalls of natural-origin broodstock requirements for the Chiwawa River Conservation program. Additional hatchery-origin broodstock were collected to ensure production obligations were achieved in the event that insufficient natural-origin collections could be made. A total of 21 hatchery-origin fish collected in 2016 were surplused at Eastbank Fish Hatchery.

Table 5.1. Numbers of wild and hatchery Chiwawa spring Chinook collected for broodstock, numbers that died before spawning, and numbers of Chinook spawned, 1989-2016. Unknown origin fish (i.e., undetermined by scale analysis, no CWT or fin clips, and no additional hatchery marks) were considered naturally produced.

Brood year	Wild spring Chinook					Hatchery spring Chinook					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
1989	28	0	0	28	0	0	0	0	0	0	28
1990	19	1	0	18	0	0	0	0	0	0	18
1991	32	0	5	27	0	0	0	0	0	0	27
1992	113	0	0	78	35	0	0	0	0	0	78
1993	100	3	3	94	0	0	0	0	0	0	94
1994	9	0	1	8	0	4	0	0	4	0	12
1995	No Program										
1996	8	0	0	8	0	10	0	0	10	0	18
1997	37	0	5	32	0	83	1	3	79	0	111
1998	13	0	0	13	0	35	1	0	34	0	47
1999	No Program										
2000	10	0	1	9	0	38	1	16	21	0	30
2001	115	2	0	113	0	267	8	0	259	0	372
2002	21	0	1	20	0	63	1	11	51	0	71
2003	44	1	2	41	0	75	2	20	53	0	94
2004	100	1	16	83	0	196	30	34	132	0	215
2005	98	1	6	91	0	185	3	1	181	0	279
2006	95	0	4	91	0	303	0	29	224	50	315
2007	45	1	1	43	0	124	2	18	104	0	147

Brood year	Wild spring Chinook					Hatchery spring Chinook					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
2008	88	2	3	83	0	241	5	16	220	0	303
2009	113	6	11	96	0	151	3	37	111	0	207
2010	83	0	6	77	0	103	0	5	98	0	175
2011	80	0	0	80	0	101	2	6	93	0	173
Average[b]	***60***	***1***	***3***	***54***	***2***	***94***	***3***	***9***	***80***	***2***	***134***
Median[b]	***45***	***0***	***1***	***43***	***0***	***75***	***1***	***3***	***53***	***0***	***94***
2012	75	1	1	73	0	41	3	0	38	0	111
2013	170	5	0	70	95	52	1	50	0	1	70
2014[d]	61	0	0	61	0	203	1	68	134	0	195
2015[e]	81	1	7	72	1	47	0	3	37	7	109
2016	62	0	0	62	0	61	2	24	37	0	99
Average[c]	***90***	***1***	***2***	***68***	***19***	***81***	***1***	***29***	***49***	***2***	***117***
Median[c]	***75***	***1***	***0***	***70***	***0***	***52***	***1***	***24***	***37***	***0***	***109***

[a] Pre-spawn loss represents the number of fish that died during the holding period before spawning. Mortality is the number of fish that were surplused following spawning.
[b] The average and median represent the program before recalculation in 2011.
[c] The average and median represent the current program, which began in 2012. Origin determinations should be considered preliminary pending scale analyses.
[d] HOR Chiwawa spring Chinook were collected to meet both Chiwawa and Nason Creek obligations; broodstock and subsequent progeny were pooled together in the hatchery. About 12 Chiwawa HOR's were used to fulfill the Chiwawa Program; about 122 Chiwawa HOR's were used to fulfill the Nason Creek safety net obligation.
[e] For the Chiwawa program, 36 hatchery-origin returns were collected in case the program fell short on natural-origin returns. After eye-up, all of the hatchery-origin recruit eggs were culled because fecundity of natural-origin recruits was high enough to meet the WxW program.

Age/Length Data

Ages were determined from scales and/or coded wire tags (CWT) collected from broodstock. For both the 2014 and 2015 returns, most adults, regardless of origin, were age-4 Chinook (Table 5.2). All age-5 Chinook were natural-origin fish; hatchery-origin Chinook were all age-4 fish. There were no age-3 natural or hatchery-origin fish collected for broodstock.

Table 5.2. Percent of hatchery and wild spring Chinook of different ages (total age) collected from broodstock, 1991-2015.

Return year	Origin	Total age			
		2	3	4	5
1991	Wild	0.0	0.0	22.0	78.0
	Hatchery	0.0	0.0	0.0	0.0
1992	Wild	0.0	0.0	28.6	71.4
	Hatchery	0.0	0.0	50.0	50.0
1993	Wild	0.0	0.0	22.0	78.0
	Hatchery	0.0	0.0	0.0	0.0
1994	Wild	0.0	0.0	28.6	71.4
	Hatchery	0.0	0.0	50.0	50.0
1995	Wild	No program			
	Hatchery				

Return year	Origin	Total age			
		2	3	4	5
1996	Wild	0.0	28.6	71.4	0.0
	Hatchery	0.0	50.0	50.0	0.0
1997	Wild	0.0	0.0	87.5	12.5
	Hatchery	0.0	1.2	98.8	0.0
1998	Wild	0.0	0.0	63.6	36.4
	Hatchery	0.0	0.0	62.9	37.1
1999	Wild	No program			
	Hatchery				
2000	Wild	0.0	20.0	70.0	10.0
	Hatchery	0.0	59.1	40.9	0.0
2001	Wild	0.0	2.8	94.4	2.8
	Hatchery	0.0	1.5	98.5	0.0
2002	Wild	0.0	0.0	66.7	33.3
	Hatchery	0.0	0.0	93.4	6.6
2003	Wild	0.0	27.0	2.7	70.3
	Hatchery	0.0	21.3	5.3	73.3
2004	Wild	1.0	6.1	88.8	4.1
	Hatchery	0.0	40.4	59.6	0.0
2005	Wild	0.0	1.0	85.0	14.0
	Hatchery	0.0	4.4	95.6	0.0
2006	Wild	0.0	2.0	70.4	27.6
	Hatchery	0.0	1.3	81.2	17.4
2007	Wild	0.0	15.6	53.3	31.1
	Hatchery	0.0	27.4	60.5	12.1
2008	Wild	0.0	6.3	78.8	15.0
	Hatchery	0.0	8.2	86.8	4.9
2009	Wild	0.0	8.6	79.0	12.4
	Hatchery	0.0	18.5	79.5	2.0
2010	Wild	0.0	5.3	94.7	0.0
	Hatchery	0.0	0.0	99.0	1.0
2011	Wild	0.0	2.7	52.7	44.6
	Hatchery	0.0	20.4	60.2	19.4
2012	Wild	0.0	0.0	79.0	21.0
	Hatchery	0.0	4.3	95.7	0.0
2013	Wild	0.0	0.0	65.7	34.3
	Hatchery	0.0	2.2	86.7	11.1
2014	Wild	0.0	0.0	91.2	8.8
	Hatchery[a]	0.0	0.0	98.5	1.5

Return year	Origin	Total age			
		2	3	4	5
2015	Wild	0.0	0.0	88	11.0
	Hatchery[a]	0.0	0.0	100	0.0
Average	***Wild***	***0.0***	***5.5***	***64.5***	***29.9***
	Hatchery	***0.0***	***11.3***	***67.5***	***12.5***
Median	***Wild***	***0.0***	***1.0***	***70.4***	***21.0***
	Hatchery	***0.0***	***1.5***	***79.5***	***1.5***

[a] Comprised of age results for both Chiwawa and Nason Creek obligations.

There was little difference in mean lengths between hatchery and natural-origin broodstock of age-4 Chinook in 2014 and 2015; however, age-5 natural-origin Chinook in 2014 were larger than hatchery-origin broodstock (Table 5.3). All age-5 Chinook in 2015 were natural-origin fish.

Table 5.3. Mean fork length (cm) at age (total age) of hatchery and wild spring Chinook collected from broodstock, 1991-2015; N = sample size and SD = 1 standard deviation.

Return year	Origin	Spring Chinook fork length (cm)											
		Age-2			Age-3			Age-4			Age-5		
		Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD
1991	Wild	-	0	-	-	5	-	-	19	-	-	8	-
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-
1992	Wild	-	0	-	-	0	-	-	0	-	-	0	-
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-
1993	Wild	-	0	-	-	0	-	79	4	3	92	8	4
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-
1994	Wild	-	0	-	-	0	-	79	2	3	96	5	6
	Hatchery	-	0	-	-	0	-	82	2	11	92	2	2
1995	Wild	No program											
	Hatchery												
1996	Wild	-	0	-	51	2	1	79	5	7	-	0	-
	Hatchery	-	0	-	56	5	4	74	5	6	-	0	-
1997	Wild	-	0	-	-	0	-	80	28	5	99	4	8
	Hatchery	-	0	-	56	1	-	82	82	4	-	0	-
1998	Wild	-	0	-	-	0	-	78	7	13	83	4	18
	Hatchery	-	0	-	-	0	-	77	22	8	93	13	7
1999	Wild	No program											
	Hatchery												
2000	Wild	-	0	-	51	2	3	82	7	4	98	1	-
	Hatchery	-	0	-	59	13	4	79	9	8	-	0	-
2001	Wild	-	0	-	49	3	6	82	101	6	95	3	3
	Hatchery	-	0	-	56	4	7	83	261	5	-	0	-

Return year	Origin	Spring Chinook fork length (cm)											
		Age-2			Age-3			Age-4			Age-5		
		Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD
2002	Wild	-	0	-	-	0	-	79	12	4	96	6	10
	Hatchery	-	0	-	-	0	-	81	57	6	94	4	9
2003	Wild	-	0	-	55	10	5	83	1	-	99	26	6
	Hatchery	-	0	-	59	16	5	86	4	18	96	55	6
2004	Wild	47	1	-	60	6	6	80	87	5	99	4	3
	Hatchery	-	0	-	51	80	7	80	118	5	-	0	-
2005	Wild	-	0	-	49	1	-	80	85	6	96	14	8
	Hatchery	-	0	-	56	8	5	82	175	6	-	0	-
2006	Wild	-	0	-	50	2	2	79	69	7	97	27	5
	Hatchery	-	0	-	46	1	-	80	205	6	95	43	7
2007	Wild	-	0	-	54	7	3	79	24	6	93	14	7
	Hatchery	-	0	-	59	34	8	81	75	5	93	15	7
2008	Wild	-	0	-	54	5	9	83	63	5	93	12	6
	Hatchery	-	0	-	56	20	10	82	211	6	96	12	7
2009	Wild	-	0	-	52	9	6	81	83	5	94	13	6
	Hatchery	-	0	-	56	28	6	82	120	5	87	3	11
2010	Wild	-	0	-	58	4	9	80	72	6	-	0	-
	Hatchery	-	0	-	-	0	-	82	102	6	101	1	-
2011	Wild	-	0	-	56	2	3	79	39	5	95	33	7
	Hatchery	-	0	-	63	21	7	80	62	6	95	20	6
2012	Wild	-	0	-	-	0	-	81	49	6	97	13	8
	Hatchery	-	0	-	51	2	0	80	41	5	-	0	-
2013	Wild	-	0	-	-	1	-	74	44	6	92	23	8
	Hatchery	-	0	-	60	1	-	78	39	6	88	5	7
2014	Wild	-	0	-	-	0	-	82	52	7	93	5	6
	Hatchery[a]	-	0	-	-	0	-	81	192	6	85	3	2
2015	Wild	-	0	-	-	0	-	83	45	4	93	10	5
	Hatchery	-	0	-	-	0	-	80	35	6	-	0	-
Average	***Wild***	***47***	***0***	***-***	***53***	***3***	***5***	***80***	***39***	***6***	***95***	***10***	***7***
	Hatchery	***-***	***0***	***-***	***56***	***10***	***6***	***81***	***79***	***7***	***93***	***8***	***6***

[a] Comprised of age results from HOR's used for both Chiwawa and Nason Creek obligations.

Sex Ratios

Male spring Chinook in the 2014-2016 return years made up 49.2%, 53.5%, and 47.2%, respectively, of the adults collected. This resulted in overall male to female ratios of 0.97:1.00, 1.15:1.00, and 0.89:1.00, respectively (Table 5.4). For the 2016 return year, natural-origin and hatchery-origin fish both consisted of a slightly lower proportion of males than females (Table 5.4).

Table 5.4. Numbers of male and female wild and hatchery spring Chinook collected for broodstock, 1989-2016. Ratios of males to females are also provided.

Return year	Number of wild spring Chinook			Number of hatchery spring Chinook			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
1989	11	17	0.65:1.00	-	-	-	0.65:1.00
1990	7	12	0.58:1.00	-	-	-	0.58:1.00
1991	13	19	0.68:1.00	-	-	-	0.68:1.00
1992	39	39	1.00:1.00	-	-	-	1.00:1.00
1993	50	50	1.00:1.00	-	-	-	1.00:1.00
1994	5	4	1.25:1.00	2	2	1.00:1.00	1.17:1.00
1995	No program						
1996	6	2	3.00:1.00	8	2	4.00:1.00	3.50:1.00
1997	14	23	0.61:1.00	34	49	0.69:1.00	0.67:1.00
1998	9	4	2.25:1.00	18	17	1.06:1.00	1.29:1.00
1999	No program						
2000	5	5	1.00:1.00	32	6	5.33:1.00	3.36:1.00
2001	45	70	0.64:1.00	90	177	0.51:1.00	0.55:1.00
2002	9	12	0.75:1.00	30	33	0.91:1.00	0.87:1.00
2003	28	16	1.75:1.00	42	33	1.27:1.00	1.43:1.00
2004	58	42	1.38:1.00	102	94	1.09:1.00	1.18:1.00
2005	58	40	1.45:1.00	89	96	0.93:1.00	1.08:1.00
2006	49	46	1.07:1.00	123	179	0.69:1.00	0.77:1.00
2007	20	25	0.80:1.00	66	58	1.14:1.00	1.04:1.00
2008	41	47	0.87:1.00	109	132	0.83:1.00	0.84:1.00
2009	53	60	0.88:1.00	79	72	1.10:1.00	1.00:1.00
2010	41	42	0.98:1.00	53	50	1.06:1.00	1.02:1.00
2011	38	42	0.90:1.00	53	48	1.10:1.00	1.01:1.00
2012	35	40	0.87:1.00	20	21	0.95:1.00	0.90:1.00
2013	83	87	0.95:1.00	26	26	1.00:1.00	0.96:1.00
2014[a]	29	32	0.91:1.00	101	102	0.99:1.00	0.97:100
2015	44	36	1.22:1.00	24	23	1.04:1.00	1.15:1.00
2016	29	33	0.88:1.00	29	32	0.90:1.00	0.89:1.00
Total	***819***	***845***	***0.97:1.00***	***1,130***	***1,252***	***0.90:1.00***	***0.93:1.00***

[a] Comprised of HOR's used for both Chiwawa and Nason Creek obligations.

Fecundity

Mean fecundities for the 2014-2016 returns of spring Chinook ranged from 4,045-4,847 eggs per female (Table 5.5). These fecundities were generally more than the overall average of 4,655 eggs per female, but were close to the expected fecundity of 4,400 eggs per female assumed in the broodstock protocols. For the 2016 return year, natural-origin Chinook produced more eggs per female than did hatchery-origin fish. This could be attributed to differences in size and age of hatchery and natural-origin fish described above (Tables 5.2 and 5.3).

Table 5.5. Mean fecundity of wild, hatchery, and all female spring Chinook collected for broodstock, 1989-2016; NA = not available.

Return year	Mean fecundity		
	Wild	**Hatchery**	**Total**
1989*	NA	NA	2,832
1990*	NA	NA	5,024
1991*	NA	NA	4,600
1992*	NA	NA	5,199[a]
1993*	NA	NA	5,249
1994*	NA	NA	5,923
1995	No program		
1996*	NA	NA	4,645
1997	4,752	4,479	4,570
1998	5,157	5,376	5,325
1999	No program		
2000	5,028	5,019	5,023
2001	4,530	4,663	4,624
2002	5,024	4,506	4,654
2003	6,191	5,651	5,844
2004	4,846	4,775	4,799
2005	4,365	4,312	4,327
2006	4,773	4,151	4,324
2007	4,656	4,351	4,441
2008	4,691	4,560	4,592
2009	4,691	4,487	4,573
2010	4,548	4,114	4,314
2011	4,969	3,884	4,385
2012	4,522	3,682	4,223
2013	4,716	No program	4,716
2014	4,467	3,834	4,045
2015	5,132	4,278	4,847
2016	4,674	4,126	4,467
Average	***4,828***	***4,458***	***4,655***
Median	***4,716***	***4,415***	***4,583***

* Individual fecundities were not tracked with females until 1997.
[a] Estimated as the mean of fecundities two years before and two years after 1992.

5.2 Hatchery Rearing

Rearing History

Number of eggs taken

Based on the unfertilized egg-to-release survival standard of 81%, a total of 829,630 eggs were required to meet the program release goal of 672,000 smolts for brood years 1989-2010. For the 2011 and 2012 brood years, a total of 367,536 and 252,410 eggs were required to meet the release goals of 298,000 and 204,452 smolts, respectively. Since 2013, 169,442 eggs have been required to achieve a release goal of 144,026 smolts for the Chiwawa spring Chinook Program. Between 1989 and 2016, the egg take goal was reached only in 2001, 2015, and 2016[10] (Table 5.6). The green egg takes for 2014-2016 brood years were 99.7%, 109.0%, and 109.0% of program goals, respectively.

At the beginning of the Chiwawa spring Chinook program, the production level was set at 372,000 smolts. The primary reason for not meeting the egg take requirements included a lack of returning hatchery adults (because of program start up) and low wild fish abundance (along with no weir in the Chiwawa for first few years). Post ESA listing and issuance of Section 10(a)(1(A) permit 1196 in 1999, continued low abundance (hatchery and natural origin), as well as the permit limitation requiring a minimum of 33% natural-origin fish in the broodstock further constrained meeting the requisite egg take goal for a 672,000 program. In 2010, it was expected that recalculation of the mitigation obligation beginning with the 2012 brood year was going to result in a significant reduction in the production level and the Hatchery Committees subsequently agreed to reduce the production target to 298,000 in advance of recalculation to increase the likelihood of meeting the overall production goal. In 2011, the Joint Fisheries Parties developed the Wenatchee Basin Spring Chinook Management Plan, which split the program into a conservation and safety-net component; the conservation program using natural origin fish to meet recovery objectives and the safety net using returning adults from the conservation program to satisfy the balance of the production requirement.

Per amended Section 10(a)(1)(A) permit 18121, natural-origin broodstock is currently collected for the Chiwawa spring Chinook Program using PIT-tagged wild fish (tagged as juveniles) intercepted at Tumwater Dam and at the Chiwawa Weir. Operational limitations (e.g., flows, days per season, and bull trout encounters) reduce the opportunity to meet the natural-origin broodstock requirement, particularly in years of low adult abundance. Subsequently, to ensure the mitigation obligation is met, a component of hatchery adult returns are trapped and retained from Tumwater Dam during broodstock collection for the Nason Creek Program, which uses a composited broodstock (for the conservation component) identified through genetic analysis. The genetic analysis is used to prioritize those adults assigned with the highest probability to either the Nason or Chiwawa spawning aggregates, and excludes those assigned to the White River spawning aggregate.

[10] In 2016, the natural-origin egg-take goal was not achieved, but the program egg-take goal was achieved.

Table 5.6. Numbers of eggs taken from spring Chinook broodstock, 1989-2016; NP = no program.

Return year	Number of eggs taken for the Chiwawa Program
1989	45,311
1990	60,287
1991	73,601
1992	111,624
1993	257,208
1994	35,539
1995	NP
1996	18,579
1997	312,182
1998	90,521
1999	NP
2000	55,256
2001	1,099,630
2002	196,186
2003	247,501
2004	538,176
2005	536,490
2006	744,344
2007	359,739
2008	761,821
2009	564,912
2010	383,944
2011	366,244
Average (1989-2011)	***326,624***
Median (1989-2011)	***257,208***
2012	250,695
2013	165,047
2014	163,358
2015	184,734
2016*	184,712
Average (2012-present)	***189,709***
Median (2012-present)	***184,712***

* Although the program egg-take goal was achieved, the natural-origin egg-take goal was not.

Number of acclimation days

Early rearing of the 2014 brood Chiwawa spring Chinook was similar to previous years with fish being held on well water before being transferred to the Chiwawa Acclimation Facility for final acclimation. Beginning in 2006 (2005 brood acclimation), modifications were made to the Chiwawa Acclimation Facility intakes so that Wenatchee River water could be applied to the Chiwawa River intakes during severe cold periods to prevent the formation of frazzle ice. During acclimation of the 2014 brood, fish were acclimated for 190 to 198 days on Chiwawa River water (Table 5.7).

Table 5.7. Number of days spring Chinook broods were acclimated and water source, brood years 1989-2014; NA = not available.

Brood year	Release year	Transfer date	Release date	Number of days and water source		
				Total	Chiwawa	Wenatchee
1989	1991	19-Oct	11-May	204	NA	NA
1990	1992	13-Sep	27-Apr	227	NA	NA
1991	1993	24-Sep	24-Apr	212	NA	NA
1992	1994	30-Sep	20-Apr	202	NA	NA
1993	1995	28-Sep	20-Apr	204	NA	NA
1994	1996	1-Oct	25-Apr	207	NA	NA
1995	1997	No Program				
1996	1998	25-Sep	29-Apr	216	NA	NA
1997	1999	28-Sep	22-Apr	206	NA	NA
1998	2000	27-Sep	24-Apr	210	NA	NA
1999	2001	No Program				
2000	2002	26-Sep	25-Apr	211	NA	NA
2001	2003	22-Oct	1-May	191	NA	NA
2002	2004	25-Sep	2-May	220	NA	NA
2003	2005	30-Sep	3-May	215	NA	NA
		30-Sep	18-Apr-18-May	200	NA	NA
2004	2006	3-Sep	1-May	240	88-104	124
		3-Sep	17-Apr-17-May	226	NA	NA
2005	2007	25-Sep	1-May	217	217	98[a]
		26-Sep	16-Apr-15-May	202-232	202-232	98[a]
2006	2008	24-27-Sep	14-Apr-13-May	231	231	95[a]
2007	2009	1-Oct	15-Apr-13-May	223	223	103[a]
2008	2010	14-15-Sep	14-Apr-12-May	212-241	212-241	129
2009	2011	14-15-Sep	26-Apr-19-May	225-249	225-249	88

Brood year	Release year	Transfer date	Release date	Number of days and water source		
				Total	Chiwawa	Wenatchee
2010	2012	3, 5-6-Oct	17-Apr-1-May	195-212	195-212	132
2011	2013	24-26-Sep	16-22-Apr	202-210	202-210	40
2012	2014	23-25-Sep	14-21-Apr	204-211	204-211	107[a]
2013	2015	29-Sep	13-20-Apr	196-203	196-203	0
2014	2016	5-8-Oct	15-20-Apr	190-198	190-198	0

[a] Represents the number of days Wenatchee River water was applied to the Chiwawa River intake screen to prevent the formation of frazzle ice.

Release Information

Numbers released

The 2014 brood Chiwawa spring Chinook program achieved 100% of the 144,026 goal with about 144,360 smolts (126,330 WxW and 18,030 HxH) being released volitionally into the Chiwawa River in 2016 (Table 5.8). Water-intake issues with the Nason spring Chinook program resulted in the transfer of the safety-net program to the Chiwawa Acclimation Facility. Release numbers in Table 5.8 reflect the inclusion of Nason Spring Chinook.

Table 5.8. Numbers of spring Chinook smolts tagged and released from the hatchery, brood years 1989-2013. The release target for Chiwawa spring Chinook is 144,026 smolts. For brood years 2012 to present, conservation program fish are not adipose fin clipped (they receive CWT only).

Brood year	Release year	Type of release	CWT mark rate	Number released that were PIT tagged	Number of smolts released	Total number of smolts released
1989	1991	Volitional	0.9932	0	43,000	43,000
1990	1992	Volitional	0.9931	0	53,170	53,170
1991	1993	Volitional	0.9831	0	62,138	62,138
1992	1994	Volitional	0.9747	0	85,113	85,113
1993	1995	Volitional	0.9892	0	223,610	223,610
1994	1996	Volitional	0.9967	0	27,226	27,226
1995	1997	No program				
1996	1998	Forced	0.8413	0	15,176	15,176
1997	1999	Volitional	0.9753	0	266,148	266,148
1998	2000	Volitional	0.9429	0	75,906	75,906
1999	2001	No program				
2000	2002	Volitional	0.9920	0	47,104	47,104
2001	2003	Forced	0.9961	0	192,490[a]	377,544
		Volitional	0.9856	0	185,054[a]	
2002	2004	Volitional	0.9693	0	149,668	149,668
2003	2005	Forced	0.9783	0	69,907	222,131

Brood year	Release year	Type of release	CWT mark rate	Number released that were PIT tagged	Number of smolts released	Total number of smolts released
		Volitional	0.9743	0	152,224	
2004	2006	Forced	0.9533	0	243,505	494,517
		Volitional	0.9493	0	251,012	
2005	2007	Forced	0.9882	4,993	245,406	494,012
		Volitional	0.9864	4,988	248,606	
2006	2007	Direct	0.0000	0	12,977[b]	612,482
	2008	Volitional	0.9795	9,894	612,482	
2007	2008	Direct	0.0000	0	9,494	305,542
	2009	Volitional	0.9948	10,035	296,048	
2008	2010	Volitional	0.9835	10,006	609,789	609,789
2009	2011	Forced	0.9874	0	241,181	438,561
		Volitional	0.9874	9,412	197,380	
2010[c]	2012	Volitional	0.9904	5,020	346,248	346,248
2011	2013	Volitional	0.9902	9,945	281,821	281,821
2012[d]	2014	Volitional	0.9841	5,061	222,504	222,504
2013[d]	2015	Volitional	0.9753	10,021	147,480	147,480
2014[d]	2016	Volitional	0.9818	10,179	144,360	341,226[e]
		Volitional	0.9853	0	196,866[f]	

[a] This does not include the 226,456 eyed eggs that were planted in the Chiwawa River.
[b] This high ELISA group was only adipose fin clipped and directly planted into Big Meadow Creek in May.
[c] This does not include 18,480 eyed eggs that were culled because of high ELISA.
[d] Brood years 2013 to present WxW spring Chinook are not adipose fin clipped (they receive CWT only); HxH Chinook are adipose fin clipped and receive a CWT.
[e] The total number of smolts released includes the HxH Nason Creek program that was transferred to the Chiwawa Acclimation Facility on 2-3 March 2016 because of water-intake concerns at the Nason Creek Acclimation Facility.
[f] The HxH Nason Creek program that was released from the Chiwawa Acclimation Facility.

Numbers tagged

The 2014 brood Chiwawa spring Chinook were 98% CWT (Table 5.8).

In 2016, a total of 10,207 WxW Chiwawa spring Chinook from the 2015 brood were PIT tagged at Eastbank Hatchery on 11-14 July 2016. These were tagged and released into raceway #11. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 87 mm in length and 8.0 g at time of tagging. These fish were transferred to the Chiwawa Acclimation Facility in October 2016.

Table 5.9 summarizes the number of hatchery spring Chinook that have been PIT-tagged and released into the Chiwawa River.

Table 5.9. Summary of PIT-tagging activities for Chiwawa hatchery spring Chinook, brood years 2005-2014.

Brood year	Release year	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
2005	2007	10,063	74	8	9,981[a]
2006	2008	10,055	134	27	9,894
2007	2009	10,112	61	16	10,035
2008	2010	10,101	81	14	10,006
2009	2011	10,101	655	34	9,412
2010	2012	5,102	82	0	5,020
2011	2013	10,200	254	1	9,945
2012	2014	5,100	37	2	5,061
2013	2015	10,114	93	0	10,021
2014	2016	10,200	21	0	10,179

[a] This release consisted of 4,988 tagged Chinook that were released volitionally and 4,993 that were forced released.

Fish size and condition at release

Spring Chinook from the 2014 brood were released as yearling smolts between 15 and 20 April 2016. Size at release (13 fpp) was larger than the target of 18 fpp established for the program. The CV for fork length was 55% over the target (Table 5.10).

Table 5.10. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of spring Chinook smolts released from the hatchery, brood years 1989-2014. Size targets are provided in the last row of the table.

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
1989	1991	147	4.4	37.8	12
1990	1992	137	5.0	32.4	14
1991	1993	135	4.2	30.3	15
1992	1994	133	5.0	28.4	16
1993	1995	136	4.5	30.2	15
1994	1996	139	7.1	34.4	13
1995	1997	No Program			
1996	1998	157	5.3	52.1	9
1997	1999	146	7.2	38.7	12
1998	2000	143	9.1	39.5	12
1999	2001	No Program			
2000	2002	150	6.8	46.7	10
2001	2003	142	7.1	37.6	12
2002	2004	146	8.5	40.3	11

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
2003	2005	167[a]	5.9	59.4	8
		151[b]	7.4	44.2	10
2004	2006	146[a]	6.4	39.1	12
		139[b]	5.7	34.3	13
2005	2007	136[a]	4.6	30.8	15
		129[b]	5.8	26.6	17
2006	2008	124	8.8	23.5	19
2007	2008	70[a]	4.0	3.7	122
	2009	140[b]	11.0	33.6	14
2008	2010	141	10.7	36.0	13
2009	2011	167	12.9	56.8	8
2010	2012	129	8.1	25.8	18
2011	2013	134	6.4	29.5	15
2012	2014	130	6.7	28.5	16
2013	2015	130	8.2	25.3	18
2014[c]	2016	141	16.3	34.8	13
Average		***140***	***7.3***	***35.0***	***17***
Median		***140***	***6.8***	***34.4***	***13***
Targets		***155***	***9.0***	***37.8***	***18***

[a] Forced-release group.
[b] Volitional-release group.
[c] This represents the combination of the WxW Chiwawa, HxH Chiwawa, and the HxH Nason Creek programs. The HxH Nason Creek program was transferred to the Chiwawa Acclimation Facility on 2-3 March 2016 because of water-intake concerns at the Nason Creek Acclimation Facility.

Survival Estimates

Overall survival of the 2014 brood Chiwawa spring Chinook from green (unfertilized) egg to release was above the standard set for the program (Table 5.11). There was higher than expected survivals throughout most stages except unfertilized to eye-egg, contributing to increased program performance. Pre-spawn survival of adults was also above the standard set for the program.

Table 5.11. Hatchery life-stage survival rates (%) for spring Chinook, brood years 1989-2014. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
1989	100.0	100.0	98.0	99.1	99.1	99.0	96.4	99.3	94.8
1990	100.0	85.7	91.8	98.1	99.5	98.9	97.9	99.2	88.2
1991	100.0	100.0	94.4	96.1	99.6	97.9	93.2	95.0	84.4
1992	100.0	100.0	98.4	96.7	99.9	99.9	80.0	80.6	76.2
1993	96.0	98.0	89.7	98.0	99.7	99.3	98.9	99.7	86.9

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
1994	100.0	100.0	98.6	100.0	99.8	99.4	77.0	78.9	76.6
1995	No program								
1996	100.0	100.0	88.3	100.0	93.8	93.0	89.9	97.7	81.7
1997	98.6	100.0	93.2	95.7	98.3	99.6	95.6	99.3	85.3
1998	95.2	100.0	94.5	99.0	98.5	98.3	89.6	99.1	83.9
1999	No program								
2000	100.0	100.0	91.0	98.1	97.2	96.6	95.4	99.3	85.2
2001	97.6	97.0	88.9	98.1	99.7	99.6	51.3	51.8	34.3
2002	97.8	100.0	82.1	98.0	97.4	96.7	94.8	99.1	76.3
2003	93.9	100.0	93.2	97.7	99.5	99.3	98.5	98.1	89.7
2004	97.8	82.5	93.3	98.4	98.8	94.3	93.9	97.2	91.9
2005	97.1	100.0	95.9	98.0	99.2	99.0	97.9	99.1	92.1
2006	100.0	100.0	90.1	98.1	99.2	99.0	95.3	97.7	84.2
2007	98.8	97.7	92.9	97.2	99.4	99.0	98.0	99.4	88.5
2008	96.6	99.3	90.8	93.2	97.4	97.1	95.6	97.6	80.0
2009	94.4	97.6	92.5	88.3	97.6	97.4	89.2	92.8	77.6
2010[a]	98.9	100.0	99.2	100.0	97.9	97.5	95.6	98.2	94.8
2011	98.9	98.9	93.2	88.4	96.8	96.4	93.4	97.1	76.9
2012	98.3	100.0	94.6	98.3	99.7	99.3	98.5	99.4	91.6
2013	91.7	94.6	96.5	97.0	97.9	96.8	95.5	98.9	89.4
2014[b]	100.0	100.0	91.1	98.8	99.6	99.1	98.0	99.3	88.3
Average	***98.0***	***98.0***	***93.0***	***97.1***	***98.6***	***98.0***	***92.1***	***94.7***	***83.3***
Median	***98.7***	***100.0***	***93.2***	***98.1***	***99.2***	***99.0***	***95.5***	***98.6***	***85.3***
Standard	***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

[a] Survival estimates do not include the 18,840 eyed eggs that were culled because of high ELISA levels.
[b] Survival estimates do not include the HxH Nason Creek program that was transferred to the Chiwawa Acclimation Facility because of water-intake concerns at the Nason Creek Acclimation Facility.

5.3 Disease Monitoring

Results of 2016 adult broodstock bacterial kidney disease (BKD) monitoring indicated that most females had ELISA values less than 0.199. About 81.1% of females had ELISA values less than 0.120, which would have required about 18.9% of the progeny to be reared at densities not to exceed 0.06 fish per pound (Table 5.12).

For the 2014 brood, a formalin drip was used shortly after transfer to the Chiwawa Acclimation Facility to prevent infection associated with stress caused by the transfer. No significant health issues were encountered for the remainder of juvenile rearing.

Table 5.12. Proportion of bacterial kidney disease (BKD) titer groups for the Chiwawa spring Chinook broodstock, brood years 1996-2016. Also included are the proportions to be reared at either 0.125 fish per pound or 0.060 fish per pound.

Brood year[a]	Optical density values by titer group				Proportion at rearing densities (fish per pound, fpp)[b]	
	Very Low (≤ 0.099)	Low (0.1-0.199)	Moderate (0.2-0.449)	High (≥ 0.450)	≤ 0.125 fpp (<0.119)	≤ 0.060 fpp (>0.120)
1996	0.0000	0.2500	0.2500	0.5000	0.0000	1.0000
1997	0.1176	0.7353	0.0588	0.0882	0.3529	0.6471
1998	0.1176	0.8235	0.0588	0.0000	0.4706	0.5294
1999	No Program					
2000	0.0000	0.9091	0.0909	0.0000	0.1818	0.8182
2001	0.4066	0.5436	0.0373	0.0124	0.6515	0.3485
2002	0.2195	0.6585	0.0732	0.0488	0.5610	0.4390
2003	0.6957	0.1087	0.0652	0.1304	0.7174	0.2826
2004	0.8182	0.1515	0.0227	0.0076	0.8939	0.1061
2005	0.9084	0.0916	0.0000	0.0000	0.9695	0.0305
2006	0.7222	0.2556	0.0000	0.0222	0.8444	0.1556
2007	0.5854	0.3415	0.0244	0.0488	0.7073	0.2927
2008	0.8304	0.1520	0.0058	0.0117	0.9357	0.0643
2009	0.7600	0.1840	0.0080	0.0480	0.8480	0.1520
2010	0.8791	0.0769	0.0000	0.0439	0.9451	0.0549
2011	0.7640	0.2022	0.0000	0.0337	0.8764	0.1236
2012	0.8333	0.1333	0.0167	0.0167	0.9170	0.0830
2013	0.0829	0.1429	0.0286	0.0000	0.8857	0.1143
2014[c]	0.8282	0.1720	0.0000	0.0000	0.8889	0.1111
2015	0.9818	0.0000	0.0000	0.0182	0.9818	0.0182
2016	0.7547	0.2075	0.0189	0.0189	0.8113	0.1887
Average	***0.5653***	***0.3070***	***0.0380***	***0.0525***	***0.7220***	***0.2780***
Median	***0.7385***	***0.1931***	***0.0208***	***0.0186***	***0.8462***	***0.1538***

[a] Individual ELISA samples were not collected before the 1996 brood.
[b] ELISA values from broodstock BKD testing dictate what density the progeny of the broodstock are reared. Progeny of broodstock with high ELISA values are reared at lower density.
[c] Comprised of HOR's used for both Chiwawa and Nason Creek obligations.

5.4 Natural Juvenile Productivity

During 2016, juvenile spring Chinook were sampled at the Lower Wenatchee, Nason Creek, White River, and Chiwawa River traps and counted during snorkel surveys within the Chiwawa River basin. Results from sampling at the Nason Creek Trap are provided in Section 6 and from the White River Trap in Section 7.

Parr Estimates

Based on snorkel surveys, a total of 140,172 (±10%) subyearling and 282 (±43%) yearling spring Chinook were estimated in the Chiwawa River basin in August 2016 (Table 5.13 and 5.14). During the survey period 1992-2016, numbers of subyearling and yearling Chinook have ranged from 5,815 to 149,563 and 5 to 967, respectively, in the Chiwawa River basin (Table 5.13 and 5.14; Figure 5.1). Numbers of all fish counted in the Chiwawa River basin are reported in Appendix A.

Table 5.13. Total numbers of subyearling spring Chinook estimated in different streams in the Chiwawa River basin during snorkel surveys in August 1992-2016; NS = not sampled.

Sample Year	Number of subyearling spring Chinook									
	Chiwawa River	Phelps Creek	Chikamin Creek	Rock Creek	Unnamed Creek	Big Meadow Creek	Alder Creek	Brush Creek	Clear Creek	Total
1992	45,483	NS	NS	NS	NS	NS	NS	NS	NS	**45,483**
1993	77,269	0	1,258	586	NS	NS	NS	NS	NS	**79,113**
1994	53,492	0	398	474	68	624	0	0	0	**55,056**
1995	52,775	0	1,346	210	0	683	67	160	0	**55,241**
1996	5,500	0	29	10	0	248	28	0	0	**5,815**
1997	15,438	0	56	92	0	480	0	0	0	**16,066**
1998	65,875	0	1,468	496	57	506	0	13	0	**68,415**
1999	40,051	0	366	592	0	598	22	0	0	**41,629**
2000	NS	NS	NS	NS	NS	NS	NS	NS	NS	**NS**
2001	106,753	168	2,077	2,855	354	2,332	78	0	0	**114,617**
2002	117,230	75	8,233	2,953	636	5,021	429	0	297	**134,874**
2003	80,250	4,508	1,570	3,255	118	1,510	22	45	0	**91,278**
2004	43,360	102	717	215	54	637	21	71	0	**45,177**
2005	45,999	71	2,092	660	17	792	0	0	0	**49,631**
2006	73,478	113	2,500	1,681	51	1,890	62	127	0	**79,902**
2007	53,863	125	5,235	870	51	538	20	28	22	**60,752**
2008	72,431	214	3,287	4,730	163	1,221	28	255	22	**82,351**
2009	101,085	125	2,486	1,849	14	1,082	29	18	17	**106,705**
2010	117,499	526	4,571	4,052	0	1,449	56	42	25	**128,220**
2011	136,424	64	2,762	1,330	53	581	42	214	40	**141,510**
2012	96,036	78	4,125	2,227	49	1,322	35	31	37	**103,940**
2013	140,485	120	3,301	3,214	0	2,345	31	21	46	**149,563**
2014	113,869	361	2,384	3,124	28	1,367	11	28	68	**121,240**
2015	103,710	285	1,917	4,158	0	1,013	71	62	8	**111,224**
2016	135,819	107	1,644	991	0	1,508	20	58	25	**140,172**
Average	***78,924***	***306***	***2,340***	***1,766***	***78***	***1,261***	***49***	***53***	***28***	***84,499***
Median	***75,374***	***102***	***2,077***	***1,330***	***39***	***1,048***	***28***	***28***	***4***	***81,127***

Table 5.14. Total numbers of yearling spring Chinook estimated in different streams in the Chiwawa River basin during snorkel surveys in August 1992-2016; NS = not sampled.

Sample Year	Number of yearling spring Chinook									
	Chiwawa River	Phelps Creek	Chikamin Creek	Rock Creek	Unnamed Creek	Big Meadow Creek	Alder Creek	Brush Creek	Y Creek	Total
1992	563	NS	NS	NS	NS	NS	NS	NS	NS	**563**
1993	174	0	0	0	NS	NS	NS	NS	NS	**174**
1994	14	0	0	4	0	0	0	0	0	**18**
1995	13	0	0	0	0	0	0	0	0	**13**
1996	22	0	0	0	0	0	0	0	0	**22**
1997	5	0	0	0	0	0	0	0	0	**5**
1998	63	0	0	0	0	0	0	0	0	**63**
1999	41	0	0	0	0	0	0	0	0	**41**
2000	NS	NS	NS	NS	NS	NS	NS	NS	NS	**NS**
2001	66	0	3	0	0	0	0	0	0	**69**
2002	32	0	0	0	0	0	0	0	0	**32**
2003	134	0	0	0	0	0	0	0	0	**134**
2004	14	0	0	0	0	7	0	0	0	**21**
2005	62	0	17	0	0	0	0	0	0	**79**
2006	345	0	0	43	0	0	0	0	0	**388**
2007	41	0	0	0	0	0	0	0	0	**41**
2008	144	0	45	0	0	0	0	0	0	**189**
2009	49	0	0	5	0	0	0	0	0	**54**
2010	207	27	19	38	0	0	0	0	0	**291**
2011	645	0	71	194	0	57	0	0	0	**967**
2012	748	0	0	19	0	0	0	0	0	**767**
2013	836	0	0	8	0	8	0	0	0	**852**
2014	867	28	4	38	0	2	0	0	0	**939**
2015	488	0	22	110	0	0	0	0	0	**620**
2016	254	0	0	0	0	28	0	0	0	**282**
Average	***243***	***2***	***8***	***20***	***0***	***5***	***0***	***0***	***0***	***276***
Median	***100***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***107***

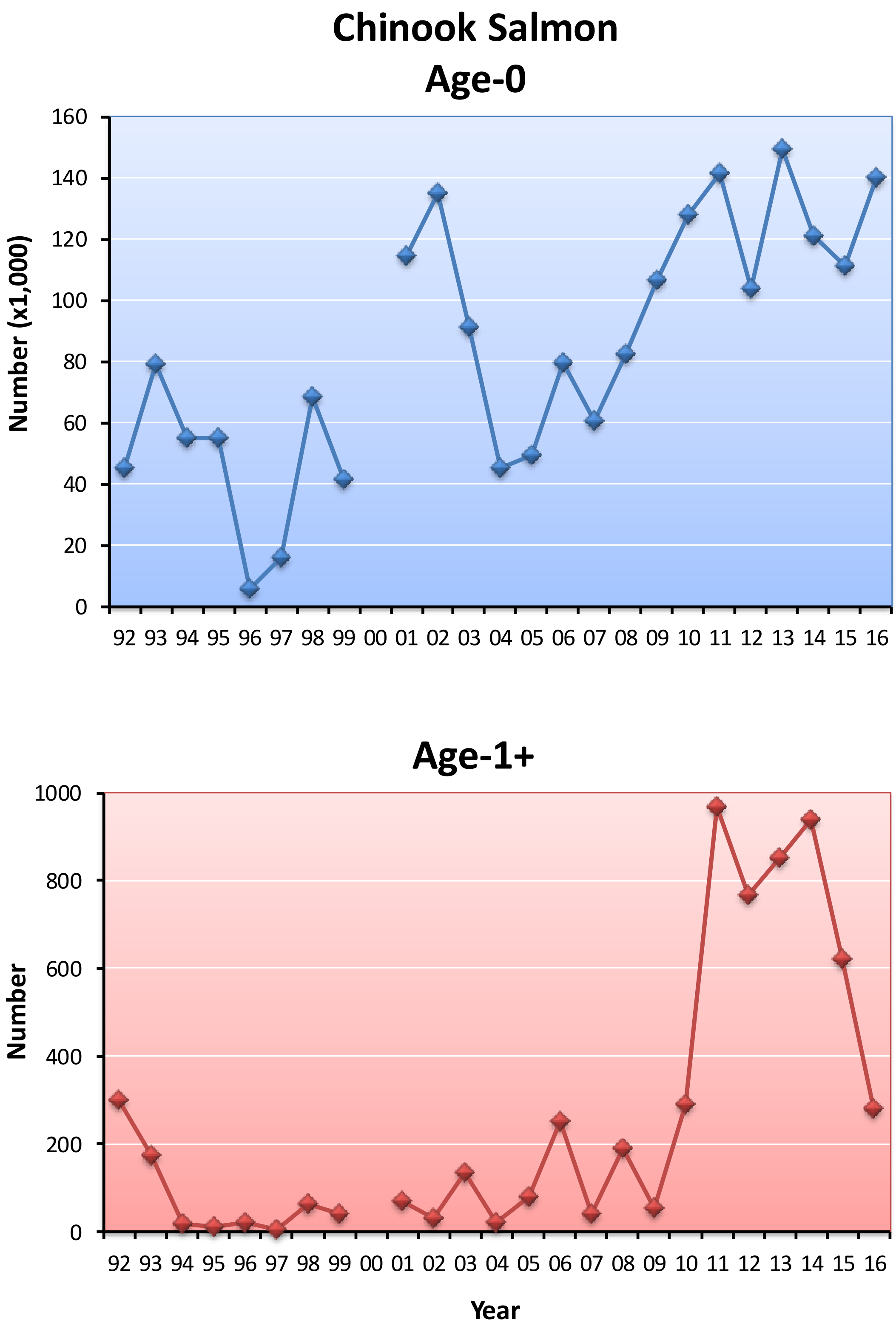

Figure 5.1. Numbers of subyearling and yearling Chinook salmon within the Chiwawa River Basin in August 1992-2016; ND = no data.

Juvenile Chinook were distributed contagiously among reaches in the Chiwawa River. Their densities were highest in the upper portions of the basin, with the highest densities within tributaries. Juvenile Chinook were most abundant in multiple channels and least abundant in glides and riffles. Most Chinook associated closely with woody debris in multiple channels. These sites (multiple channels) made up 16% of the total area of the Chiwawa River basin, but they provided habitat for 56% of all subyearling Chinook in the basin in 2016. In contrast, riffles made up 54% of the total area, but provided habitat for only 8% of all juvenile Chinook in the Chiwawa River basin. Pools made up 24% of the total area and provided habitat for 35% of all juvenile Chinook in the basin. Virtually no Chinook used glides that lacked woody debris.

Mean densities of juvenile Chinook in two reaches of the Chiwawa River were generally less than those in corresponding reference areas on Nason Creek and the Little Wenatchee River (Figure 5.2). Within both the Chiwawa River and its reference areas, pools and multiple channels consistently had the highest densities of juvenile Chinook.

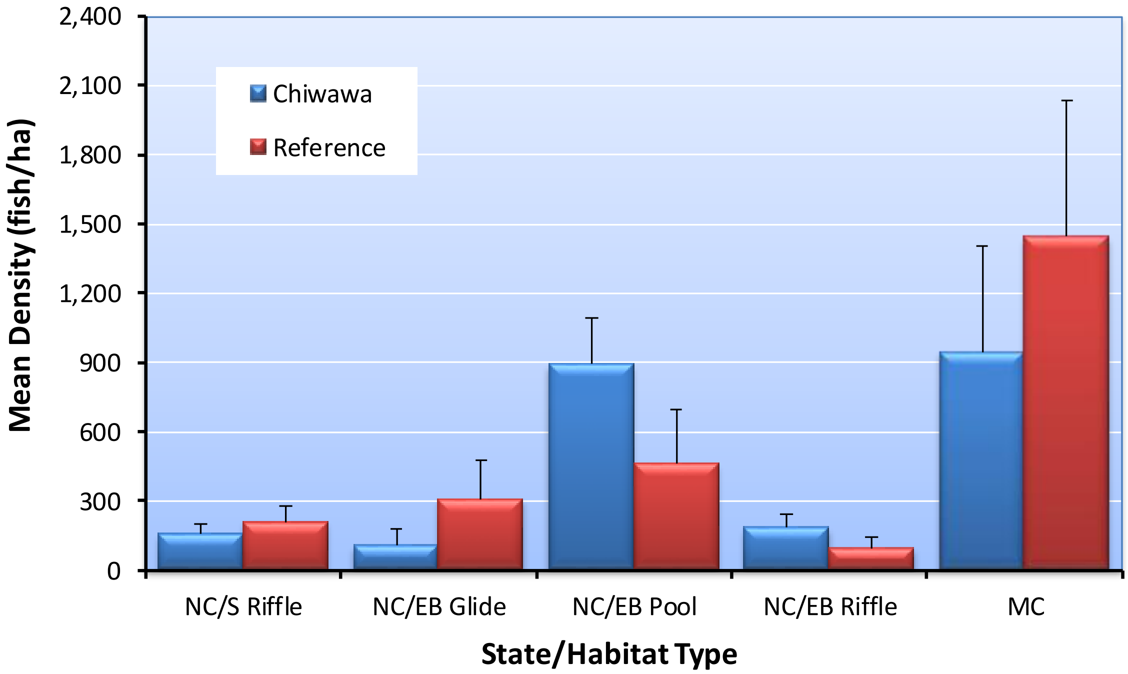

Figure 5.2. Comparison of the 23-year means of subyearling spring Chinook densities within state/habitat types in reaches 3 and 8 of the Chiwawa River and their matched reference areas on Nason Creek and the Little Wenatchee River. NC = natural channel; S = straight channel; EB = eroded banks; MC = multiple channel. There was no sampling in 2000 and no sampling within reference areas in 1992.

Smolt and Emigrant Estimates

Numbers of spring Chinook smolts and emigrants were estimated at the Chiwawa and Lower Wenatchee traps in 2016.

Chiwawa Trap

The Chiwawa Trap operated between 2 March and 21 November 2016. During that time, the trap was inoperable for 72 days because of high and low river flows, debris, major hatchery releases, and mechanical issues. The trap operated in a single position throughout the sampling season. Daily trap efficiencies were estimated for each age class of fish (e.g., subyearling and yearling). The daily number of fish captured was expanded by the estimated trap efficiency to estimate daily total emigration. Monthly captures of all fish and results of mark-recapture efficiency tests at the Chiwawa Trap are reported in Appendix B.

Wild yearling spring Chinook (2014 brood year) were primarily captured in March and April 2016 (Figure 5.3). A significant relationship between trap efficiency and river flow was found (R^2 = 0.875; $P < 0.028$) and the total number of wild yearling Chinook emigrating from the Chiwawa River was estimated at 37,170 (±6,524; 95% CI). Combining the total number of subyearling spring Chinook (77,510 ±9,074) that emigrated during the fall of 2015 with the total number of yearling Chinook (37,170 ±6,524) that emigrated during 2016, the total emigrant estimate for brood year 2014 was 114,680 (± 12,268) (Table 5.15). No non-trapping estimate was calculated for brood year 2014 (see Appendix B).

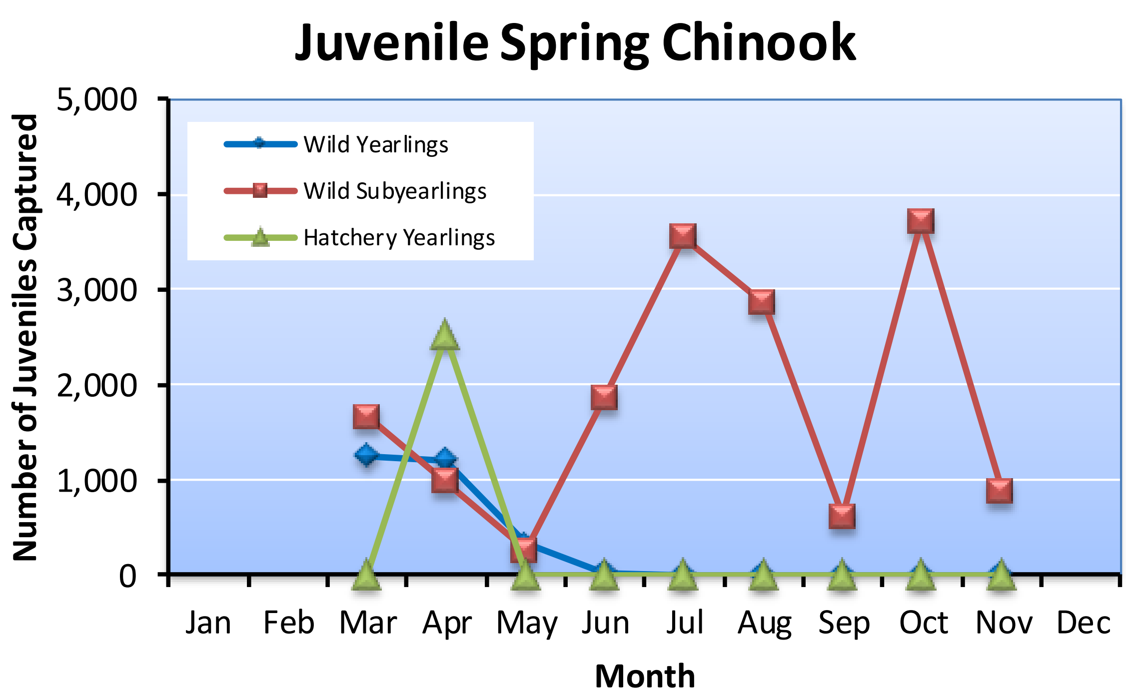

Figure 5.3. Monthly captures of wild subyearling, wild yearling, and hatchery yearling spring Chinook at the Chiwawa Trap, 2016.

Table 5.15. Numbers of redds and juvenile spring Chinook at different life stages in the Chiwawa River basin for brood years 1991-2016; NS = not sampled.

Brood year	Number of redds	Egg deposition	Number of parr	Number of smolts produced within Chiwawa River basin[a]	Number of emigrants
1991	104	478,400	45,483[b]	42,525	NS
1992	302	1,570,098	79,113	39,723	65,541
1993	106	556,394	55,056	8,662	22,698
1994	82	485,686	55,240	16,472	25,067
1995	13	66,248	5,815	3,830	5,951
1996	23	106,835	16,066	15,475	19,183
1997	82	374,740	68,415	28,334	44,562
1998	41	218,325	41,629	23,068	25,923
1999	34	166,090	NS	10,661	15,649
2000	128	642,944	114,617	40,831	55,685
2001	1,078	4,984,672	134,874	86,482	546,266
2002	345	1,605,630	91,278	90,948	184,279
2003	111	648,684	45,177	16,755	33,637
2004	241	1,156,559	49,631	72,080	116,158
2005	332	1,436,564	79,902	69,064	177,659
2006	297	1,284,228	60,752	45,050	107,972
2007	283	1,256,803	82,351	25,809	86,006
2008	689	3,163,888	106,705	35,023	120,184
2009	421	1,925,233	128,220	30,959	61,955
2010	502	2,165,628	141,510	47,511	101,130
2011	492	2,157,420	103,940	37,185	108,832
2012	880	3,716,240	149,563	34,334	109,413
2013	714	3,367,224	121,240	39,396	113,091
2014	485	1,961,825	111,224	37,170	114,680
2015	543	2,631,921	140,172	-	-
Average	***333***	***1,525,131***	***84,499***	***37,389***	***98,327***
Median	***297***	***1,284,228***	***81,127***	***36,097***	***86,006***

[a] The estimated number of smolts (yearlings) that are produced entirely within the Chiwawa River basin. Smolt estimates for brood years 1992-1996 were calculated with a mark-recapture model; brood years 1997-present were calculated with a flow model.
[b] Estimate only includes numbers of Chinook in the Chiwawa River. Tributaries were not sampled at that time.

Wild subyearling spring Chinook (2015 brood year) were captured between March and November 2016. Based on capture efficiencies, the total number of wild subyearling (fry and parr) Chinook from the Chiwawa River basin was 145,971 (±48,393). Removing fry from the estimate, a total of 80,543 (±27,967) subyearling parr emigrated from the Chiwawa River basin in 2016. Although subyearling parr migrated during all months of sampling, the majority (83%) migrated during March, June, July, August, and October (Figure 5.3).

Yearling spring Chinook sampled in 2016 averaged 91 mm in length, 8.3 g in weight, and had a mean condition of 1.06 (Table 5.16). These size estimates were similar to the overall mean of yearling spring Chinook sampled in previous years (overall means: 93 mm, 9.1 g, and condition of 1.08). Subyearling spring Chinook sampled in 2016 at the Chiwawa Trap averaged 71 mm in length, averaged 4.5 g, and had a mean condition of 1.10 (Table 5.16). In general, subyearlings were slightly smaller than previous years (overall means, 76 mm, 5.3 g, and condition of 1.09).

Table 5.16. Mean fork length (mm), weight (g), and condition factor of subyearling (excluding fry) and yearling spring Chinook collected in the Chiwawa Trap, 1996-2016. Numbers in parentheses indicate 1 standard deviation.

Sample year	Life stage	Sample size[a]	Mean size		
			Length (mm)	Weight (g)	Condition (K)
1996	Subyearling	514	78 (25)	6.9 (4.2)	1.11 (0.11)
	Yearling	1,589	94 (9)	9.5 (3.0)	1.11 (0.08)
1997	Subyearling	840	86 (8)	7.5 (2.1)	1.16 (0.08)
	Yearling	1,114	100 (7)	10.2 (2.6)	1.02 (0.10)
1998	Subyearling	3,743	82 (11)	6.2 (2.2)	1.08 (0.09)
	Yearling	2,663	97 (7)	10.3 (2.8)	1.12 (0.23)
1999	Subyearling	569	89 (9)	8.5 (2.4)	1.15 (0.07)
	Yearling	3,664	95 (8)	9.6 (3.4)	1.09 (0.19)
2000	Subyearling	1,810	85 (10)	7.4 (2.4)	1.15 (0.10)
	Yearling	1,891	97 (8)	10.5 (5.2)	1.13 (0.07)
2001	Subyearling	4,657	82 (11)	6.6 (3.4)	1.14 (0.09)
	Yearling	2,935	97 (7)	10.5 (2.4)	1.15 (0.08)
2002	Subyearling	6,130	64 (12)	3.0 (1.6)	1.06 (0.10)
	Yearling	1,735	94 (8)	9.0 (2.3)	1.09 (0.08)
2003	Subyearling	3,679	64 (12)	3.2 (1.7)	1.08 (0.10)
	Yearling	2,657	87 (9)	7.2 (3.5)	1.07 (0.10)
2004	Subyearling	2,278	75 (16)	4.3 (2.1)	0.92 (0.16)
	Yearling	1,032	91 (9)	8.5 (2.7)	1.09 (0.10)
2005	Subyearling	2,702	73 (12)	4.6 (2.2)	1.08 (0.09)
	Yearling	803	96 (9)	9.9 (2.8)	1.08 (0.08)
2006	Subyearling	3,462	76 (11)	5.1 (2.0)	1.12 (0.21)
	Yearling	4,645	95 (7)	9.4 (2.3)	1.10 (0.13)
2007	Subyearling	1,718	72 (12)	4.5 (2.1)	1.13 (0.16)
	Yearling	2,245	91 (8)	8.6 (2.5)	1.10 (0.09)
2008	Subyearling	10,443	79 (12)	5.9 (2.3)	1.15 (0.15)
	Yearling	8,792	93 (7)	8.8 (2.1)	1.08 (0.10)
2009	Subyearling	10,536	75 (10)	5.0 (2.2)	0.91 (0.11)
	Yearling	3,630	92 (7)	8.8 (2.1)	0.89 (0.07)
2010	Subyearling	3,888	77 (12)	5.4 (2.3)	1.11 (0.16)
	Yearling	5,799	91 (8)	8.9 (2.2)	1.15 (0.14)

Sample year	Life stage	Sample size[a]	Mean size		
			Length (mm)	Weight (g)	Condition (K)
2011	Subyearling	6,870	73 (11)	4.8 (2.2)	1.15 (0.16)
	Yearling	4,734	94 (8)	8.7 (2.2)	1.04 (0.10)
2012	Subyearling	8,756	75 (10)	4.8 (2.2)	1.13 (0.28)
	Yearling	7,290	90 (7)	8.0 (2.6)	1.06 (0.24)
2013	Subyearling	10,181	71 (10)	4.1 (1.7)	1.09 (0.39)
	Yearling	3,135	88 (9)	7.7 (2.8)	1.09 (0.20)
2014	Subyearling	7,122	71 (10)	3.7 (1.6)	1.08 (0.10)
	Yearling	3,956	89 (8)	7.7 (2.2)	1.05 (0.08)
2015	Subyearling	15,241	71 (11)	4.2 (2.4)	1.10 (0.39)
	Yearling	6,304	93 (9)	8.8 (2.9)	1.09 (0.15)
2016	Subyearling	12,198	71 (13)	4.5 (2.3)	1.08 (0.08)
	Yearling	2,789	91 (9)	8.3 (3.1)	1.06 (0.26)
Average	***Subyearling***	***5,587***	***76 (12)***	***5.2 (2.3)***	***1.09 (0.15)***
	Yearling	***3,495***	***93 (8)***	***9.0 (2.7)***	***1.08 (0.13)***
Median	***Subyearling***	***3,888***	***75 (11)***	***4.8 (2.2)***	***1.11 (0.11)***
	Yearling	***2,935***	***93 (8)***	***8.8 (2.6)***	***1.09 (0.10)***

[a] Sample size represents the number of fish that were measured for both length and weight.

Lower Wenatchee Trap

The lower Wenatchee Trap operated in a new location beginning in 2013. Hence, historic flow-discharge relationships are invalid and new models to estimate trap efficiency are being developed for all species.

The Lower Wenatchee Trap operated between 29 January and 26 July 2016. During that time, the trap was inoperable for 23 days because of high and low river discharge, debris, elevated river temperature, large hatchery releases, and mechanical issues. During the sampling period, a total of 610 wild yearling Chinook, 27,407 wild subyearling Chinook (mostly summer Chinook), and 7,701 hatchery yearling Chinook were captured at the Lower Wenatchee Trap. Based on capture efficiencies and river discharge, a significant model was developed (R^2 = 0.620, $P < 0.02$). The flow efficiency model estimated the total number of wild yearling Chinook that emigrated past the Lower Wenatchee Trap at 36,752 (±5,330; 95% CI) (Table 5.17). Monthly captures of all fish collected at the Lower Wenatchee Trap are reported in Appendix B.

Table 5.17. Numbers of redds and wild spring Chinook smolts produced in the Wenatchee River basin for brood years 2000-2014; NS = not sampled. From 2000-2010 the trap operated at Monitor; from 2013 to present the trap operated near Cashmere.

Brood year	Number of redds	Egg deposition	Number of smolts produced within Wenatchee River basin
2000	350	1,758,050	76,643
2001	2,109	8,674,624	243,516
2002	1,139	5,300,906	165,116
2003	323	1,887,612	70,738

Brood year	Number of redds	Egg deposition	Number of smolts produced within Wenatchee River basin
2004	574	2,663,445	55,619
2005	830	3,587,083	302,116
2006	588	2,542,512	85,558
2007	466	2,069,506	60,219
2008	1,411	6,479,312	82,137
2009	733	NS	NS
2010	968	NS	NS
2011	872	3,823,720	89,917
2012	1,704	7,195,992	67,973
2013	1,159	5,512,204	58,595
2014	885	3,894,000	36,752
Average	***941***	***4,260,690***	***107,300***
Median	***872***	***3,823,720***	***76,643***

Yearling spring Chinook sampled in 2016 at the Lower Wenatchee Trap averaged 94 mm in length, 9.0 g in weight, and had a mean condition of 1.06 (Table 5.18). These size estimates were similar to the overall mean of yearling spring Chinook sampled in previous years (overall means: 98 mm, 10.5 g, and condition of 1.10).

Table 5.18. Mean fork length (mm), weight (g), and condition factor of yearling spring Chinook collected in the Lower Wenatchee Trap, 2000-2016. From 2000-2010 the trap operated at Monitor; from 2013 to present the trap operated near Cashmere. Numbers in parentheses indicate 1 standard deviation.

Sample year	Sample size[a]	Mean size		
		Length (mm)	Weight (g)	Condition (K)
2000	29	111 (15.1)	15.6 (7.4)	1.15 (0.1)
2001	204	106 (9.6)	13.0 (3.6)	1.10 (0.1)
2002	301	99 (10.0)	10.7 (3.3)	1.11 (0.1)
2003	1,427	96 (9.4)	9.7 (10.0)	1.11 (0.1)
2004	1,046	97 (10.3)	10.0 (3.4)	1.11 (0.1)
2005	325	101 (10.5)	11.3 (3.7)	1.08 (0.1)
2006	642	99 (9.5)	10.6 (4.9)	1.08 (0.1)
2007	1,902	94 (8.4)	9.4 (2.5)	1.12 (0.1)
2008	615	97 (9.3)	10.5 (3.1)	1.14 (0.1)
2009	483	98 (10.8)	10.8 (3.9)	1.16 (0.1)
2010	1,057	98 (9.4)	10.5 (3.1)	1.10 (0.1)
2011	ND	ND	ND	ND
2012	ND	ND	ND	ND
2013	1729	94 (9.6)	9.0 (2.9)	1.07 (0.1)
2014	1,643	94 (9.8)	8.7 (2.8)	1.04 (0.1)

Sample year	Sample size[a]	Mean size		
		Length (mm)	Weight (g)	Condition (K)
2015	1,491	96 (9.8)	9.4 (3.7)	1.06 (0.1)
2016	598	94 (9.4)	9.0 (2.9)	1.08 (0.1)
Average	***900***	***98.3 (10.1)***	***10.5 (4.0)***	***1.10 (0.1)***
Median	***642***	***97.2 (9.6)***	***10.5 (3.4)***	***1.10 (0.1)***

[a] Sample size represents the number of fish that were measured for both length and weight.

PIT Tagging Activities

As part of the Comparative Survival Study (CSS) and PUD studies, a total of 14,158 wild juvenile Chinook (10,888 subyearling and 3,270 yearlings) were PIT tagged and released in 2016 in the Wenatchee River basin (Table 5.19a). Most of these (71.2%) were tagged at the Chiwawa trap. See Appendix C for a complete list of all fish captured, tagged, lost, and released.

Table 5.19a. Numbers of wild Chinook that were captured, tagged, and released at different locations within the Wenatchee River basin, 2016. Numbers of fish that died or shed tags are also given.

Sampling Location	Chinook Salmon Life Stage	Number captured	Number of recaptures	Number tagged	Number died	Shed tags	Total tags released	Percent mortality
Chiwawa Trap	Subyearling	16,393	89	7,355	82	1	7354	0.50
	Yearling	2,807	79	2,729	4	3	2,729	0.14
	Total	**19,200**	**168**	**10,084**	**86**	**4**	**10,083**	**0.45**
Chiwawa River (Electrofishing)	Subyearling	1,829	24	1,776	5	0	1,776	0.27
	Yearling	0	0	0	0	0	0	0.00
	Total	**1,829**	**24**	**1,776**	**5**	**0**	**1,776**	**0.27**
Nason Creek Trap	Subyearling	791	48	434	6	0	434	0.76
	Yearling	61	4	61	0	0	61	0.00
	Total	**852**	**52**	**495**	**6**	**0**	**495**	**0.70**
Nason Creek (Electrofishing)	Subyearling	828	10	802	14	0	802	1.66
	Yearling	0	0	0	0	0	0	0.00
	Total	**828**	**10**	**802**	**14**	**0**	**802**	**1.69**
White River Trap	Subyearling	197	3	137	2	1	136	1.02
	Yearling	3	0	3	0	0	3	0.00
	Total	**200**	**3**	**140**	**2**	**1**	**139**	**0.01**
Lower Wenatchee Trap	Subyearling	27,407	38	18	184	0	18	0.07
	Yearling	610	4	538	2	0	538	0.33
	Total	**28,017**	**42**	**556**	**186**	**0**	**556**	**0.66**
Total:	**Subyearling**	**47,482**	**174**	**10,890**	**301**	**2**	**10,888**	**0.01**
	Yearling	**3,420**	**83**	**3,270**	**6**	**3**	**3,270**	**0.00**
Grand Total:		***50,902***	***257***	***14,160***	***307***	***5***	***14,158***	***0.01***

Numbers of wild Chinook salmon PIT-tagged and released as part of CSS and PUD studies during the period 2006-2016 are shown in Table 5.19b.

Table 5.19b. Summary of the numbers of wild Chinook that were tagged and released at different locations within the Wenatchee River basin, 2006-2016.

Sampling Location	Life Stage	Numbers of PIT-tagged wild Chinook salmon released										
		2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Chiwawa Trap	Subyearling	5,130	6,137	8,755	8,765	3,324	6,030	7,644	9,086	11,358	10,471	7,354
	Yearling	2,793	4,659	8,397	3,694	6,281	4,318	7,980	3,093	4,383	6,204	2,729
	Total	**7,923**	**10,796**	**17,152**	**12,459**	**9,605**	**10,348**	**15,624**	**12,179**	**15,741**	**16,675**	**10,083**
Chiwawa River (Angling or Electrofishing)	Subyearling	111	20	43	128	531	0	3,181	3,017	1,032	1,054	1,776
	Yearling	0	0	0	3	4	0	0	0	0	0	0
	Total	**111**	**20**	**43**	**131**	**535**	**0**	**3,181**	**3,017**	**1,032**	**1,054**	**1,776**
Upper Wenatchee Trap	Subyearling	0	15	0	37	3	1	1	0	--	--	--
	Yearling	81	1,434	159	296	486	714	75	94	--	--	--
	Total	**81**	**1,449**	**159**	**333**	**489**	**715**	**76**	**94**	**--**	**--**	**--**
Nason Creek Trap	Subyearling	1,434	545	1,741	1,890	2,828	822	1,939	3,290	1,113	219	**434**
	Yearling	365	577	894	185	364	147	357	237	456	142	**61**
	Total	**1,799**	**1,122**	**2,635**	**2,075**	**3,192**	**969**	**2,296**	**3,527**	**1,569**	**361**	**495**
Nason Creek (Angling or Electrofishing)	Subyearling	68	6	4	701	595	0	0	0	1,816	1,089	802
	Yearling	1	7	0	13	3	0	0	0	0	0	0
	Total	**69**	**13**	**4**	**714**	**598**	**0**	**0**	**0**	**1,816**	**1,089**	**802**
White River Trap	Subyearling	0	0	0	441	143	144	285	374	156	149	**136**
	Yearling	0	0	0	265	359	65	180	22	49	34	**3**
	Total	**0**	**0**	**0**	**706**	**502**	**209**	**465**	**396**	**205**	**183**	**139**
Upper Wenatchee (Angling or Electrofishing)	Subyearling	0	61	1	0	2	--	--	--	--	--	--
	Yearling	27	0	0	0	0	--	--	--	--	--	--
	Total	**27**	**61**	**1**	**0**	**2**	**--**	**--**	**--**	**--**	**--**	**--**
Middle Wenatchee (Angling or Electrofishing)	Subyearling	0	0	65	284	233	--	--	--	--	--	--
	Yearling	0	0	0	0	0	--	--	--	--	--	--
	Total	**0**	**0**	**65**	**284**	**233**	**--**	**--**	**--**	**--**	**--**	**--**
Lower Wenatchee (Angling or Electrofishing)	Subyearling	0	0	0	0	0	--	--	--	--	--	--
	Yearling	0	0	0	0	0	--	--	--	--	--	--
	Total	**0**	**0**	**0**	**0**	**0**	**--**	**--**	**--**	**--**	**--**	**--**
Peshastin Creek (Angling or Electrofishing)	Subyearling	0	0	0	0	1	--	--	--	--	--	--
	Yearling	0	0	0	0	0	--	--	--	--	--	--
	Total	**0**	**0**	**0**	**0**	**1**	**--**	**--**	**--**	**--**	**--**	**--**
Lower Wenatchee Trap	Subyearling	0	0	2	0	0	0	0	0	36	0	18
	Yearling	522	1,641	506	468	917	0	0	1,712	1,506	1,301	538
	Total	**522**	**1,641**	**508**	**468**	**917**	**0**	**0**	**1,712**	**1,542**	**1,301**	**556**

Sampling Location	Life Stage	Numbers of PIT-tagged wild Chinook salmon released										
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total:	Subyearling	6,743	6,784	10,611	12,246	7,660	6,997	13,050	15,767	15,511	12,982	10,520
	Yearling	3,789	8,318	9,956	4,924	8,414	5,244	8,592	5,158	6,394	7,681	3,331
Grand Total:		*10,532*	*15,102*	*20,567*	*17,170*	*16,074*	*12,241*	*21,642*	*20,925*	*21,905*	*20,663*	*13,851*

Freshwater Productivity

Both productivity and survival estimates for different life stages of spring Chinook in the Chiwawa River basin are provided in Table 5.20. Estimates for brood year 2014 fall within the ranges estimated over the period of brood years 1991-2014. During that period, freshwater productivities ranged from 125-1,015 parr/redd, 39-673 smolts/redd, and 124-834 emigrants/redd. Survivals during the same period ranged from 2.7-19.1% for egg-parr, 0.9-14.5% for egg-smolt, and 2.9-18.0% for egg-emigrants. Overwinter survival rates for juvenile spring Chinook within the Chiwawa River basin have ranged from 15.7-100.0%.

Table 5.20. Productivity (fish/redd) and survival (%) estimates for different juvenile life stages of spring Chinook in the Chiwawa River basin for brood years 1991-2014; ND = no data. These estimates were derived from data in Table 5.15.

Brood year	Parr/Redd	Smolts/Redd[a]	Emigrants/ Redd	Egg-Parr (%)	Parr-Smolt[b] (%)	Egg-Smolt[a] (%)	Egg-Emigrant (%)
1991	437	409	ND	9.5	93.5	8.9	ND
1992	262	132	217	5.0	50.2	2.5	4.2
1993	519	82	214	9.9	15.7	1.6	4.1
1994	674	201	306	11.4	29.8	3.4	5.2
1995	447	295	458	8.8	65.9	5.8	9.0
1996	699	673	834	15.0	96.3	14.5	18.0
1997	834	346	543	18.3	41.4	7.6	11.9
1998	1,015	563	632	19.1	55.4	10.6	11.9
1999	ND	314	460	ND	ND	6.4	9.4
2000	895	319	435	17.8	35.6	6.4	8.7
2001	125	80	507	2.7	64.1	1.7	11.0
2002	265	264	534	5.7	99.6	5.7	11.5
2003	407	151	303	7.0	37.1	2.6	5.2
2004	206	299	482	4.3	100.0	6.2	10.0
2005	241	208	535	5.6	86.4	4.8	12.4
2006	205	152	364	4.7	74.2	3.5	8.4
2007	291	91	304	6.6	31.3	2.1	6.8
2008	155	51	174	3.4	32.8	1.1	3.8
2009	305	74	147	6.7	24.1	1.6	3.2
2010	282	95	201	6.5	33.6	2.2	4.7
2011	211	76	221	4.8	35.8	1.7	5.0

Brood year	Parr/Redd	Smolts/Redd[a]	Emigrants/ Redd	Egg-Parr (%)	Parr-Smolt[b] (%)	Egg-Smolt[a] (%)	Egg-Emigrant (%)
2012	170	39	124	4.0	23.0	0.9	2.9
2013	170	55	158	3.6	32.5	1.2	3.4
2014	229	77	236	5.7	33.4	1.9	5.8
Average	***388***	***210***	***365***	***8.0***	***51.8***	***4.4***	***7.7***
Median	***273***	***151***	***306***	***6.1***	***37.1***	***3.0***	***6.8***

[a] These estimates include Chiwawa smolts produced only within the Chiwawa River basin.
[b] These estimates represent overwinter survival within the Chiwawa River basin. It does not include Chiwawa smolts produced outside the Chiwawa River basin.

Seeding level (egg deposition) explained most of the variability in productivity and survival of juvenile spring Chinook in the Chiwawa River basin. That is, for estimates based on "within-Chiwawa-Basin" life stages (e.g., parr and smolts), survival and productivity decreased as seeding levels increased (Figure 5.4). This suggests that density dependence regulates juvenile productivity and survival within the Chiwawa River basin. This form of population regulation is less apparent with total emigrants. However, one would expect the number of emigrants to increase as seeding levels exceed the rearing capacity of the Chiwawa River basin.

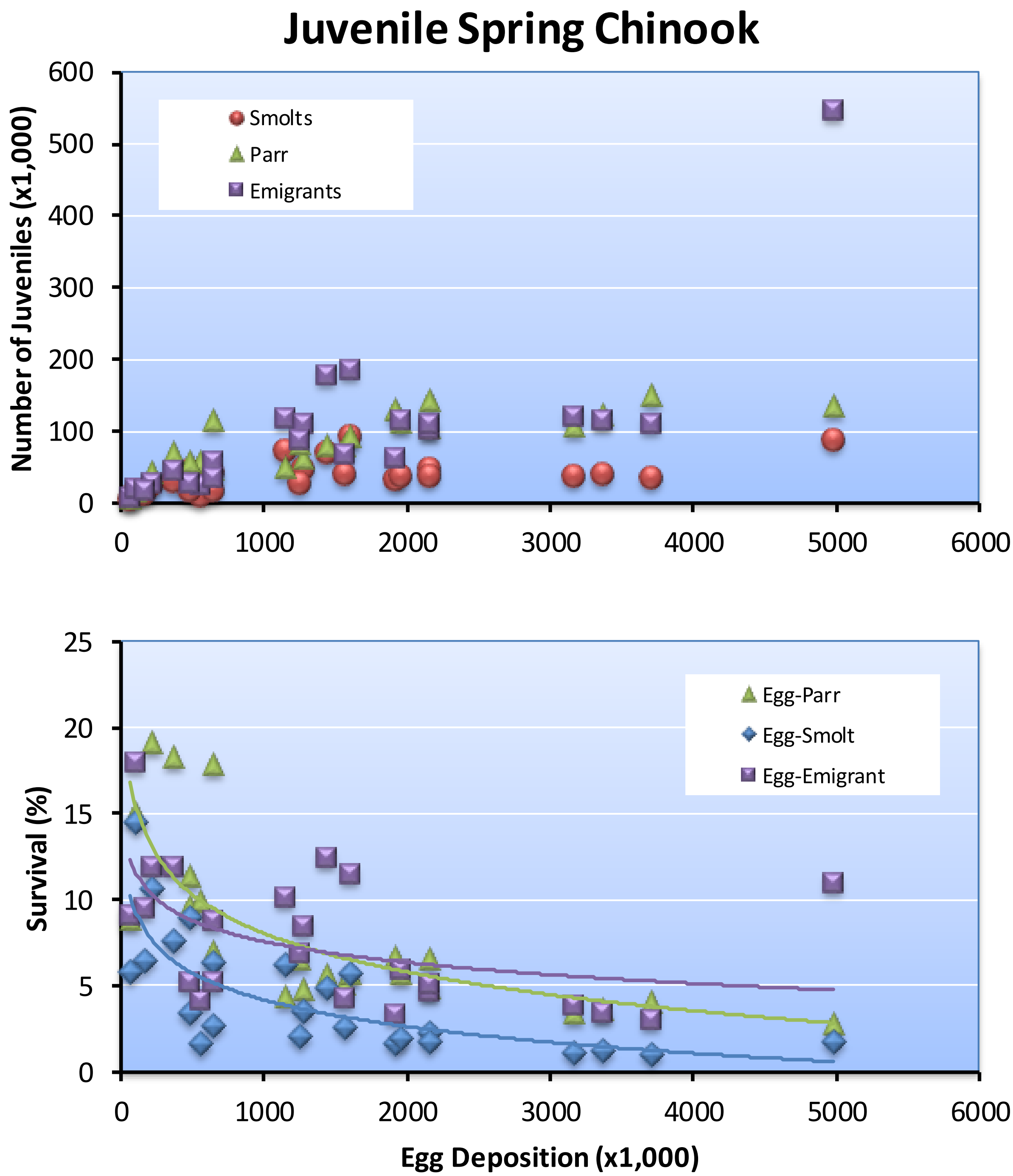

Figure 5.4. Relationships between seeding levels (egg deposition) and juvenile life-stage survivals and productivities for Chiwawa spring Chinook, brood years 1991-2014. Smolts represent yearling Chinook produced within the Chiwawa River basin.

Population Carrying Capacity

Population carrying capacity (*K*) is defined as the maximum equilibrium population size estimated with population models (e.g., logistic equation, Beverton-Holt model, hockey stick model, and the

Ricker model).[11] Maximum equilibrium population size is generated from density dependent mechanisms that reduce population growth rates as population size increases (negative density dependence). This is referred to as compensation. Population size fluctuates about the maximum equilibrium size because of variability in vital rates that are unrelated to density (density independent factors) and measurement error. In this section, we estimate parr and smolt carrying capacities using the smooth hockey stick stock-recruitment model (see Appendix C in Hillman et al. 2012 for a detailed description of methods). This model explains most of the information contained in the juvenile spring Chinook data (see Appendix A).

Based on the smooth hockey stick model, the population carrying capacity for spring Chinook parr in the Chiwawa River basin is 113,801 parr (95% CI: 94,343 – 139,922) (Figure 5.5). The capacity for spring Chinook smolts is 45,161 (95% CI: 34,226 – 55,445) (Figure 5.6). Here, smolts are defined as the number of yearling spring Chinook produced entirely within the Chiwawa River basin. These estimates reflect current conditions (most recent two decades) within the Chiwawa River basin. Land use activities such as logging, mining, roads, development, and recreation have altered the historical conditions of the watershed. Thus, the estimated population capacity estimates may not reflect historical capacities for spring Chinook parr and smolts in the Chiwawa River basin.

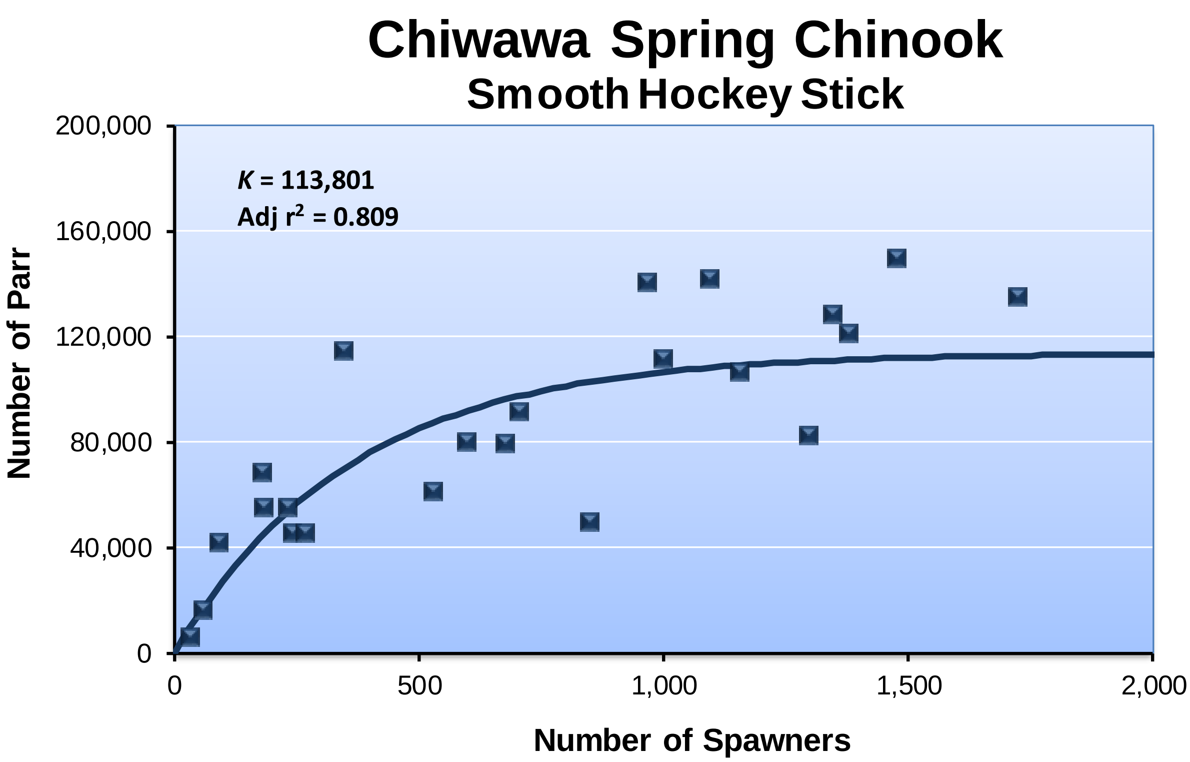

Figure 5.5. Relationship between spawners and number of parr produced in the Chiwawa River basin. Population carrying capacity (*K*) was estimated using the smooth hockey stick model, which explained most of the information in the data.

[11] Population carrying capacity (*K*) should not be confused with habitat carrying capacity (*C*), which is defined as the maximum population of a given species that a particular environment can sustain.

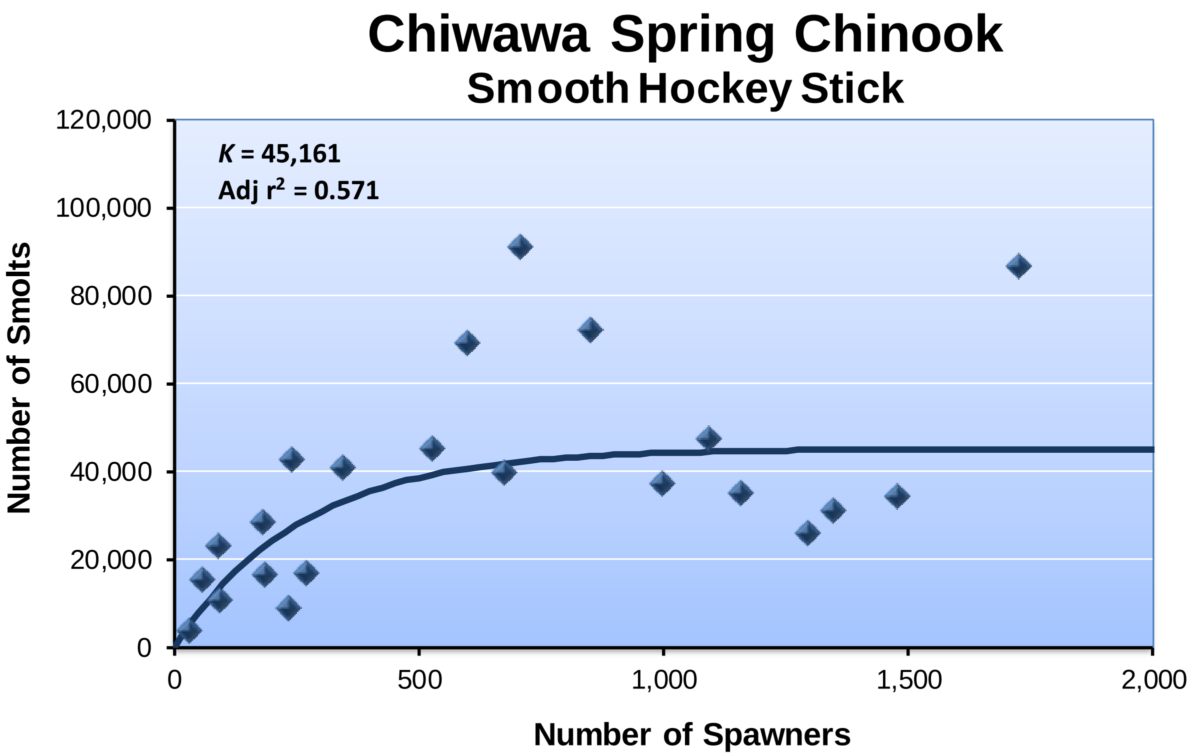

Figure 5.6. Relationship between spawners and number of yearling smolts produced in the Chiwawa River basin. Population carrying capacity (*K*) was estimated using the smooth hockey stick model, which explained most of the information in the data.

We tracked the precision of the smooth hockey stick parameters for Chiwawa spring Chinook smolts over time to see if precision improves with additional years of data, and the parameters and statistics stabilize over time. Examination of variation in the alpha (*A*) and beta (*B*) parameters of the smooth hockey stick model and their associated standard errors and confidence intervals indicates that the parameters appear to stabilize after 19 years of smolt and spawning escapement data (Table 5.21; Figure 5.7). This was also apparent in the estimates of population carrying capacity (Figure 5.8). That is, after 19 years of data, additional years of data had relatively little effect on the parameters of the smooth hockey stick model and its statistics. This observation will change if more extreme spawning escapements occur in the future or density independent factors overwhelm the influence of density dependent factors.

Table 5.21. Estimated parameters and statistics associated with fitting the smooth hockey stick model to spawning escapement and smolt data. Smolts represent numbers of smolts produced entirely within the Chiwawa River basin. *A* = alpha parameter; *B* = beta parameter; SE = standard error (estimated from 5,000 bootstrap samples); and r^2 = coefficient of determination. Spawners represent the stock size needed to achieve population capacity.

Years of data	Parameter				Population capacity	Intrinsic productivity	Spawners	r^2
	A	SE	*B*	SE				
5	10.80	11.51	110.23	942.46	49,257	110	1,339	0.706
6	10.43	30.61	163.03	28174.86	34,022	163	625	0.562
7	10.47	70.66	173.00	1918.57	35,362	173	613	0.567
8	10.40	13.26	206.97	41705.63	32,750	207	474	0.513
9	10.43	16.70	190.98	96463.71	33,727	191	529	0.518
10	10.56	41.60	184.83	719.39	38,590	185	625	0.564
11	11.10	8.98	154.07	246309.06	66,371	154	1,291	0.653
12	11.31	71.48	150.98	2254.06	81,605	151	1,620	0.701
13	11.28	43.85	142.41	236.06	79,572	142	1,674	0.664
14	11.34	5.26	141.43	118.39	84,292	141	1,786	0.699
15	11.40	15.61	141.76	35.71	89,256	142	1,887	0.718
16	11.38	2.77	141.35	37.66	87,522	141	1,856	0.723
17	11.02	3.10	155.71	38.89	60,965	156	1,173	0.651
18	10.92	0.79	160.92	38.85	55,020	161	1,023	0.635
19	10.82	0.25	166.78	39.68	50,150	167	901	0.614
20	10.82	0.20	166.99	39.58	49,972	167	897	0.622
21	10.78	0.17	169.82	38.50	48,142	170	849	0.618
22	10.75	0.15	172.32	39.35	46,494	172	809	0.611
23	10.73	0.13	173.36	40.07	45,815	173	792	0.612
24	10.73	0.13	173.36	39.82	45,815	173	792	0.612
25	10.72	0.12	174.08	41.00	45,161	174	777	0.610

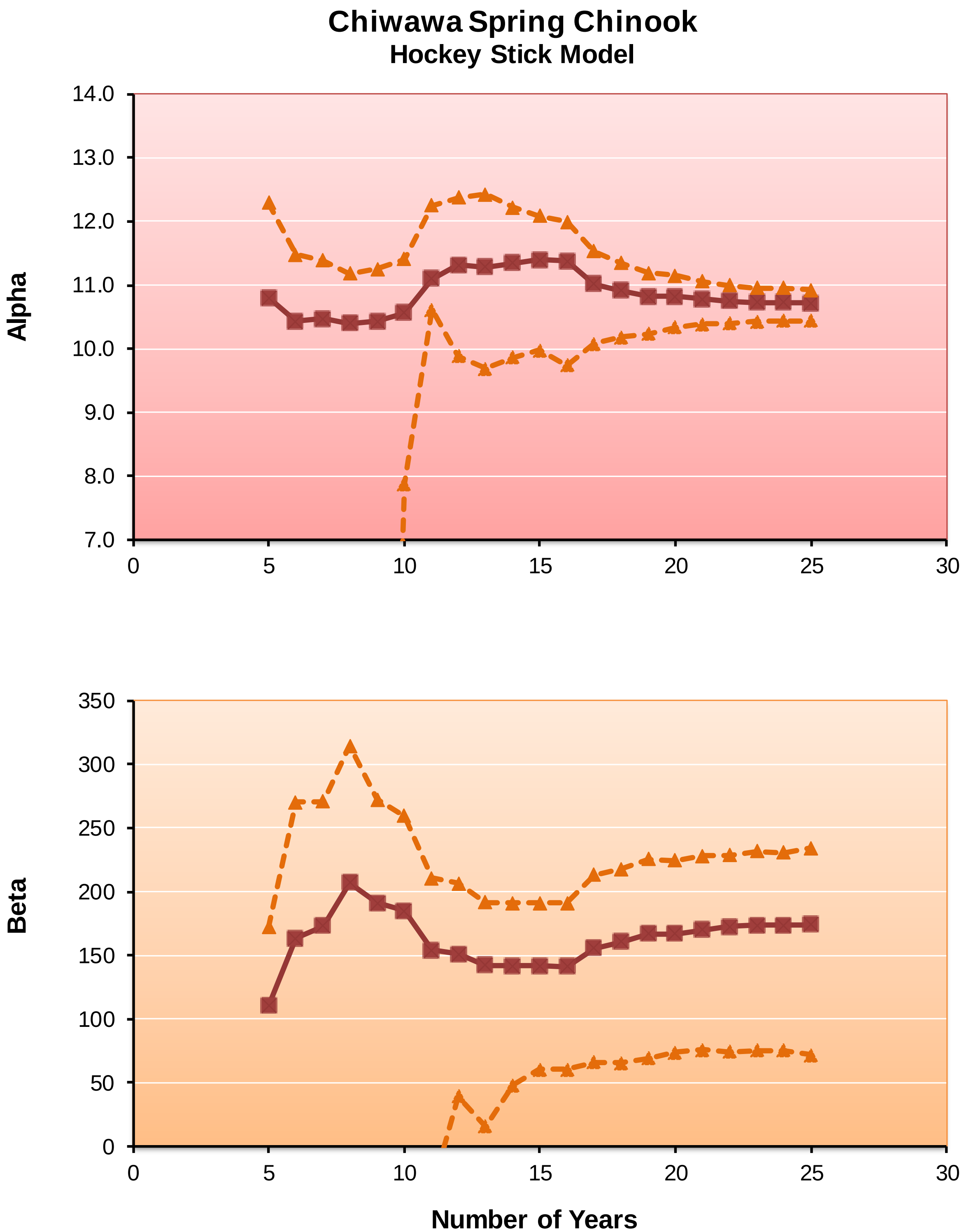

Figure 5.7. Time series of alpha and beta parameters and 95% confidence intervals for the smooth hockey stick model that was fit to Chiwawa spring Chinook smolt and spawning escapement data. Confidence intervals were estimated from 5,000 bootstrap samples.

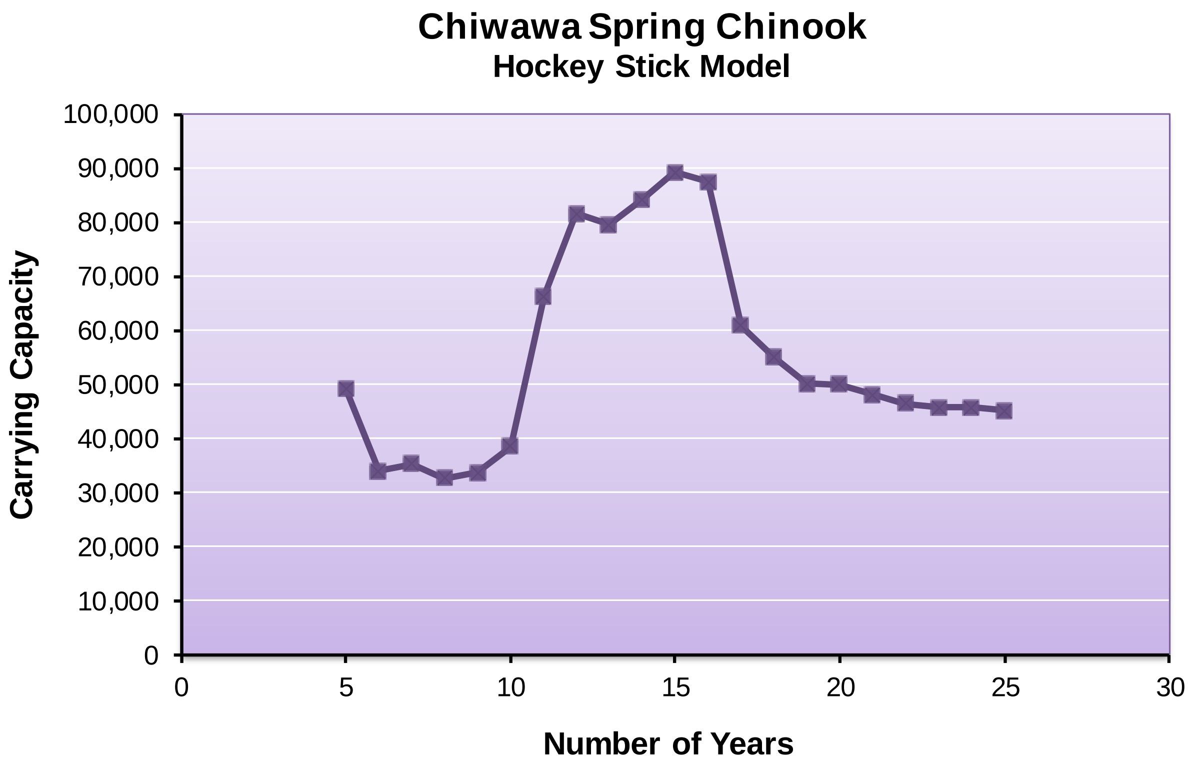

Figure 5.8. Time series of population carrying capacity estimates derived from fitting the smooth hockey stick model to Chiwawa spring Chinook smolt and spawning escapement data.

5.5 Spawning Surveys

Surveys for spring Chinook redds were conducted during the last week of July through September 2016 in the Chiwawa River (including Rock, Chikamin, and Phelps creeks), Nason Creek, Icicle Creek, Peshastin Creek (including Ingalls Creek), Upper Wenatchee River (including Chiwaukum Creek), Little Wenatchee River, and the White River (including the Napeequa River and Panther Creek).

Spawning escapement for spring Chinook was calculated as the total number of redds times the male-to-female ratio (i.e., fish per redd expansion factor) estimated from broodstock and fish sampled at adult trapping sites.[12] Beginning with return year 2015, WDFW used the Gaussian area-under-the-curve (AUC) method (Millar et al. 2012) to estimate the number of redds within survey reaches (see Appendix J). The number of redds within each reach were then divided by the mean net error (ratio of observed redds to true number of redds) to estimate the "true" number of redds within each reach. The Mean net error was modeled based on covariates such as surveyor experience, channel complexity (mean thalweg CV), and observed redd density (number of redds per km).

[12] Expansion factor = (1 + (number of males/number of females)).

Redd Counts

A total of 554 spring Chinook redds were counted in the Wenatchee River basin in 2016 (Table 5.22). This is lower than the average of 674 redds counted during the period 1989-2015 in the Wenatchee River basin. Most spawning occurred in the Chiwawa River (56.3% or 312 redds) (Table 5.22; Figure 5.9). Nason Creek contained 15.3% (85 redds), Icicle Creek contained 13.0% (72 redds), White River contained 7.9% (44 redds), Little Wenatchee contained 4.0% (22 redds), the Upper Wenatchee River 3.1% (17 redds), and Peshastin Creek contained 0.4% (2 redds).

Table 5.22. Numbers of spring Chinook redds counted (not "true" estimates) within different streams or watersheds within the Wenatchee River basin, 1989-2016. WDFW began full implementation of adult management in 2014.

Sample year	Number of spring Chinook redds							
	Chiwawa	Nason	Little Wenatchee	White	Wenatchee River	Icicle	Peshastin	Total
1989	314	98	45	64	94	24	NS	**639**
1990	255	103	30	22	36	50	4	**500**
1991	104	67	18	21	41	40	1	**292**
1992	302	81	35	35	38	37	0	**528**
1993	106	223	61	66	86	53	5	**600**
1994	82	27	7	3	6	15	0	**140**
1995	13	7	0	2	1	9	0	**32**
1996	23	33	3	12	1	12	1	**85**
1997	82	55	8	15	15	33	1	**209**
1998	41	29	8	5	0	11	0	**94**
1999	34	8	3	1	2	6	0	**54**
2000	128	100	9	8	37	68	0	**350**
2001	1,078	374	74	104	218	88	173*	**2,109**
2002	345	294	42	42	64	245	107*	**1,139**
2003	111	83	12	15	24	18	60	**323**
2004	239	169	13	22	46	30	55	**574**
2005	333	193	64	86	143	8	3	**830**
2006	297	152	21	31	27	50	10	**588**
2007	283	101	22	20	12	17	11	**466**
2008	689	336	38	31	180	116	21	**1,411**
2009	421	167	39	54	5	32	15	**733**
2010	502	188	38	33	47	155	5	**968**
2011	492	170	30	20	12	122	26	**872**
2012	880	413	43	86	73	199	10	**1,704**
2013	714	212	51	54	17	107	4	**1,159**
2014	485	115	25	26	23	211	0	**885**
2015	543	85	28	70	55	132	10	**923**
2016	312	85	22	44	17	72	2	**554**

Sample year	Number of spring Chinook redds							
	Chiwawa	Nason	Little Wenatchee	White	Wenatchee River	Icicle	Peshastin	Total
Average	***329***	***142***	***28***	***35***	***47***	***70***	***10***	***670***
Median	***300***	***102***	***27***	***29***	***32***	***45***	***4***	***581***

* Redd counts in Peshastin Creek in 2001 and 2002 were elevated because the U.S. Fish and Wildlife Service planted 487 and 350 spring Chinook adults, respectively, into the stream. These counts were not included in the total or average calculations.

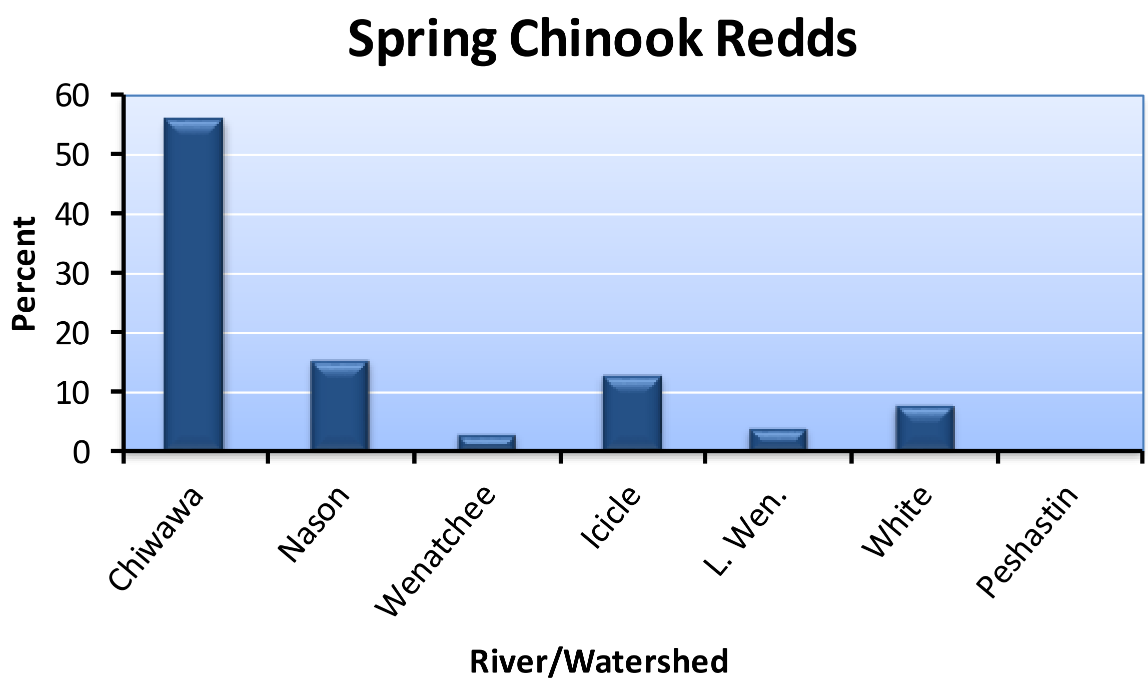

Figure 5.9. Percent of the total number of spring Chinook redds counted in different streams/watersheds within the Wenatchee River basin during August through September 2016.

As noted above, since 2015, WDFW has estimated the "true" number of redds within survey areas in the Wenatchee River basin using the Gaussian area-under-the-curve method. Based on two years of data, the average difference between the observed (counted) and true estimate is about 105 redds (Table 5.23).

Table 5.23. Comparison of the observed number and estimated "true" number of spring Chinook redds within different streams/watersheds within the Wenatchee River basin, 2015-2016.

Survey stream	Survey year			
	2015		2016	
	Observed	Estimated	Observed	Estimated
Chiwawa	542	607	312	354
Nason	85	103	85	100
Little Wenatchee	28	38	22	35
White	70	91	44	53

Survey stream	Survey year			
	2015		2016	
	Observed	Estimated	Observed	Estimated
Wenatchee	55	66	17	22
Peshastin	--	--	2	2
Icicle	--	--	72	72
Total	***780***	***905***	***554***	***638***

Redd Distribution

Spring Chinook redds were not evenly distributed among reaches within survey streams in 2016 (Table 5.24). Most of the spawning in the Chiwawa River basin occurred in Reaches 1 through 6. About 66% of the spawning in the Chiwawa River basin occurred in the lower two reaches (RKM 0.0-36.97; from the mouth to Rock Creek). Relatively few fish spawned in Rock and Chikamin creeks. The spatial distribution of redds in Nason Creek was weighted towards Reach 3, having 45% of the Nason Creek redds. In the Little Wenatchee River, about 89% of all spawning occurred in Reach 3 (RKM 9.2-14.0; Lost Creek to Falls). On the White River, 81% of the spawning occurred in Reach 3 (RKM 20.3-23.3; Napeequa River to Grasshopper Meadows). In the Wenatchee River about 50% of the fish spawned downstream from the mouth of the Chiwawa River, 41% spawned upstream from the mouth, and about 9% spawned in Chiwaukum Creek. In Icicle Creek, about 85% of spawning occurred in Reach 2 (RKM 4.9-6.7; Hatchery to Sleeping Lady). All the spawning in Peshastin Creek occurred upstream from the confluence with Camas Creek (RKM 9.0).

Table 5.24. Numbers (both observed and estimated) and proportions of spring Chinook redds estimated within different streams/watersheds within the Wenatchee River basin during August through September 2016. NS = not surveyed. See Table 2.8 for description of survey reaches.

Stream/watershed	Reach	Observed number of redds	Estimated number of redds	Proportion of estimated redds within stream/watershed
Chiwawa	Chiwawa 1 (C1)	56	64	0.18
	Chiwawa 2 (C2)	139	170	0.48
	Chiwawa 3 (C3)	21	21	0.06
	Chiwawa 4 (C4)	27	31	0.09
	Chiwawa 5 (C5)	33	34	0.10
	Chiwawa 6 (C6)	32	28	0.08
	Chiwawa 7 (C7)	3	5	0.01
	Phelps 1 (S1)	0	0	0.00
	Rock 1 (R1)	0	0	0.00
	Chikamin 1 (K1)	1	1	0.00
	Total	**312**	**354**	**1.00**
Nason	Nason 1 (N1)	14	14	0.14
	Nason 2 (N2)	20	23	0.23

Stream/watershed	Reach	Observed number of redds	Estimated number of redds	Proportion of estimated redds within stream/watershed
	Nason 3 (N3)	37	45	0.45
	Nason 4 (N4)	14	18	0.18
	Total	**85**	**100**	**1.00**
Little Wenatchee	Little Wen 1 (L1)	NS	--	--
	Little Wen 2 (L2)	3	4	0.11
	Little Wen 3 (L3)	19	31	0.89
	Total	**22**	**35**	**1.00**
White	White 1 (H1)[a]	0	--	--
	White 2 (H2)	4	6	0.11
	White 3 (H3)	37	43	0.81
	White 4 (H4)	2	3	0.06
	Napeequa 1 (Q1)	1	1	0.02
	Panther 1 (T1)	0	0	0.00
	Total	**44**	**53**	**1.00**
Wenatchee River	Wen 9 (W9)	7	11	0.50
	Wen 10 (W10)	8	9	0.41
	Chiwaukum (A1)	2	2	0.09
	Total	**17**	**22**	**1.00**
Icicle	Icicle 1 (I1)	2	2	0.03
	Icicle 2 (I2)	61	61	0.85
	Icicle 3 (I3)	9	9	0.13
	Total	**72**	**72**	**1.00**
Peshastin	Peshastin 1 (P1)	0	0	0.00
	Peshastin 2 (P2)	2	2	1.00
	Ingalls (D1)	0	0	0.00
	Total	**2**	**2**	**1.00**
Grand Total		***554***	***638***	***1.00***

[a] Reach H1 of the White River was surveyed once during the peak of the season to verify that no spawning was occurring in the lower portion of the river.

Spawn Timing

Spring Chinook began spawning during the last week of July in Nason Creek and the second week of August in the Chiwawa River. Spawning began the third week of August in the Little Wenatchee and White rivers, the fourth week of August in Icicle Creek, the fifth week of August in Peshastin Creek, and the first week of September in the Wenatchee River (Figure 5.10). Spawning peaked the last week of August in Icicle Creek and the Little Wenatchee River. The Chiwawa River and Nason Creek peaked during the first week of September. The White River peaked during the second week of September and the Wenatchee River peaked during the fourth week of September.

The 11 redds observed on the Wenatchee River during the fourth week of September may have been present the previous week when no survey occurred. Peshastin Creek had two redds, one occurring the last week of August and one during the second week of September. Chinook completed spawning by the end of September.

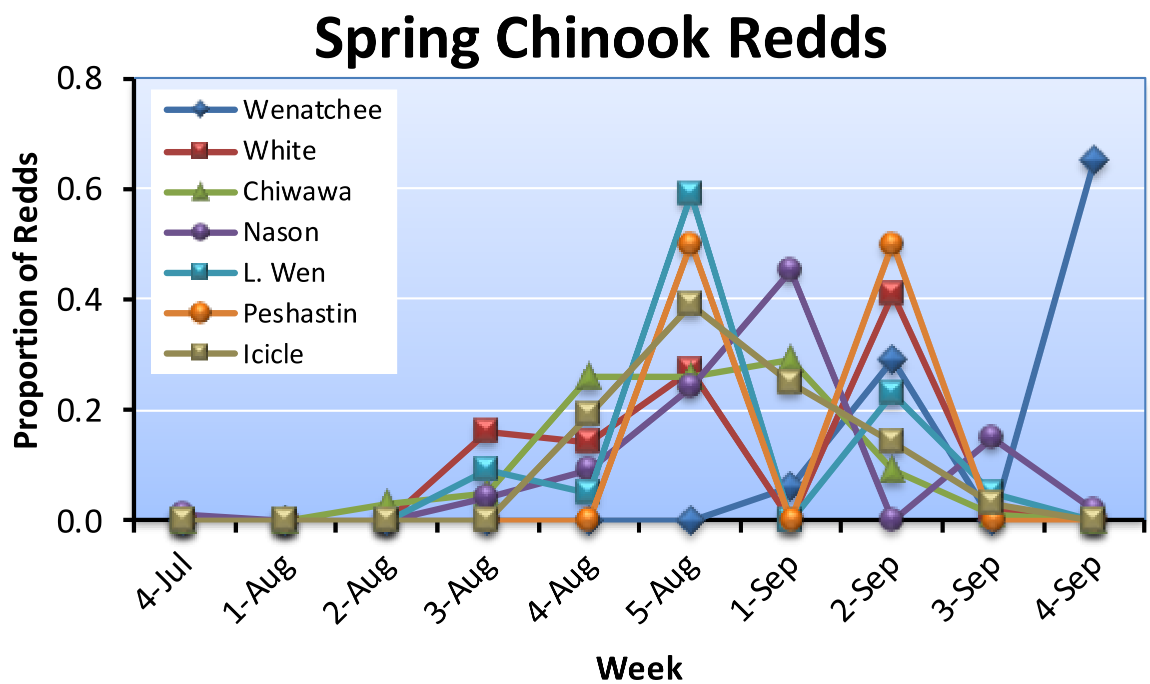

Figure 5.10. Proportion of spring Chinook redds counted during different weeks in different sampling streams within the Wenatchee River basin, August through September 2016.

Spawning Escapement

Spawning escapement for spring Chinook was calculated as the observed number of redds times the male-to-female ratio (i.e., fish per redd expansion factor) estimated from broodstock and fish sampled at adult trapping sites.[13] The estimated fish per redd ratio for spring Chinook upstream from Tumwater in 2016 was 1.83 (based on sex ratios estimated at Tumwater Dam). The estimated fish per redd ratio for spring Chinook downstream from Tumwater (Icicle and Peshastin creeks) was 1.81 (derived from broodstock collected at the Leavenworth National Fish Hatchery). Multiplying these ratios by the number of redds counted in the Wenatchee River basin resulted in a total spawning escapement of 1,012 spring Chinook (Table 5.25). The Chiwawa River basin had the highest spawning escapement (574 Chinook), while Peshastin Creek had the lowest (4 Chinook).

[13] Expansion factor = (1 + (number of males/number of females)).

Table 5.25. Number of observed redds, fish per redd ratios, and total spawning escapement for spring Chinook in the Wenatchee River basin, 2016. Spawning escapement was estimated as the product of redds times fish per redd.

Sampling area	Total number of redds	Fish/redd	Total spawning escapement*
Chiwawa	312	1.83	571
Nason	85	1.83	156
Upper Wenatchee River	17	1.83	31
Icicle	72	1.81	130
Little Wenatchee	22	1.83	40
White	44	1.83	81
Peshastin	2	1.81	4
Total	***554***	***--***	***1,012***

* Spawning escapement estimate is based on total number of observed redds by stream. If escapement is calculated at the reach scale, then the total escapement may vary from what is shown here because of rounding errors.

The estimated total spawning escapement of 1,012 spring Chinook in 2016 was less than the overall average of 1,367 spring Chinook (Table 5.26). The escapement in the Chiwawa River basin in 2016 was 3.7 times the escapement in Nason Creek, the second most abundant escapement in the Wenatchee River basin (Table 5.26).

Table 5.26. Spawning escapements for spring Chinook in the Wenatchee River basin for return years 1989-2016; NA = not available.

Return year	Upper basin spawning escapement						Lower basin spawning escapement			Total
	Fish/redd	Chiwawa	Nason	Little Wenatchee	White	Wenatchee River	Fish/redd	Icicle	Peshastin	
1989	2.27	713	222	102	145	213	1.56	37	NA	**1,419**
1990	2.24	571	231	67	49	81	1.71	86	7	**1,053**
1991	2.33	242	156	42	49	96	1.73	69	2	**626**
1992	2.24	676	181	78	78	85	1.65	61	0	**1,135**
1993	2.20	233	491	134	145	189	1.66	88	8	**1,250**
1994	2.24	184	60	16	7	13	2.11	32	0	**295**
1995	2.51	33	18	0	5	3	2.01	18	0	**68**
1996	2.53	58	83	8	30	3	2.09	25	2	**195**
1997	2.22	182	122	18	33	33	1.69	56	2	**422**
1998	2.21	91	64	18	11	0	1.81	20	0	**195**
1999	2.77	94	22	8	3	6	2.06	12	0	**139**
2000	2.70	346	270	24	22	100	1.68	114	0	**830**
2001	1.60	1,725	598	118	166	349	1.72	151	298	**3,217**
2002	2.05	707	603	86	86	131	1.55	380	166	**1,965**
2003	2.43	270	202	29	36	58	1.93	35	116	**673**
2004[a]	3.56/3.00	851	507	39	66	138	1.76	53	97	**1,686**
2005	1.80	599	347	115	155	257	1.67	13	5	**1,484**
2006	1.78	529	271	37	55	48	1.68	84	17	**1,000**
2007	4.58	1,296	463	101	92	55	1.91	32	21	**2,035**
2008	1.68	1,158	565	64	52	302	1.78	206	37	**2,278**

Return year	Upper basin spawning escapement						Lower basin spawning escapement			Total
	Fish/redd	Chiwawa	Nason	Little Wenatchee	White	Wenatchee River	Fish/redd	Icicle	Peshastin	
2009	3.20	1,347	534	125	173	16	2.22	71	33	**2,299**
2010	2.18	1,094	410	83	72	102	1.56	242	8	**1,921**
2011	4.13	2,032	702	124	83	50	2.60	317	68	**3,139**
2012	1.68	1,478	694	72	144	123	1.60	318	16	**2,720**
2013	1.93	1,378	409	98	104	33	1.98	212	8	**2,133**
2014	2.06	999	237	52	54	47	1.93	407	0	**1,600**
2015	1.78	967	151	50	125	98	1.87	247	19	**1,533**
2016	1.83	571	156	40	81	31	1.81	130	4	**953**
Average	***--***	***729***	***313***	***62***	***76***	***95***	***--***	***126***	***35***	***1,367***
Median	***--***	***638***	***254***	***58***	***69***	***70***	***--***	***78***	***8***	***1,335***

[a] In 2004, the fish/redd expansion estimate of 3.56 was applied to the Chiwawa River only and 3.00 fish/redd was applied to the rest of the upper basin.

5.6 Carcass Surveys

Surveys for spring Chinook carcasses were conducted during August through September 2016 in the Chiwawa River (including Rock, Chikamin, and Phelps creeks), Nason Creek, Icicle Creek, Peshastin Creek (including Ingalls Creek), Upper Wenatchee River (including Chiwaukum Creek), Little Wenatchee River, and White River (including the Napeequa River and Panther Creek).

Number sampled

A total of 362 spring Chinook carcasses were sampled during August through September in the Wenatchee River basin (Table 5.27). Most were sampled in the Chiwawa River basin (58% or 211 carcasses) and Nason Creek (26% or 95 carcasses) (Figure 5.11). A total of 25 carcasses were sampled in Icicle Creek, 13 in the Wenatchee River, 13 in the White River, and 5 in the Little Wenatchee River.

Table 5.27. Numbers of spring Chinook carcasses sampled within different streams/watersheds within the Wenatchee River basin, 1996-2016.

Survey year	Number of spring Chinook carcasses							
	Chiwawa	Nason	Little Wenatchee	White	Wenatchee River	Icicle	Peshastin	Total
1996	22	3	0	2	0	1	0	**28**
1997	17	42	3	8	1	28	1	**100**
1998	24	25	3	2	1	6	0	**61**
1999	15	5	0	0	2	1	0	**23**
2000	122	110	8	1	37	52	0	**330**
2001	763	388	68	81	213	163	63	**1,739**
2002	210	292	30	25	34	91	65	**747**
2003	70	100	8	8	11	37	64	**298**
2004	178	186	1	13	29	16	40	**463**
2005	391	217	48	52	120	2	0	**830**

Survey year	Number of spring Chinook carcasses							
	Chiwawa	Nason	Little Wenatchee	White	Wenatchee River	Icicle	Peshastin	Total
2006	241	190	13	25	15	7	0	**491**
2007	250	201	16	13	24	15	6	**525**
2008	386	243	15	13	94	67	5	**823**
2009	240	128	20	20	1	67	2	**478**
2010	192	141	7	11	29	39	2	**421**
2011	177	98	7	4	3	40	3	**332**
2012	390	332	24	21	23	61	3	**854**
2013	396	142	20	22	8	28	1	**671**
2014	320	68	15	8	19	44	0	**474**
2015	275	43	12	25	25	67	3	**450**
2016	211	95	5	13	13*	25	0	**362**
Average	***233***	***145***	***15***	***17***	***33***	***41***	***12***	***500***
Median	***211***	***128***	***12***	***13***	***19***	***37***	***2***	***463***

* The number of carcasses sampled in the Wenatchee River in 2016 include two recovered in reach (W6) just downstream from the mouth of Icicle Creek.

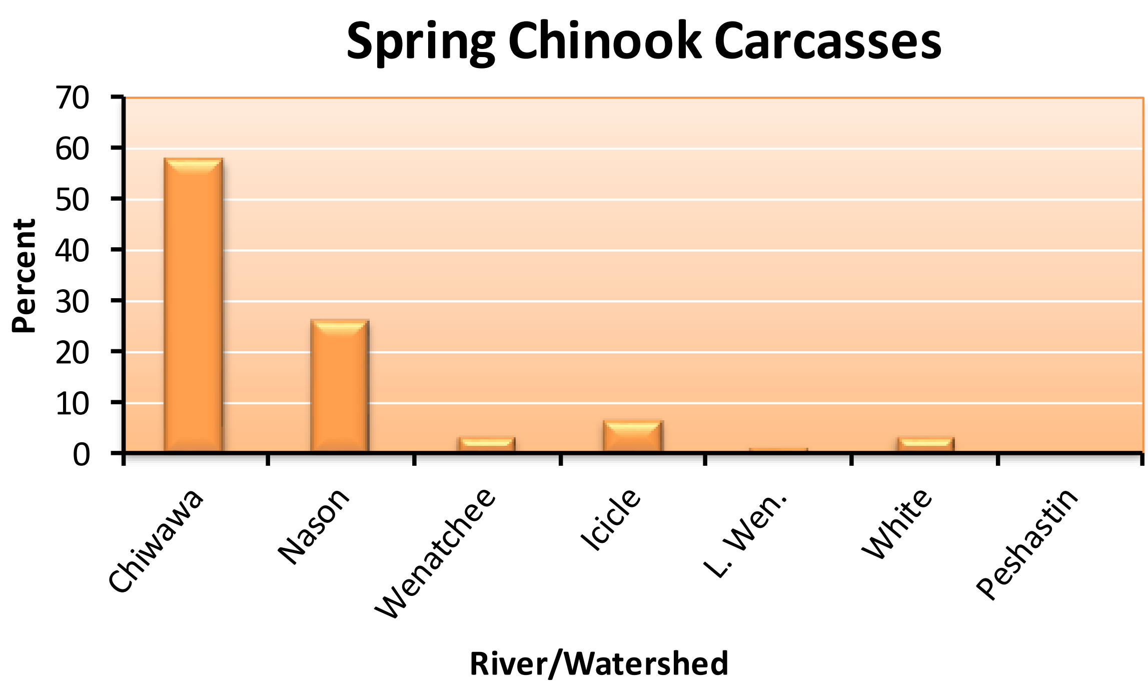

Figure 5.11. Percent of the total number of spring Chinook carcasses sampled in different streams/watersheds within the Wenatchee River basin during August through September 2016.

Carcass Distribution and Origin

Spring Chinook carcasses were not evenly distributed among reaches within survey streams in 2016 (Table 5.28). Most of the carcasses (71%) in the Chiwawa River basin occurred in Reaches

1 and 2 (downstream from Rock Creek). In Nason Creek, most carcasses (51%) were collected in Reach 3 and the fewest (8%) in Reach 4. Most carcasses in the Little Wenatchee River were sampled in Reach 3 (Lost Creek to Rainy Creek). On the White River, most (85%) occurred in Reach 3 (Napeequa River to Grasshopper Meadows). On the Wenatchee River, 62% of the carcasses were found upstream from the confluence of the Chiwawa River and 38% were found downstream from the confluence. Most of the carcasses in Icicle Creek (60%) were found in Reach 2 (Hatchery to Sleeping Lady). No carcasses were found in Peshastin Creek.

Table 5.28. Numbers and proportions of carcasses sampled within different streams/watersheds within the Wenatchee River basin during August through September 2016. See Table 2.8 for description of survey reaches.

Stream/watershed	Reach	Number of carcasses	Proportion of carcasses within stream/watershed
Chiwawa	Chiwawa 1 (C1)	38	0.18
	Chiwawa 2 (C2)	111	0.53
	Chiwawa 3 (C3)	9	0.04
	Chiwawa 4 (C4)	22	0.10
	Chiwawa 5 (C5)	17	0.08
	Chiwawa 6 (C6)	11	0.05
	Chiwawa 7 (C7)	1	0.00
	Phelps 1 (S1)	0	0.00
	Rock 1 (R1)	0	0.00
	Chikamin 1 (K1)	1	0.00
	Total	**211**	**1.00**
Nason	Nason 1 (N1)	21	0.22
	Nason 2 (N2)	8	0.08
	Nason 3 (N3)	48	0.51
	Nason 4 (N4)	18	0.19
	Total	**95**	**1.00**
Little Wenatchee	Little Wen 1 (L1)	NS	--
	Little Wen 2 (L2)	1	0.20
	Little Wen 3 (L3)	4	0.80
	Total	**5**	**1.00**
White	White 1 (H1)	0	0.00
	White 2 (H2)	1	0.08
	White 3 (H3)	11	0.85
	White 4 (H4)	1	0.08
	Napeequa 1 (Q1)	0	0.00
	Panther 1 (T1)	0	0.00
	Total	**13**	**1.00**
Wenatchee River	Wen 6 (W6)[a]	2	0.15
	Wen 9 (W9)	2	0.15
	Wen 10 (W10)	8	0.62

Stream/watershed	Reach	Number of carcasses	Proportion of carcasses within stream/watershed
	Chiwaukum 1 (U1)	1	0.08
	Total	**13**	**1.00**
Icicle	Icicle 1 (I1)	7	0.28
	Icicle 2 (I2)	15	0.60
	Icicle 3 (I3)	3	0.12
	Total	**25**	**1.00**
Peshastin	Peshastin 1 (P1)	0	0.00
	Peshastin 2 (P2)	0	0.00
	Ingalls (D1)	0	0.00
	Total	**0**	**0.00**
Grand Total		**362**	**1.00**

[a] Reach Wen 6 is not a survey reach for spring Chinook surveys; however, in 2016 two carcasses were sampled during a spring Chinook survey on the Icicle River. The carcasses were located downstream of the confluence of the Icicle River and Wenatchee River.

Final origin was determined for 208 of the 211 carcasses sampled in the Chiwawa River basin in 2016. Of those 208, 30% were hatchery fish (Table 5.29). In the Chiwawa River basin, the spatial distribution of hatchery and wild fish was not equal (Table 5.29). A larger percentage of hatchery fish were found in the lower reaches (C1 and C2; i.e., Mouth to Rock Creek). This general trend was also apparent in the pooled data (Figure 5.12).

Table 5.29. Numbers of wild and hatchery spring Chinook carcasses sampled within different reaches in the Chiwawa River basin, 1993-2016. Numbers represent recovered carcasses that had definitive origins. See Table 2.8 for description of survey reaches.

Survey year	Origin	Survey Reach									Total
		C-1	C-2	C-3	C-4	C-5	C-6	C-7	Chikamin	Rock	
1993	Wild	0	0	0	0	0	0	--	0	0	**0**
	Hatchery	1	0	0	0	0	0	--	0	0	**1**
1994	Wild	0	6	0	2	0	2	--	0	0	**10**
	Hatchery	1	1	0	2	0	0	--	0	0	**4**
1995	Wild	0	0	0	0	0	0	--	0	0	**0**
	Hatchery	2	3	0	1	0	0	--	0	0	**6**
1996	Wild	13	1	1	1	0	0	--	0	0	**16**
	Hatchery	6	0	0	0	0	0	--	0	0	**6**
1997	Wild	5	2	0	1	0	0	--	0	0	**8**
	Hatchery	3	1	0	0	0	1	--	1	3	**9**
1998	Wild	0	3	6	1	2	4	--	0	0	**16**
	Hatchery	1	3	2	0	1	1	--	0	0	**8**
1999	Wild	1	8	0	5	0	0	--	0	0	**14**
	Hatchery	0	0	0	0	1	0	--	0	0	**1**
2000	Wild	29	29	1	1	1	1	--	0	0	**62**

Survey year	Origin	Survey Reach									Total
		C-1	C-2	C-3	C-4	C-5	C-6	C-7	Chikamin	Rock	
	Hatchery	42	12	0	0	0	2	--	0	0	**56**
2001	Wild	27	60	15	43	16	21	--	1	3	**186**
	Hatchery	164	284	19	58	14	21	--	8	0	**568**
2002	Wild	22	15	10	6	9	7	--	1	0	**70**
	Hatchery	46	41	12	5	1	15	--	15	4	**139**
2003	Wild	7	13	0	12	4	2	--	0	0	**38**
	Hatchery	14	14	0	3	1	0	--	0	0	**32**
2004	Wild	25	50	2	12	7	2	--	0	1	**99**
	Hatchery	48	21	1	1	1	4	--	0	2	**78**
2005	Wild	18	36	3	5	3	2	--	0	0	**67**
	Hatchery	170	132	7	7	4	3	--	0	1	**324**
2006	Wild	10	17	2	8	4	3	--	1	0	**45**
	Hatchery	84	75	5	7	6	13	--	3	3	**196**
2007	Wild	3	15	3	4	2	2	--	0	0	**29**
	Hatchery	42	118	15	14	18	12	--	2	0	**221**
2008	Wild	4	23	0	4	4	8	--	0	0	**43**
	Hatchery	174	122	2	9	15	15	--	4	1	**342**
2009	Wild	3	21	4	8	4	1	--	0	3	**44**
	Hatchery	89	70	6	14	7	5	--	0	5	**196**
2010	Wild	4	30	7	8	10	3	--	0	0	**62**
	Hatchery	64	35	2	10	7	5	--	0	5	**128**
2011	Wild	8	26	10	6	8	6	--	0	1	**65**
	Hatchery	43	40	4	5	5	10	--	1	4	**112**
2012	Wild	11	74	6	21	13	18	0	0	3	**146**
	Hatchery	94	91	9	13	16	16	0	0	6	**245**
2013	Wild	8	38	7	21	16	14	1	0	3	**108**
	Hatchery	101	112	19	23	13	15	0	5	3	**291**
2014	Wild	18	77	9	28	19	21	0	0	0	**172**
	Hatchery	64	48	6	10	6	9	1	2	2	**148**
2015	Wild	14	37	6	12	12	13	0	0	0	**94**
	Hatchery	65	89	7	9	6	5	0	0	0	**181**
2016	Wild	15	77	8	18	15	10	0	2	0	**145**
	Hatchery	22	33	1	4	1	1	1	0	0	**63**
Average	***Wild***	***10***	***27***	***4***	***9***	***6***	***6***	***0***	***0***	***1***	***64***
	Hatchery	***56***	***56***	***5***	***8***	***5***	***6***	***0***	***2***	***2***	***140***
Median	***Wild***	***8***	***22***	***3***	***6***	***4***	***3***	***0***	***0***	***0***	***54***
	Hatchery	***45***	***38***	***2***	***5***	***3***	***5***	***0***	***0***	***1***	***120***

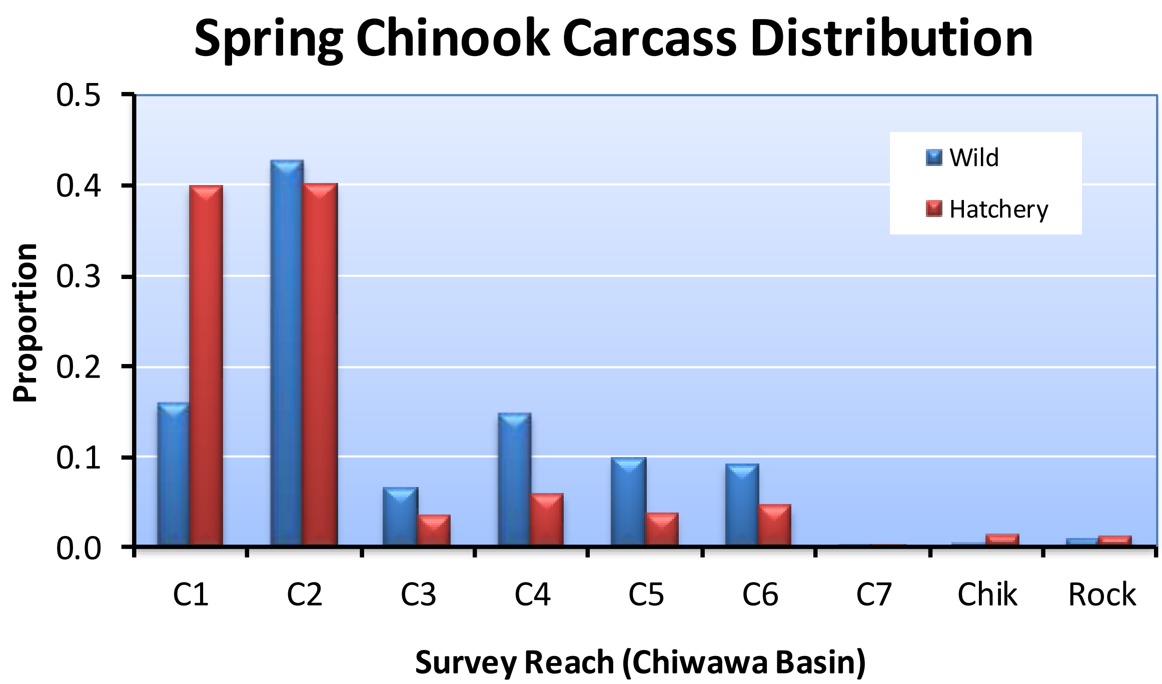

Figure 5.12. Distribution of wild and hatchery produced carcasses in different reaches in the Chiwawa River basin, 1993-2016; Chik = Chikamin Creek and Rock = Rock Creek. Reach codes are described in Table 2.8.

Sampling Rate

Overall, 36% of the estimated total spawning escapement of spring Chinook in the Wenatchee River basin was sampled in 2016 (Table 5.30). Sampling rates among streams/watershed varied from 0 to 61%.

Table 5.30. Number of redds and carcasses, total spawning escapement, and sampling rates for spring Chinook salmon in the Wenatchee River basin, 2016.

Sampling area	Total number of observed redds	Total number of carcasses	Total spawning escapement	Sampling rate
Chiwawa	312	211	571	0.37
Nason	85	95	156	0.61
Upper Wenatchee	17	13	31	0.42
Icicle	72	25	130	0.19
Little Wenatchee	22	5	40	0.13
White	44	13	81	0.16
Peshastin	2	0	4	0.00
Total	***554***	***362***	***1,012***	***0.36***

Length Data

Mean lengths (POH, cm) of male and female spring Chinook carcasses sampled during surveys in the Wenatchee River basin in 2016 are provided in Table 5.31. The average size of males and females sampled in the Wenatchee River basin was 63 cm.

Table 5.31. Mean lengths (postorbital-to-hypural length; cm) and standard deviations (in parentheses) of male and female spring Chinook carcasses sampled in different streams/watersheds in the Wenatchee River basin, 2016.

Stream/watershed	Mean lengths (cm)	
	Male	Female
Chiwawa	64 (12.0)	65 (6.5)
Nason	59 (10.1)	64 (6.2)
Upper Wenatchee	63 (13.2)	63 (6.8)
Icicle	61 (11.4)	60 (4.2)
Little Wenatchee	82 (4.2)	64 (5.7)
White	69 (4.0)	66 (6.2)
Peshastin	--	--
Total	***62 (11.5)***	***64 (6.3)***

5.7 Life History Monitoring

Life history characteristics of spring Chinook were assessed by examining carcasses on spawning grounds and fish collected at broodstock collection sites, and by reviewing tagging data and fisheries statistics.

Migration Timing

In 2016, there was a small difference in migration timing of hatchery and wild spring Chinook past Tumwater Dam (Table 5.32a and b; Figure 5.13). Hatchery fish arrived at the dam later than did wild fish, but ended their migration earlier than did wild fish. This same pattern was also observed in the overall average. Most hatchery and wild spring Chinook migrated upstream past Tumwater Dam during June and July (Figure 5.13).

Table 5.32a. The Julian day and date that 10%, 50% (median), and 90% of the wild and hatchery spring Chinook salmon passed Tumwater Dam, 1998-2016. The average Julian day and date are also provided. Migration timing is based on video sampling at Tumwater. Data for 1998 through 2003 were based on videotapes and broodstock trapping and may not reflect the actual number of hatchery spring Chinook. All spring Chinook were visually examined during trapping from 2004 to present.

Survey year	Origin	Spring Chinook Migration Time (days)								Sample size
		10 Percentile		50 Percentile		90 Percentile		Mean		
		Julian	Date	Julian	Date	Julian	Date	Julian	Date	
1998	Wild	156	5-Jun	156	5-Jun	156	5-Jun	156	5-Jun	49
	Hatchery	156	5-Jun	156	5-Jun	156	5-Jun	156	5-Jun	25
1999	Wild	192	11-Jul	207	26-Jul	224	12-Aug	207	26-Jul	173
	Hatchery	200	19-Jul	211	30-Jul	229	17-Aug	213	1-Aug	25
2000	Wild	171	19-Jun	186	4-Jul	194	12-Jul	184	2-Jul	651

Survey year	Origin	Spring Chinook Migration Time (days)								Sample size
		10 Percentile		50 Percentile		90 Percentile		Mean		
		Julian	Date	Julian	Date	Julian	Date	Julian	Date	
	Hatchery	179	27-Jun	189	7-Jul	201	19-Jul	190	8-Jul	357
2001	Wild	154	3-Jun	166	15-Jun	185	4-Jul	167	16-Jun	2,073
	Hatchery	157	6-Jun	169	18-Jun	185	4-Jul	170	19-Jun	4,244
2002	Wild	174	23-Jun	189	8-Jul	204	23-Jul	189	8-Jul	1,033
	Hatchery	178	27-Jun	189	8-Jul	199	18-Jul	189	8-Jul	1,363
2003	Wild	162	11-Jun	181	30-Jun	200	19-Jul	181	30-Jun	919
	Hatchery	157	6-Jun	179	28-Jun	192	11-Jul	178	27-Jun	423
2004	Wild	156	4-Jun	172	20-Jun	189	7-Jul	172	20-Jun	969
	Hatchery	161	9-Jun	177	25-Jun	189	7-Jul	177	25-Jun	1,295
2005	Wild	153	2-Jun	172	21-Jun	193	12-Jul	173	22-Jun	1,038
	Hatchery	153	2-Jun	173	22-Jun	187	6-Jul	172	21-Jun	2,808
2006	Wild	177	26-Jun	184	3-Jul	193	12-Jul	185	4-Jul	577
	Hatchery	178	27-Jun	185	4-Jul	194	13-Jul	186	5-Jul	1601
2007	Wild	169	18-Jun	185	4-Jul	203	22-Jul	185	4-Jul	351
	Hatchery	174	23-Jun	192	11-Jul	209	28-Jul	192	11-Jul	3,232
2008	Wild	173	21-Jun	188	6-Jul	209	27-Jul	189	7-Jul	634
	Hatchery	177	25-Jun	193	11-Jul	210	28-Jul	193	11-Jul	5,368
2009	Wild	174	23-Jun	186	5-Jul	201	20-Jul	187	6-Jul	1,008
	Hatchery	175	24-Jun	187	6-Jul	202	21-Jul	188	7-Jul	4,106
2010	Wild	173	22-Jun	190	9-Jul	214	2-Aug	191	10-Jul	977
	Hatchery	180	29-Jun	194	13-Jul	213	1-Aug	195	14-Jul	4,450
2011	Wild	183	2-Jul	198	17-Jul	213	1-Aug	198	17-Jul	1,433
	Hatchery	187	6-Jul	200	19-Jul	210	29-Jul	199	18-Jul	4,707
2012	Wild	180	28-Jun	191	9-Jul	205	23-Jul	192	10-Jul	1,482
	Hatchery	182	30-Jun	194	12-Jul	206	24-Jul	194	12-Jul	4,449
2013	Wild	163	12-Jun	182	1-Jul	199	18-Jul	183	2-Jul	1,106
	Hatchery	164	13-Jun	181	30-Jun	195	14-Jul	181	30-Jun	3,681
2014	Wild	171	20-Jun	188	7-Jul	202	21-Jul	187	6-Jul	1,329
	Hatchery	167	16-Jun	182	1-Jul	195	14-Jul	181	30-Jun	2,510
2015	Wild	150	30-May	170	19-Jun	184	3-Jul	170	19-Jun	1,370
	Hatchery	148	28-May	168	17-Jun	180	29-Jun	167	16-Jun	1,773
2016	Wild	158	6-Jun	180	28-Jun	200	18-Jul	181	29-Jun	1,252
	Hatchery	160	8-Jun	179	27-Jun	191	9-Jul	178	26-Jun	1,284
Average	Wild	***168***		***183***		***198***		***183***		***970***
	Hatchery	***170***		***184***		***197***		***184***		***2,511***
Median	Wild	***171***		***185***		***200***		***185***		***1,008***
	Hatchery	***174***		***185***		***195***		***186***		***2,510***

Table 5.32b. The week that 10%, 50% (median), and 90% of the wild and hatchery spring Chinook salmon passed Tumwater Dam, 1998-2016. The average week is also provided. Migration timing is based on video sampling at Tumwater. Data for 1998 through 2003 were based on videotapes and broodstock trapping and may not reflect the actual number of hatchery spring Chinook. All spring Chinook were visually examined during trapping from 2004 to present.

Survey year	Origin	Spring Chinook Migration Time (week)				Sample size
		10 Percentile	50 Percentile	90 Percentile	Mean	
1998	Wild	23	23	23	23	49
	Hatchery	23	23	23	23	25
1999	Wild	28	30	32	30	173
	Hatchery	29	31	34	31	25
2000	Wild	24	27	27	27	651
	Hatchery	26	27	29	28	357
2001	Wild	22	24	27	24	2,073
	Hatchery	23	25	27	25	4,244
2002	Wild	25	27	30	27	1,033
	Hatchery	26	27	29	27	1,363
2003	Wild	24	26	29	26	919
	Hatchery	23	26	28	26	423
2004	Wild	23	25	27	25	969
	Hatchery	23	26	27	26	1,295
2005	Wild	22	25	28	25	1,038
	Hatchery	22	25	27	25	2,808
2006	Wild	26	27	28	27	577
	Hatchery	26	27	28	27	1,601
2007	Wild	25	27	29	27	351
	Hatchery	25	28	30	28	3,232
2008	Wild	25	27	30	27	634
	Hatchery	26	28	30	28	5,368
2009	Wild	25	27	29	27	1,008
	Hatchery	25	27	29	27	4,106
2010	Wild	25	28	31	28	977
	Hatchery	26	28	31	28	4,450
2011	Wild	27	29	31	29	1,433
	Hatchery	27	29	30	29	4,707
2012	Wild	26	28	30	28	1,482
	Hatchery	26	28	30	28	4,449
2013	Wild	24	26	29	27	1,106
	Hatchery	24	26	28	26	3,681
2014	Wild	25	27	29	27	1,329
	Hatchery	24	26	28	26	2,510

Survey year	Origin	Spring Chinook Migration Time (week)				Sample size
		10 Percentile	50 Percentile	90 Percentile	Mean	
2015	Wild	22	25	27	25	1,370
	Hatchery	22	24	26	24	1,773
2016	Wild	23	26	29	26	1,252
	Hatchery	23	26	28	26	1,284
Average	Wild	***24***	***27***	***29***	***27***	***970***
	Hatchery	***25***	***27***	***29***	***27***	***2,511***
Median	Wild	***25***	***27***	***29***	***27***	***1,008***
	Hatchery	***25***	***27***	***28***	***27***	***2,510***

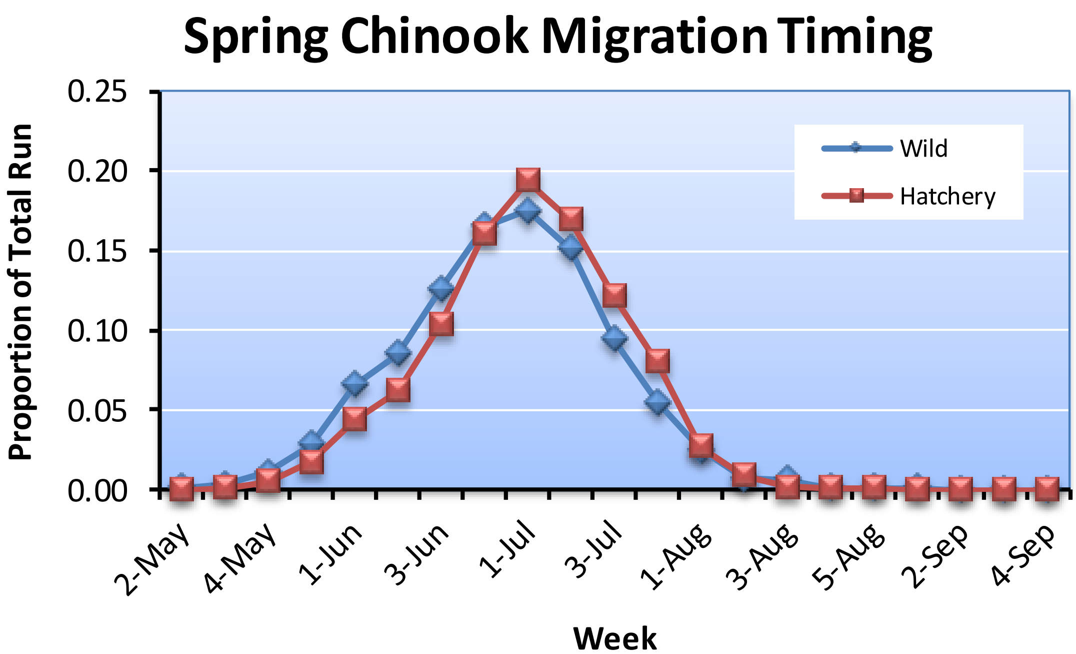

Figure 5.13. Proportion of wild and hatchery spring Chinook observed (using video) passing Tumwater Dam each week during their migration period May through September; data were pooled over survey years 1998-2016.

Age at Maturity

Most of the wild and hatchery spring Chinook sampled during the period 1994-2016 in the Chiwawa River basin were age-4 fish (total age) (Table 5.33; Figure 5.14). On average, hatchery fish made up a higher percentage of age-3 Chinook than did wild fish. In contrast, a higher proportion of age-5 wild fish returned than did age-5 hatchery fish. Thus, wild fish tended to return at an older age than hatchery fish.

Table 5.33. Proportions of wild and hatchery spring Chinook of different ages (total age) sampled on spawning grounds in the Chiwawa River basin, 1994-2016.

Sample year	Origin	Total age					Sample size
		2	3	4	5	6	
1994	Wild	0.00	0.00	0.33	0.67	0.00	9
	Hatchery	0.00	0.20	0.00	0.80	0.00	5
1995	Wild	0.00	0.00	0.00	0.00	0.00	0
	Hatchery	0.00	0.00	1.00	0.00	0.00	5
1996	Wild	0.00	0.36	0.64	0.00	0.00	14
	Hatchery	0.00	0.83	0.17	0.00	0.00	6
1997	Wild	0.00	0.00	0.75	0.25	0.00	8
	Hatchery	0.00	0.00	1.00	0.00	0.00	9
1998	Wild	0.00	0.00	0.00	1.00	0.00	15
	Hatchery	0.00	0.00	0.13	0.88	0.00	8
1999	Wild	0.00	0.07	0.50	0.43	0.00	14
	Hatchery	0.00	0.00	0.00	1.00	0.00	1
2000	Wild	0.00	0.02	0.95	0.04	0.00	56
	Hatchery	0.00	0.50	0.50	0.00	0.00	52
2001	Wild	0.00	0.01	0.95	0.04	0.00	176
	Hatchery	0.00	0.02	0.98	0.00	0.00	571
2002	Wild	0.00	0.00	0.56	0.44	0.00	54
	Hatchery	0.00	0.00	0.91	0.09	0.00	129
2003	Wild	0.00	0.08	0.00	0.92	0.00	36
	Hatchery	0.00	0.19	0.03	0.78	0.00	32
2004	Wild	0.00	0.05	0.94	0.01	0.00	99
	Hatchery	0.00	0.42	0.58	0.00	0.00	78
2005	Wild	0.00	0.02	0.78	0.21	0.00	67
	Hatchery	0.00	0.04	0.96	0.00	0.00	324
2006	Wild	0.02	0.02	0.51	0.44	0.00	45
	Hatchery	0.01	0.04	0.78	0.18	0.00	196
2007	Wild	0.00	0.10	0.24	0.67	0.00	29
	Hatchery	0.00	0.35	0.59	0.06	0.00	221
2008	Wild	0.02	0.02	0.81	0.14	0.00	43
	Hatchery	0.00	0.07	0.89	0.05	0.00	340
2009	Wild	0.00	0.09	0.86	0.05	0.00	44
	Hatchery	0.00	0.24	0.75	0.02	0.00	196
2010	Wild	0.00	0.00	0.90	0.10	0.00	63
	Hatchery	0.00	0.07	0.91	0.02	0.00	127
2011	Wild	0.00	0.08	0.38	0.54	0.00	65
	Hatchery	0.00	0.26	0.45	0.30	0.00	112

Sample year	Origin	Total age					Sample size
		2	3	4	5	6	
2012	Wild	0.00	0.01	0.80	0.19	0.00	141
	Hatchery	0.00	0.03	0.96	0.02	0.00	243
2013	Wild	0.00	0.09	0.60	0.31	0.00	105
	Hatchery	0.00	0.13	0.78	0.09	0.00	275
2014	Wild	0.00	0.04	0.89	0.07	0.00	169
	Hatchery	0.00	0.08	0.90	0.02	0.00	148
2015	Wild	0.00	0.01	0.83	0.16	0.00	96
	Hatchery	0.00	0.06	0.93	0.01	0.00	185
2016	Wild	0.00	0.04	0.67	0.29	0.00	138
	Hatchery	0.00	0.04	0.80	0.16	0.00	71
Average	***Wild***	***0.00***	***0.04***	***0.74***	***0.22***	***0.00***	***65***
	Hatchery	***0.00***	***0.11***	***0.83***	***0.06***	***0.00***	***145***
Median	***Wild***	***0.00***	***0.03***	***0.73***	***0.25***	***0.00***	***54***
	Hatchery	***0.00***	***0.07***	***0.90***	***0.03***	***0.00***	***127***

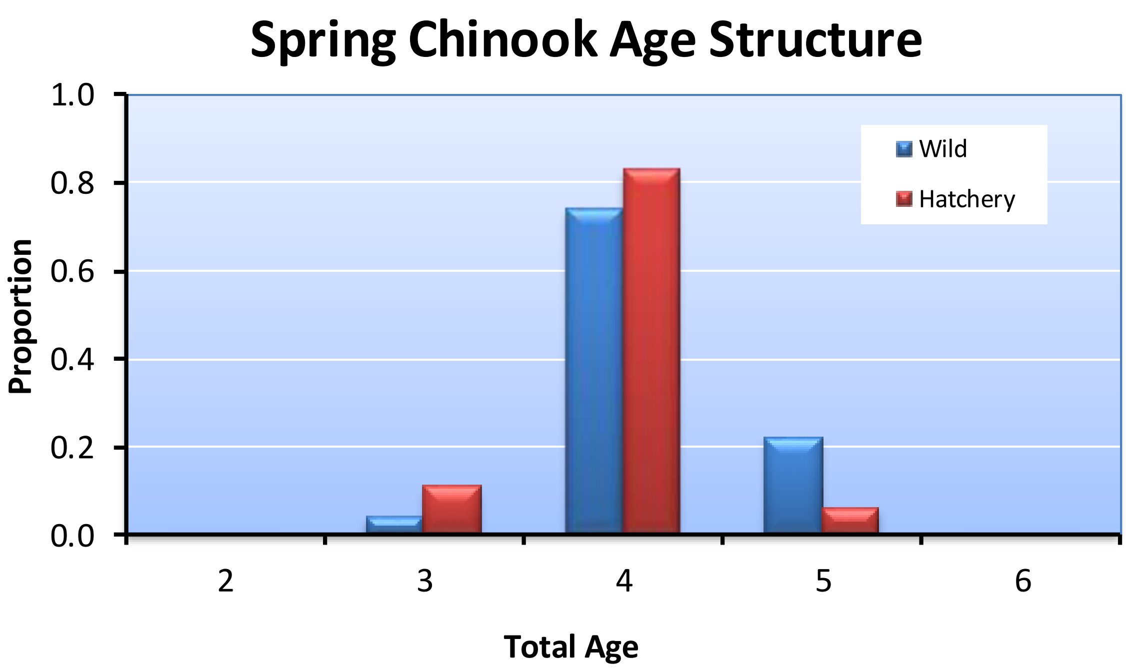

Figure 5.14. Proportions of wild and hatchery spring Chinook of different total ages sampled at the Chiwawa Weir and on spawning grounds in the Chiwawa River basin for the combined years 1994-2016.

Size at Maturity

On average, hatchery and wild spring Chinook of a given age differed slightly in length (Table 5.34). Differences were usually no more than 4 cm between hatchery and wild fish of the same age.

Table 5.34. Mean lengths (POH in cm; ±1SD) and sample sizes (in parentheses) of different ages (total age) of male and female spring Chinook of wild and hatchery-origin sampled in the Chiwawa River basin, 1994-2016. Return years 2004-2016 include carcasses and live fish PIT-tag detections. In addition, 2005 and 2006 include fish released at the weir.

Return year	Total age	Mean length (cm)			
		Male		Female	
		Wild	Hatchery	Wild	Hatchery
1994	3				43 ±0 (1)
	4			62 ±3 (3)	
	5	76 ±0 (1)		73 ±2 (5)	
	6				
1995	3				
	4		61 ±5 (5)		
	5				
	6				
1996	3	45 ±3 (5)	49 ±7 (10)		
	4	69 ±4 (6)	69 ±0 (1)	67 ±8 (2)	
	5				
	6				
1997	3				
	4	61 ±1 (2)	68 ±0 (1)	67 ±5 (3)	63 ±3 (8)
	5	67 ±5 (2)			
	6				
1998	3				
	4				54 ±0 (1)
	5	77 ±7 (8)	75 ±4 (4)	74 ±4 (7)	76 ±4 (3)
	6				
1999	3	44 ±0 (1)			
	4	61 ±0 (1)		64 ±3 (6)	
	5	76 ±5 (3)		72 ±5 (3)	66 ±0 (1)
	6				
2000	3		46 ±3 (17)		50 ±7 (3)
	4	60 ±8 (23)	62 ±5 (5)	61 ±5 (26)	62 ±3 (20)
	5	77 ±1 (2)			
	6				
2001	3	37 ±0 (1)	42 ±4 (11)	41 ±0 (1)	60 ±0 (1)
	4	63 ±5 (57)	65 ±5 (151)	62 ±4 (110)	63 ±4 (407)
	5	75 ±5 (2)	83 ±0 (1)	76 ±1 (5)	
	6				
2002	3				
	4	64 ±4 (14)	66 ±5 (46)	60 ±4 (15)	63 ±4 (71)
	5	80 ±6 (13)	75 ±5 (4)	72 ±3 (12)	73 ±6 (6)
	6				
2003	3	45 ±2 (3)	45 ±1 (6)		

Return year	Total age	Mean length (cm)			
		Male		Female	
		Wild	Hatchery	Wild	Hatchery
	4		63 ±0 (1)		
	5	78 ±5 (12)	74 ±8 (11)	75 ±3 (19)	72 ±5 (14)
	6				
2004	3	42 ±3 (3)	44 ±5 (33)		
	4	63 ±7 (60)	66 ±5 (9)	63 ±4 (59)	63 ±6 (36)
	5			74 ±0 (1)	
	6				
2005	3		43 ±5 (48)		
	4	61 ±5 (32)	65 ±5 (224)	62 ±4 (61)	62 ±4 (382)
	5	74 ±5 (6)	54±0 (1)	71 ±3 (11)	
	6				
2006	3	45 ±3 (3)	43 ±3 (73)		
	4	64 ±3 (7)	62 ±6 (91)	63 ±5 (41)	60 ±4 (227)
	5	74 ±6 (8)	75 ±6 (17)	71 ±4 (26)	71± 4 (37)
	6				
2007	3	39 ±3 (5)	45 ±6 (90)		50 ±3 (7)
	4	60 ±4 (4)	66 ±5 (45)	61 ±4 (10)	63 ±3 (142)
	5	78 ±6 (15)	76 ±5 (8)	74 ±3 (20)	73 ±5 (12)
	6				
2008	3	43 ±0 (1)	44 ±5 (22)		
	4	65 ±4 (9)	64 ±6 (73)	62 ±4 (26)	64 ±4 (229)
	5	65 ±5 (3)	79 ±5 (10)	73 ±3 (4)	72 ±3 (5)
	6				
2009	3	45 ±3 (8)	46 ±6 (68)		65 ±0 (1)
	4	64 ±4 (38)	65 ±5 (136)	63 ±3 (67)	64 ±4 (202)
	5	79 ±0 (1)		72 ±2 (4)	71 ±4 (10)
	6				
2010	3		46 ±4 (11)		65 ±3 (3)
	4	64 ±5 (31)	66 ±5 (74)	64 ±4 (82)	65 ±3 (196)
	5	77 ±4 (6)		73 ±5 (9)	73 ±6 (4)
	6				
2011	3	43 ±4 (133)	44 ±4 (1374)		53 ±4 (17)
	4	62 ±5 (137)	64 ±5 (169)	64 ±3 (94)	64 ±3 (258)
	5	80 ±5 (78)	79 ±4 (85)	75 ±3 (116)	75 ±3 (63)
	6				
2012	3	56 ±0 (1)	52 ±7 (7)		
	4	79 ± 6 (37)	80 ±6 (49)	79 ±3 (76)	78 ±4 (180)
	5	97 ±7 (11)	96 ±3 (4)	93 ±4 (16)	87 ±0 (1)
	6				
2013	3	45 ±4 (8)	43 ±4 (32)	35 ±0 (1)	49 ±12 (3)
	4	60 ±6 (29)	63 ±7 (41)	61 ±6 (34)	61 ±4 (171)

Return year	Total age	Mean length (cm)			
		Male		Female	
		Wild	Hatchery	Wild	Hatchery
	5	75 ±5 (9)	71 ±2 (7)	71 ±3 (24)	69 ±4 (18)
	6				
2014	3	45 ±7 (5)	45±4 (11)	50±0 (1)	47±0 (1)
	4	64 ±7 (60)	62 ±7 (30)	63 ±4 (91)	61 ±4 (99)
	5	81 ±4 (4)		72 ±6 (8)	69 ±4 (3)
	6				
2015	3	56±0 (1)	48±4 (11)		52±0 (1)
	4	65±5 (23)	65±6 (42)	63±5 (57)	63±4 (126)
	5	75±7 (6)	71±0 (1)	69±6 (9)	73±0 (1)
	6				
2016	3	41±5 (5)	43±4 (3)		
	4	63±7 (30)	64±7 (12)	63±5 (62)	61±5 (45)
	5	76±7 (13)	75±0 (1)	73±5 (27)	67±4 (10)
	6				

Contribution to Fisheries

Nearly all the harvest on hatchery-origin Chiwawa spring Chinook occurs within the Columbia River basin. Ocean catch records (Pacific Fishery Management Council) indicate that very few Upper Columbia spring Chinook are taken in ocean fisheries. Most of the harvest on hatchery-origin Chiwawa spring Chinook occurs in the Lower Columbia River fisheries, which are managed by the states and tribes pursuant to management plans developed in *U.S. v Oregon*. The Lower Columbia River fisheries occur during what is referred to in *U.S. v Oregon* as the winter, spring, and summer seasons, which begin in February and ends 31 July of each year. The Tribal fishery occurs upstream from Bonneville Dam, but primarily in Zone 6, the area between Bonneville and McNary dams; the non-treaty commercial fisheries occur in Zones 1-5, which are downstream from Bonneville Dam. The non-treaty recreational (sport) fishery occurs in the lower mainstem.

The total number of hatchery-origin spring Chinook captured in different fisheries has been relatively low (Table 5.35). The largest harvest occurred on the 2008 brood year.

Table 5.35. Estimated number and percent (in parentheses) of hatchery-origin Chiwawa spring Chinook captured in different fisheries, brood years 1989-2011; NP = no hatchery program.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational[a] (sport)	
1989	3 (13)	5 (21)	0 (0)	16 (67)	24
1990	0 (0)	0 (0)	0 (0)	18 (100)	18
1991	0 (0)	3 (100)	0 (0)	0 (0)	3
1992	0 (0)	1 (100)	0 (0)	0 (0)	1
1993	3 (75)	1 (25)	0 (0)	0 (0)	4
1994	0 (0)	0 (0)	0 (0)	0 (0)	0

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational[a] (sport)	
1995	NP	NP	NP	NP	NP
1996	0 (0)	2 (100)	0 (0)	0 (0)	2
1997	1 (0)	193 (51)	68 (18)	115 (31)	377
1998	10 (5)	47 (24)	12 (6)	126 (65)	195
1999	NP	NP	NP	NP	NP
2000	0 (0)	17 (74)	0 (0)	6 (26)	23
2001	36 (64)	8 (14)	1 (2)	11 (20)	56
2002	12 (17)	11 (15)	22 (31)	26 (37)	71
2003	18 (21)	29 (35)	11 (13)	26 (31)	84
2004	3 (1)	188 (40)	31 (7)	253 (53)	475
2005	6 (5)	31 (24)	18 (14)	74 (57)	129
2006	25 (3)	469 (60)	84 (11)	201 (26)	779
2007	14 (3)	180 (43)	75 (18)	151 (36)	420
2008	8 (1)	298 (21)	41 (3)	1,047 (75)	1,394
2009	6 (2)	85 (22)	73 (19)	228 (58)	392
2010	0 (0)	372 (57)	45 (7)	236 (28)	653
2011	3 (0)	393 (53)	138 (19)	206 (28)	740
Average	***7 (10)***	***111 (42)***	***29 (8)***	***130 (35)***	***278***
Median	***3 (1)***	***29 (35)***	***12 (6)***	***26 (31)***	***84***

[a] Includes the Wanapum fishery and the Icicle and Wenatchee fisheries when they occurred.

Straying

Stray rates were determined by examining CWTs recovered on spawning grounds within and outside the Wenatchee River basin. Targets for strays based on return year (recovery year) within the Wenatchee River basin should be less than 10% and targets for strays outside the Wenatchee River basin should be less than 5%. The target for brood year stray rates should be less than 5%.

The percentage of the spawning escapement made up of hatchery-origin Chiwawa spring Chinook in non-target spawning areas within the Wenatchee River basin has been high in some years and exceeded the target of 10% (Table 5.36). Over the years of sampling, Chiwawa spring Chinook have strayed into all non-target spawning areas, but, on average, have contributed most to the Nason Creek and Upper Wenatchee spawning escapements.

Table 5.36. Number (No.) and percent (%) of the spawning escapement in other non-target spawning streams within the Wenatchee River basin that consisted of hatchery-origin Chiwawa spring Chinook, return years 1992-2015. For example, for return year 2001, 35.3% of the spring Chinook spawning escapement in Nason Creek consisted of hatchery-origin Chiwawa spring Chinook. Percent strays should be less than 10%.

Return year	Nason Creek		Icicle Creek		Peshastin Creek		Upper Wenatchee		White River		Little Wenatchee	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1992	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1993	61	12.4	0	0.0	0	0.0	34	18.0	7	4.8	0	0.0
1994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1995	0	0.0	0	0.0	0	0.0	2	66.7	0	0.0	0	0.0
1996	25	30.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1997	55	45.1	8	11.0	0	0.0	0	0.0	0	0.0	0	0.0
1998	3	4.7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2000	45	16.7	0	0.0	0	0.0	31	31.0	0	0.0	6	25.0
2001	211	35.3	0	0.0	0	0.0	271	77.7	46	27.7	52	44.1
2002	188	31.2	10	2.6	0	0.0	60	45.8	14	16.3	21	24.4
2003	14	6.9	0	0.0	0	0.0	30	51.7	0	0.0	0	0.0
2004	139	27.4	0	0.0	0	0.0	54	39.1	6	9.1	0	0.0
2005	252	72.6	7	53.8	0	0.0	256	99.6	106	68.4	65	56.5
2006	131	48.3	13	15.5	0	0.0	28	58.3	9	16.4	12	32.4
2007	303	65.4	0	0.0	0	0.0	37	67.3	7	7.6	6	5.9
2008	381	67.4	48	23.3	29	78.4	258	85.4	30	57.7	52	81.3
2009	289	54.1	8	11.3	0	0.0	16	100.0	63	36.4	56	44.8
2010	272	66.3	58	24.0	11	100.0	86	84.3	23	31.9	59	71.1
2011	397	56.6	61	19.2	0	0.0	41	82.0	0	0.0	53	42.7
2012	398	57.3	49	15.4	7	43.8	98	79.7	45	31.3	15	20.8
2013	281	68.7	15	7.1	0	0.0	24	72.7	5	4.8	10	10.2
2014	204	86.1	19	4.7	0	0.0	41	87.2	0	0.0	1	1.9
2015	11	7.3	12	4.9	0	0.0	50	51.0	8	6.4	0	0.0
Average	***153***	***35.8***	***13***	***8.0***	***2***	***9.3***	***59***	***49.9***	***15***	***13.3***	***17***	***19.2***
Median	***135***	***33.3***	***4***	***1.3***	***0***	***0.0***	***33***	***55.0***	***6***	***4.8***	***4***	***3.9***

Hatchery-origin Chiwawa spring Chinook have strayed into the Methow and Entiat basins (Table 5.37). Based on return year analyses, rates of hatchery-origin Chiwawa spring Chinook straying into these populations have been low in most years; in 2015, Chiwawa spring Chinook made up 4.7% of the spawning escapement in the Entiat River and 0.5% in the Methow River. However, during return years 2002, 2006, 2008-2009, and 2011-2013, Chiwawa spring Chinook made up more than 5% of the spawning escapement in the Entiat River basin. In three years, Chiwawa spring Chinook hatchery fish made up more than 20% of the spawning escapement in the Entiat River basin; however, in return year 2014, no strays were detected in the Entiat or Methow River basins.

Table 5.37. Number and percent of spawning escapements within other non-target basins that consisted of hatchery-origin Chiwawa spring Chinook, return years 1992-2015. For example, for return year 2002, 9.2% of the spring Chinook spawning escapement in the Entiat River basin consisted of hatchery-origin Chiwawa spring Chinook. Percent strays should be less than 5%. NS = not sampled.

Return year	Methow River basin		Entiat River basin	
	Number	%	Number	%
1992	0	0.0	0	0.0
1993	0	0.0	0	0.0
1994	0	0.0	0	0.0
1995	0	0.0	0	0.0
1996	NS	NS	0	0.0
1997	0	0.0	0	0.0
1998	NS	NS	0	0.0
1999	0	0.0	0	0.0
2000	0	0.0	1	0.6
2001	0	0.0	1	0.2
2002	0	0.0	34	9.2
2003	0	0.0	6	2.3
2004	0	0.0	0	0.0
2005	10	0.7	15	4.2
2006	8	0.5	30	9.3
2007	9	0.8	24	1.6
2008	12	1.2	61	21.9
2009	7	0.3	15	5.4
2010	10	0.4	18	3.7
2011	51	1.7	190	31.9
2012	13	1.0	133	23.5
2013	9	0.8	24	10.1
2014	0	0.0	0	0.0
2015	7	0.5	24	4.7
Average	***6***	***0.4***	***24***	***5.4***
Median	***0***	***0.0***	***4***	***1.1***

Based on brood year analyses, on average, about 30% of the hatchery returns have strayed into non-target spawning areas, exceeding the target of 5% (Table 5.38). Depending on brood year, percent strays into non-target spawning areas have ranged from 0-81%. In most years, few (<1%) have strayed into non-target hatchery programs.

Table 5.38. Number and percent of hatchery-origin Chiwawa spring Chinook that homed to target spawning areas and the target hatchery program, and number and percent that strayed to non-target spawning areas and non-target hatchery programs, by brood years 1989-2011. Percent strays should be less than 5%.

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1989	74	41.1	1	0.6	102	56.7	3	1.7
1990	0	0.0	1	100.0	0	0.0	0	0.0
1991	29	90.6	0	0.0	2	6.3	1	3.1
1992	2	6.5	4	12.9	25	80.6	0	0.0
1993	134	47.5	82	29.1	63	22.3	3	1.1
1994	4	19.0	14	66.7	3	14.3	0	0.0
1995	No program							
1996	58	75.3	7	9.1	12	15.6	0	0.0
1997	1,242	55.6	298	13.4	687	30.8	5	0.2
1998	553	55.8	109	11.0	329	33.2	0	0.0
1999	No program							
2000	149	42.1	115	32.5	90	25.4	0	0.0
2001	647	35.8	276	15.3	881	48.7	4	0.2
2002	314	44.3	238	33.6	156	22	1	0.1
2003	556	78.6	11	1.6	133	18.8	7	1.0
2004	1,198	47.4	203	8.0	1,104	43.7	23	0.9
2005	822	59.3	139	10.0	415	29.9	10	0.7
2006	1,007	54.8	147	8.0	669	36.4	14	0.8
2007	510	57.8	60	6.8	294	33.3	19	2.2
2008	1,160	47.1	62	2.5	1,144	46.4	99	4.0
2009	746	63.1	53	4.5	356	30.1	27	2.3
2010	799	54.5	366	25.0	275	18.8	25	1.7
2011	560	57.7	258	26.6	150	15.5	2	0.2
Average	***503***	***49.2***	***116***	***19.9***	***328***	***29.9***	***12***	***1.0***
Median	***553***	***54.5***	***82***	***11.0***	***156***	***29.9***	***3***	***0.7***

* Homing to the target hatchery includes Chiwawa hatchery spring Chinook that are captured and included as broodstock in the Chiwawa Hatchery program. These hatchery fish are typically collected at the Chiwawa weir and Tumwater Dam.

Ford et al. (2015) used parentage analysis to estimate rates of straying and homing of spring Chinook within the Wenatchee River basin. They found that stray rates of hatchery spring Chinook based on parentage analysis were consistent with rates estimated using physical tag recoveries (the latter estimates are shown in the tables above). They also found that stray rates among the major spawning tributaries were higher than stray rates of tagged fish to areas outside of the Wenatchee River basin (e.g., Entiat and Methow basins), which is consistent with the results shown in the tables above. Finally, the researchers noted that hatchery spring Chinook homed at a far lower rate than natural-origin fish and stray rates of natural-origin fish ranged from about 0-100%. Rates of straying of natural-origin spring Chinook were affected by spawning tributary and by parental origin (i.e., progeny of naturally spawning hatchery-produced fish strayed at higher rates than progeny whose parents were of natural origin).

Genetics

Genetic studies were conducted in 2007 to determine the potential effects of the Chiwawa Supplementation Program on natural-origin spring Chinook in the upper Wenatchee River basin (Blankenship et al. 2007; the entire report is appended as Appendix K). A total of 32 population collections of adult spring Chinook were obtained from the Wenatchee River basin between 1989 and 2006. This included nine collections of natural-origin Chinook adults from the Chiwawa River (N = 501) and nine collections of Chiwawa hatchery-origin Chinook (N = 595) at the Chiwawa weir. Collections in 1993 and 1994 included hatchery-origin smolts. Additional samples were collected from the White River, Little Wenatchee River, and Nason Creek; six collections of natural-origin Chinook from the White River (N = 179), one collection from the Little Wenatchee (N = 19), and six collections from Nason Creek (N = 268). A single collection was obtained for Chinook spawning in the mainstem Wenatchee River and from the Leavenworth National Fish Hatchery. Finally, an out-of-basin collection from the Entiat River was included in the analysis. Scale, fin clips, or operculum punches were collected from each sample. Microsatellite DNA allele frequencies were used to statistically assign individual fish to specific demes (locations) within the Wenatchee population. In addition, genetic effects of the hatchery program were assessed by examining relationships between census and effective population sizes (N_e) from samples collected before and after supplementation.

Overall, this work showed that although allele frequencies within and between natural and hatchery-origin spring Chinook were significantly different, there was no evidence (i.e., robust signal) that the difference was the result of the hatchery program. Rather, the differences were more likely the result of life history characteristics. However, there was an increasing trend toward homogenization of the allele frequencies of the natural and hatchery-origin fish that comprised the broodstock, even though there was consistent year-to-year variation in allele frequencies among hatchery and natural-origin fish. In addition, there were no robust signals indicating that hatchery-origin hatchery broodstock, hatchery-origin natural spawners, natural-origin hatchery broodstock, and natural-origin natural spawners were substantially different from each other. Finally, the N_e estimate of 387 was only slightly larger than the pre-hatchery N_e (based on demographic data from 1989-1992), which means that the Chiwawa hatchery program has not reduced the N_e of the Wenatchee spring Chinook population.

Significant differences in allele frequencies were observed within and among major spawning areas in the Upper Wenatchee River basin. However, these differences made up only a very small portion of the overall variation, indicating genetic similarity among the major spawning areas. There was no evidence that the Chiwawa program has changed the genetic structure (allele frequency) of spring Chinook in Nason Creek and the White River, despite the presence of hatchery-origin spawners in both systems.

It is important to note that no new information will be reported on genetics until the next five-year report (2018).

Proportionate Natural Influence

Another method for assessing the genetic risk of a supplementation program is to determine the influence of the hatchery and natural environments on the adaptation of the composite population. This is estimated by the proportion of natural-origin fish in the hatchery broodstock (pNOB) and the proportion of hatchery-origin fish in the natural spawning escapement (pHOS). We calculated Proportionate Natural Influence (PNI) by iterating Ford's (2002) equations 5 and 6 to equilibrium, using a heritability of 0.3 and a selection strength of three standard deviations.[14] The larger the PNI value, the greater the strength of selection in the natural environment relative to that of the hatchery environment. For the natural environment to dominate selection, PNI should be greater than 0.50, and important integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004).

For brood years 1989-1994, PNI values were greater than or equal to 0.67 (Table 5.39). Since brood year 1994, PNI has been less than 0.67, except for brood year 2016, which was 0.70.

Table 5.39. Proportionate Natural Influence (PNI) values for the Chiwawa spring Chinook supplementation program for brood years 1989-2016. NOS = number of natural-origin Chinook on the spawning grounds; HOS = number of hatchery-origin Chinook on the spawning grounds; NOB = number of natural-origin Chinook collected for broodstock; and HOB = number of hatchery-origin Chinook included in hatchery broodstock.

Brood year	Spawners			Broodstock			PNI[a]
	NOS	HOS	pHOS	NOB	HOB	pNOB	
1989	713	0	0.00	28	0	1.00	1.00
1990	571	0	0.00	18	0	1.00	1.00
1991	242	0	0.00	27	0	1.00	1.00
1992	676	0	0.00	78	0	1.00	1.00
1993	231	2	0.01	94	0	1.00	0.99
1994	123	61	0.33	8	4	0.67	0.68
1995	0	33	1.00	No Program			
1996	41	17	0.29	8	10	0.44	0.62
1997	60	122	0.67	32	79	0.29	0.32
1998	59	32	0.35	13	34	0.28	0.47
1999	87	7	0.07	No Program			
2000	233	113	0.33	9	21	0.30	0.50
2001	506	1219	0.71	113	259	0.30	0.32
2002	254	453	0.64	20	51	0.28	0.33
2003	168	102	0.38	41	53	0.44	0.55
2004	575	276	0.32	83	132	0.39	0.57
2005	139	460	0.77	91	181	0.33	0.32
2006	114	415	0.78	91	224	0.29	0.29

14 According to authorized annual take permits, PNI is calculated using the PNI approximate equation 11 (HSRG 2009; Appendix A). However, in this report, we used Ford's (2002) equations 5 and 6 with a heritability of 0.3 and a selection strength of three standard deviations to calculate PNI (C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI). This approach is more accurate than using the PNI approximate equation.

Brood year	Spawners			Broodstock			PNI[a]
	NOS	HOS	pHOS	NOB	HOB	pNOB	
2007	155	1141	0.88	43	104	0.29	0.27
2008	190	968	0.84	83	220	0.27	0.26
2009	297	1050	0.78	96	111	0.46	0.39
2010	419	675	0.62	77	98	0.44	0.43
2011	801	1231	0.61	80	93	0.46	0.45
2012	574	904	0.61	73	38	0.66	0.53
2013	422	956	0.69	70	0	1.00	0.60
2014	538	461	0.46	61	12	083	0.65
2015	337	630	0.65	72	0	1.00	0.61
2016	407	164	0.29	62	37	0.63	0.70
Average	***319***	***410***	***0.47***	***57***	***74***	***0.55***	***0.56***
Median	***248***	***220***	***0.54***	***66***	***45***	***0.44***	***0.50***

[a] PNI was calculated previously using PNI approximate equation 11 (HSRG 2009; their Appendix A). All PNI values presented here were recalculated by iterating Ford's (2002) equations 5 and 6 to equilibrium using a heritability of 0.3 and a selection strength of three standard deviations. C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI.

Post-Release Survival and Travel Time

We used PIT-tagged fish to estimate survival rates and travel time (arithmetic mean days) of hatchery spring Chinook from the Chiwawa River release site to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam (Table 5.40).[15] Over the ten brood years for which PIT-tagged hatchery fish were released, survival rates from the Chiwawa River to McNary Dam ranged from 0.435 to 0.662; SARs from release to detection at Bonneville Dam ranged from 0.003 to 0.018. Average travel time from the Chiwawa River to McNary Dam ranged from 14 to 44 days. Although there is only one year in which a forced release was compared to a volitional release (brood year 2005), hatchery spring Chinook that were forced out of the Chiwawa Acclimation Facility had slightly higher survival rates and SARs, and a faster travel time to McNary Dam, than did the volitional release.

Table 5.40. Total number of Chiwawa hatchery spring Chinook released with PIT tags, their survival and travel times (mean days) to McNary Dam, and smolt-to-adult (SAR) ratios for brood years 2005-2014. Standard errors are shown in parentheses. NA = not available (i.e., not all the adults from the release groups have returned to the Columbia River).

Brood year	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2005	4,993 (forced)	0.662 (0.027)	22.9 (6.6)	0.008 (0.001)
2005	4,988 (volitional)	0.638 (0.027)	43.6 (6.9)	0.003 (0.001)
2006	9,894	0.619 (0.038)	30.6 (7.6)	0.011 (0.001)
2007	10,031	0.435 (0.019)	32.9 (7.7)	0.007 (0.001)
2008	10,006	0.631 (0.038)	39.9 (10.3)	0.018 (0.001)

[15] It is important to point out that because of fish size differences among rearing tanks or raceways, fish PIT tagged in one tank or raceway may not represent untagged fish rearing in other tanks or raceways.

Brood year	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2009	9,412	0.547 (0.044)	30.2 (6.7)	0.006 (0.001)
2010	5,020	0.548 (0.038)	18.9 (7.3)	0.008 (0.001)
2011	9,987	0.458 (0.029)	14.2 (7.5)	0.009 (0.001)
2012	5,061	0.478 (0.043)	30.9 (6.5)	NA
2013	10,021	0.438 (0.041)	29.5 (5.9)	NA
2014	10,179	0.628 (0.029)	24.9 (6.2)	NA

Natural and Hatchery Replacement Rates

Natural replacement rates (NRR) were calculated as the ratio of natural-origin recruits (NOR) to the parent spawning population (spawning escapement). Natural-origin recruits are naturally produced (wild) fish that survive to contribute to harvest (directly or indirectly), to broodstock, and to spawning grounds. We do not account for fish that died in route to the spawning grounds (migration mortality) or died just before spawning (pre-spawn mortality) (see Appendix B in Hillman et al. 2012). We calculated NORs with and without harvest. NORs without harvest include all returning fish that either returned to the basin or were collected as wild broodstock. NORs with harvest include all fish harvested and are based on a brood year harvest rates from the hatchery program. For brood years 1989-2010, NRR for spring Chinook in the Chiwawa averaged 1.05 (range, 0.01-4.40) if harvested fish were not included in the estimate and 1.16 (range, 0.01-4.81) if harvested fish were included in the estimate (Table 5.41). NRRs for more recent brood years will be calculated as soon as all tag recoveries and sampling rates have been loaded into the database.

Hatchery replacement rates (HRR) are the hatchery adult-to-adult returns and were calculated as the ratio of hatchery-origin recruits (HOR) to the parent broodstock collected. These rates should be greater than the NRRs and greater than or equal to 6.7 (the calculated target value in Hillman et al. 2013). The target value of 6.7 includes harvest. In nearly all years, HRRs were greater than NRRs, regardless if harvest was or was not included (Table 5.41). HRRs exceeded the estimated target value of 6.7 in 9 of the 20 years.

Table 5.41. Broodstock collected, spawning escapements, natural and hatchery-origin recruits (NOR and HOR), and natural and hatchery replacement rates (NRR and HRR; with and without harvest) for spring Chinook in the Chiwawa River basin, brood years 1989-2010; NP = no hatchery program.

Brood year	Broodstock Collected	Spawning Escapement	Harvest not included				Harvest included			
			HOR	NOR	HRR	NRR	HOR	NOR	HRR	NRR
1989	28	713	180	194	6.43	0.27	204	282	7.29	0.40
1990	19	571	1	34	0.05	0.06	19	40	1.00	0.07
1991	32	242	32	2	1.00	0.01	35	2	1.09	0.01
1992	78	676	31	46	0.40	0.07	32	48	0.41	0.07
1993	100	233	282	159	2.82	0.68	286	163	2.86	0.70
1994	13	184	21	37	1.62	0.20	21	38	1.62	0.21
1995	NP	33	--	66	--	2.00	--	69	--	2.09

Brood year	Broodstock Collected	Spawning Escapement	Harvest not included				Harvest included			
			HOR	NOR	HRR	NRR	HOR	NOR	HRR	NRR
1996	18	58	77	255	4.28	4.40	79	279	4.39	4.81
1997	120	182	2,232	714	18.60	3.92	2,609	792	21.74	4.35
1998	48	91	991	349	20.65	3.84	1,186	373	24.71	4.10
1999	NP	94	--	10	--	0.11	--	11	--	0.12
2000	48	346	354	695	7.38	2.01	377	729	7.85	2.11
2001	382	1,725	1,808	309	4.73	0.18	1,864	317	4.88	0.18
2002	84	707	709	244	8.44	0.35	780	254	9.29	0.36
2003	119	270	707	107	5.94	0.40	791	115	6.65	0.43
2004	296	851	2,528	276	8.54	0.32	3,003	298	10.15	0.35
2005	283	599	1,386	396	4.90	0.66	1,515	409	5.35	0.68
2006	398	529	1,837	967	4.62	1.83	2,616	1,215	6.57	2.30
2007	169	1,296	883	478	5.22	0.37	1,303	571	7.71	0.44
2008	329	1,158	2,465	740	7.49	0.64	3,859	830	11.73	0.72
2009	264	1,347	1,182	349	4.48	0.26	1,574	379	5.96	0.28
2010	186	1,094	1,465	633	7.88	0.58	2,118	834	11.39	0.76
Average	***151***	***591***	***959***	***321***	***6.27***	***1.05***	***1,214***	***366***	***7.63***	***1.16***
Median	***110***	***550***	***796***	***266***	***5.06***	***0.38***	***989***	***290***	***6.61***	***0.43***

Smolt-to-Adult Survivals

Smolt-to-adult survival ratios (SARs) were calculated as the number of hatchery adult recaptures divided by the number of tagged hatchery smolts released. Here, SARs were based on CWT returns. For the available brood years, SARs have ranged from 0.00036 to 0.01563 for hatchery spring Chinook (Table 5.42).

Table 5.42. Smolt-to-adult ratios (SARs) for Chiwawa hatchery spring Chinook, brood years 1989-2011.

Brood year	Number of tagged smolts released[a]	Estimated adult captures[b]	SAR
1989	42,707	204	0.00478
1990	52,798	19	0.00036
1991	61,088	35	0.00057
1992	82,976	31	0.00037
1993	221,316	284	0.00128
1994	27,135	21	0.00077
1995	No hatchery program		
1996	12,767	67	0.00525
1997	259,585	2,549	0.00982
1998	71,571	1,119	0.01563
1999	No hatchery program		

Brood year	Number of tagged smolts released[a]	Estimated adult captures[b]	SAR
2000	46,726	375	0.00803
2001	374,129	1,849	0.00494
2002	145,074	760	0.00524
2003	216,702	775	0.00358
2004	491,987	2,992	0.00608
2005	489,664	1,506	0.00308
2006	548,777	2,604	0.00475
2007	292,682	1,301	0.00445
2008	609,286	3,859	0.00633
2009	433,608	1,560	0.00360
2010	342,778	2,104	0.00614
2011	278,801	1,697	0.00609
Average	***242,960***	***1,224***	***0.00482***
Median	***221,316***	***1,119***	***0.00478***

[a] Includes all tag codes and CWT released fish (CWT + Ad Clip fish and CWT-only fish).

[b] Includes estimated recoveries (spawning ground, hatcheries, harvest, etc.) and observed recoveries if estimated recoveries were unavailable.

5.8 ESA/HCP Compliance

Broodstock Collection

The collection of 2014 Brood Chiwawa River spring Chinook broodstock was consistent with the 2014 Upper Columbia River salmon and steelhead broodstock objectives and site-based broodstock collection protocols. Specifically, broodstock collection targeted previously PIT-tagged natural-origin fish at Tumwater Dam and operation of the Chiwawa Weir. In-season adjustments were made to the natural-origin spring Chinook collected for broodstock as needed and were based on in-season escapement monitoring at Tumwater Dam and estimated Chiwawa run-escapement.

Trapping at Tumwater Dam began on 8 June 2014 and concluded on 14 July 2014. Operation of the Chiwawa Weir was limited to 15 days between 1 June and 15 August and was further constrained by flows and total available bull trout effects. Broodstock collection targeted natural-origin spring Chinook and hatchery-origin spring Chinook as needed to attain a 100% natural-origin broodstock and a maximum 33% extraction of the estimated natural-origin return to the Chiwawa River.

The 2014 brood collection retained a total of 61 natural-origin spring Chinook. All spring Chinook, steelhead, and bull trout that were captured were anesthetized with tricaine methanesulfonate (MS-222) and subject to water-to-water transfers during handling. All fish were allowed to fully recover before release.

The estimated broodstock extraction rate of natural-origin Chiwawa spring Chinook and overall extraction of spring Chinook upstream from Tumwater Dam comply with provisions of ESA Permit 18121.

Hatchery Rearing and Release

The rearing and release of 2014 brood Chiwawa spring Chinook was completed without incident. No mortality events occurred that exceeded 10% of the population. Fish were acclimated on Chiwawa River water with regulated amounts of Wenatchee River water to prevent frazzle ice formation during the winter months (see Section 5.2).

The release of 2014 brood Chiwawa spring Chinook smolts totaled 144,360 fish, representing 100% of the program objective of 144,023 smolts and complied with the ESA Section 10 Permit 18121 program not to exceed the level of 158,425 smolts.

Hatchery Effluent Monitoring

Per ESA Permits 1196 (expired), 1347 (expired), 1395 (expired), 18118, 18120, and 18121, permit holders shall monitor and report hatchery effluents in compliance with applicable National Pollution Discharge Elimination Systems (NPDES) (EPA 1999) permit limitations. There were no NPDES violations reported at the Chelan PUD Hatchery facilities during the period 1 January through 31 December 2016. NPDES monitoring and reporting for Chelan PUD Hatchery Programs during 2016 are provided in Appendix F.

Smolt and Emigrant Trapping

Per ESA Section 10 Permit Nos. 18118, 18120, and 18121, the permit holders are authorized a direct take of up to 20% of the emigrating spring Chinook population during juvenile emigration monitoring and a lethal take not to exceed 2% of the fish captured (NMFS 2013). Based on the estimated wild spring Chinook population (smolt trap expansion) and hatchery juvenile spring Chinook population estimate (hatchery release data) for the Wenatchee River basin, the reported spring Chinook encounters during 2016 emigration monitoring complied with take provisions in the Section 10 permit. Spring Chinook encounter and mortality rates for each trap site (including PIT tag mortalities) are detailed in Table 5.43. Additionally, juvenile fish captured at the trap locations were handled consistent with provisions in ESA Section 10 Permits 18118, 18120, and 18121, Section B.

Table 5.43. Estimated take of Upper Columbia River spring Chinook resulting from juvenile emigration monitoring in the Wenatchee River basin, 2016.

Trap location	Population estimate			Number trapped			Total	Take allowed under Permit
	Wild[a]	Hatchery[b]	Sub-yearling[c]	Wild	Hatchery	Sub-yearling		
Chiwawa Trap								
Population	37,170	341,226	145,971	2,807	2,525	16,393	21,725	
Encounter rate	NA	NA	NA	0.0755	0.0074	0.1123	0.0414	0.20
Mortality[e]	NA	NA	NA	4	0	82	86	
Mortality rate	NA	NA	NA	0.0014	0.0000	0.0050	0.0040	0.02
Lower Wenatchee Trap								
Population	36,752	373,441	4,023,310	610	7,702	27,407	35,719	

Trap location	Population estimate			Number trapped			Total	Take allowed under Permit
	Wild[a]	Hatchery[b]	Sub-yearling[c]	Wild	Hatchery	Sub-yearling		
Encounter rate	NA	NA	NA	0.0166	0.0206	0.0019	0.0024	0.20
Mortality[d]	NA	NA	NA	2	3	184	189	
Mortality rate	NA	NA	NA	0.0033	0.001	0.0067	0.0053	0.02
Wenatchee River Basin Total								
Population	73,922	373,441	4,169,281	3,417	10,227	43,800	57,444	
Encounter rate	NA	NA	NA	0.0462	0.0274	0.0030	0.0039	0.20
Mortality[d]	NA	NA	NA	6	3	266	275	
Mortality rate	NA	NA	NA	0.0018	0.0001	0.0061	0.0048	0.02

[a] Smolt population estimate derived from juvenile emigration trap data.

[b] 2016 BY smolt release data for the Wenatchee River basin.

[c] Based on size, date of capture and location of capture, subyearling Chinook encountered at the Lower Wenatchee Trap are categorized as summer Chinook salmon.

[d] Combined trapping and PIT tagging mortality.

Spawning Surveys

Spring Chinook spawning ground surveys were conducted in the Wenatchee River basin during 2016, as authorized by ESA Section 10 Permits 18118, 18120, and 18121. Because of the difficulty of quantifying the level of take associated with spawning ground surveys, the Permit does not specify a take level associated with these activities, even though it does authorize implementation of spawning ground surveys. Therefore, no take levels are reported. However, to minimize potential effects to established redds, wading was restricted to the extent practical, and extreme caution was used to avoid established redds when wading was required.

Spring Chinook Reproductive Success Study

ESA Section 10 Permits 18118, 18120, and 18121 specifically provide authorization to capture, anesthetize, biologically sample, PIT tag, and release adult spring Chinook at Tumwater Dam for reproductive success studies and general program monitoring. During 2010 through 2016, all spring Chinook passing Tumwater Dam were enumerated, anesthetize, biologically sampled, PIT tagged, and released (not including hatchery-origin Chinook retained for broodstock) as a component of the reproductive success study (BPA Project No. 2003-039-00). Please refer to Ford et al. (2010, 2011, 2012, 2013, 2014, 2015, and 2016) for complete details on the methods and results of the spring Chinook reproductive success study for the period 2010-2016.

SECTION 6: NASON CREEK SPRING CHINOOK

The goals of the Nason Creek spring Chinook salmon supplementation program are to conserve, aid in the recovery, and prevent the extinction of naturally spawning spring Chinook in Nason Creek, and to meet the mitigation responsibilities of Grant County PUD. In 1997, a spring Chinook captive-broodstock program was initiated for the Nason Creek population to reduce the risk of extinction. Improvements in adult escapement in Nason Creek have reduced the near-term risk of extinction and therefore the captive-broodstock program was discontinued. An adult-based supplementation program began with the collection of broodstock in 2013. The first releases of the program occurred from the Nason Creek Acclimation Facility in the spring of 2015.

In 2013, natural-origin adult spring Chinook were collected for broodstock at Tumwater Dam and from Nason Creek using tangle and dip nets. In 2014, all natural-origin broodstock were collected from Nason Creek using tangle and dip nets. While these brood collection methods were successful at collecting adults from the Nason Creek spawning aggregate, they were unable to collect the necessary number of adults to meet mitigation production goals in 2013 and 2014. The PRCC Hatchery Subcommittee decided to implement the Nason Creek conservation program using a composite of Nason and Chiwawa natural-origin broodstock beginning with brood year 2015 in order to be able to consistently meet program goals. The decision was also made to collect all the brood at Tumwater Dam.

The production goal for the Nason Creek program requires collection of 126 adult spring Chinook (64 natural-origin fish and 66 hatchery-origin fish). However, the Section 10 permit requirements restrict the number of natural-origin adults collected and cannot exceed 33% of the natural-origin spring Chinook estimates to Tumwater Dam.

Adult spring Chinook broodstock are spawned and reared at Eastbank Fish Hatchery. Juvenile spring Chinook are transferred from the hatchery to the Nason Creek Acclimation Facility in late September or early October. Fish are reared in 30-foot dual-drain circular tanks throughout winter at the Nason Creek Acclimation Facility. Yearling Chinook were released volitionally during April and May the following year up until 2015. Beginning in 2016, all fish are force released at night to improve survival.

The current production goal is to release 223,670 smolts (125,000 for conservation and 98,670 for safety net). Juveniles released from the Nason facility will be 100% marked with CWTs and a minimum of 5,000 fish will be PIT tagged annually.

The following information focuses on results from monitoring the Nason Creek spring Chinook program. Information on spring Chinook collected throughout the Wenatchee River basin is presented in Section 5.

6.1 Broodstock Sampling

This section focuses on results from sampling 2014-2016 Nason Creek spring Chinook broodstock, which were collected in Nason Creek in 2014 and at Tumwater Dam in 2015 and 2016.

Origin of Broodstock

Natural-origin adults made up between 48% and 100% of the Nason Creek spring Chinook broodstock for return years 2014-2016 (Table 6.1). Beginning with brood year 2015, natural-origin adults were targeted for collection at Tumwater Dam during trapping operations. Natural-origin fish collected at Tumwater Dam were used for broodstock if genotyping confirmed they were natural-origin fish from the Wenatchee population and they were not White River fish. Fish that were genotyped to the White River were returned to the upper Wenatchee River basin to spawn naturally.

Table 6.1. Numbers of wild and hatchery Nason Creek spring Chinook collected for broodstock, numbers that died before spawning, and numbers of Chinook spawned, 2013-2016. Unknown origin fish (i.e., undetermined by scale analysis, no CWT or fin clips, and no additional hatchery marks) were considered naturally produced. Mortality includes fish that died of natural causes typically near the end of spawning and were not needed for the program or were surplus fish killed at spawning.

Brood year	Wild spring Chinook					Hatchery spring Chinook					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
2013	22	0	1	21	0	4	0	0	4	0	25
2014[b]	28	2	5	21	0	0	0	0	0	0	21
2015	78	1	6	59	12	63	0	0	63	0	122
2016	82	0	1	70	11	68	1	1	66	0	136
Average[c]	***53***	***1***	***3***	***43***	***6***	***34***	***0***	***0***	***33***	***0***	***76***
Median[c]	***53***	***1***	***3***	***40***	***6***	***34***	***0***	***0***	***34***	***0***	***74***

[a] Pre-spawn loss represents the number of fish that died during the holding period before spawning. Mortality is the number of fish that were surplused following spawning.
[b] Until sufficient Nason Creek Spring Chinook HOR's are collected to meet broodstock objectives, Chiwawa Spring Chinook HOR's are utilized to fulfill program goals (see table 5.1 and the 2014 Broodstock Protocols). About 12 Chiwawa HORs were used to fulfill the Chiwawa Program; about 122 Chiwawa HORs were used to fulfill the Nason Creek safety-net obligation.
[c] Origin determinations should be considered preliminary pending scale analyses.

Age/Length Data

Ages were determined from scales and/or coded wire tags (CWT) collected from broodstock. For both the 2015 and 2016 returns, most adults, regardless of origin, were age-4 Chinook (Table 6.2). A larger percentage of the age-3 and 5 Chinook were natural-origin fish.

Table 6.2. Percent of hatchery and wild spring Chinook of different ages (total age) collected from broodstock, 2013-2016.

Return year	Origin	Total age			
		2	3	4	5
2013	Wild	0.0	14.3	85.7	0.0
	Hatchery	0.0	0.0	100.0	0.0
2014	Wild	0.0	18.2	68.2	13.6
	Hatchery[a]	0.0	0.0	98.5	1.5
2015	Wild	0.0	0.0	92.0	8.0
	Hatchery	0.0	0.0	100.0	0.0
2016	Wild	0.0	0.0	69.6	30.4
	Hatchery	0.0	0.0	93.4	6.6

Return year	Origin	Total age			
		2	3	4	5
Average	***Wild***	0.0	8.1	78.9	13.0
	Hatchery	0.0	0.0	98.0	2.0
Median	***Wild***	0.0	7.2	77.7	10.8
	Hatchery	0.0	0.0	99.3	0.8

[a] Data from Table 5.2.

Age-4 natural-origin and hatchery-origin broodstock were similar in size in 2015; however, in 2016, age 4 hatchery-origin broodstock were larger than natural-origin broodstock (Table 6.3).

Table 6.3. Mean fork length (cm) at age (total age) of hatchery and wild spring Chinook collected from broodstock, 2013-2016; N = sample size and SD = 1 standard deviation.

Return year	Origin	Spring Chinook fork length (cm)											
		Age-2			Age-3			Age-4			Age-5		
		Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD
2013	Wild	-	0	-	56	3	2	75	16	6	-	0	-
	Hatchery	-	0	-	-	0	-	79	5	6	-	0	-
2014	Wild	-	0	-	57	4	6	82	15	7	86	3	8
	Hatchery[a]	-	0	-	-	0	-	81	192	6	85	3	2
2015	Wild	-	0	-	-	0	-	82	43	5	97	8	6
	Hatchery	-	0	-	-	0	-	82	55	5	-	0	-
2016	Wild	-	0	-	-	0	-	81	39	5	94	17	6
	Hatchery	-	0	-	-	0	-	84	57	6	89	4	9
Average	***Wild***	*-*	***0***	*-*	***57***	***4***	***4***	***80***	***28***	***6***	***92***	***7***	***7***
	Hatchery	*-*	***0***	*-*	*-*	***0***	*-*	***82***	***77***	***6***	***87***	***2***	***6***

[a] Data from Table 5.3.

Sex Ratios

Male spring Chinook in the 2014-2016 return years made up 60%, 50%, and 49%, respectively, of the adults collected. This resulted in overall male to female ratios of 1.50:1.00, 1.01:1.00, and 0.95:1.00, respectively (Table 6.4).

Table 6.4. Numbers of male and female wild and hatchery spring Chinook collected for broodstock, 2013-2016. Ratios of males to females are also provided.

Return year	Number of wild spring Chinook			Number of hatchery spring Chinook			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
2013	12	10	1.20:1:00	1	3	0.33:1.00	1.00:1.00
2014[a]	18	12	1.50:1.00	0	0	-	1.50:1.00
2015	40	38	1.05:1.00	31	32	0.97:1.00	1.01:1.00
2016	40	42	0.95:1.00	33	35	0.94:1.00	0.95:1.00
Total	***110***	***102***	***1.08:1.00***	***65***	***70***	***0.93:1.00***	***1.02:1.00***

[a] Data for HOR brood are in Table 5.4.

Fecundity

The mean fecundities for the 2014-2016 returns of Nason Creek spring Chinook ranged from 3,787- 4,487 eggs per female (Table 6.5). Fecundities in the 2013 and 2015 natural-origin brood, and in the 2013, 2014, and 2016 hatchery-origin brood were less than the expected fecundity of 4,400 eggs per female assumed in the broodstock protocol.

Table 6.5. Mean fecundity of wild, hatchery, and all female spring Chinook collected for broodstock, 2013-2016.

Return year	Mean fecundity		
	Wild	Hatchery	Total
2013	4,047	4,069	4,052
2014[a]	4,484	3,834	3,787
2015	4,380	4,535	4,463
2016	4,688	4,274	4,487
Average	***4,400***	***4,178***	***4,197***

[a] Average fecundities are from Table 5.5.

6.2 Hatchery Rearing

Rearing History

Number of eggs taken

Based on the unfertilized egg-to-release survival standard of 85%, a total of 263,141 eggs are required to meet the program release goal of 223,670 smolts (Table 6.6). The green egg take for the 2014-2016 brood years was 102%, 102%, and 119% of program goal, respectively.

Table 6.6. Numbers of eggs taken from spring Chinook broodstock, 2013-2016.

Return year	Number of eggs taken
2013[a]	49,720
2014[b]	267,783
2015	268,247
2016	314,090
Average	***224,960***
Median	***268,015***

[a] Safety-net obligation met through the White River Program. Conservation egg take goal was 116,082.
[b] Includes surrogate Chiwawa HxH egg take calculated from tagging proportions.

Number of acclimation days

Fish from the 2014 brood were acclimated for 119-166 days on Nason Creek water and 12 days on well water with oxygen (Table 6.7).

Table 6.7. Number of days spring Chinook broods were acclimated on Nason Creek water and well water, brood years 2013-2014.

Brood year	Release year	Transfer date	Release date	Number of acclimation days
2013	2015	13 Oct	13 Apr – 1 May	182-200
2014[a]	2016	21-23 Oct	15-20 Apr	119-122 Nason, 12 Well

[a] Because of water-intake concerns at the Nason Creek Acclimation Facility, the HxH Chinook were transferred to the Chiwawa Acclimation Facility on 2-3 March for final acclimation and release. The WxW fish were on Nason Creek water for 166 days. The HxH fish were on Nason Creek water for 119-122 days and on Chiwawa River water for 43-49 days. WxW and HxH fish were on well water and oxygen for 12 days while rearing at the Nason Creek Acclimation Facility.

Release Information

Numbers released

The 2014 brood Nason Creek spring Chinook program achieved 25.8% of the 125,000 target goal with about 32,215 WxW smolts forced into Nason Creek in 2016 (Table 6.8). The remainder of the smolt obligation was fulfilled with HxH progeny. The HxH Nason program was transferred to the Chiwawa Acclimation Facility on 2-3 March 2016 for final acclimation because of water-intake concerns at the Nason Creek Acclimation Facility (see Table 5.8). A total of 196,866 HxH smolts were released from the Chiwawa Acclimation Facility for the Nason spring Chinook program.

Table 6.8. Numbers of spring Chinook smolts tagged and released from the hatchery, brood years 2013-2014. The release target for Nason Creek spring Chinook is 125,000 smolts.

Brood year	Release year	Type of release	CWT mark rate	Number released that were PIT tagged	Number of smolts released	Total number of smolts released
2013	2015	Volitional	0.9303	20,139	43,082	43,082
2014[a]	2016	Forced	0.9650	5,009	32,215	32,215

[a] Only the WxW Nason program was released from the Nason Creek Acclimation Facility because of water-intake concerns. The HxH Nason program was transferred to the Chiwawa Acclimation Facility on 2-3 March 2016 (see Table 5.8).

Numbers tagged

The 2014 brood Nason spring Chinook were 96% CWT and blank CWT adipose tagged (Table 6.8).

In 2017, a total of 10,104 Nason Creek spring Chinook from the 2015 brood were tagged at the Nason Creek Acclimation Facility on 6-9 March. Chinook in Ponds 1, 3, 5, and 7 were HxH fish, while Chinook in Ponds 2, 4, 6, and 8 were WxW fish. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 110-115 mm in length and 17-19 g at time of tagging.

Table 6.9 summarizes the number of hatchery spring Chinook that have been PIT-tagged and released into Nason Creek.

Table 6.9. Summary of PIT-tagging activities for Nason Creek hatchery spring Chinook, brood years 2013-2014.

Brood year	Release year	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
2013	2015	20,234	94	1	20,139
2014	2016	5,010	1	0	5,009

Fish size and condition at release

The WxW spring Chinook from the 2014 brood were released as yearling smolts from 15-20 April 2016. Size at release (21 fpp) was larger than the approximate target of 24 fpp established for the program. The CV for fork length was just short of the target (Table 6.10).

The HxH spring Chinook were transferred to the Chiwawa Acclimation Facility for final rearing on 2-3 March 2016 because of water-intake concerns at the Nason Creek Acclimation Facility. These fish were volitionally released as yearling smolts from 15-20 April 2016 into the Chiwawa River. Size at release (16 fpp) was larger than the approximate target of 18 fpp established for the Chiwawa program. The CV for fork length was just short of the target (see Table 5.10).

Table 6.10. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of spring Chinook smolts released from the hatchery, brood years 2013-2014. Size targets are provided in the last row of the table.

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
2013	2015	129	8.3	27.6	16
2014[a]	2016	124	7.7	21.7	21
Average		***127***	***8***	***24.7***	***19***
Median		***127***	***8***	***24.7***	***19***
Targets		***155***	***9.0***	***37.8***	***18***

[a] This represents only the WxW Nason program released from the Nason Creek Acclimation Facility. The HxH program was transferred to the Chiwawa Acclimation Facility on 2-3 March 2016 for release because of water-intake concerns at the Nason Creek Acclimation Facility. Statistics on the 2014 brood HxH program pre-release sample at the Chiwawa Acclimation Facility were 134 mean length, 17.5 length CV, 28.6g mean wt., and 16 fpp.

Survival Estimates

Overall survival of Nason Creek spring Chinook from green (unfertilized) egg to release was above the standard set for the program (Table 6.11). There was higher than expected survivals throughout all stages contributing to increased program performance. Pre-spawn survival of adults was also above the standard set for the program.

Table 6.11. Hatchery life-stage survival rates (%) for spring Chinook, brood years 2013-2014. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
2013	100.0	100.0	93.5	98.8	99.4	98.2	93.8	99.1	86.6
2014[a]	97.3	100.0	91.3	97.6	99.5	99.0	98.1	99.5	87.4
Average	***98.7***	***100.0***	***92.4***	***98.2***	***99.5***	***98.6***	***96.0***	***99.3***	***87.0***
Median	***98.7***	***100.0***	***92.4***	***98.2***	***99.5***	***98.6***	***96.0***	***99.3***	***87.0***
Standard	***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

[a] The survival estimates are a combination of the WxW and HxH Nason programs. The WxW program was reared at the Nason Creek Acclimation Facility until release. The HxH Chinook that were reared at the Nason Creek Acclimation Facility until transferred to the Chiwawa Acclimation Facility on 2-3 March 2016 because of water-intake concerns at the Nason Creek Acclimation Facility. The HxH fish were released from the Chiwawa Acclimation Facility on 15-20 April 2016.

6.3 Disease Monitoring

Results of 2016 adult broodstock bacterial kidney disease (BKD) monitoring indicated that most females (90%) had ELISA values less than 0.199. Ten percent of the females had ELISA values greater than 0.120, resulting in no limitations to rearing densities (Table 6.12).

For the 2014 brood, a formalin drip treatment was used shortly after transfer to the Nason Creek Acclimation Facility to prevent infection associated with stress caused by the transfer. No significant health issues were encountered for the remainder of juvenile rearing.

Table 6.12. Proportion of bacterial kidney disease (BKD) titer groups for the Nason Creek spring Chinook broodstock by origin, brood years 2013-2016. Also included are the proportions to be reared at either 0.125 fish per pound or 0.060 fish per pound.

Brood year	Optical density values by titer group								Proportion at rearing densities (fish per pound, fpp)[b]			
	Very Low (≤ 0.099)		Low (0.1-0.199)		Moderate (0.2-0.449)		High (≥ 0.450)		≤ 0.125 fpp (<0.119)		≤ 0.060 fpp (>0.120)	
	Wild	Hatch	Wild	Hatch	Wild	Hatch	Wild	Hatch	Wild	Hatch	Wild	Hatch
2013	0.7000	0.3333	0.3000	0.6666	0.0000	0.0000	0.0000	0.0000	0.9231	0.1000	0.0769	0.0000
2014	0.5000	--	0.3000	--	0.0000	--	0.2000	--	0.8000	--	0.2000	--
2015[a]	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.000	0.0000	0.0000
2016	0.8888	0.9118	0.1111	0.0882	0.0000	0.0000	0.0000	0.0000	0.8888	0.9118	0.1111	0.0882
Average	0.7722	0.7484	0.1778	0.2516	0.0000	0.0000	0.0500	0.0000	0.9030	0.6706	0.0970	0.0294
Median	0.7944	0.9118	0.2056	0.0882	0.0000	0.0000	0.0000	0.0000	0.9060	0.9118	0.0940	0.0000

[a] Determination of origin should be considered preliminary pending scale analyses.
[b] ELISA values from broodstock BKD testing dictate what density the progeny of the broodstock are reared. Progeny of broodstock with high ELISA values are reared at lower density.

6.4 Natural Juvenile Productivity

During 2016, juvenile spring Chinook were sampled at the Nason Creek trap.

Smolt and Emigrant Estimates

Numbers of spring Chinook smolts and emigrants were estimated at the Nason Creek trap in 2016. A complete description of trapping operations on Nason Creek can be found in Appendix L.

Nason Creek Trap

The Nason Creek Trap operated between 1 March and 30 November 2016. During that time, the trap was inoperable for 62 days because of low stream discharge or flooding. Daily trap efficiencies were estimated from a flow-efficiency regression model. The daily number of fish captured was expanded by the estimated trap efficiency to estimate total emigration. If a viable flow-efficiency regression could not be developed, a pooled efficiency was used to expand daily catch. All pooled estimates will be recalculated as flow-efficiency models are developed.

Wild yearling spring Chinook (2014 brood year) were captured primarily from March through April 2016 (Figure 6.1). Because a viable yearling emigrant flow-efficiency regression model could not be established at the downstream trap location, a pooled estimate was employed as a temporary method of expansion. Based on this pooled efficiency, the total number of wild yearling Chinook from the Nason Creek basin was 930 (±5,083). Combining the number of subyearling spring Chinook (2,851) that emigrated during the fall of 2015 with the total number of yearling Chinook (930) that emigrated during 2016 resulted in an emigrant estimate of 3,781 (±5,102) spring Chinook (Table 6.13). Based on PIT-tag analysis, an additional 29 (±37) spring Chinook immigrated during the winter (1 December – 28 February) when the trap was inoperable. Thus, the total number of emigrants was 3,810 (±5,126) spring Chinook for the 2014 brood year.

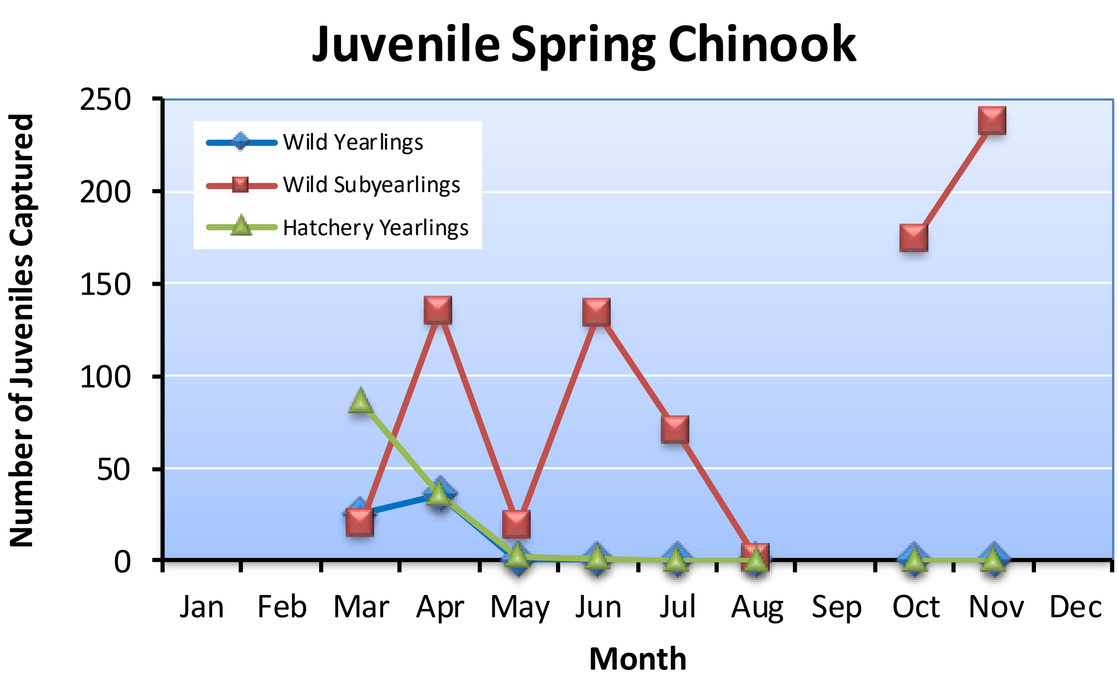

Figure 6.1. Monthly captures of wild subyearling and wild and hatchery yearling spring Chinook at the Nason Creek Trap, 2016.

Table 6.13. Numbers of redds and juvenile spring Chinook at different life stages in the Nason Creek basin for brood years 2002-2015; ND = no data.

Brood year	Number of redds	Egg deposition[a]	Number of subyearling emigrants[b]	Number of smolts produced within Nason Creek basin	Number of emigrants[c]
2002	294	1,368,276	ND	4,683	ND
2003	83	485,052	8,829	6,358	15,187
2004	169	811,031	11,822	2,597	14,419
2005	193	835,111	11,814	8,696	20,510
2006	152	657,248	4,144	7,798	11,942
2007	101	448,541	15,556	5,679	21,235
2008	336	1,542,912	23,182	3,611	26,793
2009	167	763,691	27,720	1,705	29,425
2010	188	811,032	8,491	3,535	12,026
2011	170	745,450	17,991	2,422	20,413
2012	413	1,744,099	28,110	4,561	32,671
2013	212	859,024	43,711	6,992	57,525
2014	115	435,505	2,880	930	3,810
2015	85	379,355	5,540	--	--
Average	***191***	***849,023***	***14,899***	***4,582***	***21,748***
Median	***170***	***787,361***	***11,822***	***4,561***	***20,462***

[a] Egg deposition is calculated as the number of redds times the fecundity of both wild and hatchery spring Chinook salmon (from Table 5.5.

[b] Subyearling emigrants does not include fry that left the watershed before 1 July.

[c] Brood years 2002-2012 do not include estimates of numbers of juvenile spring Chinook that emigrated during non-trapping periods (1 Dec to 28 Feb). Brood years 2013 to present include estimates of numbers of juvenile spring Chinook that emigrated during non-trapping periods.

Wild subyearling spring Chinook (2015 brood year) were captured between 10 March and 29 November 2016 (Figure 6.1). Based on capture efficiencies estimated from the flow model, the total number of wild subyearling Chinook emigrating from Nason Creek was 5,540 (±997).

Yearling spring Chinook sampled in 2016 averaged 96 mm in length, 9.0 g in weight, and had a mean condition of 1.01 (Table 6.14). Estimated length and weight for these fish were greater than the overall mean of yearling spring Chinook sampled in previous years (overall means, 93 mm and 8.5 g), while the estimated condition was less (overall mean, 1.05). Subyearling spring Chinook sampled in 2016 at the Nason Creek Trap averaged 85 mm in length, 6.9 g in weight, and had a mean condition of 1.07 (Table 6.14). These size estimates were greater than the overall mean of subyearling spring Chinook sampled in previous years (overall means, 77 mm, 5.1 g, and condition of 1.07).

Table 6.14. Mean fork length (mm), weight (g), and condition factor of subyearling and yearling spring Chinook collected in the Nason Creek Trap, 2004-2016. Numbers in parentheses indicate 1 standard deviation.

Sample year	Life stage	Sample size[a]	Mean size		
			Length (mm)	Weight (g)	Condition (K)
2004	Subyearling	656	82 (7)	5.9 (1.7)	1.04 (0.11)
	Yearling	323	92 (8)	8.2 (2.3)	1.04 (0.08)
2005	Subyearling	872	76 (9)	4.8 (1.7)	1.02 (0.13)
	Yearling	276	94 (7)	8.7 (2.0)	1.04 (0.12)
2006	Subyearling	1422	73 (9)	3.9 (1.9)	0.92 (0.16)
	Yearling	362	91 (7)	7.5 (1.8)	0.98 (0.11)
2007	Subyearling	609	78 (14)	5.9 (2.6)	1.15 (0.16)
	Yearling	678	88 (9)	7.4 (2.4)	1.05 (0.13)
2008	Subyearling	1,001	75 (14)	5.0 (2.5)	1.10 (0.11)
	Yearling	881	96 (6)	9.5 (2.0)	1.06 (0.09)
2009	Subyearling	2,147	72 (11)	4.4 (2.1)	1.08 (0.08)
	Yearling	162	96 (8)	9.6 (2.4)	1.08 (0.09)
2010	Subyearling	3,032	81 (11)	6.2 (2.3)	1.13 (0.10)
	Yearling	366	97 (7)	10.2 (2.3)	1.10 (0.09)
2011	Subyearling	1,064	72 (13)	4.7 (2.5)	1.13 (0.12)
	Yearling	150	89 (10)	7.7 (1.8)	1.09 (0.12)
2012	Subyearling	2,141	78 (11)	5.3 (2.0)	1.05 (0.09)
	Yearling	363	93 (6)	9.3 (2.2)	1.11 (0.08)
2013	Subyearling	4,408	70 (11)	3.8 (1.7)	1.03 (0.10)
	Yearling	239	91 (7)	7.9 (2.1)	1.03 (0.07)
2014	Subyearling	1,543	69 (12)	3.8 (2.3)	1.05 (0.06)
	Yearling	464	90 (7)	7.5 (1.8)	1.03 (0.06)
2015	Subyearling	209	84 (8)	6.5 (1.7)	1.08 (0.08)
	Yearling	152	93 (7)	8.4 (2.1)	1.03 (0.09)
2016	Subyearling	490	85 (13)	6.9 (2.5)	1.07 (0.09)
	Yearling	61	96 (6)	9.0 (1.7)	1.01 (0.06)
Average	***Subyearling***	***1,507***	***77 (5)***	***5.1 (1.1)***	***1.07 (0.06)***
	Yearling	***344***	***93 (3)***	***8.5 (0.9)***	***1.05 (0.04)***
Median	***Subyearling***	***1,064***	***76 (5)***	***5.0 (1.1)***	***1.07 (0.06)***
	Yearling	***323***	***93 (3)***	***8.4 (0.9)***	***1.04 (0.04)***

[a] Sample size represents the number of fish that were measured for both length and weight.

Freshwater Productivity

Both productivity and survival estimates for different life stages of spring Chinook in the Nason Creek watershed are provided in Table 6.15. Estimates for brood year 2014 were generally lower than estimates for brood years 2002-2013. During the period 2002-2014, freshwater productivities ranged from 8-77 smolts/redd and 33-271 emigrants/redd. Survivals during the same period ranged from 0.2-1.3% for egg-smolt and 0.9-5.8% for egg-emigrants.

Table 6.15. Productivity (fish/redd) and survival (%) estimates for different juvenile life stages of spring Chinook in the Nason Creek watershed for brood years 2002-2014; ND = no data. These estimates were derived from data in Table 6.13.

Brood year	Smolts/Redd[a]	Emigrants/ Redd	Egg-Smolt[a] (%)	Egg-Emigrant (%)
2002	16	ND	0.3	ND
2003	77	183	1.3	3.1
2004	15	85	0.3	1.8
2005	45	106	1.0	2.5
2006	51	79	1.2	1.8
2007	56	210	1.3	4.7
2008	11	80	0.2	1.7
2009	10	176	0.2	3.9
2010	19	64	0.4	1.5
2011	14	120	0.3	2.7
2012	11	79	0.3	1.9
2013	33	271	0.8	6.7
2014	8	33	0.2	0.9
Average	***28***	***124***	***0.6***	***2.8***
Median	***16***	***96***	***0.3***	***2.2***

[a] These estimates include Nason Creek smolts produced only within the Nason Creek basin.

Seeding level (egg deposition) explained most of the variability in productivity and survival of juvenile spring Chinook in the Nason Creek watershed. That is, for estimates based on smolts produced within the Nason Creek watershed, survival and productivity decreased as seeding levels increased (Figure 6.2). This suggests that density dependence regulates juvenile productivity and survival within the Nason Creek watershed.

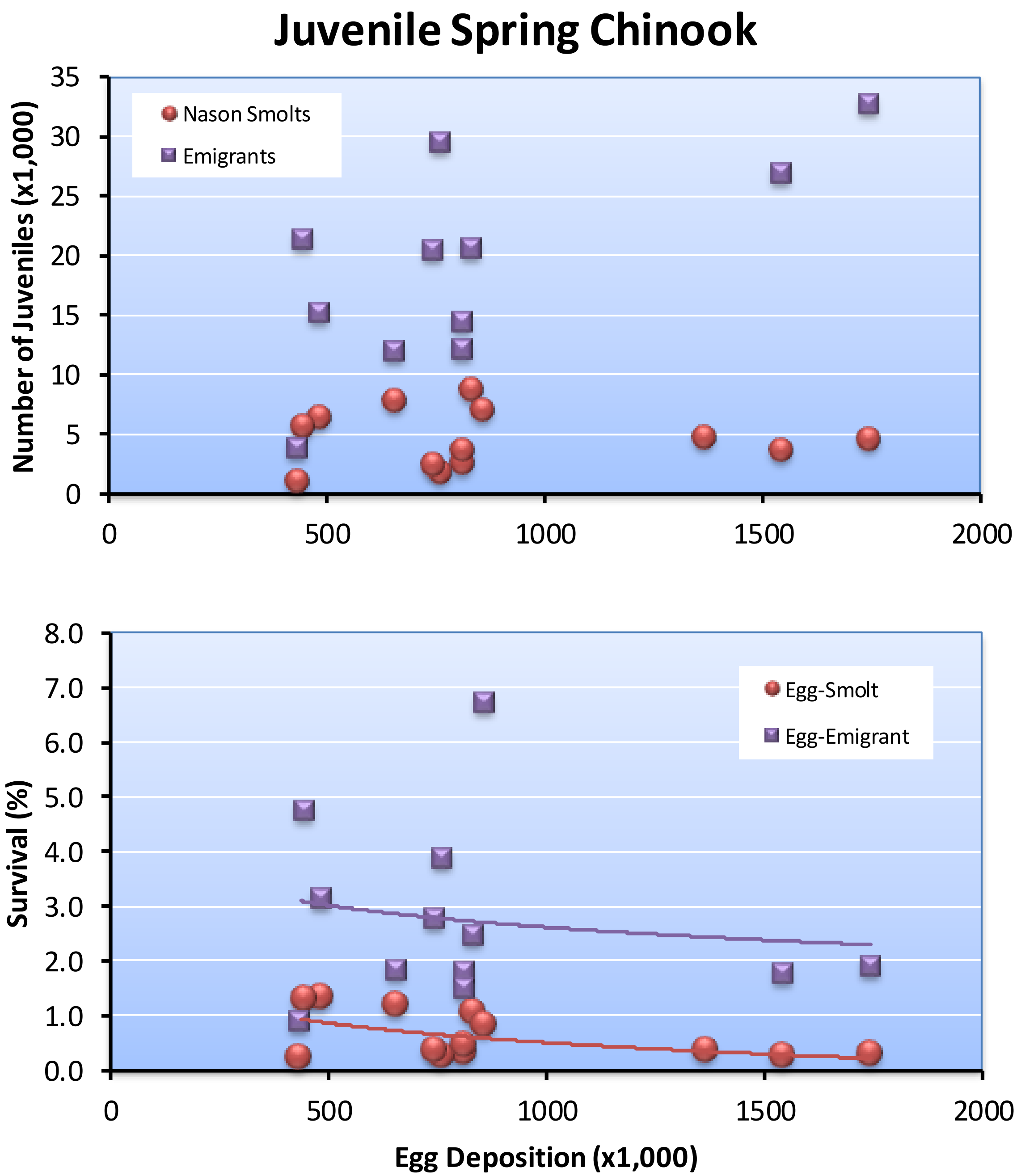

Figure 6.2. Relationships between seeding levels (egg deposition) and juvenile life-stage survivals and productivities for Nason Creek spring Chinook, brood years 2002-2014. Nason Creek smolts are smolts produced only in the Nason Creek watershed.

Population Carrying Capacity

Population carrying capacity (*K*) is defined as the maximum equilibrium population size estimated with population models (e.g., logistic equation, Beverton-Holt model, hockey stick model, and the

Ricker model).[16] Maximum equilibrium population size is generated from density dependent mechanisms that reduce population growth rates as population size increases (negative density dependence). This is referred to as compensation. Population size fluctuates about the maximum equilibrium size because of variability in vital rates that are unrelated to density (density independent factors) and measurement error. In this section, we estimate smolt carrying capacities using the Ricker stock-recruitment model (see Appendix C in Hillman et al. 2012 for a detailed description of methods). The Ricker model was the only stock-recruitment model that could be fit to the juvenile spring Chinook data.

Based on the Ricker model, the population carrying capacity for spring Chinook smolts in the Nason Creek watershed is 4,412 smolts (95% CI: 0 – 7,833) (Figure 6.3). Here, smolts are defined as the number of yearling spring Chinook produced entirely within Nason Creek. These estimates reflect current environmental conditions (most recent 13 years) within the Nason Creek watershed. Land use activities such as logging, roads, railways, development, and recreation have altered the historical conditions of the watershed. Thus, the estimated population capacity estimates may not reflect historical capacities for spring Chinook smolts in Nason Creek.

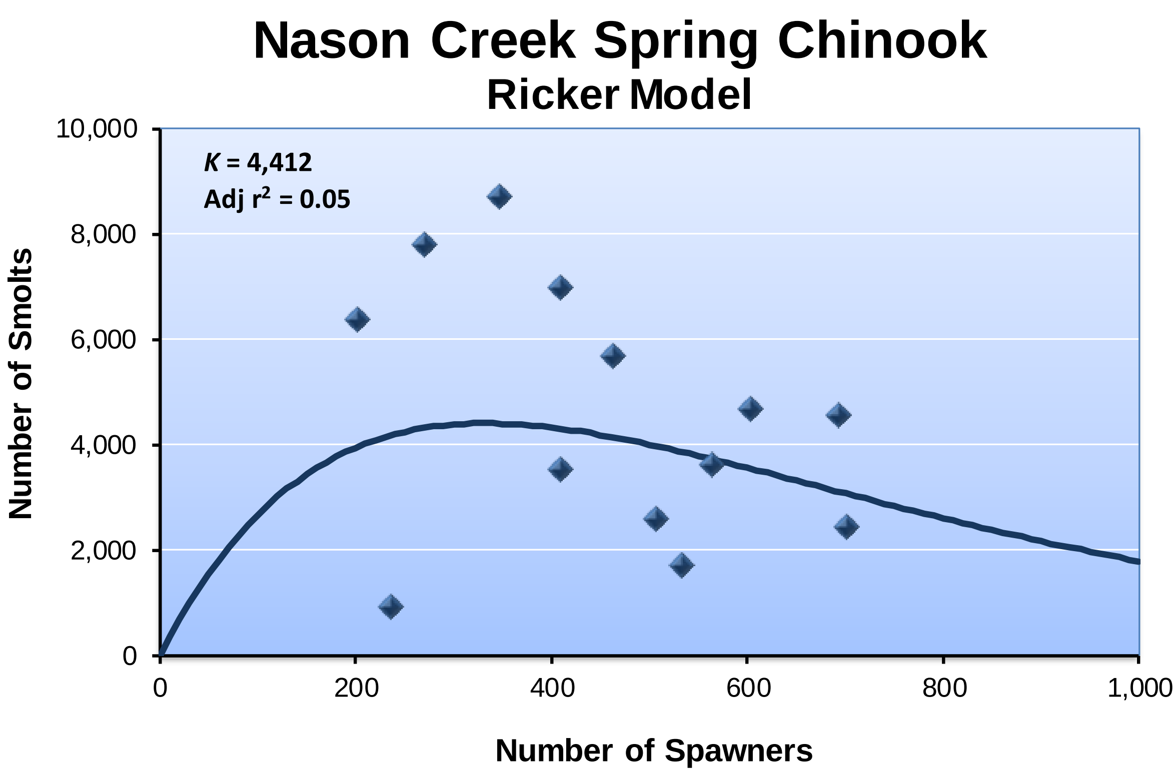

Figure 6.3. Relationship between spawners and number of yearling smolts produced in the Nason Creek watershed. Population carrying capacity (*K*) was estimated using the Ricker model.

16 Population carrying capacity (*K*) should not be confused with habitat carrying capacity (*C*), which is defined as the maximum population of a given species that a particular environment can sustain.

We tracked the precision of the Ricker parameters for Nason Creek spring Chinook smolts over time to see if precision improves with additional years of data, and the parameters and statistics stabilize over time. Examination of variation in the alpha (*A*) and beta (*B*) parameters of the Ricker model and their associated standard errors and confidence intervals indicates that the parameters have not stabilized and they lack precision (Table 6.16; Figure 6.4). This was also apparent in the estimates of population carrying capacity (Figure 6.5).

Table 6.16. Estimated parameters and statistics associated with fitting the Ricker model to spawning escapement and smolt data. Smolts represent numbers of smolts produced entirely within the Nason Creek watershed. *A* = alpha parameter; *B* = beta parameter; SE = standard error (estimated from 5,000 bootstrap samples); and r^2 = coefficient of determination. Spawners represent the stock size needed to achieve population capacity.

Years of data	Parameter				Population capacity	Intrinsic productivity	Spawners	r^2
	A	SE	*B*	SE				
5	90.60	87.13	0.0046	0.0015	7,293	91	219	0.453
6	90.02	5618.57	0.0045	0.0014	7,360	90	222	0.442
7	92.67	1696.44	0.0046	0.0009	7,395	93	217	0.517
8	107.07	1208.15	0.0052	0.0012	7,575	107	192	0.454
9	99.89	1125.42	0.0051	0.0012	7,149	100	195	0.409
10	90.35	50.04	0.0049	0.0008	6,825	90	205	0.470
11	72.26	34.50	0.0043	0.0009	6,240	72	235	0.308
12	76.76	31.24	0.0043	0.0008	6,522	77	231	0.337
13	35.98	32.48	0.0030	0.0013	4,412	36	333	0.049

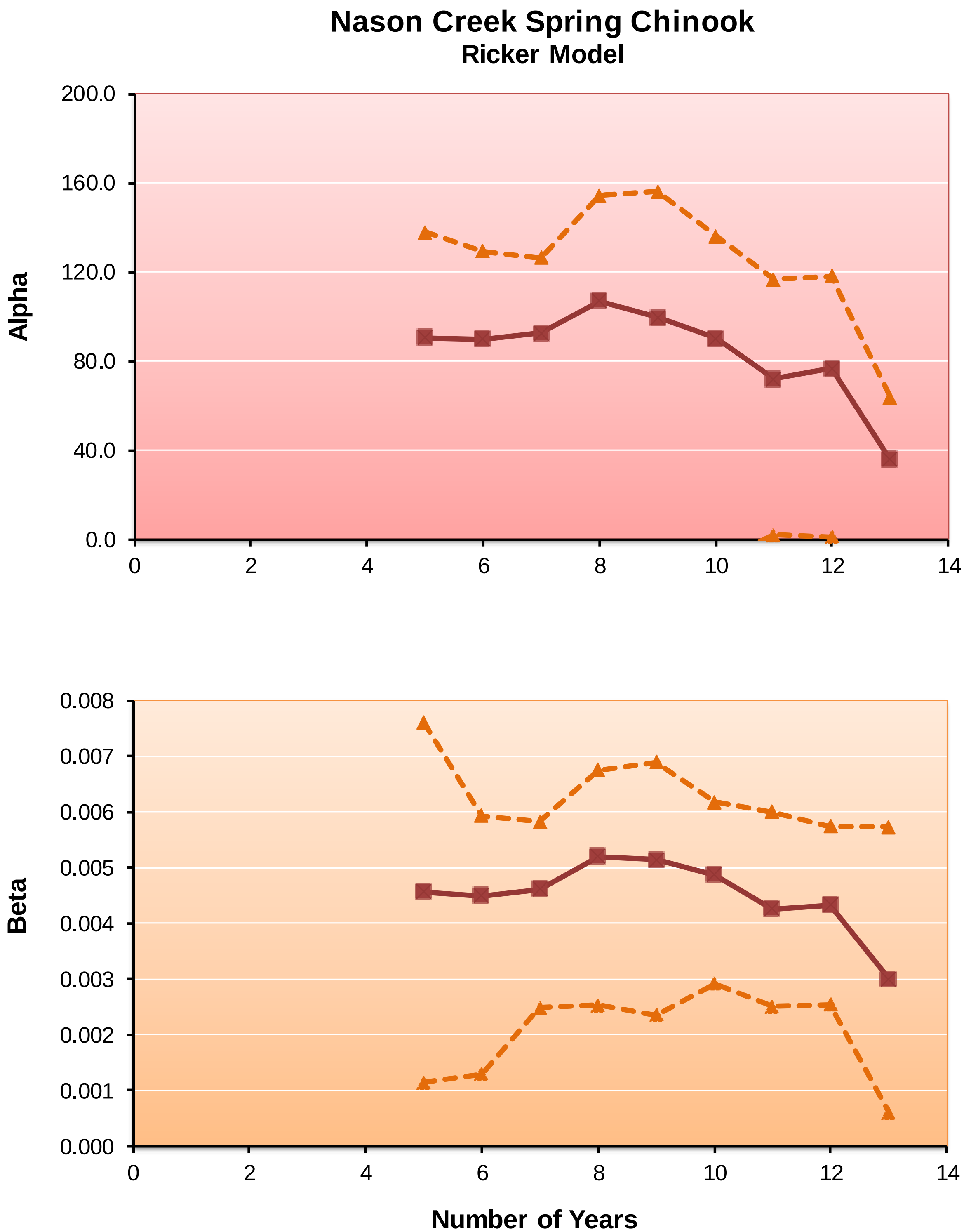

Figure 6.4. Time series of alpha and beta parameters and 95% confidence intervals for the Ricker model that was fit to Nason Creek spring Chinook smolt and spawning escapement data. Confidence intervals were estimated from 5,000 bootstrap samples.

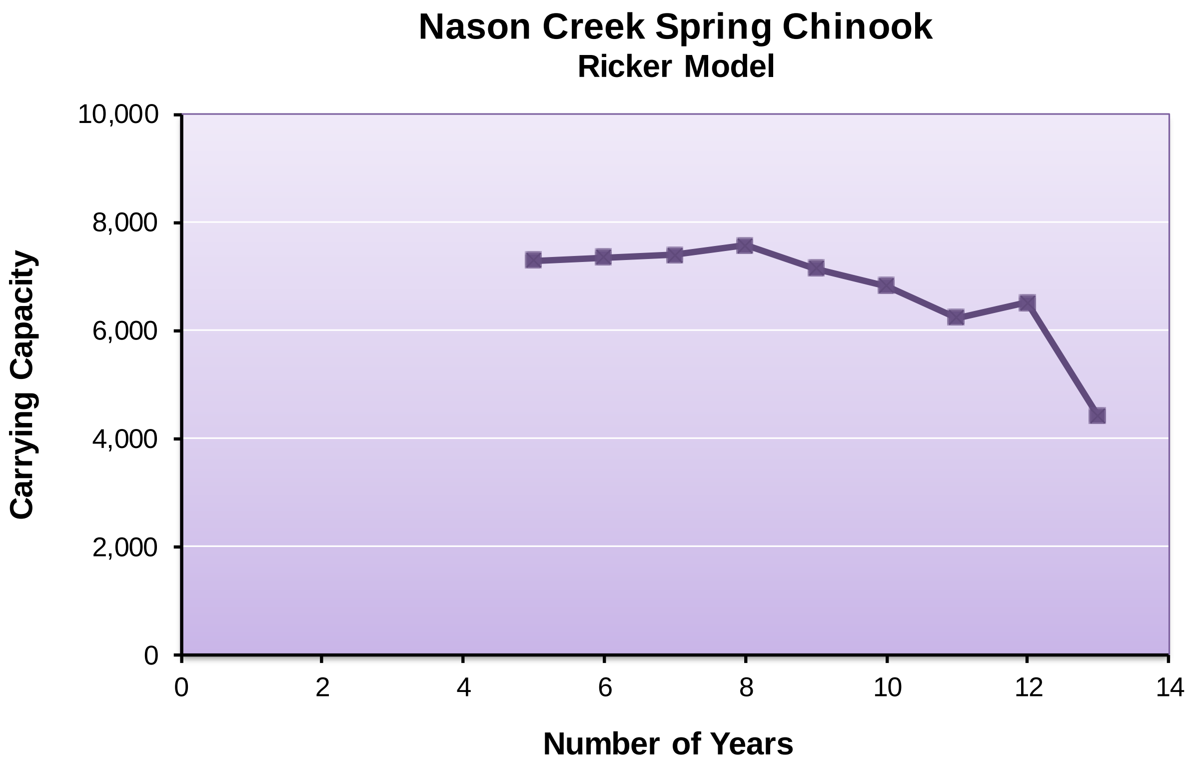

Figure 6.5. Time series of population carrying capacity estimates derived from fitting the Ricker model to Nason Creek spring Chinook smolt and spawning escapement data.

6.5 Spawning Surveys

Surveys for spring Chinook redds were conducted during late July through September 2016 in the Chiwawa River (including Rock, Chikamin, and Phelps creeks), Nason Creek, Icicle Creek, Peshastin Creek (including Ingalls Creek), Upper Wenatchee River (including Chiwaukum Creek), Little Wenatchee River, and White River (including the Napeequa River and Panther Creek). See Section 5.5 for complete coverage of spring Chinook redd surveys in the Wenatchee River basin. In the following section, we describe the number and distribution of redds within the Nason Creek basin.

Redd Counts and Distribution

A total of 85 spring Chinook redds were counted in Nason Creek in 2016 (Table 6.17; see Table 5.20 for the complete time series of redd counts). This is lower than the average of 144 redds counted during the period 1989-2015 in Nason Creek. Redds were not distributed evenly among the four reaches in Nason Creek. Most redds (68%) were located in Reach 2 and Reach 3 (Table 6.17).

Table 6.17. Numbers (both counted and estimated) and proportions of spring Chinook redds counted within different reaches within Nason Creek during August through September 2016. See Table 2.8 for description of survey reaches.

Stream/watershed	Reach	Number of observed redds	Estimated number of redds*	Proportion of redds estimated within stream/watershed
Nason	Nason 1 (N1)	14	14	0.14
	Nason 2 (N2)	20	23	0.23
	Nason 3 (N3)	37	45	0.45
	Nason 4 (N4)	14	18	0.18
Total		***85***	***100***	***1.00***

* Estimated redds represent the "true" number of redds based on Guassian area-under-the-curve method (see Appendix J).

Spawn Timing

Spring Chinook began spawning during the last week of July in Nason Creek and peaked the first week of September (Figure 6.6). Spawning in Nason Creek ended the fourth week of September.

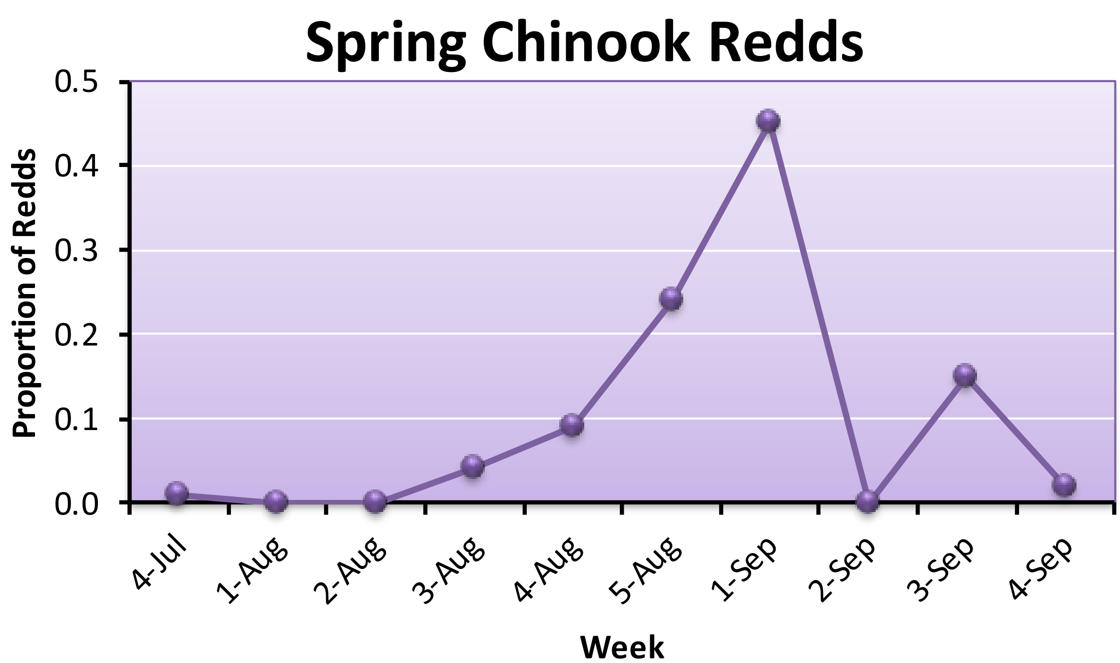

Figure 6.6. Proportion of spring Chinook redds counted during different weeks within Nason Creek, August through September 2016.

Spawning Escapement

Spawning escapement for spring Chinook was calculated as the number of redds times the male-to-female ratio (i.e., fish per redd expansion factor) estimated from broodstock and fish sampled at adult trapping sites.[17] The estimated fish per redd ratio for spring Chinook upstream from Tumwater in 2016 was 1.83 (based on sex ratios estimated at Tumwater Dam). Multiplying this ratio by the number of redds counted in Nason Creek resulted in a total spawning escapement of 156 spring Chinook. The estimated total spawning escapement of spring Chinook in 2016 was less than the overall average of 313 spring Chinook in Nason Creek (see Table 5.23).

6.6 Carcass Surveys

Surveys for spring Chinook carcasses were conducted during August through September 2016 in the Chiwawa River (including Rock, Chikamin, and Phelps creeks), Nason Creek, Icicle Creek, Peshastin Creek (including Ingalls Creek), Upper Wenatchee River (including Chiwaukum Creek), Little Wenatchee River, and the White River (including the Napeequa River and Panther Creek). In 2016, 95 spring Chinook carcasses were sampled in Nason Creek. Most of these were sampled in Reach 3. The number of carcasses sampled in 2016 was less than the overall average of 148 carcasses sampled during the period 1996-2015. See Section 5.6 for a complete coverage of spring Chinook carcass surveys in the Wenatchee River basin.

In the Nason Creek watershed, the spatial distribution of hatchery and wild fish was not equal among survey reaches (Table 6.18). In 2016, more wild fish were collected during surveys than hatchery fish. On average, over the survey years, more wild fish were collected than hatchery fish in each of the reaches except Reach 1 where more hatchery fish have been collected (Figure 6.7). It should be noted that the hatchery fish spawning in Nason Creek are primarily strays from the Chiwawa spring Chinook Program. Nason Creek hatchery fish began returning to Nason Creek in 2016 as age-3 fish.

Table 6.18. Numbers of wild and hatchery spring Chinook carcasses sampled within different reaches in the Nason Creek watershed, 1999-2016. Numbers represent recovered carcasses that had definitive origins. See Table 2.8 for description of survey reaches.

Survey year	Origin	Survey Reach				Total
		N-1	N-2	N-3	N-4	
1999	Wild	2	3	0	0	**5**
	Hatchery	0	0	0	0	**0**
2000	Wild	19	21	0	9	**49**
	Hatchery	11	9	0	1	**21**
2001	Wild	25	22	0	41	**88**
	Hatchery	91	54	0	22	**167**
2002	Wild	16	34	0	37	**87**
	Hatchery	33	29	0	35	**97**
2003	Wild	6	19	0	22	**47**
	Hatchery	3	9	0	3	**15**
2004	Wild	29	33	18	24	**104**
	Hatchery	42	26	11	3	**82**
2005	Wild	19	6	11	7	**43**
	Hatchery	130	17	22	4	**173**
2006	Wild	24	17	28	9	**78**

[17] Expansion factor = (1 + (number of males/number of females)).

Survey year	Origin	Survey Reach				Total
		N-1	N-2	N-3	N-4	
	Hatchery	50	31	17	14	**112**
2007	Wild	2	13	8	6	**29**
	Hatchery	54	77	26	15	**172**
2008	Wild	14	13	16	10	**53**
	Hatchery	102	39	36	13	**190**
2009	Wild	1	12	10	16	**39**
	Hatchery	25	21	20	23	**89**
2010	Wild	3	6	6	4	**19**
	Hatchery	47	29	30	16	**122**
2011	Wild	8	11	11	5	**35**
	Hatchery	22	12	21	8	**63**
2012	Wild	24	11	65	7	**107**
	Hatchery	95	37	70	23	**225**
2013	Wild	4	2	9	8	**23**
	Hatchery	51	12	28	27	**118**
2014	Wild	19	5	13	2	**39**
	Hatchery	25	1	3	0	**29**
2015	Wild	8	4	20	2	**34**
	Hatchery	2	0	7	0	**9**
2016	Wild	9	8	39	15	**71**
	Hatchery	10	0	9	3	**22**
Average	***Wild***	***13***	***13***	***14***	***12***	***53***
	Hatchery	***44***	***22***	***17***	***12***	***95***
Median	***Wild***	***12***	***12***	***11***	***9***	***45***
	Hatchery	***38***	***19***	***14***	***11***	***93***

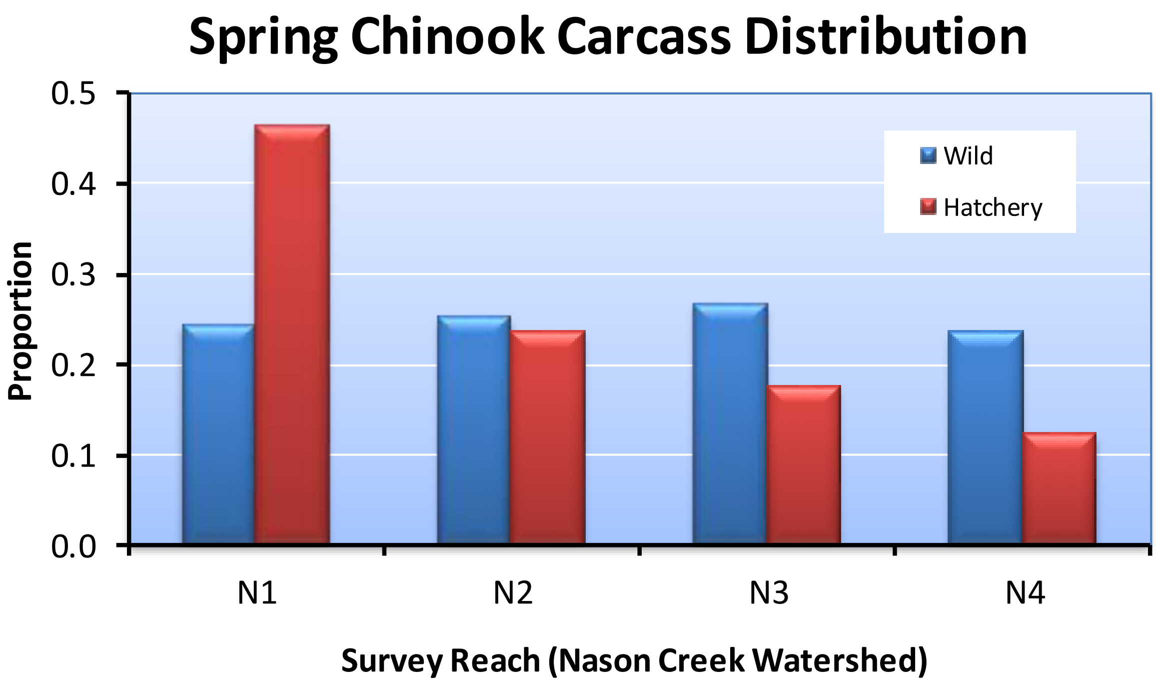

Figure 6.7. Distribution of wild and hatchery produced carcasses in different reaches in the Nason Creek watershed, 1999-2016. Reach codes are described in Table 2.8.

6.7 Life History Monitoring

Life history characteristics of spring Chinook were assessed by examining carcasses on spawning grounds and fish collected at broodstock collection sites, and by reviewing tagging data and fisheries statistics.

Migration Timing

See Section 5.7 for a description of migration timing of spring Chinook at Tumwater Dam.

Age at Maturity

Most of the wild and hatchery spring Chinook sampled during the period 1999-2016 in the Nason Creek watershed were age-4 fish (total age) (Table 6.19; Figure 6.8). Except for 2014 fish, hatchery fish made up a higher percentage of age-3 Chinook than did wild fish. As in other years, a higher proportion of age-5 wild fish returned than did age-5 hatchery fish. Thus, wild fish tended to return at an older age than hatchery fish.

Table 6.19. Numbers of wild and hatchery spring Chinook of different ages (total age) sampled on spawning grounds in the Nason Creek watershed, 1999-2016.

Sample year	Origin	Total age					Sample size
		2	3	4	5	6	
1999	Wild	0	0	5	0	0	**5**
	Hatchery	0	0	0	0	0	**0**
2000	Wild	0	1	45	0	0	**46**

Sample year	Origin	Total age					Sample size
		2	3	4	5	6	
	Hatchery	0	18	3	0	0	**21**
2001	Wild	0	0	63	13	0	**76**
	Hatchery	0	5	159	3	0	**167**
2002	Wild	0	0	58	23	0	**81**
	Hatchery	0	0	85	11	0	**96**
2003	Wild	0	4	3	36	0	**43**
	Hatchery	0	3	1	5	0	**9**
2004	Wild	0	1	101	1	0	**103**
	Hatchery	0	57	23	2	0	**82**
2005	Wild	0	1	25	17	0	**43**
	Hatchery	0	3	170	0	0	**173**
2006	Wild	0	0	60	18	0	**78**
	Hatchery	0	12	78	22	0	**112**
2007	Wild	0	0	18	11	0	**29**
	Hatchery	0	123	40	9	0	**172**
2008	Wild	0	2	46	4	0	**52**
	Hatchery	0	21	163	6	0	**190**
2009	Wild	0	1	36	2	0	**39**
	Hatchery	0	19	65	4	0	**88**
2010	Wild	0	1	18	0	0	**19**
	Hatchery	0	5	116	1	0	**122**
2011	Wild	0	3	24	8	0	**35**
	Hatchery	0	33	17	13	0	**63**
2012	Wild	0	1	89	17	0	**107**
	Hatchery	0	25	198	2	0	**225**
2013	Wild	0	0	16	7	0	**23**
	Hatchery	0	22	92	5	0	**119**
2014	Wild	0	16	19	3	0	**38**
	Hatchery	0	9	20	0	0	**29**
2015	Wild	0	1	25	4	0	**30**
	Hatchery	0	4	9	0	0	**13**
2016	Wild	0	3	61	7	0	**71**
	Hatchery	0	11	10	0	0	**21**
Average	***Wild***	***0***	***2***	***40***	***10***	***0***	***51***
	Hatchery	***0***	***22***	***73***	***5***	***0***	***100***
Median	***Wild***	***0***	***1***	***31***	***7***	***0***	***43***
	Hatchery	***0***	***12***	***65***	***3***	***0***	***96***

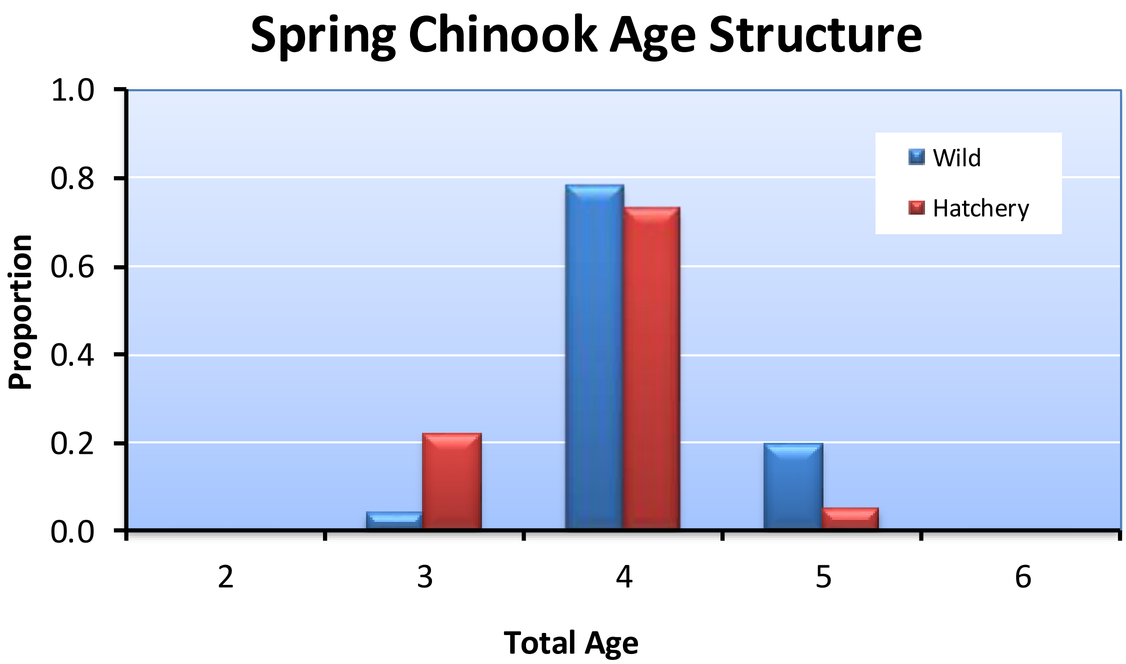

Figure 6.8. Proportions of wild and hatchery spring Chinook of different total ages sampled on spawning grounds in the Nason Creek watershed for the combined years 1999-2016.

Size at Maturity

On average, hatchery and wild spring Chinook of a given age differed little in length (Table 6.20). Differences were usually no more than 5 cm between hatchery and wild fish of the same age.

Table 6.20. Mean lengths (POH in cm; ±1SD) and sample sizes (in parentheses) of different ages (total age) of male and female spring Chinook of wild and hatchery-origin sampled in the Nason Creek watershed, 1999-2016.

Return year	Total age	Mean length (cm)			
		Male		Female	
		Wild	Hatchery	Wild	Hatchery
1999	3	0	0	0	0
	4	71 ±2 (2)	0	64 ±2 (3)	0
	5	0	0	0	0
	6	0	0	0	0
2000	3	46 ±0 (1)	44 ±4 (14)	0	52 ±10 (4)
	4	62 ±4 (19)	0	63 ±3 (25)	60 ±1 (3)
	5	0	0	0	0
	6	0	0	0	0
2001	3	0	47 ±12 (5)	0	0
	4	65 ±4 (21)	66 ±5 (36)	63 ±4 (42)	63 ±4 (123)
	5	81 ±5 (3)	0	72 ±3 (10)	71 ±7 (3)
	6	0	0	0	0
2002	3	0	0	0	0

Return year	Total age	Mean length (cm)			
		Male		Female	
		Wild	Hatchery	Wild	Hatchery
	4	62 ±6 (24)	66 ±5 (35)	63 ±4 (34)	62 ±5 (50)
	5	77 ±4 (12)	81 ±7 (8)	75 ±3 (11)	71 ±5 (3)
	6	0	0	0	0
2003	3	44 ±7 (3)	43 ±5 (3)	0	0
	4	58 ±7 (2)	79 ±0 (1)	67 ±0 (1)	0
	5	75 ±9 (11)	81 ±6 (2)	72 ±6 (25)	71 ±2 (3)
	6	0	0	0	0
2004	3	46 ±0 (1)	43 ±4 (56)	0	0
	4	61 ±4 (35)	60 ±3 (6)	61 ±3 (66)	62 ±4 (17)
	5	0	0	81 ±0 (1)	73 ±4 (2)
	6	0	0	0	0
2005	3	37 ±0 (1)	41 ±7 (3)	0	0
	4	59 ±6 (8)	63 ±4 (54)	61 ±3 (17)	61 ±3 (116)
	5	73 ±5 (4)	0	71 ±1 (13)	0
	6	0	0	0	0
2006	3	0	41 ±3 (12)	0	0
	4	60 ±5 (26)	62 ±3 (29)	61 ±3 (34)	59 ±4 (49)
	5	72 ±5 (10)	73 ±5 (6)	69 ±4 (8)	70 ±4 (16)
	6	0	0	0	0
2007	3	0	44 ±4 (122)	0	51 ±0 (1)
	4	62 ±4 (6)	60 ±7 (13)	63 ±4 (12)	61 ±4 (27)
	5	77 ±5 (7)	67 ±5 (3)	68 ±2 (4)	70 ±2 (6)
	6	0	0	0	0
2008	3	51 ±21 (2)	45 ±5 (20)	0	45 ±0 (1)
	4	60 ±5 (15)	63 ±4 (42)	61 ±3 (31)	63 ±3 (121)
	5	0	77 ±2 (3)	71 ±3 (4)	64 ±7 (3)
	6	0	0	0	0
2009	3	41 ±0 (1)	46 ±5 (18)	0	65 ±0 (1)
	4	60 ±5 (12)	63 ±4 (19)	60 ±3 (24)	61 ±4 (46)
	5	0	71 ±1 (2)	72 ±4 (2)	73 ±3 (2)
	6	0	0	0	0
2010	3	44 ±0 (1)	45 ±5 (5)	0	0
	4	62 ±5 (7)	63 ±4 (42)	61 ±3 (10)	62 ±4 (74)
	5	0	75 ±0 (1)	0	0
	6	0	0	0	0
2011	3	48 ±11 (3)	43 ±4 (31)	0	48 ±2 (2)
	4	61 ±5 (11)	59 ±11 (6)	60 ±5 (12)	63 ±5 (11)
	5	79 ±2 (3)	73 ±3 (6)	75 ±4 (5)	70 ±3 (7)
	6	0	0	0	0
2012	3	41 ±0 (1)	42 ±3 (24)	0	0
	4	61 ±7 (35)	60 ±5 (45)	61 ±4 (54)	60 ±4 (151)

Return year	Total age	Mean length (cm)			
		Male		Female	
		Wild	Hatchery	Wild	Hatchery
	5	77 ±4 (6)	0	66 ±5 (11)	70 ±3 (2)
	6	0	0	0	0
2013	3	0	42 ±4 (21)	0	0
	4	60 ±6 (5)	62 ±4 (23)	60 ±4 (10)	60 ±4 (69)
	5	71 ±0 (1)	75 ±0 (1)	68 ±3 (6)	70 ±4 (4)
	6	0	0	0	0
2014	3	44 ±5 (15)	49 ±4 (9)	60 ±0 (1)	0
	4	64 ±7 (8)	59 ±4 (8)	63 ±3 (11)	60 ±3 (12)
	5	0	0	69 ±8 (3)	0
	6	0	0	0	0
2015	3	44 ±0 (1)	45 ±1 (4)		
	4	61 ±7 (15)	56 ±4 (3)	63 ±5 (10)	58 ±2 (6)
	5	72 ±7 (3)		65 ±0 (1)	
	6				
2016	3	43 ±2 (3)	46 ±5 (10)		45 ±0 (1)
	4	64 ±6 (32)	65 ±1 (3)	64 ±5 (29)	60 ±2 (7)
	5	67 ±0 (1)		71 ±5 (6)	
	6				

Contribution to Fisheries

Because the Nason Creek program began in 2013, there will be no harvest information on Nason Creek hatchery spring Chinook until 2018, when brood year 2013 fish have returned.

Straying

Stray rates will be determined by examining CWTs and PIT tags recovered on spawning grounds within and outside the Wenatchee River basin. Targets for strays based on return year (recovery year) within the Wenatchee River basin should be less than 10% and targets for strays outside the Wenatchee River basin should be less than 5%. The target for brood year stray rates should be less than 5%. Straying of Nason Creek spring Chinook will be estimated beginning in 2017 when the 2013 brood fish return.

Genetics

Because the Nason Creek spring Chinook program began in 2013 with the collection of broodstock, there are no studies that examine the effects of the program on the genetics of natural-origin spring Chinook in the Wenatchee River basin. However, genetic studies were conducted to determine the potential effects of the Chiwawa Supplementation Program on natural-origin spring Chinook in the upper Wenatchee River basin (Blankenship et al. 2007; the entire report is appended as Appendix K). This work included the analysis of Nason Creek spring Chinook. Researchers collected microsatellite DNA allele frequencies from temporally replicated natural and hatchery-origin spring Chinook to statistically assign individual fish to specific demes (locations) within the Wenatchee population.

Significant differences in allele frequencies were observed within and among major spawning areas in the Upper Wenatchee River basin. However, these differences made up only a very small portion of the overall variation, indicating genetic similarity among the major spawning areas. There was no evidence that the Chiwawa program has changed the genetic structure (allele frequency) of spring Chinook in Nason Creek and the White River, despite the presence of hatchery-origin spawners in both systems.

Proportionate Natural Influence

Another method for assessing the genetic risk of a supplementation program is to determine the influence of the hatchery and natural environments on the adaptation of the composite population. This is estimated by the proportion of natural-origin fish in the hatchery broodstock (pNOB) and the proportion of hatchery-origin fish in the natural spawning escapement (pHOS). We calculated Proportionate Natural Influence (PNI) by iterating Ford's (2002) equations 5 and 6 to equilibrium, using a heritability of 0.3 and a selection strength of three standard deviations.[18] The larger the PNI value, the greater the strength of selection in the natural environment relative to that of the hatchery environment. For the natural environment to dominate selection, PNI should be greater than 0.50, and important integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004).

For brood years 1989-2012, when no brood stock was collected for the Nason Creek Program, the PNI values ranged from 0.28 to 1.00 (Table 6.21). During this period, PNI values varied over time because of Chiwawa spring Chinook straying into Nason Creek. For brood years 2013-2016, a period when brood stock was collected for the Nason Creek Program, PNI values for the Nason Creek Program ranged from 0.46 to 0.77 (Table 6.21).

Table 6.21. Proportionate Natural Influence (PNI) Index of hatchery spring Chinook spawning in Nason Creek, brood years 1989-2016. See notes below the table for description of each metric.

Brood year	Spawners					Broodstock			PNI
	NOS	HOS_N	HOS_S	$pHOS_N$	$pHOS_{N+S}$	NOB_N	HOB_N	pNOB	
1989	222	0	0	0.00	0.00	0	0	*1.00*	1.00
1990	231	0	0	0.00	0.00	0	0	*1.00*	1.00
1991	156	0	0	0.00	0.00	0	0	*1.00*	1.00
1992	181	0	0	0.00	0.00	0	0	*1.00*	1.00
1993	430	0	61	0.00	0.12	0	0	*1.00*	0.90
1994	60	0	0	0.00	0.00	0	0	*0.67*	1.00
1995	18	0	0	0.00	0.00	0	0	*0.00*	1.00
1996	58	0	25	0.00	0.30	0	0	*0.44*	0.61
1997	67	0	55	0.00	0.45	0	0	*0.29*	0.42
1998	61	0	3	0.00	0.05	0	0	*0.28*	0.86
1999	22	0	0	0.00	0.00	0	0	*0.00*	1.00
2000	189	0	81	0.00	0.30	0	0	*0.30*	0.52

[18] According to authorized annual take permits, PNI is calculated using the PNI approximate equation 11 (HSRG 2009; Appendix A). However, in this report, we used Ford's (2002) equations 5 and 6 with a heritability of 0.3 and a selection strength of three standard deviations to calculate PNI (C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI). This approach is more accurate than using the PNI approximate equation.

Brood year	Spawners					Broodstock			PNI
	NOS	HOS_N	HOS_S	$pHOS_N$	$pHOS_{N+S}$	NOB_N	HOB_N	pNOB	
2001	257	0	341	0.00	0.57	0	0	*0.30*	0.37
2002	313	0	290	0.00	0.48	0	0	*0.28*	0.39
2003	152	0	50	0.00	0.25	0	0	*0.44*	0.65
2004	297	0	210	0.00	0.41	0	0	*0.39*	0.51
2005	81	0	266	0.00	0.77	0	0	*0.33*	0.32
2006	117	0	154	0.00	0.57	0	0	*0.29*	0.36
2007	83	0	380	0.00	0.82	0	0	*0.29*	0.28
2008	139	0	426	0.00	0.75	0	0	*0.27*	0.29
2009	163	0	371	0.00	0.69	0	0	*0.46*	0.42
2010	59	0	351	0.00	0.86	0	0	*0.44*	0.35
2011	250	0	452	0.00	0.64	0	0	*0.46*	0.43
2012	220	0	474	0.00	0.68	0	0	*0.66*	0.50
Average*	***159***	***0***	***166***	***0.00***	***0.36***	***0***	***0***	***0.48***	***0.63***
Median*	***154***	***0***	***71***	***0.00***	***0.36***	***0***	***0***	***0.42***	***0.52***
2013	70	0	339	0.00	0.83	21	4	0.84	0.55
2014	169	0	68	0.00	0.29	21	0	1.00	0.54
2015	28	0	123	0.00	0.81	59	63	0.48	0.46
2016	125	0	31	0.00	0.20	70	66	0.51	0.77
Average**	***98***	***0***	***140***	***0.00***	***0.53***	***43***	***33***	***0.71***	***0.58***
Median**	***98***	***0***	***96***	***0.00***	***0.55***	***40***	***34***	***0.68***	***0.55***

HOS_N = hatchery-origin spawners in Nason Creek from the Nason Creek spring Chinook Supplementation Program.
$pHOS_N$ = proportion of hatchery-origin spawners from Nason Creek spring Chinook Supplementation Program.
HOS_S = stray hatchery-origin spawners in Nason Creek.
$pHOS_S$ = proportion of stray hatchery-origin spawners.
NOB_N = natural-origin broodstock spawned in the Nason Creek spring Chinook Supplementation Program.
HOB_N = hatchery-origin broodstock spawned in the Nason Creek spring Chinook Supplementation Program.
pNOB = proportion of hatchery-origin broodstock. Because of the high incidence of strays to Nason Creek from the Chiwawa River spring Chinook program, pNOB values from the Chiwawa program were used to estimate PNI values during the period from 1989 to 2012 (*italicized*). The weighting for those years was 100% based on the Chiwawa program broodstock selection, because there have been no hatchery returns from the Nason Creek spring Chinook program (see Table 5.1 for Chiwawa broodstock selection).
PNI_N = Proportionate Natural Influence for Nason Creek spring Chinook calculated using the gene-flow model for multiple programs.
* Average and median for the period 1989-2012, a period when no brood stock were collected for the Nason Creek Program.
** Average and median for the period 2013-present, a period when brood stock was collected for the Nason Creek Program.

Post-Release Survival and Travel Time

We used PIT-tagged fish to estimate survival rates and travel time (arithmetic mean days) of hatchery spring Chinook from the Nason Creek release site to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam (Table 6.22).[19] Over the two brood years for which PIT-tagged hatchery fish were released, survival rates from Nason Creek to McNary Dam ranged from 0.346 to 0.572. Average travel time from Nason Creek to McNary Dam ranged from 21 to 38 days. SARs from release to detection at Bonneville Dam will be calculated in 2018 with the return of 2013 brood fish.

[19] It is important to point out that because of fish size differences among rearing tanks or raceways, fish PIT tagged in one tank or raceway may not represent untagged fish rearing in other tanks or raceways.

Table 6.22. Total number of Nason hatchery spring Chinook released with PIT tags, their survival and travel times (mean days) to McNary Dam, and smolt-to-adult (SAR) ratios for brood years 2013-2014. Standard errors are shown in parentheses. NA = not available (i.e., not all the adults from the release groups have returned to the Columbia River).

Brood year	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2013	20,139	0.346 (0.030)	38.1 (5.9)	NA
2014	5,007	0.572 (0.038)	20.6 (5.3)	NA

Natural and Hatchery Replacement Rates

Natural replacement rates (NRR) were calculated as the ratio of natural-origin recruits (NOR) to the parent spawning population (spawning escapement). Natural-origin recruits are naturally produced (wild) fish that survive to contribute to harvest (directly or indirectly), to broodstock, and to spawning grounds. We do not account for fish that died in route to the spawning grounds (migration mortality) or died just before spawning (pre-spawn mortality) (see Appendix B in Hillman et al. 2012). We calculated NORs with and without harvest. NORs without harvest include all returning fish that either returned to the basin or were collected as wild broodstock. NORs with harvest include all fish harvested and are based on brood-year harvest rates from the Chiwawa Hatchery program. For brood years 1989-2010, NRR for spring Chinook in Nason Creek averaged 0.84 (range, 0.05-5.48) if harvested fish were not included in the estimate and 0.92 (range, 0.05-5.86) if harvested fish were included in the estimate (Table 6.23). NRRs for more recent brood years will be calculated as soon as all tag recoveries and sampling rates have been loaded into the database.

Hatchery replacement rates (HRR) are the hatchery adult-to-adult returns and will be calculated as the ratio of hatchery-origin recruits (HOR) to the parent broodstock collected. These rates should be greater than the NRRs and greater than or equal to 6.7 (the calculated target value in Hillman et al. 2013). The target value of 6.7 includes harvest and was based on HRRs for Chiwawa spring Chinook salmon. HRRs will be calculated beginning in 2018 with the return of 2013 brood fish.

Table 6.23. Spawning escapements, natural-origin recruits (NOR), and natural replacement rates (NRR; with and without harvest) for spring Chinook in the Nason Creek watershed, brood years 1989-2010.

Brood year	Spawning Escapement	Harvest not included		Harvest included	
		NOR	NRR	NOR	NRR
1989	222	171	0.77	249	1.12
1990	231	15	0.06	18	0.08
1991	156	21	0.13	23	0.15
1992	181	47	0.26	49	0.27
1993	491	133	0.27	137	0.28
1994	60	3	0.05	3	0.05
1995	18	22	1.22	23	1.28
1996	83	229	2.76	250	3.01
1997	122	306	2.51	339	2.78
1998	64	351	5.48	375	5.86

Brood year	Spawning Escapement	Harvest not included		Harvest included	
		NOR	NRR	NOR	NRR
1999	22	14	0.64	15	0.68
2000	270	337	1.25	354	1.31
2001	598	77	0.13	79	0.13
2002	603	123	0.20	128	0.21
2003	202	63	0.31	67	0.33
2004	507	131	0.26	141	0.28
2005	347	155	0.45	160	0.46
2006	271	118	0.44	148	0.55
2007	463	210	0.45	251	0.54
2008	565	244	0.43	274	0.48
2009	534	71	0.13	77	0.14
2010	410	113	0.28	140	0.34
Average	***292***	***134***	***0.84***	***150***	***0.92***
Median	***251***	***123***	***0.37***	***139***	***0.40***

Smolt-to-Adult Survivals

Smolt-to-adult survival ratios (SARs) will be calculated as the number of hatchery adult recaptures divided by the number of tagged hatchery smolts released. SARs will be calculated beginning in 2018 with the return of all 2013 brood fish.

6.8 ESA/HCP Compliance

Broodstock Collection

Collection of brood year 2014 broodstock for Nason Creek spring Chinook used a combination of natural-origin adults previously PIT tagged as juveniles and intercepted at Tumwater Dam, and tangle netting in Nason Creek to target up to 64 natural-origin broodstock. Additionally, 130 Chiwawa hatchery-origin adults were collected at Tumwater Dam to secure Grant PUD's Wenatchee spring Chinook production obligation. Total broodstock achieved for the 2014 brood Nason Creek spring Chinook program was 28 and 130 natural and hatchery-origin adults, respectively. A total of 177 bull trout were handled and/or observed during broodstock collection at Tumwater Dam. One bull trout was handled/observed during tangle netting in Nason Creek in 2014.

Hatchery Rearing and Release

The 2014 brood Nason Creek spring Chinook reared throughout all life stages without significant mortality (defined as >10% population mortality associated with a single event). A total of 32,215 WxW and 196,866 HxH smolts were released (25.5% of 2014 conservation program goal and 102.4% of the aggregate Nason program goal). Survival from green-egg through release survival was 87.4%, well above the 81.0% target.

From November 2015 through February 2016, a total of five major freshets occurred in the Nason Creek basin resulting in significant damage and blockage of the Nason Acclimation Facility (NAF) intake structure. To minimize the potential for major fish loss, in March 2016 the HxH component (derived from returning Chiwawa hatchery adults) were transferred to the Chiwawa Acclimation facility for the remainder of their rearing and release. This allowed the limited amount of surface water available at the NAF to be prioritized for the small conservation program. No additional mortality occurred as a result of these actions.

Hatchery Effluent Monitoring

Per ESA Permits 1196, 1347, 1395, 18118, 18120, and 18121, permit holders shall monitor and report hatchery effluents in compliance with applicable National Pollution Discharge Elimination Systems (NPDES) (EPA 1999) permit limitations. There were no NPDES violations reported at PUD Hatchery facilities during the period 1 January through 31 December 2015. NPDES monitoring and reporting for PUD Hatchery Programs during 2015 are provided in Appendix F.

Smolt and Emigrant Trapping

Per ESA Section 10 Permit No. 1196, 18118, 18120, and 18121 the permit holders are authorized a direct take of 20% of the emigrating spring Chinook population during juvenile emigration monitoring and a lethal take not to exceed 2% of the fish captured (NMFS 2003). Based on the estimated wild spring Chinook population (smolt trap expansion) and hatchery juvenile spring Chinook population estimate (hatchery release data) for the Wenatchee River basin, the reported spring Chinook encounters during 2015 emigration monitoring complied with take provisions in the Section 10 permit. Spring Chinook encounter and mortality rates for each trap site (including PIT tag mortalities) are detailed in Table 6.24. Additionally, juvenile fish captured at the trap locations were handled consistent with provisions in ESA Section 10 Permit 1196, 18118, 18120, and 18121, Section B. Table 6.24 includes incidental and direct take associated with the Nason Creek smolt trap operated by the Yakama Nation under separate permits.

Table 6.24. Estimated take of Upper Columbia River spring Chinook resulting from juvenile emigration monitoring in the Wenatchee River basin, 2016.

Trap location	Population estimate			Number trapped			Total	Take allowed under Permit
	Wild[a]	Hatchery[b]	Sub-yearling[c]	Wild	Hatchery	Sub-yearling		
Chiwawa Trap								
Population	37,170	341,226	145,971	2,807	2,525	16,393	21,725	
Encounter rate	NA	NA	NA	0.0755	0.0074	0.1123	0.0414	0.20
Mortality[e]	NA	NA	NA	4	0	82	86	
Mortality rate	NA	NA	NA	0.0014	0.0000	0.0050	0.0040	0.02
White River Trap								
Population	386	NA	2,430	3	NA	197	200	
Encounter rate	NA	NA	NA	0.0078	NA	0.0811	0.0710	0.2
Mortality[d]	NA	NA	NA	0	NA	2	2	
Mortality rate	NA	NA	NA	0.0000	NA	0.0102	0.0100	0.02
Nason Creek Trap								
Population	2,372	32,215	6,813	61	124	791	976	
Encounter rate	NA	NA	NA	0.0257	0.0038	0.1161	0.0236	0.2

Trap location	Population estimate			Number trapped			Total	Take allowed under Permit
	Wild[a]	Hatchery[b]	Sub-yearling[c]	Wild	Hatchery	Sub-yearling		
Mortality[d]	NA	NA	NA	0	0	6	6	
Mortality rate	NA	NA	NA	0.0000	0.0000	0.0076	0.0061	0.02
Lower Wenatchee Trap								
Population	36,752	373,441	4,023,310	610	7,702	27,407	35,719	
Encounter rate	NA	NA	NA	0.0166	0.0206	0.0019	0.0024	0.20
Mortality[d]	NA	NA	NA	2	3	184	189	
Mortality rate	NA	NA	NA	0.0033	0.001	0.0067	0.0053	0.02
Wenatchee River Basin Total								
Population	73,922	373,441	4,169,281	3,417	10,227	40,800	57,444	
Encounter rate	NA	NA	NA	0.0462	0.0274	0.0030	0.0039	0.20
Mortality[d]	NA	NA	NA	6	3	266	275	
Mortality rate	NA	NA	NA	0.0018	0.0001	0.0061	0.0048	0.02

[a] Smolt population estimate derived from juvenile emigration trap data.

[b] 2014 BY smolt release data for the Wenatchee River basin.

[c] Based on size, date of capture and location of capture, subyearling Chinook encountered at the Lower Wenatchee Trap are categorized as summer Chinook salmon.

[d] Combined trapping and PIT tagging mortality.

Spawning Surveys

Spring Chinook spawning ground surveys were conducted in the Wenatchee River basin during 2016, as authorized by ESA Section 10 Permits 18118, 18120, and 18121. Because of the difficulty of quantifying the level of take associated with spawning ground surveys, the Permit does not specify a take level associated with these activities, even though it does authorize implementation of spawning ground surveys. Therefore, no take levels are reported. However, to minimize potential effects to established redds, wading was restricted to the extent practical, and extreme caution was used to avoid established redds when wading was required.

Spring Chinook Reproductive Success Study

ESA Section 10 Permit 1196 (expired) and new Section 10 Permits 18118, 18120, and 18121 specifically provide authorization to capture, anesthetize, biologically sample, PIT tag, and release adult spring Chinook at Tumwater Dam for reproductive success studies and general program monitoring. During 2010 through 2016, all spring Chinook passing Tumwater Dam were enumerated, anesthetized, biologically sampled, PIT tagged, and released (not including hatchery-origin and natural-origin Chinook retained for broodstock) as a component of the reproductive success study (BPA Project No. 2003-039-00). Please refer to Ford et al. (2010, 2011, 2012, 2013, 2014, 2015, and 2016) for complete details on the methods and results of the spring Chinook reproductive success study for the period 2010-2016.

SECTION 7: WHITE RIVER SPRING CHINOOK

The White River spring Chinook salmon captive brood program began in 1997 with goals to conserve, aid in the recovery, and prevent the extinction of naturally spawning spring Chinook in the White River, and to meet the mitigation responsibilities of Grant County PUD. Collection of eggs or juveniles from the White River (brood years 1997-2009) made up the first-generation (F_1) component of the White River captive brood program. Initially, rearing occurred at AquaSeed in Rochester, Washington, but transitioned to the Little White Salmon National Fish Hatchery near Cook, Washington, in 2006. The F_1 component was reared to maturation and spawned within the hatchery. The resulting progeny (F_2) were then reared in the hatchery until final acclimation and released in the upper Wenatchee Basin. The first large release of F_2 juveniles was in 2008. The last release of juveniles from the captive brood program occurred in 2015.

The production goal for the White River captive brood program following the 2013 hatchery recalculation was to release 74,556 yearling smolts into the upper Wenatchee River basin at 18-24 fish per pound. Fish lengths and weights for the recent broods were manipulated to evaluate different approaches for reducing precocious maturation. All fish were marked with CWTs. In addition, from 2008 through 2015, juvenile spring Chinook were PIT tagged annually.

Since its inception, the captive brood program underwent several adaptive changes designed to improve program success. These changes included: (1) use of a pedigree approach to reduce the use of stray fish in the broodstock, (2) transfer of fish from Aquaseed to the Little White Salmon National Fish Hatchery to improve fish quality, (3) injection of hormones into F_1 females to improve maturation of eggs, (4) manipulation of diet and ration for the F_2 fish to reduce precocious maturation of males, (5) use of temporary tanks and natural enclosures during acclimation to improve homing, and (6) trucking juvenile fish around Lake Wenatchee to improve survival.

The following information focuses on results from monitoring the White River spring Chinook program. More detailed information on the White River program can be found in Lauver et al. (2012). Information on spring Chinook collected throughout the Wenatchee River basin is presented in Section 5.

7.1 Captive Brood Collection

The captive brood program was designed to provide a rapid, short-term demographic boost to the White River spring Chinook spawning aggregate, which was at a high risk of local extinction (Lauver et al. 2012). This section describes the collection of broodstock for the White River program.

Brood Collection and Rearing

A primary objective of the White River program was to collect progeny of naturally spawning spring Chinook in the White River. The progeny (eggs or juveniles) make up the first-generation (F_1) of the captive brood program. However, strays from the Chiwawa supplementation program made this a challenge. As a result, researchers attempted to identify the origin of spawners on redds in the White River and then focused egg and juvenile collection efforts on those redds that had the highest likelihood of being produced from White River parents. During most years, this limited the number of redds from which eggs or juveniles could be collected. Starting with brood year 2006, a pedigree approach was adopted to improve the likelihood that eggs or juveniles used in the captive brood program were of White River origin.

During 1997 to 2009, first-generation broodstock for the captive brood program originated from about 10,353 natural-origin eggs and juveniles collected from 122 redds in the White River. Broodstock from brood year 1997 were trapped as parr with nets in the fall of 1998. Broodstock from brood year 2006 were trapped as fry with nets in the spring of 2007. It was assumed that the parr and fry near known redds were produced from those redds, and origin was confirmed with pedigree analyses. All other brood years were collected as eggs in the fall using redd pumping techniques. Broodstock collection levels were calculated based on the following assumptions and the known number of suitable redds each year (Tonseth and Maitland 2011):

1. 150,000 smolt target/0.70 (green egg to release survival) = 214,000 green eggs
2. 214,000 green eggs/1,500 eggs per female = 143 females/0.50 (sex ratio) = 286 fish
3. 286 fish/0.30 (eyed egg to maturity survival) = 953 eyed eggs
4. 953 eyed eggs/**X** redds = **Y** eyed-eggs per redd

Eyed eggs or juveniles collected in the White River were transported to Aquaseed (brood years 1997-2007) or to the Little White Salmon Hatchery (brood years 2008-2009) and reared to adults. Table 7.1 summarizes the collection of eyed eggs or juveniles for the captive brood program.

Table 7.1. Numbers of eyed eggs or juvenile brood stock collected for the White River captive brood program, brood years 1997-2009 (2009 was the last year for broodstock collection). Also shown are the number of redds that were sampled for eggs or juveniles and the hatchery in which the fish were reared (LWSFH = Little White Salmon Fish Hatchery); NS = no sample.

Brood year	Number of eyed eggs collected	Number of juvenile Chinook collected	Number of redds sampled	Rearing facility
1997	0	527 (parr)	8	Aquaseed
1998	182	0	4	Aquaseed
1999	NS	NS	NS	--
2000	272	0	NS	Aquaseed
2001	NS	NS	NS	--
2002	167	0	3	Aquaseed
2003	250	0	8	Aquaseed
2004	1,216	0	10	Aquaseed
2005	2,733	0	21	Aquaseed/LWSFH[1]
2006	0	1,487 (fry)	29	Aquaseed/ LWSFH[2]
2007	1,153	0	13	Aquaseed/ LWSFH[3]
2008	933	0	11	LWSFH
2009	1,433	0	15	LWSFH
Average	***927***	***1,007***	***12***	

[1] Fish were transferred on 30 June and 2 July 2008 and 20 January 2009.
[2] Fish were transferred on 21 October and 13 November 2008.
[3] Fish were transferred on 26 September and 21 October 2008.

7.2 Hatchery Spawning and Release

Captive Brood Spawning

As noted above, eyed eggs or juveniles collected in the White River were transported to Aquaseed (for brood years 1997-2007) or to the Little White Salmon Hatchery (for brood years 2008-2009) and reared to adults (Lauver et al. 2012). After rearing broodstock to maturity in captivity, adult spring Chinook were spawned and their progeny were grown to smolt size, acclimated to White River water, and ultimately released into the White River, Lake Wenatchee, or trucked and released below Lake Wenatchee.

During spawning, eggs and sperm were collected and those gametes were crossed based on a 2x2 factorial spawning matrix. That is, each female was spawned with two males and each male was spawned with two females. Using pedigree analysis, spawning crosses were arranged to maximize genetic diversity. Because incomplete maturation of ova was an issue in the program, implementation of hormone treatments began in 2011 to facilitate maturation. In addition, following spawning, milt from excess males was collected for cryopreservation. Based on a pilot study, the cryopreserved milt was relatively ineffective at fertilizing eggs, so it was not used widely in the program. There are no plans to use the cryopreserved milt in the future. It is noteworthy that most of the males used in spawning were mini-jacks. Table 7.2 shows the ages of first-generation males and females spawned for the captive brood program.

Table 7.2. Total ages of first-generation (F_1) male and female spring Chinook spawned for the White River captive brood program, spawning years 2001-2011; NA = not available.

Spawning year	Sex	Total age				Total
		2	3	4	5	
2001	Female	0	0	3	0	3
	Male	0	2	0	0	2
2002	Female	0	0	4	4	8
	Male	10	0	0	0	10
2003	Female	0	5	0	0	5
	Male	0	2	0	0	2
2004	Female	0	0	2	0	2
	Male	4	0	0	0	4
2005	Female	0	85*	0	0	85
	Male	90	1	0	0	91
2006	Female	2	104	110	0	216
	Male	104	6	0	0	110
2007	Female	0	21	118	1	140
	Male	113	7	0	0	120
2008	Female	0	58	0	0	58
	Male	NA	NA	NA	NA	NA
2009	Female	0	0	119	0	119

Spawning year	Sex	Total age				Total
		2	3	4	5	
	Male	65	54	0	0	119
2010	Female	0	0	42	0	42
	Male	22	23	0	0	45
2011	Female	0	0	0	150	150
	Male	0	148	2	0	150
Average	***Female***	***0***	***25***	***36***	***14***	***75***
	Male	***41***	***24***	***0***	***0***	***65***
Median	***Female***	***0***	***0***	***3***	***0***	***58***
	Male	***16***	***4***	***0***	***0***	***68***

* Included some unknown number of second-generation females.

Release Information

Numbers released

Several different acclimation and release scenarios were conducted since 1997. Acclimation scenarios have involved naturalized features such as in-channel enclosures, stream-side tanks supplied with pass-through surface water, and net pens in Lake Wenatchee near the mouth of the White River. Release scenarios have included on-site releases from tanks, in-channel enclosures, and net pens in Lake Wenatchee. The low survival of fish released in the lake and White River prompted exploring the release of fish near the mouth of the lake and downstream from the lake. In 2010, acclimated fish were towed in net pens to the mouth of the lake and released there. In 2011, tank and net-pen acclimated fish were loaded into transport trucks and released into the Wenatchee River. In addition, subyearling and yearling Chinook with no acclimation have been released from transport trucks directly into Lake Wenatchee and the White River. A total of 944,591 second-generation (F_2) juvenile spring Chinook have been released from the captive brood program. Table 7.3 summarizes the acclimation and release history of F_2 spring Chinook released into the upper Wenatchee River basin.

Table 7.3. Numbers of White River juvenile spring Chinook released and their acclimation histories for brood years 2002-2013.

Brood year	Acclimation site	Acclimation vessel	Number of smolts released	Release scenario	Release date	Number of acclimation days
2002	WR RM 11.5	Tanks	2,589	White River	4/22/2004	17
2003	WR RM 11.5	Tanks	2,096	White River	5/2/2005	47
2004	WR RM 11.5	Tanks	1,639	White River	4/4/2006	0
2005	Lake Wen	Net Pens	69,032	Lake Wen	5/2/2007	34
2006	NA	NA	139,644*	White River	4/17, 4/25/2007	0
	NA	NA	142,033	White River	3/18, 3/20/2008	0
2007	Lake Wen	Net Pens	87,671	Lake Wen	5/5/2009	35-40
	None	None	44,172	Lake Wen	4/1/2009	0

Brood year	Acclimation site	Acclimation vessel	Number of smolts released	Release scenario	Release date	Number of acclimation days
2008	WR Bridge	Eddy Pen	10,156	Escape	~4/12/2010	~10
	Lake Wen	Net Pens	38,400	Mouth of lake	5/5, 5/6/2010	38-41
2009	WR RM 11.5	Side Channel	12,000	Escape	~3/31/2011	~7
	WR RM 11.5	Tanks	10,000	White River	5/12/2011	49
	WR Bridge	Tanks	28,000	White River	5/14/2011	51
	WR Bridge	Tanks		Wen River	5/13/2011	50
	WR Bridge	Eddy Pen	14,596	Escape	~3/27/2011	~3
	Lake Wen	Net Pens	48,000	Wen River	5/14/2011	46
	Lake Wen	Net Pens		Wen River	5/14/2011	44
2010	WR Bridge	Tanks	18,850	Wen River	5/9/2012	44
2011	WR Bridge	Tanks	42,000	Wen & White R	5/6, 5/7, 5/8/13	49, 50, 51
	Lake Wen	Net Pens	105,000	Wen River	5/8, 5/13, 5/14/13	51, 56, 57
2012	WR Bridge	Tanks	42,000	Wen River	5/6/14	50
	Lake Wen	Net Pens	55,713	Wen River	5/8/14	49
2013	WR Bridge	Tanks	31,000	Wen River	5/4/15	56

* Subyearling release.

Numbers tagged

Brood years 2005 and 2007-2014 spring Chinook were tagged with a CWT in their peduncle. None of these fish were adipose fin clipped.[20] Subyearling fish from the 2006 brood year were tagged with half of a CWT in their snouts. Yearling fish from the 2006 brood year were tagged with CWTs in the peduncle. None of these fish were adipose fin clipped. In addition, beginning in 2008 (brood year 2006), 303,207 juvenile spring Chinook have been PIT tagged before release. Table 7.4 identifies the number of second-generation (F_2) juvenile spring Chinook tagged with PIT tags.

Table 7.4. Numbers of second-generation (F2) White River spring Chinook smolts tagged and released in the upper Wenatchee River basin, brood years 2002-2013.

Brood year	Acclimation site	Acclimation vessel	Release scenario	CWT mark rate	Number released that were PIT tagged	Number of smolts released
2002	WR RM 11.5	Tanks	White River	0.00	0	2,589
2003	WR RM 11.5	Tanks	White River	0.00	0	2,096
2004	WR RM 11.5	Tanks	White River	0.00	0	1,639
2005	Lake Wen	Net Pens	Lake Wen	1.00	0	69,032

20 Given that juvenile spring Chinook were tagged with CWTs in the peduncle and were not ad-clipped, it is possible that field crews missed hatchery-origin adults on the spawning grounds because they did not know they were supposed to sample fish with adipose fins. Thus, this bias in carcass sampling may bias derived metrics such as spawning distribution of hatchery and natural-origin fish, spawn timing of hatchery and natural-origin fish, age at maturity, size at maturity, contributions to fisheries, HOR, NOR, HRR, NRR, PNI, straying, and SARs.

Brood year	Acclimation site	Acclimation vessel	Release scenario	CWT mark rate	Number released that were PIT tagged	Number of smolts released
2006	NA	NA	White River	0.00	29,881	139,644*
	NA	NA	White River	0.00		142,033
2007	Lake Wen	Net Pens	Lake Wen	1.00	29,863	87,671
	None	None	Lake Wen	1.00	9,957	44,172
2008	WR Bridge	Eddy Pen	Escape	1.00	38,148	10,156
	Lake Wen	Net Pens	Lake Mouth	1.00		38,400
2009	WR RM 11.5	Side Channel	Escape	1.00	41,886	12,000
	WR RM 11.5	Tanks	White River	1.00		10,000
	WR Bridge	Tanks	White River	1.00		28,000
	WR Bridge	Tanks	Wen River	1.00		
	WR Bridge	Eddy Pen	Escape	1.00		14,596
	Lake Wen	Net Pens	Wen River	1.00		48,000
	Lake Wen	Net Pens	Wen River	1.00		
2010	WR Bridge	Tanks	Wen River	1.00	12,283	18,850
2011	WR Bridge	Tanks	Wen & White	1.00	2,490	42,000
	Lake Wen	Net Pens	Wen River	1.00	51,697	105,000
2012	WR Bridge	Tanks	Wen River	1.00	52,097	42,000
	Lake Wen	Net Pens	Wen River	1.00		55,713
2013	WR Bridge	Tanks	Wen River	1.00	34,905	31,000

* Subyearling release.

Fish size and condition at release

Table 7.5 summarizes the size and condition of second-generation White River juvenile spring Chinook released in the upper Wenatchee River basin.

Table 7.5. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of second-generation White River (WR) juvenile spring Chinook released in the upper Wenatchee River basin, brood years 2002-2013. Size targets are provided in the last row of the table. NA = not available.

Brood year	Acclimation site	Release scenario	Fork length (mm)		Mean weight	
			Mean	CV	Grams (g)	Fish/pound
2002	WR RM 11.5	White River	NA	NA	NA	NA
2003	WR RM 11.5	White River	166	12.4	53.7	8
2004	WR RM 11.5	White River	207	11.6	117.7	4
2005	Lake Wen	Lake Wen	145	9.7	36.9	31
2006	NA	White River	NA	NA	NA	NA
	NA	White River	NA	NA	NA	NA
2007	Lake Wen	Lake Wen	135	7.8	29.2	29

Brood year	Acclimation site	Release scenario	Fork length (mm)		Mean weight	
			Mean	CV	Grams (g)	Fish/pound
	None	Lake Wen	NA	NA	NA	NA
2008	WR Bridge	Escape	--	--	--	--
	Lake Wen	Mouth of lake	138	10.0	32.5	14
2009	WR RM 11.5	Escape	--	--	--	--
	WR RM 11.5	White River	134	8.7	29.3	16
	WR Bridge	White River	138	9.3	28.6	16
	WR Bridge	Wen River	NA	NA	NA	NA
	WR Bridge	Escape	--	--	--	--
	Lake Wen	Wen River	140	8.9	31.6	14
	Lake Wen	Wen River	142	9.8	39.3	12
2010	WR Bridge	Wen River	125	8.0	22.8	20
2011	WR Bridge	Wen & White	130	8.4	24.1	19
	Lake Wen	Wen River	128	8.2	24.0	19
2012	WR Bridge	Wen River	131	8.1	24.2	18.8
	Lake Wen	Wen River	NA	NA	NA	NA
2013	WR Bridge	Wen River	132	8.7	24.5	19
Average			142	9.3	37.0	17

Post-Release Survival

We used PIT-tagged fish to estimate survival rates and travel time (arithmetic mean days) of released second-generation (F_2) White River spring Chinook smolts to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam.[21] Based on the available data, post-release survival has been low for fish released into the White River and Lake Wenatchee (Table 7.6). In contrast, survival of fish released in the Wenatchee River tends to be higher than those released in the White River or in Lake Wenatchee. These results suggest that high mortality in Lake Wenatchee may explain why adult returns of program fish have been consistently poor; however, other factors such as high precocious maturation may also contribute to the estimated low survival (e.g., see Ford et al. 2015).

Average travel time from release to McNary Dam ranged from 21 to 82 days (Table 7.6). Spring Chinook released in the Wenatchee River typically traveled faster to McNary Dam than those released in the White River or in Lake Wenatchee. Because of uncertain release times for several groups, we were unable to estimate travel times for all release groups.

[21] It is important to point out that because of fish size differences among rearing net pens, tanks, or raceways, fish PIT tagged in one pen, tank, or raceway may not represent untagged fish rearing in other pens, tanks, or raceways.

Table 7.6. Survival and travel times (mean days) of second-generation (F2) White River spring Chinook smolts to McNary Dam and SARs to Bonneville Dam for different release scenarios, brood years 2006-2013. Values in parentheses represent the standard error of the estimate. NA = not available (i.e., not all the fish from the release groups have returned to the Columbia River).

Brood year	Release scenario	Number of Chinook released with PIT tags	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2006	White River	29,881	0.037 (0.008)	82.3 (16.1)	0.000 (0.000)
2007	Lake Wen Pens	29,863	0.096 (0.010)	NA	0.000 (--)
	Lake Wenatchee	9,957	0.080 (0.015)	NA	0.000 (--)
2008	Lake Wenatchee	38,146	0.065 (0.010)	65.2 (14.0)	0.001 (0.000)
2009	White and Wenatchee rivers	19,913	0.269 (0.027)	22.9 (9.2)	0.002 (0.000)
	White River	21,829	0.055 (0.013)	45.6 (21.0)	0.000 (0.000)
2010	Wenatchee River	12,283	0.267 (0.017)	NA	0.001 (0.000)
2011	Wenatchee River	2,490	0.385 (0.042)	NA	0.004 (0.001)
	White and Wenatchee rivers	51,697	0.434 (0.010)	NA	0.003 (0.000)
2012	Wenatchee River	52,115	0.353 (0.013)	NA	NA
2013	Wenatchee River	34,905	0.767 (0.064)	20.6 (5.7)	NA

7.3 Disease Monitoring

First-Generation Health Maintenance

First-generation (F_1) adults were fed an azithromycin-medicated feed in the spring to prevent bacterial kidney disease (BKD), which is a common affliction of spring Chinook salmon. As needed, fish received a dose of 20 mg/kg of body weight. The fish also received formalin treatments as needed throughout the year to prevent and treat fungus infections. This was especially important during the pre-spawning period when individual fish were maturing in preparation for spawning. Formalin treatments were conducted three times per week and consist of one hour of flow-through at a concentration of 167 parts per million (ppm).

Second-Generation Health Maintenance

Following fertilization and initial incubation in September, second-generation (F_2) eggs were shocked in October. Eggs were treated with a 1,667 ppm formalin solution in a 15-minute flow-through treatment three times a week to prevent fungus growth. Formalin treatments ended after hatching, and water flow was increased from three to five gallons per minute. Dead and deformed fry were removed before relocating the fry to nursery tanks in late January or early February. Fry were then relocated to raceways in July, where they remained until transfer to the White River for acclimation the following March. Coded-wire tagging was typically conducted in July, and PIT tagging occurred the following January or February, just before the fish were transferred to acclimation facilities on the White River in March.

7.4 Natural Juvenile Productivity

Juvenile productivity estimation began with the monitoring of emigration of spring Chinook in the White River in 2007 (Lauver et al. 2012). A five-foot diameter rotary screw trap is operated annually from about 1 March through November. The purpose of the program is to estimate the number and timing of subyearlings and yearling spring Chinook emigrating from the White River basin.

Smolt and Emigrant Estimates

In 2016, the White River Trap operated between 1 March and 30 November 2016. During that period, the trap was not intentionally disabled under any circumstance. Daily trap efficiencies were estimated by conducting mark-recapture trials. The daily number of fish captured was expanded by the estimated trap efficiency to estimate daily total emigration. If trap efficiencies could not be assessed because of low numbers of juvenile Chinook trapped, a composite model based on efficiency trials from previous years was used to calculate abundance. Daily captures of fish and results of mark-recapture efficiency tests at the White River trap are reported in Appendix M.

Wild yearling spring Chinook (2014 brood year) were captured primarily from March through April 2016 (Figure 7.1). Based on a composite regression model, the total number of wild yearling Chinook emigrating from the White River was 386 (±701). Combining the total number of subyearling spring Chinook (1,950 ±400) that emigrated during the fall of 2015 with the total number of yearling Chinook (386) that emigrated during 2016 resulted in a total emigrant estimate of 2,336 (±847) spring Chinook for the 2014 brood year (Table 7.7).

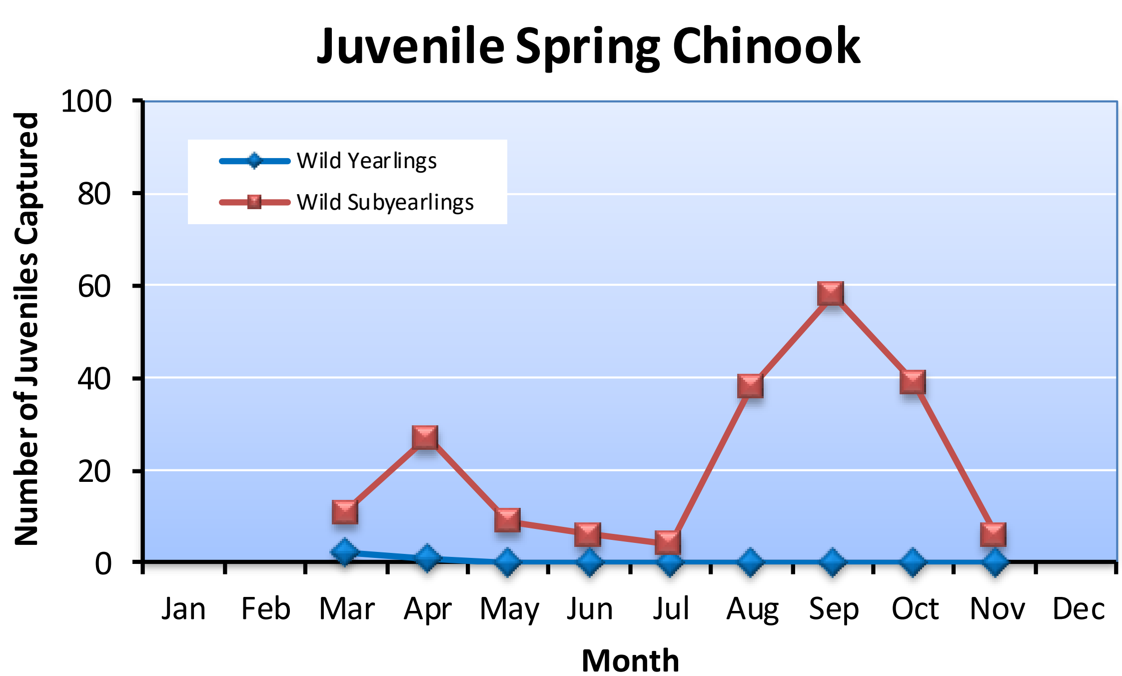

Figure 7.1. Monthly captures of wild subyearling (parr) and yearling spring Chinook at the White River Trap, 2016.

Table 7.7. Numbers of redds and juvenile spring Chinook at different life stages in the White River basin for brood years 2005-2015; ND = no data.

Brood year	Number of redds	Egg deposition[a]	Number of subyearling emigrants[b]	Number of smolts produced within White River basin	Number of emigrants
2005	86	372,122	ND	4,856	ND
2006	31	134,044	642	2,004	2,646
2007	20	88,820	2,293	3,399	5,692
2008	31	142,352	5,552	5,193	10,745
2009	54	246,942	2,485	2,939	5,424
2010	33	142,362	1,859	4,121	5,980
2011	20	87,700	3,128	1,659	4,787
2012	86	363,178	3,905	3,995	7,900
2013	54	254,664	2,461	3,023	5,484
2014	26	105,170	1,950	386	2,336
2015	70	339,290	2,430	--	--
Average[c]	***46***	***206,968***	***2,659***	***3,158***	***5,666***
Median[c]	***33***	***142,362***	***2,429***	***3,211***	***5,484***

[a] Egg deposition is calculated as the number of redds times the fecundity of both wild and hatchery spring Chinook salmon (from Table 5.5.

[b] Subyearling emigrants do not include fry that left the watershed before 1 July.

[c] Average and median are based on the entire time series of data, not just the period 2006 through 2012.

Wild subyearling spring Chinook (2015 brood year) were captured between 7 March and 30 November 2016, with peak catch during August (Figure 7.1). Based on a composite regression model, the total number of wild subyearling Chinook emigrating from the White River was 2,430 (±723).

Yearling spring Chinook sampled in 2016 averaged 106 mm in length, 12.4 g in weight, and had a mean condition of 1.05 (Table 7.8). The estimated length and weight were greater than the overall mean of yearling spring Chinook sampled in previous years (overall means, 100 mm and 11.3 g). The estimated condition for the 2014 brood was less than the overall mean (overall mean, 1.10). Subyearling spring Chinook parr sampled in 2016 at the White River Trap averaged 89 mm in length, averaged 8.3 g, and had a mean condition of 1.13 (Table 7.8). Estimated length and weight were less than the overall mean of subyearling spring Chinook sampled in previous years (overall means, 90 mm and 8.5 g), while the estimated condition was greater (overall mean, 1.10).

Table 7.8. Mean fork length (mm), weight (g), and condition factor of subyearling (parr) and yearling spring Chinook collected in the White River Trap, 2007-2016. Numbers in parentheses indicate 1 standard deviation.

Sample year	Life stage	Sample size[a]	Mean size		
			Length (mm)	Weight (g)	Condition (K)
2007	Subyearling	33	95 (12)	9.8 (4.1)	1.07 (0.11)
	Yearling	173	93 (9)	8.6 (2.2)	1.03 (0.09)

Sample year	Life stage	Sample size[a]	Mean size		
			Length (mm)	Weight (g)	Condition (K)
2008	Subyearling	202	95 (9)	9.4 (2.5)	1.08 (0.13)
	Yearling	105	100 (12)	11.3 (3.3)	1.07 (0.13)
2009	Subyearling	499	85 (11)	7.1 (2.6)	1.09 (0.11)
	Yearling	274	104 (6)	12.5 (2.6)	1.11 (0.10)
2010	Subyearling	168	87 (13)	7.8 (3.1)	1.12 (0.11)
	Yearling	346	100 (7)	11.2 (2.4)	1.12 (0.09)
2011	Subyearling	145	94 (9)	9.3 (2.5)	1.10 (0.10)
	Yearling	64	99 (8)	11.3 (2.8)	1.14 (0.09)
2012	Subyearling	285	91 (10)	8.9 (2.7)	1.13 (0.09)
	Yearling	179	98 (8)	10.9 (2.8)	1.14 (0.08)
2013	Subyearling	444	84 (12)	6.6 (2.5)	1.05 (0.09)
	Yearling	20	102 (7)	12.3 (3.0)	1.12 (0.14)
2014	Subyearling	185	86 (14)	7.5 (3.3)	1.10 (0.11)
	Yearling	43	94 (7)	9.4 (2.2)	1.11 (0.13)
2015	Subyearling	148	96 (8)	9.9 (2.3)	1.11 (0.07)
	Yearling	31	104 (7)	13.0 (2.8)	1.14 (0.07)
2016	Subyearling	147	89 (11)	8.3 (2.8)	1.13 (0.10)
	Yearling	3	106 (2)	12.4 (0.3)	1.05 (0.03)
Average	***Subyearling***	***226***	***90 (5)***	***8.5 (1.1)***	***1.10 (0.03)***
	Yearling	***124***	***100 (4)***	***11.3 (1.4)***	***1.10 (0.04)***
Median	***Subyearling***	***177***	***90 (5)***	***8.6 (1.2)***	***1.10 (0.03)***
	Yearling	***85***	***100 (4)***	***11.3 (1.4)***	***1.12 (0.04)***

[a] Sample size represents the number of fish that were measured for both length and weight.

Freshwater Productivity

Both productivity and survival estimates for different life stages of spring Chinook in the White River basin are provided in Table 7.9. Estimates for brood year 2014 generally fall below the range of productivity and survival estimates for brood years 2005-2013. During that period, freshwater productivities ranged from 15-170 smolts/redd and 85-347 emigrants/redd. Survivals during the same period ranged from 0.4-3.8% for egg-smolt and 2.0-7.5% for egg-emigrants.

Table 7.9. Productivity (fish/redd) and survival (%) estimates for different juvenile life stages of spring Chinook in the White River basin for brood years 2005-2014. These estimates were derived from data in Table 7.7. ND = no data.

Brood year	Smolts/Redd[a]	Emigrants/ Redd	Egg-Smolt[a] (%)	Egg-Emigrant (%)
2005	56	ND	1.3	ND
2006	65	85	1.5	2.0
2007	170	285	3.8	6.4
2008	168	347	3.6	7.5
2009	54	100	1.2	2.2

Brood year	Smolts/Redd[a]	Emigrants/ Redd	Egg-Smolt[a] (%)	Egg-Emigrant (%)
2010	125	181	2.9	4.2
2011	83	239	1.9	5.5
2012	46	92	1.1	2.2
2013	56	102	1.2	2.2
2014	15	90	0.4	2.2
Average	***84***	***169***	***1.9***	***3.8***
Median	***61***	***102***	***1.4***	***2.2***

[a] These estimates include White River smolts produced only within the White River basin.

Seeding level (egg deposition) explained part of the variability in productivity and survival of juvenile spring Chinook in the White River basin. That is, for estimates based on smolts produced within the White River basin, survival and productivity decreased as seeding levels increased (Figure 7.2). This suggests that density dependence in part regulates juvenile productivity and survival within the White River basin.

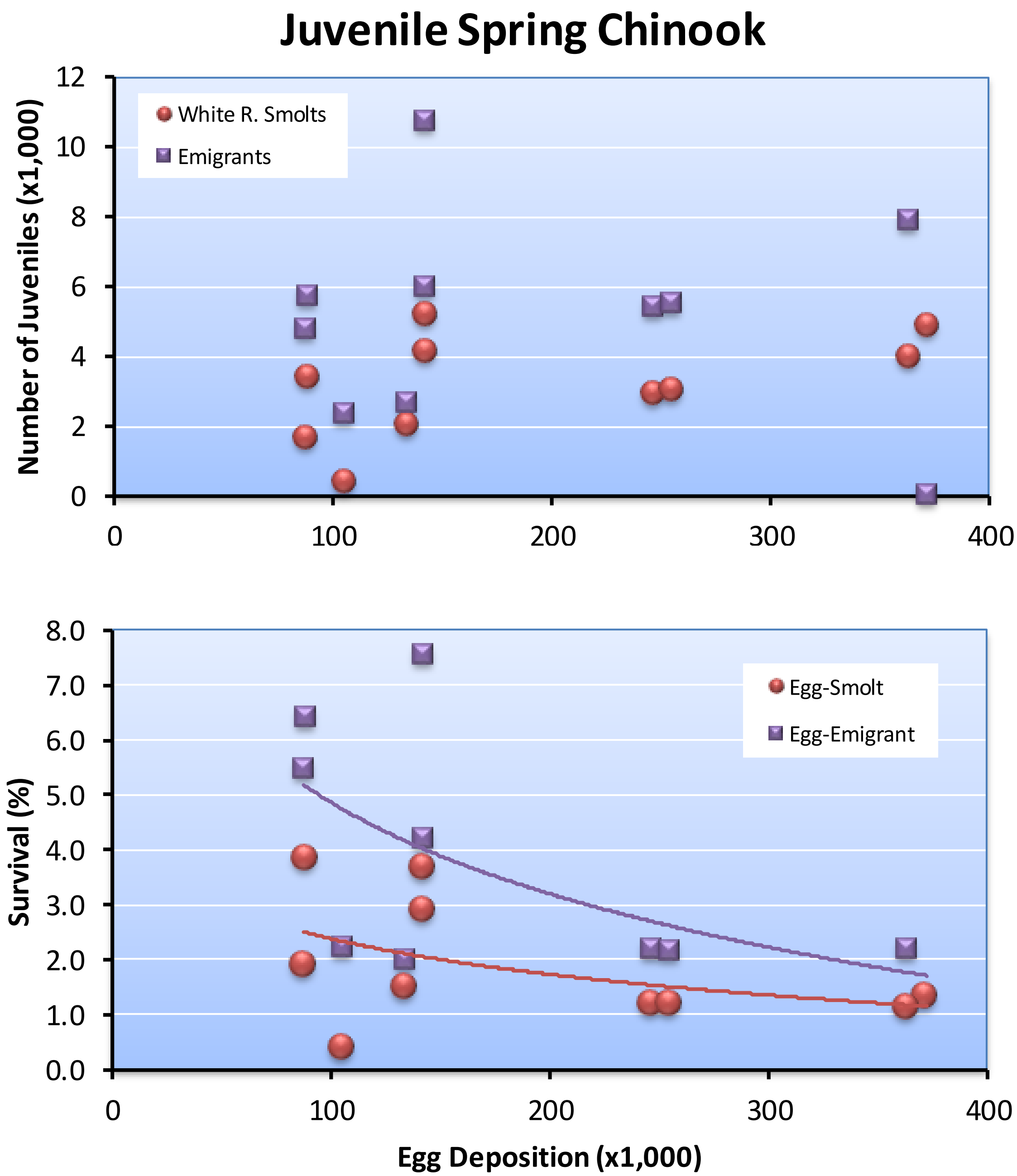

Figure 7.2. Relationships between seeding levels (egg deposition) and juvenile life-stage survivals and productivities for White River spring Chinook, brood years 2005-2014. White River smolts are smolts produced only within the White River basin.

Population Carrying Capacity

Population carrying capacity (*K*) is defined as the maximum equilibrium population size estimated with population models (e.g., logistic equation, Beverton-Holt model, hockey stick model, and the

Ricker model).[22] Maximum equilibrium population size is generated from density dependent mechanisms that reduce population growth rates as population size increases (negative density dependence). This is referred to as compensation. Population size fluctuates about the maximum equilibrium size because of variability in vital rates that are unrelated to density (density independent factors) and measurement error. In this section, we estimate smolt carrying capacities using the Ricker stock-recruitment model (see Appendix C in Hillman et al. 2012 for a detailed description of methods). The Ricker model was the only stock-recruitment model that could be fit to the juvenile spring Chinook data.

Based on the Ricker model, the population carrying capacity for spring Chinook smolts in the White River basin is 4,659 smolts (95% CI: 0 – 7,075) (Figure 7.3). Here, smolts are defined as the number of yearling spring Chinook produced entirely within the White River basin. These estimates reflect current conditions (most recent decades) within the White River basin. Land use activities such as logging, roads, development, and recreation have altered the historical conditions of the watershed. Thus, the estimated population capacity estimates may not reflect historical capacities for spring Chinook smolts in the White River basin.

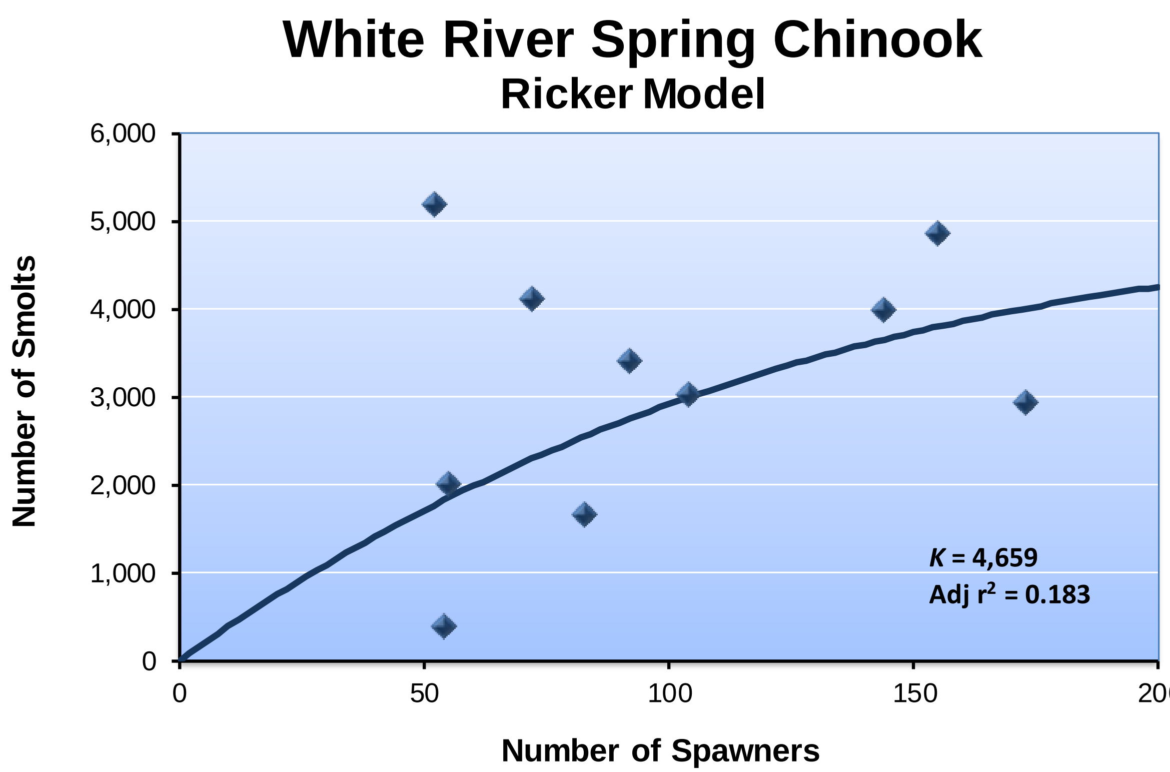

Figure 7.3. Relationship between spawners and number of smolts produced in the White River basin. Population carrying capacity (*K*) was estimated using the Ricker model.

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[22] Population carrying capacity (*K*) should not be confused with habitat carrying capacity (*C*), which is defined as the maximum population of a given species that a particular environment can sustain.

We tracked the precision of the Ricker parameters for White River spring Chinook smolts over time to see if precision improves with additional years of data, and the parameters and statistics stabilize over time. Examination of variation in the alpha (*A*) and beta (*B*) parameters of the Ricker model and their associated standard errors and confidence intervals indicates that the parameters have not stabilized and lack precision (Table 7.10; Figure 7.4). This was also apparent in the estimates of population carrying capacity (Figure 7.5).

Table 7.10. Estimated parameters and statistics associated with fitting the Ricker model to spawning escapement and smolt data. Smolts represent numbers of smolts produced entirely within the White River basin. *A* = alpha parameter; *B* = beta parameter; SE = standard error (estimated from 5,000 bootstrap samples); and r^2 = coefficient of determination. Spawners represent the stock size needed to achieve population capacity.

Years of data	Parameter				Population capacity	Intrinsic productivity	Spawners	r^2
	A	SE	*B*	SE				
5	95.89	44.84	0.0090	0.0040	3,928	96	111	0.001
6	100.65	37.65	0.0092	0.0034	4,007	101	108	0.019
7	81.75	36.97	0.0084	0.0042	3,602	82	120	0.001
8	80.32	32.78	0.0080	0.0036	3,675	80	124	0.009
9	78.79	42.85	0.0080	0.0037	3,605	79	124	0.014
10	40.02	33.48	0.0032	0.0040	4,659	40	316	0.183

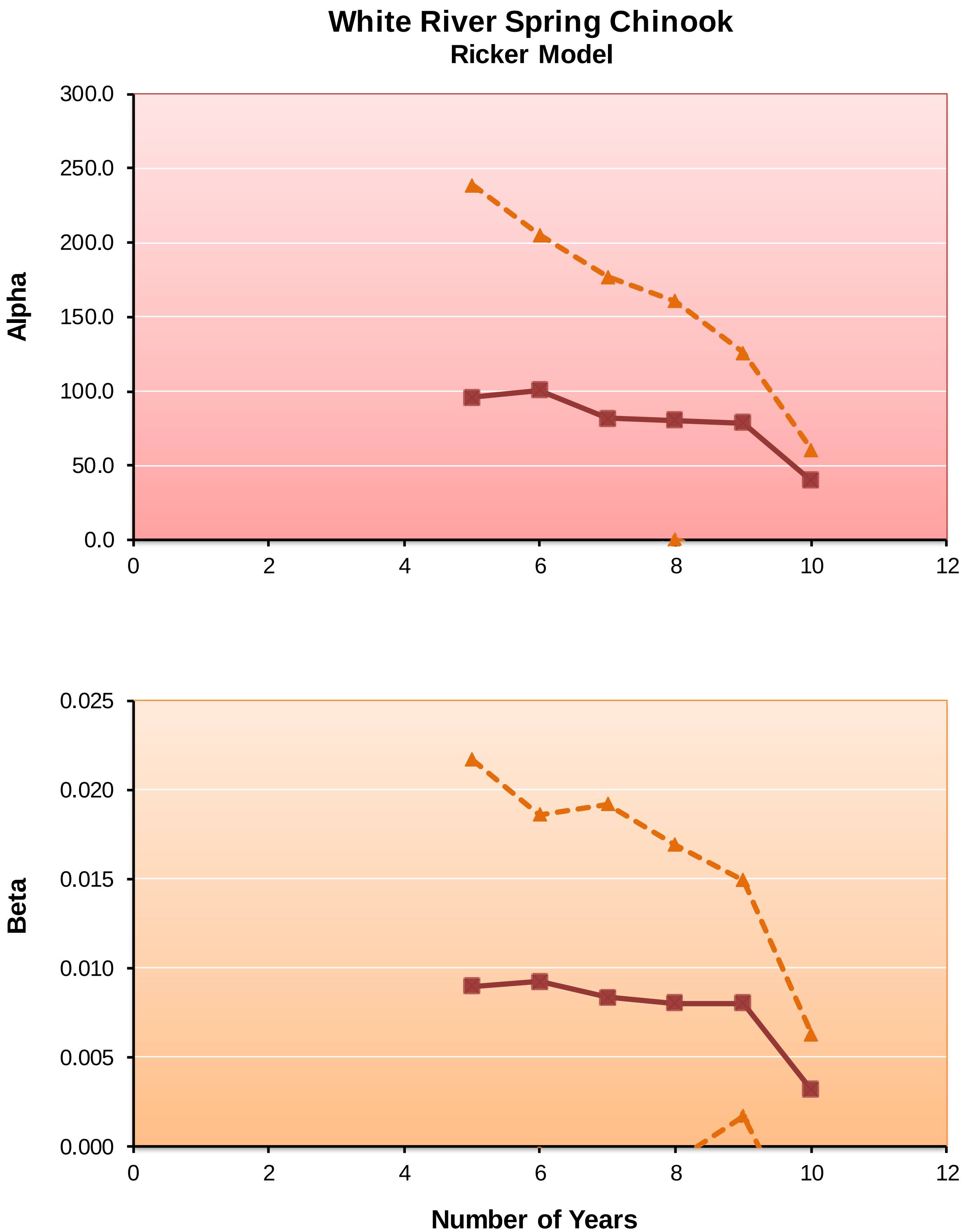

Figure 7.4. Time series of alpha and beta parameters and 95% confidence intervals for the Ricker model that was fit to White River spring Chinook smolt and spawning escapement data. Confidence intervals were estimated from 5,000 bootstrap samples.

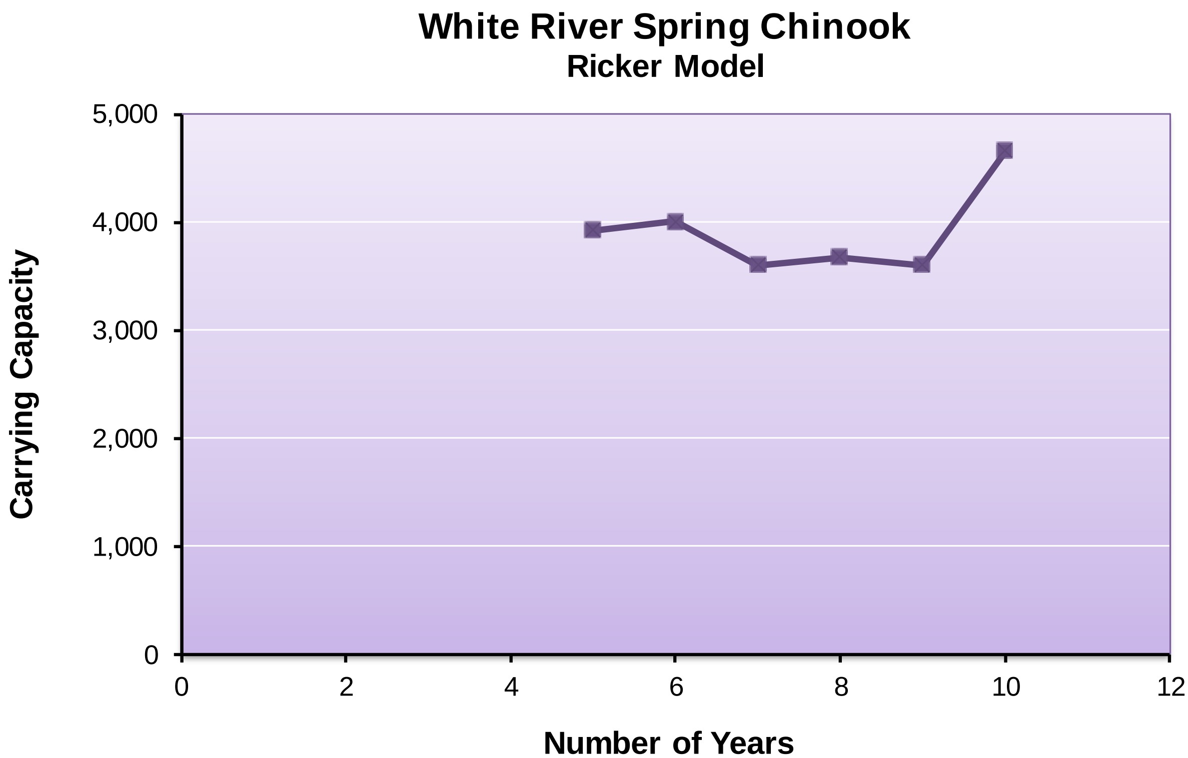

Figure 7.5. Time series of population carrying capacity estimates derived from fitting the Ricker model to White River spring Chinook smolt and spawning escapement data.

7.5 Spawning Surveys

Surveys for spring Chinook redds were conducted during August through September 2016 in the Chiwawa River (including Rock, Phelps, and Chikamin creeks), Nason Creek, Icicle Creek, Peshastin Creek (including Ingalls Creek), Upper Wenatchee River (including Chiwaukum Creek), Little Wenatchee River, and White River (including the Napeequa River and Panther Creek). See Section 5.5 for a complete coverage of spring Chinook redd surveys in the Wenatchee River basin. In the following section, we describe the number and distribution of redds within the White River basin.

Redd Counts and Distribution

A total of 44 spring Chinook redds were counted in the White River basin in 2016 (Table 7.11; see Table 5.20 for the complete time series of redd counts). This is higher than the average of 35 redds counted during the period 1989-2015 in the White River. Redds were not distributed evenly among the six survey areas in the White River basin. Most redds (81%) were located in Reach 3 (Napeequa River to Grasshopper Meadows) in the White River (Table 7.11).

Table 7.11. Numbers (both observed and estimated) and proportions of spring Chinook redds counted within different survey areas within the White River basin during August through September 2016. See Table 2.8 for description of survey reaches.

Stream/watershed	Reach	Number of observed redds	Estimated number of redds*	Proportion of estimated redds within stream/watershed
White River	White 1 (H1)	0	--	--
	White 2 (H2)	4	6	0.11
	White 3 (H3)	37	43	0.81
	White 4 (H4)	2	3	0.06
	Napeequa 1 (Q1)	1	1	0.02
	Panther 1 (T1)	0	0	0.00
Total		***44***	***53***	***1.00***

* Estimated redds represent the "true" number of redds based on Guassian area-under-the-curve method (see Appendix J).

Spawn Timing

Spring Chinook began spawning during the third week of August in the White River and peaked the second week of September (Figure 7.6). Spawning in the White River ended the third week of September.

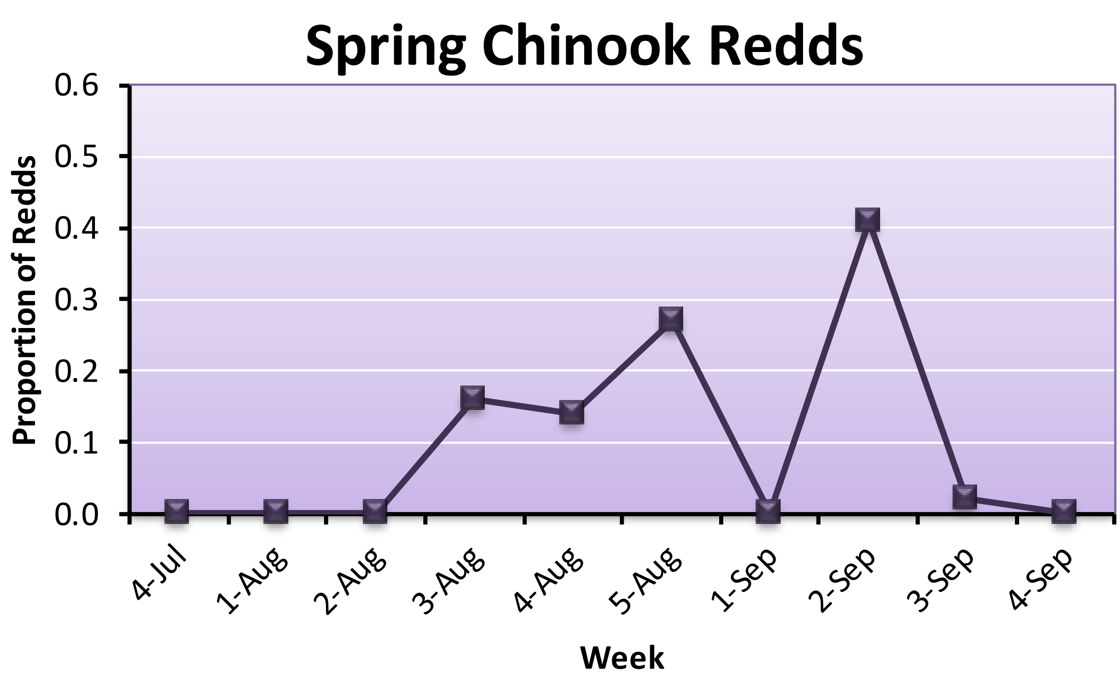

Figure 7.6. Proportion of spring Chinook redds counted during different weeks within the White River basin, August through September 2016.

Spawning Escapement

Spawning escapement for spring Chinook was calculated as the number of redds times the male-to-female ratio (i.e., fish per redd expansion factor) estimated from broodstock and fish sampled at adult trapping sites.[23] The estimated fish per redd ratio for spring Chinook upstream from Tumwater in 2016 was 1.83 (based on sex ratios estimated at Tumwater Dam). Multiplying this ratio by the number of redds counted in the White River basin resulted in a total spawning escapement of 81 spring Chinook. The estimated total spawning escapement of spring Chinook in 2016 was greater than the overall average of 76 spring Chinook in the White River basin (see Table 5.23).

7.6 Carcass Surveys

Surveys for spring Chinook carcasses were conducted during August through September 2016 in the Chiwawa River (including Rock, Phelps, and Chikamin creeks), Nason Creek, Icicle Creek, Peshastin Creek (including Ingalls Creek), Upper Wenatchee River (including Chiwaukum Creek), Little Wenatchee River, and the White River (including the Napeequa River and Panther Creek). In 2016, 13 spring Chinook carcasses were sampled in the White River basin. Most of these were sampled in Reach 3. The total number of carcasses sampled in 2016 was less than the overall average of 20 carcasses sampled during the period 1996-2015. See Section 5.6 for a complete coverage of spring Chinook carcass surveys in the Wenatchee River basin.

In the White River basin, the spatial distribution of hatchery strays (primarily from the Chiwawa Spring Chinook program) and wild spring Chinook was not equal (Table 7.12). Only one carcass was recovered in Reach 2, which was of hatchery origin, while Reach 3 had primarily wild fish (91%). In 2016, most carcasses (85%) were observed in the reach between the Napeequa River and Grasshopper Meadows (Reach 3) (Table 7.12). Over the years, spring Chinook have spawned more often in this reach than in other reaches (Figure 7.7).

Table 7.12. Numbers of wild, hatchery strays, and captive brood spring Chinook carcasses sampled within different reaches in the White River basin, 2000-2016. Numbers represent recovered carcasses that had definitive origins. See Table 2.8 for description of survey reaches.

Survey year	Origin	Survey Reach					Total
		H-2	H-3	H-4	Napeequa	Panther	
2000	Wild	1	0	0	0	0	**1**
	Hatchery Strays	0	0	0	0	0	**0**
2001	Wild	5	40	5	3	1	**54**
	Hatchery Strays	1	19	3	1	2	**26**
2002	Wild	3	15	0	0	0	**18**
	Hatchery Strays	0	6	0	0	1	**7**
2003	Wild	0	6	0	0	0	**6**
	Hatchery Strays	0	1	1	0	0	**2**
2004	Wild	1	9	1	0	0	**11**
	Hatchery Strays	0	1	0	0	1	**2**
2005	Wild	1	10	0	1	0	**12**
	Hatchery Strays	3	37	0	0	0	**40**
	Captive Brood	0	0	0	0	0	**0**
2006	Wild	2	16	0	1	0	**19**
	Hatchery Strays	0	6	0	0	0	**6**

[23] Expansion factor = (1 + (number of males/number of females)).

Survey year	Origin	Survey Reach					Total
		H-2	H-3	H-4	Napeequa	Panther	
	Captive Brood	0	0	0	0	0	**0**
2007	Wild	1	6	0	0	2	**9**
	Hatchery Strays	0	4	0	0	0	**4**
	Captive Brood	0	0	0	0	0	**0**
2008	Wild	1	3	0	0	1	**5**
	Hatchery Strays	2	5	0	0	1	**8**
	Captive Brood	0	0	0	0	0	**0**
2009	Wild	0	9	0	0	0	**9**
	Hatchery Strays	0	8	0	0	3	**11**
	Captive Brood	0	0	0	0	0	**0**
2010	Wild	0	4	0	0	0	**4**
	Hatchery Strays	0	7	0	0	0	**7**
	Captive Brood	0	0	0	0	0	**0**
2011	Wild	0	4	0	0	0	**4**
	Hatchery Strays	0	0	0	0	0	**0**
	Captive Brood	0	0	0	0	0	**0**
2012	Wild	0	13	0	0	0	**13**
	Hatchery Strays	0	8	0	0	0	**8**
	Captive Brood	0	0	0	0	0	**0**
2013	Wild	0	8	0	0	0	**8**
	Hatchery Strays	0	10	0	0	3	**13**
	Captive Brood	0	2	0	0	0	**2**
2014	Wild	0	6	0	0	0	**6**
	Hatchery Strays	0	2	0	0	0	**2**
	Captive Brood	0	0	0	0	0	**0**
2015	Wild	0	14	0	0	0	**14**
	Hatchery Strays	4	6	0	0	0	**10**
	Captive Brood	0	1	0	0	0	**1**
2016	Wild	0	10	1	0	0	**11**
	Hatchery Strays	1	1	0	0	0	**2**
	Captive Brood	0	0	0	0	0	**0**
Average	***Wild***	***1***	***10***	***0***	***0***	***0***	***204***
	Hatchery Stray	***1***	***7***	***0***	***0***	***1***	***148***
	Captive Brood	***0***	***0***	***0***	***0***	***0***	***3***
Median	***Wild***	***0***	***9***	***0***	***0***	***0***	***204***
	Hatchery Stray	***0***	***6***	***0***	***0***	***0***	***148***
	Captive Brood	***0***	***0***	***0***	***0***	***0***	***3***

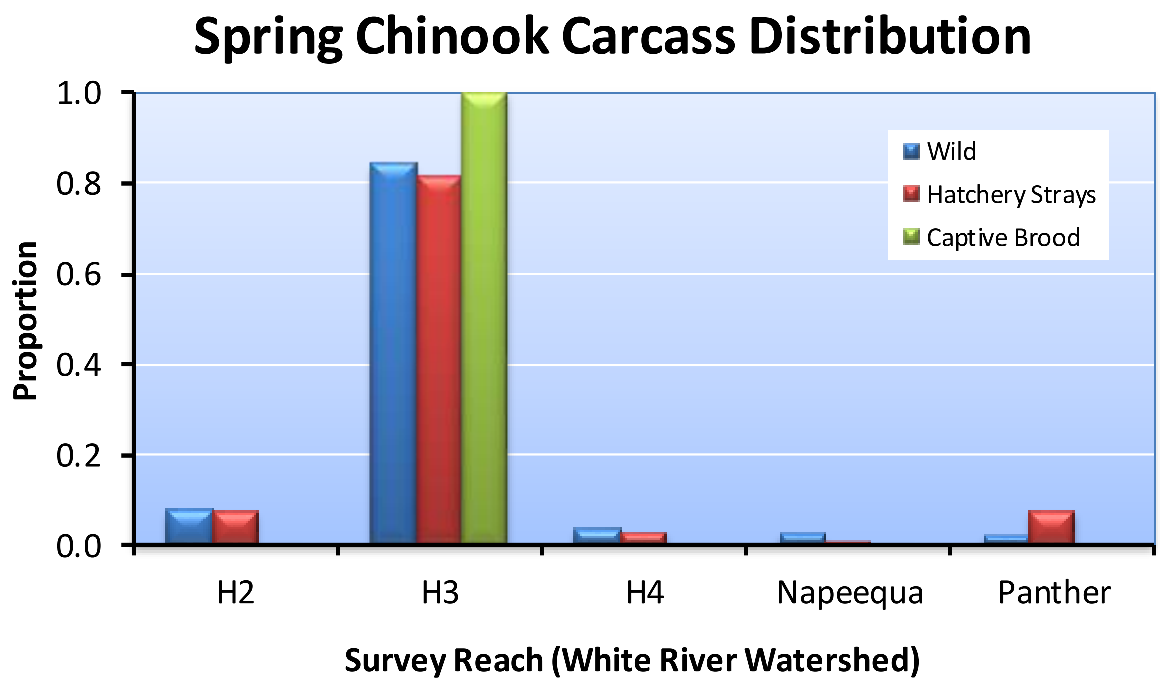

Figure 7.7. Distribution of wild, hatchery strays, and captive brood produced carcasses in different reaches in the White River basin, 2000-2016. Reach codes are described in Table 2.8.

7.7 Life History Monitoring

Life history characteristics of spring Chinook were assessed by examining carcasses on spawning grounds and fish collected at broodstock collection sites, and by reviewing tagging data and fisheries statistics.

Migration Timing

See Section 5.7 for a description of migration timing of spring Chinook at Tumwater Dam.

Age at Maturity

Most of the wild and hatchery stray spring Chinook sampled during the period 2001-2016 in the White River basin were age-4 fish (total age) (Table 7.13; Figure 7.8). A higher proportion of age-5 wild fish returned than did age-5 hatchery strays. Thus, wild fish tended to return at an older age than hatchery strays. Currently, few captive brood carcasses have been identified on the spawning grounds; most were age-4 and one was age-5. There has been a conspicuous absence of age-3 fish recovered as carcasses. In all years except 2007, no age-3 carcasses have been recovered.

Table 7.13. Numbers of wild, hatchery strays, and captive brood spring Chinook of different ages (total age) sampled on spawning grounds in the White River basin, 2001-2016.

Sample year	Origin	Total age					Sample size
		2	3	4	5	6	
2001	Wild	0	0	47	0	0	**47**
	Hatchery Strays	0	0	27	0	0	**27**

Sample year	Origin	Total age					Sample size
		2	3	4	5	6	
2002	Wild	0	0	7	11	0	**18**
	Hatchery Strays	0	0	6	1	0	**7**
2003	Wild	0	0	0	6	0	**6**
	Hatchery Strays	0	0	0	1	0	**1**
2004	Wild	0	0	9	0	0	**9**
	Hatchery Stray	0	0	2	0	0	**2**
2005	Wild	0	0	12	0	0	**12**
	Hatchery Strays	0	0	40	0	0	**40**
	Captive Brood	0	0	0	0	0	**0**
2006	Wild	0	0	7	12	0	**19**
	Hatchery Strays	0	0	3	3	0	**6**
	Captive Brood	0	0	0	0	0	**0**
2007	Wild	0	0	1	8	0	**9**
	Hatchery Strays	0	2	2	0	0	**4**
	Captive Brood	0	0	0	0	0	**0**
2008	Wild	0	0	4	1	0	**5**
	Hatchery Strays	0	0	8	0	0	**8**
	Captive Brood	0	0	0	0	0	**0**
2009	Wild	0	0	8	1	0	**9**
	Hatchery Strays	1	0	10	0	0	**11**
	Captive Brood	0	0	0	0	0	**0**
2010	Wild	0	0	4	0	0	**4**
	Hatchery Strays	0	0	6	0	0	**6**
	Captive Brood	0	0	0	0	0	**0**
2011	Wild	0	0	0	4	0	**4**
	Hatchery Strays	0	0	0	0	0	**0**
	Captive Brood	0	0	0	0	0	**0**
2012	Wild	0	0	13	0	0	**13**
	Hatchery Strays	0	0	8	0	0	**8**
	Captive Brood	0	0	0	0	0	**0**
2013	Wild	0	0	6	2	0	**8**
	Hatchery Strays	0	0	11	1	0	**12**
	Captive Brood	0	0	1	1	0	**2**
2014	Wild	0	0	54	10	0	**64**
	Hatchery Strays	0	0	21	0	0	**21**
	Captive Brood	0	0	0	0	0	**0**
2015	Wild	0	0	13	1	0	**14**
	Hatchery Strays	0	0	10	0	0	**10**

Sample year	Origin	Total age					Sample size
		2	3	4	5	6	
	Captive Brood	0	0	1	0	0	**1**
2016	Wild	0	0	5	6	0	**11**
	Hatchery Strays	0	0	2	0	0	**2**
	Captive Brood	0	0	0	0	0	**0**
Average	***Wild***	***0***	***0***	***12***	***4***	***0***	***252***
	Hatchery Strays	***0***	***0***	***10***	***0***	***0***	***165***
	Captive Brood	***0***	***0***	***0***	***0***	***0***	***3***
Median	***Wild***	***0***	***0***	***7***	***2***	***0***	***252***
	Hatchery Strays	***0***	***0***	***7***	***0***	***0***	***165***
	Captive Brood	***0***	***0***	***0***	***0***	***0***	***3***

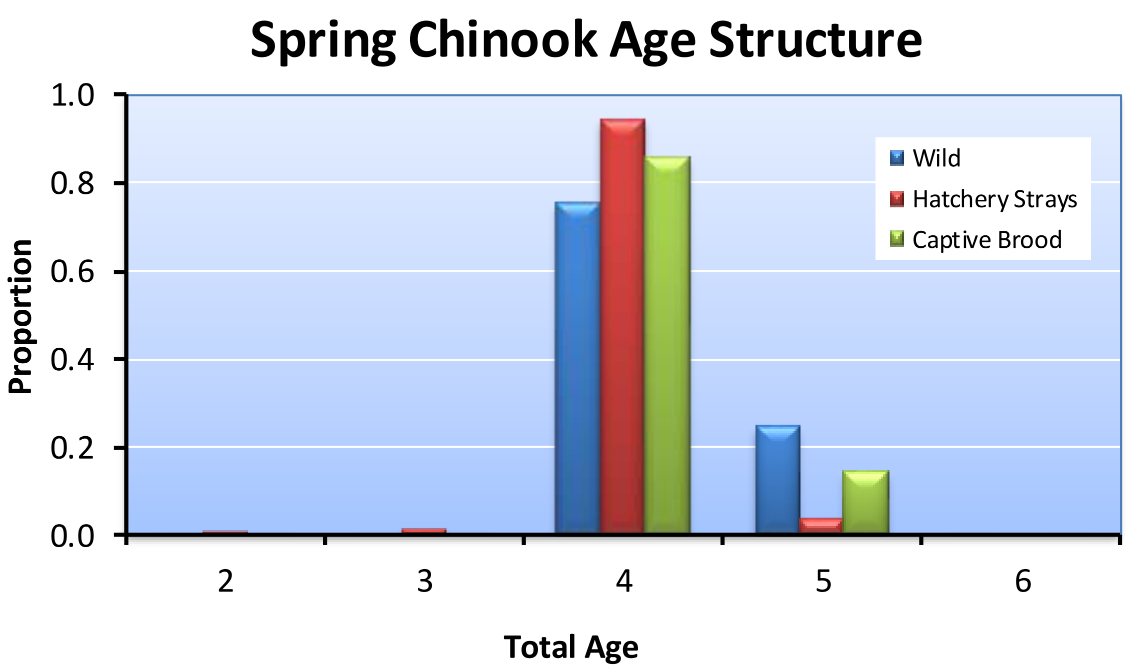

Figure 7.8. Proportions of wild, hatchery strays, and captive brood spring Chinook of different total ages sampled on spawning grounds in the White River basin for the combined years 2000-2016.

For comparison, Table 7.14 and Figure 7.9 show the age structure of spring Chinook carcasses sampled in the Little Wenatchee River. Similar to the White River, most of the wild and hatchery stray spring Chinook sampled during the period 2001-2016 in the Little Wenatchee River basin were age-4 fish (total age). A higher proportion of age-5 wild fish returned than did age-5 hatchery strays. Thus, wild fish tended to return at an older age than hatchery strays. As in the White River, few age-3 fish have been recovered in the Little Wenatchee River.

Table 7.14. Numbers of wild and hatchery stray spring Chinook of different ages (total age) sampled on spawning grounds in the Little Wenatchee River basin, 2001-2016.

Sample year	Origin	Total age					Sample size
		2	3	4	5	6	
2001	Wild	0	0	31	2	0	**33**
	Hatchery Strays	0	0	33	1	0	**34**
2002	Wild	0	0	6	8	0	**14**
	Hatchery Strays	0	0	12	2	0	**14**
2003	Wild	0	0	1	3	0	**4**
	Hatchery Strays	0	0	0	4	0	**4**
2004	Wild	0	0	1	0	0	**1**
	Hatchery Stray	0	0	0	0	0	**0**
2005	Wild	0	0	16	0	0	**16**
	Hatchery Strays	0	0	32	0	0	**32**
2006	Wild	0	0	4	4	0	**8**
	Hatchery Stray	0	1	0	3	0	**4**
2007	Wild	0	0	2	10	0	**12**
	Hatchery Strays	0	1	2	0	0	**3**
2008	Wild	0	0	3	0	0	**3**
	Hatchery Stray	0	0	12	0	0	**12**
2009	Wild	0	0	6	0	0	**6**
	Hatchery Strays	0	1	12	0	0	**13**
2010	Wild	0	0	2	0	0	**2**
	Hatchery Stray	0	0	5	0	0	**5**
2011	Wild	0	0	3	1	0	**4**
	Hatchery Strays	0	2	1	0	0	**3**
2012	Wild	0	0	12	2	0	**14**
	Hatchery Stray	0	0	9	1	0	**10**
2013	Wild	0	0	9	7	0	**16**
	Hatchery Strays	0	0	4	0	0	**4**
2014	Wild	0	1	8	2	0	**11**
	Hatchery Stray	0	0	1	0	0	**1**
2015	Wild	0	0	8	3	0	**11**
	Hatchery Strays	0	0	1	0	0	**1**
2016	Wild	0	0	1	3	0	**4**
	Hatchery Strays	0	0	1	0	0	**1**
Average	***Wild***	***0***	***0***	***7***	***3***	***0***	***10***
	Hatchery Strays	***0***	***0***	***8***	***1***	***0***	***9***
Median	***Wild***	***0***	***0***	***5***	***2***	***0***	***10***
	Hatchery Strays	***0***	***0***	***4***	***0***	***0***	***4***

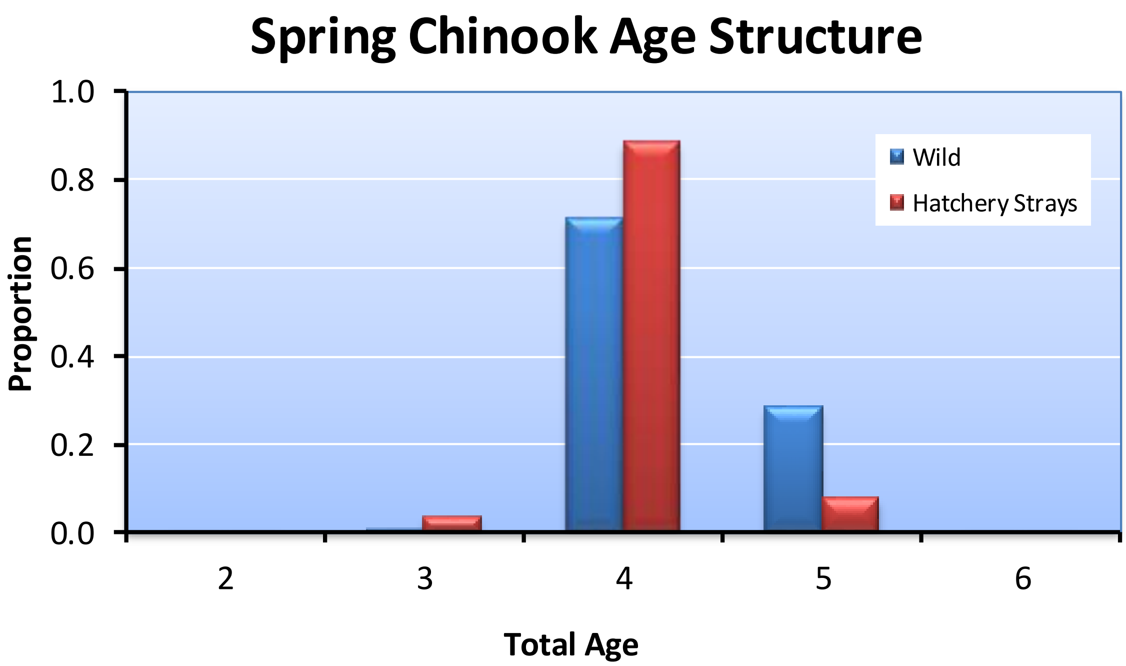

Figure 7.9. Proportions of wild and hatchery stray spring Chinook of different total ages sampled on spawning grounds in the Little Wenatchee River basin for the combined years 2000-2016.

Size at Maturity

On average, hatchery strays and wild spring Chinook of a given age differed little in length (Table 7.15). Differences were small (1-2 cm) and no more than 9 cm between hatchery strays and wild fish of the same age. Few captive brood carcasses have been identified on the spawning grounds; most were females. Those fish were about the same size as wild and hatchery strays of the same age.

Table 7.15. Mean lengths (POH in cm; ±1SD) and sample sizes (in parentheses) of different ages (total age) of male and female spring Chinook of wild, hatchery strays, and captive brood origin sampled in the White River basin, 2001-2016.

Return year	Total age	Mean length (cm)					
		Male			Female		
		Wild	Hatchery stray	Captive brood	Wild	Hatchery stray	Captive brood
2001	3	0	0	0	0	0	0
	4	65 ±3 (17)	66 ±4 (5)	0	63 ±3 (30)	63 ±4 (21)	0
	5	0	0	0	0	0	0
	6	0	0	0	0	0	0
2002	3	0	0	0	0	0	0
	4	66 ±0 (1)	69 ±0 (1)	0	63 ±4 (6)	59 ±6 (5)	0
	5	75 ±11 (2)	0	0	72 ±3 (9)	72 ±0 (1)	0
	6	0	0	0	0	0	0

Return year	Total age	Mean length (cm)					
		Male			Female		
		Wild	Hatchery stray	Captive brood	Wild	Hatchery stray	Captive brood
2003	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	75 ±5 (6)	73 ±0 (1)	0
	6	0	0	0	0	0	0
2004	3	0	0	0	0	0	0
	4	68 ±3 (3)	0	0	63 ±3 (6)	59 ±2 (2)	0
	5	0	0	0	0	0	0
	6	0	0	0	0	0	0
2005	3	0	0	0	0	0	0
	4	64 ±5 (3)	62 ±7 (5)	0	63 ±5 (8)	62 ±4 (33)	0
	5	0	0	0	0	0	0
	6	0	0	0	0	0	0
2006	3	0	0	0	0	0	0
	4	65 ±2 (3)	0	0	61 ±4 (4)	60 ±2 (3)	0
	5	69 ±4 (4)	0	0	67 ±5 (8)	70 ±5 (3)	0
	6	0	0	0	0	0	0
2007	3	0	49 ±5 (2)	0	0	0	0
	4	0	0	0	58 ±0 (1)	66 ±2 (2)	0
	5	75 ±5 (3)	0	0	75 ±1 (5)	0	0
	6	0	0	0	0	0	0
2008	3	0	0	0	0	0	0
	4	56 ±0 (1)	61 ±0 (1)	0	63 ±8 (2)	61 ±2 (7)	0
	5	0	0	0	75 ±0 (1)	0	0
	6	0	0	0	0	0	0
2009	3	0	0	0	0	0	0
	4	61 ±5 (3)	68 ±4 (2)	0	63 ±2 (5)	62 ±2 (8)	0
	5	0	0	0	78 ±0 (1)	0	0
	6	0	0	0	0	0	0
2010	3	0	0	0	0	0	0
	4	0	67 ±0 (1)	0	60 ±3 (3)	61 ±6 (5)	0
	5	0	0	0	0	0	0
	6	0	0	0	0	0	0
2011	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	73 ±5 (4)	0	0
	6	0	0	0	0	0	0
2012	3	0	0	0	0	0	0
	4	47 ±0 (1)	0	0	62 ±4 (12)	60 ±4 (8)	0
	5	0	0	0	0	0	0
	6	0	0	0	0	0	0

Return year	Total age	Mean length (cm)					
		Male			Female		
		Wild	Hatchery stray	Captive brood	Wild	Hatchery stray	Captive brood
2013	3	0	0	0	0	0	0
	4	64 ±4 (3)	60 ±4 (2)	0	61 ±2 (3)	61 ±4 (7)	63 ±0 (1)
	5	0	0	0	67 ±1 (2)	71 ±0 (1)	71 ±0 (1)
	6	0	0	0	0	0	0
2014	3	0	0	0	0	0	0
	4	0	54 ±0 (1)	0	60 ±2 (4)	58 ±0 (1)	0
	5	0	0	0	74 ±0 (1)	0	0
	6	0	0	0	0	0	0
2015	3	0	0	0	0	0	0
	4	60 ±6 (5)	74 ±0 (1)	61 ±(1)	64 ±5 (8)	63 ±4 (9)	65 ±4 (4)
	5	0	0	0	78 ±0 (1)	0	0
	6	0	0	0	0	0	0
2016	3	0	0	0	0	0	0
	4	65 ±0 (1)	0	0	63 ±4 (4)	59 ±4 (2)	0
	5	7 1 ±4 (2)	0	0	71 ±5 (4)	0	0
	6	0	0	0	0	0	0

Contribution to Fisheries

No White River spring Chinook from the captive brood program tagged with CWTs or PIT tags have been recaptured (or reported) in ocean or Columbia River (tribal, commercial, or recreational) fisheries.

Straying

Stray rates of White River spring Chinook from the captive brood program were determined by examining the locations where PIT-tagged Chinook demonstrating anadromy (based on detections at Bonneville Dam) were last detected. PIT tagging of White River spring Chinook began with release year 2008, which allows estimation of stray rates by brood return. Targets for strays based on return year (recovery year) within the Wenatchee River basin should be less than 10% and targets for strays outside the Wenatchee River basin should be less than 5%. The target for brood year stray rates should be less than 5%.

Based on PIT-tag analyses, on average, about 61% of the White River spring Chinook returns were last detected in streams outside the White River (Table 7.16). The numbers in Table 7.16 should be considered rough estimates because they are not based on confirmed spawning (only last detections) and they represent small sample sizes. In addition, last detections in adult fishways (i.e., Bonneville, Rock Island, and Tumwater dams) were not included, nor were detections in areas outside the distribution of known spring Chinook spawning (i.e., Lower and Middle Wenatchee River). All fish reported in Table 7.16 are at least age-3 fish (total age) and some of them may not have migrated all the way to the ocean but rather resided completely in freshwater downstream from Bonneville Dam.

Table 7.16. Number and percent of White River spring Chinook from the captive brood program that homed to target spawning areas on the White River and the target hatchery program (Little White Salmon Fish Hatchery), and number and percent that strayed to non-target spawning areas and hatchery programs for brood years 2006-2011. Only PIT-tagged fish demonstrating anadromy were included in the analysis. Estimates were based on last detections of PIT-tagged spring Chinook. Percent strays should be less than 5%.

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
2006	1	100.0	0	0.0	0	0.0	0	0.0
2007	0	0.0	0	0.0	0	0.0	0	0.0
2008	0	0.0	0	0.0	15	100.0	0	0.0
2009	4	14.3	0	0.0	25	85.7	0	0.0
2010	0	0.0	0	0.0	6	100.0	0	0.0
2011	14	17.1	0	0.0	68	82.9	0	0.0
Average	***3***	***21.9***	***0***	***0.0***	***19***	***61.4***	***0***	***0.0***
Median	***1***	***7.2***	***0***	***0.0***	***11***	***84.3***	***0***	***0.0***

* Homing to the target hatchery includes White River hatchery spring Chinook that are captured and included as broodstock in the White River Hatchery program.

The percentage of the PIT-tagged White River spring Chinook from the captive brood program that were last detected in different watersheds within and outside the Wenatchee River basin are shown in Table 7.17. On average, a small percentage of the PIT-tagged White River spring Chinook homed to the White River. Relatively high percentages of them were last detected in the Little Wenatchee River, Upper Wenatchee River, Nason Creek, and the Chiwawa River.

Few returning adults have strayed into spawning areas outside the Wenatchee River basin. One was last detected in the Entiat River. No other returning adults were detected outside the Wenatchee River basin. On the other hand, several juveniles were last detected in rivers outside the Wenatchee River basin. Juveniles were last detected in the Deschutes, Walla Walla, Hood, and North Fork Teanaway rivers. Juveniles were also last detected at the Little White Salmon Fish Hatchery. There is no evidence that these fish entered the ocean and returned as adults.

Table 7.17. Number and percent (in parentheses) of PIT-tagged White River spring Chinook from the captive brood program that were last detected in different tributaries within the Wenatchee River basin, return years 2010-2016. Only PIT-tagged fish demonstrating anadromy were included in the analysis.

Return year	Homing	Straying							
	White River	Chiwawa River	Chiwaukum Creek	Icicle Creek	Little Wenatchee	Nason Creek	Peshastin Creek	Upper Wenatchee	Entiat River
2010	1 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
2011	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (50.0)	1 (50.0)	0 (0.0)	0 (0.0)	0 (0.0)
2012	2 (16.7)	1 (8.3)	0 (0.0)	0 (0.0)	8 (66.7)	1 (8.3)	0 (0.0)	0 (0.0)	0 (0.0)
2013	2 (6.7)	8 (26.7)	1 (3.3)	2 (6.7)	7 (23.3)	8 (26.7)	0 (0.0)	2 (6.7)	0 (0.0)
2014	4 (8.3)	17 (35.4)	0 (0.0)	1 (2.1)	3 (6.3)	17 (35.4)	0 (0.0)	5 (10.4)	1 (2.1)
2015	10 (23.3)	24 (55.8)	1 (2.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	8 (18.6)	0 (0.0)

Return year	Homing	Straying							
	White River	Chiwawa River	Chiwaukum Creek	Icicle Creek	Little Wenatchee	Nason Creek	Peshastin Creek	Upper Wenatchee	Entiat River
2016	4 (22.2)	10 (55.6)	0 (0.0)	1 (5.6)	0 (0.0)	1 (5.6)	0 (0.0)	2 (11.1)	0 (0.0)
Average	***3 (25.3)***	***9 (26.0)***	***0 (0.8)***	***1(2.0)***	***3 (20.9)***	***4 (18.0)***	***0 (0.0)***	***2 (6.7)***	***0 (0.3)***
Median	***2 (16.7)***	***8 (26.7)***	***0 (0.0)***	***0 (0.0)***	***1 (6.3)***	***1 (8.3)***	***0 (0.0)***	***2(6.7)***	***0 (0.0)***

Genetics

At this time, there are no studies that examine the effects of the White River captive brood program on the genetics of natural-origin spring Chinook in the Wenatchee River basin. However, genetic studies were conducted to determine the potential effects of the Chiwawa Supplementation Program on natural-origin spring Chinook in the upper Wenatchee River basin (Blankenship et al. 2007; the entire report is appended as Appendix K). This work included the analysis of White River spring Chinook. Researchers collected microsatellite DNA allele frequencies from temporally replicated natural and hatchery-origin spring Chinook to statistically assign individual fish to specific demes (locations) within the Wenatchee population.

Significant differences in allele frequencies were observed within and among major spawning areas in the Upper Wenatchee River basin. However, these differences made up only a very small portion of the overall variation, indicating genetic similarity among the major spawning areas. There was no evidence that the Chiwawa program has changed the genetic structure (allele frequency) of spring Chinook in the White River, despite the presence of hatchery-origin spawners in both systems.

Proportionate Natural Influence

Another method for assessing the genetic risk of a supplementation program is to determine the influence of the hatchery and natural environments on the adaptation of the composite population. This is estimated by the proportion of natural-origin fish in the hatchery broodstock (pNOB) and the proportion of hatchery-origin fish in the natural spawning escapement (pHOS). We calculated Proportionate Natural Influence (PNI) by iterating Ford’s (2002) equations 5 and 6 to equilibrium, using a heritability of 0.3 and a selection strength of three standard deviations.[24] The larger the PNI value, the greater the strength of selection in the natural environment relative to that of the hatchery environment. In order for the natural environment to dominate selection, PNI should be greater than 0.50, and important integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004).

For brood years 1989-2000, PNI values ranged from 0.95 to 1.00 (Table 7.18). For brood years 2001-2013, PNI for the White River Program averaged 0.60 (range, 0.33-1.00) (Table 7.18).

[24] According to authorized annual take permits, PNI is calculated using the PNI approximate equation 11 (HSRG 2009; Appendix A). However, in this report, we used Ford's (2002) equations 5 and 6 with a heritability of 0.3 and a selection strength of three standard deviations to calculate PNI (C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI). This approach is more accurate than using the PNI approximate equation.

Table 7.18. Proportionate Natural Influence (PNI) values for hatchery spring Chinook spawning in the White River, brood years 1989-2013. See notes below the table for description of each metric.

Brood year	Spawners					Broodstock			PNI
	NOS	HOS$_W$	HOS$_S$	pHOS$_W$	pHOS$_S$	NOB$_N$	HOB$_N$	pNOB	
1989	145	0	0	0.00	0.00	0	0	*1.00*	1.00
1990	49	0	0	0.00	0.00	0	0	*1.00*	1.00
1991	49	0	0	0.00	0.00	0	0	*1.00*	1.00
1992	78	0	0	0.00	0.00	0	0	*1.00*	1.00
1993	138	0	7	0.00	0.05	0	0	*0.99*	0.95
1994	7	0	0	0.00	0.00	0	0	*0.67*	1.00
1995	5	0	0	0.00	0.00	0	0	*1.00*	1.00
1996	30	0	0	0.00	0.00	0	0	*0.60*	1.00
1997	33	0	0	0.00	0.00	0	0	*0.30*	1.00
1998	11	0	0	0.00	0.00	0	0	*0.44*	1.00
1999	3	0	0	0.00	0.00	0	0	*1.00*	1.00
2000	22	0	0	0.00	0.00	0	0	*0.48*	1.00
Average*	***48***	***0***	***1***	***0.00***	***0.00***	***0***	***0***	***0.79***	***1.00***
Median*	***32***	***0***	***0***	***0.00***	***0.00***	***0***	***0***	***1.00***	***1.00***
2001	111	0	55	0.00	0.33	5	0	1.00	0.50
2002	60	0	26	0.00	0.30	18	0	1.00	0.51
2003	31	0	5	0.00	0.14	7	0	1.00	0.77
2004	54	0	12	0.00	0.18	6	0	1.00	0.70
2005	38	11	106	0.07	0.68	103	73	0.59	0.33
2006	41	5	9	0.09	0.16	191	135	0.59	0.61
2007	62	23	7	0.25	0.08	254	6	0.98	0.67
2008	20	2	30	0.04	0.58	116	0	1.00	0.34
2009	81	29	63	0.17	0.36	238	0	1.00	0.53
2010	27	22	23	0.31	0.32	90	0	1.00	0.50
2011	83	0	0	0.00	0.00	306	0	1.00	1.00
2012	89	10	45	0.07	0.31	390	0	1.00	0.73
2013	44	55	5	0.53	0.05	383	0	1.00	0.64
Average**	***57***	***12***	***30***	***0.12***	***0.27***	***162***	***16***	***0.94***	***0.60***
Median**	***54***	***5***	***23***	***0.07***	***0.30***	***116***	***0***	***1.00***	***0.61***

HOS$_W$ = hatchery-origin spawners in White River from the White River spring Chinook Supplementation Program.
pHOS$_W$ = proportion of hatchery-origin spawners from White River spring Chinook Supplementation Program.
HOS$_S$ = stray hatchery-origin spawners in the White River.
pHOS$_S$ = proportion of stray hatchery-origin spawners.
NOB$_W$ = natural origin broodstock spawned for the White River spring Chinook Supplementation Program.
HOB$_W$ = hatchery-origin broodstock spawned in the White River spring Chinook Supplementation Program.
pNOB = proportion of hatchery-origin broodstock. Because of the high incidence of strays to the White River from the Chiwawa River spring Chinook program, pNOB values from the Chiwawa program were used to estimate PNI values during the period from 1989 to 2000 (*italicized*). The weighting for those years was 100% based on the Chiwawa program broodstock selection, because there have been no hatchery returns from the White River spring Chinook program during this period (see Table 5.1 for Chiwawa broodstock selection).
PNI = Proportionate Natural Influence for White River spring Chinook calculated using the gene-flow model for multiple programs.
* Average and median for the period 1989-2000.
** Average and median for the period 2001-2013.

Natural and Hatchery Replacement Rates

In general, natural replacement rates (NRR) are calculated as the ratio of natural-origin recruits (NOR) to the parent spawning population (spawning escapement). Natural-origin recruits are naturally produced (wild) fish that survive to contribute to harvest (directly or indirectly), to broodstock, and to spawning grounds. We do not account for fish that died in route to the spawning grounds (migration mortality) or died just before spawning (pre-spawn mortality) (see Appendix B in Hillman et al. 2012). We calculated NORs with and without harvest. NORs include all returning fish that either returned to the basin or were collected as wild broodstock. For brood years 1989-2010, NRR for spring Chinook in the White River basin averaged 1.03 (range, 0.00-4.91) if harvested fish were not included in the estimate and 1.25 (range, 0.00-5.91) if harvested fish were included in the estimate (Table 7.19). NRRs for more recent brood years will be calculated as soon as all tag recoveries and sampling rates have been loaded into the database.

Hatchery replacement rates (HRR) are the hatchery adult-to-adult returns and are calculated as the ratio of hatchery-origin recruits (HOR) to the parent broodstock collected. For brood years 2006-2010, hatchery replacement rates averaged 0.17 (range, 0.00-0.48) if harvest is not included and 0.62 (range, 0.00-1.99) if harvest is included (Table 7.19a). Only for brood year 2009 was HRR greater than the NRR. The HRR values are much higher when they are calculated using the number of adult equivalents taken from the natural environment to initiate the captive brood program (Table 7.19b).

Table 7.19a. Numbers of brood stock spawned, spawning escapements, hatchery-origin recruits (HOR), natural-origin recruits (NOR), hatchery replacement rates (HRR), and natural replacement rates (NRR) with and without harvest for spring Chinook in the White River basin, brood years 1989-2010.

Brood year	Brood stock spawned	Spawning Escapement	Harvest not included				Harvest included			
			HOR[1]	NOR[2]	HRR[1]	NRR[2]	HOR[3]	NOR[4]	HRR[3]	NRR[4]
1989	--	145	--	81	--	0.56	--	118	--	0.81
1990	--	49	--	2	--	0.04	--	2	--	0.04
1991	--	49	--	3	--	0.06	--	3	--	0.06
1992	--	78	--	30	--	0.38	--	32	--	0.41
1993	--	145	--	44	--	0.30	--	45	--	0.31
1994	--	7	--	1	--	0.14	--	1	--	0.14
1995	--	5	--	9	--	1.80	--	9	--	1.80
1996	--	30	--	15	--	0.50	--	16	--	0.53
1997	--	33	--	148	--	4.48	--	173	--	5.24
1998	--	11	--	54	--	4.91	--	65	--	5.91
1999	--	3	--	0	--	0.00	--	0	--	0.00
2000	--	22	--	54	--	2.45	--	58	--	2.64
2001	5	166	--	64	--	0.39	--	66	--	0.40
2002	18	86	--	70	--	0.81	--	77	--	0.90
2003	7	36	--	11	--	0.31	--	12	--	0.33
2004	6	66	--	25	--	0.38	--	30	--	0.45
2005	176	155	--	72	--	0.46	--	79	--	0.51
2006	326	55	5	110	0.02	2.00	17	157	0.05	2.85

Brood year	Brood stock spawned	Spawning Escapement	Harvest not included				Harvest included			
			HOR[1]	NOR[2]	HRR[1]	NRR[2]	HOR[3]	NOR[4]	HRR[3]	NRR[4]
2007	260	92	0	0	0.00	0.00	0	0	0.00	0.00
2008	116	52	30	100	0.26	1.92	83	156	0.72	3.00
2009	238	173	115	39	0.48	0.23	472	52	1.99	0.30
2010	90	72	10	40	0.11	0.56	32	58	0.36	0.81
Average	**124**	**70**	**32**	**44**	**0.17**	**1.03**	**121**	**55**	**0.62**	**1.25**
Median	**103**	**54**	**10**	**40**	**0.11**	**0.43**	**32**	**49**	**0.36**	**0.48**

[1] HOR and HRR values represented here are detections of PIT-tag hatchery fish detected at Tumwater Dam. These values have been expanded based on the untagged proportion of fish released from the White River spring Chinook Program and PIT-tag detection efficiency at Tumwater Dam.
[2] NOR and NRR values represented here are based on carcasses recovery in the White River adjusted by H:W ratios and age composition and expanded to the escapement in the White River.
[3] Harvest on hatchery-origin White River spring Chinook was estimated based on harvest rates observed for Chiwawa spring Chinook.
[4] Expanded NORs for harvest were based on harvest rates from Chiwawa River spring Chinook.

Table 7.19b. Hatchery-origin recruits (HOR) and hatchery replacement rates (HRR) based on adult equivalents for spring Chinook in the White River basin, brood years 2006-2009. HORs were estimated at Tumwater Dam.

Brood year	Adult equivalents	Harvest not included		Harvest included	
		HOR	HRR	HOR	HRR
2006	1.03	5	4.9	17	16.5
2007	1.21	0	0.0	0	0.0
2008	0.36	30	83.6	83	231.4
2009	1.05	115	109.6	472	449.7
Average	***0.91***	***38***	***50***	***191***	***174***
Median	***1.04***	***18***	***44***	***83***	***124***

For comparison, we calculated NRR for spring Chinook within the Little Wenatchee River basin. Fish from both the White River and Little Wenatchee River must migrate through Lake Wenatchee. Therefore, a comparison between the two subpopulations is appropriate.

NRRs for spring Chinook in the Little Wenatchee River basin were generally less than those for spring Chinook in the White River basin. For brood years 1989-2010, NRR for spring Chinook in the Little Wenatchee River basin averaged 0.83 (range, 0.00-4.50) if harvested fish were not included in the estimate and 1.01 (range, 0.00-5.28) if harvested fish were included in the estimate (Table 7.20). NRRs for more recent brood years will be calculated as soon as all tag recoveries and sampling rates have been loaded into the database.

Table 7.20. Spawning escapements, natural-origin recruits (NOR), and natural replacement rates (NRR) with and without harvest for spring Chinook in the Little Wenatchee River basin, brood years 1989-2010.

Brood year	Spawning Escapement	Harvest not included		Harvest included	
		NOR	NRR	NOR	NRR
1989	102	84	0.82	122	1.20
1990	67	0	0.00	0	0.00
1991	42	0	0.00	0	0.00

Brood year	Spawning Escapement	Harvest not included		Harvest included	
		NOR	NRR	NOR	NRR
1992	78	8	0.10	8	0.10
1993	134	21	0.16	22	0.16
1994	16	11	0.69	11	0.69
1995	0	10	0.00	10	0.00
1996	8	14	1.75	15	1.88
1997	18	81	4.50	95	5.28
1998	18	31	1.72	37	2.06
1999	8	4	0.50	4	0.50
2000	24	39	1.63	42	1.75
2001	118	51	0.43	53	0.45
2002	86	79	0.92	87	1.01
2003	29	13	0.45	15	0.52
2004	39	13	0.33	15	0.38
2005	115	43	0.37	47	0.41
2006	37	49	1.32	70	1.89
2007	101	59	0.58	87	0.86
2008	64	73	1.14	114	1.78
2009	125	52	0.42	69	0.55
2010	83	44	0.53	64	0.77
Average	**60**	**35**	**0.83**	**45**	**1.01**
Median	**53**	**35**	**0.52**	**40**	**0.62**

Smolt-to-Adult Survivals

Smolt-to-adult survival ratios (SARs) were calculated as the number of hatchery adults detected at Tumwater Dam divided by the number of tagged hatchery smolts released. SARs were based on PIT-tag detections. For the available brood years, SARs have ranged from 0.00000 to 0.00196 (Table 7.21).

Table 7.21. Smolt-to-adult ratios (SARs) for White River spring Chinook from the captive brood program, brood years 2006-2011. Detections at Tumwater Dam are adjusted for PIT-tag detection efficiency.

Brood year	Number of smolts released	Number of PIT-tagged smolts released	PIT-tags	
			Adjusted Tumwater Detections	SAR
2006	142,033	29,881	1	0.00003
2007	131,843	39,820	0	0.00000
2008	48,556	38,650	23	0.00060
2009	112,596	41,742	42	0.00101
2010	18,850	12,283	6	0.00049

Brood year	Number of smolts released	Number of PIT-tagged smolts released	PIT-tags	
			Adjusted Tumwater Detections	SAR
2011	147,000	54,187	106	0.00196
Average	***100,146***	***36,094***	***30***	***0.00068***
Median	***122,220***	***39,235***	***15***	***0.00054***

7.8 ESA/HCP Compliance

Brood Collection

The last collection of eggs or fry for this program occurred in 2010 (brood year 2009). From 2011 to 2013, the White River Captive Brood Program operated without ESA permit coverage. The hatchery program ended with the last release of juveniles in 2015 (brood year 2013).

Hatchery Rearing, Spawning, and Release

From 2011 to 2013, the White River Captive Brood Program has operated without ESA permit coverage. The hatchery program ended with the last release of juveniles in 2015 (brood year 2013). No release of juveniles occurred under Section 10(a)(1)(A) Permit 18120 in 2016.

Hatchery Effluent Monitoring

No juveniles were reared or released as part of the White River captive brood program in 2016 due to sun-setting of the program with the 2013 brood. Therefore, no effluent monitoring was required or conducted in 2016.

Smolt and Emigrant Trapping

Per ESA Section 10 Permit No. 1196 (expired), 18118, 18120, and 18121, the permit holders are authorized a direct take of 20% of the emigrating spring Chinook population during juvenile emigration monitoring and a lethal take not to exceed 2% of the fish captured (NMFS 2003). Based on the estimated wild spring Chinook population (smolt trap expansion) and hatchery juvenile spring Chinook population estimate (hatchery release data) for the Wenatchee River basin, the reported spring Chinook encounters during 2016 emigration monitoring complied with take provisions in the Section 10 permit. Spring Chinook encounter and mortality rates for each trap site (including PIT tag mortalities) are detailed in Table 7.22. Additionally, juvenile fish captured at the trap locations were handled consistent with provisions in ESA Section 10 Permit 1196 (expired), 18118, 18120, and 18121, Section B. Table 7.22 includes incidental or direct take associated with the White River smolt trap operated by the Yakama Nation under separate permits.

Table 7.22. Estimated take of Upper Columbia River spring Chinook resulting from juvenile emigration monitoring in the Wenatchee River basin, 2016.

Trap location	Population estimate			Number trapped			Total	Take allowed under Permit
	Wild[a]	Hatchery[b]	Sub-yearling[c]	Wild	Hatchery	Sub-yearling		
Chiwawa Trap								
Population	37,170	341,226	145,971	2,807	2,525	16,393	21,725	
Encounter rate	NA	NA	NA	0.0755	0.0074	0.1123	0.0414	0.20
Mortality[e]	NA	NA	NA	4	0	82	86	
Mortality rate	NA	NA	NA	0.0014	0.0000	0.0050	0.0040	0.02
White River Trap								
Population	386	NA	2,430	3	NA	197	200	
Encounter rate	NA	NA	NA	0.0078	NA	0.0811	0.0710	0.2
Mortality[d]	NA	NA	NA	0	NA	2	2	
Mortality rate	NA	NA	NA	0.0000	NA	0.0102	0.0100	0.02
Nason Creek Trap								
Population	2,372	32,215	6,813	61	124	791	976	
Encounter rate	NA	NA	NA	0.0257	0.0038	0.1161	0.0236	0.2
Mortality[d]	NA	NA	NA	0	0	6	6	
Mortality rate	NA	NA	NA	0.0000	0.0000	0.0076	0.0061	0.02
Lower Wenatchee Trap								
Population	36,752	373,441	14,235,288	610	7,702	27,407	35,719	
Encounter rate	NA	NA	NA	0.0166	0.0206	0.0019	0.0024	0.20
Mortality[d]	NA	NA	NA	2	3	184	189	
Mortality rate	NA	NA	NA	0.0033	0.0001	0.0067	0.0053	0.02
Wenatchee River Basin Total								
Population	36,752	373,441	14,381,259	3,417	10,227	43,800	57,444	
Encounter rate	NA	NA	NA	0.0930	0.0274	0.0030	0.0039	0.20
Mortality[d]	NA	NA	NA	6	3	266	275	
Mortality rate	NA	NA	NA	0.0018	0.001	0.0061	0.0048	0.02

[a] Smolt population estimate derived from juvenile emigration trap data.

[b] 2016 BY smolt release data for the Wenatchee River basin.

[c] Based on size, date of capture and location of capture, subyearling Chinook encountered at the Lower Wenatchee Trap are categorized as summer Chinook salmon.

[d] Combined trapping and PIT tagging mortality.

Spawning Surveys

Spring Chinook spawning ground surveys were conducted in the Wenatchee River basin during 2016, as authorized by ESA Section 10 Permits 18118, 18120, and 18121. Because of the difficulty of quantifying the level of take associated with spawning ground surveys, the Permit does not specify a take level associated with these activities, even though it does authorize implementation of spawning ground surveys. Therefore, no take levels are reported. However, to minimize potential effects to established redds, wading was restricted to the extent practical, and extreme caution was used to avoid established redds when wading was required.

Spring Chinook Reproductive Success Study

ESA Section 10 Permit 1196 (expired) and new Section 10 Permits 18118, 18120, and 18121 specifically provide authorization to capture, anesthetize, biologically sample, PIT tag, and release adult spring Chinook at Tumwater Dam for reproductive success studies and general program monitoring. During 2010 through 2016, all spring Chinook passing Tumwater Dam were enumerated, anesthetized, biologically sampled, PIT tagged, and released (not including hatchery-origin and natural-origin Chinook retained for broodstock) as a component of the reproductive success study (BPA Project No. 2003-039-00). Please refer to Ford et al. (2010, 2011, 2012, 2013, 2014, 2015, and 2016) for complete details on the methods and results of the spring Chinook reproductive success study for the period 2010-2016.

SECTION 8: WENATCHEE SUMMER CHINOOK

The goal of summer Chinook salmon supplementation in the Wenatchee Basin is to use artificial production to replace adult production lost because of mortality at Priest Rapids, Wanapum, and Rock Island dams, while not reducing the natural production or long-term fitness of summer Chinook in the basin. The Rock Island Fish Hatchery Complex began operation in 1989 under funding from Chelan PUD and subsequently Grant PUD began cost-sharing the program in 2012. The Complex operated originally through the Rock Island Settlement Agreement, but since 2004 has operated under the Anadromous Fish Agreement and Habitat Conservation Plans as well as the Priest Rapids Project Salmon and Steelhead Settlement Agreement.

Adult summer Chinook are collected for broodstock from the run-at-large at the right and left-bank traps at Dryden Dam, and at Tumwater Dam if the weekly quotas cannot be achieved at Dryden Dam. Before 2012, the goal was to collect up to 492 natural-origin adult summer Chinook for the Wenatchee program for an annual release of 864,000 smolts. In 2011, the Hatchery Committees reevaluated the amount of hatchery compensation needed to achieve NNI. Based on that evaluation, the goal of the program was revised. The current goal (beginning in 2012) is to collect up to 256 adult natural-origin summer Chinook for an annual release of 500,001 smolts. Broodstock collection occurs from about 1 July through 15 September with trapping occurring up to 24 hours per day, seven days a week. If natural-origin broodstock collection falls short of expectation, hatchery-origin adults can be collected to make up the difference.

Adult summer Chinook are spawned and reared at Eastbank Fish Hatchery. Juvenile summer Chinook are transferred from the hatchery to Dryden Acclimation Pond in March. They are released from the pond in late April to early May.

Before 2012, the production goal for the Wenatchee summer Chinook supplementation program was to release 864,000 yearling smolts into the Wenatchee River at ten fish per pound. Beginning with the 2012 brood, the revised production goal is to release 500,001 yearling smolts into the Wenatchee River at 10 and 15 fish per pound. Targets for fork length and weight are 163 mm (CV = 9.0) and 45.4 g, respectively. Over 95% of these fish are marked with CWTs. In addition, since 2009, about 10,000 juvenile summer Chinook have been PIT tagged annually.

8.1 Broodstock Sampling

This section focuses on results from sampling 2014-2016 Wenatchee summer Chinook broodstock, which were collected at Dryden and Tumwater dams.

Origin of Broodstock

Consistent with the broodstock collection protocol, the 2014-2016 broodstock consisted primarily of natural-origin (adipose fin present and no CWT) summer Chinook (Table 8.1). Less than 1% of the 2014-2016 broodstock was comprised of hatchery-origin fish (hatchery-origin was determined by examination of scales and/or CWTs).

Table 8.1. Numbers of wild and hatchery summer Chinook collected for broodstock, numbers that died before spawning, and numbers of Chinook spawned, 1989-2016. Unknown origin fish (i.e., undetermined by scale analysis, no CWT or fin clips, and no additional hatchery marks) were considered naturally produced. Mortality includes fish that died of natural causes typically near the end of spawning and were not needed for the program and surplus fish killed at spawning.

Brood year	Wild summer Chinook					Hatchery summer Chinook					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
1989	346	29	27	290	0	0	0	0	0	0	290
1990	87	6	24	57	0	0	0	0	0	0	57
1991	128	9	14	105	0	0	0	0	0	0	105
1992	341	48	19	274	0	0	0	0	0	0	274
1993	480	28	46	406	0	44	0	0	44	0	450
1994	363	29	1	333	0	55	1	0	54	0	387
1995	382	15	4	363	0	16	0	0	16	0	378
1996	331	34	34	263	0	3	0	0	3	0	266
1997	225	14	6	205	0	15	1	1	13	0	218
1998	378	40	39	299	0	94	4	12	78	0	377
1999	250	7	1	242	0	238	1	1	236	0	478
2000	298	18	5	275	0	194	7	7	180	0	455
2001	311	41	60	210	0	182	8	38	136	0	346
2002	469	28	32	409	0	13	1	2	10	0	419
2003	488	90	61	337	0	8	1	0	7	0	344
2004	494	24	46	424	0	2	0	0	2	0	426
2005	491	29	19	397	46	3	0	0	3	0	400
2006	483	29	21	433	0	5	1	0	4	0	437
2007	415	53	99	263	0	4	0	1	3	0	266
2008	400	11	11	378	0	72	2	1	69	0	447
2009	482	22	8	452	0	9	1	0	8	0	460
2010	427	14	25	388	0	7	2	0	5	0	393
2011	398	11	11	376	0	7	0	0	7	0	405
Average[b]	***368***	***27***	***27***	***312***	***2***	***42***	***1***	***3***	***38***	***0***	***351***
Median[b]	***382***	***28***	***21***	***333***	***0***	***8***	***1***	***0***	***7***	***0***	***387***
2012	273	5	1	267	0	1	0	0	1	0	268
2013	256	12	10	234	0	2	0	0	2	0	236
2014	279	18	0	261	0	2	0	0	2	0	263
2015	252	0	0	245	0	0	0	0	0	0	245
2016	271	9	3	259	0	0	0	0	0	0	259
Average[c]	***266***	***9***	***3***	***253***	***0***	***1***	***0***	***0***	***1***	***0***	***254***
Median[c]	***271***	***9***	***1***	***259***	***0***	***1***	***0***	***0***	***1***	***0***	***259***

[a] Pre-spawn loss represents the number of fish that died during the holding period before spawning. Mortality is the number of fish that were surplused following spawning.
[a] This average represents the program before recalculation in 2011.
[b] This average represents the current program, which began in 2012.

Age/Length Data

Ages of summer Chinook broodstock were determined from analysis of scales and/or CWTs. Broodstock collected from the 2014 return consisted primarily of age-4 and age-5 natural-origin Chinook (94.7%). Age-3 and age-6 natural-origin fish made up 4.5% and 0% of the broodstock, respectively (Table 8.2). The two hatchery Chinook included in the broodstock were age-4 and age-5 fish.

Broodstock collected from the 2015 return consisted primarily of age-4 and age-5 natural-origin Chinook (92.1%). Age-3 and age-6 natural-origin fish made up 7.8% and 0% of the broodstock, respectively (Table 8.2). No hatchery Chinook were included in broodstock.

Broodstock collected from the 2016 return consisted primarily of age-4 and age-5 natural-origin Chinook (98.4%). Age-3 and age-6 natural-origin fish made up 1.3% and 0.4% of the broodstock, respectively (Table 8.2). No hatchery Chinook were included in broodstock.

Table 8.2. Percent of hatchery and wild Wenatchee summer Chinook of different ages (total age) collected from broodstock in the Wenatchee River basin, 1991-2016.

Return Year	Origin	Total age				
		2	3	4	5	6
1991	Wild	0.0	4.6	36.8	57.5	1.1
	Hatchery	0.0	0.0	0.0	0.0	0.0
1992	Wild	0.0	2.6	40.4	50.9	6.1
	Hatchery	0.0	0.0	0.0	0.0	0.0
1993	Wild	0.0	1.5	35.7	60.4	2.3
	Hatchery	0.0	0.0	93.2	6.8	0.0
1994	Wild	0.0	1.0	33.7	64.3	1.0
	Hatchery	0.0	0.0	1.9	98.1	0.0
1995	Wild	0.0	3.3	19.2	76.3	1.2
	Hatchery	0.0	0.0	0.0	0.0	100.0
1996	Wild	0.0	4.6	40.1	53.3	2.0
	Hatchery	0.0	0.0	33.3	66.7	0.0
1997	Wild	0.0	2.3	42.6	53.2	1.9
	Hatchery	0.0	26.7	66.7	6.7	0.0
1998	Wild	0.0	5.5	34.7	58.6	1.2
	Hatchery	0.0	5.3	68.1	20.2	6.4
1999	Wild	0.5	1.9	39.0	56.3	2.3
	Hatchery	0.0	1.3	23.2	72.2	3.4
2000	Wild	2.6	6.3	24.6	66.5	0.0
	Hatchery	0.0	24.2	14.9	42.8	18.0
2001	Wild	0.3	16.6	53.6	27.7	1.7
	Hatchery	0.0	6.1	80.5	10.4	3.0
2002	Wild	0.7	8.4	61.6	28.5	0.7
	Hatchery	0.0	0.0	41.7	58.3	0.0
2003	Wild	0.9	2.8	31.4	64.8	0.0
	Hatchery	0.0	12.5	25.0	62.5	0.0
2004	Wild	0.2	3.6	10.1	83.9	2.1
	Hatchery	0.0	0.0	50.0	50.0	0.0

Return Year	Origin	Total age				
		2	3	4	5	6
2005	Wild	0.0	4.3	53.5	35.1	7.1
	Hatchery	0.0	0.0	0.0	100.0	0.0
2006	Wild	0.9	0.9	14.9	82.1	1.1
	Hatchery	0.0	0.0	0.0	80.0	20.0
2007	Wild	3.1	15.0	18.7	46.6	16.6
	Hatchery	0.0	0.0	0.0	100.0	0.0
2008	Wild	0.5	6.4	65.5	26.0	1.6
	Hatchery	0.0	2.9	13.0	69.6	14.5
2009	Wild	1.1	6.9	45.8	46.8	0.0
	Hatchery	0.0	0.0	11.1	88.9	0.0
2010	Wild	1.0	6.3	66.1	26.6	0.0
	Hatchery	0.0	0.0	62.5	37.5	0.0
2011	Wild	0.8	8.2	50.3	40.4	0.3
	Hatchery	0.0	42.9	14.3	42.9	0.0
2012	Wild	0.0	3.5	47.2	49.2	0.0
	Hatchery	0.0	0.0	0.0	100.0	0.0
2013	Wild	0.0	12.1	57.1	29.1	1.6
	Hatchery	0.0	0.0	50.0	50.0	0.0
2014	Wild	0.0	4.5	74.7	20.0	0.0
	Hatchery	0.0	0.0	100.0	0.0	0.0
2015	Wild	0.0	7.8	33.0	59.1	0.0
	Hatchery	0.0	0.0	0.0	0.0	0.0
2016	Wild	0.0	1.3	46.1	52.3	0.4
	Hatchery	0.0	0.0	0.0	0.0	0.0
Average	***Wild***	***0.48***	***5.5***	***41.4***	***50.6***	***2.0***
	Hatchery	***0.00***	***4.69***	***28.82***	***44.75***	***6.36***
Median	***Wild***	***0.00***	***4.55***	***40.25***	***52.75***	***1.15***
	Hatchery	***0.00***	***0.00***	***14.60***	***46.45***	***0.00***

Mean lengths of natural-origin summer Chinook of a given age differed little among return years 2014-2016 (Table 8.3).

Table 8.3. Mean fork length (cm) at age (total age) of hatchery and wild Wenatchee summer Chinook collected from broodstock in the Wenatchee River basin, 1991-2016; N = sample size and SD = 1 standard deviation.

Return year	Origin	Summer Chinook fork length (cm)														
		Age-2			Age-3			Age-4			Age-5			Age-6		
		Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD
1991	Wild	-	0	-	-	4	-	-	32	-	-	50	-	-	1	-
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
1992	Wild	-	0	-	66	3	10	69	46	5	81	58	3	87	7	1
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
1993	Wild	-	0	-	68	6	10	84	138	9	98	235	6	100	9	6
	Hatchery	-	0	-	-	0	-	79	41	8	101	3	8	-	0	-
1994	Wild	-	0	-	74	3	5	86	101	8	96	193	7	106	3	7
	Hatchery	-	0	-	-	0	-	75	1	-	90	53	8	-	0	-
1995	Wild	-	0	-	66	11	8	85	64	7	97	255	6	106	4	7
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-	91	16	8
1996	Wild	-	0	-	69	14	5	86	121	6	97	161	6	104	6	5
	Hatchery	-	0	-	-	0	-	63	1	-	96	2	4	-	0	-
1997	Wild	-	0	-	54	5	10	85	92	7	98	115	6	97	4	9
	Hatchery	-	0	-	46	4	2	74	10	4	98	1	-	-	0	-
1998	Wild	-	0	-	66	19	9	85	119	7	99	201	7	106	4	7
	Hatchery	-	0	-	53	5	2	77	64	8	95	19	8	98	6	8
1999	Wild	42	1	-	65	4	6	86	83	6	97	120	7	103	5	8
	Hatchery	-	0	-	52	3	6	79	55	7	90	171	6	100	8	6
2000	Wild	43	7	3	60	17	7	84	67	5	98	181	6	-	0	-
	Hatchery	-	0	-	53	47	7	76	29	8	93	83	7	102	35	9
2001	Wild	48	1	-	66	48	7	88	155	7	97	80	6	102	5	3
	Hatchery	-	0	-	51	10	3	75	132	8	91	17	8	100	5	8
2002	Wild	51	3	3	64	37	8	89	270	7	100	125	7	99	7	5
	Hatchery	-	0	-	-	0	-	78	5	8	95	7	5	-	0	-
2003	Wild	41	4	2	58	13	4	87	144	8	100	297	7	-	0	-
	Hatchery	-	0	-	40	1	-	78	2	4	101	5	8	-	0	-
2004	Wild	51	1	-	69	17	5	84	47	8	99	392	6	109	10	7
	Hatchery	-	0	-	-	0	-	84	1	-	108	1	-	-	0	-
2005	Wild	-	0	-	68	20	7	86	247	8	95	162	6	101	33	6
	Hatchery	-	0	-	-	0	-	-	0	-	90	3	9	-	0	-
2006	Wild	44	4	7	63	4	11	88	66	7	99	363	6	96	5	7
	Hatchery	-	0	-	-	0	-	-	0	-	99	4	7	100	1	-
2007	Wild	44	12	5	65	58	7	89	72	8	99	180	7	102	64	6
	Hatchery	-	0	-	-	0	-	-	0	-	90	4	5	-	0	-
2008	Wild	46	2	3	69	24	7	90	247	6	98	98	7	105	6	9
	Hatchery	-	0	-	63	2	14	81	9	7	93	48	6	99	10	5
2009	Wild	46	5	5	68	31	8	89	207	8	101	209	6	-	0	-

Return year	Origin	Summer Chinook fork length (cm)														
		Age-2			Age-3			Age-4			Age-5			Age-6		
		Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD
	Hatchery	-	0	-	61	4	7	81	1	-	98	8	14	-	0	-
2010	Wild	45	4	4	70	26	9	89	273	7	99	110	6	-	0	-
	Hatchery	-	0	-	-	0	-	72	5	8	88	3	7	-	0	-
2011	Wild	49	3	3	66	30	7	88	183	7	98	147	7	114	1	-
	Hatchery	-	0	-	55	3	2	90	1	-	81	3	5	-	0	-
2012	Wild	-	0	-	71	9	4	87	120	7	96	125	7	-	0	-
	Hatchery	-	0	-	-	0	-	-	0	-	83	1	-	-	0	-
2013	Wild	-	0	-	72	30	3	87	141	7	98	72	7	97	4	6
	Hatchery	-	0	-	-	0	-	79	1	-	96	1	-	-	0	-
2014	Wild	-	0	-	74	12	5	88	198	6	98	53	7	-	0	-
	Hatchery	-	0	-	-	0	-	86	2	6	-	0	-	-	0	-
2015	Wild	-	0	-	72	18	3	86	76	6	98	136	6	-	0	-
	Hatchery	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2016	Wild	-	0	-	70	3	8	86	106	7	95	121	7	99	1	-
	Hatchery	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	***Wild***	***46***	***2***	***4***	***67***	***18***	***7***	***86***	***131***	***7***	***97***	***163***	***6***	***102***	***7***	***6***
	Hatchery	***-***	***0***	***-***	***53***	***5***	***5***	***78***	***16***	***7***	***94***	***19***	***7***	***99***	***5***	***7***

Sex Ratios

Male summer Chinook in the 2014 and 2015 broodstock made up nearly 50% of the adults collected, resulting in overall male to female ratios of 0.99:1.00 and 0.99:1.00, respectively (Table 8.4). In 2016, males made up just under 50% of the adults collected, resulting in an overall male to female ratio of 0.99:1.00 (Table 8.4). The ratios in 2014-2016 were nearly equal to the 1:1 ratio goal in the broodstock protocol.

Table 8.4. Numbers of male and female wild and hatchery summer Chinook collected for broodstock in the Wenatchee River basin, 1989-2016. Ratios of males to females are also provided.

Return year	Number of wild summer Chinook			Number of hatchery summer Chinook			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
1989	166	180	0.92:1.00	0	0	-	0.92:1.00
1990	45	39	1.15:1.00	0	0	-	1.15:1.00
1991	60	68	0.88:1.00	0	0	-	0.88:1.00
1992	154	187	0.82:1.00	0	0	-	0.82:1.00
1993	208	228	0.91:1.00	35	9	3.89:1.00	1.03:1.00
1994	158	179	0.88:1.00	24	31	0.77:1.00	0.87:1.00
1995	169	213	0.79:1.00	1	15	0.07:1.00	0.75:1.00
1996	150	181	0.83:1.00	2	1	2.00:1.00	0.84:1.00
1997	104	121	0.86:1.00	15	0	-	0.98:1.00
1998	211	167	1.26:1.00	64	30	2.13:1.00	1.40:1.00

Return year	Number of wild summer Chinook			Number of hatchery summer Chinook			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
1999	130	120	1.08:1.00	108	130	0.83:1.00	0.95:1.00
2000	153	145	1.06:1.00	112	82	1.37:1.00	1.17:1.00
2001	187	124	1.51:1.00	132	50	2.64:1.00	1.83:1.00
2002	266	203	1.31:1.00	5	8	0.63:1.00	1.28:1.00
2003	270	218	1.24:1.00	5	3	1.67:1.00	1.24:1.00
2004	230	264	0.87:1.00	1	1	1.00:1.00	0.87:1.00
2005	291	200	1.46:1.00	2	1	2.00:1.00	1.46:1.00
2006	237	246	0.96:1.00	1	4	0.25:1.00	0.95:1.00
2007	239	176	1.36:1.00	2	2	1.00:1.00	1.35:1.00
2008	208	192	1.08:1.00	29	43	0.67:1.00	1.01:1.00
2009	223	236	0.94:1.00	25	7	3.57:1.00	1.02:1.00
2010	217	198	1.10:1.00	5	2	2.50:1.00	1.12:1.00
2011	198	200	0.99:1.00	4	3	1.33:1.00	0.99:1.00
2012	138	135	1.02:1.00	1	0	-	1.03:1.00
2013	127	130	0.98:1.00	1	1	1.00:1.00	0.98:1.00
2014	140	139	1.01:1.00	0	2	0.00:1.00	0.99:1.00
2015	122	123	0.99:1.00	0	0	--	0.99:1.00
2016	134	136	0.99:1.00	0	0	--	0.99:1.00
Total	***4935***	***4748***	***1.04:1.00***	***574***	***425***	***1.35:1.00***	***1.06:1.00***

Fecundity

Fecundities for the 2014-2016 returns of summer Chinook averaged 4,756, 4,982, and 4,423 eggs per female, respectively (Table 8.5). These values are less than the overall average of 5,112 eggs per female. Mean observed fecundities for the 2014-2016 returns were lower than the expected fecundities of 5,099, 5,031, and 4,902 eggs per female assumed in the broodstock collection protocols, respectively.

Table 8.5. Mean fecundity of wild, hatchery, and all female summer Chinook collected for broodstock in the Wenatchee River basin, 1989-2016; NA = not available.

Return year	Mean fecundity		
	Wild	Hatchery	Total
1989*	NA	NA	5,280
1990*	NA	NA	5,436
1991*	NA	NA	4,333
1992*	NA	NA	5,307
1993*	NA	NA	5,177
1994*	NA	NA	5,899
1995*	NA	NA	4,402
1996*	NA	NA	4,941

Return year	Mean fecundity		
	Wild	Hatchery	Total
1997	5,385	5,272	5,390
1998	5,393	4,825	5,297
1999	5,036	4,942	4,987
2000	5,464	5,403	5,441
2001	5,280	4,647	5,097
2002	5,502	5,027	5,484
2003	5,357	5,696	5,361
2004	5,372	6,681	5,377
2005	5,045	6,391	5,053
2006	5,126	5,633	5,133
2007	5,124	4,510	5,115
2008	5,147	4,919	5,108
2009	5,308	4,765	5,291
2010	4,971	3,323	4,963
2011	4,943	2,983	4,913
2012	4,801	NA	4,801
2013	4,987	5,272	4,990
2014	4,788	4,429	4,756
2015	4,982	NA	4,982
2016	4,423	NA	4,423
Average	***5,122***	***4,983***	***4,948***
Median	***5,125***	***4,942***	***5,112***

* Individual fecundities were not tracked with females until 1997.

8.2 Hatchery Rearing

Rearing History

Number of eggs taken

Based on the unfertilized egg-to-release survival standard of 81%, a total of 1,066,667 eggs were required to meet the program release goal of 864,000 smolts for brood years 1989-2011. An evaluation of the program in 2011 determined that 617,285 eggs are needed to meet the revised release goal of 500,001 smolts. This revised goal began with brood year 2012. From 1989 to 2011, the egg take goal was reached in seven of those years (Table 8.6). The egg takes from 2013-2016 were lower than the revised goal of 617,285 eggs.

Table 8.6. Numbers of eggs taken from Wenatchee summer Chinook broodstock, 1989-2015.

Return year	Number of eggs taken
1989	829,012
1990	163,109
1991	247,000

Return year	Number of eggs taken
1992	827,911
1993	1,133,852
1994	999,364
1995	949,531
1996	756,000
1997	554,617
1998	854,997
1999	1,182,130
2000	1,113,159
2001	733,882
2002	1,049,255
2003	901,095
2004	1,311,051
2005	883,669
2006	1,190,757
2007	655,201
2008	1,145,330
2009	1,217,028
2010	947,875
2011	959,202
Average (1989-2011)	***895,871***
Median (1989-2011)	***947,875***
2012	633,677
2013	578,513
2014	612,422
2015	610,718
2016	***588,606***
Average (2012-present)	***604,787***
Median (2012-present)	***610,718***

Number of acclimation days

The 2014 brood Wenatchee summer Chinook were transferred to the Dryden Acclimation Pond between 21 and 24 March 2016. These fish received 25-37 days of acclimation on Wenatchee River water before being volitionally released from 18-27 April 2016 (Table 8.7).

Table 8.7. Number of days Wenatchee summer Chinook were acclimated at Dryden Acclimation Pond, brood years 1989-2014. Numbers in parenthesis represents the number of days fish reared at Chiwawa Acclimation Facility.

Brood year	Release year	Transfer date	Release date	Number of days
1989	1991	2-Mar	7-May	66
1990	1992	19-Feb	2-May	73
1991	1993	10-Mar	8-May	59
1992	1994	1-Mar	6-May	66
1993	1995	3-Mar	1-May	59
1994	1996	2-Oct	6-May	217 (154)
		5-Mar	6-May	62
1995	1997	16-Oct	8-May	205 (139)
		27-Feb	8-May	70
1996	1998	6-Oct	28-Apr	204 (142)
		25-Feb	28-Apr	62
1997	1999	23-Feb	27-Apr	63
1998	2000	5-Mar	1-May	57
1999	2001	8-Mar	23-Apr	46
2000	2002	1-Mar	6-May	66
2001	2003	19-Feb	23-Apr	63
2002	2004	5-Mar	23-Apr	49
2003	2005	15-Mar	25-Apr	41
2004	2006	25-Mar	27-Apr	33
2005	2007	15-Mar	30-Apr	46
2006	2008	11-14-Mar	28-Apr	45-48
2007	2009	30-31-Mar	29-Apr	29-30
2008	2010	9-12, 15, 22-Mar	28-Apr	38-51
2009	2011	15-18, 21-Mar, 22-Apr	26-Apr	5-43
2010	2012	26-30-Mar	25-Apr	26-30
2011	2013	25-29-Mar	24-Apr	26-30
2012	2014	17-27-Mar	30-Apr	34-44
2013	2015	9-13-Mar, 17-Apr	28-Apr	11-50
2014	2016	21-24-Mar	18-27-Apr	25-37

Release Information

Numbers released

The 2014 Wenatchee summer Chinook program achieved 107.1% of the 500,001 goal with 535,255 fish being released in 2016 (Table 8.8). For brood years 2012-2014, the Wenatchee summer Chinook program has averaged 104% of the smolt obligation.

Table 8.8. Numbers of Wenatchee summer Chinook smolts released from the hatchery, brood years 1989-2014. Up to 2012, the release target for Wenatchee summer Chinook was 864,000 smolts. Beginning in 2012, the release target is 500,001 smolts.

Brood year	Release year	CWT mark rate	Number released with PIT tags	Number of smolts released
1989	1991	0.2013	0	720,000
1990	1992	0.9597	0	124,440
1991	1993	0.9957	0	191,179
1992	1994	0.9645	0	627,331
1993	1995	0.9881	0	900,429
1994	1996	0.9697	0	797,350
1995	1997	0.9725	0	687,439
1996	1998	0.9758	0	600,127
1997	1999	0.9913	0	438,223
1998	2000	0.9869	0	649,612
1999	2001	0.9728	0	1,005,554
2000	2002	0.9723	0	929,496
2001	2003	0.9868	0	604,668
2002	2004	0.9644	0	835,645
2003	2005	0.9778	0	653,764
2004	2006	0.9698	0	892,926
2005	2007	0.9596	0	644,182
2006	2008	0.9676	0	51,550[a]
		0.9676	0	899,107
2007	2009	0.9768	0	456,805
2008	2010	0.9664	10,035	888,811
2009	2011	0.9767	29,930	843,866
2010	2012	0.9964	0	792,746
2011	2013	0.9904	5,020	827,709
Average (1989-2011)		***0.9761***	***1,874***	***667,085***
Median (1989-2011)		***0.9727***	***0***	***720,000***
2012	2014	0.9700	19,911	550,877
2013	2015	0.9872	20,486	470,570
2014	2016	0.9639	10,432	535,255
Average (2012-present)		***0.9737***	***16,943***	***518,901***
Median (2012-present)		***0.9700***	***19,911***	***535,255***

[a] Represents high ELISA group planted directly in the Wenatchee River at Leavenworth Boat Launch.

Numbers tagged

The 2014 brood Wenatchee summer Chinook were 96.4% CWT and adipose fin-clipped (Table 8.8).

In 2016, a total of 10,565 Wenatchee summer Chinook (brood year 2015) were tagged at Eastbank Hatchery on 19-22 September. These were tagged and released into raceway #12. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 84-86 mm in length and 6.1-6.5 g at time of tagging.

An additional 10,429 Wenatchee summer Chinook were tagged at Eastbank Hatchery on 10-13 October 2016. These were tagged and released into water-reuse circular ponds #1 and #2. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 90-95 mm in length and 7.5-7.8 g at time of tagging.

Table 8.9 summarizes the number of hatchery summer Chinook that have been PIT-tagged and released into the Wenatchee River.

Table 8.9. Summary of PIT-tagging activities for Wenatchee hatchery summer Chinook, brood years 2008-2014.

Brood year	Release year	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
2008	2010	10,100	64	1	10,035
2009	2011	10,108 (Control)	140	3	9,965
		10,100 (R1)	129	0	9,971
		10,099 (R2)	105	0	9,994
2010	2012	0	0	0	0
2011	2013	5,100	80	0	5,020
2012	2014 (Raceway)	5,150 (small-size)	90	12	5,048
		5,153 (big-size)	379	34	4,740
	2014 (Reuse Circular)	5,150 (small-size)	109	0	5,041
		5,151 (big-size)	69	0	5,082
2013	2015 (Raceway)	5,150 (small-size)	44	0	5,116
		5,153 (big-size)	31	0	5,129
	2015 (Reuse Circular)	5,150 (small-size)	41	0	5,120
		5,151 (big-size)	38	1	5,121
2014	2016 (Raceway)	5,250 (small-size)	54	0	5,196
		5,250 (big-size)	92	0	5,158
		5,250 (small-size)	19	0	5,231

Brood year	Release year	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
	2016 (Reuse Circular)	5,250 (big-size)	49	0	5,201

Fish size and condition at release

About 535,255 summer Chinook from the 2014 brood were volitionally released from Dryden Acclimation Pond on 18-27 April 2016. Assessing size-target achievement from pre-release sampling was not practical because of size-target studies on the 2012 and 2013 brood years. However, since the program began, Wenatchee summer Chinook have not met the target length and CV values (Table 8.10). The target weight (fish/pound or FPP) of juvenile fish has been met occasionally (Table 8.10).

Table 8.10. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of Wenatchee summer Chinook smolts released from the hatchery, brood years 1989-2014; NA = not available. Size targets are provided in the last row of the table.

Brood year	Release year	Fork length (cm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
1989	1991	158	13.7	45.4	10
1990	1992	155	14.2	45.4	10
1991	1993	156	15.5	42.3	11
1992	1994	152	13.1	40.1	10
1993	1995	149	NA	34.9	13
1994	1996	138	NA	21.7	21
1995	1997	149	12.2	42.5	11
1996	1998	151	16.6	43.2	10
1997	1999	154	10.1	42.8	11
1998	2000	166	9.7	53.1	9
1999	2001	137	16.1	29.0	16
2000	2002	148	14.6	37.1	12
2001	2003	148	NA	38.9	12
2002	2004	146	15.1	37.3	14
2003	2005	147	13.2	36.5	12
2004	2006	147	10.7	35.4	13
2005	2007	153	16.3	40.6	11
2006	2008	136	21.5	29.2	16
2007	2009	163	21.6	49.7	9
2008	2010	166	15.0	52.0	9
2009	2011	152	15.9	39.0	12
2010	2012	154	17.2	43.1	11
2011	2013	149	13.8	41.4	11
Average (1989-2011)		***151***	***14.8***	***40.0***	***12***

Brood year	Release year	Fork length (cm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
Targets (1989-2011)		***176***	***9.0***	***45.4***	***10***
2012	2014	158	12.6	40.7	11
2013	2015	156	10.1	40.7	11
2014	2016	145	10.2	31.1	15
Average (2012-present)		***153***	***11.0***	***37.5***	***12***
Targets (2012-present)[a]		***163***	***9.0***	***45.4***	***18***

[a] For brood year 2012, the fish per pound (fpp) targets were 10 fpp and 15 fpp.

Survival Estimates

Overall survival of the 2014 brood Wenatchee summer Chinook from green (unfertilized) egg to release was higher than the standard set for the program. This was in part because of a high survival at all stages (Table 8.11).

Table 8.11. Hatchery life-stage survival rates (%) for Wenatchee summer Chinook, brood years 1989-2014. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
1989	90.0	93.4	90.9	97.0	99.7	99.3	98.5	99.4	86.9
1990	89.7	95.6	80.9	96.6	99.6	99.2	97.7	98.8	76.3
1991	88.2	98.3	86.9	96.1	99.3	98.5	94.9	98.1	77.4
1992	84.3	92.2	79.8	97.8	99.9	99.9	97.1	98.1	75.8
1993	92.4	95.9	84.2	97.5	99.6	99.3	96.7	98.8	79.4
1994	90.7	95.3	83.7	100	99.2	97.0	95.3	98.4	79.8
1995	94.7	98.2	86.0	100	96.7	96.4	74.9	90.8	72.4
1996	84.6	96.1	84.1	100	97.9	97.7	94.4	97.7	79.4
1997	89.3	98.3	82.6	97.3	97.1	96.9	98.3	98.2	79.0
1998	85.3	94.6	80.9	98.3	99.4	98.6	95.6	99.8	76.0
1999	98.4	98.3	90.4	97.9	98.1	97.9	96.2	99.4	85.1
2000	93.0	96.6	88.3	98.0	99.6	99.3	96.5	98.9	83.5
2001	87.4	91.5	90.6	97.7	99.8	99.6	93.1	93.3	82.4
2002	93.8	94.1	85.1	99.8	98.1	97.6	93.7	96.5	79.6
2003	77.4	85.1	80.5	98.1	99.6	99.1	91.9	93.5	72.6
2004	92.8	97.8	85.7	87.8	99.9	99.6	86.6	92.1	65.1
2005	97.3	89.6	83.5	98.0	99.7	99.4	89.1	99.5	72.9
2006	92.4	95.2	85.6	98.4	99.3	98.4	94.8	97.2	79.8
2007	73.6	97.5	73.7	97.9	99.5	98.7	96.6	99.1	69.7
2008	96.6	97.9	90.4	97.3	99.4	98.7	88.2	89.6	77.6
2009	95.1	95.6	92.0	99.6	97.3	97.3	84.8	98.2	78.1
2010	94.7	97.8	96.1	99.3	97.6	97.1	87.2	90.3	83.2

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
2011	98.0	96.4	92.3	97.9	99.5	98.9	95.9	97.3	86.7
2012	97.8	97.2	92.3	98.1	99.7	99.1	96.1	97.3	86.9
2013	91.5	98.4	87.5	98.8	97.1	96.6	94.1	98.4	81.3
2014	92.2	95.0	92.6	99.4	99.6	98.7	97.8	99.3	90.0
Average	***90.8***	***95.5***	***86.4***	***97.9***	***98.9***	***98.4***	***93.3***	***96.8***	***79.1***
Median	***92.3***	***96.0***	***85.9***	***98.0***	***99.5***	***98.7***	***95.1***	***98.2***	***79.4***
Standard	***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

8.3 Disease Monitoring

Rearing of the 2014 brood Wenatchee summer Chinook was similar to previous years with fish being held on well water before being transferred to Dryden Acclimation Pond for final acclimation in March 2016. Fish were transferred to Dryden Acclimation Pond from 21-24 March. Increased mortality caused by external fungus began to occur during the acclimation period at Dryden Acclimation Pond at which time a formalin treatment for 21 days was initiated to prevent the fungus from proliferating.

Results of the 2016 adult broodstock bacterial kidney disease (BKD) monitoring indicated that all females (100%) had ELISA values less than 0.199. Additionally, all females had ELISA values less than 0.120, which means that none of the progeny needed to be reared at densities less than 0.06 fish per pound (Table 8.12).

Table 8.12. Proportion of bacterial kidney disease (BKD) titer groups for the Wenatchee summer Chinook broodstock, brood years 1997-2016. Also included are the proportions to be reared at either 0.125 fish per pound or 0.060 fish per pound.

Brood year[a]	Optical density values by titer group				Proportion at rearing densities (fish per pound, fpp)[b]	
	Very Low (≤ 0.099)	Low (0.1-0.199)	Moderate (0.2-0.449)	High (≥ 0.450)	≤ 0.125 fpp (<0.119)	≤ 0.060 fpp (>0.120)
1997	0.7714	0.0857	0.0381	0.1048	0.8095	0.1905
1998	0.3067	0.2393	0.1656	0.2883	0.4479	0.5521
1999	0.9590	0.0123	0.0123	0.0164	0.9713	0.0287
2000	0.6268	0.1053	0.1627	0.1053	0.7321	0.2679
2001	0.6513	0.0263	0.0987	0.2237	0.6776	0.3224
2002	0.7868	0.0457	0.0711	0.0964	0.8325	0.1675
2003	0.9825	0.0000	0.0058	0.0117	0.9825	0.0175
2004	0.9593	0.0081	0.0163	0.0163	0.9675	0.0325
2005	0.9833	0.0056	0.0000	0.0111	0.9833	0.0167
2006	0.9134	0.0563	0.0000	0.0303	0.9351	0.0649
2007	0.9535	0.0078	0.0078	0.0310	0.9535	0.0465
2008	0.9868	0.0088	0.0044	0.0000	0.9868	0.0132

Brood year[a]	Optical density values by titer group				Proportion at rearing densities (fish per pound, fpp)[b]	
	Very Low (≤ 0.099)	Low (0.1-0.199)	Moderate (0.2-0.449)	High (≥ 0.450)	≤ 0.125 fpp (<0.119)	≤ 0.060 fpp (>0.120)
2009	0.9957	0.0000	0.0000	0.0043	0.9957	0.0043
2010	0.9897	0.0025	0.0000	0.0025	0.9949	0.0051
2011	0.9585	0.0363	0.0000	0.0052	0.9896	0.0104
2012	0.9697	0.0303	0.0000	0.0000	1.0000	0.0000
2013	0.8120	0.1790	0.0000	0.0090	0.8890	0.1110
2014	0.9462	0.0154	0.0000	0.0385	0.9462	0.0538
2015	0.9919	0.0000	0.0000	0.0081	0.9919	0.0081
2016	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Average	***0.8772***	***0.0432***	***0.0291***	***0.0501***	***0.9043***	***0.0957***
Median	***0.9588***	***0.0139***	***0.0022***	***0.0140***	***0.9694***	***0.0306***

[a] Individual ELISA samples were not collected before the 1997 brood.
[b] ELISA values from broodstock BKD testing dictate what density the progeny of the broodstock are reared. Progeny of broodstock with high ELISA values are reared at lower density.

8.4 Natural Juvenile Productivity

During 2016, juvenile summer Chinook were sampled at the Lower Wenatchee Trap located near the town of Cashmere. The Lower Wenatchee Trap was moved to its present location in 2013 and as a result flow efficiency models need to be created and updated. These relationships continue to be developed and improved.

Emigrant Estimates

Lower Wenatchee Trap

The Lower Wenatchee Trap operated between 29 January and 26 July 2016. During that time, the trap was inoperable for 23 days because of high and low river discharge, debris, elevated river temperatures, large hatchery releases, and mechanical issues. During the sampling period, a total of 27,407 wild subyearling Chinook were captured at the Lower Wenatchee Trap. Based on 22 capture efficiencies, a significant relationship between trap efficiency and river discharge was created ($R^2 = 0.56$, $P < 0.040$) and an estimate of 4,023,310 (±676,633; 95% CI) wild subyearling Chinook passed the trap within the sampling period (Table 8.13).

Table 8.13. Numbers of redds and juvenile summer Chinook emigrants in the Wenatchee River basin for brood years 1999-2015; NS = not sampled. From 2000-2010 the trap operated at Monitor; from 2013 to present the trap operated near Cashmere.

Brood year	Number of redds	Egg deposition	Number of emigrants upstream from trap	Total number of emigrants
1999	2,738	13,654,406	9,572,392	9,685,591
2000	2,540	13,820,140	1,299,476	1,322,383
2001	3,550	18,094,350	8,229,920	8,340,342
2002	6,836	37,488,624	13,167,855	13,475,368

Brood year	Number of redds	Egg deposition	Number of emigrants upstream from trap	Total number of emigrants
2003	5,268	28,241,748	20,336,968	20,426,149
2004	4,874	26,207,498	14,764,141	14,935,745
2005	3,538	17,877,514	11,612,939	11,695,581
2006	8,896	45,663,168	9,397,044	9,595,512
2007	1,970	10,076,550	4,470,672	4,546,838
2008	2,800	14,302,400	4,309,496	4,405,473
2009	3,441	18,206,331	6,695,977	6,814,805
2010	3,261	16,184,343	NS	NS
2011	3,078	15,122,214	NS	NS
2012	2,504	12,021,704	9,333,214	10,034,508
2013	3,241	16,162,867	11,936,928	12,605,925
2014	3,458	16,556,904	14,157,778	14,763,064
2015	1,804	11,491,325	4,023,310	4,199,697
Average	***3,345***	***19,480,711***	***9,553,874***	***9,789,799***
Median	***2,953***	***16,184,343***	***9,397,044***	***9,685,591***

A total of 114 summer Chinook redds were observed downstream from the trap in 2016. Thus, the total number of summer Chinook emigrating from the Wenatchee River in 2015 was expanded using the ratio of the number of redds downstream from the trap to the number upstream from the trap. This resulted in a total summer Chinook emigrant estimate of 4,199,697 fish (Table 8.13). Most of the fish emigrated during April with another pulse in June (Figure 8.1). Monthly captures and mortalities of all fish collected at the Lower Wenatchee Trap are reported in Appendix B.

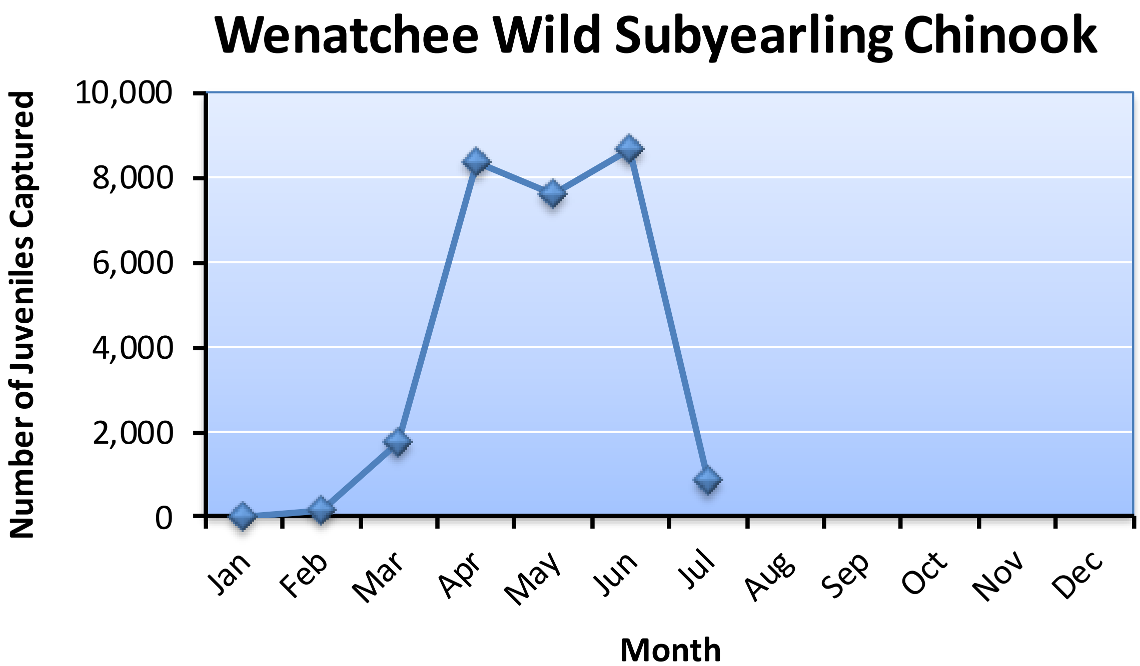

Figure 8.1. Numbers of wild subyearling Chinook captured at the Lower Wenatchee Trap during late January through July 2016.

Subyearling summer Chinook sampled in 2016 averaged 53 mm in length, 2.0 g in weight, and had a mean condition of 1.34 (Table 8.14). These size estimates were similar to the overall mean of subyearling summer Chinook sampled in previous years (overall means: 49 mm, 1.6 g, and condition of 1.28).

Table 8.14. Mean fork length (mm), weight (g), and condition factor of subyearling summer Chinook collected in the Lower Wenatchee Trap, 2000-2016; NS = not sampled. From 2000-2010 the trap operated at Monitor; from 2013 to present the trap operated near Cashmere. Numbers in parentheses indicate 1 standard deviation.

Sample year	Sample size[a]	Mean size		
		Length (mm)	Weight (g)	Condition (K)
2000	1,099	49 (14.7)	1.7 (2.2)	1.40 (0.29)
2001	403	56 (15.1)	2.3 (1.9)	1.33 (0.17)
2002	2,337	59 (18.0)	2.9 (2.7)	1.42 (0.17)
2003	818	59 (15.6)	2.8 (2.6)	1.40 (0.16)
2004	1,725	46 (11.2)	1.2 (1.5)	1.23 (0.20)
2005	2,944	45 (9.2)	1.0 (1.0)	1.13 (0.21)
2006	2,873	50 (15.2)	1.8 (2.0)	1.39 (0.21)
2007	2,864	46 (9.1)	1.0 (1.0)	1.10 (0.28)
2008	2,136	46 (11.6)	1.3 (1.4)	1.29 (0.21)
2009	2,185	45 (9.3)	1.0 (0.9)	1.16 (0.21)
2010	2,318	43 (8.3)	0.9 (0.9)	1.11 (0.29)

Sample year	Sample size[a]	Mean size		
		Length (mm)	Weight (g)	Condition (K)
2011	NS	NS	NS	NS
2012	NS	NS	NS	NS
2013	4,452	51 (16.9)	2.1 (4.0)	1.52 (0.31)
2014	5,166	45 (10.5)	1.1 (1.3)	1.19 (0.44)
2015	4,560	49 (13.0)	1.5 (1.5)	1.25 (0.18)
2016	5,998	53 (14.8)	2.0 (1.9)	1.34 (0.17)
Average	2,792	49 (12.8)	1.6 (1.8)	1.28
Median	2,337	49 (13.0)	1.5 (1.5)	1.29

[a] Sample size represents the number of fish that were measured for both length and weight.

8.5 Spawning Surveys

Surveys for Wenatchee summer Chinook redds were conducted from 5 September to 11 November 2016 in the Wenatchee River and Icicle Creek.

Redd Counts

A total count of summer Chinook redds was estimated in 2016 based on weekly census surveys conducted in the Wenatchee River. Redds were counted in Icicle Creek when feasible. A total of 2,797 summer Chinook redds were counted in the Wenatchee River basin in 2016 (Table 8.15).

In the future, spawning escapement estimates may be derived using the area-under-the-curve (AUC) method described in Millar et al. (2012). WDFW now has three years of data (2014, 2015, and 2016) to inform model parameters (e.g., observer efficiency of redd counts at variable temporal and spatial scales). Model calibration has begun with existing data. After the conclusion of 2018 surveys, WDFW will have a complete model to generate updated spawning escapements with associated variance.

Table 8.15. Numbers of redds counted in the Wenatchee River basin, 1989-2016; ND = no data. From 1989-2013, numbers of redds were based on expanding "peak counts" to generate a Total Count. Since 2014, numbers of redds were based on weekly census surveys that encompass all reaches.

Survey year	Redd counts		Total count
	Wenatchee River	Icicle Creek	
1989	3,331	ND	4,215
1990	2,479	ND	3,103
1991	2,180	ND	2,748
1992	2,328	ND	2,913
1993	2,334	ND	2,953
1994	2,426	ND	3,077
1995	1,872	ND	2,350
1996	1,435	ND	1,814
1997	1,388	ND	1,739
1998	1,660	ND	2,230
1999	2,188	ND	2,738

Survey year	Redd counts		Total count
	Wenatchee River	Icicle Creek	
2000	2,022	ND	2,540
2001	2,857	ND	3,550
2002	5,419	ND	6,836
2003	4,281	ND	5,268
2004	4,003	ND	4,874
2005	2,895	ND	3,538
2006	7,165	68	8,896
2007	1,857	13	1,970
2008	2,338	23	2,800
2009	2,667	21	3,441
2010	2,553	11	3,261
2011	2,583	9	3,078
2012	2,301	2	2,504
2013	2,875	42	3,241
2014	3,383	75	3,458
2015	1,781	23	1,804
2016	2,725	72	2,797
Average			***3,348***
Median			***3,015***

Redd Distribution

Summer Chinook redds were not evenly distributed among reaches within the Wenatchee River basin in 2016 (Table 8.16; Figure 8.2). Most of the spawning occurred upstream from the Leavenworth Bridge in Reaches 6, 9, and 10. The highest density of redds occurred in Reach 6 near the confluence of the Icicle River.

Table 8.16. Total numbers of summer Chinook redds counted in different reaches in the Wenatchee River basin during September through mid-November 2016. Reach codes are described in Table 2.10.

Survey reach	Total redd count
Wenatchee 1 (W1)	1
Wenatchee 2 (W2)	144
Wenatchee 3 (W3)	224
Wenatchee 4 (W4)	41
Wenatchee 5 (W5)	103
Wenatchee 6 (W6)	687
Wenatchee 7 (W7)	192
Wenatchee 8 (W8)	309
Wenatchee 9 (W9)	502
Wenatchee 10 (W10)	522

Survey reach	Total redd count
Icicle Creek (I1)	72
Totals	***2,797***

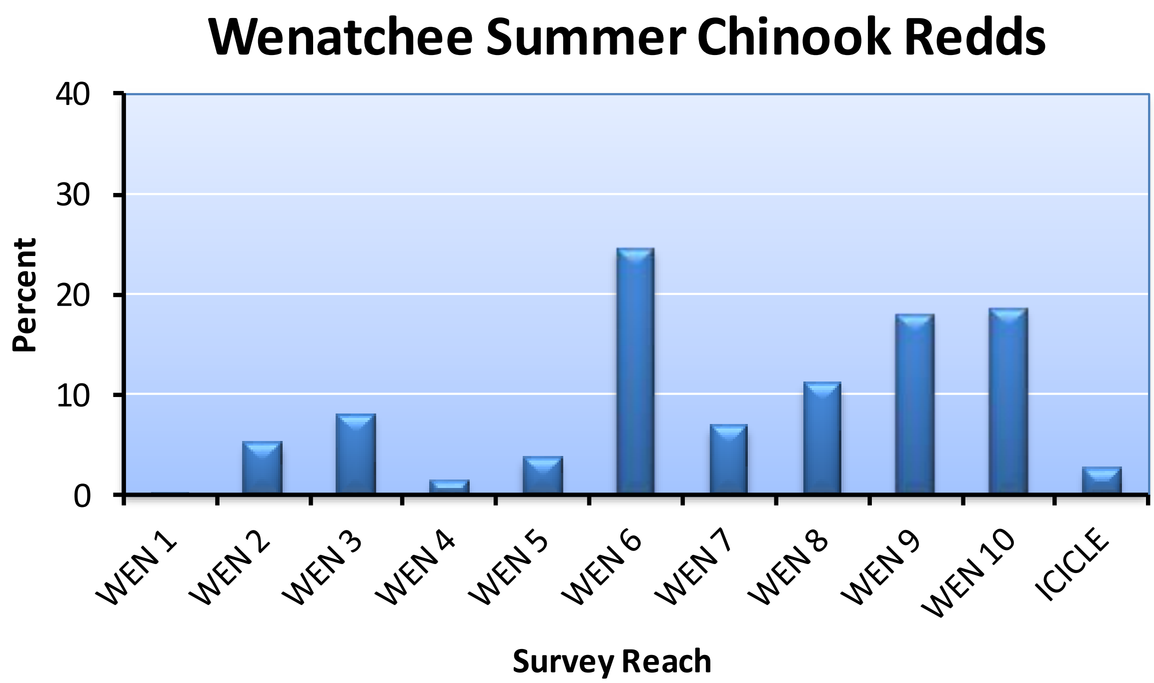

Figure 8.2. Percent of the total number of summer Chinook redds counted in different reaches in the Wenatchee River basin during September through early-November 2016. Reach codes are described in Table 2.10.

Spawn Timing

In 2016, spawning in the Wenatchee River began during the fourth week of September, peaked the first week of October, and ended the first week of November (Figure 8.3).

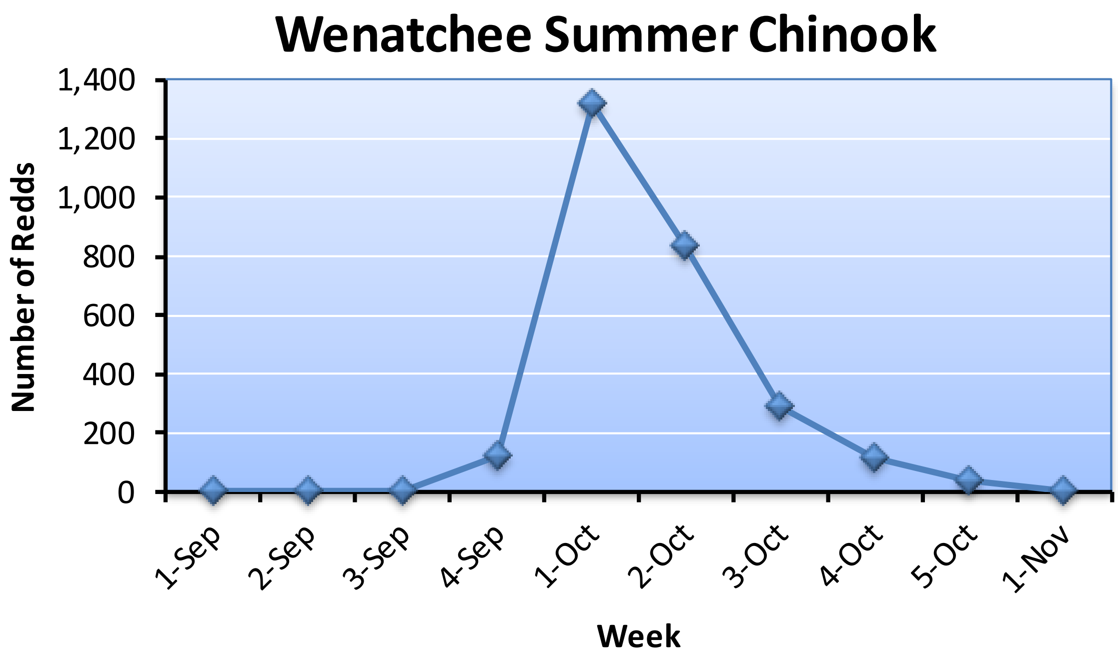

Figure 8.3. Number of new summer Chinook redds counted during different weeks in the Wenatchee River, September through mid-November 2016.

Spawning Escapement

Spawning escapement for Wenatchee summer Chinook was calculated as the total number of redds (expanded peak counts for return years 1989-2013) times the fish per redd ratio estimated from broodstock and fish sampled at adult trapping sites.[25] The estimated fish per redd ratio for summer Chinook in 2016 was 2.11. Multiplying this ratio by the number of redds counted in the Wenatchee River basin resulted in a total spawning escapement of 5,902 summer Chinook (Table 8.17). This is less than the overall average spawning escapement of 9,100 summer Chinook.

Table 8.17. Spawning escapements for summer Chinook in the Wenatchee River basin, return years 1989-2016. Number of redds is based on expanded peak redd counts for the period 1989-2013.

Return year	Fish/Redd	Redds	Total spawning escapement
1989	3.40	4,215	14,331
1990	3.50	3,103	10,861
1991	3.70	2,748	10,168
1992	4.00	2,913	11,652
1993	3.20	2,953	9,450
1994	3.30	3,077	10,154
1995	3.30	2,350	7,755
1996	3.40	1,814	6,168
1997	3.40	1,739	5,913

[25] Expansion factor = (1 + (number of males/number of females)).

Return year	Fish/Redd	Redds	Total spawning escapement
1998	2.40	2,230	5,352
1999	2.00	2,738	5,476
2000	2.17	2,540	5,512
2001	3.20	3,550	11,360
2002	2.30	6,836	15,723
2003	2.24	5,268	11,800
2004	2.15	4,874	10,479
2005	2.46	3,538	8,703
2006	2.00	8,896	17,792
2007	2.33	1,970	4,590
2008	2.32	2,800	6,496
2009	2.42	3,441	8,327
2010	2.29	3,261	7,468
2011	3.20	3,078	9,850
2012	3.41	2,504	8,539
2013	3.15	3,241	10,209
2014	3.02	3,458	10,443
2015	2.40	1,804	4,330
2016	2.11	2,797	5,902
Average	***2.81***	***3,348***	***9,100***
Median	***2.74***	***3,015***	***9,077***

8.6 Carcass Surveys

Surveys for Wenatchee summer Chinook carcasses were conducted from mid-September to early November 2016 in the Wenatchee River and Icicle Creek.

Number sampled

A total of 1,309 summer Chinook carcasses were sampled during early September through early November in the Wenatchee River basin in 2016 (Table 8.18).

Table 8.18. Numbers of summer Chinook carcasses sampled within each survey reach in the Wenatchee River basin, 1993-2016. Reach codes are described in Table 2.10.

Survey year	Number of summer Chinook carcasses											
	W-1	W-2	W-3	W-4	W-5	W-6	W-7	W-8	W-9	W-10	Icicle	Total
1993	68	151	696	13	82	150	215	41	0	0	0	**1,416**
1994	0	6	25	1	21	50	20	49	131	1	0	**304**
1995	0	10	14	0	0	117	50	37	20	0	0	**248**
1996	0	5	84	42	10	206	27	37	43	0	0	**454**
1997	1	47	127	5	29	312	8	80	70	13	0	**692**

Survey year	**Number of summer Chinook carcasses**											
	W-1	**W-2**	**W-3**	**W-4**	**W-5**	**W-6**	**W-7**	**W-8**	**W-9**	**W-10**	**Icicle**	**Total**
1998	6	81	159	4	1	270	32	395	354	65	0	**1,367**
1999	0	169	112	16	35	932	68	146	185	79	0	**1,742**
2000	8	118	178	9	85	693	82	121	172	208	0	**1,674**
2001	0	49	138	31	0	338	36	124	101	94	0	**911**
2002	0	249	189	0	205	848	0	341	564	166	6	**2,568**
2003	6	369	195	72	149	768	66	266	537	58	40	**2,526**
2004	8	157	193	177	173	1,086	103	346	493	409	16	**3,161**
2005	8	85	106	39	46	709	70	140	353	258	7	**1,821**
2006	22	140	160	64	112	953	435	343	703	658	18	**3,608**
2007	3	15	49	10	26	475	38	38	96	91	8	**849**
2008	10	34	63	38	36	676	47	42	106	144	8	**1,204**
2009	11	29	43	32	27	389	16	58	240	175	6	**1,026**
2010	3	31	98	57	122	681	135	49	124	194	15	**1,509**
2011	5	88	126	19	38	1,332	77	45	211	289	9	**2,239**
2012	8	82	95	22	40	600	53	62	173	183	0	**1,318**
2013	3	100	149	22	109	767	5	60	353	265	14	**1,847**
2014	3	42	64	18	59	659	89	160	329	282	34	**1,739**
2015	9	7	36	15	19	296	27	110	314	150	5	**988**
2016	7	55	96	33	90	494	27	79	245	178	5	**1,309**
Average	***8***	***88***	***133***	***31***	***63***	***575***	***72***	***132***	***247***	***165***	***8***	***1522***
Median	***6***	***68***	***109***	***21***	***39***	***630***	***49***	***80***	***198***	***158***	***6***	***1392***

Carcass Distribution and Origin

Summer Chinook carcasses were not evenly distributed among reaches within the Wenatchee River basin in 2016 (Table 8.18; Figure 8.4). Most of the carcasses in the Wenatchee River basin were found upstream from the Leavenworth Bridge. The highest percentage of carcasses (37.8%) was sampled in Reach 6.

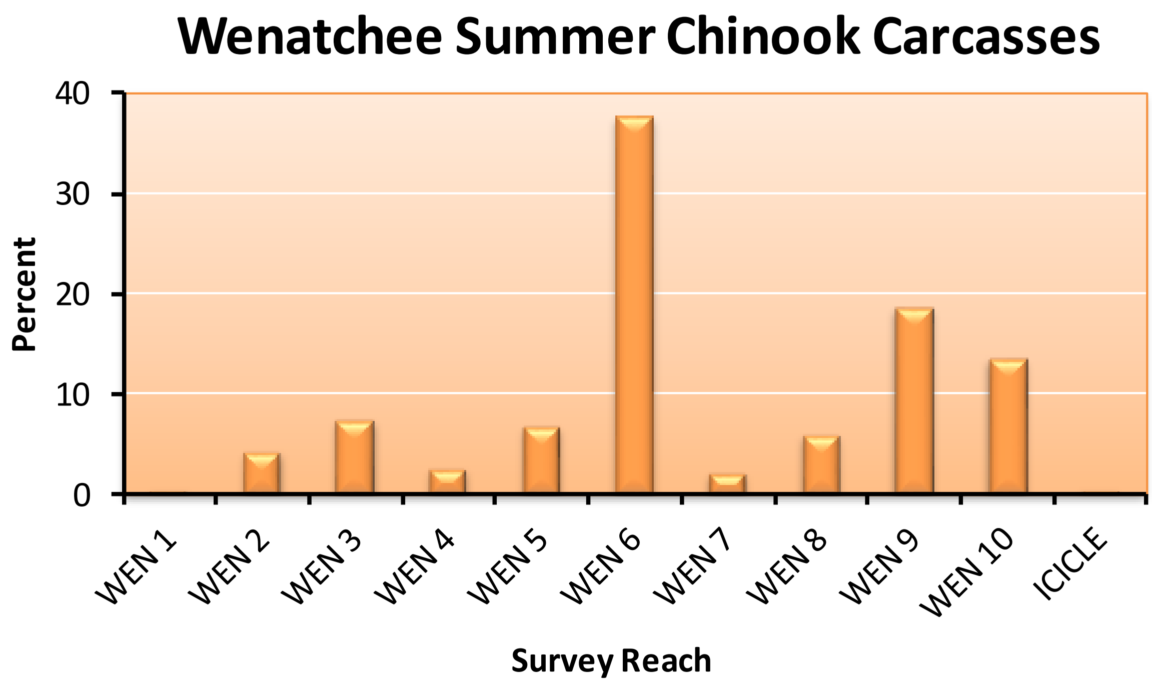

Figure 8.4. Percent of summer Chinook carcasses sampled within different reaches in the Wenatchee River basin during September through mid-November 2016. Reach codes are described in Table 2.10.

As in previous years, regardless of origin, most summer Chinook were found in Reach 6 (Leavenworth Bridge to Icicle Road Bridge) (Table 8.19). In general, a larger percentage of wild fish were found in the upper reaches than were hatchery fish (Figure 8.5). In contrast, a larger percentage of hatchery fish were found in reaches downstream from the Icicle Road Bridge.

Table 8.19. Numbers of wild and hatchery summer Chinook carcasses sampled within different reaches in the Wenatchee River basin, 1993-2016.

Survey year	Origin	Survey reach											Total
		W-1	W-2	W-3	W-4	W-5	W-6	W-7	W-8	W-9	W-10	Icicle	
1993	Wild	59	146	660	12	82	133	213	40	0	0	0	**1,345**
	Hatchery	9	5	36	1	0	17	2	1	0	0	0	**71**
1994	Wild	0	2	18	1	19	36	20	49	130	1	0	**276**
	Hatchery	0	4	7	0	2	14	0	0	1	0	0	**28**
1995	Wild	0	4	11	0	0	105	50	35	20	0	0	**225**
	Hatchery	0	6	3	0	0	12	0	2	0	0	0	**23**
1996	Wild	0	5	82	40	9	196	27	37	43	0	0	**439**
	Hatchery	0	0	2	2	1	10	0	0	0	0	0	**15**
1997	Wild	1	38	112	5	22	266	8	80	69	13	0	**614**
	Hatchery	0	9	15	0	7	46	0	0	1	0	0	**78**
1998	Wild	6	62	124	3	1	191	29	374	327	62	0	**1,179**
	Hatchery	0	19	35	1	0	79	3	21	27	3	0	**188**
1999	Wild	0	88	70	8	18	600	58	137	169	75	0	**1,223**

Survey year	Origin	Survey reach											Total
		W-1	W-2	W-3	W-4	W-5	W-6	W-7	W-8	W-9	W-10	Icicle	
	Hatchery	0	81	42	8	17	332	10	9	16	4	0	**519**
2000	Wild	5	78	115	8	57	485	75	110	167	200	0	**1,300**
	Hatchery	3	40	63	1	28	208	7	11	5	8	0	**374**
2001	Wild	0	37	100	9	0	245	32	122	97	91	0	**733**
	Hatchery	0	12	38	22	0	93	4	2	4	3	0	**178**
2002	Wild	0	151	127	0	103	479	0	330	558	161	3	**1,912**
	Hatchery	0	98	62	0	102	369	0	11	6	5	3	**656**
2003	Wild	5	261	147	32	111	519	62	252	498	57	15	**1,959**
	Hatchery	1	108	48	40	38	249	4	14	39	1	25	**567**
2004	Wild	7	124	163	120	112	749	90	316	481	399	11	**2,572**
	Hatchery	1	33	30	56	61	337	13	30	12	10	5	**588**
2005	Wild	4	49	78	24	26	399	66	125	336	244	0	**1,351**
	Hatchery	4	36	28	15	20	310	4	15	17	14	7	**470**
2006	Wild	15	91	122	44	75	688	388	309	646	593	5	**2,976**
	Hatchery	7	49	38	20	37	265	47	34	57	65	13	**632**
2007	Wild	1	7	24	1	10	197	34	30	95	81	3	**483**
	Hatchery	2	8	25	9	16	278	4	8	1	10	5	**366**
2008	Wild	7	15	38	24	21	361	41	31	98	133	2	**771**
	Hatchery	3	19	25	14	15	315	6	11	8	11	6	**433**
2009	Wild	6	22	32	23	19	288	13	55	236	173	4	**871**
	Hatchery	5	7	11	9	8	101	3	3	4	2	2	**155**
2010	Wild	2	22	62	44	64	477	125	47	121	192	0	**1,156**
	Hatchery	1	9	36	13	58	204	10	2	3	2	15	**353**
2011	Wild	4	46	75	11	25	914	74	45	211	287	3	**1,695**
	Hatchery	1	42	51	7	13	418	3	0	0	2	6	**543**
2012	Wild	4	49	72	13	24	490	47	62	173	182	0	**1,116**
	Hatchery	4	33	23	9	16	110	6	0	0	1	0	**202**
2013	Wild	1	63	89	16	69	374	5	59	340	261	0	**1,277**
	Hatchery	2	52	60	6	40	395	0	1	13	4	0	**573**
2014	Wild	3	35	57	16	48	572	89	158	329	281	12	**1600**
	Hatchery	0	7	7	2	11	87	0	2	0	0	22	**139**
2015	Wild	6	6	36	13	16	263	26	107	301	148	6	**928**
	Hatchery	3	1	0	2	3	33	1	3	13	2	0	**61**
2016	Wild	5	40	78	29	75	426	27	79	243	175	4	**1,181**
	Hatchery	2	15	18	4	15	68	0	0	3	3	1	**129**
Average	***Wild***	***6***	***60***	***104***	***21***	***42***	***394***	***67***	***125***	***237***	***159***	***3***	***1,216***
	Hatchery	***2***	***29***	***29***	***10***	***21***	***181***	***5***	***8***	***10***	***6***	***5***	***306***
Median	***Wild***	***4***	***43***	***78***	***13***	***25***	***387***	***44***	***80***	***192***	***155***	***0***	***1,180***
	Hatchery	***1***	***17***	***29***	***7***	***15***	***157***	***3***	***3***	***4***	***3***	***1***	***278***

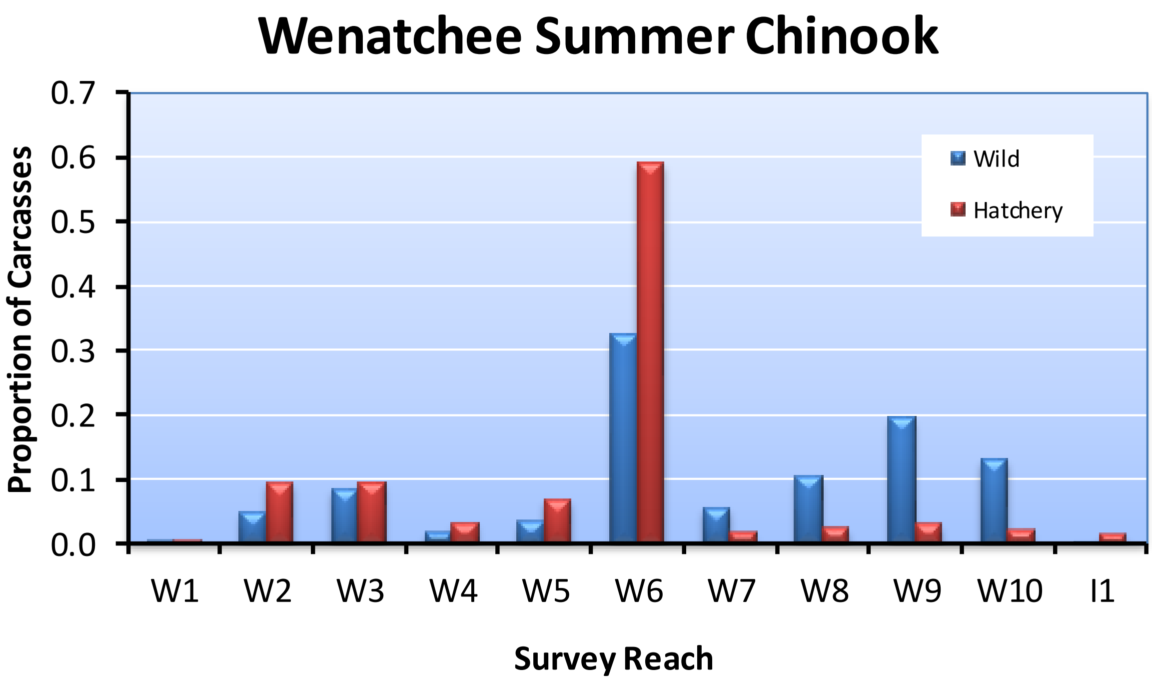

Figure 8.5. Distribution of wild and hatchery produced carcasses in different reaches in the Wenatchee River basin, 1993-2016. Reach codes are described in Table 2.10.

Sampling Rate

If spawning escapement is based on total numbers of redds, then about 22% of the total spawning escapement of summer Chinook in the Wenatchee River basin was sampled in 2016 (Table 8.20). Sampling rates among survey reaches varied from 7 to 332%.

Table 8.20. Number of redds and carcasses, total spawning escapement, and sampling rates for summer Chinook in the Wenatchee River basin, 2016.

Sampling reach	Total number of redds	Total number of carcasses	Total spawning escapement	Sampling rate
Wenatchee 1 (W1)	1	7	2	3.32
Wenatchee 2 (W2)	144	55	304	0.18
Wenatchee 3 (W3)	224	96	473	0.20
Wenatchee 4 (W4)	41	33	87	0.38
Wenatchee 5 (W5)	103	90	217	0.41
Wenatchee 6 (W6)	687	494	1,450	0.34
Wenatchee 7 (W7)	192	27	405	0.07
Wenatchee 8 (W8)	309	79	652	0.12
Wenatchee 9 (W9)	502	245	1,059	0.23
Wenatchee 10 (W10)	522	178	1,101	0.16
Icicle Creek (I1)	72	5	152	0.08
Total	***2,797***	***1,309***	***5,902***	***0.22***

Length Data

Mean lengths (POH, cm) of male and female summer Chinook carcasses sampled during surveys in the Wenatchee River basin in 2016 are provided in Table 8.21. The average size of males and females sampled in the Wenatchee River basin were 68 cm and 70 cm, respectively.

Table 8.21. Mean lengths (postorbital-to-hypural length; cm) and standard deviations (in parentheses) of male and female summer Chinook carcasses sampled in different streams/watersheds in the Wenatchee River basin, 2016.

Stream/watershed	Mean length (cm)	
	Male	Female
Wenatchee 1 (W1)	63.0 (10.2)	70.0 (0)
Wenatchee 2 (W2)	71.5 (8.3)	70.9 (5.1)
Wenatchee 3 (W3)	70.2 (10.2)	70.4 (4.8)
Wenatchee 4 (W4)	71.9 (6.7)	69.5 (2.9)
Wenatchee 5 (W5)	67.0 (8.7)	69.1 (5.0)
Wenatchee 6 (W6)	69.0 (6.9)	69.4 (4.8)
Wenatchee 7 (W7)	69.8 (10.3)	71.6 (4.4)
Wenatchee 8 (W8)	67.5 (8.4)	67.3 (4.9)
Wenatchee 9 (W9)	67.7 (8.1)	70.8 (4.0)
Wenatchee 10 (W10)	66.0 (8.2)	67.4 (5.8)
Icicle Creek (I1)	62.0 (0)	75.3 (2.6)
Total	***68.2 (8.3)***	***69.5 (4.9)***

8.7 Life History Monitoring

Life history characteristics of Wenatchee summer Chinook were assessed by examining carcasses on spawning grounds and fish collected or examined at broodstock collection sites, and by reviewing tagging data and fisheries statistics.

Migration Timing

Migration timing of hatchery and wild Wenatchee summer Chinook was determined from broodstock data and stock assessment data collected at Dryden Dam. Sampling at Dryden Dam occurs from early July through mid-October. On average, during the early part of the migration, hatchery summer Chinook arrived about two weeks later than wild Chinook (Table 8.22). This pattern carried through the migration distribution of summer Chinook at Dryden Dam. By the end of the migration, hatchery fish passed Dryden Dam about two weeks after 90% of the wild fish passed the dam.

Table 8.22. The week that 10%, 50% (median), and 90% of the wild and hatchery summer Chinook salmon passed Dryden Dam, 2007-2016. The average week is also provided. Migration timing is based on collection of summer Chinook broodstock at Dryden Dam.

Survey year	Origin	Wenatchee Summer Chinook Migration Time (week)				Sample size
		10 Percentile	50 Percentile	90 Percentile	Mean	
2007	Wild	28	31	37	31	274
	Hatchery	30	33	41	35	305
2008	Wild	29	31	40	32	219
	Hatchery	32	37	41	37	576
2009	Wild	27	29	41	31	469
	Hatchery	28	34	42	35	382
2010	Wild	30	33	35	32	403
	Hatchery	29	30	33	30	268
2011	Wild	30	31	34	32	293
	Hatchery	32	34	39	35	304
2012	Wild	30	32	39	33	247
	Hatchery	31	37	41	36	366
2013	Wild	28	30	34	31	494
	Hatchery	29	33	39	33	570
2014	Wild	29	31	37	32	512
	Hatchery	29	32	40	33	338
2015	Wild	25	30	40	31	511
	Hatchery	28	35	40	35	88
2016	Wild	28	30	40	32	407
	Hatchery	29	34	41	35	184
Average	***Wild***	***28***	***31***	***38***	***32***	***383***
	Hatchery	***30***	***34***	***40***	***34***	***338***
Median	***Wild***	***29***	***31***	***38***	***32***	***405***
	Hatchery	***29***	***34***	***41***	***35***	***322***

Age at Maturity

Because hatchery summer Chinook are released after one year of rearing and natural-origin summer Chinook migrate primarily as age-0 fish, total ages will differ between hatchery and natural-origin Chinook (see Hillman et al. 2011). Therefore, in this section, we evaluated age at maturity by comparing differences in salt (ocean) ages between the two groups.

Most of the wild and hatchery summer Chinook sampled during the period 1993-2016 in the Wenatchee River basin were salt age-3 fish (Table 8.23; Figure 8.6). Over the survey years, a higher percentage of salt age-4 wild Chinook returned to the basin than did salt age-4 hatchery Chinook. In contrast, a higher proportion of salt age-1 and 2 hatchery fish returned than did salt age-1 and 2 wild fish. Thus, a higher percentage of wild fish returned at an older age than did hatchery fish.

Table 8.23. Proportions of wild and hatchery summer Chinook of different salt (ocean) ages sampled on spawning grounds in the Wenatchee River basin, 1993-2016.

Sample year	Origin	Salt age					Sample size
		1	2	3	4	5	
1993	Wild	0.02	0.24	0.62	0.12	0.00	1,224
	Hatchery	0.03	0.91	0.03	0.03	0.00	64
1994	Wild	0.02	0.21	0.45	0.32	0.00	257
	Hatchery	0.00	0.14	0.86	0.00	0.00	21
1995	Wild	0.02	0.15	0.65	0.18	0.00	216
	Hatchery	0.00	0.00	0.05	0.95	0.00	21
1996	Wild	0.01	0.25	0.66	0.08	0.00	512
	Hatchery	0.00	0.33	0.33	0.29	0.05	21
1997	Wild	0.01	0.24	0.57	0.18	0.00	561
	Hatchery	0.05	0.20	0.67	0.08	0.00	75
1998	Wild	0.02	0.23	0.66	0.09	0.00	1,041
	Hatchery	0.03	0.49	0.38	0.10	0.00	187
1999	Wild	0.01	0.34	0.55	0.10	0.00	1,087
	Hatchery	0.01	0.15	0.79	0.05	0.00	510
2000	Wild	0.02	0.20	0.64	0.15	0.00	1,181
	Hatchery	0.07	0.11	0.66	0.15	0.00	342
2001	Wild	0.01	0.16	0.74	0.08	0.00	653
	Hatchery	0.05	0.76	0.14	0.04	0.00	181
2002	Wild	0.00	0.14	0.62	0.24	0.00	1,744
	Hatchery	0.01	0.16	0.80	0.02	0.00	646
2003	Wild	0.01	0.07	0.51	0.41	0.00	1,653
	Hatchery	0.05	0.07	0.75	0.12	0.00	530
2004	Wild	0.00	0.12	0.32	0.54	0.01	2,233
	Hatchery	0.08	0.57	0.25	0.10	0.00	566
2005	Wild	0.00	0.12	0.75	0.13	0.00	1,190
	Hatchery	0.02	0.09	0.86	0.03	0.00	450
2006	Wild	0.00	0.02	0.27	0.71	0.00	2,972
	Hatchery	0.02	0.16	0.24	0.57	0.00	299
2007	Wild	0.01	0.09	0.31	0.53	0.07	480
	Hatchery	0.00	0.15	0.75	0.07	0.03	275
2008	Wild	0.01	0.06	0.76	0.17	0.00	767
	Hatchery	0.02	0.12	0.76	0.11	0.00	329
2009	Wild	0.01	0.07	0.51	0.41	0.00	797
	Hatchery	0.10	0.36	0.49	0.05	0.00	132
2010	Wild	0.01	0.18	0.65	0.16	0.00	1,068
	Hatchery	0.00	0.49	0.47	0.03	0.00	294

Sample year	Origin	Salt age					Sample size
		1	2	3	4	5	
2011	Wild	0.01	0.11	0.60	0.29	0.00	1,533
	Hatchery	0.06	0.04	0.90	0.01	0.00	472
2012	Wild	0.00	0.04	0.48	0.48	0.00	1,017
	Hatchery	0.00	0.03	0.88	0.08	0.03	200
2013	Wild	0.00	0.07	0.58	0.34	0.01	1,277
	Hatchery	0.00	0.01	0.13	0.86	0.00	573
2014	Wild	0.00	0.05	0.70	0.25	0.00	1,437
	Hatchery	0.02	0.06	0.20	0.70	0.02	128
2015	Wild	0.00	0.09	0.40	0.51	0.00	819
	Hatchery	0.00	0.10	0.65	0.24	0.00	49
2016	Wild	0.00	0.03	0.66	0.31	0.00	1,023
	Hatchery	0.03	0.11	0.83	0.03	0.00	97
Average	***Wild***	***0.01***	***0.12***	***0.54***	***0.33***	***0.00***	***1,114***
	Hatchery	***0.03***	***0.20***	***0.59***	***0.18***	***0.00***	***269***
Median	***Wild***	***0.01***	***0.11***	***0.67***	***0.21***	***0.00***	***1,055***
	Hatchery	***0.03***	***0.29***	***0.57***	***0.11***	***0.00***	***238***

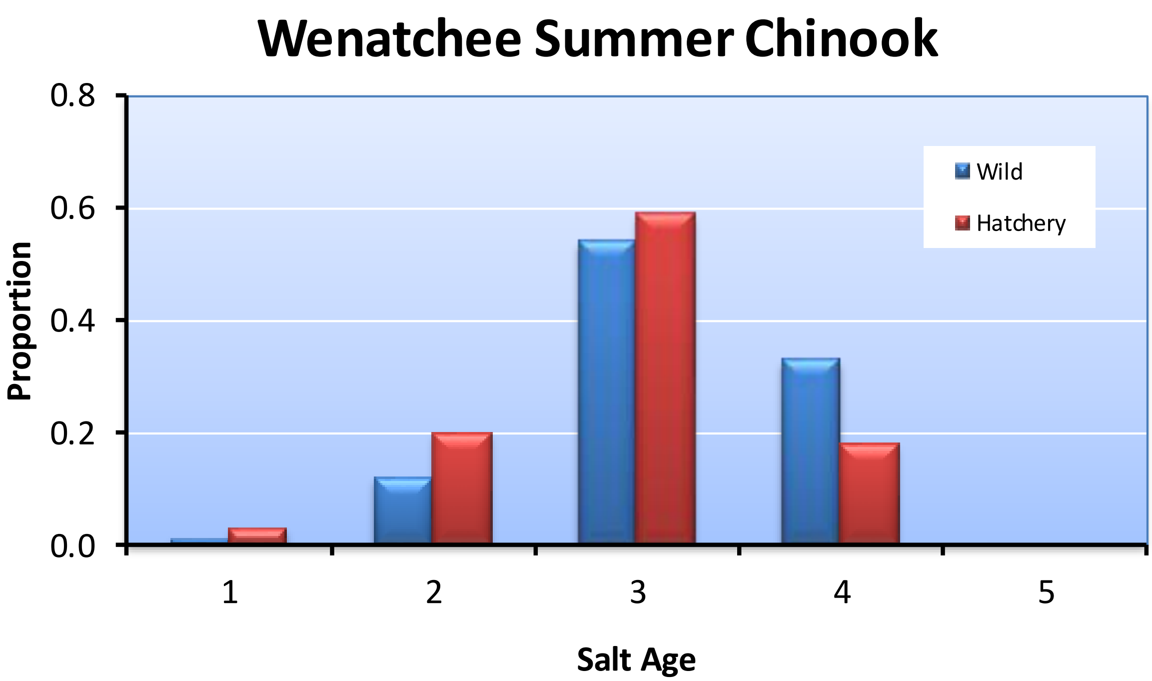

Figure 8.6. Proportions of wild and hatchery summer Chinook of different salt (ocean) ages sampled at broodstock collection sites and on spawning grounds in the Wenatchee River basin for the combined years 1993-2016.

Size at Maturity

On average, hatchery summer Chinook were about 4 cm smaller than wild summer Chinook sampled in the Wenatchee River basin (Table 8.24). This is likely because a higher percentage of hatchery fish returned as salt age-2 and 3 fish than did wild fish. In contrast, a higher percentage of wild fish returned as salt age-4 fish than did hatchery fish. Analyses for the five-year reports will compare sizes of hatchery and wild fish of the same age groups and sex.

Table 8.24. Mean lengths (POH; cm) and variability statistics for wild and hatchery summer Chinook sampled in the Wenatchee River basin, 1993-2016; SD = 1 standard deviation.

Sample year	Origin	Sample size	Summer Chinook length (POH; cm)			
			Mean	SD	Minimum	Maximum
1993[a]	Wild	1,344	73	8	33	94
	Hatchery	68	61	9	37	83
1994[a]	Wild	276	73	8	31	89
	Hatchery	25	70	8	54	85
1995[a]	Wild	225	75	7	48	87
	Hatchery	23	74	7	57	85
1996[a]	Wild	210	74	7	43	92
	Hatchery	9	66	12	52	84
1997	Wild	614	74	8	29	99
	Hatchery	79	69	10	29	83
1998	Wild	1,179	73	8	28	97
	Hatchery	188	67	10	37	87
1999	Wild	1,217	72	8	29	95
	Hatchery	518	71	8	26	94
2000	Wild	1,301	71	10	24	94
	Hatchery	369	69	11	33	91
2001	Wild	728	70	9	30	93
	Hatchery	178	63	10	28	86
2002	Wild	1,911	72	8	39	94
	Hatchery	656	71	8	34	95
2003	Wild	1,943	74	9	24	105
	Hatchery	554	69	10	26	97
2004	Wild	2,570	72	9	32	98
	Hatchery	584	59	11	25	91
2005	Wild	1,352	69	7	41	92
	Hatchery	469	69	8	39	91
2006	Wild	3,249	74	6	29	99
	Hatchery	350	71	9	35	90
2007	Wild	566	73	9	29	92
	Hatchery	269	70	7	45	87

Sample year	Origin	Sample size	Summer Chinook length (POH; cm)			
			Mean	SD	Minimum	Maximum
2008	Wild	836	69	8	29	89
	Hatchery	363	70	9	24	94
2009	Wild	872	71	8	30	94
	Hatchery	153	64	11	32	84
2010	Wild	1,147	68	8	32	92
	Hatchery	351	65	10	25	87
2011	Wild	1,698	68	8	33	101
	Hatchery	541	66	9	34	85
2012	Wild	1,116	70	7	29	91
	Hatchery	202	60	7	40	79
2013	Wild	1,277	66	9	24	95
	Hatchery	573	67	7	24	85
2014	Wild	1,600	68	7	29	98
	Hatchery	139	66	10	26	85
2015	Wild	928	68	8	39	86
	Hatchery	61	62	9	36	81
2016	Wild	1,180	69	6	43	93
	Hatchery	129	67	8	37	82
Pooled	***Wild***	***29,339***	***71***	***8***	***32***	***94***
	Hatchery	***6,851***	***67***	***9***	***35***	***87***

[a] These years include sizes reported in annual reports. The data contained in the WDFW database do not include all these data.

Contribution to Fisheries

Most of the harvest on hatchery-origin Wenatchee summer Chinook occurred in the ocean (Table 8.25). Ocean harvest has made up 47% to 100% of all hatchery Wenatchee summer Chinook harvested. Total harvest on early brood years (1990-1996 and 2007) was lower than for brood years 1997-2010.

Table 8.25. Estimated number and percent (in parentheses) of hatchery-origin Wenatchee summer Chinook captured in different fisheries, brood years 1989-2010.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
1989	1,510 (51)	1,432 (48)	0 (0)	20 (1)	2,962
1990	30 (100)	0 (0)	0 (0)	0 (0)	30
1991	30 (63)	0 (0)	0 (0)	18 (38)	48
1992	147 (79)	39 (21)	0 (0)	0 (0)	186
1993	35 (58)	25 (42)	0 (0)	0 (0)	60
1994	641 (91)	62 (9)	2 (0)	0 (0)	705
1995	562 (98)	9 (2)	5 (1)	0 (0)	576

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
1996	200 (96)	3 (1)	0 (0)	6 (3)	209
1997	3,033 (95)	49 (2)	12 (0)	106 (3)	3,200
1998	4,991 (92)	128 (2)	16 (0)	287 (5)	5,422
1999	1,550 (84)	168 (9)	21 (1)	104 (6)	1,843
2000	7,966 (73)	1,248 (11)	447 (4)	1,224 (11)	10,885
2001	1,061 (60)	238 (13)	106 (6)	364 (21)	1,769
2002	1,527 (56)	557 (21)	189 (7)	430 (16)	2,703
2003	833 (50)	484 (29)	89 (5)	257 (15)	1,663
2004	409 (47)	218 (25)	70 (8)	167 (19)	864
2005	1,329 (58)	481 (21)	187 (8)	287 (13)	2,284
2006	3,738 (52)	1,969 (27)	406 (6)	1,142 (16)	7,255
2007	212 (60)	81 (23)	8 (2)	53 (15)	354
2008	3,746 (59)	1,042 (16)	227 (4)	1,364 (21)	6,379
2009	1,594 (61)	453 (17)	99 (4)	452 (17)	2,598
2010	1,192 (51)	653 (28)	81 (3)	403 (17)	2,329
Average	***1,652 (70)***	***425 (17)***	***89 (3)***	***304 (11)***	***2,469***
Median	***1,127 (61)***	***193 (17)***	***19 (2)***	***137 (12)***	***1,806***

Straying

Stray rates were determined by examining CWTs recovered on spawning grounds within and outside the Wenatchee River basin. Targets for strays based on return year (recovery year) within the upper Columbia River basin (Priest Rapids Dam to Chief Joseph Dam) should be less than 10% and targets for strays outside the upper Columbia River should be less than 5%. The target for brood year stay rates should be less than 5%.

Hatchery-origin Wenatchee summer Chinook have strayed into the Entiat, Chelan, Methow, and Okanogan River basins and onto the Hanford Reach (Table 8.26). In only one year did Wenatchee summer Chinook strays make up more than 10% of the spawning escapement in the Chelan Tailrace. They made up more than 10% of the spawning escapement in the Entiat River basin in five different years. They made up less than 10% of the spawning escapements in the Methow and Okanogan River basins and the Hanford Reach.

Table 8.26. Number and percent of spawning escapements within other non-target spawning streams within the upper Columbia River basin that consisted of hatchery-origin Wenatchee summer Chinook, return years 1994-2015. For example, for return year 2000, 3% of the summer Chinook escapement in the Methow River basin consisted of hatchery-origin Wenatchee summer Chinook. Percent strays should be less than 10%.

Return year	Methow		Okanogan		Chelan		Entiat		Hanford Reach	
	Number	%	Number	%	Number	%	Number	%	Number	%
1994	0	0.0	75	1.9	--	--	--	--	--	--
1995	0	0.0	0	0.0	--	--	--	--	--	--
1996	0	0.0	0	0.0	--	--	--	--	--	--
1997	0	0.0	0	0.0	--	--	--	--	--	--
1998	25	3.7	0	0.0	0	0.0	0	0.0	0	0.0
1999	20	2.0	3	0.1	0	0.0	0	0.0	13	0.0
2000	36	3.0	13	0.4	0	0.0	0	0.0	0	0.0
2001	163	5.9	57	0.5	30	3.0	0	0.0	0	0.0
2002	153	3.3	53	0.4	40	6.9	74	14.8	0	0.0
2003	80	2.0	24	0.7	44	10.5	132	19.1	26	0.0
2004	113	5.2	42	0.6	30	7.1	0	0.0	0	0.0
2005	245	9.6	67	0.8	51	9.7	49	13.4	0	0.0
2006	170	6.2	12	0.1	12	2.9	61	10.6	0	0.0
2007	127	9.3	5	0.1	9	4.8	49	20.0	20	0.1
2008	87	4.5	24	0.3	10	2.0	31	9.7	0	0.0
2009	101	5.7	13	0.2	2	0.3	12	4.8	0	0.0
2010	206	8.3	35	0.6	55	4.9	34	7.8	0	0.0
2011	258	8.8	5	0.1	78	6.1	15	3.2	0	0.0
2012	109	3.7	24	0.3	53	4.1	54	6.0	0	0.0
2013	252	7.0	57	0.7	2	0.1	8	1.1	0	0.0
2014	15	0.9	0	0.0	4	0.4	12	2.2	0	0.0
2015	75	1.9	13	0.1	4	0.3	12	2.9	0	0.0
Average	***102***	***4.1***	***24***	***0.4***	***24***	***3.5***	***30***	***6.4***	***3***	***0.0***
Median	***94***	***3.7***	***13***	***0.2***	***11***	***3.0***	***14***	***4.0***	***0***	***0.0***

Based on brood year analyses, on average, about 10% of the hatchery-origin Wenatchee summer Chinook returns have strayed into non-target populations, exceeding the target of 5% (Table 8.27). Depending on brood year, percent strays into non-target spawning areas have ranged from 0-20%. In addition, on average, about 7% have strayed into non-target hatchery programs.

Table 8.27. Number and percent of hatchery-origin Wenatchee summer Chinook that homed to target spawning areas and the target hatchery program, and number and percent that strayed to non-target spawning areas and non-target hatchery programs, by brood years 1989-2010. Percent stays should be less than 5%.

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1989	1,352	62.9	60	2.8	75	3.5	662	30.8
1990	74	84.1	1	1.1	0	0.0	13	14.8
1991	15	65.2	0	0.0	0	0.0	8	34.8
1992	375	84.8	7	1.6	0	0.0	60	13.6
1993	67	72.8	9	9.8	4	4.3	12	13.0
1994	890	71.8	207	16.7	61	4.9	81	6.5
1995	748	74.8	139	13.9	48	4.8	65	6.5
1996	261	70.4	42	11.3	53	14.3	15	4.0
1997	3,609	83.0	171	3.9	397	9.1	170	3.9
1998	1,790	78.5	11	0.5	416	18.2	64	2.8
1999	507	79.7	0	0.0	121	19.0	8	1.3
2000	2,745	82.5	0	0.0	545	16.4	37	1.1
2001	521	80.4	0	0.0	118	18.2	9	1.4
2002	1,521	83.4	10	0.5	284	15.6	8	0.4
2003	1,268	88.5	42	2.9	114	8.0	9	0.6
2004	497	84.2	3	0.5	72	12.2	18	3.1
2005	1,126	84.0	3	0.2	193	14.4	19	1.4
2006	2,693	79.4	8	0.2	623	18.4	67	2.0
2007	99	78.0	1	0.8	25	19.7	2	1.6
2008	3,264	84.6	61	1.6	458	11.9	77	2.0
2009	762	78.6	54	5.6	108	11.1	45	4.6
2010	164	67.5	47	19.3	12	4.9	20	8.2
Average	***1,107***	***78.1***	***40***	***4.2***	***169***	***10.4***	***67***	***7.2***
Median	***755***	***79.6***	***10***	***1.4***	***92***	***11.5***	***20***	***3.5***

* Homing to the target hatchery includes Wenatchee hatchery summer Chinook that are captured and included as broodstock in the Wenatchee Hatchery program. These hatchery fish are typically collected at Dryden and Tumwater dams.

Genetics

Genetic studies were conducted in 2011 to investigate relationships among temporally replicated collections of summer Chinook from the Wenatchee River, Methow River, and Okanogan River in the upper Columbia River basin (Kassler et al. 2011; the entire report is appended as Appendix N). A total of 2,416 summer Chinook were collected from tributaries in the upper Columbia River basin. Two collections of natural-origin summer Chinook from 1993 (prior to the supplementation program) were taken from the Wenatchee River basin (N = 139) and compared to collections of hatchery and natural-origin Chinook from 2006 and 2008 (N = 380). Two pre-supplementation collections from the Methow River (1991 and 1993) were compared to supplementation collections from 2006 and 2008 (N = 362). Three pre-supplementation collections from the Okanogan River Basin (1991, 1992, and 1993) were compared with supplementation collections from 2006 and 2008 (N = 669). A collection of natural-origin summer Chinook from the Chelan River was also analyzed (N = 70). Additionally, hatchery collections from Eastbank Hatchery (Wenatchee and Methow/Okanogan stock; N = 221) and Wells Hatchery (N = 294) were analyzed and compared to the in-river collections. Summer Chinook data (provided by the USFWS) from the Entiat River (N = 190) were used for comparison. Lastly, data from eight collections of fall Chinook (N = 2,408) were compared to the collections of summer Chinook. Samples of natural and hatchery-origin summer Chinook were analyzed and compared to determine if the supplementation programs have affected the genetic structure of these populations. The study also calculated the effective number of breeders for collection locations of natural and hatchery-origin summer Chinook from 1993 and 2008.

In general, population differentiation was not observed among the temporally replicated collection locations. A single collection from the Okanogan River (1993) was the only collection showing statistically significant differences. The effective number of breeders was not statistically different from the early collection in 1993 in comparison to the late collection in 2008. Overall, these analyses revealed a lack of differentiation among the temporal replicates from the same locations and among the collection from different locations, suggesting the populations have been homogenized or that there has been substantial gene flow among populations. Additional comparisons among summer-run and fall-run Chinook populations in the upper Columbia River were conducted to determine if there was any differentiation between Chinook with different run timing. These analyses revealed pairwise F_{ST} values that were less than 0.01 for the collections of summer Chinook to collections of fall Chinook from Hanford Reach, lower Yakima River, Priest Rapids, and Umatilla. Collections of fall Chinook from Crab Creek, Lyons Ferry Hatchery, Marion Drain, and Snake River had pairwise F_{ST} values that were higher in comparison to the collections of summer Chinook. The consensus clustering analysis did not provide good statistical support to the groupings, but did show relationships among collections based on geographic proximity. Overall the summer and fall run Chinook that have historically been spawned together were not differentiated while fall Chinook from greater geographic distances were differentiated.

It is important to note that no new information will be reported on genetics until the next five-year report (2018).

Proportionate Natural Influence

Another method for assessing the genetic risk of a supplementation program is to determine the influence of the hatchery and natural environments on the adaptation of the composite population. This is estimated by the proportion of natural-origin fish in the hatchery broodstock (pNOB) and the proportion of hatchery-origin fish in the natural spawning escapement (pHOS). We calculated Proportionate Natural Influence (PNI) by iterating Ford's (2002) equations 5 and 6 to equilibrium, using a heritability of 0.3 and a selection strength of three standard deviations. The larger the PNI value, the greater the strength of selection in the natural environment relative to that of the hatchery environment. For the natural environment to dominate selection, PNI should be greater than 0.50, and important integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004).

For all brood years the PNI value has been greater than or equal to 0.67 (Table 8.28). This suggests that the natural environment has a greater influence on adaptation of Wenatchee summer Chinook than does the hatchery environment.

Table 8.28. Proportionate Natural Influence (PNI) values for the Wenatchee summer Chinook supplementation program for brood years 1989-2015. NOS = number of natural-origin Chinook on the spawning grounds; HOS = number of hatchery-origin Chinook on the spawning grounds; NOB = number of natural-origin Chinook collected for broodstock; and HOB = number of hatchery-origin Chinook included in hatchery broodstock.

Brood year	Spawners			Broodstock			PNI[a]
	NOS	HOS	pHOS	NOB	HOB	pNOB	
1989	14,331	0	0.00	290	0	1.00	1.00
1990	10,861	0	0.00	57	0	1.00	1.00
1991	10,168	0	0.00	105	0	1.00	1.00
1992	11,652	0	0.00	274	0	1.00	1.00
1993	8,868	582	0.06	406	44	0.90	0.94
1994	8,476	1,678	0.17	333	54	0.86	0.84
1995	6,862	893	0.12	363	16	0.96	0.89
1996	6,002	166	0.03	263	3	0.99	0.97
1997	5,408	505	0.09	205	13	0.94	0.92
1998	4,611	741	0.14	299	78	0.79	0.85
1999	4,101	1,375	0.25	242	236	0.51	0.68
2000	4,462	1,050	0.19	275	180	0.60	0.77
2001	9,414	1,946	0.17	210	136	0.61	0.79
2002	11,892	3,831	0.24	409	10	0.98	0.81
2003	10,025	1,775	0.15	337	7	0.98	0.87
2004	9,220	1,259	0.12	424	2	1.00	0.90
2005	6,862	1,841	0.21	397	3	0.99	0.83
2006	16,060	1,732	0.10	433	4	0.99	0.91
2007	3,173	1,417	0.31	263	3	0.99	0.77
2008	4,452	2,044	0.31	378	69	0.85	0.74
2009	7,098	1,229	0.15	452	8	0.98	0.87
2010	5,886	1,582	0.21	388	5	0.99	0.83
2011	8,150	1,700	0.17	376	7	0.98	0.86
2012	7,327	1,212	0.14	267	1	1.00	0.88
2013	7,431	2,778	0.27	234	2	0.99	0.79
2014	9,676	767	0.07	261	2	0.99	0.94
2015	4,076	254	0.06	245	0	1.00	0.95
Average	***8,020***	***1,198***	***0.14***	***303***	***33***	***0.92***	***0.87***
Median	***7,431***	***1,229***	***0.14***	***290***	***5***	***0.99***	***0.87***

[a] PNI was calculated previously using PNI approximate equation 11 (HSRG 2009; their Appendix A). All PNI values presented here were recalculated by iterating Ford's (2002) equations 5 and 6 to equilibrium using a heritability of 0.3 and a selection strength of three standard deviations. C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI.

Post-Release Survival and Travel Time

We used PIT-tagged fish to estimate survival rates and travel time (arithmetic mean days) of hatchery summer Chinook from the Wenatchee River release site to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam (Table 8.29).[26] Over the six brood years for which PIT-tagged hatchery fish were released, survival rates from the Wenatchee River to McNary Dam ranged from 0.619 to 0.910; SARs from release to detection at Bonneville Dam ranged from 0.001 to 0.017. Average travel time from the Wenatchee River to McNary Dam ranged from 11 to 29 days.

Most of the variation in survival rates and travel time resulted from releases of different experimental groups (Table 8.29). For example, brood year 2009 was split into three groups (control raceway group, long-term recirculating aquaculture system (RAS) group (R1), and short-term RAS group (R2)). In this case, the control group appeared to have a higher survival rate but a longer travel time from release to McNary Dam than did the two treatment groups. SARs varied little among the three groups.

Another experiment was conducted with brood years 2012 and 2013. These brood years were split into four different treatment groups (small-size fish in raceway, large-size fish in raceway, small-size fish in RAS, and large-size fish in RAS). Although the number of replicates is small, releases from the RAS had higher survival rates to McNary Dam and faster travel times. Large-size fish from the RAS had the highest survival rates and fastest travel times.

Table 8.29. Total number of Wenatchee hatchery summer Chinook released with PIT tags, their survival and travel times (mean days) to McNary Dam, and smolt-to-adult (SAR) ratios for brood years 2008-2014. Standard errors are shown in parentheses. RAS = recirculating aquaculture system; NA = not available (i.e., not all the fish from the release groups have returned to the Columbia River).

Brood year	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2008	10,035	0.847 (0.054)	28.9 (9.6)	0.017 (0.001)
2009	9,965 (Control)	0.702 (0.039)	19.3 (10.3)	0.006 (0.001)
	9,971 (R1)	0.646 (0.030)	16.4 (8.8)	0.005 (0.001)
	9,994 (R2)	0.648 (0.031)	16.0 (8.4)	0.005 (0.001)
2010	0	--	--	--
2011	5,018	0.753 (0.070)	20.9 (8.9)	0.010 (0.001)
2012 (Raceway)	5,047 (small size)	0.724 (0.066)	18.9 (9.2)	0.001 (0.001)
	4,740 (large size)	0.619 (0.061)	16.9 (8.6)	0.002 (0.001)
2012 (RAS)	5,041 (small size)	0.784 (0.060)	11.8 (5.0)	0.001 (0.000)
	5,082 (large size)	0.910 (0.077)	11.1 (4.6)	0.002 (0.001)
2013 (Raceway)	5,196 (small size)	0.692 (0.054)	19.3 (6.1)	NA
	5,158 (large size)	0.823 (0.071)	19.1 (5.6)	NA

[26] It is important to point out that because of fish size differences among rearing tanks or raceways, fish PIT tagged in one tank or raceway may not represent untagged fish rearing in other tanks or raceways.

Brood year	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2013 (RAS)	5,229 (small size)	0.788 (0.057)	18.1 (5.6)	NA
	5,201 (large size)	0.859 (0.068)	16.8 (4.8)	NA
2014	10,241 (Circular)	0.800 (0.083)	15.1 (4.9)	NA
	10,243 (Raceway)	0.735 (0.065)	17.1 (6.1)	NA

Natural and Hatchery Replacement Rates

Natural replacement rates (NRR) were calculated as the ratio of natural-origin recruits (NOR) to the parent spawning population (spawning escapement). Natural-origin recruits are naturally produced (wild) fish that survive to contribute to harvest (directly or indirectly), to broodstock, and to spawning grounds. We do not account for fish that died in route to the spawning grounds (migration mortality) or died just before spawning (pre-spawn mortality) (see Appendix B in Hillman et al. 2012). We calculated NORs with and without harvest. NORs without harvest include all returning fish that either returned to the basin or were collected as wild broodstock. NORs with harvest include all fish harvested and are based on brood year harvest rates from the hatchery program. For brood years 1989-2009, NRR for summer Chinook in the Wenatchee averaged 0.98 (range, 0.15-2.95) if harvested fish were not included in the estimate and 2.60 (range, 0.33-9.55) if harvested fish were included in the estimate (Table 8.30). NRRs for more recent brood years will be calculated as soon as all tag recoveries and sampling rates have been loaded into the database.

Hatchery replacement rates (HRR) are the hatchery adult-to-adult returns and were calculated as the ratio of hatchery-origin recruits (HOR) to the parent broodstock collected. These rates should be greater than the NRRs and greater than or equal to 5.7 (the calculated target value in Hillman et al. 2013). The target value of 5.7 includes harvest. HRRs exceeded NRRs in 16 of the 21 years of data, regardless if harvest was or was not included in the estimate (Table 8.30). Hatchery replacement rates for Wenatchee summer Chinook have exceeded the estimated target value of 5.7 in 10 of the 21 years of data.

Table 8.30. Broodstock collected, spawning escapements, natural and hatchery-origin recruits (NOR and HOR), and natural and hatchery replacement rates (NRR and HRR; with and without harvest) for summer Chinook in the Wenatchee River basin, brood years 1989-2009.

Brood year	Broodstock Collected	Spawning Escapement	Harvest not included				Harvest included			
			HOR	NOR	HRR	NRR	HOR	NOR	HRR	NRR
1989	346	14,331	2,149	9,181	6.21	0.64	5,111	21,808	14.77	1.52
1990	87	10,861	88	9,595	1.01	0.88	118	12,984	1.36	1.20
1991	128	10,168	23	5,562	0.18	0.55	71	17,167	0.55	1.69
1992	341	11,652	442	5,858	1.30	0.50	628	8,393	1.84	0.72
1993	524	9,450	92	5,385	0.18	0.57	152	8,901	0.29	0.94
1994	418	10,154	1,239	4,219	2.96	0.42	1,944	6,634	4.65	0.65
1995	398	7,755	1,000	5,329	2.51	0.69	1,576	8,459	3.96	1.09
1996	334	6,168	371	4,441	1.11	0.72	580	6,896	1.74	1.12

Brood year	Broodstock Collected	Spawning Escapement	Harvest not included				Harvest included			
			HOR	NOR	HRR	NRR	HOR	NOR	HRR	NRR
1997	240	5,913	4,347	9,761	18.11	1.65	7,547	16,743	31.45	2.83
1998	472	5,352	2,289	15,795	4.83	2.95	7,703	51,117	16.32	9.55
1999	488	5,476	636	12,081	1.30	2.21	2,479	44,253	5.08	8.08
2000	492	5,512	3,334	3,885	6.76	0.70	14,212	15,988	28.89	2.90
2001	493	11,360	648	19,209	1.31	1.69	2,417	70,621	4.90	6.22
2002	482	15,723	1,823	4,954	3.78	0.32	4,526	12,354	9.39	0.79
2003	496	11,800	1,433	1,782	2.89	0.15	3,096	3,874	6.24	0.33
2004	496	10,479	590	7,197	1.19	0.69	1,454	17,468	2.93	1.67
2005	494	8,703	1,345	5,131	2.71	0.59	3,625	13,190	7.34	1.52
2006	488	17,792	3,394	6,814	6.95	0.38	10,646	17,121	21.82	0.96
2007	419	4,590	127	10,733	0.30	2.34	481	30,064	1.15	6.55
2008	472	6,496	3,887	6,282	8.18	0.97	10,239	12,873	21.69	1.98
2009	491	8,327	969	7,434	1.97	0.89	3,567	19,667	7.26	2.36
Average	***409***	***9,432***	***1,439***	***7,649***	***3.61***	***0.98***	***3,913***	***19,837***	***9.22***	***2.60***
Median	***472***	***9,450***	***1,000***	***6,282***	***2.51***	***0.69***	***2,479***	***15,988***	***5.08***	***1.52***

Smolt-to-Adult Survivals

Smolt-to-adult survival ratios (SARs) were calculated as the number of hatchery adult recaptures divided by the number of tagged hatchery smolts released. Here, SARs were based on CWT returns. For the available brood years, SARs have ranged from 0.00037 to 0.01562 for hatchery summer Chinook in the Wenatchee River basin (Table 8.31).

Table 8.31. Smolt-to-adult ratios (SARs) for Wenatchee hatchery summer Chinook, brood years 1989-2010.

Brood year	Number of tagged smolts released[a]	Estimated adult captures[b]	SAR
1989	144,905	1,027	0.00709
1990	119,214	115	0.00096
1991	190,371	71	0.00037
1992	605,055	613	0.00101
1993	210,626	152	0.00072
1994	452,340	1,919	0.00424
1995	668,409	1,542	0.00231
1996	585,590	572	0.00098
1997	480,418	7,506	0.01562
1998	641,109	7,630	0.01190
1999	988,328	2,457	0.00249
2000	903,368	13,861	0.01534

Brood year	Number of tagged smolts released[a]	Estimated adult captures[b]	SAR
2001	596,618	2,403	0.00403
2002	805,919	4,395	0.00545
2003	639,381	3,048	0.00477
2004	875,758	1,439	0.00164
2005	631,492	3,578	0.00567
2006	931,880	10,468	0.01123
2007	453,719	481	0.00106
2008	859,401	9,934	0.01156
2009	822,986	3,538	0.00430
2010	789,056	2,570	0.00326
Average	***608,907***	***3,605***	***0.00527***
Median	***635,437***	***2,430***	***0.00414***

[a] Includes all tag codes and CWT released fish (CWT + Ad Clip fish and CWT-only fish).

[b] Includes estimated recoveries (spawning ground, hatcheries, harvest, etc.) and observed recoveries if estimated recoveries were unavailable.

8.8 ESA/HCP Compliance

Broodstock Collection

Per the 2014 broodstock collection protocol, 278 natural-origin (adipose fin present) summer Chinook adults were targeted for collection at Dryden and Tumwater dams. The actual 2014 collection totaled 281 summer Chinook (279 natural-origin and two hatchery-origin; the hatchery-origin fish were not direct collections but rather adipose-present non-wired fish with a hatchery scale pattern) in combination from Dryden and Tumwater dams. Trapping began 23 June and ended 24 September2014.

Summer Chinook and steelhead broodstock collections occurred concurrently at Dryden Dam. Thus, steelhead and spring Chinook encounters at Dryden Dam during Wenatchee summer Chinook broodstock collection were attributable to steelhead broodstock collections authorized under ESA Permit 1395 take authorizations. No steelhead or spring Chinook takes were associated with the Wenatchee summer Chinook collection. No bull trout were encountered during summer Chinook broodstock collection at Dryden Dam in 2014.

Consistent with impact minimization measures in ESA Permit 1347, all ESA-listed species handled during summer Chinook broodstock collection were subject to water-to-water transfers or anesthetized if removed from the water during handling.

Hatchery Rearing and Release

The 2014 Wenatchee summer Chinook program released an estimated 535,255 smolts, representing 107.1% of the 500,001-programmed production, and was within the 110% overage allowance identified in ESA permit 1347.

Hatchery Effluent Monitoring

Per ESA Permits 1196, 1347, 1395, 18118, 18120, and 18121, permit holders shall monitor and report hatchery effluents in compliance with applicable National Pollution Discharge Elimination Systems (NPDES) (EPA 1999) permit limitations. There were no NPDES violations reported at PUD Hatchery facilities during the period 1 January through 31 December 2016. NPDES monitoring and reporting for Chelan PUD Hatchery Programs during 2016 are provided in Appendix F.

Smolt and Emigrant Trapping

ESA-listed spring Chinook and steelhead were encountered during operation of the Lower Wenatchee Trap. ESA takes are reported in the steelhead (Section 3.8) and spring Chinook (Section 5.8) sections and are not repeated here.

Spawning Surveys

Summer Chinook spawning ground surveys conducted in the Wenatchee River basin during 2016 were consistent with ESA Section 10 Permit No. 1347. Because of the difficulty of quantifying the level of take associated with spawning ground surveys, the Permit does not specify a take level associated with these activities, even though it does authorize implementation of spawning ground surveys. Therefore, no take levels are reported. However, to minimize potential effects to established redds, wading was restricted to the extent practical, and extreme caution was used to avoid established redds when wading was required.

SECTION 9: METHOW SUMMER CHINOOK

The original goal of summer Chinook salmon supplementation in the Methow Basin was in part to use artificial production to replace adult production lost because of mortality at Wells, Rocky Reach, and Rock Island dams[27], while not reducing the natural production or long-term fitness of summer Chinook in the basin. The Rock Island Fish Hatchery Complex began operation in 1989 under funding from Chelan PUD. The Complex operated originally through the Rock Island Settlement Agreement, but since 2004 has operated under the Anadromous Fish Agreement and Habitat Conservation Plans. Beginning with broodstock collection in 2012, Grant PUD took over the summer Chinook salmon supplementation program in the Methow River basin. Grant PUD constructed a new overwinter acclimation facility adjacent to the Carlton Acclimation Pond and the first fish released from this facility was 2014. The first fish that were overwinter acclimated in the facility were released in 2015. The new facility includes eight, 30-foot diameter dual-drain circular tanks.

Presently, adult summer Chinook are collected for broodstock from the run-at-large at the west-ladder trapping facility at Wells Dam. Before 2012, the goal was to collect up to 222 natural-origin adult summer Chinook for the Methow program. In 2011, the Hatchery Committees reevaluated that amount of hatchery compensation needed to achieve NNI. Based on that evaluation, the goal of the program was revised. The current goal (beginning in 2012) is to collect up to 102 natural-origin summer Chinook for the Methow program. Broodstock collection occurs from about 1 July through 15 September with trapping occurring no more than 16 hours per day, three days a week. If natural-origin broodstock collection falls short of expectation, hatchery-origin adults can be collected to make up the difference.

Adult summer Chinook are spawned and reared at Eastbank Fish Hatchery. Juvenile summer Chinook were transferred from the hatchery to Carlton Acclimation Pond in March until overwinter acclimation was initiated with the 2013 brood year. They are now transferred to the Carlton Acclimation Facility in October or November and released from the new facility in late April to early May.

Before 2012, the production goal for the Methow summer Chinook supplementation program was to release 400,000 yearling smolts into the Methow River at ten fish per pound. Beginning with the 2012 brood, the revised goal is to release 200,000 yearling smolts at 15 fish per pound. Targets for fork length and weight are 163 mm (CV = 9.0) and 45.4 g, respectively. Over 90% of these fish are marked with CWTs. In addition, since 2009, juvenile summer Chinook have been PIT tagged annually.

9.1 Broodstock Sampling

This section focuses on results from sampling 2014-2016 Methow summer Chinook broodstock that were collected in the West Ladder of Wells Dam.

[27] Most of the production at Carlton Acclimation Pond is initial production, which terminated in 2013, and is not necessarily tied to hydro facility mortality. The balance of the production is the result of a swap between spring and summer Chinook. That is, Chelan PUD is currently producing summer Chinook at Carlton for Douglas PUD in exchange for Douglas PUD producing spring Chinook at the Methow Fish Hatchery for Chelan PUD.

Origin of Broodstock

Broodstock collected in 2014, 2015, and 2016 consisted almost entirely of natural-origin (adipose fin present) summer Chinook (Table 9.1).

Table 9.1. Numbers of wild and hatchery summer Chinook collected for broodstock, numbers that died before spawning, and numbers of Chinook spawned for the Methow/Okanogan programs during 1989-2011. Numbers of broodstock collected from 2012 to present are only for the Methow summer Chinook Program. Unknown origin fish (i.e., undetermined by scale analysis, no CWT or fin clips, and no additional hatchery marks) were considered naturally produced. Mortality includes fish that died of natural causes typically near the end of spawning and were not needed for the program and surplus fish killed at spawning.

Brood year	Wild summer Chinook					Hatchery summer Chinook					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
1989[b]	1,419	72	-	1,297	-	341	17	-	312	-	1,609
1990[b]	864	34	-	828	-	214	8	-	206	-	1,034
1991[b]	1,003	59	-	924	-	341	20	-	314	-	1,238
1992[b]	312	6	-	297	-	428	9	-	406	-	703
1993[b]	813	48	-	681	-	464	28	-	388	-	1,069
1994	385	33	11	341	12	266	15	7	244	1	585
1995	254	13	10	173	58	351	28	9	240	74	413
1996	316	15	11	290	0	234	2	9	223	0	513
1997	214	11	5	198	0	308	24	20	264	0	462
1998	239	28	58	153	0	348	18	119	211	0	364
1999	248	5	19	224	0	307	2	16	289	0	513
2000	184	15	5	164	0	373	17	17	339	0	503
2001	135	8	36	91	0	423	29	128	266	0	357
2002	270	2	21	247	0	285	11	33	241	0	488
2003	449	14	53	381	0	112	2	9	101	0	482
2004	541	23	12	506	0	17	0	1	16	0	522
2005	551	29	76	391	55	12	2	0	9	1	400
2006	579	50	10	500	19	12	2	0	10	0	510
2007	504	22	26	456	0	19	0	2	17	0	473
2008	418	5	9	404	0	41	0	0	41	0	445
2009	553	31	15	507	0	5	5	0	0	0	507
2010	503	13	6	484	0	8	0	0	8	0	492
2011	498	18	13	467	0	30	4	0	26	0	493
Average[c]	***380***	***19***	***22***	***332***	***8***	***175***	***9***	***21***	***141***	***4***	***473***
Median[c]	***434***	***18***	***13***	***391***	***0***	***266***	***8***	***8***	***223***	***0***	***503***
2012	125	5	0	98	22	3	0	0	1	2	99
2013	98	1	0	97	0	4	0	0	4	0	101
2014	100	4	0	96	0	0	0	0	0	0	96
2015	97	0	0	97	0	1	0	0	1	0	98
2016	106	2	1	103	0	0	0	0	0	0	103
Average[d]	***105***	***2***	***0***	***98***	***4***	***2***	***0***	***0***	***1***	***0***	***99***
Median[d]	***100***	***2***	***0***	***97***	***0***	***1***	***0***	***0***	***1***	***0***	***99***

[a] Pre-spawn loss represents the number of fish that died during the holding period before spawning. Mortality is the number of fish that were surplused following spawning.

[b] Number of fish spawned and collected during these years included fish retained from the right- and left-bank ladder traps at Wells Dam and fish collected from the volunteer channel. There was no distinction made between fish collected at trap locations and program (i.e., aggregated population used for Wells, Methow, and Okanogan summer Chinook programs).
[c] The average and median represent broodstock collected for the combined Methow and Okanogan programs. Because of bias from aggregating the spawning population from 1989-1993, averages are based on adult numbers collected from 1994-2011.
[d] The average and median represent broodstock collected only for the Methow program.

Age/Length Data

Ages of summer Chinook broodstock were determined from analysis of scales and/or CWTs. Broodstock collected from the 2014 return consisted primarily of age-4 and 5 natural-origin Chinook (95.8%). Age-3 natural-origin fish made up 4.1% of the broodstock (Table 9.2).

Broodstock collected from the 2015 return consisted primarily of age-4 and 5 natural-origin Chinook (87.8%). Age-3 natural-origin Chinook made up 12.2% of the broodstock (Table 9.2).

Broodstock collected from the 2016 return consisted primarily of age-4 and 5 natural-origin Chinook (97.8%). Age-3 natural-origin Chinook made up 1.1% of the broodstock (Table 9.2).

Table 9.2. Percent of hatchery and wild summer Chinook of different ages (total age) collected from broodstock for the Methow/Okanogan programs, 1991-2016.

Return Year	Origin	Total age				
		2	3	4	5	6
1991	Wild	0.5	6.8	35.1	55.4	2.2
	Hatchery	0.5	5.1	36.2	49.0	9.2
1992	Wild	0.0	13.0	36.2	50.7	0.0
	Hatchery	0.0	0.0	0.0	0.0	0.0
1993	Wild	0.0	3.9	75.3	20.8	0.0
	Hatchery	0.0	1.0	85.7	13.3	0.0
1994	Wild	3.1	9.7	26.3	60.3	0.6
	Hatchery	0.0	14.7	11.2	74.0	0.0
1995	Wild	0.0	4.6	15.3	75.6	4.6
	Hatchery	0.0	0.4	13.0	25.6	61.0
1996	Wild	0.0	8.4	56.7	30.4	4.6
	Hatchery	0.0	3.0	31.0	47.0	19.0
1997	Wild	0.5	9.4	53.0	35.1	2.0
	Hatchery	0.0	20.6	11.1	61.8	6.5
1998	Wild	1.1	12.1	56.3	30.5	0.0
	Hatchery	2.1	18.9	56.2	16.0	6.8
1999	Wild	4.7	5.1	53.7	36.0	0.5
	Hatchery	0.3	3.5	29.3	65.0	1.9
2000	Wild	0.6	14.0	28.7	56.1	0.6
	Hatchery	0.0	27.0	14.3	54.3	4.3
2001	Wild	0.0	23.5	58.8	11.8	5.9
	Hatchery	1.8	21.1	64.6	10.1	2.4
2002	Wild	0.4	17.4	65.6	16.6	0.0

Return Year	Origin	Total age				
		2	3	4	5	6
	Hatchery	0.0	2.4	39.4	58.3	0.0
2003	Wild	0.7	3.9	65.8	29.5	0.0
	Hatchery	0.0	5.6	18.7	70.1	5.6
2004	Wild	0.6	15.4	11.6	72.2	0.2
	Hatchery	0.0	6.7	53.3	33.3	6.7
2005	Wild	0.0	17.1	69.9	11.0	1.9
	Hatchery	0.0	10.0	40.0	50.0	0.0
2006	Wild	1.7	3.0	41.0	52.9	1.5
	Hatchery	0.0	16.7	25.0	50.0	8.3
2007	Wild	1.8	15.3	8.2	70.3	4.4
	Hatchery	0.0	0.0	21.1	57.9	21.1
2008	Wild	0.3	17.9	67.1	13.3	1.4
	Hatchery	0.0	7.2	62.7	47.7	2.4
2009	Wild	1.3	10.1	68.7	19.9	0.0
	Hatchery	0.0	0.0	16.7	83.3	0.0
2010	Wild	0.2	16.2	51.0	32.6	0.0
	Hatchery	0.0	12.5	50.0	25.0	12.5
2011	Wild	0.1	7.1	75.5	17.0	0.0
	Hatchery	0.0	30.0	20.0	40.0	0.0
2012	Wild	0.0	3.9	49.0	46.1	1.0
	Hatchery	0.0	0.0	0.0	100.0	0.0
2013	Wild	0.0	15.2	70.7	14.1	0.0
	Hatchery	0.0	0.0	50.0	50.0	0.0
2014	Wild	0.0	4.1	71.1	24.7	0.0
	Hatchery	0.0	0.0	0.0	0.0	0.0
2015	Wild	0.0	12.2	42.2	45.6	0.0
	Hatchery	0.0	0.0	100.0	0.0	0.0
2016	Wild	0.0	1.1	71.7	26.1	1.1
	Hatchery	0.0	0.0	0.0	0.0	0.0
Average	***Wild***	***0.7***	***10.4***	***50.9***	***36.7***	***1.3***
	Hatchery	***0.2***	***7.9***	***32.7***	***41.6***	***6.7***
Median	***Wild***	***0.3***	***9.9***	***55.0***	***31.6***	***0.6***
	Hatchery	***0.0***	***4.3***	***27.2***	***48.4***	***2.4***

Mean lengths of natural-origin summer Chinook of a given age differed little among return years 2014-2016 (Table 9.3). For 2015, average fork lengths for age-4 natural-origin adults were 8 cm longer than that of age-4 hatchery fish (Table 9.3). There were no hatchery-origin adults collected for the 2014 and 2016 brood. Differences in hatchery-origin and natural-origin fish were hard to assess given the small sample size of hatchery-origin fish (i.e., few hatchery fish were included in the broodstock).

Table 9.3. Mean fork length (cm) at age (total age) of hatchery and wild Methow/Okanogan summer Chinook collected from broodstock for the Methow/Okanogan programs, 1991-2016; N = sample size and SD = 1 standard deviation.

Return year	Origin	Summer Chinook fork length (cm)														
		Age-2			Age-3			Age-4			Age-5			Age-6		
		Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD
1991	Wild	47	1	-	68	15	6	82	78	10	94	123	8	97	5	5
	Hatchery	47	1	-	49	10	6	78	71	5	91	96	8	96	18	6
1992	Wild	-	0	-	55	9	5	69	25	6	78	35	6	-	0	-
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
1993	Wild	-	0	-	72	3	4	86	58	7	98	16	5	-	0	-
	Hatchery	-	0	-	42	1	-	75	84	8	88	13	6	-	0	-
1994	Wild	42	10	6	50	31	7	80	84	9	93	193	8	104	2	13
	Hatchery	-	0	-	49	38	5	76	29	7	88	191	7	-	0	-
1995	Wild	-	0	-	67	6	8	79	20	9	96	99	5	94	6	5
	Hatchery	-	0	-	52	1	-	73	32	9	89	63	9	95	150	7
1996	Wild	-	0	-	68	22	9	83	149	8	95	79	7	101	12	5
	Hatchery	-	0	-	52	7	10	77	72	7	90	109	8	100	44	6
1997	Wild	31	1	-	60	19	7	85	107	8	96	71	7	98	4	11
	Hatchery	-	0	-	45	63	5	72	34	9	92	189	7	97	20	7
1998	Wild	39	2	1	59	23	6	83	107	7	96	58	7	-	0	-
	Hatchery	43	7	6	50	64	6	74	190	7	92	54	8	98	23	5
1999	Wild	38	10	3	64	11	8	82	115	7	96	76	6	104	1	-
	Hatchery	37	1	-	53	11	9	75	92	6	91	204	6	98	6	5
2000	Wild	39	1	-	66	23	7	83	47	6	96	92	5	95	1	-
	Hatchery	-	0	-	54	100	7	78	53	8	92	201	6	99	16	6
2001	Wild	-	0	-	63	4	12	88	10	9	90	2	4	94	1	-
	Hatchery	41	9	3	55	107	9	79	327	8	93	51	7	101	12	9
2002	Wild	56	1	-	65	44	7	88	166	6	100	42	7	-	0	-
	Hatchery	-	0	-	45	6	5	76	100	7	95	148	5	-	0	-
2003	Wild	43	3	6	61	16	6	87	268	7	99	120	6	-	0	-
	Hatchery	-	0	-	55	6	9	73	20	8	91	75	7	102	6	9
2004	Wild	51	3	5	67	78	6	81	59	6	97	367	7	99	1	-
	Hatchery	-	0	-	52	1	-	70	8	5	97	5	8	109	1	-
2005	Wild	-	0	-	68	89	6	83	363	7	94	57	6	101	10	7
	Hatchery	-	0	-	55	1	-	70	4	4	89	5	4	-	0	-
2006	Wild	38	9	3	54	16	4	69	221	6	77	286	5	78	8	4
	Hatchery	-	0	-	42	2	1	62	3	2	69	6	6	76	1	-
2007	Wild	39	8	5	53	69	5	67	37	6	78	317	5	77	20	7
	Hatchery	-	0	-	-	0	-	54	4	2	75	11	5	78	4	3
2008	Wild	41	1	-	55	62	4	69	233	6	76	46	4	82	5	3

Return year	Origin	Summer Chinook fork length (cm)														
		Age-2			Age-3			Age-4			Age-5			Age-6		
		Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD
	Hatchery	-	0	-	59	6	9	67	52	5	73	23	6	79	2	8
2009	Wild	38	7	5	54	54	5	72	367	5	79	106	5	-	0	-
	Hatchery	-	0	-	-	0	-	59	1	-	71	5	7	-	0	-
2010	Wild	43	1	-	54	78	5	71	246	5	78	157	5	-	0	-
	Hatchery	-	0	-	57	1	-	67	4	5	79	2	1	89	1	-
2011	Wild	43	2	3	66	32	8	87	338	7	97	76	5	-	0	-
	Hatchery	-	0	-	63	9	11	78	9	6	92	12	9	-	0	-
2012	Wild	-	0	-	70	10	3	84	62	5	96	54	6	-	0	-
	Hatchery	-	0	-	-	0	-	-	0	-	90	1	-	-	0	-
2013	Wild	-	0	-	72	14	5	86	65	7	97	13	5	-	0	-
	Hatchery	-	0	-	-	0	-	76	2	6	92	2	0	-	0	-
2014	Wild	-	0	-	75	4	3	88	69	6	94	24	4	-	0	-
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
2015	Wild	-	0	-	71	11	4	83	38	5	94	41	6	-	0	-
	Hatchery	-	0	-	-	0	-	75	1	0	-	0	-	-	0	-
2016	Wild	-	0	-	72	1	-	84	66	6	96	24	7	102	1	-
	Hatchery	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
Average	***Wild***	***42***	***2***	***4***	***63***	***28***	***6***	***81***	***128***	***7***	***92***	***99***	***6***	***95***	***4***	***7***
	Hatchery	***42***	***1***	***5***	***52***	***17***	***7***	***72***	***45***	***6***	***87***	***58***	***6***	***94***	***11***	***6***

Sex Ratios

Male summer Chinook in the 2014 broodstock made up about 50.0% of the adults collected, resulting in an overall male to female ratio of 1.00:1.00 (Table 9.4.). In 2015, males made up about 51.0% of the adults collected, resulting in an overall male to female ratio of 1.02:1.00 (Table 9.4). In 2016, males made up about 49% of the adults collected, resulting in an overall male to female ratio of 0.96:1.00 (Table 9.4). The ratios for 2014 and 2015 broodstock were above or at the assumed 1:1 ratio goal in the broodstock protocol.

Table 9.4. Numbers of male and female wild and hatchery summer Chinook collected for broodstock at Wells Dam for the Methow/Okanogan programs, 1991-2016. Ratios of males to females are also provided.

Return year	Number of wild summer Chinook			Number of hatchery summer Chinook			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
1989[a]	752	667	1.13:1.00	181	160	1.13:1.00	1.13:1.00
1990[a]	381	482	0.79:1.00	95	120	0.79:1.00	0.79:1.00
1991[a]	443	559	0.79:1.00	151	191	0.79:1.00	0.79:1.00
1992[a]	349	318	1.10:1.00	38	35	1.09:1.00	1.10:1.00
1993[a]	513	300	1.71:1.00	293	171	1.71:1.00	1.71:1.00
1994	205	180	1.14:1.00	165	101	1.63:1.00	1.32:1.00
1995	103	149	0.69:1.00	158	197	0.80:1.00	0.75:1.00
1996	178	138	1.29:1.00	132	102	1.29:1.00	1.29:1.00

Return year	Number of wild summer Chinook			Number of hatchery summer Chinook			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
1997	102	112	0.91:1.00	174	134	1.30:1.00	1.12:1.00
1998	130	109	1.19:1.00	263	85	3.09:1.00	2.03:1.00
1999	138	110	1.25:1.00	161	146	1.10:1.00	1.17:1.00
2000	82	102	0.80:1.00	243	130	1.87:1.00	1.40:1.00
2001	89	46	1.93:1.00	311	112	2.78:1.00	2.53:1.00
2002	166	104	1.60:1.00	149	136	1.10:1.00	1.31:1.00
2003	255	194	1.31:1.00	61	51	1.20:1.00	1.29:1.00
2004	263	278	0.95:1.00	12	5	2.40:1.00	0.97:1.00
2005	365	186	1.96:1.00	6	6	1.00:1.00	1.93:1.00
2006	287	292	0.98:1.00	9	3	3.00:1.00	1.00:1.00
2007	228	276	0.83:1.00	11	8	1.38:1.00	0.84:1.00
2008	210	208	1.01:1.00	13	28	0.46:1.00	0.94:1.00
2009	261	292	0.89:1.00	2	3	0.67:1.00	0.89:1.00
2010	248	255	0.97:1.00	5	3	1.67:1.00	0.98:1.00
2011	236	262	0.90:1.00	23	7	3.29:1.00	0.96:1.00
2012	50	53	0.94:1.00	1	0	--	0.96:1.00
2013	49	49	1.00:1.00	3	1	3.00:1.00	1.04:1.00
2014	50	50	1.00:1.00	0	0	--	1.00:1.00
2015	49	49	1.00:1.00	1	0	--	1.02:1.00
2016	52	54	0.96:1.00	0	0	--	0.96:1.00
Total[b]	***3796***	***3548***	***1.07:1.00***	***1903***	***1258***	***1.51:1.00***	***1.19:1.00***

[a] Numbers and male to female ratios were derived from the aggregate population collected at Wells Fish Hatchery volunteer channel and left- and right-ladder traps at Wells Dam.
[b] Total values were derived from 1994-present data to exclude aggregate population bias from 1989-1993 returns.

Fecundity

Fecundities for the 2014, 2015, and 2016 summer Chinook broodstock averaged 4,685, 4,410, and 4,509 eggs per female, respectively (Table 9.5). These values are close to the overall average of 4,899 eggs per female. Mean observed fecundities for the 2014, 2015, and 2016 returns were below the expected fecundity of 4,982, 4,861, and 4,721 eggs per female assumed in the broodstock protocols, respectively.

Table 9.5. Mean fecundity of wild, hatchery, and all female summer Chinook collected for broodstock at Wells Dam for the Methow/Okanogan programs, 1989-2016; NA = not available.

Return year	Mean fecundity		
	Wild	Hatchery	Total
1989*	NA	NA	4,750
1990*	NA	NA	4,838
1991*	NA	NA	4,819
1992*	NA	NA	4,804
1993*	NA	NA	4,849

Return year	Mean fecundity		
	Wild	Hatchery	Total
1994*	NA	NA	5,907
1995*	NA	NA	4,930
1996*	NA	NA	4,870
1997	5,166	5,296	5,237
1998	5,043	4,595	4,833
1999	4,897	4,923	4,912
2000	5,122	5,206	5,170
2001	5,040	4,608	4,735
2002	5,306	5,258	5,279
2003	5,090	4,941	5,059
2004	5,130	5,118	5,130
2005	4,545	4,889	4,553
2006	4,854	4,824	4,854
2007	5,265	5,093	5,260
2008	4,814	4,588	4,787
2009	5,115	--	5,115
2010	5,124	4,717	5,116
2011	4,594	3,915	4,578
2012	4,470	--	4,470
2013	4,700	5,490	4,717
2014	4,685	--	4,685
2015	4,410	--	4,410
2016	4,509	--	4,509
Average	***4,894***	***4,897***	***4,899***
Median	***4,969***	***4,923***	***4,844***

* Individual fecundities were not assigned to females until 1997 brood.

9.2 Hatchery Rearing

Rearing History

Number of eggs taken

Based on the unfertilized egg-to-release survival standard of 81%, a total of 493,827 eggs were needed to meet the program release goal of 400,000 smolts for brood years 1989-2011. An evaluation of the program in 2011 determined that 246,913 eggs are needed to meet the revised release goal of 200,000 smolts. This revised goal began with brood year 2012. From 1989 through 2011, the egg take goal was reached in eight of those years (Table 9.6). From 2012 to present, the egg take goal was not achieved (Table 9.6).

Table 9.6. Numbers of eggs taken from summer Chinook broodstock collected at Wells Dam for the Methow/Okanogan programs, 1989-2016.

Return year	Number of eggs taken
1989	482,800
1990	464,097
1991	586,594
1992	486,260
1993	531,490
1994	595,390
1995	491,000
1996	448,000
1997	401,162
1998	389,346
1999	483,726
2000	403,268
2001	279,272
2002	466,530
2003	473,681
2004	537,210
2005	305,826
2006	509,334
2007	549,802
2008	441,778
2009	560,602
2010	505,188
2011	488,747
Average (1989-2011)	***473,091***
Median (1989-2011)	***483,726***
2012	245,245
2013	231,136
2014	223,839
2015	216,098
2016	239,025
Average (2012-present)	***231,069***
Median (2012-present)	***231,136***

Number of acclimation days

Improvements to Carlton Acclimation Pond made overwinter rearing feasible beginning with the 2013 brood Methow summer Chinook. Fish are held on well water at Eastbank Fish Hatchery before being transferred to Carlton Acclimation Pond for final acclimation on Methow River water in October (Table 9.7). Only the 1994 and 1995 broods were reared for longer durations at the Methow Fish Hatchery on Methow River water.

Table 9.7. Number of days Methow summer Chinook were acclimated at Carlton Acclimation Pond, brood years 1989-2014.

Brood year	Release year	Transfer date	Release date	Number of days
1989	1991	15-Mar	6-May	52
1990	1992	26-Feb	28-Apr	61
1991	1993	10-Mar	23-Apr	44
1992	1994	4-Mar	21-Apr	48
1993	1995	18-Mar	2-May	45
1994	1996	25-Sep	28-Apr	215
		19-Mar	28-Apr	40
1995	1997	22-Oct	8-Apr	168
		19-Mar	22-Apr	34
1996	1998	9-Mar	14-Apr	36
1997	1999	10-Mar	20-Apr	41
1998	2000	19-Mar	2-May	44
1999	2001	18-Mar	18-Apr	31
2000	2002	28-Mar	1-May	34
2001	2003	27-Mar	24-Apr	28
2002	2004	16-Mar	24-Apr	39
2003	2005	18-Mar	21-Apr	34
2004	2006	12-Mar	22-Apr	41
2005	2007	12-Mar	15-Apr – 8-May	34-57
2006	2008	4-7-Mar	16-Apr – 2 May	40-59
2007	2009	18-24-Mar	21-Apr	28-34
2008	2010	4-5, 8-9-Mar	4-21-Apr	33-50
2009	2011	25, 29, 31-Mar & 4-Apr	11-25-Apr	8-31
2010	2012	19-21, 24-Mar	23-24-Apr	31-37
2011	2013	13-21-Mar	15-23-Apr	25-41
2012	2014	19-21-Mar	7-Apr – 14 May	18-57
2013	2015	20-21-Oct	13-May	204-205
2014	2016	26 & 28-Oct	18-Apr	173 & 175

Release Information

Numbers released

The 2014 brood Methow summer Chinook program achieved 83.3% of the 200,000 goal with about 167,616 Chinook being force released from the circular ponds on the night of 18 April 2016 (Table 9.8). Forced releases at night were initiated in 2016 to improve post-release survival.

Table 9.8. Numbers of Methow summer Chinook smolts released from the hatchery, brood years 1989-2014. Beginning with the 2014 release group (brood year 2012), the release target for Methow summer Chinook is 200,000 smolts.

Brood year	Release year	CWT mark rate	Number of smolts released
1989	1991	0.8529	420,000
1990	1992	0.9485	391,650
1991	1993	0.6972	540,900
1992	1994	0.9752	402,641
1993	1995	0.4623	433,375
1994	1996	0.9851	406,560
1995	1997	0.9768	353,182
1996	1998	0.9221	298,844
1997	1999	0.9884	384,909
1998	2000	0.9429	205,269
1999	2001	0.9955	424,363
2000	2002	0.9928	336,762
2001	2003	0.9902	248,595
2002	2004	0.9913	399,975
2003	2005	0.9872	354,699
2004	2006	0.9848	400,579
2005	2007	0.9897	263,723
2006	2008	0.9783	419,734
2007	2009	0.9837	433,256
2008	2010	0.9394	397,554
2009	2011	0.9862	404,956
2010	2012	0.9962	439,000
2011	2013	0.9734	436,092
Average (1989-2011)		***0.9365***	***382,462***
Median (1989-2011)		***0.9837***	***400,579***
2012	2014	0.9987	197,391
2013	2015	0.9903	188,834
2014	2016	0.9921	167,616
Average (2012-present)		***0.9937***	***184,614***
Median (2012-present)		***0.9921***	***188,834***

Numbers tagged

The 2014 brood Methow summer Chinook were 99% CWT and adipose fin-clipped (Table 9.8).

A total of 5,064 Methow summer Chinook (brood 2015) were PIT tagged at the Carlton Acclimation Facility on 27-29 March 2017. These fish were tagged in circular ponds #1 through #8. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 130 mm in length and 28 g at time of tagging.

Table 9.9 summarizes the number of hatchery summer Chinook that have been PIT-tagged and released into the Methow River.

Table 9.9. Summary of PIT-tagging activities for Methow hatchery summer Chinook, brood years 2008-2014.

Brood year	Release year	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
2008	2010	10,100	4	0	10,096
2009	2011	5,050	17	9	5,024
2010	2012	0	0	0	0
2011	2013	0	0	0	0
2012	2014	10,099	41	7	10,051
2013	2015	10,159	35	1	10,123
2014	2016	5,000	8	0	4,992

Fish size and condition at release

A forced release of yearling Chinook smolts took place on the night of 18 April 2016. Size at release from the acclimated fish was 76.7% and 50.8% of the respective target fork length and weight goals, respectively (Table 9.10). This brood year exceeded the target CV for length by 20%.

Table 9.10. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of Methow summer Chinook smolts released from the hatchery, brood years 1991-2014. Size targets are provided in the last row of the table.

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
1991	1993	152	13.6	40.3	11
1992	1994	145	16.0	37.2	12
1993	1995	154	8.6	37.1	12
1994	1996	163	8.2	48.2	9
1995	1997	141	9.6	37.0	12
1996	1998	199	13.1	105.1	4
1997	1999	153	7.6	39.5	12
1998	2000	164	8.7	51.7	9
1999	2001	153	9.3	41.5	11

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
2000	2002	170	10.2	54.2	8
2001	2003	167	7.4	52.7	9
2002	2004	148	13.1	35.7	13
2003	2005	148	10.1	35.5	13
2004	2006	142	9.8	31.1	15
2005	2007	158	15.0	42.2	11
2006	2008	156	18.0	42.8	11
2007	2009	138	21.0	32.1	14
2008	2010	155	14.2	42.0	11
2009	2011	170	15.8	56.9	8
2010	2012	145	16.7	34.5	13
2011	2013	160	13.0	43.6	6
Average		***156***	***12.3***	***44.8***	***11***
Targets		***163***	***9.0***	***45.4***	***10***
2012	2014	158	12.1	41.6	11
2013	2015	130	12.6	27.2	17
2014	2016	125	10.8	23.0	20
Average		***138***	***11.8***	***30.6***	***16***
Targets		***163***	***9.0***	***45.4***	***13-17***

Survival Estimates

Overall survival of the 2014 brood Methow summer Chinook from green (unfertilized) egg-to-release was below the standard set for the program (Table 9.11). This was largely because of lower eyed to ponding, ponding to release, and transport to release survivals.

Table 9.11. Hatchery life-stage survival rates (%) for Methow summer Chinook, brood years 1989-2014. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
1989[a]	89.8	99.5	89.9	96.7	99.7	99.4	73.3	98.5	87.0
1990[a]	93.9	99.0	84.9	97.1	81.2	80.6	97.7	99.5	84.4
1991[a]	93.1	95.5	88.2	98.0	99.4	99.1	97.5	99.6	92.2
1992[a]	96.9	99.0	87.8	98.0	99.9	99.9	90.9	98.3	82.8
1993[a]	82.2	99.4	85.4	97.6	99.8	99.5	92.0	99.4	81.5
1994	96.1	90.0	86.6	100.0	98.1	97.4	73.1	99.1	68.3
1995	91.9	96.2	98.2	84.1	96.5	96.2	92.7	89.6	71.9
1996	95.4	98.1	83.2	100.0	97.7	96.9	86.5	89.0	66.7

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
1997	91.9	94.6	86.1	98.4	98.7	98.3	98.8	99.7	95.9
1998	84.0	96.2	54.1	98.0	99.4	98.9	96.6	99.9	52.7
1999	98.8	98.7	92.9	96.9	98.0	97.6	96.9	99.9	87.7
2000	90.5	96.9	89.2	98.1	98.5	98.3	94.6	94.4	83.5
2001	96.2	92.3	89.1	97.6	97.2	97.1	97.5	99.8	89.0
2002	97.1	98.1	88.3	99.9	97.7	97.5	96.7	99.9	85.7
2003	96.7	97.5	82.8	98.2	99.7	99.2	93.7	99.9	74.9
2004	93.6	98.2	84.0	97.8	99.6	99.2	98.3	98.5	74.6
2005	97.0	89.6	88.0	95.5	99.6	98.9	96.6	99.9	86.2
2006	92.9	89.5	86.3	98.3	99.6	98.7	97.2	99.5	82.4
2007	92.6	99.6	84.1	98.5	99.7	99.5	98.9	99.8	81.9
2008	99.6	97.9	91.9	99.5	99.3	98.9	98.5	99.9	90.0
2009[b]	93.6	93.5	91.0	97.7	99.7	99.2	98.8	100.0	87.9
2010[c]	96.5	100.0	91.1	100.0	96.4	96.1	95.4	99.5	86.9
2011	94.9	96.4	93.8	97.8	99.7	99.1	98.6	99.9	90.4
2012	94.3	94.2	93.1	97.8	99.4	99.0	97.0	98.3	88.3
2013	98.0	100.0	89.5	97.8	99.9	99.2	93.4	94.2	81.7
2014	96.0	96.0	94.0	95.8	99.6	99.4	87.1	88.0	78.4
Average	***94.0***	***96.4***	***87.4***	***97.5***	***98.2***	***97.8***	***93.8***	***97.8***	***82.0***
Median	***94.6***	***97.2***	***88.3***	***97.9***	***99.4***	***98.9***	***96.7***	***99.5***	***84.0***
Standard	***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

[a] Survival rates were calculated from aggregate population collected at Wells Fish Hatchery volunteer channel and left- and right-ladder traps at Wells Dam.

[b] Survival rates were calculated from aggregate collections at Wells east fish ladder for the Methow and Okanogan/Similkameen programs. About 41% of the total fish collected were used to estimate survival rates.

[c] Survival rates were calculated from aggregate collections at Wells West Ladder for the Methow and Similkameen programs. About 71% of the total fish collected were used to estimate survival rates.

9.3 Disease Monitoring

Results of 2016 adult broodstock bacterial kidney disease (BKD) monitoring indicated that all females had ELISA values less than 0.120 (Table 9.12).

Table 9.12. Proportion of bacterial kidney disease (BKD) titer groups for the Methow/Okanogan summer Chinook broodstock, brood years 1997-2016. Also included are the proportions to be reared at either 0.125 fish per pound or 0.060 fish per pound.

Brood year[a]	Optical density values by titer group				Proportion at rearing densities (fish per pound, fpp)[b]	
	Very Low (≤ 0.099)	Low (0.1-0.199)	Moderate (0.2-0.449)	High (≥ 0.450)	≤ 0.125 fpp (<0.119)	≤ 0.060 fpp (>0.120)
1997	0.6267	0.1333	0.0622	0.1778	0.6844	0.3156
1998	0.9632	0.0184	0.0123	0.0061	0.9816	0.0184
1999	0.9444	0.0198	0.0238	0.0119	0.9643	0.0357
2000	0.7476	0.0952	0.0238	0.1333	0.8000	0.2000
2001	0.9801	0.0199	0.0000	0.0000	1.0000	0.0000
2002	0.9567	0.0130	0.0130	0.0173	0.9740	0.0260
2003	0.9620	0.0127	0.0169	0.0084	0.9747	0.0253
2004	0.9585	0.0151	0.0075	0.0189	0.9736	0.0264
2005	0.9884	0.0000	0.0000	0.0116	0.9884	0.0116
2006	0.9962	0.0038	0.0000	0.0000	0.9962	0.0038
2007	0.9202	0.0266	0.0152	0.0380	0.9354	0.0646
2008	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
2009	0.9891	0.0073	0.0037	0.0000	0.9927	0.0073
2010	0.9960	0.0040	0.0000	0.0000	1.0000	0.0000
2011	0.9766	0.0140	0.0000	0.0093	0.9860	0.0140
2012	0.9341	0.0440	0.0110	0.0110	0.9780	0.0220
2013	0.8776	0.1224	0.0000	0.0000	0.9388	0.0612
2014	0.9170	0.0210	0.0210	0.0420	0.9381	0.0630
2015	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
2016	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Average	***0.9367***	***0.0285***	***0.0105***	***0.0243***	***0.9553***	***0.0447***
Median	***0.9626***	***0.0146***	***0.0056***	***0.0089***	***0.9798***	***0.0202***

[a] Individual ELISA samples were not collected before the 1997 brood.
[b] ELISA values from broodstock BKD testing dictate what density the progeny of the broodstock are reared. Progeny of broodstock with high ELISA values are reared at lower density.

9.4 Natural Juvenile Productivity

During 2016, juvenile summer Chinook were sampled at the Methow Trap located near RM 18.6. Trapping has occurred in this location since 2004.

Emigrant Estimates

Methow Trap

On the Methow River, WDFW used traps with cone diameters of 2.4 m and 1.5 m to increase trap efficiency over a greater range of river discharge. Large variation in discharge and channel configuration required the use of two trapping positions. The 1.5-m trap was deployed in the lower position at discharges less than 45.3 m^3/s. At discharges greater than 45.3 m^3/s, the 2.4-m trap was installed and operated in tandem with the 1.5 m trap.

A pooled-efficiency model estimated the total number of emigrants when the trap was operated in the low trapping position. A flow-efficiency model estimated the total number of emigrants when the trap was operated in the upper trapping position. The pooled-efficiency estimate was based on four mark-recapture release groups in 2016. The flow-efficiency estimate was based on 15 mark-recapture release groups that were conducted over the period 2007-2016.

The Methow Trap operated at night between 19 February and 5 December 2016. During that time, the trap was inoperable for 17 days because of high river discharge. During the ten-month sampling period, a total of 6,512 wild subyearling summer Chinook were captured at the Methow Trap. Based on the pooled-efficiency model and the flow efficiency model, the total number of wild subyearling summer Chinook that emigrated past the Methow Trap in 2016 was 761,769 (±4,082,084) (Table 9.13). This value contains an estimated 49,126 fish that likely emigrated past the trapping location during the 17 days in which the trap was not operating. Because 462 summer Chinook redds were observed downstream from the trap in 2015, the total number of summer Chinook emigrating from the Methow River in 2016 was expanded using the ratio of the number of redds downstream from the trap to the number upstream from the trap. This resulted in a total summer Chinook emigrant estimate of 1,219,425 (±5,164,732) fish (Table 9.13). Most of these fish emigrated during April (Figure 9.1).

Table 9.13. Numbers of redds and juvenile summer Chinook emigrants in the Methow River basin for brood years 2003-2015; NA = not available.

Brood year	Number of redds	Egg deposition	Number of emigrants upstream from trap	Total number of emigrants
2003	1,624	8,215,816	1,454,913	NA
2004*	973	4,991,490	2,016,696	NA
2005*	874	3,979,322	269,870	NA
2006	1,353	6,567,462	2,481,762	3,465,247
2007	620	3,261,200	446,860	664,396
2008	599	2,867,413	385,087	508,077
2009	692	3,539,580	838,989	1,202,030
2010	887	4,537,892	514,724	703,483
2011	941	4,307,898	1,861,614	2,292,904
2012	960	4,291,200	7,533,462	11,212,595
2013	1,551	7,316,067	473,625	709,066
2014	591	2,768,835	706,071	742,505
2015	1,231	5,428,710	761,769	1,219,425
Average	***696***	***3,409,000***	***1,518,880***	***2,271,973***

Brood year	Number of redds	Egg deposition	Number of emigrants upstream from trap	Total number of emigrants
Median	***599***	***2,867,413***	***761,769***	***972,268***

* Trap did not operate for entire migration period.

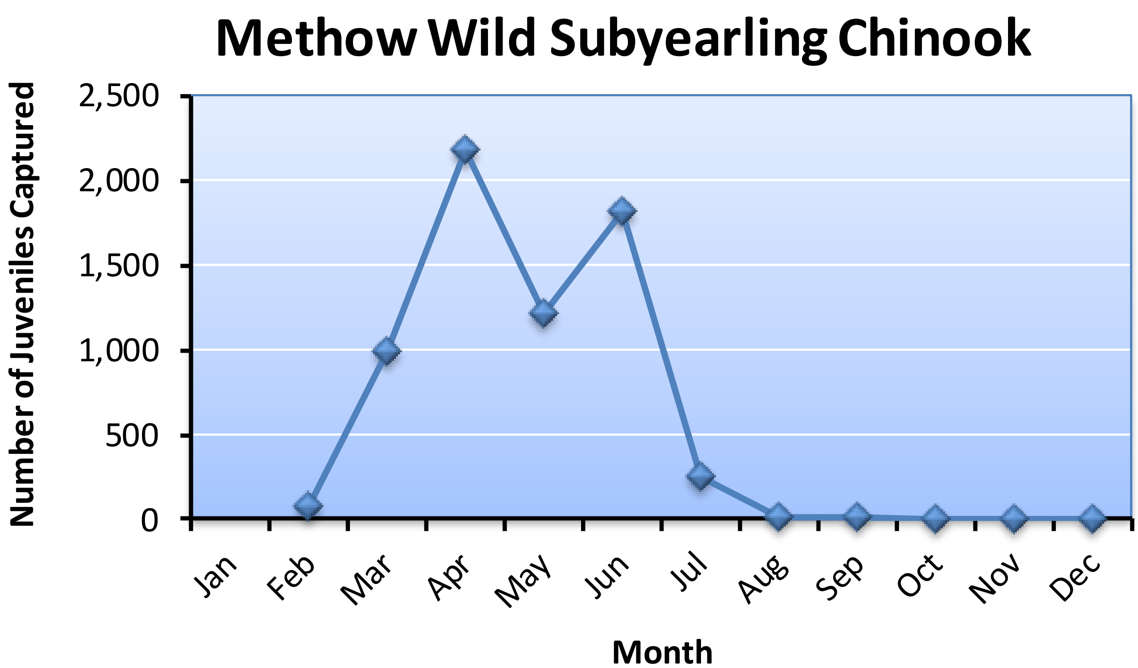

Figure 9.1. Numbers of wild subyearling Chinook captured at the Methow Trap during February to early December 2016.

Subyearling summer Chinook sampled in 2016 averaged 65.6 mm in length, 3.8 g in weight, and had a mean condition of 1.20 (Table 9.14). These size estimates were similar to the overall mean of subyearling summer Chinook sampled in previous years (overall means: 63.3 mm, 3.8 g, and condition of 1.23). Environmental conditions at the trapping location do not allow for accurate weight measurements on fry (i.e., <50 mm fork length), so this size class is underrepresented in the averages.

Table 9.14. Mean fork length (mm), weight (g), and condition factor of subyearling summer Chinook collected in the Methow Trap, 2004-2016. Numbers in parentheses indicate 1 standard deviation.

Sample year	Sample size[a]	Mean size		
		Length (mm)	Weight (g)	Condition (K)
2004	506	56.5 (17.5)	2.8 (2.8)	1.29 (0.36)
2005	326	42.6 (6.5)	1.1 (0.6)	1.34 (0.39)
2006	787	38.5 (3.0)	0.6 (0.3)	1.02 (0.28)
2007	437	73.9 (17.3)	5.8 (3.8)	1.24 (0.26)
2008	123	78.8 (16.3)	6.7 (3.9)	1.27 (0.35)
2009	162	67.4 (12.4)	4.3 (2.3)	1.31 (0.34)

Sample year	Sample size[a]	Mean size		
		Length (mm)	Weight (g)	Condition (K)
2010	142	69.7 (14.4)	4.6 (2.9)	1.26 (0.50)
2011	590	70.6 (13.5)	4.9 (2.8)	1.28 (0.31)
2012	373	61.4 (10.9)	2.9 (2.1)	1.16 (0.22)
2013	602	62.0 (11.0)	3.2 (2.1)	1.22 (0.23)
2014	707	67.1 (13.2)	3.9 (2.6)	1.16 (0.18)
2015	633	69.2 (13.6)	4.6 (2.8)	1.25 (0.22)
2016	645	65.6 (12.8)	3.8 (2.6)	1.20 (0.24)
Average	***464***	***63.3 (12.5)***	***3.8 (2.4)***	***1.23 (0.30)***
Median	***506***	***67.1 (13.2)***	***3.9 (2.6)***	***1.25 (0.28)***

[a] Sample size represents the number of fish that were measured for both length and weight.

9.5 Spawning Surveys

Surveys for Methow summer Chinook redds were conducted from late September to mid-November 2016 in the Methow River. Total redd counts (not peak counts) were conducted in the river (see Appendix O for more details).

Redd Counts

A total of 1,115 summer Chinook redds were counted in the Methow River in 2016 (Table 9.15). This is greater than the overall average of 711 redds.

Table 9.15. Total number of redds counted in the Methow River, 1989-2016.

Survey year	Total redd count
1989	149*
1990	418*
1991	153
1992	107
1993	154
1994	310
1995	357
1996	181
1997	205
1998	225
1999	448
2000	500
2001	675
2002	2,013
2003	1,624
2004	973
2005	874
2006	1,353

Survey year	Total redd count
2007	620
2008	599
2009	692
2010	887
2011	941
2012	960
2013	1,551
2014	591
2015	1,231
2016	1,115
Average	***711***
Median	***610***

* Total counts based on expanded aerial counts.

Redd Distribution

Summer Chinook redds were not evenly distributed among the seven reaches in the Methow River. Most redds (81%) were located within the lower three reaches (downstream from Twisp) (Table 9.16; Figure 9.2). Few Chinook spawned upstream from Winthrop (Reaches 6 and 7).

Table 9.16. Total number of summer Chinook redds counted in different reaches on the Methow River during September through early November 2016. Reach codes are described in Table 2.11.

Survey reach	Total redd count	Percent
Methow 1 (M1)	182	16.3
Methow 2 (M2)	309	27.7
Methow 3 (M3)	410	36.8
Methow 4 (M4)	57	5.1
Methow 5 (M5)	147	13.2
Methow 6 (M6)	1	0.1
Methow 7 (M7)	9	0.8
Totals	***1,115***	***100.0***

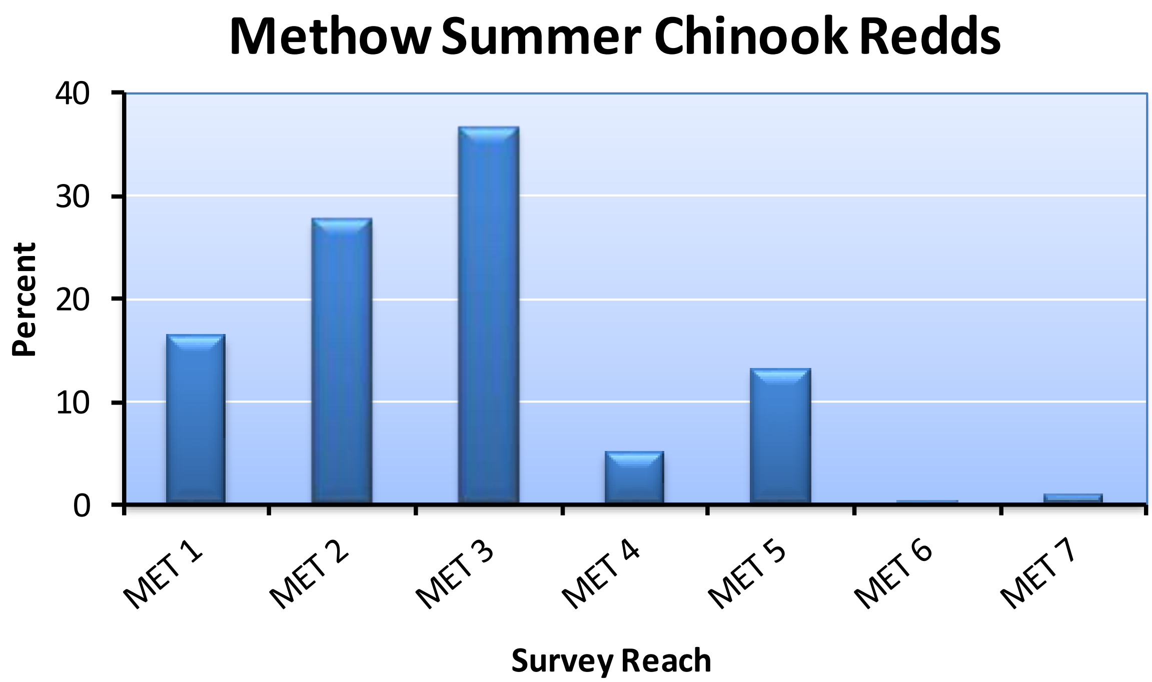

Figure 9.2. Percent of the total number of summer Chinook redds counted in different reaches on the Methow River during September through mid-November 2016. Reach codes are described in Table 2.11.

Spawn Timing

Spawning in 2016 began the last week of September, peaked in early October, and ended the third week of November (Figure 9.3). Stream temperatures in the Methow River, when spawning began, varied from 10.5-11.0°C. Peak spawning occurred during the first week of October in the upper reaches of the Methow River and one-two weeks later in the lower reaches.

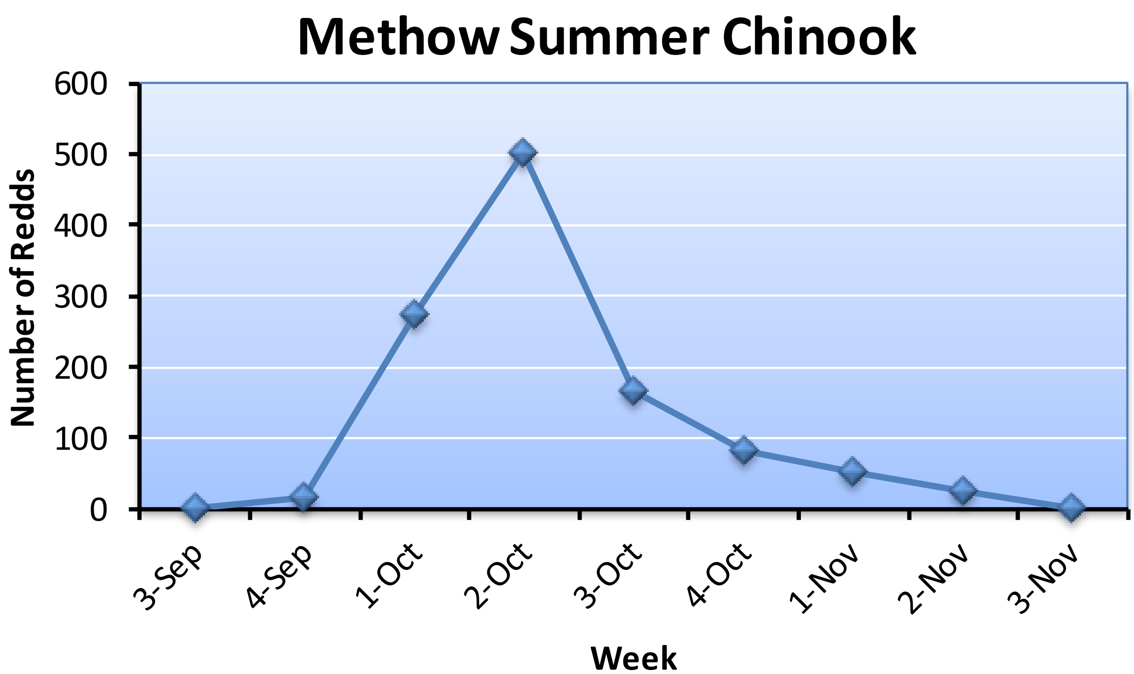

Figure 9.3. Number of new summer Chinook redds counted during different weeks in the Methow River, September through mid-November 2016.

Spawning Escapement

Spawning escapement for Methow summer Chinook was calculated as the total number of redds times the fish per redd ratio estimated from fish sampled at Wells Dam.[28] The estimated fish per redd ratio for Methow summer Chinook in 2016 was 2.01. Multiplying this ratio by the number of redds counted in the Methow River resulted in a total spawning escapement of 2,241 summer Chinook (Table 9.17).

Table 9.17. Spawning escapements for summer Chinook in the Methow River for return years 1989-2016.

Return year	Fish/Redd	Redds	Total spawning escapement
1989*	3.30	149	492
1990*	3.40	418	1,421
1991*	3.70	153	566
1992*	4.30	107	460
1993*	3.30	154	508
1994*	3.50	310	1,085
1995*	3.40	357	1,214
1996*	3.40	181	615
1997*	3.40	205	697

[28] Expansion factor = (1 + (number of males/number of females)).

Return year	Fish/Redd	Redds	Total spawning escapement
1998	3.00	225	675
1999	2.20	448	986
2000	2.40	500	1,200
2001	4.10	675	2,768
2002	2.30	2,013	4,630
2003	2.42	1,624	3,930
2004	2.25	973	2,189
2005	2.93	874	2,561
2006	2.02	1,353	2,733
2007	2.20	620	1,364
2008	3.25	599	1,947
2009	2.54	692	1,758
2010	2.81	887	2,492
2011	3.10	941	2,917
2012	3.07	960	2,947
2013	2.31	1,551	3,583
2014	2.75	591	1,625
2015	3.21	1,231	3,952
2016	2.01	1,115	2,241
Average	***2.95***	***711***	***1,913***
Median	***3.04***	***610***	***1,692***

* Spawning escapement was calculated using the “Modified Meekin Method” (i.e., 3.1 x jack multiplier).

9.6 Carcass Surveys

Surveys for Methow summer Chinook carcasses were conducted during late September to mid-November 2016 in the Methow River (see Appendix O for more details).

Number sampled

A total of 587 summer Chinook carcasses were sampled during September through mid-November in the Methow River (Table 9.18). This was greater than the overall average of 523 carcasses sampled since 1991.

Table 9.18. Numbers of summer Chinook carcasses sampled within each survey reach on the Methow River, 1991-2016. Reach codes are described in Table 2.11.

Survey year	Number of summer Chinook carcasses							
	M-1	M-2	M-3	M-4	M-5	M-6	M-7	Total
1991	0	12	8	4	2	0	0	**26**
1992	8	8	19	0	17	1	0	**53**
1993	19	25	14	2	5	0	0	**65**
1994[a]	43	33	20	5	13	0	0	**114**
1995	14	33	58	7	7	0	0	**119**

Survey year	Number of summer Chinook carcasses							
	M-1	**M-2**	**M-3**	**M-4**	**M-5**	**M-6**	**M-7**	**Total**
1996	6	30	46	5	2	0	0	**89**
1997	6	12	38	2	19	1	0	**78**
1998	90	84	99	17	30	0	0	**320**
1999	47	144	232	32	37	12	2	**506**
2000	62	118	105	9	99	5	0	**398**
2001	392	275	88	14	76	11	1	**857**
2002	551	318	518	164	219	34	10	**1,814**
2003	115	268	317	115	128	5	0	**948**
2004	40	173	187	82	92	2	1	**577**
2005	154	173	182	42	112	3	0	**666**
2006	121	148	110	56	144	3	1	**583**
2007	142	132	108	27	53	0	0	**462**
2008	64	128	197	33	57	3	0	**482**
2009	144	158	159	36	94	0	0	**591**
2010	105	180	184	38	63	5	1	**576**
2011	56	134	201	78	83	5	1	**558**
2012	127	154	169	75	82	14	7	**628**
2013	296	287	385	90	100	7	5	**1,170**
2014	6	14	176	53	148	73	17	**487**
2015	229	194	221	56	95	19	25	**839**
2016	82	168	216	44	70	1	5	**586**
Average	***112***	***131***	***156***	***42***	***71***	***8***	***3***	***523***
Median	***73***	***139***	***164***	***35***	***73***	***3***	***0***	***532***

[a] An additional 113 carcasses were sampled, but reach was not identified.

Carcass Distribution and Origin

Summer Chinook carcasses were not evenly distributed among reaches within the Methow River in 2016 (Table 9.18; Figure 9.4). Most of the carcasses were found in the lower three reaches (downstream from Twisp). Few carcasses were observed upstream from Winthrop (Reaches 6 and 7).

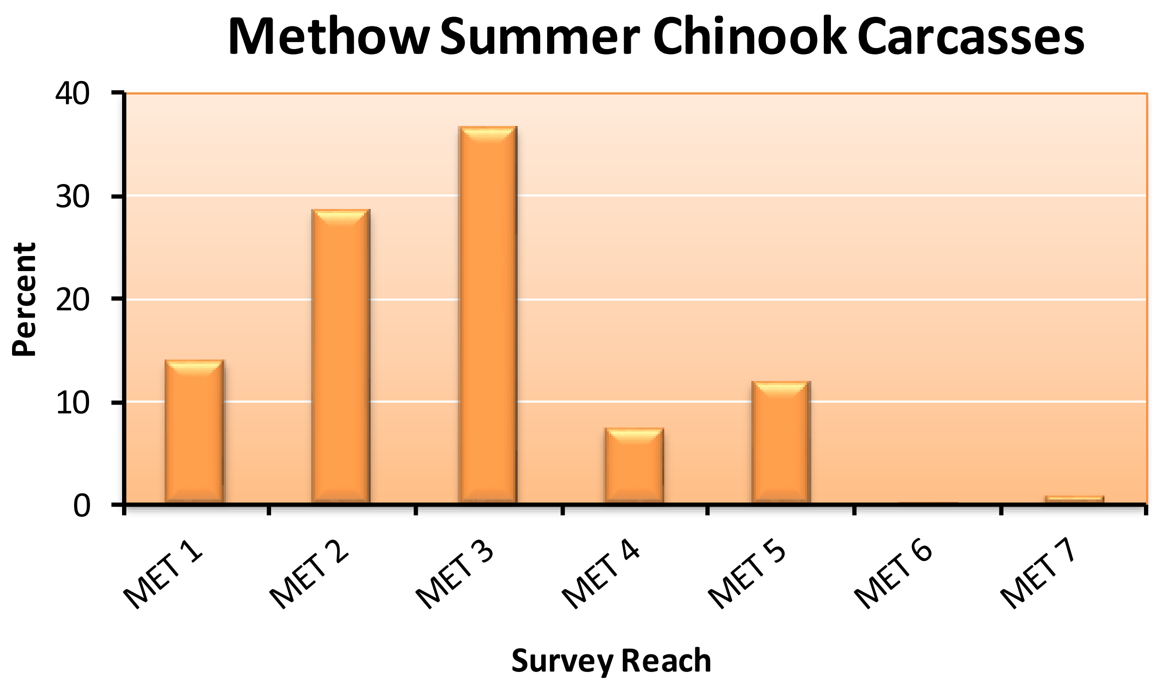

Figure 9.4. Percent of summer Chinook carcasses sampled within different reaches on the Methow River during September through mid-November 2016. Reach codes are described in Table 2.11.

Based on the available data (1991-2015), hatchery and wild summer Chinook carcasses were not distributed equally among the reaches in the Methow River (Table 9.19). A larger percentage of hatchery carcasses occurred in the lower reaches, while a larger percentage of wild summer Chinook carcasses occurred in upstream reaches (Figure 9.5).

Table 9.19. Numbers of wild and hatchery summer Chinook carcasses sampled within different reaches on the Methow River, 1991-2016.

Survey year	Origin	Survey reach							Total
		M-1	M-2	M-3	M-4	M-5	M-6	M-7	
1991	Wild	0	12	8	4	2	0	0	**26**
	Hatchery	0	0	0	0	0	0	0	**0**
1992	Wild	8	8	19	0	17	1	0	**53**
	Hatchery	0	0	0	0	0	0	0	**0**
1993	Wild	11	18	9	0	3	0	0	**41**
	Hatchery	8	7	5	2	2	0	0	**24**
1994	Wild	23	18	9	5	10	0	0	**65**
	Hatchery	20	15	11	0	3	0	0	**49**
1995	Wild	7	9	33	7	6	0	0	**62**
	Hatchery	7	24	25	0	1	0	0	**57**
1996	Wild	1	23	35	4	2	0	0	**65**
	Hatchery	5	7	11	1	0	0	0	**24**

Survey year	Origin	Survey reach							Total
		M-1	M-2	M-3	M-4	M-5	M-6	M-7	
1997	Wild	5	8	31	1	17	0	0	**62**
	Hatchery	1	4	7	1	2	1	0	**16**
1998	Wild	42	48	71	11	25	0	0	**197**
	Hatchery	48	36	28	6	5	0	0	**123**
1999	Wild	32	87	130	15	24	4	2	**294**
	Hatchery	15	57	102	17	13	8	0	**212**
2000	Wild	25	85	85	8	83	3	0	**289**
	Hatchery	37	33	20	1	16	2	0	**109**
2001	Wild	62	118	56	10	70	11	1	**328**
	Hatchery	330	157	32	4	6	0	0	**529**
2002	Wild	138	177	380	140	197	34	9	**1,075**
	Hatchery	413	141	138	24	22	0	1	**739**
2003	Wild	33	146	188	76	92	3	0	**538**
	Hatchery	82	122	129	39	36	2	0	**410**
2004	Wild	16	120	155	65	78	1	0	**435**
	Hatchery	24	53	32	17	14	1	1	**142**
2005	Wild	62	99	133	33	107	3	0	**437**
	Hatchery	92	74	49	9	5	0	0	**229**
2006	Wild	52	82	67	44	109	2	1	**357**
	Hatchery	69	66	43	12	35	1	0	**226**
2007	Wild	35	58	59	16	40	0	0	**208**
	Hatchery	107	74	49	11	13	0	0	**254**
2008	Wild	13	62	146	27	52	2	0	**302**
	Hatchery	51	66	51	6	5	1	0	**180**
2009	Wild	45	87	103	27	84	0	0	**346**
	Hatchery	99	71	56	9	10	0	0	**245**
2010	Wild	33	79	101	24	53	5	1	**296**
	Hatchery	72	101	83	14	10	0	0	**280**
2011	Wild	21	56	87	54	56	5	1	**280**
	Hatchery	35	78	114	24	27	0	0	**278**
2012	Wild	59	53	96	58	74	13	7	**360**
	Hatchery	73	101	73	17	8	1	0	**273**
2013	Wild	110	128	178	67	64	7	5	**559**
	Hatchery	186	160	208	23	36	0	0	**613**
2014	Wild	5	10	148	48	140	70	17	**438**
	Hatchery	2	4	27	5	8	3	0	**49**
2015	Wild	169	136	182	50	90	19	25	**671**
	Hatchery	60	58	39	6	5	0	0	**168**
2016	Wild	51	107	126	33	61	1	5	**384**
	Hatchery	32	61	90	11	9	0	0	**203**
Average	***Wild***	***41***	***71***	***101***	***32***	***60***	***7***	***3***	***314***

Survey year	Origin	Survey reach							Total
		M-1	M-2	M-3	M-4	M-5	M-6	M-7	
	Hatchery	*72*	*60*	*55*	*10*	*11*	*1*	*0*	*209*
Median	*Wild*	*33*	*71*	*92*	*26*	*59*	*2*	*0*	*299*
	Hatchery	*43*	*60*	*41*	*8*	*8*	*0*	*0*	*192*

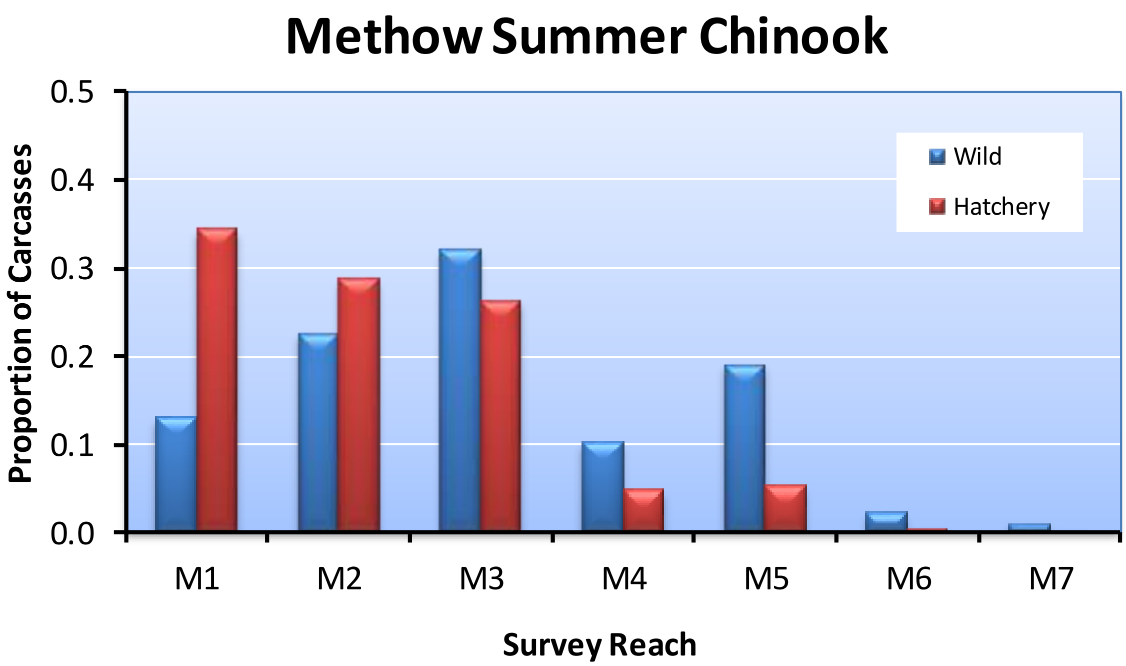

Figure 9.5. Distribution of wild and hatchery produced carcasses in different reaches on the Methow River, 1993-2016. Reach codes are described in Table 2.11.

Sampling Rate

Overall, 26% of the total spawning escapement of summer Chinook in the Methow River basin was sampled in 2016 (Table 9.20). Sampling rates among survey reaches varied from 23 to 50%.

Table 9.20. Number of redds and carcasses, total spawning escapement, and sampling rates for summer Chinook in the Methow River basin, 2016. Reach codes are described in Table 2.11.

Survey reach	Total number of redds	Total number of carcasses	Total spawning escapement	Sampling rate
Methow 1 (M1)	182	83	366	0.23
Methow 2 (M2)	309	168	621	0.27
Methow 3 (M3)	410	216	824	0.26
Methow 4 (M4)	57	44	115	0.38
Methow 5 (M5)	147	70	295	0.24
Methow 6 (M6)	1	1	2	0.50

Survey reach	Total number of redds	Total number of carcasses	Total spawning escapement	Sampling rate
Methow 7 (M7)	9	5	18	0.28
Total	***1,115***	***587***	***2,241***	***0.26***

Length Data

Mean lengths (POH, cm) of male and female summer Chinook carcasses sampled during surveys on the Methow River in 2016 are provided in Table 9.21. The average size of males and females sampled in the Methow River were 66 cm and 68 cm, respectively.

Table 9.21. Mean lengths (postorbital-to-hypural length; cm) and standard deviations (in parentheses) of male and female summer Chinook carcasses sampled in different reaches on the Methow River, 2016. Reach codes are described in Table 2.11.

Stream/watershed	Mean length (cm)	
	Male	Female
Methow 1 (M1)	65.3 (6.0)	67.9 (5.2)
Methow 2 (M2)	64.4 (8.7)	67.9 (5.4)
Methow 3 (M3)	67.2 (7.6)	68.5 (4.1)
Methow 4 (M4)	65.2 (9.1)	66.8 (4.6)
Methow 5 (M5)	68.3 (5.6)	69.2 (4.9)
Methow 6 (M6)	--	67.0 (-)
Methow 7 (M7)	67.3 (2.1)	64.0 (2.8)
Total	***65.5 (8.0)***	***68.3 (4.7)***

9.7 Life History Monitoring

Life history characteristics of Methow summer Chinook were assessed by examining carcasses on spawning grounds and fish collected or examined at broodstock collection sites, and by reviewing tagging data and fisheries statistics.

Migration Timing

Migration timing of hatchery and wild Methow/Okanogan summer Chinook was determined from broodstock data collected at Wells Dam. Counting of summer/fall Chinook at Wells Dam occurs from 29 June to 15 November. Broodstock collection at the Dam occurs from early July (week 27) to mid-September (week 37) (Table 2.1). Based on broodstock sampling in 2016, hatchery summer Chinook arrived at Wells Dam earlier than wild summer Chinook (Table 9.22). This was true throughout most of the migration period. In contrast, there was little difference in migration timing between wild and hatchery summer Chinook when data were pooled for the 2007-2016 survey period.

Table 9.22. The week that 10%, 50% (median), and 90% of the wild and hatchery summer Chinook salmon passed Wells Dam, 2007-2016. The average week is also provided. Migration timing is based on collection of summer Chinook broodstock at Wells Dam.

Survey year	Origin	Methow/Okanogan Summer Chinook Migration Time (week)				Sample size
		10 Percentile	50 Percentile	90 Percentile	Mean	
2007	Wild	27	30	34	30	485
	Hatchery	27	30	33	30	433
2008	Wild	28	30	34	30	542
	Hatchery	28	30	36	31	884
2009	Wild	27	29	34	30	585
	Hatchery	27	29	33	29	708
2010	Wild	27	29	33	29	377
	Hatchery	27	29	32	29	801
2011	Wild	30	32	36	32	516
	Hatchery	30	32	35	33	1223
2012	Wild	28	30	34	31	192
	Hatchery	28	31	34	31	591
2013	Wild	27	30	33	30	229
	Hatchery	27	30	33	30	282
2014	Wild	27	31	40	32	316
	Hatchery	27	30	35	30	208
2015	Wild	26	28	30	28	217
	Hatchery	27	28	31	29	164
2016	Wild	26	29	39	30	314
	Hatchery	25	28	34	29	251
Average	***Wild***	***27***	***30***	***35***	***30***	***377***
	Hatchery	***27***	***30***	***34***	***30***	***555***
Median	***Wild***	***27***	***30***	***34***	***30***	***347***
	Hatchery	***27***	***30***	***34***	***30***	***512***

Age at Maturity

Because hatchery summer Chinook are released after one year of rearing and natural-origin summer Chinook migrate primarily as age-0 fish, total ages will differ between hatchery and natural-origin Chinook (see Hillman et al. 2011). Therefore, in this section, we evaluated age at maturity by comparing differences in salt (ocean) ages between the two groups.

Most of the wild and hatchery summer Chinook sampled during the period 1993-2016 in the Methow River were salt age-3 fish (Table 9.23; Figure 9.6). A higher percentage of salt age-4 wild Chinook returned to the basin than did salt age-4 hatchery Chinook. In contrast, a higher proportion of salt age-1 and 2 hatchery fish returned than did salt age-1 and 2 wild fish. Thus, a higher percentage of wild fish returned at an older age than did hatchery fish.

Table 9.23. Proportions of wild and hatchery summer Chinook of different salt (ocean) ages sampled on spawning grounds in the Methow River, 1993-2015.

Sample year	Origin	Salt age						Sample size
		1	2	3	4	5	6	
1993	Wild	0.05	0.08	0.76	0.11	0.00	0.00	38
	Hatchery	0.00	1.00	0.00	0.00	0.00	0.00	20
1994	Wild	0.03	0.26	0.51	0.20	0.00	0.00	101
	Hatchery	0.00	0.07	0.93	0.00	0.00	0.00	111
1995	Wild	0.00	0.09	0.70	0.20	0.00	0.00	54
	Hatchery	0.02	0.04	0.44	0.51	0.00	0.00	55
1996	Wild	0.04	0.30	0.54	0.13	0.00	0.00	56
	Hatchery	0.00	0.05	0.50	0.41	0.05	0.00	22
1997	Wild	0.00	0.22	0.51	0.27	0.00	0.00	55
	Hatchery	0.13	0.06	0.56	0.25	0.00	0.00	16
1998	Wild	0.09	0.38	0.45	0.09	0.00	0.00	188
	Hatchery	0.02	0.52	0.41	0.04	0.00	0.00	123
1999	Wild	0.01	0.51	0.43	0.05	0.00	0.00	252
	Hatchery	0.00	0.07	0.90	0.03	0.00	0.00	210
2000	Wild	0.01	0.09	0.75	0.16	0.00	0.00	257
	Hatchery	0.10	0.16	0.62	0.11	0.00	0.00	97
2001	Wild	0.02	0.20	0.72	0.07	0.00	0.00	292
	Hatchery	0.10	0.60	0.26	0.04	0.00	0.00	526
2002	Wild	0.01	0.17	0.61	0.21	0.00	0.00	1,003
	Hatchery	0.01	0.41	0.57	0.01	0.00	0.00	734
2003	Wild	0.01	0.11	0.50	0.37	0.00	0.00	478
	Hatchery	0.02	0.03	0.90	0.04	0.00	0.00	399
2004	Wild	0.00	0.09	0.35	0.56	0.00	0.00	394
	Hatchery	0.07	0.28	0.30	0.35	0.00	0.00	141
2005	Wild	0.11	0.74	0.14	0.01	0.00	0.00	410
	Hatchery	0.06	0.26	0.65	0.02	0.00	0.00	220
2006	Wild	0.00	0.02	0.33	0.64	0.00	0.00	356
	Hatchery	0.01	0.19	0.50	0.30	0.00	0.00	164
2007	Wild	0.03	0.09	0.24	0.59	0.05	0.00	208
	Hatchery	0.07	0.09	0.75	0.09	0.01	0.00	213
2008	Wild	0.01	0.14	0.71	0.13	0.01	0.00	298
	Hatchery	0.10	0.45	0.30	0.15	0.00	0.00	138
2009	Wild	0.00	0.11	0.41	0.48	0.00	0.00	317
	Hatchery	0.17	0.26	0.53	0.04	0.00	0.00	242
2010	Wild	0.01	0.16	0.59	0.24	0.00	0.00	269
	Hatchery	0.01	0.69	0.29	0.02	0.00	0.00	247

Sample year	Origin	Salt age						Sample size
		1	2	3	4	5	6	
2011	Wild	0.02	0.09	0.60	0.30	0.00	0.00	255
	Hatchery	0.16	0.10	0.74	0.01	0.00	0.00	261
2012	Wild	0.03	0.24	0.53	0.21	0.00	0.00	315
	Hatchery	0.09	0.71	0.16	0.04	0.00	0.00	243
2013	Wild	0.02	0.25	0.62	0.11	0.00	0.00	533
	Hatchery	0.02	0.18	0.79	0.01	0.00	0.00	570
2014	Wild	0.01	0.12	0.69	0.18	0.00	0.00	412
	Hatchery	0.06	0.43	0.47	0.04	0.00	0.00	47
2015	Wild	0.00	0.20	0.45	0.35	0.00	0.00	588
	Hatchery	0.02	0.61	0.35	0.02	0.00	0.00	136
2016	Wild	0.0	0.02	0.77	0.20	0.00	0.00	350
	Hatchery	0.02	0.14	0.84	0.00	0.00	0.00	175
Average	***Wild***	***0.02***	***0.19***	***0.53***	***0.26***	***0.00***	***0.00***	***312***
	Hatchery	***0.05***	***0.32***	***0.57***	***0.06***	***0.00***	***0.00***	***213***
Median	***Wild***	***0.01***	***0.16***	***0.59***	***0.25***	***0.00***	***0.00***	***295***
	Hatchery	***0.05***	***0.24***	***0.65***	***0.06***	***0.00***	***0.00***	***170***

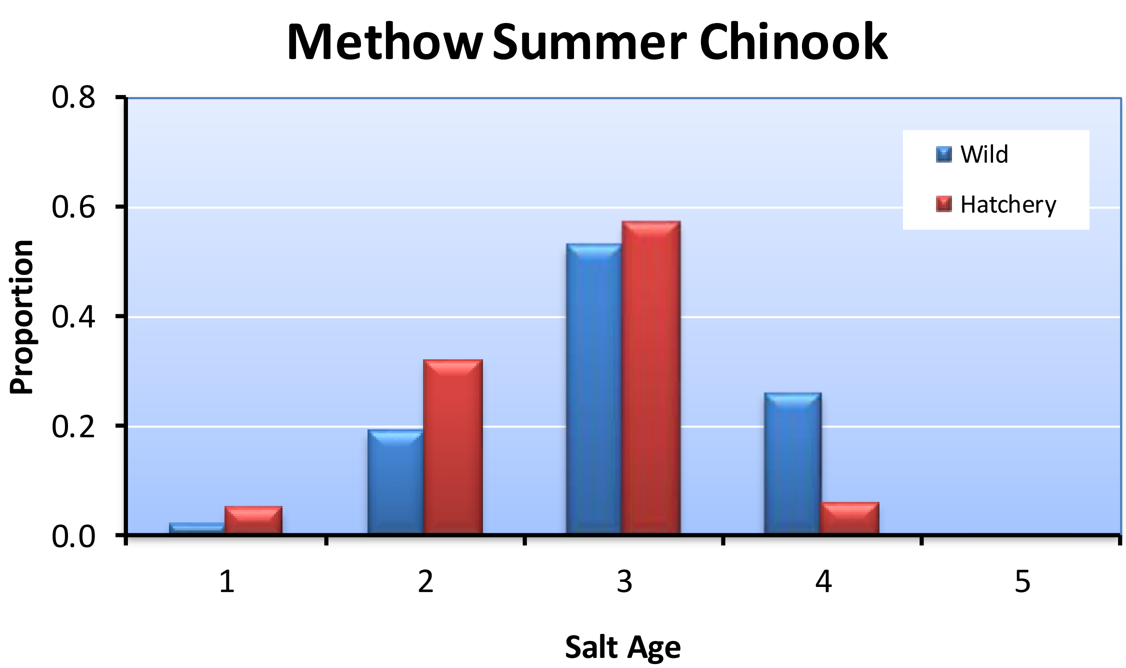

Figure 9.6. Proportions of wild and hatchery summer Chinook of different salt (ocean) ages sampled at broodstock collection sites and on spawning grounds in the Methow River for the combined years 1993-2016.

Size at Maturity

On average, hatchery summer Chinook were about 5 cm smaller than wild summer Chinook sampled in the Methow River basin (Table 9.24). This is likely because a higher percentage of wild fish returned as salt age-4 fish than did hatchery fish. Future analyses will compare sizes of hatchery and wild fish of the same age groups and sex.

Table 9.24. Mean lengths (POH; cm) and variability statistics for wild and hatchery summer Chinook sampled in the Methow River basin, 1993-2015; SD = 1 standard deviation.

Survey year	Origin	Sample size	Summer Chinook length (POH; cm)			
			Mean	SD	Minimum	Maximum
1993[a]	Wild	41	74	9	51	89
	Hatchery	24	62	8	36	80
1994[a]	Wild	112	69	8	35	87
	Hatchery	114	67	5	43	77
1995	Wild	62	74	6	52	88
	Hatchery	56	73	7	46	85
1996	Wild	64	70	11	34	91
	Hatchery	23	72	7	58	85
1997	Wild	62	76	9	35	90
	Hatchery	16	68	15	33	87
1998	Wild	196	67	10	38	97
	Hatchery	123	63	10	37	87
1999	Wild	292	66	8	43	99
	Hatchery	212	66	7	26	89
2000	Wild	288	74	8	37	89
	Hatchery	109	68	12	24	87
2001	Wild	328	67	10	29	86
	Hatchery	529	63	10	31	87
2002	Wild	1,075	70	8	37	94
	Hatchery	739	67	9	33	87
2003	Wild	538	71	8	35	88
	Hatchery	410	69	8	35	89
2004	Wild	435	73	7	38	89
	Hatchery	142	65	12	34	85
2005	Wild	437	69	8	45	86
	Hatchery	229	64	9	36	79
2006	Wild	438	73	7	35	92
	Hatchery	149	69	8	38	91
2007	Wild	249	72	11	33	89
	Hatchery	219	69	9	22	84
2008	Wild	384	69	8	30	90

Survey year	Origin	Sample size	Summer Chinook length (POH; cm)			
			Mean	SD	Minimum	Maximum
	Hatchery	210	63	15	23	86
2009	Wild	363	71	9	32	88
	Hatchery	228	63	12	30	83
2010	Wild	296	69	8	33	90
	Hatchery	280	62	9	39	81
2011	Wild	280	70	9	31	89
	Hatchery	278	64	11	26	82
2012	Wild	355	68	8	36	85
	Hatchery	273	59	9	21	81
2013	Wild	559	65	9	31	89
	Hatchery	613	66	8	27	83
2014	Wild	438	67	7	31	88
	Hatchery	49	60	10	35	76
2015	Wild	588	66	8	38	87
	Hatchery	136	59	8	38	79
2016	Wild	384	68	6	46	84
	Hatchery	203	66	7	37	83
Pooled	***Wild***	***8,264***	***70***	***8***	***37***	***89***
	Hatchery	***5,364***	***65***	***9***	***34***	***84***

[a] These years include sizes reported in annual reports. The data contained in the WDFW database do not include all these data.

Contribution to Fisheries

Most of the harvest on hatchery-origin Methow summer Chinook occurred in the Ocean (Table 9.25). Ocean harvest has made up 13% to 99% of all hatchery-origin Methow summer Chinook harvested. Brood years 1989, 1998, 2006, 2008, and 2010 provided the largest harvests, while brood years 1996 and 1999 provided the lowest.

Table 9.25. Estimated number and percent (in parentheses) of hatchery-origin Methow summer Chinook captured in different fisheries, brood years 1989-2010.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
1989	1,043 (52)	884 (44)	0 (0)	66 (3)	1,993
1990	55 (57)	41 (43)	0 (0)	0 (0)	96
1991	12 (20)	49 (80)	0 (0)	0 (0)	61
1992	17 (55)	14 (45)	0 (0)	0 (0)	31
1993	29 (58)	17 (34)	4 (8)	0 (0)	50
1994	153 (81)	34 (18)	1 (1)	1 (1)	189
1995	77 (99)	0 (0)	1 (1)	0 (0)	78
1996	12 (92)	1 (8)	0 (0)	0 (0)	13

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
1997	219 (89)	7 (3)	0 (0)	21 (9)	247
1998	1,752 (83)	101 (5)	14 (1)	234 (11)	2,101
1999	2 (13)	13 (87)	0 (0)	0 (0)	15
2000	366 (71)	88 (17)	27 (5)	33 (6)	514
2001	326 (52)	97 (15)	43 (7)	160 (26)	626
2002	271 (48)	96 (17)	61 (11)	137 (24)	565
2003	58 (58)	17 (17)	7 (7)	18 (18)	100
2004	133 (49)	55 (20)	16 (6)	68 (25)	272
2005	298 (54)	137 (25)	50 (9)	66 (12)	551
2006	1,128 (48)	811 (34)	100 (4)	314 (13)	2,353
2007	205 (60)	69 (20)	16 (5)	54 (16)	344
2008	1,231 (52)	366 (15)	65 (3)	717 (30)	2,379
2009	318 (42)	203 (27)	28 (4)	209 (28)	758
2010	526 (50)	282 (27)	26 (2)	217 (105)	1,051
Average	***374 (58)***	***154 (27)***	***21 (3)***	***105 (11)***	***654***
Median	***212 (55)***	***62 (20)***	***11 (3)***	***44 (10)***	***308***

Straying

Stray rates were determined by examining CWTs recovered on spawning grounds within and outside the Methow River basin. Targets for strays based on return year (recovery year) within the upper Columbia River basin (Priest Rapids Dam to Chief Joseph Dam) should be less than 10% and targets for strays outside the upper Columbia River should be less than 5%. The target for brood year stay rates should be less than 5%.

Few hatchery-origin Methow summer Chinook have strayed into basins outside the Methow (Table 9.26). Although hatchery-origin Methow summer Chinook have strayed into the Wenatchee River basin, Okanogan River basin, Entiat River basin, Chelan tailrace, and Hanford Reach, on average, they have made up less than 1% of the spawning escapement within those areas.

Table 9.26. Number and percent of spawning escapements within other non-target basins that consisted of hatchery-origin Methow summer Chinook, return years 1994-2015. For example, for return year 2002, 0.4% of the summer Chinook escapement in the Okanogan River basin consisted of hatchery-origin Methow summer Chinook. Percent strays should be less than 10%.

Return year	Wenatchee		Okanogan		Chelan		Entiat		Hanford Reach	
	Number	%	Number	%	Number	%	Number	%	Number	%
1994	0	0.0	72	1.8	-	-	-	-	-	-
1995	0	0.0	9	0.3	-	-	-	-	-	-
1996	0	0.0	0	0.0	-	-	-	-	-	-
1997	0	0.0	0	0.0	-	-	-	-	-	-
1998	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

Return year	Wenatchee		Okanogan		Chelan		Entiat		Hanford Reach	
	Number	%	Number	%	Number	%	Number	%	Number	%
1999	0	0.0	9	0.2	0	0.0	0	0.0	7	0.0
2000	0	0.0	3	0.1	0	0.0	0	0.0	0	0.0
2001	0	0.0	0	0.0	0	0.0	0	0.0	7	0.0
2002	0	0.0	54	0.4	0	0.0	0	0.0	0	0.0
2003	0	0.0	1	0.0	6	1.4	0	0.0	0	0.0
2004	0	0.0	7	0.1	3	0.7	0	0.0	0	0.0
2005	0	0.0	24	0.3	0	0.0	0	0.0	0	0.0
2006	0	0.0	12	0.1	0	0.0	0	0.0	0	0.0
2007	0	0.0	17	0.4	2	1.1	3	1.2	0	0.0
2008	0	0.0	12	0.2	0	0.0	0	0.0	0	0.0
2009	0	0.0	14	0.2	0	0.0	0	0.0	0	0.0
2010	6	0.1	44	0.7	22	2.0	0	0.0	0	0.0
2011	0	0.0	45	0.5	8	0.6	0	0.0	0	0.0
2012	0	0.0	31	0.4	0	0.0	0	0.0	0	0.0
2013	0	0.0	10	0.1	0	0.0	0	0.0	0	0.0
2014	0	0.0	17	0.1	0	0.0	0	0.0	0	0.0
2015	0	0.0	40	0.3	4	0.3	0	0.0	0	0.0
Average	***0***	***0.0***	***19***	***0.3***	***3***	***0.3***	***0***	***0.1***	***1***	***0.0***
Median	***0***	***0.0***	***12***	***0.2***	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***

Based on brood year analyses, on average, about 3.9% of the returns have strayed into non-target populations, falling within the acceptable level of less than 5% (Table 9.27). Depending on brood year, percent strays into non-target spawning areas have ranged from 0-17.1%. Few (<1% on average) have strayed into non-target hatchery programs.

Table 9.27. Number and percent of hatchery-origin Methow summer Chinook that homed to target spawning areas and the target hatchery program, and number and percent that strayed to non-target spawning areas and non-target hatchery programs, by brood years 1989-2010. Percent stays should be less than 5%.

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1989	773	55.7	459	33.0	81	5.8	76	5.5
1990	199	70.6	81	28.7	0	0.0	2	0.7
1991	82	65.6	43	34.4	0	0.0	0	0.0
1992	68	63.0	40	37.0	0	0.0	0	0.0
1993	54	65.9	22	26.8	6	7.3	0	0.0
1994	419	79.7	94	17.9	13	2.5	0	0.0
1995	126	81.8	28	18.2	0	0.0	0	0.0

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1996	57	93.4	4	6.6	0	0.0	0	0.0
1997	379	93.8	7	1.7	18	4.5	0	0.0
1998	1,653	94.7	32	1.8	60	3.4	0	0.0
1999	18	100.0	0	0.0	0	0.0	0	0.0
2000	239	93.0	4	1.6	14	5.4	0	0.0
2001	272	88.3	6	1.9	29	9.4	1	0.3
2002	315	94.6	4	1.2	14	4.2	0	0.0
2003	131	99.2	1	0.8	0	0.0	0	0.0
2004	194	85.5	6	2.6	27	11.9	0	0.0
2005	373	90.5	13	3.2	23	5.6	3	0.7
2006	1,317	91.4	15	1.0	109	7.6	0	0.0
2007	134	98.5	2	1.5	0	0.0	0	0.0
2008	1,886	97.8	15	0.8	25	1.3	3	0.2
2009	185	93.0	14	7.0	0	0.0	0	0.0
2010	203	80.6	6	2.4	43	17.1	0	0.0
Average	***413***	***85.3***	***41***	***10.5***	***21***	***3.9***	***4***	***0.3***
Median	***201***	***91.0***	***14***	***2.5***	***14***	***3.0***	***0***	***0.0***

* Homing to the target hatchery includes Methow hatchery summer Chinook that are captured and included as broodstock in the Methow Hatchery program. These hatchery fish are typically collected at Wells Dam.

Genetics

Genetic studies were conducted to investigate relationships among temporally replicated collections of summer Chinook from the Wenatchee River, Methow River, and Okanogan River in the upper Columbia River basin (Kassler et al. 2011; the entire report is appended as Appendix N). A total of 2,416 summer Chinook were collected from tributaries in the upper Columbia River basin. Two collections of natural-origin summer Chinook from 1993 (prior to the supplementation program) were taken from the Wenatchee River basin (N = 139) and compared to collections of hatchery and natural-origin Chinook from 2006 and 2008 (N = 380). Two pre-supplementation collections from the Methow River (1991 and 1993) were compared to supplementation collections from 2006 and 2008 (N = 362). Three pre-supplementation collections from the Okanogan River Basin (1991, 1992, and 1993) were compared with supplementation collections from 2006 and 2008 (N = 669). A collection of natural-origin summer Chinook from the Chelan River was also analyzed (N = 70). Additionally, hatchery collections from Eastbank Hatchery (Wenatchee and Methow/Okanogan stock; N = 221) and Wells Hatchery (N = 294) were analyzed and compared to the in-river collections. Summer Chinook data (provided by the USFWS) from the Entiat River (N = 190) were used for comparison. Lastly, data from eight collections of fall Chinook (N = 2,408) were compared to the collections of summer Chinook. Samples of natural and hatchery-origin summer Chinook were analyzed and compared to determine if the supplementation programs have affected the genetic structure of these populations. The study also calculated the effective number of breeders for collection locations of natural and hatchery-origin summer Chinook from 1993 and 2008.

In general, population differentiation was not observed among the temporally replicated collection locations. A single collection from the Okanogan River (1993) was the only collection showing statistically significant differences. The effective number of breeders was not statistically different from the early collection in 1993 in comparison to the late collection in 2008. Overall, these analyses revealed a lack of differentiation among the temporal replicates from the same locations and among the collection from different locations, suggesting the populations have been homogenized or that there has been substantial gene flow among populations. Additional comparisons among summer-run and fall-run Chinook populations in the upper Columbia River were conducted to determine if there was any differentiation between Chinook with different run timing. These analyses revealed pairwise F_{ST} values that were less than 0.01 for the collections of summer Chinook to collections of fall Chinook from Hanford Reach, lower Yakima River, Priest Rapids, and Umatilla. Collections of fall Chinook from Crab Creek, Lyons Ferry Hatchery, Marion Drain, and Snake River had pairwise F_{ST} values that were higher in comparison to the collections of summer Chinook. The consensus clustering analysis did not provide good statistical support to the groupings, but did show relationships among collections based on geographic proximity. Overall the summer and fall run Chinook that have historically been spawned together were not differentiated while fall Chinook from greater geographic distances were differentiated.

Proportionate Natural Influence

Another method for assessing the genetic risk of a supplementation program is to determine the influence of the hatchery and natural environments on the adaptation of the composite population. This is estimated by the proportion of natural-origin fish in the hatchery broodstock (pNOB) and the proportion of hatchery-origin fish in the natural spawning escapement (pHOS). We calculated Proportionate Natural Influence (PNI) by iterating Ford's (2002) equations 5 and 6 to equilibrium, using a heritability of 0.3 and a selection strength of three standard deviations. The larger the PNI value, the greater the strength of selection in the natural environment relative to that of the hatchery environment. For the natural environment to dominate selection, PNI should be greater than 0.50, and important integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004).

For brood years 1993-2003, the PNI values were generally less than 0.67 (Table 9.28). However, since brood year 2003, PNI has generally been greater than 0.67; brood year 2015 had a PNI value of 0.83.

Table 9.28. Proportionate Natural Influence (PNI) values for the Methow summer Chinook supplementation program for brood years 1989-2015. NOS = number of natural-origin Chinook on the spawning grounds; HOS = number of hatchery-origin Chinook on the spawning grounds; NOB = number of natural-origin Chinook collected for broodstock; and HOB = number of hatchery-origin Chinook included in hatchery broodstock.

Brood year	Spawners			Broodstock			PNI[a]
	NOS	HOS	pHOS	NOB	HOB	pNOB	
1989	492	0	0.00	1,297	312	0.81	1.00
1990	1,421	0	0.00	828	206	0.80	1.00
1991	566	0	0.00	924	314	0.75	1.00

Brood year	Spawners			Broodstock			PNI[a]
	NOS	HOS	pHOS	NOB	HOB	pNOB	
1992	460	0	0.00	297	406	0.42	1.00
1993	314	194	0.38	681	388	0.64	0.64
1994	596	489	0.45	341	244	0.58	0.58
1995	596	618	0.51	173	240	0.42	0.47
1996	435	180	0.29	287	155	0.65	0.70
1997	529	168	0.24	197	265	0.43	0.66
1998	436	239	0.35	153	211	0.42	0.56
1999	573	413	0.42	224	289	0.44	0.53
2000	861	339	0.28	164	337	0.33	0.56
2001	1,122	1,646	0.59	12	345	0.03	0.09
2002	2,572	2,058	0.44	247	241	0.51	0.55
2003	2,307	1,623	0.41	381	101	0.79	0.67
2004	1,622	567	0.26	506	16	0.97	0.79
2005	1,672	889	0.35	391	9	0.98	0.74
2006	1,675	1,058	0.39	500	10	0.98	0.72
2007	660	704	0.52	456	17	0.96	0.66
2008	1,194	753	0.39	359	86	0.81	0.68
2009	1,042	716	0.41	503	4	0.99	0.72
2010	1,326	1,166	0.47	484	8	0.98	0.68
2011	1,503	1,414	0.48	467	26	0.95	0.67
2012	1,593	1,354	0.46	98	1	0.99	0.69
2013	1,693	1,890	0.53	97	4	0.96	0.65
2014	1,451	174	0.11	96	0	1.00	0.90
2015	3,138	814	0.21	103	0	1.00	0.83
Average	***1,180***	***721***	***0.33***	***380***	***157***	***0.73***	***0.69***
Median	***1,122***	***618***	***0.39***	***341***	***155***	***0.80***	***0.68***

[a] PNI was calculated previously using PNI approximate equation 11 (HSRG 2009; their Appendix A). All PNI values presented here were recalculated by iterating Ford's (2002) equations 5 and 6 to equilibrium using a heritability of 0.3 and a selection strength of three standard deviations. C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI.

Post-Release Survival and Travel Time

We used PIT-tagged fish to estimate survival rates and travel time (arithmetic mean days) of hatchery summer Chinook from the Methow River release site to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam (Table 9.29).[29] Over the five brood years for which PIT-tagged hatchery fish were released, survival rates from the Methow River to McNary Dam ranged from 0.485 to 0.747; SARs from release to detection at Bonneville Dam ranged from 0.000 to 0.016. Average travel time from the Methow River to McNary Dam ranged from 17 to 55 days.

[29] It is important to point out that because of fish size differences among rearing tanks or raceways, fish PIT tagged in one tank or raceway may not represent untagged fish rearing in other tanks or raceways.

Table 9.29. Total number of Methow hatchery summer Chinook released with PIT tags, their survival and travel times (mean days) to McNary Dam, and smolt-to-adult (SAR) ratios for brood years 2008-2014. Standard errors are shown in parentheses. NA = not available (i.e., not all the fish from the release groups have returned to the Columbia River).

Brood year	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2008	10,094	0.747 (0.055)	39.1 (13.0)	0.016 (0.001)
2009	5,020	0.485 (0.037)	30.2 (11.1)	0.002 (0.001)
2010	0	--	--	--
2011	0	--	--	--
2012	9,801	0.545 (0.046)	17.0 (8.1)	0.000 (0.000)
2013	9,825	0.560 (0.101)	54.5 (8.3)	NA
2014	4,992	0.624 (0.053)	24.5 (8.1)	NA

Natural and Hatchery Replacement Rates

Natural replacement rates (NRR) were calculated as the ratio of natural-origin recruits (NOR) to the parent spawning population (spawning escapement). Natural-origin recruits are naturally produced (wild) fish that survive to contribute to harvest (directly or indirectly), to broodstock, and to spawning grounds. We do not account for fish that died in route to the spawning grounds (migration mortality) or died just before spawning (pre-spawn mortality) (see Appendix B in Hillman et al. 2012). We calculated NORs with and without harvest. NORs without harvest include all returning fish that either returned to the basin or were collected as wild broodstock. NORs with harvest include all fish harvested and are based on a brood year harvest rates from the hatchery program. For brood years 1989-2009, NRR for summer Chinook in the Methow averaged 1.11 (range, 0.10-4.90) if harvested fish were not included in the estimate and 2.13 (range, 0.18-10.84) if harvested fish were included in the estimate (Table 9.30). NRRs for more recent brood years will be calculated as soon as all tag recoveries and sampling rates have been loaded into the database.

Hatchery replacement rates (HRR) are the hatchery adult-to-adult returns and were calculated as the ratio of hatchery-origin recruits (HOR) to the parent broodstock collected. These rates should be greater than the NRRs and greater than or equal to 3.0 (the calculated target value in Hillman et al. 2013). The target value of 3.0 includes harvest. HRRs exceeded NRRs in 13 out of the 21 years of data, regardless if harvest was or was not included in the estimate (Table 9.30). Hatchery replacement rates for Methow summer Chinook have exceeded the estimated target value of 3.0 in ten of the 20 years of data.

Table 9.30. Broodstock collected, spawning escapements, natural and hatchery-origin recruits (NOR and HOR), and natural and hatchery replacement rates (NRR and HRR; with and without harvest) for wild summer Chinook in the Methow River basin, brood years 1989-2009.

Brood year	Broodstock Collected	Spawning Escapement	Harvest not included				Harvest included			
			HOR	NOR	HRR	NRR	HOR	NOR	HRR	NRR
1989	202	492	1,389	631	6.88	1.28	3,382	1,532	16.74	3.11
1990	202	1,421	282	978	1.40	0.69	378	1,318	1.87	0.93
1991	266	566	125	287	0.47	0.51	186	429	0.70	0.76
1992	214	460	108	614	0.50	1.33	139	792	0.65	1.72
1993	234	508	82	430	0.35	0.85	132	701	0.56	1.38
1994	260	1,085	526	542	2.02	0.50	715	738	2.75	0.68
1995	242	1,214	154	1,201	0.64	0.99	232	1,809	0.96	1.49
1996	220	615	61	445	0.28	0.72	74	541	0.34	0.88
1997	209	697	404	1,493	1.93	2.14	651	2,315	3.11	3.32
1998	235	675	1,745	3,307	7.43	4.90	3,846	6,601	16.37	9.78
1999	222	986	18	2,862	0.08	2.90	33	5,251	0.15	5.33
2000	222	1,200	257	800	1.16	0.67	771	2,286	3.47	1.91
2001	223	2,768	308	2,574	1.38	0.93	934	6,435	4.19	2.32
2002	222	4,630	333	924	1.50	0.20	898	2,504	4.05	0.54
2003	224	3,930	132	352	0.59	0.09	232	619	1.04	0.16
2004	223	2,189	227	1,540	1.02	0.70	499	3,392	2.24	1.55
2005	225	2,561	412	1,120	1.83	0.44	963	2,489	4.28	0.97
2006	236	2,733	1,441	1,706	6.11	0.62	3,794	3,842	16.08	1.41
2007	209	1,364	136	1,509	0.65	1.11	480	3,992	2.30	2.93
2008	184	1,947	1,929	1,501	10.48	0.77	4,308	2,575	23.41	1.32
2009	223	1,758	199	1,542	0.89	0.88	957	4,047	4.29	2.30
Average	***224***	***1,609***	***489***	***1,255***	***2.27***	***1.11***	***1,124***	***2,581***	***5.22***	***2.13***
Median	***223***	***1,214***	***257***	***1,120***	***1.16***	***0.77***	***651***	***2,315***	***2.75***	***1.49***

Smolt-to-Adult Survivals

Smolt-to-adult survival ratios (SARs) were calculated as the number of hatchery adult recaptures divided by the number of tagged hatchery smolts released. Here, SARs were based on CWT returns. For the available brood years, SARs have ranged from 0.00008 to 0.01883 for hatchery summer Chinook in the Methow River basin (Table 9.31).

Table 9.31. Smolt-to-adult ratios (SARs) for Methow summer Chinook, brood years 1989-2010.

Brood year	Number of tagged smolts released[a]	Estimated adult captures[b]	SAR
1989	358,237	2,871	0.008010
1990	371,483	361	0.000970
1991	377,097	130	0.000340

Brood year	Number of tagged smolts released[a]	Estimated adult captures[b]	SAR
1992	392,636	138	0.000350
1993	200,345	62	0.000310
1994	400,488	710	0.001770
1995	344,974	229	0.000660
1996	289,880	73	0.000250
1997	380,430	647	0.001700
1998	202,559	3,812	0.018820
1999	422,473	33	0.000080
2000	334,337	770	0.002300
2001	246,159	930	0.003780
2002	310,846	895	0.002880
2003	353,495	232	0.000660
2004	394,490	496	0.001260
2005	262,496	961	0.003660
2006	417,795	3,786	0.009060
2007	426,188	479	0.001120
2008	373,234	4,088	0.010950
2009	450,237	952	0.002110
2010	428,458	1,289	0.003008
Average	***351,743***	***1,088***	***0.00337***
Median	***372,359***	***679***	***0.00174***

[a] Includes all tag codes and CWT released fish (CWT + Ad Clip fish and CWT-only fish).

[b] Includes estimated recoveries (spawning ground, hatcheries, harvest, etc.) and observed recoveries if estimated recoveries were unavailable.

9.8 ESA/HCP Compliance

Broodstock Collection

Summer Chinook adults collected at Wells Dam are used primarily for the Methow supplementation programs. On an as needed basis, adults collected at Wells Dam may be used to augment adult collections for the Okanogan summer Chinook supplementation program. Per the 2014 broodstock collection protocol, 100 natural-origin (adipose fin present) adults were targeted for collection between 1 July and 15 September at the West Ladder of Wells Dam for the Methow summer Chinook program. Actual collections occurred between 1 July and 3 September and totaled 100 summer Chinook. ESA Permit 1347 provides authorization to collect Methow and Okanogan summer Chinook at Wells Dam three days per week and up to 16 hours per day from July through November. During 2014, broodstock collection activities were accomplished within the allowable trapping days authorized under ESA Permit 1347.

Collection of Methow summer Chinook broodstock at Wells Dam occurred concurrently with collection of summer steelhead for the Wells steelhead program authorized under ESA Section 10 Permit 1395. Encounters with steelhead and spring Chinook during Methow summer Chinook broodstock collections did not result in takes that were outside those authorized in Permit 1347 and in Permit 1395 for the Wells Steelhead program. Steelhead encountered during summer Chinook collections that were not required for steelhead broodstock were passed at the trap site and were not physically handled. Any spring Chinook encountered during summer Chinook broodstock activities were also passed without handling. No chinook were collected at Wells Dam for the 2014 Okanogan summer Chinook program.

Hatchery Rearing and Release

The 2014 brood Methow summer Chinook reared throughout their juvenile life-stages at Eastbank Fish Hatchery and the Carlton Acclimation Pond without incident (see Section 9.2). The 2014 brood smolt release totaled 167,616 summer Chinook, representing 83.8% of the 200,000-production objective and was compliant with the 10% overage allowable in ESA Section 10 Permit 1347. Lower than anticipated fecundity (94% of the biological assumption used in the 2014 broodstock collection protocols) was the largest factor in not meeting the full program, followed by lower than expected overwinter survival (87.1%).

Hatchery Effluent Monitoring

Per ESA Permits 1196, 1347, 1395, 18118, 18120, and 18121, permit holders shall monitor and report hatchery effluents in compliance with applicable National Pollution Discharge Elimination Systems (NPDES) (EPA 1999) permit limitations. There were no NPDES violations reported at PUD Hatchery facilities during the period 1 January through 31 December 2016. NPDES monitoring and reporting for PUD Hatchery Programs during 2016 are provided in Appendix F.

Spawning Surveys

Summer Chinook spawning ground surveys conducted in the Methow River basin during 2016 were consistent with ESA Section 10 Permit No. 1347. Because of the difficulty of quantifying the level of take associated with spawning ground surveys, the Permit does not specify a take level associated with these activities, even though it does authorize implementation of spawning ground surveys. Therefore, no take levels are reported. However, to minimize potential effects to established redds, wading was restricted to the extent practical, and extreme caution was used to avoid established redds when wading was required.

SECTION 10: OKANOGAN/SIMILKAMEEN SUMMER CHINOOK

The goal of summer Chinook salmon supplementation in the Okanogan Basin is to use artificial production to replace adult production lost because of mortality at Wells, Rocky Reach, and Rock Island dams, while not reducing the natural production or long-term fitness of summer Chinook in the basin. The Rock Island Fish Hatchery Complex began operation in 1989 under funding from Chelan PUD. The Complex operated originally through the Rock Island Settlement Agreement, but since 2004 has operated under the Anadromous Fish Agreement and Habitat Conservation Plans.

Before 2012, adult summer Chinook were collected for broodstock from the run-at-large at the east ladder trapping facility at Wells Dam. Since then, the Colville Tribes collect broodstock using purse seines in the Okanogan and Columbia rivers. The goal was to collect up to 334 adult summer Chinook for the Okanogan program. Broodstock collection occurred from about 7 July through 15 September with trapping occurring no more than 16 hours per day, three days a week. If natural-origin broodstock collection fell short of expectation, hatchery-origin adults could be collected to make up the difference.

Before 2012, adult summer Chinook were spawned and reared at Eastbank Fish Hatchery. Juvenile summer Chinook were transferred from the hatchery to Similkameen Acclimation Pond in October. In addition, since 2005, about 20% (100,000) of the juveniles were transferred to Bonaparte Pond. Chinook were released from the ponds in April to early May.

Prior to 2012, the production goal for the Okanogan summer Chinook supplementation program was to release 576,000 yearling smolts into the Similkameen and Okanogan rivers at ten fish per pound. Beginning with the 2012 brood, the revised production goal is to release 166,569 yearling smolts into the rivers. Targets for fork length and weight are 176 mm (CV = 9.0) and 45.4 g, respectively. Over 90% of these fish are marked with CWTs. In addition, since 2009, juvenile summer Chinook have been PIT tagged annually.

The Colville Tribes began monitoring the Okanogan/Similkameen summer Chinook program in 2013. Their monitoring results are published in annual reports to Bonneville Power Administration (BPA). The purpose of retaining this section is to provide readers with monitoring data collected with Chelan PUD funding through brood year 2012. Thus, this section tracks the status and life histories of summer Chinook up to and including brood year 2012. Results from monitoring brood year 2013 and beyond will be included in annual reports to BPA.

10.1 Broodstock Sampling

Summer Chinook broodstock for the Okanogan/Similkameen and Methow programs was typically collected at the East and West Ladders of Wells Dam. In 2012, broodstock was also collected at the mouth of the Okanogan River via purse seine. In 2012, a total of 81 summer Chinook (79 wild Chinook and two hatchery Chinook)[30] were spawned for the Okanogan program. Refer to Section

[30] It is important to point out that some summer Chinook were used for both the Methow and Okanogan programs in 2012 because of the availability of ripe adults at the time of spawning. In addition, some eyed-eggs were split between the two programs

9.1 for information on the origin, age and length, sex ratios, and fecundity of summer Chinook broodstock collected at Wells Dam before 2013.

10.2 Hatchery Rearing

In this section, we describe the hatchery rearing of the Okanogan summer Chinook program through brood year 2012. The Colville Tribes began operating the program in 2013. Information on rearing history since brood year 2012 can be found in annual reports prepared by the Colville Tribes and submitted to BPA.

Rearing History

Number of eggs taken

Based on the unfertilized egg-to-release survival standard of 81%, a total of 711,111 eggs were required to meet the program release goal of 576,000 smolts through the 2011 brood year. An evaluation of the program in 2012 determined that 205,134 eggs were needed to meet the revised release goal of 166,569 smolts. This revised goal began with brood year 2012. From 1989 through 2012, the egg take goal was reached in 13 of those years (Table 10.1).

Table 10.1. Numbers of eggs taken from summer Chinook broodstock for the Okanogan program during 1989-2012. From 1989-2011, broodstock were collected at Wells Dam. In 2012, broodstock were collected in purse seines in the Okanogan River.

Return year	Number of eggs taken
1989	724,200
1990	696,144
1991	879,892
1992	729,389
1993	797,234
1994	893,086
1995	736,500
1996	672,000
1997	601,744
1998	584,018
1999	725,589
2000	645,403
2001	418,907
2002	718,599
2003	710,521
2004	805,814
2005	452,928
2006	757,350
2007	824,703
2008	662,668
2009	840,902
2010	726,979

Return year	Number of eggs taken
2011	683,419
Average (1989-2011)	***708,173***
Median (1989-2011)	***724,200***
2012	201,295
Average (2012)	***201,295***
Median (2012)	***201,295***

Number of acclimation days

Summer Chinook were released volitionally from Similkameen Pond as yearling smolts. Transfer dates, release dates, and the number of acclimation days for Okanogan summer Chinook are shown in Table 10.2.

Table 10.2. Number of days Okanogan summer Chinook broods were acclimated at Similkameen and Bonaparte ponds, brood years 1989-2012.

Brood year	Release year	Rearing facility	Transfer date	Release date	Number of days
1989	1991	Similkameen	29-Oct	7-May	190
1990	1992	Similkameen	5-Nov	25-Apr	171
1991	1993	Similkameen	1-Nov	9-Apr	159
1992	1994	Similkameen	2-Nov	1-Apr	150
			26-Feb	1-Apr	34
1993	1995	Similkameen	24-Oct	1-Apr	159
			24-Feb	1-Apr	36
1994	1996	Similkameen	30-Oct	6-Apr	158
			14-Mar	6-Apr	23
1995	1997	Similkameen	1-Oct	1-Apr	182
1996	1998	Similkameen	10-Oct	15-Mar	156
1997	1999	Similkameen	7-Oct	19-Apr	194
1998	2000	Similkameen	5-Oct	19-Apr	196
1999	2001	Similkameen	5-Oct	18-Apr	195
2000	2002	Similkameen	10-Oct	8-Apr	180
2001	2003	Similkameen	1-Oct	29-Apr	210
2002	2004	Similkameen	9-Nov	23-Apr	165
2003	2005	Similkameen	19-Oct	28-Apr	191
2004	2006	Similkameen	26-Oct	23-Apr	179
2005	2007	Bonaparte	6-Nov	11-Apr	156
		Similkameen	25-Oct	18-Apr – 9-May	179-200

Brood year	Release year	Rearing facility	Transfer date	Release date	Number of days
2006	2008	Similkameen	15-17-Oct	16-Apr – 7-May	182-205
2007	2009	Bonaparte	3-4-Nov	10-22-Apr	157-170
		Similkameen	20-24-Oct	14-Apr – 9-May	172-201
2008	2010	Bonaparte	2-4-Nov	19-Apr – 5-May	167-185
		Similkameen	26-28-Oct	19-Apr – 14-May	176-201
2009	2011	Bonaparte	8-9-Nov	12-Apr	155-156
		Similkameen	25-27-Oct	13-Apr – 5-May	169-193
2010	2012	Bonaparte	No program	No program	No program
		Similkameen	25-27 Oct	16-Apr – 7-May	173-196
2011	2013	Bonaparte	No program	No program	No program
		Similkameen	23-26 Oct	16-Apr – 8-May	175-197
2012	2014	Bonaparte	No program	No program	No program
		Similkameen	28-30 Oct	15 Apr – 5 May	167-189

Release Information

Numbers released

The 2012 Okanogan summer Chinook program achieved 68.4% of the 166,569 target goal with about 114,000 fish being released volitionally into the Similkameen River (Table 10.3).

Table 10.3. Numbers of Okanogan summer Chinook smolts released from the Similkameen and Bonaparte ponds, brood years 1989-2012; NA = not available. For brood years 1998-2012, the release target was 576,000 smolts. Since brood year 2013, the release target for Okanogan summer Chinook is 114,000 smolts.

Brood year	Release year	Rearing facility	CWT mark rate	Number of smolts released
1989	1991	Similkameen	0.5732	352,600
1990	1992	Similkameen	0.6800	540,000
1991	1993	Similkameen	0.5335	675,500
1992	1994	Similkameen	0.9819	548,182
1993	1995	Similkameen	0.6470	586,000
1994	1996	Similkameen	0.4176	536,299
1995	1997	Similkameen	0.9785	587,000
1996	1998	Similkameen	0.9769	507,913
1997	1999	Similkameen	0.9711	589,591
1998	2000	Similkameen	0.9825	293,191
1999	2001	Similkameen	0.9689	630,463
2000	2002	Similkameen	0.9928	532,453
2001	2003	Similkameen	0.9877	26,642

Brood year	Release year	Rearing facility	CWT mark rate	Number of smolts released
2002	2004	Similkameen	0.9204	388,589
2003	2005	Similkameen	0.9929	579,019
2004	2006	Similkameen	0.9425	703,359
2005	2007	Bonaparte	0	0 (assumed)
		Similkameen	0.9862	275,919
2006	2008	Similkameen	0.9878	604,035
2007	2009	Bonaparte	0.9920	102,099
		Similkameen	0.9914	513,039
2008	2010	Bonaparte	0.9947	175,729
		Similkameen	0.9947	343,628
2009	2011	Bonaparte	0.9981	151,382
		Similkameen	0.9953	524,521
2010	2012	Similkameen	0.9886	617,950
2011	2013	Similkameen	0.9956	627,978
Average (1989-2011)		***Bonaparte***	***0.7462***	***143,070***
		Similkameen	***0.8907***	***503,647***
Median (1989-2011)		***Bonaparte***	***0.9819***	***540,000***
		Similkameen	***0.9934***	***151,382***
2012	2014	Bonaparte	No program	No program
		Similkameen	0.9939	114,000
Average (2012-present)		***Bonaparte***	***No program***	***No program***
		Similkameen	***0.9939***	***114,000***
Median (2012-present)		***Bonaparte***	***No program***	***No program***
		Similkameen	***0.9939***	***114,000***

Numbers tagged

The 2012 brood Okanogan summer Chinook from the Similkameen facility were 99.4% CWT and adipose fin-clipped (Table 10.3). Table 10.4 summarizes the number of hatchery summer Chinook that have been PIT-tagged and released into the Okanogan River basin. No fish from the 2012 brood year were PIT tagged.

Table 10.4. Summary of PIT-tagging activities for Okanogan hatchery summer Chinook, brood years 2008-2011.

Brood year	Release year	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
2008	2010	5,700 (high density)	1,169	0	4,531
		5,700 (low density)	1,407	0	4,293
2009	2011	5,100	11	0	5,089
2010	2012	0	0	0	0

Brood year	Release year	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
2011	2013	5,100	64	0	5,036

Fish size and condition at release

Size at release of the Similkameen population was 73.3% and 56.8% of the fork length and weight targets, respectively. The CV for fork length exceeded the target by 18.9% (Table 10.5). There was no Bonaparte program for the 2014 release year.

Table 10.5. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of Okanogan summer Chinook smolts released from the hatchery, brood years 1989-2012. Size targets are provided in the last row of the table.

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
1989	1991	-	-	41.3	11
1990	1992	143	9.5	37.8	12
1991	1993	125	15.5	22.4	20
1992	1994	120	15.4	20.7	22
1993	1995	132	-	23.2	20
1994	1996	136	16.0	29.6	15
1995	1997	137	8.2	32.8	14
1996	1998	127	12.8	26.2	17
1997	1999	144	9.9	36.0	13
1998	2000	148	5.9	41.0	11
1999	2001	141	15.7	35.4	13
2000	2002	121	13.4	20.4	22
2001	2003	132	8.2	25.7	18
2002	2004	119	13.4	20.8	22
2003	2005	133	10.6	28.9	16
2004	2006	132	9.9	29.8	15
2005	2007	132	9.6	25.9	18
2006	2008	120	12.3	20.9	22
2007	2009	124	12.6	21.9	21
2008	2010	140	12.3	35.1	13
2009	2011	132	11.6	24.7	18
2010	2012	125	10.1	23.2	20
2011	2013	132	9.5	27.9	16
2012	2014	129	7.3	25.8	18
Average		***131***	***11.4***	***28.2***	***17***
Median		***132***	***11.1***	***26.1***	***18***
Targets		***176***	***9.0***	***45.4***	***10***

Survival Estimates

Overall survival of Okanogan summer Chinook from green (unfertilized) egg to release was above the standard set for the program (Table 10.6). Low survival can be attributed to high mortality after ponding through release because of external fungus. Currently, it is unknown if gamete viability is sex biased or is uniform between sexes and more influenced by between-year environmental variations.

Table 10.6. Hatchery life-stage survival rates (%) for Okanogan summer Chinook, brood years 1989-2012. Survival standards or targets are provided in the last row of the table.

Brood year	Rearing facility	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
		Female	Male							
1989[a]	Similkameen	89.8	99.5	89.9	96.7	99.7	99.4	73.3	57.4	48.7
1990[a]	Similkameen	93.9	99.0	84.9	97.1	81.2	80.6	97.7	98.6	77.6
1991[a]	Similkameen	93.1	95.5	88.2	97.1	99.4	99.1	98.4	97.1	76.8
1992[a]	Similkameen	96.9	99.0	87.0	98.0	99.9	99.9	91.7	92.6	75.2
1993[a]	Similkameen	82.2	99.4	85.4	97.6	99.8	99.5	92.0	90.2	73.5
1994	Similkameen	96.1	90.0	86.6	100.0	98.1	97.4	73.1	89.8	60.1
1995	Similkameen	91.9	96.2	98.2	84.1	96.5	96.2	92.7	98.2	79.7
1996	Similkameen	95.4	98.1	83.2	100.0	97.7	96.9	86.5	92.5	75.6
1997	Similkameen	91.9	94.6	86.1	98.4	98.7	98.3	98.8	99.4	98.0
1998	Similkameen	84.0	96.2	54.1	98.0	99.4	98.9	96.6	99.6	50.2
1999	Similkameen	98.8	98.7	92.9	96.9	98.0	97.6	96.9	99.0	86.9
2000	Similkameen	90.5	96.9	89.2	98.5	98.2	98.0	93.6	97.2	82.5
2001	Similkameen	96.2	92.3	89.1	97.6	99.7	99.5	7.4	11.9	6.4
2002	Similkameen	97.1	98.1	89.8	98.0	99.7	99.5	51.6	52.2	54.1
2003	Similkameen	96.7	97.5	86.8	97.6	99.3	98.5	98.0	98.8	81.5
2004	Similkameen	93.6	98.2	84.0	97.6	99.6	99.3	97.8	98.8	80.2
	Bonaparte	93.6	98.2	84.0	97.6	99.6	99.3	97.9	98.9	80.3
2005	Similkameen	97.0	89.6	88.0	99.5	99.5	99.0	93.5	94.6	81.8
	Bonaparte	97.0	89.6	88.0	99.5	99.5	99.0	0.0	0.0	0.0
2006	Similkameen	92.9	89.5	86.3	98.3	99.6	99.3	94.1	95.5	79.8
2007	Similkameen	92.6	99.6	80.8	99.1	99.5	99.1	97.0	98.1	77.7
	Bonaparte	92.6	99.6	80.8	99.1	99.5	99.1	95.6	96.7	76.6
2008	Similkameen	97.9	99.6	91.2	96.8	99.7	99.3	89.8	90.5	79.3
	Bonaparte	97.9	99.6	91.2	96.8	99.7	99.3	86.9	87.8	76.7
2009[b]	Similkameen	93.6	93.5	91.0	98.2	99.7	99.5	97.8	98.6	87.4
	Bonaparte	93.6	93.5	91.0	98.2	99.7	99.5	74.8	75.3	66.8
2010	Similkameen	96.5	100.0	91.2	99.9	97.4	97.1	93.3	96.3	85.0
2011	Similkameen	100.0	90.2	95.9	98.3	99.8	99.1	97.8	98.8	92.2
2012	Similkameen	100.0	100.0	85.1	98.6	99.7	99.3	70.6	71.2	59.3
Mean	***Similkameen***	***94.1***	***96.3***	***86.9***	***97.6***	***98.3***	***97.9***	***86.7***	***88.2***	***72.9***
	Bonaparte	***94.9***	***96.1***	***87.0***	***98.2***	***99.6***	***99.2***	***71.0***	***71.7***	***60.1***
Median	***Similkameen***	***94.7***	***97.8***	***87.5***	***98.0***	***99.5***	***99.1***	***93.6***	***96.7***	***78.5***
	Bonaparte	***93.6***	***98.2***	***88.0***	***98.2***	***99.6***	***99.3***	***86.9***	***87.8***	***76.6***
Standard		***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

[a] Survival rates were calculated from the aggregate population collected at Wells Fish Hatchery volunteer channel and left- and right-ladder traps at Wells Dam.
[b]Survival rates were calculated from aggregate collections at Wells east fish ladder for the Methow and Okanogan/Similkameen programs. About 59% of the total fish collected were used to estimate survival rates.

10.3 Disease Monitoring

Results of adult broodstock bacterial kidney disease (BKD) monitoring for Methow/Okanogan summer Chinook are shown in Table 9.12 in Section 9.3.

10.4 Spawning Surveys

Surveys for Okanogan/Similkameen summer Chinook redds were conducted from late September to mid-November in the Okanogan and Similkameen rivers. Total redd counts (not peak counts) were conducted in the rivers.

Redd Counts

During the survey period 1989 through 2016, the number of summer Chinook redds in the Okanogan River basin averaged 2,179 and ranged from 110 to 6,025 (Table 10.7).

Table 10.7. Total number of redds counted in the Okanogan River basin, 1989-2016. The Colville Tribes provided data for survey years 2013 to present.

Survey year	Number of summer Chinook redds		
	Okanogan River	Similkameen River	Total count
1989	151	370	521
1990	99	147	246
1991	64	91	155
1992	53	57	110
1993	162	288	450
1994	375*	777	1,152
1995	267*	616	883
1996	116	419	535
1997	158	486	644
1998	88	276	364
1999	369	1,275	1,644
2000	549	993	1,542
2001	1,108	1,540	2,648
2002	2,667	3,358	6,025
2003	1,035	378	1,413
2004	1,327	1,660	2,987
2005	1,611	1,423	3,034
2006	2,592	1,666	4,258
2007	1,301	707	2,008
2008	1,146	1,000	2,146
2009	1,672	1,298	2,970

Survey year	Number of summer Chinook redds		
	Okanogan River	Similkameen River	Total count
2010	1,011	1,107	2,118
2011	1,714	1,409	3,123
2012	1,613	1,066	2,679
2013	2,267	1,280	3,547
2014	2,231	2,022	4,253
2015	2,379	1,897	4,276
2016	3,486	1,790	5,276
Average	***1,129***	***1,050***	***2,179***
Median	***1,072***	***1,033***	***2,063***

* Reach-expanded aerial counts.

Spawning Escapement

Spawning escapement for Okanogan/Similkameen summer Chinook was calculated as the total number of redds times the fish per redd ratio estimated from fish sampled at Wells Dam.[31] During the survey period 1989 through 2016, the summer Chinook spawning escapement within the Okanogan River basin averaged 5,870 and ranged from 473 to 13,857 (Table 10.8).

Table 10.8. Spawning escapements for summer Chinook in the Okanogan and Similkameen rivers for return years 1989-2016. The Colville Tribes provided data for return years 2013 to present.

Return year	Fish/Redd	Spawning escapement		
		Okanogan	Similkameen	Total
1989*	3.30	498	1,221	1,719
1990*	3.40	337	500	837
1991*	3.70	237	337	574
1992*	4.30	228	245	473
1993*	3.30	535	950	1,485
1994*	3.50	1,313	2,720	4,033
1995*	3.40	908	2,094	3,002
1996*	3.40	394	1,425	1,819
1997*	3.40	537	1,652	2,189
1998	3.00	264	828	1,092
1999	2.20	812	2,805	3,617
2000	2.40	1,318	2,383	3,701
2001	4.10	4,543	6,314	10,857
2002	2.30	6,134	7,723	13,857
2003	2.42	2,505	915	3,420
2004	2.25	2,986	3,735	6,721
2005	2.93	4,720	4,169	8,889

[31] Expansion factor = (1 + (number of males/number of females)).

Return year	Fish/Redd	Spawning escapement		
		Okanogan	Similkameen	Total
2006	2.02	5,236	3,365	8,601
2007	2.20	2,862	1,555	4,417
2008	3.25	3,725	3,250	6,975
2009	2.54	4,247	3,297	7,544
2010	2.81	2,841	3,111	5,952
2011	3.10	5,313	4,368	9,681
2012	3.07	4,952	3,273	8,225
2013	2.31	5,237	2,957	8,194
2014	2.86	6,381	5,783	12,164
2015	3.21	7,637	6,089	13,726
2016	2.01	7,007	3,598	10,605
Average	***2.95***	***2,990***	***2,881***	***5,870***
Median	***3.04***	***2,852***	***2,881***	***5,185***

* Spawning escapement was calculated using the "Modified Meekin Method" (i.e., 3.1 x jack multiplier).

10.5 Carcass Surveys

Surveys for summer Chinook carcasses were conducted during late September to mid-November in the Okanogan and Similkameen rivers.

Number sampled

During the survey period 1993 through 2016, the number of summer Chinook carcasses sampled in the Okanogan River basin averaged 1,727 and ranged from 115 to 5,276 (Table 10.9). In all years, most were sampled in the upper Okanogan River and lower Similkameen River (Table 10.9).

Table 10.9. Numbers of summer Chinook carcasses sampled within each survey reach in the Okanogan River basin, 1993-2016. Reach codes are described in Table 2.11. The Colville Tribes provided data for survey years 2013 to present.

Survey year	Number of summer Chinook carcasses								
	Okanogan						Similkameen		Total
	O-1	O-2	O-3	O-4	O-5	O-6	S-1	S-2	
1993[a]	0	2	3	0	23	13	73	1	115
1994[b]	0	4	4	0	27	5	318	60	418
1995	0	0	2	0	30	0	239	15	286
1996	0	0	0	2	5	2	226	0	235
1997	0	0	2	0	9	3	225	1	240
1998	0	1	8	1	7	7	340	4	368
1999	0	0	3	2	23	53	766	48	895
2000	0	2	20	15	47	16	727	41	868
2001	0	26	75	10	127	112	1,141	105	1,596

Survey year	Number of summer Chinook carcasses								
	Okanogan						Similkameen		Total
	O-1	O-2	O-3	O-4	O-5	O-6	S-1	S-2	
2002	10	32	83	35	204	572	1,265	259	2,460
2003[c]	0	0	28	0	17	243	596	381	1,265
2004	0	4	31	24	146	283	1,392	298	2,178
2005	0	8	93	37	371	434	731	276	1,950
2006	4	3	31	16	120	291	508	106	1,079
2007	2	0	55	1	453	519	658	29	1,717
2008	4	10	40	36	248	665	859	157	2,019
2009	2	7	31	32	348	500	703	150	1,773
2010	3	10	30	42	241	352	627	148	1,453
2011	0	0	55	14	361	478	753	114	1,775
2012	1	0	56	15	256	537	495	54	1,414
2013	3	2	158	46	397	1,661	1,254	26	3,547
2014	11	57	191	111	851	1,010	1,737	285	4,253
2015	36	113	284	79	1,008	859	1,611	286	4,276
2016	2	57	52	130	907	2,338	1,645	145	5,276
Average	***3***	***14***	***56***	***27***	***259***	***456***	***787***	***125***	***1,727***
Median	***0***	***3***	***31***	***15***	***175***	***322***	***715***	***106***	***1,525***

[a] 25 additional carcasses were sampled on the Similkameen and 46 on the Okanogan without any reach designation.
[b] One additional carcasses was sampled on the Similkameen without any reach designation.
[c] 793 carcasses were sampled on the Similkameen before initiation of spawning (pre-spawn mortality) and an additional 40 carcasses were sampled on the Okanogan. The cause of the high mortality (*Ichthyophthirius multifilis* and *Flavobacterium columnarae*) was exacerbated by high river temperatures.

Carcass Distribution and Origin

Based on the available data (1991-2015), most fish, regardless of origin, were found in Reach 1 on the Similkameen River (Driscoll Channel to Oroville Bridge) (Table 10.10). However, a slightly larger percentage of hatchery fish were found in reaches on the Similkameen River than were wild fish (Figure 10.1). In contrast, a larger percentage of wild fish were found in reaches on the Okanogan River.

Table 10.10. Numbers of wild and hatchery summer Chinook carcasses sampled within different reaches in the Okanogan River basin, 1993-2015.

Survey year	Origin	Survey reach								Total
		O-1	O-2	O-3	O-4	O-5	O-6	S-1	S-2	
1993	Wild	0	0	3	0	13	4	48	1	69
	Hatchery	0	2	0	0	10	9	25	0	46
1994	Wild	0	0	1	0	7	1	113	22	144
	Hatchery	0	4	3	0	20	4	205	38	274
1995	Wild	0	0	1	0	10	0	66	4	81
	Hatchery	0	0	1	0	20	0	173	11	205
1996	Wild	0	0	0	1	3	1	53	0	58

Survey year	Origin	Survey reach								Total
		O-1	O-2	O-3	O-4	O-5	O-6	S-1	S-2	
	Hatchery	0	0	0	1	2	1	173	0	177
1997	Wild	0	0	1	0	0	3	83	0	87
	Hatchery	0	0	1	0	9	0	142	1	153
1998	Wild	0	1	3	1	6	5	162	4	182
	Hatchery	0	0	5	0	1	2	178	0	186
1999	Wild	0	0	0	0	9	23	293	9	334
	Hatchery	0	0	3	2	14	30	473	39	561
2000	Wild	0	0	8	8	24	11	189	4	244
	Hatchery	0	2	12	7	23	5	538	37	624
2001	Wild	0	10	23	5	67	42	390	54	591
	Hatchery	0	16	52	5	60	70	751	51	1,005
2002	Wild	6	14	20	10	81	212	340	72	755
	Hatchery	4	18	63	25	123	360	925	187	1,705
2003	Wild	0	0	13	0	12	152	231	124	532
	Hatchery	0	0	15	0	5	91	365	257	733
2004	Wild	0	2	19	19	108	225	1,125	260	1,758
	Hatchery	0	2	12	5	38	58	267	38	420
2005	Wild	0	5	51	21	256	364	531	176	1,404
	Hatchery	0	3	42	16	115	70	200	100	546
2006	Wild	2	2	22	10	105	247	370	73	831
	Hatchery	2	1	9	6	15	44	138	33	248
2007	Wild	1	0	30	1	284	322	405	20	1,063
	Hatchery	1	0	25	0	169	197	253	9	654
2008	Wild	2	1	14	11	107	324	347	41	847
	Hatchery	2	9	26	25	141	341	512	116	1,172
2009	Wild	2	3	13	14	189	347	330	75	973
	Hatchery	0	4	18	18	159	153	373	75	800
2010	Wild	1	5	19	18	154	180	329	69	775
	Hatchery	2	5	11	24	87	172	296	79	676
2011	Wild	0	0	21	4	201	362	216	19	823
	Hatchery	0	0	34	10	160	116	537	95	952
2012	Wild	0	0	18	9	133	427	206	23	816
	Hatchery	1	0	38	6	123	110	288	31	597
2013	Wild	0	0	23	7	37	360	216	4	647
	Hatchery	0	0	7	2	15	72	164	3	263
2014	Wild	0	1	62	47	233	717	648	426	2,134
	Hatchery	0	1	17	7	42	66	122	63	318
2015	Wild	0	5	39	9	209	931	1,186	176	2,555
	Hatchery	0	5	22	2	74	63	516	56	738
Average	***Wild***	***1***	***2***	***18***	***8***	***98***	***229***	***342***	***72***	***770***
	Hatchery	***1***	***3***	***18***	***7***	***62***	***88***	***331***	***57***	***568***

Survey year	Origin	Survey reach								Total
		O-1	O-2	O-3	O-4	O-5	O-6	S-1	S-2	
Median	*Wild*	*0*	*0*	*18*	*7*	*81*	*212*	*293*	*23*	*755*
	Hatchery	*0*	*1*	*12*	*5*	*38*	*66*	*267*	*38*	*561*

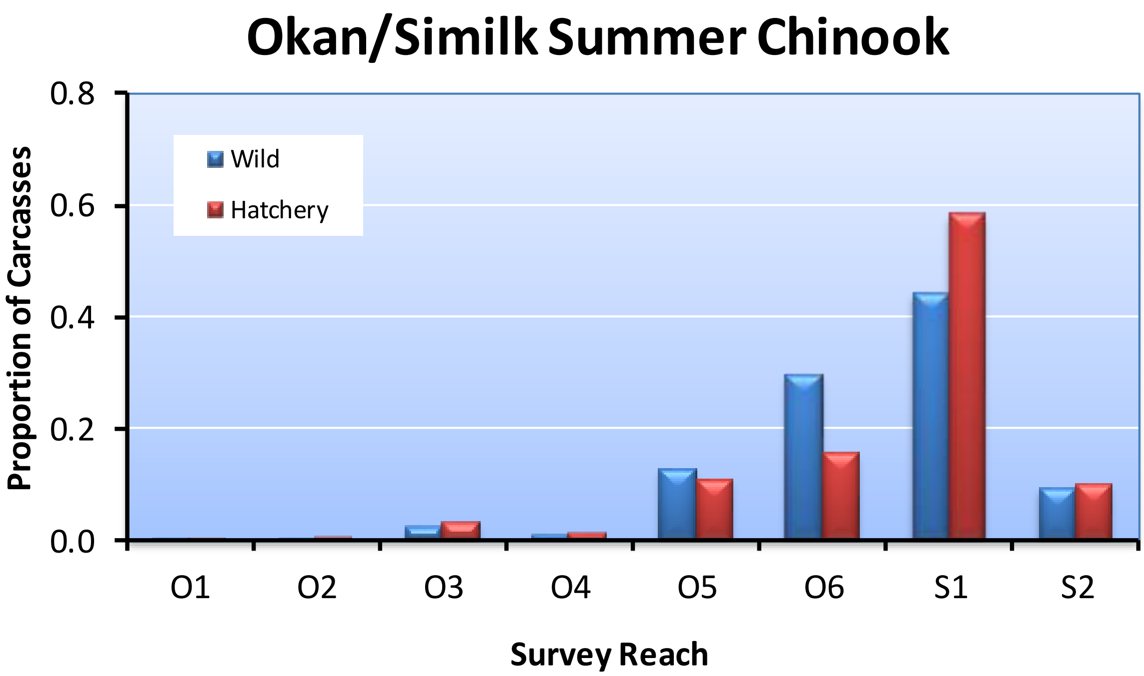

Figure 10.1. Distribution of wild and hatchery produced carcasses in different reaches in the Okanogan River basin, 1993-2015. Reach codes are described in Table 2.11.

10.6 Life History Monitoring

Life history characteristics of Okanogan/Similkameen summer Chinook were assessed by examining carcasses on spawning grounds and fish collected or examined at broodstock collection sites, and by reviewing tagging data and fisheries statistics.

Migration Timing

Migration timing for Okanogan/Similkameen summer Chinook is described in Section 9.6.

Age at Maturity

Because hatchery summer Chinook are released after one year of rearing and natural-origin summer Chinook migrate primarily as age-0 fish, total ages will differ between hatchery and natural-origin Chinook (see Hillman et al. 2011). Therefore, in this section, we evaluated age at maturity by comparing differences in salt (ocean) ages between the two groups.

Most of the wild and hatchery summer Chinook sampled during the period 1993-2015 in the Okanogan River basin were salt age-3 fish (Table 10.11; Figure 10.2). A higher percentage of salt age-4 wild Chinook returned to the basin than did salt age-4 hatchery Chinook. In contrast, a higher proportion of salt age-1 and 2 hatchery fish returned than did salt age-1 and 2 wild fish. Thus, a higher percentage of wild fish returned at an older age than did hatchery fish.

Table 10.11. Proportions of wild and hatchery summer Chinook of different salt (ocean) ages sampled on spawning grounds in the Okanogan River basin, 1993-2015.

Sample year	Origin	Salt age					Sample size
		1	2	3	4	5	
1993	Wild	0.00	0.21	0.70	0.10	0.00	63
	Hatchery	0.00	0.98	0.02	0.00	0.00	44
1994	Wild	0.02	0.13	0.54	0.31	0.00	134
	Hatchery	0.02	0.09	0.89	0.00	0.00	290
1995	Wild	0.00	0.19	0.59	0.22	0.00	68
	Hatchery	0.01	0.15	0.36	0.49	0.00	200
1996	Wild	0.03	0.28	0.61	0.08	0.00	36
	Hatchery	0.02	0.22	0.56	0.20	0.01	174
1997	Wild	0.04	0.27	0.53	0.15	0.00	73
	Hatchery	0.00	0.02	0.87	0.11	0.00	148
1998	Wild	0.02	0.35	0.52	0.11	0.00	151
	Hatchery	0.05	0.50	0.23	0.22	0.00	185
1999	Wild	0.00	0.20	0.64	0.16	0.00	268
	Hatchery	0.00	0.12	0.85	0.02	0.00	552
2000	Wild	0.03	0.15	0.62	0.20	0.00	216
	Hatchery	0.12	0.02	0.76	0.10	0.00	545
2001	Wild	0.02	0.18	0.76	0.04	0.00	531
	Hatchery	0.05	0.88	0.02	0.05	0.00	1,005
2002	Wild	0.02	0.15	0.62	0.21	0.00	692
	Hatchery	0.01	0.19	0.80	0.01	0.00	1,681
2003	Wild	0.03	0.18	0.63	0.17	0.00	477
	Hatchery	0.03	0.06	0.79	0.12	0.00	653
2004	Wild	0.01	0.17	0.26	0.55	0.00	1,528
	Hatchery	0.01	0.32	0.45	0.23	0.00	382
2005	Wild	0.00	0.12	0.79	0.08	0.01	1,281
	Hatchery	0.02	0.06	0.77	0.15	0.00	530
2006	Wild	0.00	0.02	0.53	0.45	0.00	830
	Hatchery	0.05	0.18	0.24	0.53	0.00	139
2007	Wild	0.02	0.07	0.12	0.78	0.02	1,061
	Hatchery	0.22	0.30	0.42	0.05	0.01	559
2008	Wild	0.01	0.32	0.63	0.04	0.01	846

Sample year	Origin	Salt age					Sample size
		1	2	3	4	5	
	Hatchery	0.02	0.60	0.36	0.02	0.00	1,108
2009	Wild	0.01	0.03	0.81	0.15	0.00	926
	Hatchery	0.05	0.05	0.86	0.03	0.00	783
2010	Wild	0.00	0.16	0.45	0.39	0.00	708
	Hatchery	0.02	0.65	0.27	0.06	0.00	619
2011	Wild	0.01	0.07	0.82	0.10	0.00	787
	Hatchery[a]	0.16	0.08	0.76	0.00	0.00	873
2012	Wild	0.02	0.23	0.41	0.34	0.00	750
	Hatchery	0.05	0.55	0.35	0.05	0.00	532
2013	Wild	0.01	0.17	0.75	0.07	0.00	520
	Hatchery	0.03	0.21	0.74	0.02	0.00	252
2014	Wild	0.02	0.08	0.76	0.14	0.00	1892
	Hatchery	0.18	0.26	0.55	0.02	0.00	300
2015	Wild	0.00	0.40	0.34	0.25	0.00	2,167
	Hatchery	0.03	0.68	0.26	0.02	0.00	549
Average	***Wild***	***0.01***	***0.17***	***0.55***	***0.26***	***0.00***	***695***
	Hatchery	***0.05***	***0.32***	***0.56***	***0.07***	***0.00***	***527***
Median	***Wild***	***0.01***	***0.16***	***0.67***	***0.17***	***0.00***	***692***
	Hatchery	***0.04***	***0.23***	***0.64***	***0.09***	***0.00***	***532***

[a] There was one salt age-6 hatchery fish that was not included in this table.

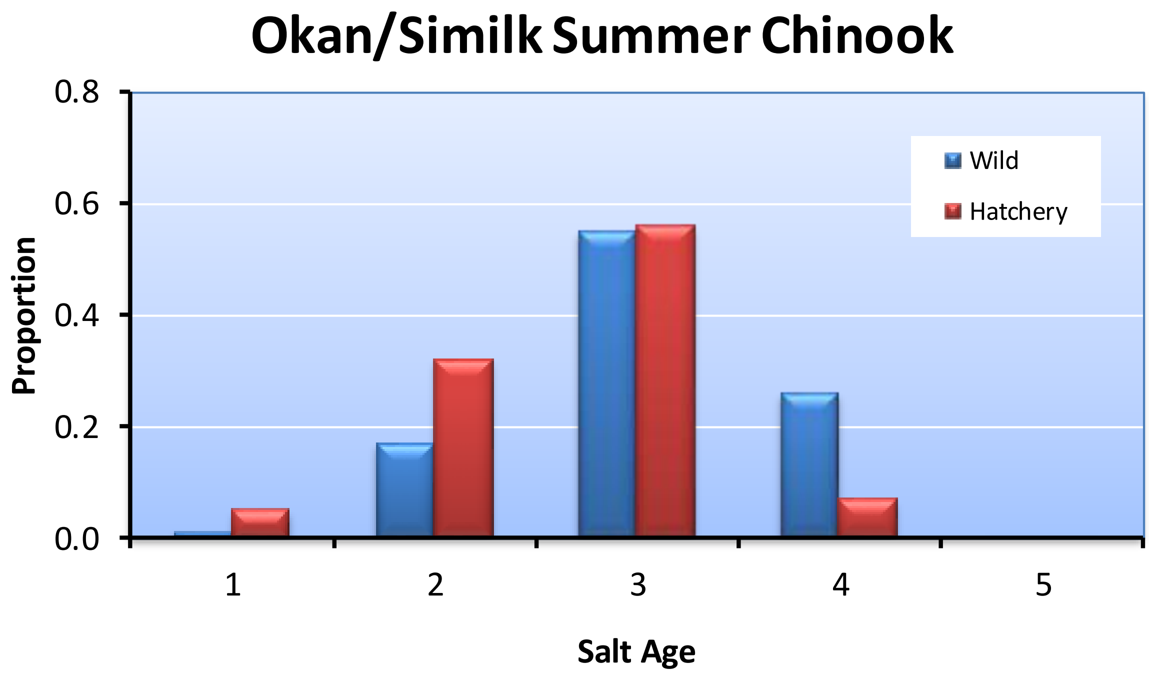

Figure 10.2. Proportions of wild and hatchery summer Chinook of different salt (ocean) ages sampled at broodstock collection sites and on spawning grounds in the Okanogan River basin for the combined years 1993-2015.

Size at Maturity

For the period 1993 through 2015, on average, hatchery summer Chinook were about 2 cm smaller than wild summer Chinook sampled in the Okanogan River basin (Table 10.12). This is likely because a higher percentage of wild fish returned as salt age-4 fish than did hatchery fish.

Table 10.12. Mean lengths (POH; cm) and variability statistics for wild and hatchery summer Chinook sampled in the Okanogan River basin, 1993-2015; SD = 1 standard deviation.

Sample year	Origin	Sample size	Summer Chinook length (POH; cm)			
			Mean	SD	Minimum	Maximum
1993[a]	Wild	69	73	7	52	90
	Hatchery	59	62	6	47	75
1994	Wild	136	71	7	40	86
	Hatchery	268	69	8	30	84
1995	Wild	81	75	6	54	87
	Hatchery	201	73	8	39	87
1996	Wild	22	68	14	22	85
	Hatchery	26	75	8	60	88
1997	Wild	87	70	7	44	84
	Hatchery	148	74	6	48	88

Sample year	Origin	Sample size	Summer Chinook length (POH; cm)			
			Mean	SD	Minimum	Maximum
1998	Wild	182	70	8	45	94
	Hatchery	186	65	12	30	87
1999	Wild	333	73	7	56	91
	Hatchery	559	71	7	23	84
2000	Wild	241	70	10	32	86
	Hatchery	624	69	12	24	92
2001	Wild	578	67	9	26	86
	Hatchery	997	61	8	32	90
2002	Wild	755	69	9	28	91
	Hatchery	1705	70	8	33	87
2003	Wild	532	68	9	30	93
	Hatchery	733	69	10	26	90
2004	Wild	1756	71	10	33	94
	Hatchery	417	66	9	41	92
2005	Wild	1403	66	7	41	99
	Hatchery	546	68	8	31	85
2006	Wild	831	72	6	31	91
	Hatchery	248	71	9	33	87
2007	Wild	1063	75	9	27	99
	Hatchery	654	64	13	30	87
2008	Wild	847	65	9	29	86
	Hatchery	1172	65	8	32	89
2009	Wild	973	70	7	28	89
	Hatchery	799	70	9	35	86
2010	Wild	775	71	9	43	90
	Hatchery	676	64	10	22	87
2011	Wild	823	68	7	29	89
	Hatchery	952	66	11	26	86
2012	Wild	816	67	10	27	93
	Hatchery	597	63	9	23	86
2013	Wild	642	67	8	23	87
	Hatchery	267	71	8	36	88
2014	Wild	2,134	68	8	30	83
	Hatchery	318	64	13	30	89
2015	Wild	2,572	60	9	24	87
	Hatchery	720	58	8	23	78
Pooled	***Wild***	***17,651***	***69***	***8***	***22***	***99***
	Hatchery	***12,872***	***67***	***9***	***22***	***92***

[a] This year includes sizes reported in the annual report. The data contained in the WDFW database do not include all these data.

Contribution to Fisheries

Most of the harvest on hatchery-origin Okanogan/Similkameen summer Chinook occurred in the Ocean (Table 10.13). Ocean harvest has made up 37-100% of all hatchery-origin Okanogan/Similkameen summer Chinook harvested. Brood year 2008 provided the largest harvest, while brood years 1993 and 1996 provided the lowest.

Table 10.13. Estimated number and percent (in parentheses) of hatchery-origin Okanogan/Similkameen summer Chinook captured in different fisheries, brood years 1989-2010.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
1989	2,371 (80)	553 (19)	0 (0)	42 (1)	2,966
1990	355 (89)	34 (8)	0 (0)	12 (3)	401
1991	220 (86)	37 (14)	0 (0)	0 (0)	257
1992	422 (91)	28 (6)	2 (0)	10 (2)	462
1993	24 (80)	6 (20)	0 (0)	0 (0)	30
1994	372 (92)	23 (6)	2 (0)	7 (2)	406
1995	643 (93)	9 (1)	12 (2)	25 (4)	698
1996	6 (100)	0 (0)	0 (0)	0 (0)	6
1997	6,618 (92)	136 (2)	36 (0)	416 (6)	7,206
1998	4,395 (90)	251 (5)	45 (1)	219 (4)	4,910
1999	1,357 (68)	224 (11)	31 (2)	384 (19)	1,996
2000	3,139 (69)	533 (12)	222 (5)	665 (15)	4,559
2001	184 (58)	81 (25)	31 (10)	23 (7)	319
2002	706 (56)	200 (16)	90 (7)	258 (21)	1,254
2003	711 (38)	568 (30)	130 (7)	466 (25)	1,875
2004	3,156 (39)	2,162 (26)	694 (8)	2,165 (26)	8,177
2005	470 (46)	306 (30)	79 (8)	167 (16)	1,022
2006	3,136 (37)	3,352 (40)	469 (6)	1,419 (17)	8,376
2007	1,549 (45)	951 (27)	67 (2)	905 (26)	3,477
2008	4,237 (41)	1,963 (19)	218 (2)	3,958 (38)	10,376
2009	2,009 (46)	980 (23)	207 (5)	1,138 (26)	4,334
2010	3,213 (50)	1,845 (29)	247 (4)	1,063 (17)	6,368
Average	***1,786 (68)***	***647 (17)***	***117 (3)***	***606 (13)***	***3,157***
Median	***1,034 (69)***	***238 (18)***	***41 (2)***	***239 (11)***	***1,936***

Straying

Stray rates were determined by examining CWTs recovered on spawning grounds within and outside the Okanogan River basin. Targets for strays based on return year (recovery year) within the upper Columbia River basin (Priest Rapids Dam to Chief Joseph Dam) should be less than

10% and targets for strays outside the upper Columbia River should be less than 5%. The target for brood year stay rates should be less than 5%.

Few hatchery-origin Okanogan summer Chinook have strayed into basins outside the Okanogan (Table 10.14). Although hatchery-origin Okanogan summer Chinook have strayed into other spawning areas, they usually made up less than 10% of the spawning escapement within those areas. The Chelan tailrace has received the largest number of Okanogan strays.

Table 10.14. Number and percent of spawning escapements within other non-target basins that consisted of hatchery-origin Okanogan summer Chinook, return years 1994-2015. For example, for return year 2002, 1% of the summer Chinook spawning escapement in the Entiat Basin consisted of hatchery-origin Okanogan summer Chinook. Percent strays should be less than 10%.

Return year	Wenatchee		Methow		Chelan		Entiat		Hanford Reach	
	Number	%	Number	%	Number	%	Number	%	Number	%
1994	0	0.0	0	0.0	-	-	-	-	-	-
1995	0	0.0	0	0.0	-	-	-	-	-	-
1996	0	0.0	0	0.0	-	-	-	-	-	-
1997	0	0.0	0	0.0	-	-	-	-	-	-
1998	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2000	0	0.0	6	0.5	30	4.5	0	0.0	3	0.0
2001	12	0.1	0	0.0	10	1.0	0	0.0	0	0.0
2002	0	0.0	3	0.1	4	0.7	5	1.0	0	0.0
2003	0	0.0	8	0.2	22	5.3	14	2.0	0	0.0
2004	0	0.0	0	0.0	5	1.2	0	0.0	0	0.0
2005	5	0.1	27	1.1	36	6.9	7	1.9	8	0.0
2006	0	0.0	5	0.2	4	1.0	7	1.3	0	0.0
2007	0	0.0	3	0.2	4	2.1	0	0.0	0	0.0
2008	0	0.0	9	0.5	46	9.3	4	1.3	0	0.0
2009	15	0.2	3	0.2	11	1.8	18	7.2	0	0.0
2010	6	0.1	0	0.0	33	3.0	0	0.0	0	0.0
2011	0	0.0	0	0.0	46	3.6	0	0.0	0	0.0
2012	7	0.1	5	0.2	19	1.5	0	0.0	0	0.0
2013	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2014	0	0.0	4	0.2	8	0.7	0	0.0	0	0.0
2015	4	0.1	5	0.1	4	0.3	0	0.0	0	0.0
Average	**2**	**0.0**	**4**	**0.2**	**16**	**2.4**	**3**	**0.8**	**1**	**0.0**
Median	**0**	**0.0**	**2**	**0.1**	**9**	**1.4**	**0**	**0.0**	**0**	**0.0**

On average, about 1% of the brood year returns have strayed into non-target populations, falling within the acceptable level of less than 5% (Table 10.15). Depending on brood year, percent strays into non-target spawning areas have ranged from 0-4.4%. Few (<1% on average) have strayed into non-target hatchery programs.

Table 10.15. Number and percent of hatchery-origin Okanogan summer Chinook that homed to target spawning areas and the target hatchery, and number and percent that strayed to non-target spawning areas and non-target hatchery programs, by brood years 1989-2010. Percent stays should be less than 5%.

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1989	3,132	69.7	1,328	29.6	2	0.0	31	0.7
1990	729	71.4	291	28.5	0	0.0	1	0.1
1991	1,125	71.3	453	28.7	0	0.0	0	0.0
1992	1,264	68.5	572	31.0	8	0.4	1	0.1
1993	54	62.1	32	36.8	0	0.0	1	1.1
1994	924	80.8	203	17.7	16	1.4	1	0.1
1995	1,883	85.4	271	12.3	50	2.3	0	0.0
1996	27	100.0	0	0.0	0	0.0	0	0.0
1997	11,629	97.1	309	2.6	34	0.3	3	0.0
1998	2,727	95.3	102	3.6	31	1.1	2	0.1
1999	828	96.7	18	2.1	10	1.2	0	0.0
2000	2,091	93.6	29	1.3	99	4.4	15	0.7
2001	105	98.1	2	1.9	0	0.0	0	0.0
2002	702	96.2	17	2.3	11	1.5	0	0.0
2003	1,580	96.2	47	2.9	16	1.0	0	0.0
2004	4,947	94.4	206	3.9	85	1.6	2	0.0
2005	606	93.2	22	3.4	22	3.4	0	0.0
2006	5,220	97.6	60	1.1	68	1.3	0	0.0
2007	1,396	97.8	21	1.5	10	0.7	0	0.0
2008	3,600	97.2	78	2.1	23	0.6	4	0.1
2009	1,006	85.9	152	13.0	12	1.0	1	0.1
2010	909	61.3	566	38.1	9	0.6	0	0.0
Average	**2,117**	**86.8**	**217**	**12.0**	**23**	**1.0**	**3**	**0.1**
Median	**1,195**	**94.0**	**90**	**3.5**	**12**	**0.9**	**1**	**0.0**

* Homing to the target hatchery includes Okanogan/Similkameen hatchery summer Chinook that are captured and included as broodstock in the Okanogan/Similkameen Hatchery program. These hatchery fish were typically collected at Wells Dam.

Genetics

Genetic studies were conducted to investigate relationships among temporally replicated collections of summer Chinook from the Wenatchee River, Methow River, and Okanogan River in the upper Columbia River basin (Kassler et al. 2011; the entire report is appended as Appendix N). A total of 2,416 summer Chinook were collected from tributaries in the upper Columbia River basin. Two collections of natural-origin summer Chinook from 1993 (prior to the supplementation program) were taken from the Wenatchee River basin (N = 139) and compared to collections of hatchery and natural-origin Chinook from 2006 and 2008 (N = 380). Two pre-supplementation collections from the Methow River (1991 and 1993) were compared to supplementation collections from 2006 and 2008 (N = 362). Three pre-supplementation collections from the Okanogan River Basin (1991, 1992, and 1993) were compared with supplementation collections from 2006 and 2008 (N = 669). A collection of natural-origin summer Chinook from the Chelan River was also analyzed (N = 70). Additionally, hatchery collections from Eastbank Hatchery (Wenatchee and Methow/Okanogan stock; N = 221) and Wells Hatchery (N = 294) were analyzed and compared to the in-river collections. Summer Chinook data (provided by the USFWS) from the Entiat River (N = 190) were used for comparison. Lastly, data from eight collections of fall Chinook (N = 2,408) were compared to the collections of summer Chinook. Samples of natural and hatchery-origin summer Chinook were analyzed and compared to determine if the supplementation programs have affected the genetic structure of these populations. The study also calculated the effective number of breeders for collection locations of natural and hatchery-origin summer Chinook from 1993 and 2008.

In general, population differentiation was not observed among the temporally replicated collection locations. A single collection from the Okanogan River (1993) was the only collection showing statistically significant differences. The effective number of breeders was not statistically different from the early collection in 1993 in comparison to the late collection in 2008. Overall, these analyses revealed a lack of differentiation among the temporal replicates from the same locations and among the collection from different locations, suggesting the populations have been homogenized or that there has been substantial gene flow among populations. Additional comparisons among summer-run and fall-run Chinook populations in the upper Columbia River were conducted to determine if there was any differentiation between Chinook with different run timing. These analyses revealed pairwise F_{ST} values that were less than 0.01 for the collections of summer Chinook to collections of fall Chinook from Hanford Reach, lower Yakima River, Priest Rapids, and Umatilla. Collections of fall Chinook from Crab Creek, Lyons Ferry Hatchery, Marion Drain, and Snake River had pairwise F_{ST} values that were higher in comparison to the collections of summer Chinook. The consensus clustering analysis did not provide good statistical support to the groupings, but did show relationships among collections based on geographic proximity. Overall the summer and fall run Chinook that have historically been spawned together were not differentiated while fall Chinook from greater geographic distances were differentiated.

Proportionate Natural Influence

Another method for assessing the genetic risk of a supplementation program is to determine the influence of the hatchery and natural environments on the adaptation of the composite population. This is estimated by the proportion of natural-origin fish in the hatchery broodstock (pNOB) and the proportion of hatchery-origin fish in the natural spawning escapement (pHOS). We calculated Proportionate Natural Influence (PNI) by iterating Ford's (2002) equations 5 and 6 to equilibrium, using a heritability of 0.3 and a selection strength of three standard deviations. The larger the PNI value, the greater the strength of selection in the natural environment relative to that of the hatchery environment. For the natural environment to dominate selection, PNI should be greater than 0.50, and important integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004).

For brood years 1993-2003, the PNI values were less than 0.67 (Table 10.16). However, since brood year 2003, PNI has generally been greater than 0.67, save 2008 and 2011. PNI results reported here end with brood year 2012. Beginning with brood year 2013, the Colville

Confederated Tribes report PNI values for Okanogan summer Chinook in their annual reports to BPA.

Table 10.16. Proportionate Natural Influence (PNI) values for the Okanogan/Similkameen summer Chinook supplementation program for brood years 1989-2012. NOS = number of natural-origin Chinook on the spawning grounds; HOS = number of hatchery-origin Chinook on the spawning grounds; NOB = number of natural-origin Chinook collected for broodstock; and HOB = number of hatchery-origin Chinook included in hatchery broodstock.

Brood year	Spawners			Broodstock			PNI[a]
	NOS	HOS	pHOS	NOB	HOB	pNOB	
1989	1,719	0	0	1,297	312	0.81	1.00
1990	837	0	0	828	206	0.80	1.00
1991	574	0	0	924	314	0.75	1.00
1992	473	0	0	297	406	0.42	1.00
1993	915	570	0.38	681	388	0.64	0.64
1994	1,323	2,710	0.67	341	244	0.58	0.48
1995	979	2,023	0.67	173	240	0.42	0.40
1996	568	1,251	0.69	287	155	0.65	0.50
1997	862	1,327	0.61	197	265	0.43	0.43
1998	600	492	0.45	153	211	0.42	0.50
1999	1,274	2,343	0.65	224	289	0.44	0.42
2000	1,174	2,527	0.68	164	337	0.33	0.35
2001	4,306	6,551	0.6	12	345	0.03	0.09
2002	4,346	9,511	0.69	247	241	0.51	0.44
2003	1,933	1,487	0.43	381	101	0.79	0.66
2004	5,309	1,412	0.21	506	16	0.97	0.83
2005	6,441	2,448	0.28	391	9	0.98	0.78
2006	5,507	3,094	0.36	500	10	0.98	0.74
2007	2,983	1,434	0.32	456	17	0.96	0.76
2008	2,998	3,977	0.57	359	86	0.81	0.60
2009	4,204	3,340	0.44	503	4	0.99	0.70
2010	3,189	2,763	0.46	484	8	0.98	0.69
2011	4,642	5,039	0.52	467	26	0.95	0.65
2012	4,494	3,731	0.45	79	2	0.98	0.69
Average	***2,569***	***2,418***	***0.42***	***415***	***176***	***0.69***	***0.64***
Median	***1,826***	***2,183***	***0.45***	***370***	***209***	***0.77***	***0.66***

[a] PNI was calculated previously using PNI approximate equation 11 (HSRG 2009; their Appendix A). All PNI values presented here were recalculated by iterating Ford's (2002) equations 5 and 6 to equilibrium using a heritability of 0.3 and a selection strength of three standard deviations. C. Busack, NOAA Fisheries, 21 March 2016, provided the model for calculating PNI.

Post-Release Survival and Travel Time

We used PIT-tagged fish to estimate survival rates and travel times (arithmetic mean days) of hatchery summer Chinook from the Similkameen River release site to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam (Table 10.17).[32] Over the three brood years for which PIT-tagged hatchery fish were released, survival rates from the Similkameen River to McNary Dam ranged from 0.432 to 0.720; SARs from release to detection at Bonneville Dam ranged from 0.016 to 0.031. Average travel time from the Similkameen River to McNary Dam ranged from 41 to 44 days. Although there is only one year in which low densities were compared to high densities (brood year 2008), there was little difference in survival rates and travel times between the two groups (Table 10.17).

Table 10.17. Total number of Okanogan hatchery summer Chinook released with PIT tags, their survival and travel times (mean days) to McNary Dam, and smolt-to-adult (SAR) ratios for brood years 2008-2011. Standard errors are shown in parentheses. NA = not available (i.e., not all the fish from the release groups have returned to the Columbia River).

Brood year	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam (d)	SAR to Bonneville Dam
2008	4,531 (high density)	0.445 (0.061)	44.0 (10.2)	0.028 (0.002)
	4,293 (low density)	0.432 (0.050)	41.4 (9.7)	0.030 (0.003)
2009	5,089	0.720 (0.102)	41.5 (10.1)	0.016 (0.002)
2010	0	--	--	--
2011	5,036	0.683 (0.064)	41.9 (12.3)	0.031 (0.002)

Natural and Hatchery Replacement Rates

Natural replacement rates (NRR) were calculated as the ratio of natural-origin recruits (NOR) to the parent spawning population (spawning escapement). Natural-origin recruits are naturally produced (wild) fish that survive to contribute to harvest (directly or indirectly), to broodstock, and to spawning grounds. We do not account for fish that died in route to the spawning grounds (migration mortality) or died just before spawning (pre-spawn mortality) (see Appendix B in Hillman et al. 2012). We calculated NORs with and without harvest. NORs without harvest include all returning fish that either returned to the basin or were collected as wild broodstock. NORs with harvest include all fish harvested and are based on brood year harvest rates from the hatchery program. For brood years 1989-2009, NRR for summer Chinook in the Okanogan averaged 1.01 (range, 0.16-3.82) if harvested fish were not included in the estimate and 2.41 (range, 0.32-10.26) if harvested fish were included in the estimate (Table 10.18). NRRs for more recent brood years will be calculated as soon as all tag recoveries and sampling rates have been loaded into the database.

Hatchery replacement rates (HRR) are the hatchery adult-to-adult returns and were calculated as the ratio of hatchery-origin recruits (HOR) to the parent broodstock collected. These rates should be greater than the NRRs and greater than or equal to 8.6 (the calculated target value in Hillman et al. 2013). The target value of 8.6 includes harvest. HRRs exceeded NRRs in 18 of the 21 years of data, regardless if harvest was or was not included in the estimate (Table 10.18). Hatchery

[32] It is important to point out that because of fish size differences among rearing tanks or raceways, fish PIT tagged in one tank or raceway may not represent untagged fish rearing in other tanks or raceways.

replacement rates for Okanogan summer Chinook have exceeded the estimated target value of 8.6 in 10 of the 21 years of data.

Table 10.18. Broodstock collected, spawning escapements, natural and hatchery-origin recruits (NOR and HOR), and natural and hatchery replacement rates (NRR and HRR; with and without harvest) for wild summer Chinook in the Okanogan River basin, brood years 1989-2009.

Brood year	Broodstock Collected	Spawning Escapement	Harvest not included				Harvest included			
			HOR	NOR	HRR	NRR	HOR	NOR	HRR	NRR
1989	304	1,719	4,493	2,146	14.78	1.25	7,459	3,577	24.54	2.08
1990	288	837	1,021	1,477	3.55	1.76	1,422	2,063	4.94	2.46
1991	364	574	1,578	629	4.34	1.10	1,835	728	5.04	1.27
1992	304	473	1,845	752	6.07	1.59	2,307	942	7.59	1.99
1993	328	1,485	87	1,003	0.27	0.68	117	1,348	0.36	0.91
1994	302	4,033	1,144	2,168	3.79	0.54	1,548	2,946	5.13	0.73
1995	385	3,002	2,204	959	5.72	0.32	2,893	1,267	7.51	0.42
1996	330	1,819	27	466	0.08	0.26	33	574	0.10	0.32
1997	313	2,189	12,005	4,363	38.35	1.99	19,211	6,959	61.38	3.18
1998	352	1,092	2,919	4,166	8.29	3.82	7,829	11,199	22.24	10.26
1999	333	3,617	856	6,641	2.57	1.84	2,852	22,211	8.56	6.14
2000	334	3,701	2,234	1,716	6.69	0.46	6,793	5,232	20.34	1.41
2001	335	10,857	107	8,946	0.32	0.82	426	35,784	1.27	3.30
2002	333	13,857	730	6,061	2.19	0.44	1,984	16,470	5.96	1.19
2003	337	3,420	1,643	562	4.88	0.16	3,518	1,201	10.44	0.35
2004	335	6,721	5,240	3,112	15.64	0.46	13,417	7,959	40.05	1.18
2005	338	8,889	650	6,173	1.92	0.69	1,672	15,951	4.95	1.79
2006	355	8,601	5,348	2,422	15.06	0.28	13,724	6,242	38.66	0.73
2007	314	4,417	1,427	6,334	4.54	1.43	4,899	21,841	15.60	4.94
2008	276	6,975	3,705	2,674	13.42	0.38	14,081	10,445	51.02	1.50
2009	335	7,544	1,171	6,937	3.50	0.92	5,505	34,342	16.43	4.55
Average	***328***	***4,563***	***2,402***	***3,319***	***7.43***	***1.01***	***5,406***	***9,966***	***16.77***	***2.41***
Median	***333***	***3,617***	***1,578***	***2,422***	***4.54***	***0.69***	***2,893***	***6,242***	***8.56***	***1.50***

Smolt-to-Adult Survivals

Smolt-to-adult survival ratios (SARs) were calculated as the number of hatchery adult recaptures divided by the number of tagged hatchery smolts released. Here, SARs were based on CWT returns. For the available brood years, SARs have ranged from 0.00007 to 0.03239 for hatchery summer Chinook in the Okanogan River basin (Table 10.19).

Table 10.19. Smolt-to-adult ratios (SARs) for Okanogan/Similkameen summer Chinook, brood years 1989-2010.

Brood year	Number of tagged smolts released[a]	Estimated adult captures[b]	SAR
1989	202,125	4,293	0.02124
1990	367,207	972	0.00265
1991	360,380	975	0.00271
1992	537,190	2,282	0.00425
1993	379,139	117	0.00031
1994	217,818	1,528	0.00702
1995	574,197	2,851	0.00497
1996	487,776	32	0.00007
1997	572,531	18,543	0.03239
1998	287,948	7,641	0.02654
1999	610,868	2,776	0.00454
2000	528,639	6,765	0.01280
2001	26,315	424	0.01611
2002	245,997	1,969	0.00800
2003	574,908	3,484	0.00606
2004	676,222	12,892	0.01906
2005	273,512	1,662	0.00608
2006	597,276	13,622	0.02281
2007	610,379	4,881	0.00800
2008	516,533	14,026	0.02715
2009	522,295	5,497	0.01052
2010	610,927	7,805	0.01278
Average	***444,554***	***5,229***	***0.01164***
Median	***519,414***	***3,168***	***0.00800***

[a] Includes all tag codes and CWT released fish (CWT + Ad Clip fish and CWT-only fish).

[b] Includes estimated recoveries (spawning ground, hatcheries, harvest, etc.) and observed recoveries if estimated recoveries were unavailable.

10.7 ESA/HCP Compliance

Broodstock Collection

Because summer Chinook adults collected at Wells Dam are used for both the Methow and Okanogan supplementation programs, please refer to Section 9.7 for information on ESA compliance during broodstock collection. Direct and/or indirect take of ESA-listed species during broodstock collection for the Okanogan summer Chinook outside of Wells Dam is covered by permits held by the Colville Tribes. For 2014, no summer Chinook were collected at Wells Dam for the Okanogan summer Chinook program.

Hatchery Rearing and Release

Activities associated with the spawning, rearing, and release of Okanogan summer Chinook that could result in either direct or incidental take of listed species is covered under ESA permits held by the Colville Tribes.

Hatchery Effluent Monitoring

Per ESA Permits 1196, 1347, 1395, 18118, 18120, and 18121, permit holders shall monitor and report hatchery effluents in compliance with applicable National Pollution Discharge Elimination Systems (NPDES) (EPA 1999) permit limitations. There were no NPDES violations reported at PUD Hatchery facilities during the period 1 January through 31 December 2016. NPDES monitoring and reporting for PUD Hatchery Programs during 2016 are provided in Appendix F. NPDES reporting for Okanogan summer Chinook only covers the Similkameen acclimation facility and only during the time fish are present.

SECTION 11: CHELAN FALLS SUMMER CHINOOK

Although the Chelan Falls summer Chinook program (formerly the Turtle Rock program) is an augmentation program, the production of 200,000 fish is No Net Impact (NNI) compensation for passage mortalities associated with Rocky Reach Dam. In addition, the conversion of the subyearling program to a 400,000-yearling program is compensation for lost spawning habitat as a result of the construction of Rocky Reach Dam. In 2011, as part of the periodic recalculation of NNI for Rocky Reach Dam, the previous 200,000 NNI program was reduced to 176,000 fish. This reduced the combined Chelan Falls summer Chinook production from 600,000 to 576,000 beginning with the 2012 brood.

Before 2012, broodstock were collected at Wells Dam and consisted of volunteers to the Wells Fish Hatchery. Summer Chinook were spawned at Wells Fish Hatchery and fertilized eggs were then transferred to Eastbank Fish Hatchery for hatching and rearing. In 2012, adults were collected at Wells Fish Hatchery and then transferred to Eastbank Fish Hatchery for spawning, hatching, and rearing. Beginning in 2013, broodstock collection was initiated at the Eastbank Fish Hatchery Outfall. With returns to the Outfall diminishing, a pilot broodstock collection program was initiated in 2016 at the outlet structure of the water conveyance canal for the Chelan Tailrace Pump Station. Because the pilot collection program was successful, future broodstock for the Chelan Falls Program will be collected at the outlet structure of the water conveyance canal.

The original program consisted of both subyearling (normal and accelerated groups) and yearling releases. Subyearlings were transferred to Turtle Rock Fish Hatchery for acclimation in May. These fish were released in June after about 30 days of acclimation on Columbia River water. The goal of this program was to release 1,620,000 subyearling summer Chinook (810,000 normal and 810,000 accelerated subyearlings) into the Columbia River at 40 fish per pound. Targets for fork length and weight were 112 mm (CV = 9.0) and 11.4 g, respectively. Over 50% of both subyearling groups were marked with CWTs. In 2010, the subyearling program was converted to a 400,000-yearling program.

The goal of the yearling program was to release 200,000 summer Chinook smolts into the Columbia River from Turtle Rock Fish Hatchery at 10 fish per pound. Targets for fork length and weight were 176 mm (CV = 9.0) and 45.4 g, respectively. Beginning with the 2006 brood year, yearling summer Chinook were acclimated at both Turtle Rock Fish Hatchery and the Chelan River net pens. With the conversion of the subyearling program to a yearling program and the reduction of the NNI component to 176,000, the current goal is to release 576,000 yearling summer Chinook smolts (176,000 from the NNI program plus 400,000 from the converted subyearling program). Beginning in 2012, the 576,000 yearlings are acclimated overwinter at facilities at Chelan Hatchery on Chelan River water. In 2012, the Turtle Rock program officially became the Chelan Falls summer Chinook program.

Over 90% of yearling summer Chinook have been marked with CWTs and all are ad-clipped. In addition, juvenile summer Chinook were PIT tagged within each of the circular and standard raceways.

11.1 Broodstock Sampling

Before 2013, broodstock for the program were collected as part of the Wells summer Chinook volunteer program. Refer to Snow et al. (2012) for information related to adults collected for those programs. Beginning in 2013, broodstock collection for the Chelan Falls program was piloted at the Eastbank Hatchery Outfall and at the outlet structure of the water conveyance canal for the Chelan Tailrace Pump Station. This section focuses on results from sampling broodstock from 2013 to present.

Origin of Broodstock

Broodstock collected in 2013-2016 consisted entirely of hatchery-origin summer Chinook (Table 11.1). A total of 85 hatchery-origin Chinook collected from Chief Joseph Fish Hatchery were surplused from the 2015 brood year.

Table 11.1. Numbers of wild and hatchery summer Chinook collected for broodstock, numbers that died before spawning, and numbers of Chinook spawned for the Chelan Falls summer Chinook program during 2013-2016. Unknown origin fish (i.e., undetermined by scale analysis, no CWT or fin clips, and no additional hatchery marks) were considered naturally produced. Mortality includes fish that died of natural causes typically near the end of spawning and were not needed for the program and surplus fish killed at spawning.

Brood year	Wild summer Chinook					Hatchery summer Chinook					Total number spawned
	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	Number collected	Prespawn loss[a]	Mortality	Number spawned	Number released	
2013	-	-	-	-	-	318	4	0	314	0	314
2014	-	-	-	-	-	331	19	15	297	0	297
2015	-	-	-	-	-	351	17	14[b]	320	0	320
2016	-	-	-	-	-	350	5	1	344	0	344
Average	-	-	-	-	-	***338***	***11***	***8***	***319***	***0***	***319***
Median	-	-	-	-	-	***341***	***11***	***8***	***317***	***0***	***317***

[a] Pre-spawn loss represents the number of fish that died during the holding period before spawning. Mortality is the number of fish that were surplused following spawning.
[b] There was an additional 85 fish surplused that were excess from collections at Chief Joseph Fish Hatchery and were not included in mortality estimates.

Age/Length Data

Ages of summer Chinook broodstock were determined from analysis of scales and/or CWTs. Broodstock collected from the 2014 return consisted primarily of age-4 and 5 hatchery-origin Chinook (99%). Age-3 hatchery-origin fish made up 1% of the broodstock (Table 11.2).

Broodstock collected from the 2015 return consisted primarily of age-4 and 5 hatchery-origin Chinook (97.3%). Age-3 hatchery-origin Chinook made up 2.3% of the broodstock. Age-6 hatchery-origin Chinook made up 0.3% of the broodstock (Table 11.2).

Broodstock collected from the 2016 return consisted primarily of age-4 and 5 natural-origin Chinook (98.7%). Age-3 natural-origin Chinook made up 0.6% of the broodstock (Table 11.2).

Table 11.2. Percent of hatchery and wild summer Chinook of different ages (total age) collected from broodstock for the Chelan Falls summer Chinook program, 2013-2016.

Return Year	Origin	Total age				
		2	3	4	5	6
2013	Wild	--	--	--	--	--
	Hatchery	0.0	0.0	37.0	62.0	1.0
2014	Wild	--	--	--	--	--
	Hatchery	0.0	0.0	37.0	62.0	1.0
2015	Wild	--	--	--	--	--
	Hatchery	0.0	2.3	53.8	43.5	0.3
2016	Wild	--	--	--	--	--
	Hatchery	0.0	0.0	35.4	64.0	0.7
Average	***Wild***	**--**	**--**	**--**	**--**	**--**
	Hatchery	***0***	***0.6***	***40.8***	***57.9***	***0.8***
Median	***Wild***	**--**	**--**	**--**	**--**	**--**
	Hatchery	***0***	***0***	***37***	***62***	***0.85***

Mean lengths of hatchery-origin summer Chinook of a given age differed little among return years 2013-2016 (Table 11.3).

Table 11.3. Mean fork length (cm) at age (total age) of hatchery and wild summer Chinook collected from broodstock for the Chelan Falls program, 2013-2016; N = sample size and SD = 1 standard deviation.

Return year	Origin	Summer Chinook fork length (cm)														
		Age-2			Age-3			Age-4			Age-5			Age-6		
		Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD	Mean	N	SD
2013	Wild	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
	Hatchery	-	0	-	-	0	-	77	99	6	91	196	5	-	0	-
2014	Wild	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
	Hatchery	-	0	-	-	0	-	78	114	6	90	191	5	95	3	6
2015	Wild	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
	Hatchery	-	0	-	70	7	3	78	162	5	87	131	6	107	1	-
2016	Wild	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-
	Hatchery	-	0	-	-	0	-	77	104	5	88	188	6	89	2	8
Average	***Wild***	**-**	***0***	**-**	**-**	***0***	**-**	**-**	***0***	**-**	**-**	***0***	**-**	**-**	***0***	**-**
	Hatchery	**-**	***0***	**-**	***70***	***2***	***3***	***78***	***120***	***6***	***89***	***177***	***6***	***97***	***2***	***7***

Sex Ratios

Male summer Chinook in the 2014 broodstock made up about 50.8% of the adults collected, resulting in an overall male to female ratio of 1.03:1.00 (Table 11.4.). In 2015, males made up about 46.0% of the adults collected, resulting in an overall male to female ratio of 0.85:1.00 (Table 11.4). In 2016, males made up about 50.6% of the adults collected, resulting in an overall male to female ratio of 1.02:1.00 (Table 11.4). The ratios for 2014 and 2016 broodstock were above the assumed 1:1 ratio goal in the broodstock protocol. The ratios for 2015 broodstock were below the assumed 1:1 ratio goal in the broodstock protocol.

Table 11.4. Numbers of male and female wild and hatchery summer Chinook collected for broodstock at for the Chelan Falls program, 2013-2016. Ratios of males to females are also provided.

Return year	Number of wild summer Chinook			Number of hatchery summer Chinook			Total M/F ratio
	Males (M)	Females (F)	M/F	Males (M)	Females (F)	M/F	
2013	-	-	-	160	158	1.01:1.00	1.01:1.00
2014	-	-	-	168	163	1.03:1.00	1.03:1.00
2015	-	-	-	149	175	0.85:1.00	0.85:1.00
2016	-	-	-	177	173	1.02:1.00	1.02:1.00
Total	**-**	**-**	**-**	***654***	***669***	***0.98:1.00***	***0.98:1.00***

Fecundity

Fecundities for the 2014, 2015, and 2016 summer Chinook broodstock averaged 4,275, 3,597, and 4,008 eggs per female, respectively (Table 11.5). These values are close to the overall average of 4,086 eggs per female. Mean observed fecundities for the 2014-2016 returns were below the expected fecundity of 4,475, 4,372, and 4,372 eggs per female assumed in the broodstock protocol, respectively.

Table 11.5. Mean fecundity of wild, hatchery, and all female summer Chinook collected for broodstock for the Chelan Falls program, 2013-2016; NA = not available.

Return year	Mean fecundity		
	Wild	Hatchery	Total
2013	-	4,462	4,462
2014	-	4,275	4,275
2015	-	3,597	3,597
2016	-	4,008	4,008
Average	**-**	***4,086***	***4,086***
Median	**-**	***4,142***	***4,142***

* Individual fecundities were not assigned to females until 1997 brood.

11.2 Hatchery Rearing

Rearing History

Number of eggs taken

Based on the unfertilized egg-to-release standard of 81%, a total of 688,995 eggs were needed to meet the program goal of 576,000 smolts for brood years 2012 and 2013. An evaluation of the program in 2014 concluded that 696,493 eggs were needed to attain the 576,000 smolts. From 2013-2016, the egg take goal has not been reached (Table 11.6).

Table 11.6. Numbers of eggs taken from summer Chinook broodstock for the Chelan Falls program, 2013-2016.

Return year	Number of eggs taken
2013	696,131
2014	618,092
2015	573,144
2016	680,448
Average	***641,954***
Median	***649,270***

Number of acclimation days

Rearing of the 2014 brood Chelan Falls summer Chinook was similar to previous years with fish being held on well water at Eastbank Hatchery until transfer to the Chelan Falls Acclimation Facility for overwinter acclimation. This was the fourth year that the whole program was transferred to the Chelan Falls Acclimation Facility for final overwinter acclimation on Chelan River water. Transfer occurred on 2-4 November 2014. Fish were volitionally released from 15-18 April 2016 after 163-168 days of acclimation (Table 11.7).

Table 11.7. Number of days Chelan summer Chinook were acclimated at Chelan Falls Acclimation Facility, brood years 2013-2014.

Brood year	Release year	Transfer date	Release date	Number of days
2013	2015	3-6 Nov	15 Apr	160-163
2014	2016	2-4-Nov	15-18-Apr	163-168

Release Information

Numbers released

The subyearling Turtle Rock summer Chinook program was discontinued in 2010; however, releases of subyearling Chinook in past years are shown in Tables 11.8 and 11.9. Production from the subyearling programs was converted to the yearling program.

The 2014 yearling summer Chinook program achieved 80.8% of the 576,000 goal with about 465,450 fish being released from the Chelan River Acclimation Ponds (Table 11.10).

Table 11.8. Numbers of Turtle Rock summer Chinook subyearlings released from the hatchery, brood years 1995-2009. The release target for Turtle Rock summer Chinook subyearlings was 810,000 fish.

Brood year	Release year	CWT mark rate	Number of subyearlings released
1995	1996	0.1873	1,074,600
1996	1997	0.9653	385,215
1997	1998	0.9780	508,060
1998	1999	0.6453	301,777
1999	2000	0.9748	369,026

Brood year	Release year	CWT mark rate	Number of subyearlings released
2000	2001	0.3678	604,892
2001	2002	0.9871	214,059
2002	2003	0.3070	656,399
2003	2004	0.4138	491,480
2004	2005	0.4591	411,707
2005	2006	0.4337	490,074
2006	2007	0.3388	538,392
2007	2008	0.4385	439,806
2008	2009	0.6355	309,003
2009	2010	NA	713,130
Average		***0.6111***	***500,508***
Median		***0.4488***	***490.074***

Table 11.9. Numbers of Turtle Rock summer Chinook accelerated subyearlings released from the hatchery, brood years 1995-2008. The release target for Turtle Rock summer Chinook accelerated subyearlings was 810,000 fish.

Brood year	Release year	CWT mark rate	Number of subyearlings released
1995	1996	0.9834	169,000
1996	1997	0.4163	477,300
1997	1998	0.3767	521,480
1998	1999	0.6033	307,571
1999	2000	0.9556	347,946
2000	2001	0.4331	449,329
2001	2002	0.4086	480,584
2002	2003	0.5492	364,461
2003	2004	0.6414	289,696
2004	2005	0.5471	364,453
2005	2006	0.9783	457,340
2006	2007	0.5510	342,273
2007	2008	0.4745	392,024
2008	2009	0.5295	372,320
Average		***0.6034***	***381,127***
Median		***0.5482***	***368,391***

Table 11.10. Numbers of Turtle Rock/Chelan Falls summer Chinook yearling smolts released from the hatchery, brood years 1995-2014. The release target for Turtle Rock summer Chinook was 200,000 smolts for the period before brood year 2010. The current release target is 600,000 smolts.

Brood year	Release year	Acclimation facility	CWT mark rate	Number of smolts released
1995	1997	Turtle Rock	0.9688	150,000
1996	1998	Turtle Rock	0.9582	202,727
1997	1999	Turtle Rock	0.9800	202,989
1998	2000	Turtle Rock	0.9337	217,797
1999	2001	Turtle Rock	0.9824	285,707
2000	2002	Turtle Rock	0.9941	279,969
2001	2003	Turtle Rock	0.9824	203,279
2002	2004	Turtle Rock	0.9799	195,851
2003	2005	Turtle Rock	0.9258	215,366
2004	2006	Turtle Rock	0.9578	206,734
2005	2007	Chelan	0.9810	204,644
2006	2008	Chelan	0.9752	99,271
		Turtle Rock	0.9752	43,943
2007	2009	Chelan Falls	0.9426	112,604
		Turtle Rock	0.9426	61,003
2008	2010	Chelan Falls	0.9818	200,999
		Turtle Rock	0.9818	252,762
2009	2011	Chelan Falls[a]	-	190,449
		Turtle Rock	0.9721	250,667
Average (1995-2009)		***Chelan Falls***	***0.9665***	***137,625***
		Turtle Rock	***0.9745***	***233,429***
Median (1995-2009)		***Chelan Falls***	***0.9737***	***205,007***
		Turtle Rock	***0.9781***	***190,449***
2010	2012	Chelan Falls	0.9702	563,824
2011	2013	Chelan Falls	0.9859	582,460
2012	2014	Chelan Falls	0.9879	566,188
2013	2015	Chelan Falls	0.9917	599,584
2014	2016	Chelan Falls	0.9901	465,450
Average (2010-present)		***Chelan Falls***	***0.9852***	***555,501***
Median (2010-present)		***Chelan Falls***	***0.9879***	***566,188***

[a] No CWT mark rate was provided because of the early release of this group.

Numbers tagged

Brood year 2014 yearling Chinook were 99.0% CWT and 99.4% adipose fin-clipped.

In 2017, a total of 10,103 Chelan River summer Chinook (brood 2015) were tagged at Chelan Falls Hatchery on 13-16 March (Table 11). These were tagged and released into water-reuse circular ponds. Fish were not fed during tagging or for two days before and after tagging. Fish averaged 133-137 mm in length and 25-26 g at time of tagging.

Table 11.11 summarizes the number of yearling summer Chinook that have been PIT-tagged and released from the Turtle Rock/Chelan Falls Program.

Table 11.11. Summary of PIT-tagging activities for Turtle Rock/Chelan Falls yearling summer Chinook, brood years 2007-2014; fpp = fish per pound.

Brood year	Release year	Raceway/Program	Number of fish tagged	Number of tagged fish that died	Number of tags shed	Number of tagged fish released
2007	2009	Circular Reuse	10,104	128	1	9,975
		Standard	10,102	162	3	9,937
2008	2010	Circular Reuse	11,102	20	0	11,082
		Standard	11,100	28	2	11,070
2009	2011	Turtle Rock	5,051	106	0	4,945
		Chelan Net Pens	5,050	2	0	5,048
2010	2012	Chelan Falls	4,200	10	0	4,186
2011	2013	Chelan Falls	4,101	26	0	4,075
2012	2014	Chelan Falls (small)	2,500	17	0	4,983
		Chelan Falls (large)	5,000	40	0	4,960
2013	2015	Chelan Falls (small)	5,000	41	0	4,959
		Chelan Falls (large)	5,000	37	0	4,963
2014	2016	Chelan Falls (18 fpp)	2,500	5	0	2,495
		Chelan Falls (22 fpp)	2,500	19	0	2,481
		Chelan Falls (10 fpp)	2,500	22	0	2,478
		Chelan Falls (13 fpp)	2,500	140	0	2,360

Fish size and condition at release

Although the subyearling summer Chinook program was discontinued, sizes of subyearlings released from Turtle Rock Hatchery before 2010 are shown in Tables 11.12 and 11.13.

Table 11.12. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of Turtle Rock summer Chinook subyearlings released from the hatchery, brood years 1995-2009. Size targets are provided in the last row of the table.

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
1995	1996	102	6.3	12.6	36
1996	1997	87	8.0	7.4	62
1997	1998	98	6.2	10.2	45
1998	1999	96	6.3	10.7	43

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
1999	2000	90	9.0	9.8	46
2000	2001	100	7.1	11.3	40
2001	2002	104	7.2	13.4	34
2002	2003	97	7.3	11.8	39
2003	2004	101	8.0	12.0	43
2004	2005	100	7.8	11.4	40
2005	2006	100	6.5	12.5	36
2006	2007	95	7.2	9.5	48
2007	2008	79	7.4	5.6	81
2008	2009	86	7.9	7.9	57
2009[a]	2010	89	7.1	7.0	65
Average		***95***	***7.3***	***10.2***	***48***
Targets		***112***	***9.0***	***11.4***	***40***

[a] Pre-release growth sample was conducted using pond mortalities.

Table 11.13. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of Turtle Rock summer Chinook accelerated subyearlings released from the hatchery, brood years 1995-2008. Size targets are provided in the last row of the table.

Brood year	Release year	Fork length (mm)		Mean weight	
		Mean	CV	Grams (g)	Fish/pound
1995	1996	129	7.1	27.3	17
1996	1997	107	6.5	15.6	29
1997	1998	117	6.0	18.9	24
1998	1999	119	8.0	18.9	24
1999	2000	114	6.7	19.0	24
2000	2001	111	7.0	16.8	27
2001	2002	117	8.4	19.5	23
2002	2003	116	11.3	21.2	21
2003	2004	113	14.9	17.0	30
2004	2005	117	11.3	20.1	23
2005	2006	119	9.1	22.2	21
2006	2007	118	8.3	19.1	24
2007	2008	95	7.7	10.0	45
2008[a]	2009	97	8.6	10.6	43
Average		***114***	***8.6***	***18.3***	***27***
Targets		***112***	***9.0***	***11.4***	***40***

[a] The 2008 brood year was the last year of the accelerated subyearling program.

Size at release of the brood year 2014 yearling summer Chinook was 87.6% and 69.4% of the fork length and weight targets, respectively, for the Chelan Falls group. This group exceeded the target CV for length (Table 11.14).

Table 11.14. Mean lengths (FL, mm), weight (g and fish/pound), and coefficient of variation (CV) of Turtle Rock/Chelan summer Chinook yearling releases, brood years 1995-2014. Size targets are provided in the last row of the table.

Brood year	Release year	Acclimation facility	Fork length (mm)		Mean weight	
			Mean	CV	Grams (g)	Fish/pound
1995	1997	Turtle Rock	-	-	-	-
1996	1998	Turtle Rock	166	14.2	60.9	7
1997	1999	Turtle Rock	198	4.6	91.3	5
1998	2000	Turtle Rock	161	11.9	53.9	8
1999	2001	Turtle Rock	164	18.6	59.0	8
2000	2002	Turtle Rock	170	15.3	59.0	8
2001	2003	Turtle Rock	154	22.3	48.6	9
2002	2004	Turtle Rock	157	16.7	44.0	12
2003	2005	Turtle Rock	173	13.8	54.7	8
2004	2006	Turtle Rock	176	20.6	45.3	7
2005	2007	Turtle Rock	158	11.0	43.5	10
2006	2008	Chelan Nets	172	14.5	58.4	8
		Turtle Rock	157	25.8	54.1	8
2007	2009	Chelan Nets	153	18.8	45.7	10
		Turtle Rock	167	14.6	49.3	9
2008	2010	Chelan Nets	146	22.9	40.6	11
		Turtle Rock	172	15.9	58.5	8
2009	2011	Chelan Nets	158	15.1	46.6	10
		Turtle Rock	174	17.5	59.3	8
2010	2012	Chelan Falls	132	27.4	33.2	14
2011	2013	Chelan Falls	148	18.6	42.6	11
2012	2014	Chelan Falls	129	17.1	24.5	19
2013	2015	Chelan Falls	137	9.8	26.8	17
2014	2016	Chelan Falls	141	13.5	31.5	14
Average			***159***	***16.5***	***49.2***	***10***
Targets[a]			***161***	***9.0***	***45.4***	***13***

[a] For size-target studies, fish per pound (fpp) targets for brood year 2012 were 10, 13, 18, 22 fpp.

Survival Estimates

Normal subyearling releases

Overall survival of the normal subyearling Turtle Rock summer Chinook program from green egg to release was below the standard set for the program (Table 11.15). Lower than expected survival at ponding and post-ponding reduced the overall program performance. This program was discontinued in 2010.

Table 11.15. Hatchery life-stage survival rates (%) for Turtle Rock subyearling (zero program) summer Chinook, brood years 2004-2009. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
2004	NA	NA	93.5	74.4	93.9	91.4	90.8	99.7	63.1
2005	NA	NA	94.4	87.9	85	84.8	84.2	99.4	69.8
2006	NA	NA	97.8	87.9	85.0	84.8	84.2	99.4	72.4
2007	NA	NA	92.7	84.9	88.5	86.7	84.8	99.6	66.7
2008	NA	NA	78.8	95.0	80.7	79.3	79.9	99.8	59.8
2009	NA	NA	95.0	89.4	89.5	89.2	79.7	89.5	67.7
Average	***NA***	***NA***	***92.0***	***86.6***	***87.1***	***86.0***	***83.9***	***97.9***	***66.6***
Median	***NA***	***NA***	***94.0***	***87.9***	***86.8***	***85.8***	***84.2***	***99.5***	***67.2***
Standard	***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

Accelerated subyearling releases

Overall survival of the accelerated subyearling Turtle Rock summer Chinook program from green egg to release was below the standard set for the program (Table 11.16). Lower than expected survival in post-ponding reduced the overall program performance. This program was discontinued in 2010.

Table 11.16. Hatchery life-stage survival rates (%) for Turtle Rock subyearling (accelerated program) summer Chinook, brood years 2004-2009. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Unfertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Unfertilized egg-release
	Female	Male							
2004	NA	NA	92.5	98.3	93.4	92.4	90.0	97.8	81.8
2005	NA	NA	93.8	94.6	83.7	83.4	81.7	98.8	72.5
2006	NA	NA	86.1	94.6	83.7	83.4	81.7	98.8	66.5
2007	NA	NA	93.4	95.4	78.4	77.5	76.3	98.9	67.9
2008[a]	NA	NA	93.4	95.0	79.8	78.8	78.2	99.3	67.1
Average	***NA***	***NA***	***91.8***	***95.6***	***83.8***	***83.1***	***81.6***	***98.7***	***71.2***
Median	***NA***	***NA***	***93.4***	***95.0***	***83.7***	***83.4***	***81.7***	***98.8***	***67.9***
Standard	***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

[a] The 2008 brood year was the last year of the accelerated subyearling program.

Yearling releases

Overall survival of the 2014 brood yearling Chelan Falls summer Chinook program from green egg to release was below the standard set for the program (Table 11.17). This is largely because of lower unfertilized egg to eyed egg and eyed egg to ponding survival.

Table 11.17. Hatchery life-stage survival rates (%) for Turtle Rock/Chelan Falls yearling summer Chinook, brood years 2004-2014. Survival standards or targets are provided in the last row of the table.

Brood year	Collection to spawning		Un-fertilized egg-eyed	Eyed egg-ponding	30 d after ponding	100 d after ponding	Ponding to release	Transport to release	Un-fertilized egg-release
	Female	Male							
2004	NA	NA	92.9	97.7	96.8	96.4	95.5	99.6	86.7
2005	NA	NA	89.1	97.5	98.1	97.8	96.6	99.1	83.9
2006	NA	NA	86.2	78.8	97.6	97.1	95.2	98.7	64.8
2007 (Turtle Rock)	NA	NA	80.3	97.6	98.8	98.2	95.4	99.1	74.8
2007 (Chelan Falls)	NA	NA	80.3	97.6	98.8	98.2	94.9	97.1	74.4
2008 (Turtle Rock)	NA	NA	93.5	98.0	99.4	97.2	95.9	98.8	87.8
2008 (Chelan Falls)	NA	NA	93.5	98.0	97.6	98.7	96.4	99.3	88.2
2009 (Turtle Rock)	NA	NA	90.8	96.8	99.7	99.0	97.2	98.1	85.5
2009 (Chelan Falls)	NA	NA	90.9	96.9	99.8	99.0	96.7	97.7	85.2
2010 (Chelan Falls)	NA	NA	94.8	97.7	99.4	95.2	92.4	97.6	85.5
2011 (Chelan Falls)	NA	NA	90.0	99.4	91.7	98.2	83.4	85.2	74.6
2012 (Chelan Falls)	NA	NA	93.5	98.5	99.8	99.3	95.9	96.7	88.3
2013 (Chelan Falls)	100.0	98.1	90.6	96.5	99.5	98.9	98.5	99.7	86.1
2014 (Chelan Falls)	89.6	98.8	83.6	96.3	99.6	98.8	97.0	98.3	78.1
Average (Chelan)	***94.8***	***98.5***	***89.3***	***96.2***	***98.3***	***98.0***	***95.1***	***97.5***	***81.7***
Median (Chelan)	***94.8***	***98.5***	***90.7***	***97.6***	***99.1***	***98.2***	***95.9***	***98.5***	***85.4***
Standard	***90.0***	***85.0***	***92.0***	***98.0***	***97.0***	***93.0***	***90.0***	***95.0***	***81.0***

11.3 Spawning Surveys

Surveys for summer Chinook redds in the Chelan River were conducted from late September to late-November 2016. Total redd counts were conducted in the river (see Appendix O for more details).

Redd Counts

A total of 448 summer Chinook redds were counted in the Chelan River in 2016 (Table 11.18). This was higher than the overall average of 305 redds.

Table 11.18. Total number of redds counted in the Chelan River, 2000-2016.

Survey year	Total redd count
2000	196
2001	240
2002	253
2003	173

Survey year	Total redd count
2004	185
2005	179
2006	208
2007	86
2008	153
2009	246
2010	398
2011	413
2012	426
2013	729
2014	400
2015	448
2016	448
Average	***305***
Median	***246***

Redd Distribution

Summer Chinook redds were not evenly distributed among the four sampling areas within the Chelan River. Most redds (46%) were located in the Chelan Tailrace (Table 11.19). Fewer summer Chinook spawned in the Habitat Pool and Columbia Tailrace.

Table 11.19. Total number of summer Chinook redds counted in different survey areas within the Chelan River during September through early November 2016.

Survey area	Total redd count	Percent
Chelan Tailrace	207	46
Columbia Tailrace	74	16
Habitat Channel	106	24
Habitat Pool	61	14
Totals	***448***	***100***

Spawn Timing

Spawning in 2016 began the first week of October, peaked mid-October, and ended mid-November. Peak spawning occurred in the Habitat Pool in early October and during mid-October in the Chelan Tailrace, Habitat Channel, and Columbia Tailrace (Figure 11.1).

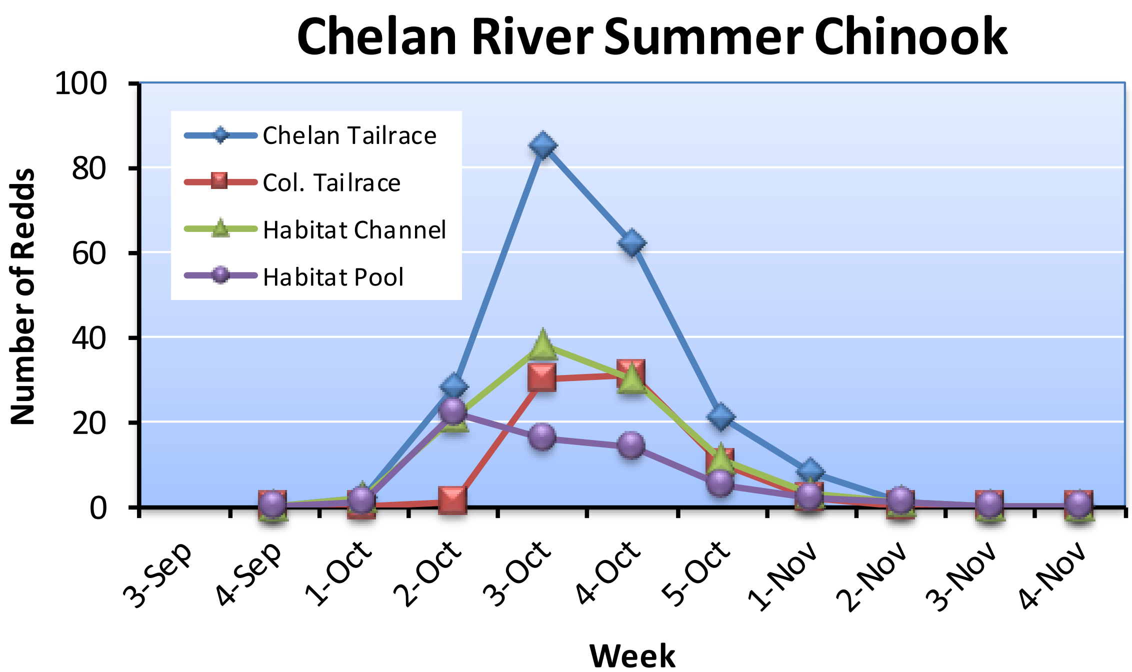

Figure 11.1. Number of new summer Chinook redds counted during different weeks within different sections of the Chelan River, September through November 2016.

Spawning Escapement

Spawning escapement for summer Chinook in the Chelan River was calculated as the total number of redds times the fish per redd ratio estimated from fish sampled at Wells Dam.[33] The estimated fish per redd ratio for Methow summer Chinook in 2016 was 2.01. Multiplying this ratio by the number of redds counted in the Chelan River resulted in a total spawning escapement of 900 summer Chinook (Table 11.20).

Table 11.20. Spawning escapements for summer Chinook in the Chelan River for return years 2000-2016.

Return year	Fish/Redd	Redds	Total spawning escapement
2000	2.40	196	470
2001	4.10	240	984
2002	2.30	253	582
2003	2.42	173	419
2004	2.25	185	416
2005	2.93	179	524
2006	2.02	208	420
2007	2.20	86	189
2008	3.25	153	497

[33] Expansion factor = (1 + (number of males/number of females)).

Return year	Fish/Redd	Redds	Total spawning escapement
2009	2.54	246	625
2010	2.81	398	1,118
2011	3.10	413	1,280
2012	3.07	426	1,308
2013	2.31	729	1,684
2014	2.75	400	1,100
2015	3.21	448	1,438
2016	2.01	448	900
Average	***2.69***	***305***	***821***
Median	***2.54***	***246***	***625***

11.4 Carcass Surveys

Surveys for summer Chinook carcasses within the Chelan River were conducted during late September to mid-November 2016 (see Appendix O for more details).

Number sampled

A total of 253 summer Chinook carcasses were sampled during September through late-November in the Chelan River (Table 11.21). This was higher than the overall average of 178 carcasses sampled since 2000.

Table 11.21. Numbers of summer Chinook carcasses sampled within each survey area within the Chelan River, 2000-2016; ND = no data.

Survey year	Number of summer Chinook carcasses				
	Chelan Tailrace	Columbia Tailrace	Habitat Channel	Habitat Pool	Total
2000	ND	ND	ND	ND	**48**
2001	ND	ND	ND	ND	**101**
2002	ND	ND	ND	ND	**145**
2003	ND	ND	ND	ND	**168**
2004	ND	ND	ND	ND	**159**
2005	ND	ND	ND	ND	**103**
2006	ND	ND	ND	ND	**107**
2007	ND	ND	ND	ND	**106**
2008	ND	ND	ND	ND	**132**
2009	ND	ND	ND	ND	**51**
2010	ND	ND	ND	ND	**106**
2011	ND	ND	ND	ND	**201**
2012	ND	ND	ND	ND	**317**
2013	50	120	157	28	**355**
2014	171	82	50	6	**309**

Survey year	Number of summer Chinook carcasses				
	Chelan Tailrace	Columbia Tailrace	Habitat Channel	Habitat Pool	Total
2015	49	255	41	18	**363**
2016	27	128	64	34	**253**
Average	***74***	***146***	***78***	***22***	***178***
Median	***50***	***124***	***57***	***23***	***145***

Carcass Distribution and Origin

Summer Chinook carcasses were not evenly distributed among survey areas within the Chelan River in 2016 (Table 11.22). Most of the carcasses in the Chelan River were found in the Columbia Tailrace.

In 2016, hatchery and wild summer Chinook carcasses were not distributed equally among the survey areas within the Chelan River (Table 11.22; Figure 11.2). A larger percentage of hatchery carcasses occurred in the Columbia Tailrace, Habitat Channel, and Habitat Pool, while a larger percentage of wild summer Chinook carcasses occurred in the Chelan Tailrace. There was a larger sample size of hatchery than wild summer Chinook carcasses in the Chelan River in 2016.

Table 11.22. Numbers of wild and hatchery summer Chinook carcasses sampled within different survey areas on the Chelan River, 2000-2016; ND = no data.

Survey year	Origin	Survey reach				Total
		Chelan Tailrace	Columbia Tailrace	Habitat Channel	Habitat Pool	
2000	Wild	ND	ND	ND	ND	**17**
	Hatchery	ND	ND	ND	ND	**31**
2001	Wild	ND	ND	ND	ND	**26**
	Hatchery	ND	ND	ND	ND	**75**
2002	Wild	ND	ND	ND	ND	**37**
	Hatchery	ND	ND	ND	ND	**108**
2003	Wild	ND	ND	ND	ND	**33**
	Hatchery	ND	ND	ND	ND	**135**
2004	Wild	ND	ND	ND	ND	**91**
	Hatchery	ND	ND	ND	ND	**68**
2005	Wild	ND	ND	ND	ND	**42**
	Hatchery	ND	ND	ND	ND	**61**
2006	Wild	ND	ND	ND	ND	**69**
	Hatchery	ND	ND	ND	ND	**38**
2007	Wild	ND	ND	ND	ND	**35**
	Hatchery	ND	ND	ND	ND	**71**
2008	Wild	ND	ND	ND	ND	**69**
	Hatchery	ND	ND	ND	ND	**63**
2009	Wild	ND	ND	ND	ND	**2**
	Hatchery	ND	ND	ND	ND	**49**
2010	Wild	ND	ND	ND	ND	**46**

Survey year	Origin	Survey reach				Total
		Chelan Tailrace	Columbia Tailrace	Habitat Channel	Habitat Pool	
	Hatchery	ND	ND	ND	ND	**60**
2011	Wild	ND	ND	ND	ND	**89**
	Hatchery	ND	ND	ND	ND	**112**
2012	Wild	ND	ND	ND	ND	**64**
	Hatchery	ND	ND	ND	ND	**253**
2013	Wild	18	55	51	6	**130**
	Hatchery	23	65	106	22	**225**
2014	Wild	32	142	18	1	**193**
	Hatchery	17	113	23	17	**170**
2015	Wild	35	137	11	0	**183**
	Hatchery	21	117	23	21	**180**
2016	Wild	15	63	26	7	**111**
	Hatchery	12	65	38	27	**142**
Average	***Wild***	***25***	***99***	***27***	***4***	***73***
	Hatchery	***18***	***90***	***48***	***22***	***108***
Median	***Wild***	***25***	***99***	***26***	***4***	***64***
	Hatchery	***18***	***90***	***38***	***22***	***75***

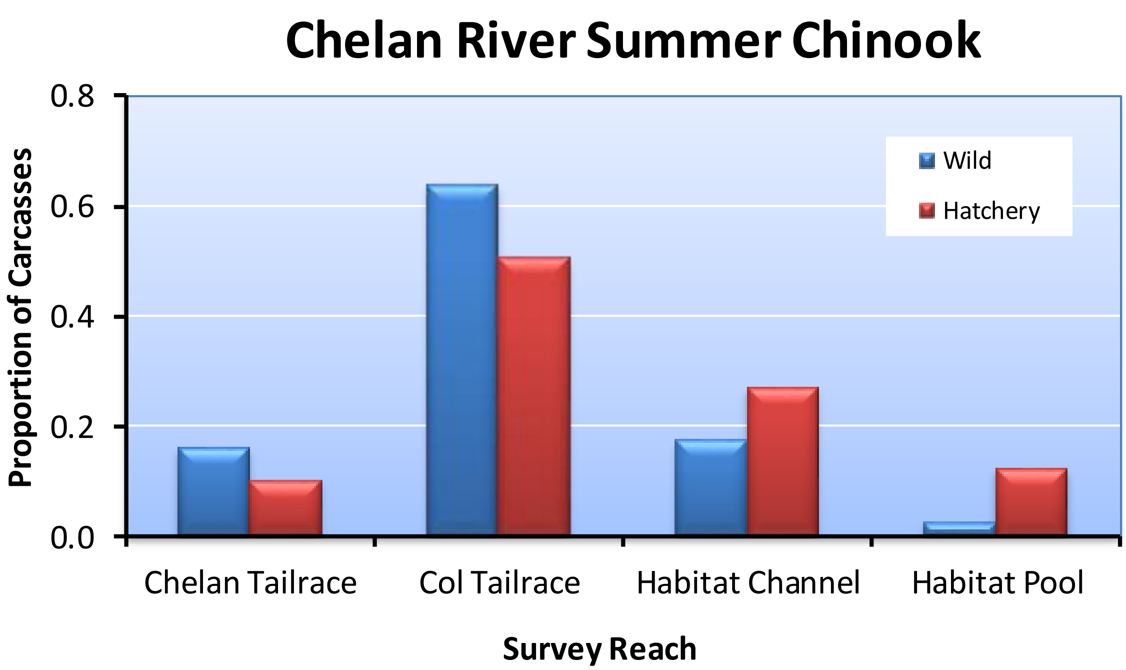

Figure 11.2. Average distribution of wild and hatchery produced carcasses in different survey areas within the Chelan River, 2013-2016.

Sampling Rate

Overall, 28% of the total spawning escapement of summer Chinook in the Chelan River was sampled in 2016 (Table 11.16). Sampling rates among survey reaches varied from 6 to 86%.

Table 11.23. Number of redds and carcasses, total spawning escapement, and sampling rates for summer Chinook in the Chelan River, 2016.

Survey reach	Total number of redds	Total number of carcasses	Total spawning escapement	Sampling rate
Chelan Tailrace	207	27	416	0.06
Columbia Tailrace	74	128	149	0.86
Habitat Channel	106	64	213	0.30
Habitat Pool	61	34	123	0.28
Total	***448***	***253***	***900***	***0.28***

Length Data

Mean lengths (POH, cm) of male and female summer Chinook carcasses sampled during surveys on the Chelan River in 2016 are provided in Table 11.24. The average size of males and females sampled in the Chelan River were 62 cm and 68 cm, respectively.

Table 11.24. Mean lengths (postorbital-to-hypural length; cm) and standard deviations (in parentheses) of male and female summer Chinook carcasses sampled in different areas on the Chelan River, 2016.

Stream/watershed	Mean length (cm)	
	Male	Female
Chelan Tailrace	64.5 (4.2)	66.0 (4.3)
Columbia Tailrace	62.7 (8.8)	67.6 (4.7)
Habitat Channel	60.7 (7.6)	68.6 (5.1)
Habitat Pool	62.5 (6.6)	67.4 (5.7)
Total	***62.2 (7.8)***	***67.7 (4.9)***

11.5 Life History Monitoring

Life history characteristics of Chelan Falls and Turtle Rock summer Chinook were assessed by examining carcasses on spawning grounds and by reviewing tagging data and fisheries statistics.

Contribution to Fisheries

Normal subyearling releases

Most of the harvest on Turtle Rock summer Chinook (normal subyearling releases) occurred in the Ocean (10-100% of the fish harvested; Table 11.25). Brood years 1995 and 2006 provided the largest total harvests, while brood year 1997 and 1998 provided the lowest. The subyearling hatchery program was discontinued after brood year 2009.

Table 11.25. Estimated number and percent (in parentheses) of Turtle Rock summer Chinook (normal subyearling releases) captured in different fisheries, brood years 1995-2009.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
1995	688 (84)	106 (13)	11 (1)	16 (2)	821
1996	72 (80)	0 (0)	5 (6)	13 (14)	90
1997	10 (100)	0 (0)	0 (0)	0 (0)	10
1998	21 (100)	0 (0)	0 (0)	0 (0)	21
1999	184 (64)	26 (9)	4 (1)	75 (26)	289
2000	36 (55)	8 (12)	8 (12)	14 (21)	66
2001	164 (64)	30 (12)	20 (8)	44 (17)	258
2002	23 (20)	33 (29)	3 (3)	56 (49)	115
2003	9 (10)	55 (61)	2 (2)	24 (27)	90
2004	42 (37)	29 (25)	2 (2)	42 (37)	115
2005	100 (38)	95 (36)	24 (9)	44 (17)	263
2006	305 (41)	288 (38)	53 (7)	104 (14)	750
2007	110 (34)	91 (28)	21 (6)	104 (32)	326
2008	42 (31)	32 (24)	4 (3)	56 (42)	134
2009	82 (39)	68 (33)	6 (3)	52 (25)	208
Average	***126 (53)***	***57 (21)***	***11 (4)***	***43 (21)***	***237***
Median	***72 (41)***	***32 (24)***	***5 (3)***	***44 (21)***	***134***

Accelerated subyearling releases

Most of the harvest on Turtle Rock summer Chinook (accelerated subyearling releases) occurred in ocean fisheries (Table 11.26). Ocean harvest has made up 0% to 100% of all Turtle Rock summer Chinook harvested. Brood year 1999 provided the largest total harvest, while brood years 1995, 1997, 2002, and 2003 provided the lowest. This program was discontinued after brood year 2008.

Table 11.26. Estimated number and percent (in parentheses) of Turtle Rock summer Chinook (accelerated subyearling releases) captured in different fisheries, brood years 1995-2008.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
1995	3 (100)	0 (0)	0 (0)	0 (0)	3
1996	77 (89)	5 (6)	5 (6)	0 (0)	87
1997	3 (100)	0 (0)	0 (0)	0 (0)	3
1998	102 (95)	2 (2)	3 (3)	0 (0)	107
1999	1,026 (76)	142 (10)	12 (1)	178 (13)	1,358
2000	117 (100)	0 (0)	0 (0)	0 (0)	117
2001	205 (59)	49 (14)	13 (4)	80 (23)	347

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
2002	9 (100)	0 (0)	0 (0)	0 (0)	9
2003	0 (0)	0 (0)	0 (0)	0 (0)	0
2004	50 (30)	79 (47)	6 (4)	34 (20)	169
2005	65 (59)	12 (11)	26 (24)	7 (6)	110
2006	130 (43)	113 (37)	16 (5)	43 (14)	302
2007	169 (41)	168 (41)	15 (4)	59 (14)	411
2008	20 (54)	2 (5)	4 (11)	11 (30)	37
Average	***141 (68)***	***41 (12)***	***7 (4)***	***29 (9)***	***219***
Median	***71 (67)***	***4 (6)***	***5 (3)***	***4 (3)***	***109***

Yearling releases

Most of the harvest on Turtle Rock/Chelan Falls summer Chinook (yearling releases) occurred in ocean fisheries (Table 11.27). Ocean harvest has made up 39% to 95% of all Turtle Rock summer Chinook harvested. Brood years 1998, 2008, and 2010 provided the largest harvest, while brood years 1995 and 1996 provided the lowest.

Table 11.27. Estimated number and percent (in parentheses) of Turtle Rock/Chelan Falls summer Chinook (yearling releases) captured in different fisheries, brood years 1995-2010.

Brood year	Ocean fisheries	Columbia River Fisheries			Total
		Tribal	Commercial (Zones 1-5)	Recreational (sport)	
1995	456 (75)	51 (8)	31 (5)	70 (12)	608
1996	771 (95)	14 (2)	2 (0)	21 (3)	808
1997	2,835 (91)	61 (2)	27 (1)	176 (6)	3,099
1998	4,284 (90)	224 (5)	16 (0)	230 (5)	4,754
1999	1,658 (73)	233 (10)	7 (0)	383 (17)	2,281
2000	1,214 (72)	147 (9)	54 (3)	273 (16)	1,688
2001	1,952 (59)	453 (14)	178 (5)	729 (22)	3,312
2002	1,018 (50)	384 (19)	102 (5)	537 (26)	2,041
2003	758 (46)	449 (27)	70 (4)	378 (23)	1,655
2004	827 (39)	560 (26)	127 (6)	605 (29)	2,119
2005	500 (44)	303 (27)	123 (11)	206 (18)	1,132
2006	1,163 (39)	880 (30)	231 (8)	688 (23)	2,962
2007	753 (49)	367 (24)	67 (4)	349 (23)	1,536
2008	3,697 (51)	1,155 (16)	248 (3)	2,168 (30)	7,268
2009	1,698 (51)	773 (23)	122 (4)	742 (22)	3,335
2010	3,882 (46)	2,798 (33)	394 (5)	1,395 (16)	8,469
Average	***1,717 (61)***	***553 (17)***	***112 (4)***	***559 (18)***	***2,942***
Median	***1,189 (51)***	***367 (17)***	***86 (4)***	***381 (20)***	***2,200***

Straying

Normal subyearling releases

Assessment of straying was based on evaluating the location of CWT recoveries. There were 17 tag codes used to differentiate Turtle Rock/Chelan normal subyearling releases by brood year, release type, and location. There was one subyearling group released into the Chelan River in 2010 (brood year 2009). There were also six non-associated releases.[34] All tag codes, except brood year 2009, recovered in the Chelan River or other tributaries in the Upper Columbia were considered strays.

Rates of Turtle Rock summer Chinook (normal subyearling releases) straying into spawning areas in the upper basin have been low. Although Turtle Rock summer Chinook have strayed into other spawning areas, they made up less than 10% of the spawning escapement within those areas (Table 11.28). The Chelan tailrace has received the largest number of Turtle Rock strays. This hatchery program was discontinued after brood year 2009.

Table 11.28. Number (No.) and percent of spawning escapements within other non-target basins that consisted of Turtle Rock summer Chinook (normal subyearling releases), return years 1998-2015. For example, for return year 2003, 0.6% of the summer Chinook spawning escapement in the Okanogan River basin consisted of Turtle Rock summer Chinook. Percent strays should be less than 10%.

Return year	Wenatchee		Methow		Okanogan		Chelan		Entiat		Hanford Reach	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1998	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2000	8	0.1	3	0.3	13	0.4	63	13.4	0	0.0	0	0.0
2001	0	0.0	5	0.2	13	0.1	0	0.0	0	0.0	0	0.0
2002	0	0.0	0	0.0	13	0.1	0	0.0	0	0.0	0	0.0
2003	7	0.1	7	0.2	19	0.6	6	1.4	0	0.0	0	0.0
2004	5	0.0	4	0.2	13	0.2	6	1.4	0	0.0	0	0.0
2005	5	0.1	0	0.0	5	0.1	0	0.0	2	0.5	0	0.0
2006	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2007	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2008	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2009	0	0.0	16	0.9	0	0.0	2	0.3	9	3.6	0	0.0
2010	0	0.0	26	1.0	0	0.0	0	0.0	14	3.2	0	0.0
2011	0	0.0	14	0.5	0	0.0	34	2.7	0	0.0	0	0.0
2012	0	0.0	0	0.0	0	0.0	0	0.0	8	0.9	0	0.0
2013	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2014	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2015	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Average	***1***	***0.0***	***4***	***0.2***	***4***	***0.1***	***6***	***1.1***	***2***	***0.5***	***0***	***0.0***

34 Non-associated releases are release groups not containing any coded-wire tagged fish.

Return year	Wenatchee		Methow		Okanogan		Chelan		Entiat		Hanford Reach	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Median	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***

On average, about 29% of the brood year returns have strayed into spawning areas in the upper basin (Table 11.29). Depending on brood year, percent strays into spawning areas have ranged from 0-100%. Few (2.3% on average) have strayed into non-target hatchery programs.

Table 11.29. Number and percent of Turtle Rock summer Chinook (normal subyearling releases) that homed to the target hatchery and strayed to non-target spawning areas and non-target hatchery programs, by brood years 1995-2009.

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1995	-	-	197	74.1	64	24.1	5	1.9
1996	-	-	54	54.5	44	44.4	1	1.0
1997	-	-	2	28.6	5	71.4	0	0.0
1998	-	-	0	0.0	24	100.0	0	0.0
1999	-	-	40	43.5	52	56.5	0	0.0
2000	-	-	5	50.0	5	50.0	0	0.0
2001	-	-	56	77.8	16	22.2	0	0.0
2002	-	-	10	100.0	0	0.0	0	0.0
2003	-	-	27	100.0	0	0.0	0	0.0
2004	-	-	71	97.3	2	2.7	0	0.0
2005	-	-	80	92.0	7	8.0	0	0.0
2006	-	-	194	72.1	72	26.8	3	1.1
2007	-	-	113	68.5	34	20.6	18	10.9
2008	-	-	16	80.0	0	0.0	4	20.0
2009	27	42.2	29	45.3	8	12.5	0	0.0
Average	***27***	***42.2***	***60***	***65.6***	***22***	***29.3***	***2***	***2.3***
Median	***27***	***42.2***	***40***	***72.1***	***8***	***22.2***	***0***	***0.0***

* Homing to the target hatchery includes Turtle Rock hatchery fish that were captured and included as broodstock in the Turtle Rock Hatchery program. These hatchery fish were typically collected at Wells Dam and Wells Hatchery.

Accelerated subyearling releases

Assessment of straying was based on evaluating the location of CWT recoveries. There were 16 tag codes used to differentiate Turtle Rock accelerated subyearling releases by brood year and release type. There were also four non-associated releases. All tag codes recovered in the Chelan River or other tributaries in the Upper Columbia were considered strays.

Rates of Turtle Rock summer Chinook (accelerated subyearling releases) straying into spawning areas in the upper basin have been low. Although Turtle Rock summer Chinook have strayed into other spawning areas, they made up less than 10% of the spawning escapement within those areas

(Table 11.30). The Chelan tailrace, Entiat Basin, and Methow River basin have received the largest numbers of Turtle Rock strays. This hatchery program was discontinued after brood year 2008.

Table 11.30. Number (No.) and percent of spawning escapements within other non-target basins that consisted of Turtle Rock summer Chinook (accelerated subyearling releases), return years 1998-2014. For example, for return year 2001, 0.2% of the summer Chinook spawning escapement in the Methow River basin consisted of Turtle Rock summer Chinook. Percent strays should be less than 10%.

Return year	Wenatchee		Methow		Okanogan		Chelan		Entiat		Hanford Reach	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1998	3	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2000	7	0.1	0	0.0	0	0.0	24	3.6	0	0.0	0	0.0
2001	0	0.0	12	0.4	31	0.3	0	0.0	0	0.0	0	0.0
2002	0	0.0	5	0.1	0	0.0	0	0.0	0	0.0	0	0.0
2003	0	0.0	45	1.1	0	0.0	22	5.3	13	1.9	16	0.0
2004	0	0.0	7	0.3	0	0.0	14	3.3	0	0.0	18	0.0
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2006	0	0.0	0	0.0	0	0.0	0	0.0	7	1.3	0	0.0
2007	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2008	0	0.0	7	0.4	0	0.0	27	5.4	0	0.0	0	0.0
2009	19	0.2	0	0.0	0	0.0	2	0.3	0	0.0	0	0.0
2010	0	0.0	19	0.8	0	0.0	0	0.0	10	2.3	0	0.0
2011	17	0.2	10	0.3	10	0.1	0	0.0	15	3.2	0	0.0
2012	0	0.0	0	0.0	0	0.0	0	0.0	8	0.9	0	0.0
2013	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2014	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Average	***3***	***0.0***	***6***	***0.2***	***2***	***0.0***	***5***	***1.1***	***3***	***0.6***	***2***	***0.0***
Median	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***	***0***	***0.0***

On average, about 29% of the brood year returns have strayed into spawning areas in the upper basin (Table 11.31). Depending on brood year, percent strays into spawning areas have ranged from 0-83%. Few (1.3% on average) have strayed into non-target hatchery programs.

Table 11.31. Number and percent of Turtle Rock summer Chinook (accelerated subyearling releases) that homed to the target hatchery and strayed to non-target spawning areas and non-target hatchery programs, by brood years 1995-2008.

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1995	-	-	7	70.0	3	30.0	0	0.0
1996	-	-	33	32.4	69	67.6	0	0.0
1997	-	-	6	100.0	0	0.0	0	0.0

Brood year	Homing				Straying			
	Target stream		Target hatchery*		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1998	-	-	2	16.7	10	83.3	0	0.0
1999	-	-	138	54.1	117	45.9	0	0.0
2000	-	-	12	40.0	18	60.0	0	0.0
2001	-	-	57	89.1	7	10.9	0	0.0
2002	-	-	0	0.0	0	0.0	0	0.0
2003	-	-	3	100.0	0	0.0	0	0.0
2004	-	-	90	75.6	29	24.4	0	0.0
2005	-	-	64	75.3	19	22.4	2	2.4
2006	-	-	88	88.9	7	7.1	4	4.0
2007	-	-	133	61.9	81	35.8	12	5.3
2008	-	-	21	84.0	8	25.8	2	6.5
Average	**-**	**-**	***47***	***63.4***	***26***	***29.5***	***1***	***1.3***
Median	**-**	**-**	***27***	***72.7***	***9***	***25.1***	***0***	***0.0***

* Homing to the target hatchery includes Turtle Rock hatchery fish that were captured and included as broodstock in the Turtle Rock Hatchery program. These hatchery fish were typically collected at Wells Dam and Wells Hatchery.

Yearling releases

Assessment of straying was based on evaluating the location of CWT recoveries. Yearlings have been released in the Columbia River and in the Chelan River. There were 16 tag codes used to differentiate Turtle Rock yearling releases by brood year, release type, and location. All these fish were released into the Columbia River and therefore any tag recoveries in the Chelan River or other tributaries were considered strays. In contrast, there were 21 tag codes[35] used to differentiate Chelan River yearling releases by brood year, release type, and location (there were four non-associated releases). All these fish were released into the Chelan River and therefore any tag recoveries in tributaries other than the Chelan River were considered strays.

Rates of Turtle Rock/Chelan Falls summer Chinook (yearling releases) straying into spawning areas in the upper basin have varied widely depending on spawning area. Most of these fish strayed to spawning areas within the Chelan tailrace (Turtle Rock released fish), Entiat Basin, and Methow River basin. On average, Turtle Rock summer Chinook have made up 4-13% of the spawning escapement within those basins (Table 11.32). Relatively few, on average, have strayed to spawning areas in the Okanogan River basin, Wenatchee River basin, and the Hanford Reach (i.e., they made up less than 2% of the spawning escapement in these areas).

[35] The Regional Mark Information System (RMIS) indicates that one tag code was released into Lake Chelan. Interestingly, some of these fish have been reported in ocean and Columbia River fisheries.

Table 11.32. Number (No.) and percent of spawning escapements within other non-target basins that consisted of Turtle Rock/Chelan Falls summer Chinook (yearling releases), return years 1998-2015. For example, for return year 2003, 4.3% of the summer Chinook spawning escapement in the Methow River basin consisted of Turtle Rock summer Chinook. Percent strays should be less than 10%.

Return year	Wenatchee		Methow		Okanogan		Chelan		Entiat		Hanford Reach	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1998	0	0.0	2	0.3	0	0.0	0	0.0	0	0.0	0	0.0
1999	3	0.1	2	0.2	0	0.0	0	0.0	0	0.0	0	0.0
2000	18	0.3	57	4.8	167	4.5	73	15.5	0	0.0	10	0.0
2001	109	1.0	523	18.9	334	3.1	316	32.1	0	0.0	7	0.0
2002	92	0.6	437	9.4	194	1.4	191	32.8	136	27.1	0	0.0
2003	64	0.5	170	4.3	14	0.4	165	39.4	180	26.0	9	0.0
2004	10	0.1	55	2.5	116	1.7	75	18.0	0	0.0	0	0.0
2005	5	0.1	73	2.9	78	0.9	88	16.8	46	12.5	0	0.0
2006	0	0.0	100	3.7	25	0.3	64	15.2	30	5.5	0	0.0
2007	0	0.0	65	4.8	31	0.7	40	21.2	58	24.0	19	0.1
2008	18	0.3	72	3.7	60	0.9	110	22.1	46	14.4	0	0.0
2009	8	0.1	95	5.4	32	0.4	5	0.8	18	7.1	0	0.0
2010	12	0.2	105	4.2	111	1.9	0	0.0	30	6.9	0	0.0
2011	8	0.1	88	3.0	35	0.4	15	1.2	12	2.6	0	0.0
2012	21	0.2	33	1.1	43	0.5	110	8.4	29	3.2	0	0.0
2013	0	0.0	128	3.6	20	0.2	14	0.8	0	0.0	0	0.0
2014	7	0.1	22	1.4	24	0.2	16	1.5	18	3.2	0	0.0
2015	0	0.0	176	4.5	10	0.1	0	0.0	6	1.5	0	0.0
Average	***21***	***0.2***	***122***	***4.4***	***72***	***1.0***	***71***	***12.5***	***34***	***7.4***	***3***	***0.0***
Median	***8***	***0.1***	***81***	***3.7***	***34***	***0.5***	***52***	***11.8***	***18***	***3.2***	***0***	***0.0***

Since 2005, on average, about 17% of the brood year returns have strayed into spawning areas in the upper basin (Table 11.33). Depending on brood year, percent strays into spawning areas have ranged from 8-29%. Few (4% on average) have strayed into non-target hatchery programs.

Table 11.33. Number and percent of Turtle Rock/Chelan Falls summer Chinook (yearling releases) that homed to the target hatchery and strayed to non-target spawning areas and non-target hatchery programs, by brood years 1995-2010.

Brood year	Homing				Straying			
	Target stream		Target hatchery[a]		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1995	-	-	180	39.3	278	60.7	0	0.0
1996	-	-	218	27.2	583	72.8	0	0.0
1997	-	-	254	14.2	1531	85.6	3	0.2
1998	-	-	166	16.1	864	83.8	1	0.1

Brood year	Homing				Straying			
	Target stream		Target hatchery[a]		Non-target streams		Non-target hatcheries	
	Number	%	Number	%	Number	%	Number	%
1999	-	-	181	42.7	243	57.3	0	0.0
2000	-	-	102	29.1	249	70.9	0	0.0
2001	-	-	389	58.2	279	41.8	0	0.0
2002	-	-	303	54.3	254	45.5	1	0.2
2003	-	-	373	62.3	225	37.6	1	0.2
2004	-	-	287	56.6	219	43.2	1	0.2
Average[b]	-	-	***245***	***40.0***	***473***	***59.9***	***1***	***0.1***
Median[b]	-	-	***236***	***41.0***	***266***	***59.0***	***1***	***0.0***
2005	149	29.4	202	39.9	144	28.5	11	2.2
2006	429	40.3	376	35.3	223	21.0	36	3.4
2007	121	27.5	218	49.5	69	15.7	32	7.3
2008	775	40.5	736	38.5	326	17.1	75	3.9
2009	97	8.8	877	79.4	92	8.3	39	3.5
2010	583	53.4	404	37.0	95	8.7	10	0.9
Average[c]	***359***	***33.3***	***469***	***46.6***	***158***	***16.5***	***34***	***3.5***
Median[c]	***289***	***34.9***	***390***	***39.2***	***119.5***	***16.4***	***34***	***3.5***

[a] Homing to the target hatchery includes Turtle Rock/Chelan Hatchery fish that were captured and included as broodstock in the Turtle Rock/Chelan Hatchery program. These hatchery fish are typically collected at Wells Dam, Wells Hatchery, and the Eastbank Hatchery Outfall.
[b] Summary statistics for yearling Turtle Rock summer Chinook released into the Columbia River (brood years 1995-2004).
[c] Summary statistics for yearling Turtle Rock/Chelan River summer Chinook released into the Chelan River (brood years 2005 to present).

Post-Release Survival and Travel Time

We used PIT-tagged fish to estimate survival rates and travel times (arithmetic mean days) of hatchery summer Chinook from the Turtle Rock/Chelan River release sites to McNary Dam, and smolt to adult ratios (SARs) from release to detection at Bonneville Dam (Table 11.34).[36] Over the seven brood years for which PIT-tagged hatchery fish were released, survival rates from the release sites to McNary Dam ranged from 0.423 to 0.798; SARs from release to detection at Bonneville Dam ranged from 0.010 to 0.028. Average travel times from release sites to McNary Dam ranged from 15 to 33 days.

Much of the variation in survival rates and travel time among brood years resulted from releases of different experimental groups (Table 11.34). For example, brood years 2007 and 2008 were each split into two experimental groups (Circular Reuse group and Standard Raceway group). For both brood years, survival from the release site to McNary Dam and SARs were greater for the Circular Reuse fish than for the Standard Raceway fish. For both brood years, travel time from

[36] It is important to point out that because of fish size differences among rearing tanks or raceways, fish PIT tagged in one tank or raceway may not represent untagged fish rearing in other tanks or raceways.

release to McNary Dam appeared to be longer for the Standard Raceway fish than for the Circular Reuse fish.

Another experiment was conducted with brood years 2012, 2013, and 2014 (Table 11.34). These brood years were split into different treatment groups based on fish size. Based on available information, there were no clear differences in survival rates and travel times to McNary Dam among the different experimental groups. SARs for these fish will be calculated after all fish have returned to the Columbia River.

Table 11.34. Total number of Turtle Rock/Chelan Falls yearling summer Chinook released with PIT tags, their survival and travel times (mean days) to McNary Dam, and smolt-to-adult (SAR) ratios for brood years 2007-2014. Standard errors are shown in parentheses. NA = not available (i.e., not all the fish from the release groups have returned to the Columbia River); fpp = fish per pound.

Brood year	Raceway/Program	Number of tagged fish released	Survival to McNary Dam	Travel time to McNary Dam	SAR to Bonneville Dam
2007	Circular Reuse	9,975	0.722 (0.036)	22.4 (8.6)	0.017 (0.001)
	Standard	9,937	0.550 (0.034)	28.4 (11.6)	0.010 (0.001)
2008	Circular Reuse	11,082	0.631 (0.040)	26.5 (9.8)	0.028 (0.002)
	Standard	11,070	0.581 (0.038)	27.9 (18.7)	0.025 (0.001)
2009	Turtle Rock	4,945	0.603 (0.061)	15.4 (8.6)	0.018 (0.002)
	Chelan Net Pens	5,048	0.616 (0.059)	19.5 (10.2)	0.012 (0.002)
2010	Chelan Falls	4,186	0.655 (0.050)	22.5 (12.1)	0.025 (0.002)
2011*	Chelan Falls	4,075	0.552 (0.054)	27.2 (11.5)	0.016 (0.002)
2012	Chelan Falls (Small Fish)	4,983	0.590 (0.049)	25.0 (11.2)	NA
	Chelan Falls (Big Fish)	4,960	0.579 (0.043)	24.4 (10.1)	NA
2013	Chelan Falls (Small Fish)	4,958	0.423 (0.068)	33.0 (13.6)	NA
	Chelan Falls (Big Fish)	4,963	0.760 (0.175)	28.6 (12.4)	NA
2014	Chelan Falls (10 fpp)	2,478	0.798 (0.077)	16.4 (5.9)	NA
	Chelan Falls (13 fpp)	2,360	0.672 (0.074)	16.1 (5.6)	NA
	Chelan Falls (18 fpp)	2,495	0.637 (0.064)	18.7 (7.8)	NA
	Chelan Falls (22 fpp)	2,481	0.449 (0.049)	20.6 (9.6)	NA

* Brood year 2011 experienced high mortality due to fungus, bacterial cold-water disease, bacterial gill disease, and erythrocytic inclusion body syndrome during April 2013.

Smolt-to-Adult Survivals

Subyearling-to-adult and smolt-to-adult survival ratios (SARs) were calculated as the number of hatchery adult recaptures divided by the number of tagged hatchery subyearling or yearling Chinook released. For these analyses, SARs were based on CWT returns.

Normal subyearling releases

For the available brood years, SARs for normal subyearling-released Chinook have ranged from 0.000036 to 0.001886 (Table 11.35). This hatchery program was discontinued after brood year 2009.

Table 11.35. Subyearling-to-adult ratios (SARs) for Turtle Rock normal subyearling-released summer Chinook, brood years 1995-2009.

Brood year	Number released[a]	Estimated adult captures[b]	SAR
1995	201,230	204	0.001014
1996	371,848	187	0.000503
1997	496,904	18	0.000036
1998	194,723	28	0.000144
1999	197,793	203	0.001026
2000	222,460	28	0.000126
2001	211,306	328	0.001552
2002	200,163	38	0.000190
2003	203,410	49	0.000241
2004	198,019	91	0.000460
2005	197,135	143	0.000725
2006	188,250	355	0.001886
2007	194,437	216	0.001111
2008	152,993	77	0.000503
2009	341,928	133	0.000389
Average	***238,173***	***140***	***0.000660***
Median	***200,163***	***133***	***0.000503***

[a] Includes all tag codes and CWT released fish (CWT + Ad Clip fish and CWT-only fish).

[b] Includes estimated recoveries (spawning ground, hatcheries, harvest, etc.) and observed recoveries if estimated recoveries were unavailable.

Accelerated subyearling releases

For the available brood years, SARs for accelerated subyearling-released Chinook have ranged from 0.000011 to 0.004614 (Table 11.36). This hatchery program was discontinued after brood year 2008.

Table 11.36. Subyearling-to-adult ratios (SARs) for Turtle Rock accelerated subyearling-released summer Chinook, brood years 1995-2008.

Brood year	Number released[a]	Estimated adult captures[b]	SAR
1995	166,203	13	0.000078
1996	198,720	79	0.000398
1997	196,459	3	0.000015
1998	185,551	72	0.000388

Brood year	Number released[a]	Estimated adult captures[b]	SAR
1999	192,665	889	0.004614
2000	194,603	63	0.000324
2001	196,355	169	0.000861
2002	200,165	5	0.000025
2003	185,834	2	0.000011
2004	203,255	159	0.000782
2005	192,045	82	0.000427
2006	186,324	217	0.001165
2007	188,328	309	0.001641
2008	197,136	35	0.000178
Average	***191,689***	***150***	***0.000779***
Median	***193,634***	***76***	***0.000393***

[a] Includes all tag codes and CWT released fish (CWT + Ad Clip fish and CWT-only fish).

[b] Includes estimated recoveries (spawning ground, hatcheries, harvest, etc.) and observed recoveries if estimated recoveries were unavailable.

Yearling releases

For the available brood years since 2004, SARs for yearling-released Chinook have ranged from 0.008056 to 0.028164 (Table 11.37).

Table 11.37. Smolt-to-adult ratios (SARs) for Turtle Rock/Chelan Falls yearling-released summer Chinook, brood years 1995-2010.

Brood year	Number released[a]	Estimated adult captures[b]	SAR
1995	145,318	1,047	0.007205
1996	194,251	1,558	0.008021
1997	198,924	4,813	0.024195
1998	215,646	5,764	0.026729
1999	280,683	2,673	0.009523
2000	278,308	2,038	0.007323
2001	199,694	3,937	0.019715
2002	192,234	2,570	0.013369
2003	199,386	2,100	0.010532
2004	202,682	2,594	0.012798
Average[c]	***210,713***	***2,909***	***0.013941***
Median[c]	***199,540***	***2,582***	***0.011665***
2005	202,329	1,630	0.008056
2006	142,699	4,019	0.028164
2007	161,071	1,870	0.011610

Brood year	Number released[a]	Estimated adult captures[b]	SAR
2008	447,155	9,112	0.020378
2009	423,565	4,354	0.010279
2010	547,205	9,284	0.016966
Average[d]	***320,671***	***5,045***	***0.015909***
Median[d]	***312,947***	***4,187***	***0.014288***

[a] Includes all tag codes and CWT released fish (CWT + Ad Clip fish and CWT-only fish).

[b] Includes estimated recoveries (spawning ground, hatcheries, harvest, etc.) and observed recoveries if estimated recoveries were unavailable.

[c] Summary statistics for yearling Turtle Rock summer Chinook released into the Columbia River (brood years 1995-2004).

[d] Summary statistics for yearling Turtle Rock/Chelan River summer Chinook released into the Chelan River (brood years 2005 to present).

11.6 ESA/HCP Compliance

Broodstock Collection

The 2014 brood Chelan Falls (formerly Turtle Rock) summer Chinook program was supported through adult collections at the Eastbank outfall and surplus adults from Chief Joe Hatchery. During 2014, broodstock collections at the Eastbank outfall were consistent with the 2014 Upper Columbia River Salmon and Steelhead Broodstock Objectives and site-based broodstock collection protocols as required in ESA permit 1347. The 2014 collection target totaled 312 summer Chinook. Actual 2014 broodstock collection was 331 adults.

Hatchery Rearing and Release

The brood year 2014 release totaled 465,450 yearling fish. These releases represented 80.8% of the 576,000 Rocky Reach HCP and ESA Section 10 Permit 1347 production for the Chelan Falls yearling summer Chinook production. Lower than expected fertilization rates (83.6%) followed by eyed-egg to ponding survival were the primary factors in not meeting the release goal.

Hatchery Effluent Monitoring

Per ESA Permits 1196, 1347, 1395, 18118, 18120, and 18121, permit holders shall monitor and report hatchery effluents in compliance with applicable National Pollution Discharge Elimination Systems (NPDES) (EPA 1999) permit limitations. There were no NPDES violations reported at PUD Hatchery facilities during the period 1 January through 31 December 2016. NPDES monitoring and reporting for Chelan PUD Hatchery Programs during 2016 are provided in Appendix F.

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SECTION 13: APPENDICES

Appendix A: **Abundance and Total Numbers of Chinook Salmon and Trout in the Chiwawa River Basin, Washington, 2016.**

Appendix B: **Fish Trapping at the Chiwawa and Wenatchee Smolt Traps during 2016.**

Appendix C: **Summary of CSS PIT-Tagging Activities in the Wenatchee River Basin, 2016.**

Appendix D: **Wenatchee Steelhead Spawning Escapement Estimates, 2016.**

Appendix E: **Examining the Genetic Structure of Wenatchee River Basin Steelhead and Evaluating the Effects of the Supplementation Program.**

Appendix F: **NPDES Hatchery Effluent Monitoring, 2016.**

Appendix G: **Steelhead Stock Assessment at Priest Rapids Dam, 2016.**

Appendix H: **Wenatchee Sockeye Salmon Spawning Escapement, 2016.**

Appendix I: **Genetic Diversity of Wenatchee Sockeye Salmon.**

Appendix J: **Wenatchee Spring Chinook Redd Estimates, 2016.**

Appendix K: **Genetic Diversity of Natural Chiwawa River Spring Chinook Salmon.**

Appendix L: **Fish Trapping at the Nason Creek Smolt Trap during 2016.**

Appendix M: **Fish Trapping at the White River Smolt Trap during 2016.**

Appendix N: **Genetic Diversity of Upper Columbia Summer Chinook Salmon.**

Appendix O: **Summer Chinook Spawning Ground Surveys in the Methow and Chelan Rivers, 2016.**

Appendix A

Abundance and Total Numbers of Chinook Salmon and Trout in the Chiwawa River basin, Washington, 2016

BioAnalysts, Inc.
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January 25, 2017

TO: HCP Hatchery Committee

FROM: Tracy Hillman

Subject: Abundance and Total Numbers of Chinook Salmon and Trout in the Chiwawa River basin, Washington, 2016

The Chelan County Public Utility District (PUD) hatchery program is operated through a habitat conservation plan (HCP) that was incorporated into the PUD's license in 2004. The HCP directed the signatories to develop a monitoring and evaluation plan within one year of the effective date. This resulted in the development of the Conceptual Approach to Monitoring and Evaluating the Chelan County Public Utility District Hatchery Programs (Murdoch and Peven 2005). In 2013, the Hatchery Committees updated the hatchery monitoring and evaluation plan (Hillman et al. 2013). This study will help the Hatchery Committees determine if it is meeting Objective 2 in the updated monitoring and evaluation plan.

Objective 2: *Determine if the proportion of hatchery fish on the spawning grounds affects the freshwater productivity of supplemented stocks.*

We estimated densities and total numbers of age-0 spring Chinook salmon *Oncorhynchus tshawytscha*, trout *Oncorhynchus* sp., and char *Salvelinus* sp. in the Chiwawa River basin, Washington, in August 2016. This was the 24th year of an ongoing study to assess the freshwater productivity (juveniles/redd) of Chinook salmon in the Chiwawa River basin. We used landscape classification to stratify streams in the basin that supported juvenile Chinook salmon (Hillman and Miller 2004). Classification "explained" most of the variability in fish numbers caused by geology, land type, valley bottom type, stream state condition, and habitat type. We identified ten reaches on the lower 31 miles (50 km) of the Chiwawa River and one reach in each of Phelps, Rock, Chikamin, Big Meadow, Alder, Brush, Clear, Y, and Unnamed[1] creeks (Figure 1). Each reach consisted of several combinations of state-type and habitat-type strata. We used classification to find reference areas for reaches in the Chiwawa River. We matched Reach 3 and Reach 8 of the Chiwawa River with a moderately-confined section of Nason Creek (RM 0.62-1.70) and an unconfined area of the Little Wenatchee River (RM 4.39-8.55), respectively

[1] Unnamed tributary that drains the eastside of Chiwawa Ridge. Its confluence with the Chiwawa River is about 1 mile (1.6 km) downstream from the mouth of Phelps Creek.

(Hillman and Miller 2004). Because of the supplementation program in Nason Creek, the use of Nason Creek as a reference for the Chiwawa River is no longer valid. However, as directed by the Hatchery Committee, we continue to sample sites in Nason Creek. Following methods described in Hillman and Miller (2004), we used underwater observations to estimate numbers of fish in 187 randomly selected sites.

During sampling in August 2016, discharge in the Chiwawa River averaged 202 cubic feet per second (cfs) and ranged from 126-325 cfs (Figure 2). Stream temperatures during the study period ranged from 8.0 to 18.0ºC. Fish species observed in the Chiwawa River basin and reference areas during the 1992-2016 survey period[2] included: spring Chinook salmon, coho salmon *O. kisutch*, sockeye salmon *O. nerka*, steelhead/rainbow trout *O. mykiss* (hatchery rainbow were present only in 1992 and 1993), cutthroat trout *O. clarki lewisi*, bull trout *S. confluentus*, brook trout *S. fontinalis*, mountain whitefish *Prosopium williamsoni*, dace *Rhinichthys* sp., northern pikeminnow *Ptychocheilus oregonensis*, suckers *Catostomus* sp., and sculpin *Cottus* sp. The age-0 spring Chinook that we observed in the Chiwawa River basin during the 2016 survey were produced from 543 redds counted in the fall of 2015 (Hillman et al. 2016). Assuming a mean fecundity of 4,847 eggs per female Chinook (from females collected for broodstock), and that no female produced more than one redd (Murdoch et al. 2009), we estimated that the Chiwawa River basin was seeded with 2,631,921 eggs in 2015 (Appendix A).

In 2016, riffles made up the largest fraction of habitat types in reaches of the Chiwawa River basin (54% of the total stream surface area) (Table 1). Pools (24%), glides (6%), and multiple channels (16%) constituted the remaining 46% of the stream surface area. We found woody debris associated with most multiple-channel habitat.

Chinook Salmon Abundance

Chinook salmon were the most abundant salmonid in the Chiwawa River basin. We estimated, based on surface area, that age-0 Chinook salmon numbered 140,172 (±10% of the estimated total) in the Chiwawa River basin in August 2016 (Table 2). Extrapolating based on volume of habitat types, age-0 Chinook numbered 137,525 (±13%) in the Chiwawa River basin. About 3% of the juvenile Chinook were in tributaries to the Chiwawa River. During the 1992-2016 surveys, numbers of age-0 Chinook ranged from 5,815 to 149,563 in the Chiwawa River basin (Figure 3; Appendix A and B). Most of the difference in juvenile numbers among years resulted from different seeding (stock) levels (Figure 4). Numbers of Chinook redds in the Chiwawa River basin during 1992-2015 ranged from 13 to 1,078, resulting in seeding levels of 66,248 to 4,984,672 eggs (Appendix A).

As in most years, age-0 Chinook in 2016 were distributed contagiously among reaches in the Chiwawa River (Table 2). In the Chiwawa River, densities of age-0 Chinook were highest in the upper reaches (Reaches 7-10). The highest densities in the Chiwawa River basin were in tributaries to the Chiwawa River (Table 2). Age-0 Chinook were most abundant in multiple channels and least abundant in glides and riffles. We found the majority of the Chinook

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[2] The study period 1992-2016 includes only 24 years of sampling because there was no sampling in 2000.

associated with woody debris in multiple channels (multiple channel use index = 2.83)[3]. These sites (multiple channels) made up 16% of the total surface area of the Chiwawa River basin, but they provided habitat for 56% of all the age-0 Chinook in the basin in 2016 (Appendix C). In contrast, riffles made up 54% of the total surface area, but provided habitat for only 8% of all age-0 Chinook in the Chiwawa River basin (riffle use index = 0.24). Pools made up 24% of the total surface area and provided habitat for 35% of all age-0 Chinook in the basin (pool use index = 1.59). Few Chinook used glides that lacked woody debris (glide use index = 0.25).

As noted earlier, we assumed that the Chiwawa River was seeded with 2,631,921 Chinook eggs (543 redds times 4,847 eggs/female) in fall, 2015, and that at least 140,172 of those survived to August 2016. This means that the egg-to-parr survival was at least 5.3% (95% confidence bound 4.8-5.9%). During 1992-2016, egg-to-parr survival averaged 8.0% (range 2.7-19.1%) in the Chiwawa River basin (Appendix A). This survival rate comports with those from other streams. For example, Mullan et al. (1992) estimated an egg-to-parr survival rate of 9.8% for spring Chinook salmon in Icicle Creek, a tributary of the Wenatchee River. Using a Beverton and Holt model, Hubble (1993) estimated that egg-to-parr survival of Chinook in the Chewuck River, a tributary to the Methow River, ranged between 13% and 32%, depending on percent seeding level in the basin. Kiefer and Forster (1991) estimated a mean egg-to-parr survival rate of 5.5% (range 5.1-6.7%) for naturally-spawning spring Chinook salmon in the entire upper Salmon River. They also noted that egg-to-parr survival of natural spawners and adult outplants in the headwater streams of the upper Salmon River averaged 24.4% (range 16.1-32.0%). Petrosky (1990) reported an egg-to-parr survival range of 1.2-29.0% for Chinook in the upper Salmon River, Idaho. Konopacky et al. (1986) estimated egg-to-parr survival of Chinook in Bear Valley Creek, Idaho, as 8.1-9.4%. Work by Richards and Cernera (1987) in Bear Valley Creek indicated an egg-to-parr survival of 2.1%.

Mean densities of age-0 Chinook salmon in two reaches of the Chiwawa River were generally less than those in corresponding reference areas (Figure 5). Within both the Chiwawa River and its reference areas, pools and multiple channels consistently had the highest densities of age-0 Chinook.

We estimated a total of 282 (±43% of the estimated total) age-1+ Chinook salmon in the Chiwawa River basin in August 2016 (Table 3). In August 1992-2016, numbers of age-1+ Chinook ranged from 5 to 967 in the Chiwawa River basin (Figure 3; Appendix B). These fish occurred throughout the Chiwawa River. We found relatively few age-1+ Chinook in tributaries; although, numbers in Big Meadow Creek were higher in 2015 than in past years. Age-1+ Chinook were most abundant in multiple channels and pools.

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[3] The habitat use index was calculated as follows: Multiple channel use = ($parr_{mc}/parr_t$) / ($area_{mc}/area_t$), where $parr_{mc}$ = the number of parr counted in multiple channel habitat, $parr_t$ = the total number of parr counted within all habitat types, $area_{mc}$ = the area of multiple channel habitat within the sampling frame, and $area_t$ = the total area of the sampling frame. A multiple channel use index value of 1 would indicate that parr were uniformly distributed among habitat types and exhibited no preference for multiple habitat types. Values greater than 1 indicate use of multiple channels to a greater extent than the average, while scores between 0 and 1 indicate below-average use of multiple channel habitat.

Juvenile Chinook Salmon Productivity (Fish/Redd)

Freshwater productivity of juvenile Chinook salmon was estimated as the number of parr (age-0 Chinook) per redd in the Chiwawa River basin. Theoretically, the relationship between number of parr and redds can be explained mathematically provided the relationship between the two parameters goes through the origin, increases monotonically at low spawning levels, and shows some level of density dependence at high spawning levels. We identified four alternative hypotheses that may explain the relationship between spawning level (redds) and numbers of age-0 Chinook:

1. The first hypothesis assumed that the number of juveniles increases constantly toward an asymptote as the number of redds increases. After the asymptote is reached, the number of juveniles neither increases nor decreases. The asymptote represents the maximum number of juveniles the system can support (i.e., carrying capacity for the system). This hypothesis was modeled with a Beverton-Holt curve that took the form:

$$\boldsymbol{J} = \frac{(\boldsymbol{\alpha R})}{(\boldsymbol{\beta} + \boldsymbol{R})}$$

   where $\boldsymbol{J}$ is the number of juvenile (age-0) Chinook, $\boldsymbol{R}$ is the number or redds, $\boldsymbol{\alpha}$ is the maximum number of juveniles produced, and $\boldsymbol{\beta}$ is the number of redds needed to produce (on average) juveniles equal to one-half the maximum number of juveniles.

2. The second hypothesis, like the first, assumed that the number of juveniles increases toward an asymptote (carrying capacity) as the number of redds increases. After the carrying capacity is reached, the number of juveniles neither increases nor decreases. The carrying capacity represents the maximum number of juveniles the system can support. This hypothesis was modeled with a smooth hockey stick function that took the form:

$$\boldsymbol{J} = \boldsymbol{J}_{\infty}\left(\boldsymbol{1} - \boldsymbol{e}^{-\left(\frac{\boldsymbol{\alpha}}{\boldsymbol{J}_{\infty}}\right)\boldsymbol{R}}\right)$$

   where $\boldsymbol{J}$ and $\boldsymbol{R}$ are as above, $\boldsymbol{\alpha}$ is the slope at the origin of the spawner-recruitment curve, and $\boldsymbol{J}_{\infty}$ is the carrying capacity of juveniles.

3. The third hypothesis assumed that the number of juveniles increases to a maximum and then declines as the number or redds increases. In this case, mortality rate of juveniles (or eggs) is proportional to the initial number of redds. Higher mortality rate is associated with density-dependent growth coupled with size-dependent predation. This hypothesis was modeled with a Ricker curve that took the form:

$$\boldsymbol{J} = \boldsymbol{\alpha R e^{-\beta R}}$$

   where $\boldsymbol{J}$ and $\boldsymbol{R}$ are as above, $\boldsymbol{\alpha}$ is the number of juveniles per redd at low spawning levels, and $\boldsymbol{\beta}$ describes how quickly the juveniles per redd drop as the number of redds increases.

4. The fourth hypothesis, like the first, assumed that the number of juveniles increases constantly, but unlike the first, the number of juveniles does not reach an asymptote. Rather, the number of juveniles increases indefinitely, but at a slowing rate of increase. This hypothesis was modeled with both a Cushing curve and a Gamma function. The

Cushing curve took the form:

$$J = \alpha R^{\gamma}$$

where J and R are as above, α is the number of juveniles per redd at low spawning levels, and γ describes the level of density dependence at high spawning levels. The Gamma function is a three-parameter model that has the form:

$$J = \alpha R^{\gamma} e^{-\beta R}.$$

This is an un-normalized gamma function that is similar to the Cushing curve when $\beta = 0$.

We used Akaike's Information Criterion for small sample size (AIC_c) to determine which model(s) best explained the productivity of juvenile Chinook in the Chiwawa River basin. AIC_c was estimated as:

$$AIC_c = -2log\big(£(\theta|data)\big) + 2K + \left(\frac{2K(K+1)}{n-K-1}\right)$$

where $log(£(\theta|data))$ is the maximum likelihood estimate, K is the number of estimable parameters (structural parameters plus the residual variance parameter), and n is the sample size (Burnham and Anderson 2002). We used least-squares methods to estimate $log(£(\theta|data))$, which was calculated as $log(\sigma^2)$, where σ^2 = residual sum of squares divided by the sample size ($\sigma^2 = RSS/n$). AIC_c assesses model fit in relation to model complexity (number of parameters). The model with the smallest AIC_c value represents the "best approximating" model within the model set. Remaining models were ranked relative to the best model using AIC_c difference scores (**ΔAIC_c**), Akaike weights (w_i), and evidence ratios. Models with **ΔAIC_c** values less than 2 indicate that there is substantial support for these models as being the best-fitting models within the set (Burnham and Anderson 2002). Models with values greater than 2 have less support. Akaike weights are probabilities estimating the strength of the evidence supporting a particular model as being the best model within the model set. Models with small w_i values are less plausible as competing models (Burnham and Anderson 2002). If no single model could be specified as the best model, a "best subset" of competing models was identified using (1) AIC_c differences to indicate the level of empirical support each model had as being the best model, (2) evidence ratios based on Akaike weights to indicate the relative probability that any model is the best model, and (3) coefficients of determination (R^2) assessing the explanatory power of each model.

The use of AIC_c indicated that the Beverton-Holt model best approximated the information in the juveniles/redd data (Table 4; Figure 6). The estimated structural parameters for this model were:

$$Juveniles = \frac{(152{,}439 \times Redds)}{(191 + Redds)}$$

where the bootstrap estimated standard errors for the two parameters were 17,210 and 56, respectively. The adjusted $R^2 = 0.84$. The second-best model was the smooth hockey stick model, which was 1.70 AIC_c units from the best model (Table 4; Figure 6). The estimated parameters for this model were:

$$LN(Juveniles) = 11.7 + LN\left(1 - e^{-\left(\frac{715.9}{116,314}\right)Redds}\right)$$

where the bootstrap estimated standard errors of the two parameters were 0.1 and 391, respectively, and the $R^2 = 0.83$. The AIC_c difference scores, Akaike weights, and evidence ratios indicated that there was substantial support for both the Beverton-Holt and smooth hockey stick models (Table 4). There was less support for the remaining models (Ricker, Gamma[4], and Cushing), which were > 2 AIC_c units from the best models. This was further supported by the fact that, relative to the best models, the remaining models had evidence ratios greater than 10.

Although the Beverton-Holt, smooth hockey stick, and Ricker models have different biological assumptions, they all indicated a density-dependent relationship between spawning levels (redds) and juvenile Chinook production. This was not only evident in the best approximating models, but there was also a significant negative relationship between juveniles per redd and numbers of redds in the Chiwawa River basin (Figure 7). Although data at high seeding levels are lacking, the Beverton-Holt model estimates the population capacity[5] of juvenile Chinook in the Chiwawa River basin at about 152,000 parr. This equates to about 1,197 Chinook parr per hectare. In contrast, the smooth hockey stick model, which fit the data as well as the Beverton-Holt model, estimates the population carrying capacity for juvenile Chinook at about 116,000 parr. This equates to about 913 Chinook parr per hectare. As a comparison, Thorson et al. (2013) estimated the carrying capacity for 15 populations of juvenile Chinook in the Snake River metapopulation as 5,000 juveniles per hectare. However, those authors noted that the estimate could be biased because of imperfect detectability and estimates of spawning numbers.

Steelhead/Rainbow Abundance

Based on stream surface area, we estimated a total of 16,244 (±14% of the estimated total) age-0 steelhead/rainbow (<4 in) in reaches of the Chiwawa River basin in August 2016 (Table 5). During the 1992-2016 survey period, numbers of age-0 steelhead/rainbow ranged from 1,410 to 45,727 in the Chiwawa River basin (Figure 8; Appendix B). In 1992-2016, numbers of age-0 steelhead/rainbow varied among reaches, but were typically highest in the lower reaches of the Chiwawa River. In all years they most often used riffle and multiple channel habitats in the Chiwawa River, although we also found them associated with woody debris in pool and glide habitat. In tributaries, they were generally most abundant in small pools. Those that we observed in riffles selected stations in quiet water behind small and large boulders or occupied stations in quiet water along the stream margin. In pool and multiple-channel habitats, we found age-0 steelhead/rainbow using the same kinds of habitat as age-0 Chinook salmon.

We estimated that 4,031 (±15% of the estimated total) age-1+ steelhead/rainbow (4-8 in) lived in reaches of the Chiwawa River basin in August 2016 (Table 6). During the survey period 1992-

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[4] The γ parameter in the Gamma model was greater than 0, which means that this model is nearly identical to the Ricker model.

[5] In these analyses, we are calculating "population" carrying capacity (*K*), which is defined as the maximum equilibrium population size estimated with population models. This should not be confused with "habitat" carrying capacity (*C*), which is defined as the maximum population of a given species that a particular environment can sustain.

2016, numbers of age-1+ steelhead/rainbow ranged from 754 to 22,130 (Figure 8; Appendix B). In most years, we found these fish in nearly all reaches, but they were typically most numerous in lower reaches of the Chiwawa River. We observed age-1+ steelhead/rainbow mostly in pool, riffle, and multiple-channel habitats. Those that we observed in pools were usually in deeper water than age-0 steelhead/rainbow and Chinook. Like age-0 steelhead/rainbow, age-1+ steelhead/rainbow selected stations in quiet water behind boulders in riffles, but we generally did not find the two age groups together. Age-1+ steelhead/rainbow appeared to use deeper and faster water than did age-0 steelhead/rainbow.

We estimated that steelhead/rainbow larger than 8 inches numbered 14 (±71% of the estimated total) in the Chiwawa River basin in August 2016 (Table 7). During the period 1992-2016, steelhead/rainbow numbers ranged from 8 to 1,869 (Appendix B). Steelhead/rainbow larger than 8 inches were most abundant in the lower Chiwawa River; however, in 1992 and 1993, they were most abundant near campgrounds in Reaches 8, 9, and 10 (these were mostly hatchery rainbow trout planted near the campgrounds). We found very few in tributaries. Most of the steelhead/rainbow larger than 8 inches used deep pools (>5 feet), and occupied stations near the bottom at the upstream end of pools.

Bull Trout Abundance

We estimated, based on surface area that at least 291 (±20% of the estimated total) juvenile (2-8 in) bull trout lived in reaches of the Chiwawa River basin in August 2016 (Table 8). We found most of these fish in the upper-most reaches of the Chiwawa River and in Rock and Phelps creeks. During 1992-2016, numbers of juvenile bull trout ranged from 79 to 505 (Figure 9; Appendix B). These estimates and those for adult bull trout are incomplete because we did not sample the entire range of bull trout in all tributaries. That is, we did not extend our surveys into the headwaters of the Chiwawa River because there were no juvenile Chinook there. Areas beyond the distribution of juvenile Chinook salmon are known to support bull trout, steelhead/rainbow, and cutthroat trout (USFS 1993). In addition, our estimates of bull trout abundance were based on daytime snorkel surveys, which may underestimate the actual abundance of bull trout.[6] Several studies (e.g., Goetz 1994; Thurow and Schill 1996; Hillman and Chapman 1996; Bonar et al. 1997) have found bull trout population estimates based on nighttime snorkeling to be in some cases more accurate than daytime snorkeling, especially for juvenile bull trout. Our estimates of adult bull trout numbers may be more accurate than those for juveniles.

In all years, we found most juvenile bull trout in the upstream reaches of the Chiwawa River. In 2016, they occurred primarily in Reaches 9-10 on the Chiwawa River. We found the majority of these fish in multiple channels, pools, and riffles, and few in glides. They consistently occupied stations close to the stream bottom over rubble and small boulder substrate or near woody debris. This is similar to the observation of Pratt (1984) in the upper Flathead River Basin in Montana. She found that juvenile bull trout lay close to instream cover and that they tended to conceal

[6] Because there are no estimates for probability of detecting bull trout with daytime underwater observation methods in the Chiwawa River basin, we could not adjust bull trout numbers based on detectability. Therefore, the numbers reported in this report likely underestimate the "true" number of bull trout in the survey area.

themselves. Consequently, she found it difficult to estimate accurately their numbers. Although this implies that we underestimated numbers of juvenile bull trout in the Chiwawa River, the relative distribution of juvenile bull trout is valid if we assume that we saw the same fraction of juveniles in all reaches (i.e., detection probability was the same across survey sites).

We estimated a total of 1,254 (±12% of the estimated total) adult (>8 in) bull trout in reaches of the Chiwawa River basin in August 2016 (Table 9). This was the second highest number of adult bull trout that we recorded during the more than 20-year survey period. During 1992-2016, numbers of adult bull trout ranged from 76 to 2,286 (Figure 9; Appendix B). As with juvenile bull trout, we found most of the adult bull trout upstream from Reach 6; although they were found in all reaches on the Chiwawa River. We found few adult bull trout in tributaries of the Chiwawa River. Adult bull trout primarily used pools and multiple channel habitat, although most of the smaller adults (<10 in) used riffles.

Abundance of Other Salmonids

In August 2016, we estimated that at least 66 brook trout, an exotic species closely related to the bull trout, occurred in the Chiwawa River, Chikamin Creek, Big Meadow Creek, Minnow Creek, and in the Little Wenatchee River survey areas. In both the Chiwawa and Little Wenatchee rivers, brook trout usually used multiple channels and pools. Few appeared to be bull trout/brook trout hybrids. In Chikamin, Minnow, and Big Meadow creeks, brook trout were most abundant in pools. Brook trout lengths ranged from 2-12 inches.

At least 550 westslope cutthroat trout occurred in the Chiwawa River, Phelps Creek, Rock Creek, and Little Wenatchee River survey areas in August 2016. These fish most often occurred in pools and multiple channel habitats. They ranged in size from 2-22 inches. Juvenile coho salmon were observed in Nason Creek and the Chiwawa River.

We observed both juvenile and adult mountain whitefish in the Chiwawa River, Phelps Creek, Rock Creek, Nason Creek, and the Little Wenatchee River survey areas. In sum, at least 6,031 adult and 1,454 juvenile whitefish lived in these streams in August 2016. We found few whitefish in most tributaries to the Chiwawa River.

Conclusion

This was the 24th year of a study to monitor trends in juvenile spring Chinook production in the Chiwawa River basin. As shown in Figure 3, numbers of juvenile Chinook salmon in the Chiwawa River basin have fluctuated widely over the 24-year period. Numbers of juveniles in 2001, 2002, and 2009-2016 were some of the highest recorded, while numbers in the mid-1990s were some of the lowest. Interestingly, the highest spawning escapements (highest redd numbers) resulted in the lowest egg-parr survival rates (Appendix A). This is supported by the fact that the best approximating models clearly demonstrated a density-dependent relationship between seeding levels and juvenile production. Indeed, there was a significant negative relationship between parr per redd and numbers of redds in the Chiwawa River basin. This is an important observation because some of the hypotheses in the revised monitoring and evaluation plan (Hillman et al. 2013) are only valid when the supplemented population is below its carrying capacity.

The best fitting stock-recruitment models indicate that the population capacity of the Chiwawa River basin is between 140,000 to 185,000 spring Chinook parr. This equates to an overall density of about 1,100-1,400 parr per hectare. These densities can be achieved with about 490 redds. Assuming a female Chinook produces only one redd (Murdoch et al. 2009), a spawning escapement of about 490 females is needed to fill the capacity of the Chiwawa River basin.

The proportion of hatchery-origin spawners (pHOS) within the Chiwawa River basin during the survey period has ranged from 0 to 100%. Thus, some of the variation in juvenile productivity may be related to pHOS. Although there appeared to be a negative relationship between juvenile productivity (parr/redd) and pHOS, the correlation was not significant (Figure 10). In addition, there was no relationship between juvenile productivity and pHOS after the effects of spawning escapement were removed from the analysis (Figure 10). This suggests that spawning escapement has a larger effect on juvenile productivity than does the presence of hatchery spawners.

The presence of density dependence in the early life stages of spring Chinook is not surprising. Rarely does density dependence appear in numbers of adult spring Chinook or on their spawning grounds. The Chiwawa River basin appears to have plenty of spawning habitat, as indicated by the large numbers of spawners and redds widely distributed throughout the basin during high spawning escapements. However, those large spawning escapements did not translate into large numbers of juveniles or smolts. Thus, density-dependent regulation appears to occur sometime during the early life stages of the fish, likely at the fry stage. It is possible that physical habitat (space) during higher flows when fry are emerging may limit juvenile Chinook production in the basin. Low nutrient levels and its effects on food webs may also be a limiting factor in the basin. If spawning escapements remain relatively high, marine-derived nutrients should increase in the basin, resulting in more food for juvenile Chinook salmon.

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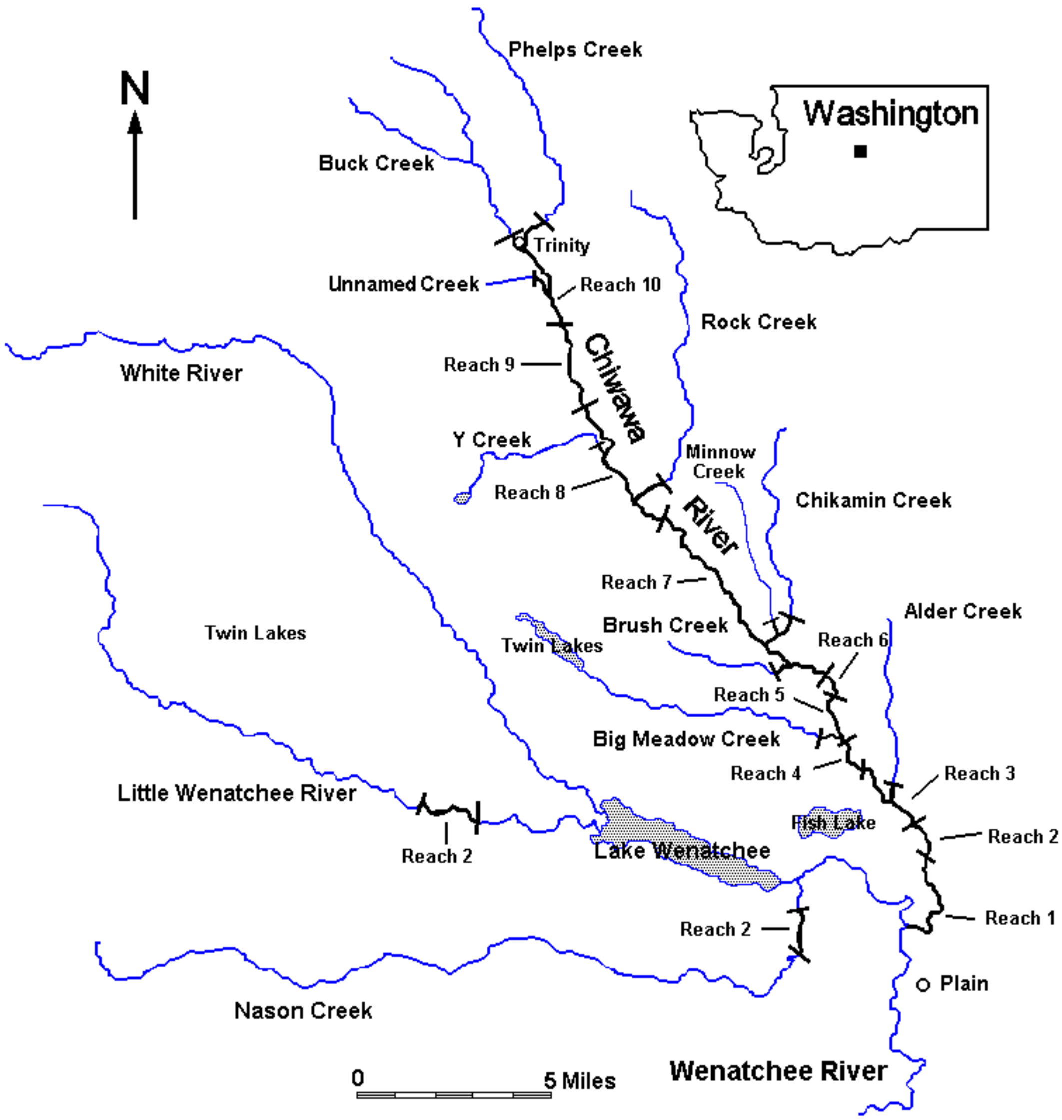

Figure 1. Location of study reaches on the Chiwawa River, and Chikamin, Rock, Big Meadow, Unnamed, Alder, Brush and Phelps creeks, Chelan County, Washington. Reach 2 on Nason Creek and Reach 2 on the Little Wenatchee River were matched with Reaches 3 and 8 on the Chiwawa River, respectively.

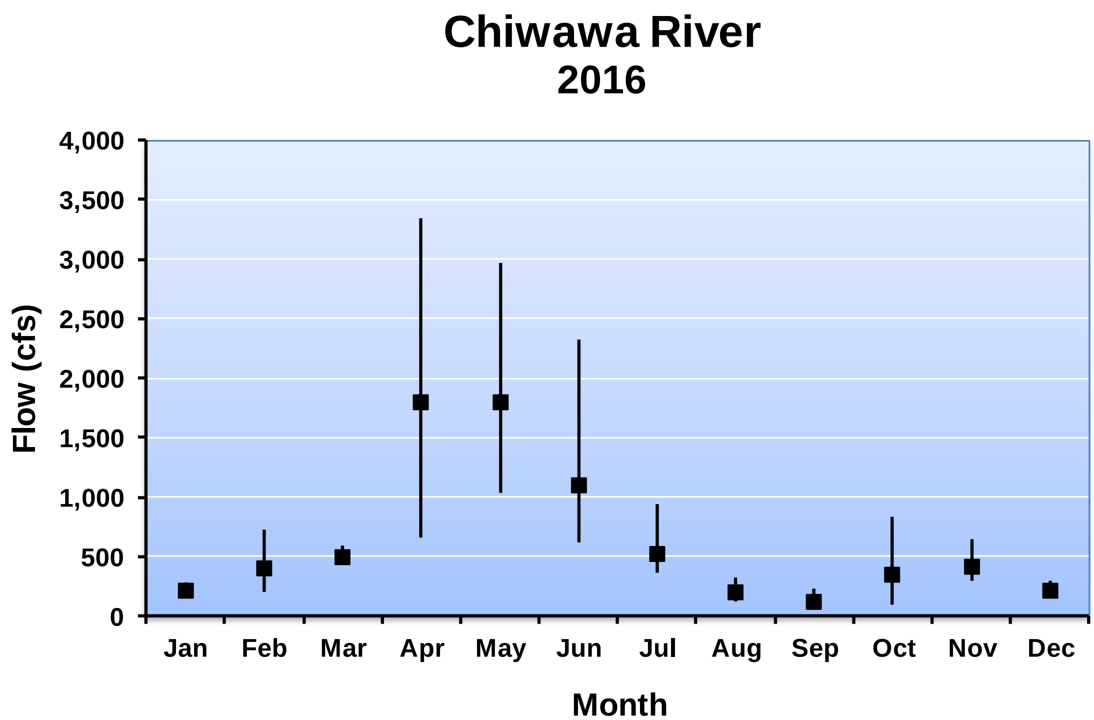

Figure 2. Mean, minimum, and maximum monthly flows in the Chiwawa River for 2016.

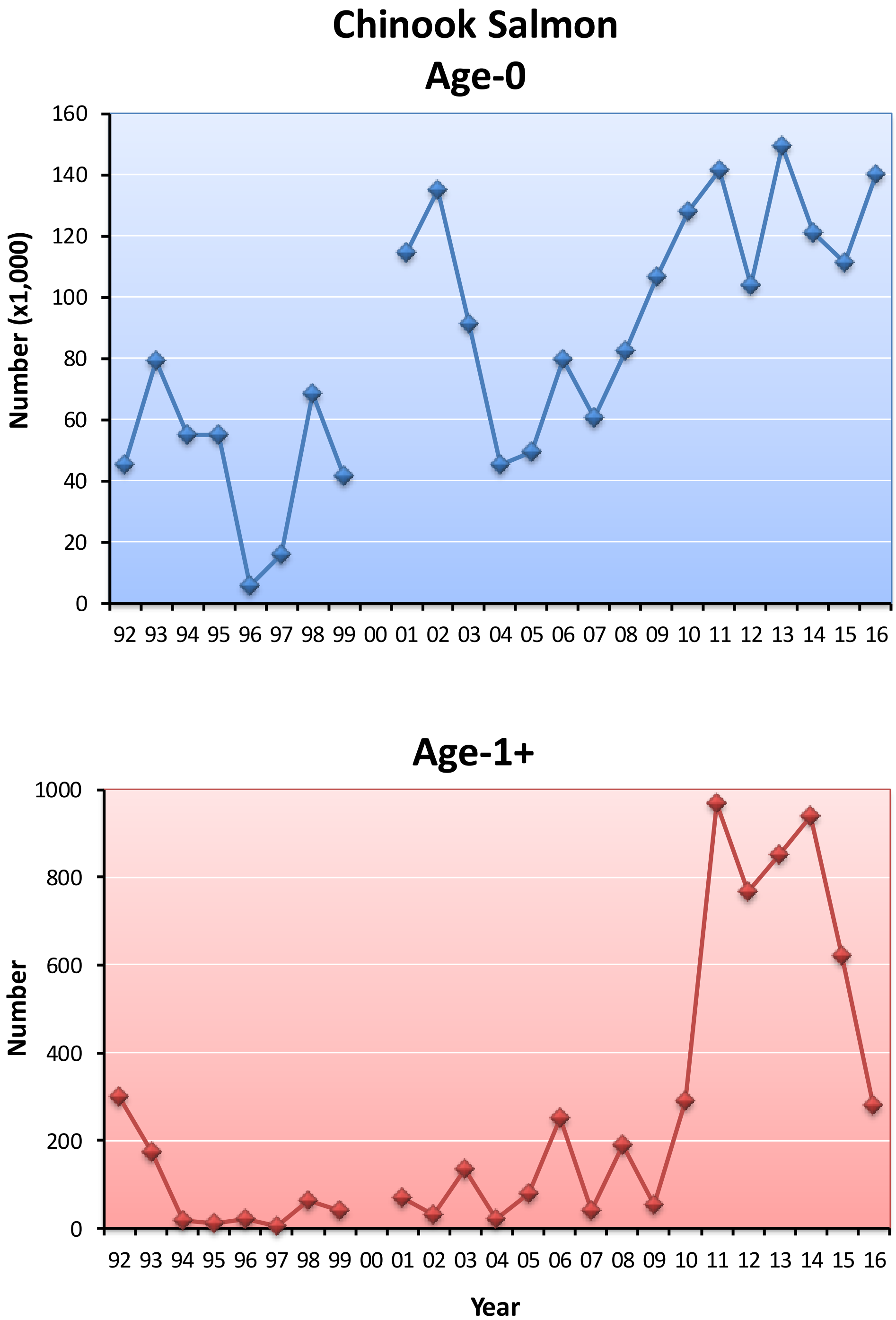

Figure 3. Numbers of age-0 and age-1+ Chinook salmon within the Chiwawa River basin in August 1992-2016; ND = no data.

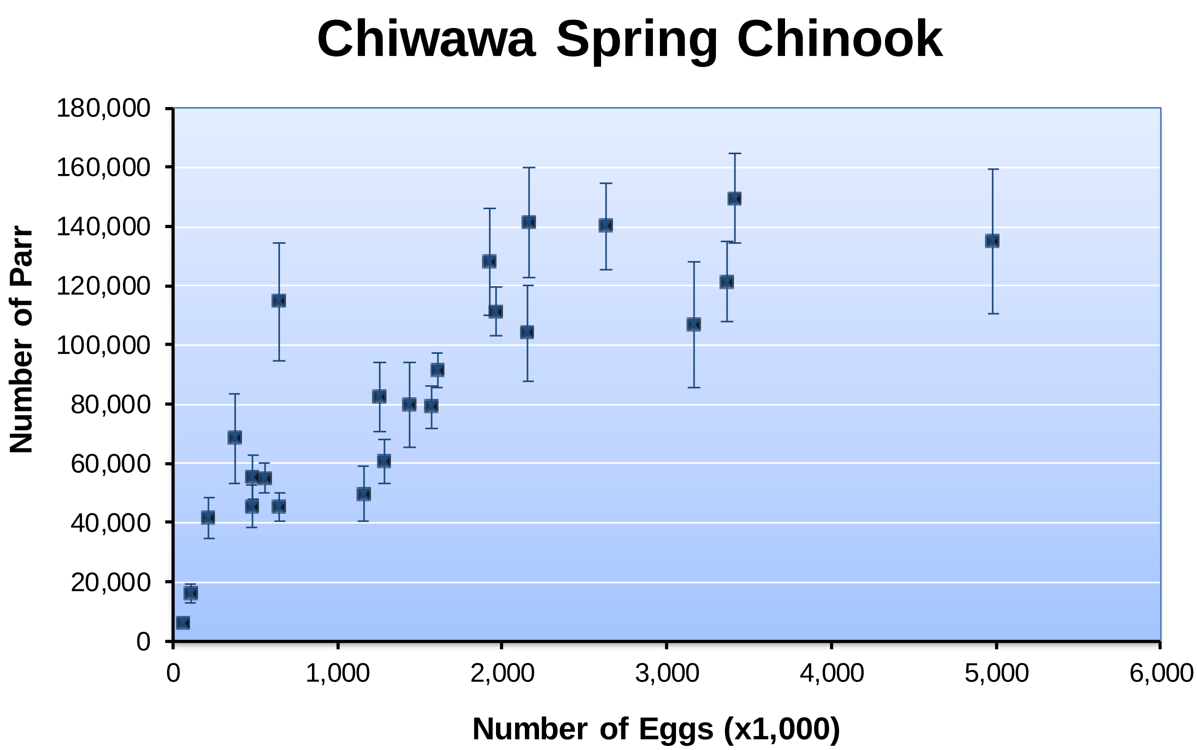

Figure 4. Relationship between total number of Chinook salmon parr counted during the summer (based on fish/ha) and number of eggs deposited in the Chiwawa River basin, 1992-2016. Vertical bars indicate 95% confidence bounds.

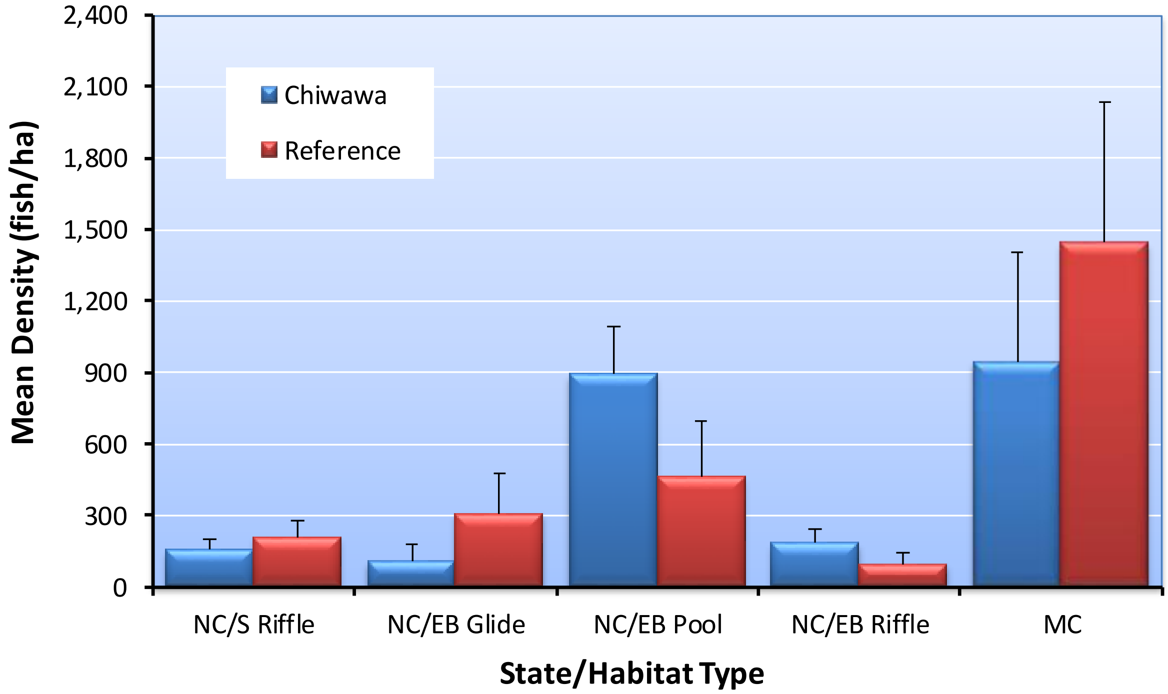

Figure 5. Comparison of the means (95% CI) of age-0 Chinook salmon densities (fish/ha) within state/habitat types in Reaches 3 and 8 of the Chiwawa River and their matched reference areas on Nason Creek and the Little Wenatchee River. There was no sampling in 2000 and no sampling in reference areas in 1992.

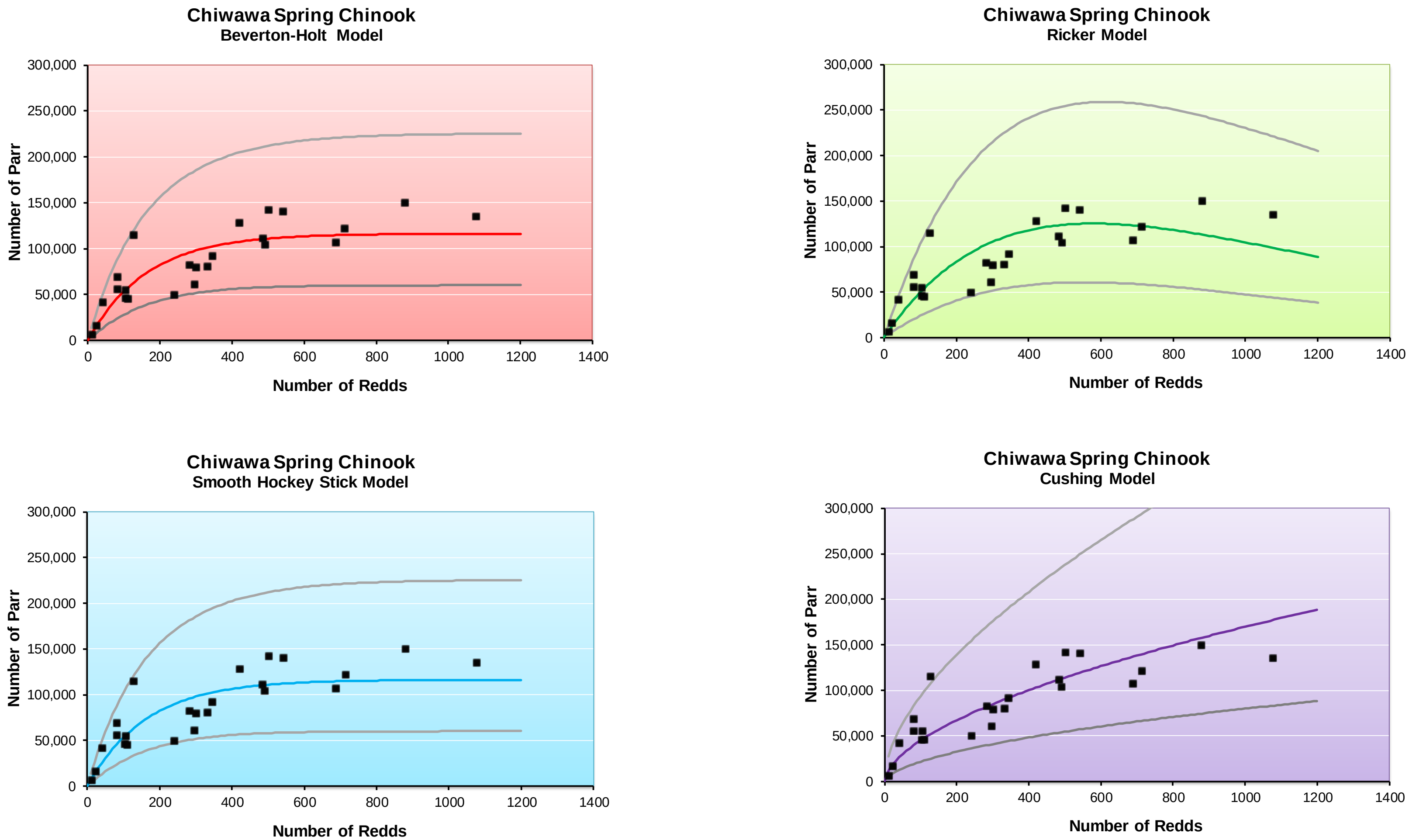

Figure 6. Relationship between numbers of juvenile (age-0) Chinook and redds in the Chiwawa River basin, 1992-2016 (no sampling occurred in 2000). Figures show the fit of the Beverton-Holt model, smooth hockey stick, Ricker model, and the Cushing model to the data. Gray lines indicate the upper and lower 95% C.B.

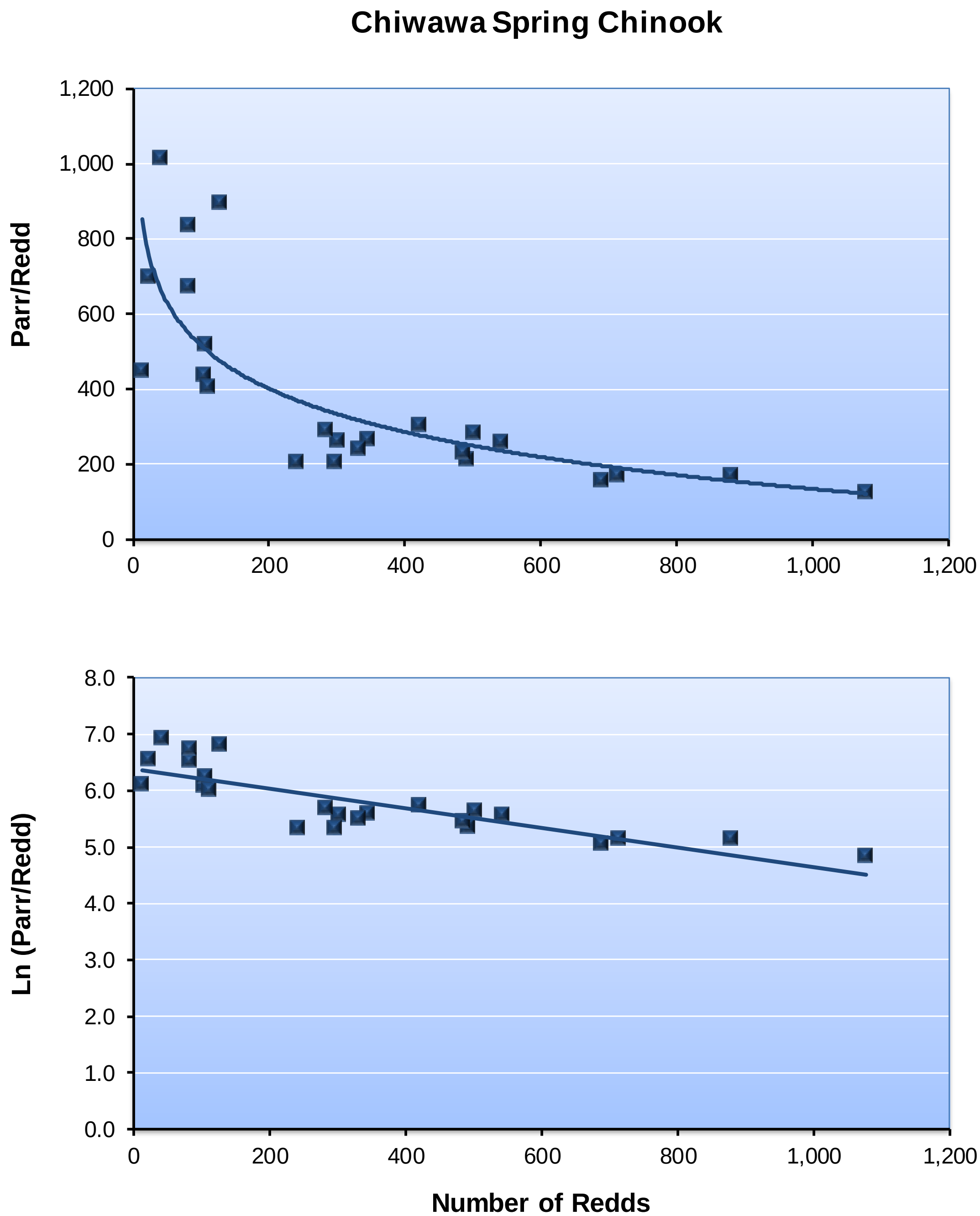

Figure 7. Relationship between parr/redd and numbers of redds (top figure) and natural log parr/redd and numbers of redds (bottom figure) in the Chiwawa River basin, 1992-2016. No sampling was conducted in 2000. Estimates for 1993-2016 included the Chiwawa River and its tributaries; the 1992 estimate included only the Chiwawa River. The linear relationship LN(P/R) = 6.38 – 0.002(Redds) was significant with P = 0.0000; R^2 = 0.690.

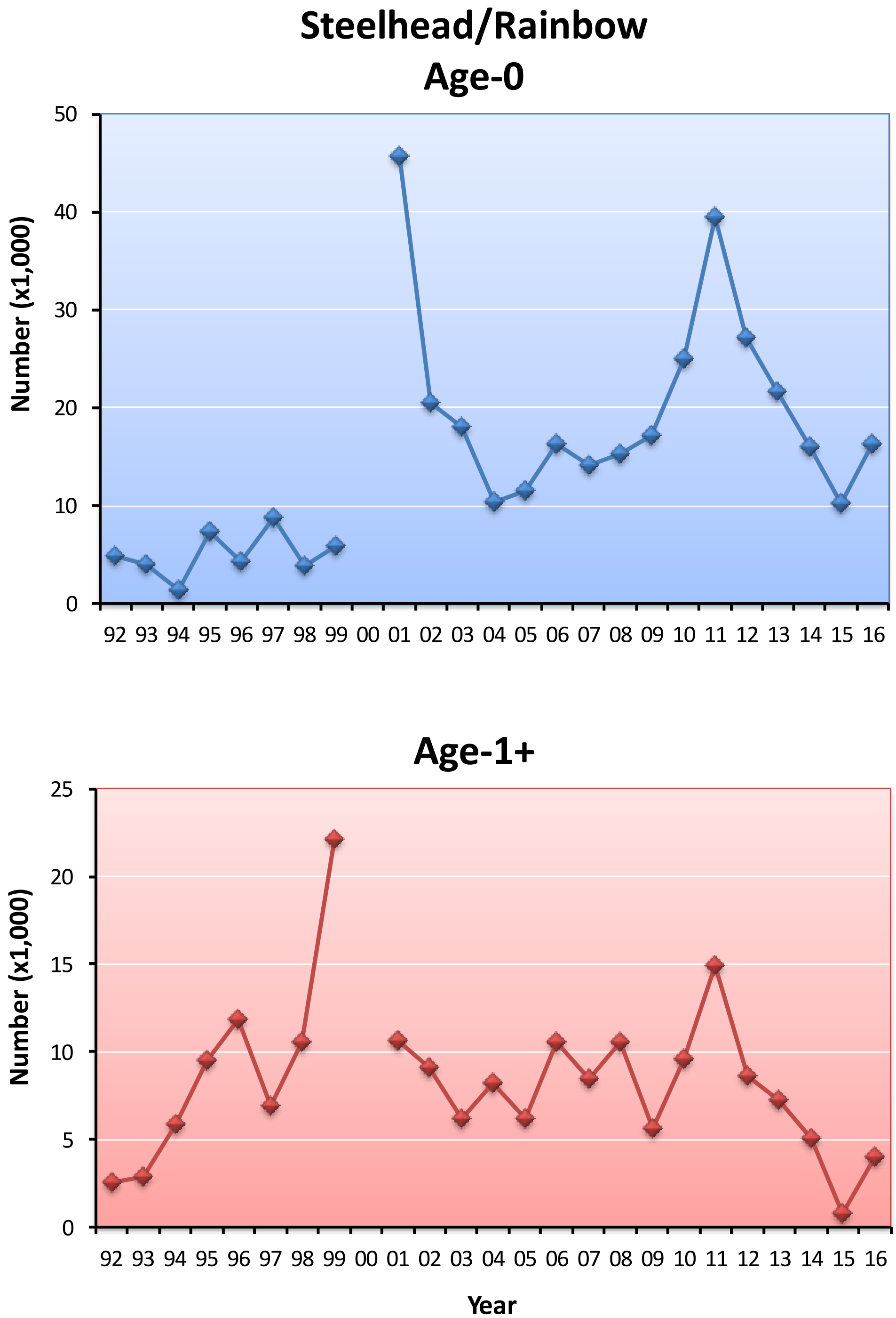

Figure 8. Numbers of age-0 (<4 in) and age-1+ (4-8 in) steelhead/rainbow within the Chiwawa River basin in August 1992-2016; ND = no data.

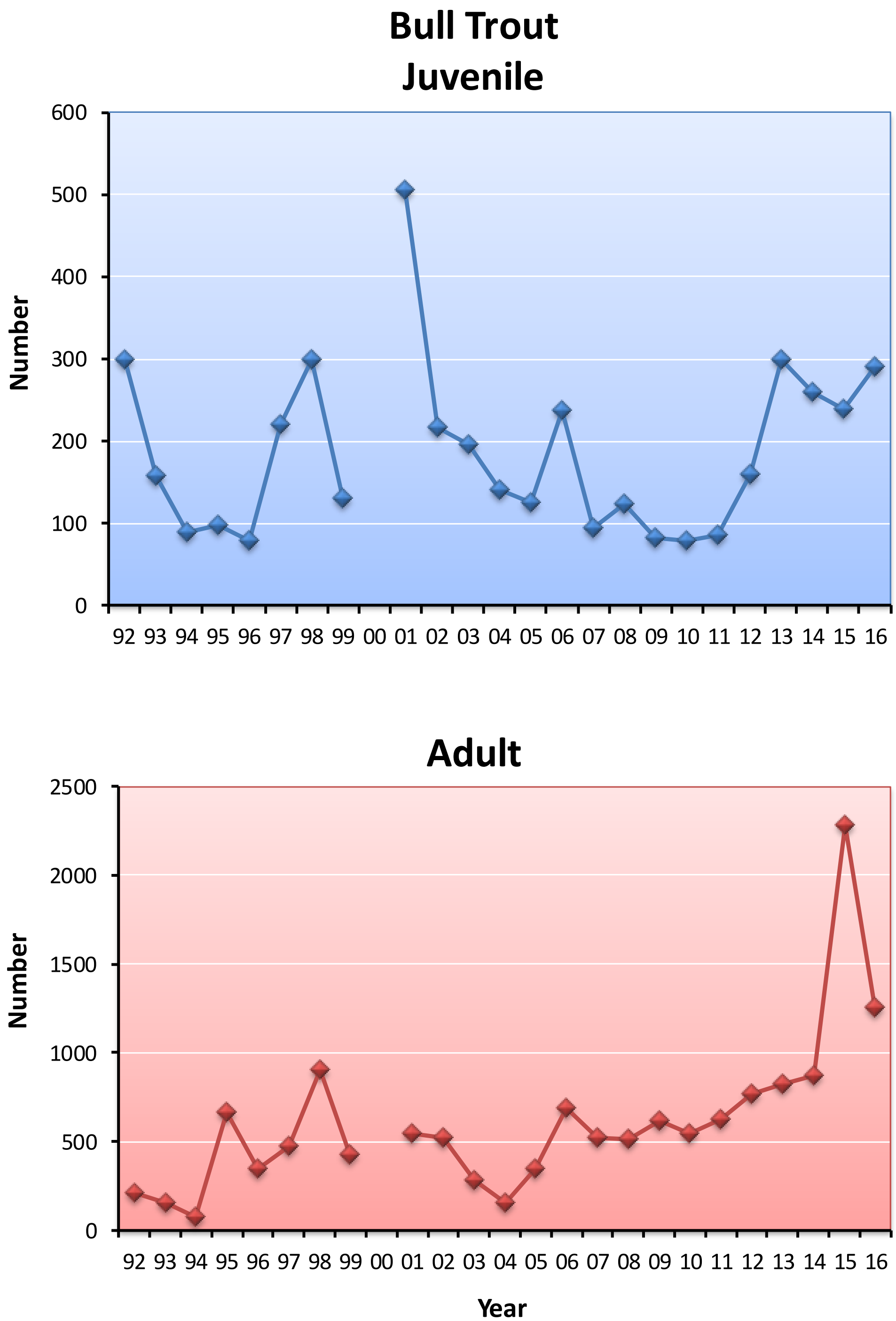

Figure 9. Numbers of juvenile (2-8 inches) and adult (>8 inches) bull trout within the Chiwawa River basin in August 1992-2016; ND = no data.

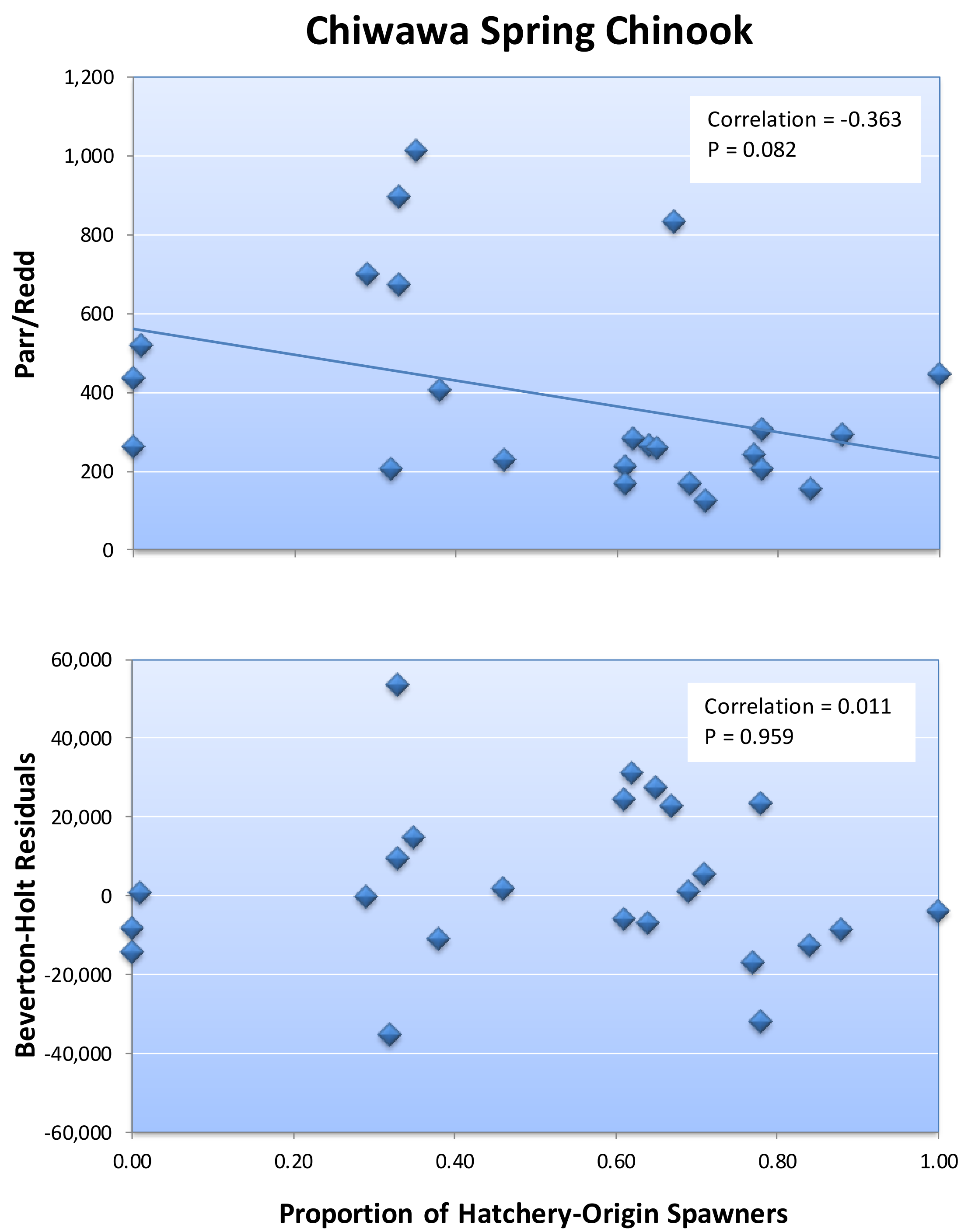

Figure 10. Relationship between juvenile productivity (parr/redd) and the proportion of hatchery-origin spawners (pHOS) (top figure) and the relationship between the residuals from the Beverton-Holt stock/recruitment relationship and pHOS (bottom figure).

Table 1. Description, location (river mile), and area (hectares) of land-class strata (reaches) used by age-0 Chinook salmon in the Chiwawa River basin, 2016. Reaches were classified according to geologic district, landtype association, valley-bottom type, stream state-type, and habitat type within the Cascade Ecoregion; MCV = moderately confined valley, CC = confined canyon, UCV = unconfined valley, NC = natural channel, EB = eroded banks, S = straight, G = glide, P = pool, R = riffle, and MC = multiple channel. See Hillman and Miller (2004) for definitions of stream state codes.

Reach	RM	Gradient	Geologic district	Landtype association	Valley bottom type	Stream state type	Habitat type	Area (ha)	
								Total	Sample
Chiwawa River									
1	0.00-3.77	0.007	Glacial Drift over Chumstick Formation	Glacial Valley	MCV Alluvial	NC/EB	G	0.60	0.60
						NC/EB	P	1.37	1.01
						NC/EB	R	16.35	1.75
2	3.77-5.51	0.010	Glacial Drift over Chumstick Formation	Glacial Canyon	CC Fluvial	NC/EB	G	0.26	0.26
						NC/EB	P	0.78	0.29
						NC/EB	R	7.21	0.67
3	5.51-7.88	0.009	Glacial Drift over Chumstick Formation	Glacial Valley	MCV Alluvial	NC/S	R	5.71	0.80
						NC/EB	G	0.13	0.13
						NC/EB	R	4.21	0.47
						MC	MC	0.32	0.32
4	7.88-8.90	0.007	Glacial Drift over Chumstick Formation	Glacial Canyon	CC Fluvial	NC/EB	P	0.39	0.27
						NC/EB	R	2.86	0.42
						MC	MC	0.44	0.44
5	8.90-10.83	0.011	Glacial Drift over Chumstick Formation	Glacial Valley	MCV Alluvial	NC/EB	P	0.13	0.13
						NC/EB	R	11.44	0.99
6	10.83-11.80	0.008	Glacial Drift over Chumstick Formation	Glacial Canyon	CC Fluvial	NC/EB	P	0.37	0.37
						NC/EB	R	3.53	0.98
						MC	MC	0.36	0.36
7	11.80-20.03	0.001	Glacial Drift over Chumstick Formation	Glacial Valley	UCV Alluvial	NC	G	2.13	0.73
						NC	P	6.52	0.70
						NC	R	0.99	0.20
						NC/EB	G	2.55	1.36
						NC/EB	P	6.89	1.84
						NC/EB	R	4.75	0.52
						MC	MC	4.30	1.65
8	20.03-25.42	0.003	Glacial Drift over Swakane Gneiss	Glacial Valley	UCV Alluvial	NC/EB	G	2.44	1.06
						NC/EB	P	7.41	2.24
						NC/EB	R	5.24	0.98
						EB	P	0.22	0.22
						EB	R	0.34	0.34
						MC	MC	7.79	2.65
9	25.42-28.81	0.007	Glacial Drift over Swakane Gneiss	Glacial Valley	MCV Alluvial	NC	P	4.52	0.51
						NC	R	2.80	0.58
						MC	MC	2.88	0.95
10	28.81-31.11	0.011	Pre-upper Jurassic Gneiss	Glacial Valley	MCV Alluvial	NC	P	0.60	0.31
						NC	R	2.24	0.49
						MC	MC	4.13	0.44

Table 1. Concluded.

Reach	RM	Gradient	Geologic district	Landtype association	Valley bottom type	Stream state type	Habitat type	Area (ha)	
								Total	Sampled
Trinity Side Channel									
10b	0.00-0.75	0.011	Pre-upper Jurassic Gneiss	Glacial Valley	MCV Alluvial	NC	P	0.39	0.09
						NC	R	0.12	0.03
						NC	MC	0.18	0.18
Phelps Creek									
1	0.00-0.35	0.043	Pre-upper Jurassic Gneiss	Glacial Valley	MCV Alluvial	NC	R	0.00	0.00
						NC	MC	0.18	0.18
Chikamin Creek[1]									
1	0.00-0.94	0.013	Glacial Drift over Chumstick Formation	Glacial Valley	UCV Alluvial	NC	G	0.02	0.02
						NC	P	0.21	0.05
						NC	R	0.32	0.03
						MC	MC	0.09	0.09
Rock Creek									
1	0.00-0.73	0.020	Glacial Drift over Swakane Gneiss	Glacial Valley	UCV Alluvial	NC	P	0.18	0.04
						NC	R	0.36	0.05
						MC	MC	0.07	0.07
Unnamed Creek									
1	0.00-0.05		Pre-upper Jurassic Gneiss	Glacial Valley	MCV Alluvial	NC	P	0.00	0.00
						NC	R	0.00	0.00
Big Meadow Creek									
1	0.00-0.35	0.025	Glacial Drift over Chumstick Formation	Glacial Valley	MCV Alluvial	NC	G	0.01	0.01
						NC	P	0.17	0.08
						NC	R	0.13	0.05
						NC	MC	0.00	0.00
Alder Creek									
1	0.00-0.01		Glacial Drift over Chumstick Formation	Glacial Valley	MCV Alluvial	NC	P	0.003	0.003
						NC	R	0.007	0.007
Brush Creek									
1	0.00-0.01		Glacial Drift over Chumstick Formation	Glacial Valley	UCV Alluvial	NC	P	0.002	0.002
						NC	R	0.006	0.006
Clear Creek									
1	0.00-0.05		Glacial Drift over Chumstick Formation	Glacial Valley	UCV Alluvial	NC	P	0.002	0.002
						NC	R	0.004	0.004
Y Creek									
1	0.00-0.05		Glacial Drift over Swakane Gneiss	Glacial Valley	UCV Alluvial	NC	P	0.000	0.000
						NC	R	0.000	0.000

[1] Includes the lower 0.2 miles of Minnow Creek.

Table 2. Estimated mean densities (fish/hectare and fish/m^3), total numbers, 95% confidence bounds on total numbers, and error of the estimated total number of age-0 Chinook salmon in reaches in the Chiwawa River basin, Washington, August 2016.

Reach	Mean density		Surface area (ha)			Volume (m^3)		
	Fish/ha	Fish/m^3	Total No.	95% C.B.	± Error	Total No.	95% C.B.	± Error
Chiwawa River								
1	197.7	0.061	3,621	±480	0.13	3,975	±311	0.08
2	349.8	0.079	2,886	±597	0.21	3,004	±601	0.20
3	167.7	0.041	1,739	±97	0.06	1,726	±97	0.06
4	365.3	0.080	1,348	±153	0.11	1,365	±128	0.09
5	86.6	0.020	1,002	±57	0.06	897	±69	0.08
6	188.3	0.051	802	±107	0.13	753	±116	0.15
7	1,301.4	0.186	36,608	±7,797	0.21	35,873	±8,470	0.24
8	1,078.2	0.177	25,272	±7,382	0.29	22,786	±10,263	0.45
9	2,420.1	0.410	24,685	±7,779	0.32	23,332	±7,993	0.34
10	4,942.0	1.393	37,856	±5,774	0.15	39,575	±9,230	0.23
Phelps Creek								
1	594.4	0.301	107	±0	0.00	107	±0	0.00
Chikamin Creek[1]								
1	2,568.8	1.178	1,644	±519	0.32	1,576	±654	0.41
Rock Creek								
1	1,624.6	0.641	991	±302	0.30	1,018	±388	0.38
Unnamed Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Big Meadow Creek								
1	4,928.1	2.265	1,508	±408	0.27	1,435	±801	0.56
Alder Creek								
1	2000.0	2.326	20	±0	0.00	20	±0	0.00
Brush Creek								
1	7,250.0	9.508	58	±0	0.00	58	±0	0.00
Clear Creek								
1	5,000.0	4.808	25	±0	0.00	25	±0	0.00
Y Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Grand Total	**1,098.1**	**0.217**	**140,172**	**±14,502**	**0.10**	**137,525**	**±18,108**	**0.13**

[1] Includes lower 0.2 miles of Minnow Creek.

Table 3. Estimated mean densities (fish/hectare and fish/m^3), total numbers, 95% confidence bounds on total numbers, and error of the estimated total number of age-1+ Chinook salmon in reaches in the Chiwawa River basin, Washington, August 2016.

Reach	Mean density		Surface area (ha)			Volume (m^3)		
	Fish/ha	Fish/m^3	Total No.	95% C.B.	± Error	Total No.	95% C.B.	± Error
Chiwawa River								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
2	1.0	0.000	8	±10	1.25	8	±12	1.50
3	0.0	0.000	0	±0	0.00	0	±0	0.00
4	1.9	0.000	7	±0	0.00	7	±0	0.00
5	0.0	0.000	0	±0	0.00	0	±0	0.00
6	0.5	0.000	2	±0	0.00	1	±0	0.00
7	0.4	0.000	11	±12	1.09	19	±13	0.68
8	2.8	0.000	65	±56	0.86	52	±72	1.38
9	14.6	0.003	149	±96	0.64	142	±119	0.84
10	1.7	0.001	12	±12	1.00	13	±16	1.23
Phelps Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Chikamin Creek[1]								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Rock Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Unnamed Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Big Meadow Creek								
1	91.5	0.041	28	±47	1.68	26	±30	1.15
Alder Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Brush Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Clear Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Y Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Grand Total	**2.2**	**0.000**	**282**	**±122**	**0.43**	**268**	**±144**	**0.54**

[1] Includes lower 0.2 miles of Minnow Creek.

Table 4. Summary of the five productivity models of juvenile (age-0) Chinook salmon in the Chiwawa River basin. Models are shown, including the number of parameters (*K*), AIC_c values, AIC_c difference scores (Δ_i), the likelihood of the model given the data ($\pounds(g_i|x)$), Akaike weights (w_i), and adjusted R^2 values. The sample size (*n*) for all models was 24. Models describe the relationship between juvenile Chinook numbers (dependent variable) and redd numbers (independent variable).

Model	K^a	AIC_c	Δ_i	$\pounds(g_i\|x)$	w_i	Adj R^2
Beverton-Holt	3	-130.391	0.000	1.000	0.661	0.841
Smooth Hockey Stick	3	-128.692	1.698	0.428	0.283	0.829
Gamma[b]	4	-123.826	6.565	0.038	0.025	0.805
Ricker	3	-123.279	7.112	0.029	0.019	0.786
Cushing	3	-122.355	8.036	0.018	0.012	0.777

[a] ***K*** is the number of structural parameters in the model plus 1 for σ^2.
[b] The γ parameter in the Gamma model was greater than 0, which means that this model is nearly identical to the Ricker model.

Table 5. Estimated mean densities (fish/hectare and fish/m^3), total numbers, 95% confidence bounds on total numbers, and error of the estimated total number of age-0 (<4 in) steelhead/rainbow in reaches in the Chiwawa River basin, Washington, August 2016.

Reach	Mean density		Surface area (ha)			Volume (m^3)		
	Fish/ha	Fish/m^3	Total No.	95% C.B.	± Error	Total No.	95% C.B.	± Error
Chiwawa River								
1	139.0	0.044	2,546	±280	0.11	2,861	±221	0.08
2	234.8	0.053	1,937	±336	0.17	2,035	±342	0.17
3	264.7	0.064	2,745	±179	0.07	2,679	±162	0.06
4	191.9	0.043	708	±174	0.25	743	±163	0.22
5	97.7	0.022	1,130	±20	0.02	997	±33	0.03
6	70.7	0.018	301	±44	0.15	265	±55	0.21
7	57.0	0.008	1,604	±598	0.37	1,546	±703	0.45
8	0.0	0.000	0	±0	0.00	0	±0	0.00
9	0.0	0.000	0	±0	0.00	0	±0	0.00
10	0.0	0.000	0	±0	0.00	0	±0	0.00
Phelps Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Chikamin Creek[1]								
1	2,217.2	1.053	1,419	±467	0.33	1,409	±501	0.36
Rock Creek								
1	1,632.8	0.607	996	±261	0.26	963	±311	0.32
Unnamed Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Big Meadow Creek								
1	8,892.2	4.131	2,721	±2,003	0.74	2,618	±2,887	1.10
Alder Creek								
1	5,000.0	5.581	50	±0	0.00	48	±0	0.00
Brush Creek								
1	7,750.0	10.164	62	±0	0.00	62	±0	0.00
Clear Creek								
1	5,000.0	4.808	25	±0	0.00	25	±0	0.00
Y Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Grand Total	**127.3**	**0.026**	**16,244**	**±2,217**	**0.14**	**16,251**	**±3,066**	**0.19**

[1] Includes lower 0.2 miles of Minnow Creek.

Table 6. Estimated mean densities (fish/hectare and fish/m^3), total numbers, 95% confidence bounds on total numbers, and error of the estimated total number of age-1+ (4-8 in) steelhead/rainbow in reaches in the Chiwawa River basin, Washington, August 2016.

Reach	Mean density		Surface area (ha)			Volume (m^3)		
	Fish/ha	Fish/m^3	Total No.	95% C.B.	± Error	Total No.	95% C.B.	± Error
Chiwawa River								
1	54.9	0.017	1,005	±145	0.14	1,126	±141	0.13
2	41.9	0.010	346	±162	0.47	363	±164	0.45
3	93.9	0.024	974	±49	0.05	986	±45	0.05
4	60.4	0.014	223	±117	0.52	233	±112	0.48
5	44.3	0.010	513	±34	0.07	453	±45	0.10
6	32.2	0.008	137	±31	0.23	121	±36	0.30
7	7.8	0.001	220	±185	0.84	213	±171	0.80
8	0.0	0.000	0	±0	0.00	0	±0	0.00
9	0.0	0.000	0	±0	0.00	0	±0	0.00
10	0.0	0.000	0	±0	0.00	0	±0	0.00
Phelps Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Chikamin Creek[1]								
1	400.0	0.180	256	±392	1.53	241	±320	1.33
Rock Creek								
1	65.6	0.025	40	±0	0.00	40	±0	0.00
Unnamed Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Big Meadow Creek								
1	1,009.8	0.466	309	±307	0.99	295	±396	1.34
Alder Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Brush Creek								
1	1,000.0	1.312	8	±0	0.00	8	±0	0.00
Clear Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Y Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Grand Total	**31.6**	**0.006**	**4,031**	**±590**	**0.15**	**4,079**	**±594**	**0.15**

[1] Includes lower 0.2 miles of Minnow Creek.

Table 7. Estimated mean densities (fish/hectare and fish/m^3), total numbers, 95% confidence bounds on total numbers, and error of the estimated total number of steelhead/rainbow larger than 8 inches in reaches in the Chiwawa River basin, Washington, August 2016.

Reach	Mean density		Surface area (ha)			Volume (m^3)		
	Fish/ha	Fish/m^3	Total No.	95% C.B.	± Error	Total No.	95% C.B.	± Error
Chiwawa River								
1	0.3	0.000	5	±6	1.20	7	±10	0.42
2	0.4	0.000	3	±2	0.67	4	±4	1.00
3	0.0	0.000	0	±0	0.00	0	±0	0.00
4	0.0	0.000	0	±0	0.00	0	±0	0.00
5	0.0	0.000	0	±0	0.00	0	±0	0.00
6	0.0	0.000	0	±0	0.00	0	±0	0.00
7	0.0	0.000	0	±0	0.00	0	±0	0.00
8	0.3	0.000	6	±8	1.33	6	±10	1.67
9	0.0	0.000	0	±0	0.00	0	±0	0.00
10	0.0	0.000	0	±0	0.00	0	±0	0.00
Phelps Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Chikamin Creek[1]								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Rock Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Unnamed Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Big Meadow Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Alder Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Brush Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Clear Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Y Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Grand Total	**0.1**	**0.000**	**14**	**±10**	**0.71**	**17**	**±15**	**0.88**

[1] Includes lower 0.2 miles of Minnow Creek.

Table 8. Estimated mean densities (fish/hectare and fish/m^3), total numbers, 95% confidence bounds on total numbers, and error of the estimated total number of juvenile bull trout (2-8 in) in reaches in the Chiwawa River basin, Washington, August 2016.

Reach	Mean density		Surface area (ha)			Volume (m^3)		
	Fish/ha	Fish/m^3	Total No.	95% C.B.	± Error	Total No.	95% C.B.	± Error
Chiwawa River								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
2	1.6	0.000	13	±17	1.31	15	±20	1.33
3	0.0	0.000	0	±0	0.00	0	±0	0.00
4	0.0	0.000	0	±0	0.00	0	±0	0.00
5	0.0	0.000	0	±0	0.00	0	±0	0.00
6	0.0	0.000	0	±0	0.00	0	±0	0.00
7	0.0	0.000	0	±0	0.00	0	±0	0.00
8	0.0	0.000	0	±0	0.00	0	±0	0.00
9	7.6	0.001	78	±38	0.49	74	±44	0.59
10	21.9	0.011	168	±40	0.24	310	±43	0.14
Phelps Creek								
1	144.4	0.073	26	±0	0.00	26	±0	0.00
Chikamin Creek[1]								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Rock Creek								
1	9.8	0.004	6	±0	0.00	6	±0	0.00
Unnamed Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Big Meadow Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Alder Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Brush Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Clear Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Y Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Grand Total	**2.3**	**0.001**	**291**	**±58**	**0.20**	**431**	**±65**	**0.15**

[1] Includes lower 0.2 miles of Minnow Creek.

Table 9. Estimated mean densities (fish/hectare and fish/m^3), total numbers, 95% confidence bounds on total numbers, and error of the estimated total number of adult bull trout (>8 in) in reaches in the Chiwawa River basin, Washington, August 2016.

Reach	Mean density		Surface area (ha)			Volume (m^3)		
	Fish/ha	Fish/m^3	Total No.	95% C.B.	± Error	Total No.	95% C.B.	± Error
Chiwawa River								
1	1.1	0.000	20	±15	0.75	20	±15	0.75
2	2.3	0.001	19	±15	0.79	19	±28	1.47
3	2.0	0.001	21	±3	0.14	21	±4	0.19
4	3.3	0.001	12	±4	0.33	12	±5	0.42
5	0.3	0.000	4	±0	0.00	5	±0	0.00
6	1.4	0.000	6	±0	0.00	6	±0	0.00
7	8.6	0.001	242	±74	0.31	232	±133	0.57
8	7.3	0.001	171	±46	0.27	155	±117	0.75
9	22.8	0.004	233	±39	0.17	222	±96	0.43
10	74.5	0.020	519	±117	0.23	540	±92	0.17
Phelps Creek								
1	38.9	0.020	7	±0	0.00	7	±0	0.00
Chikamin Creek[1]								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Rock Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Unnamed Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Big Meadow Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Alder Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Brush Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Clear Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Y Creek								
1	0.0	0.000	0	±0	0.00	0	±0	0.00
Grand Total	**9.8**	**0.002**	**1,254**	**±152**	**0.12**	**1,239**	**±224**	**0.18**

[1] Includes lower 0.2 miles of Minnow Creek.

APPENDIX A. Numbers of redds, eggs, age-0 Chinook salmon, parr per redd, and percent egg-to-parr survival in the Chiwawa River basin, brood years 1991-2016; NS = not sampled. Numbers of eggs were calculated as the number of redds times the mean fecundity of females collected for broodstock.

Brood Year	Chinook Salmon			Parr/Redd	Egg-to-parr survival (%)
	Redds	Eggs	Age-0 (parr)		
1991	104	478,400	45,483	437	9.5
1992	302	1,570,098	79,113	262	5.0
1993	106	556,394	55,056	519	9.9
1994	82	485,686	55,240	674	11.4
1995	13	66,248	5,815	447	8.8
1996	23	106,835	16,066	699	15.0
1997	82	374,740	68,415	834	18.3
1998	41	218,325	41,629	1,015	19.1
1999	34	166,090	NS	NS	NS
2000	128	642,944	114,617	895	17.8
2001	1,078	4,984,672	134,874	125	2.7
2002	345	1,605,630	91,278	265	5.7
2003	111	648,684	45,177	407	7.0
2004	241	1,156,559	49,631	206	4.3
2005	332	1,436,564	79,902	241	5.6
2006	297	1,284,228	60,752	205	4.7
2007	283	1,256,803	82,351	291	6.6
2008	689	3,163,888	106,705	155	3.4
2009	421	1,925,233	128,220	305	6.7
2010	502	2,165,628	141,510	282	6.5
2011	492	2,157,420	103,940	211	4.8
2012	880	3,716,240	149,563	185	4.4
2013	714	3,367,224	121,240	170	3.6
2014	485	1,961,825	111,224	229	5.7
2015	543	2,631,921	140,172	258	5.3
Average	**333**	**1,525,131**	**84,499**	**388**	**8.0**

APPENDIX B. Estimated numbers of salmonids (based on fish/ha) in the Chiwawa River basin, Washington, 1992-2016; NS = not sampled.

Survey year	Chinook salmon		Steelhead/Rainbow			Bull trout		Cutthroat trout
	Age-0	Age-1+	Age-0	Age-1+	>8 in[1]	2-8 in	>8 in	
1992[2]	45,483	563	4,927	2,533	1,869	299	208	NS
1993	79,113	174	4,004	2,860	768	158	156	NS
1994	55,056	18	1,410	5,856	67	90	76	NS
1995	55,241	13	7,357	9,517	140	97	664	NS
1996	5,815	22	4,245	11,849	78	79	343	NS
1997	16,066	5	8,823	6,905	48	220	472	56
1998	68,415	63	3,921	10,585	78	300	900	93
1999	41,629	41	5,838	22,130	33	130	423	80
2000	NS	NS	NS	NS	NS	NS	NS	NS
2001	114,617	69	45,727	10,623	420	505	542	108
2002	134,874	32	20,521	9,090	181	217	521	111
2003	91,278	134	18,020	6,179	49	196	282	52
2004	45,177	21	10,380	8,190	8	140	157	22
2005	49,631	79	11,463	6,188	48	125	346	23
2006	79,902	388	16,245	10,533	50	238	686	68
2007	60,752	41	14,073	8,448	77	95	520	47
2008	82,351	189	15,230	10,576	144	124	510	109
2009	106,705	54	17,179	5,629	85	82	618	128
2010	128,220	291	25,018	9,616	63	79	547	252
2011	141,510	967	39,446	14,903	65	86	621	240
2012	103,940	767	27,134	8,576	65	159	768	188
2013	149,563	852	21,682	7,253	76	299	820	358
2014	121,240	939	16,083	5,084	87	259	875	761
2015	111,224	620	10,208	754	18	239	2,286	292
2016	140,172	282	16,244	4,031	14	291	1,254	544

[1]During 1992-1993, numbers of steelhead/rainbow greater than 8 inches included both hatchery and wild rainbow trout. Thereafter, only wild trout were observed.
[2]Only the Chiwawa River was sampled in 1992. No tributaries were sampled in that year.

APPENDIX C. Proportion of total habitat available, fraction of all age-0 Chinook within each habitat type, and densities (fish/ha) and numbers of age-0 Chinook within each habitat type in the Chiwawa River basin, survey years 1992-2016; NS = not sampled.

Habitat	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Proportion of total habitat available											
Glide	0.10	0.09	0.10	0.10	0.10	0.09	0.09	0.09	NS	0.07	0.08
Pool	0.19	0.19	0.21	0.18	0.18	0.17	0.16	0.17	NS	0.15	0.16
Riffle	0.61	0.61	0.57	0.59	0.57	0.57	0.58	0.55	NS	0.49	0.48
M. Chan	0.10	0.11	0.12	0.14	0.14	0.17	0.17	0.19	NS	0.29	0.28
Fraction of all age-0 Chinook within habitat types											
Glide	0.07	0.03	0.02	0.01	0.02	0.01	0.01	0.01	NS	0.03	0.01
Pool	0.30	0.28	0.22	0.21	0.30	0.16	0.17	0.14	NS	0.23	0.24
Riffle	0.19	0.16	0.12	0.11	0.43	0.23	0.08	0.11	NS	0.18	0.15
M. Chan	0.45	0.53	0.64	0.67	0.24	0.60	0.74	0.74	NS	0.57	0.60
Densities of age-0 Chinook within habitat types (fish/ha)											
Glide	254	251	93	55	11	12	78	13	NS	351	187
Pool	584	1,049	619	541	82	122	607	257	NS	1,392	1,468
Riffle	116	188	124	91	38	52	79	62	NS	336	300
M. Chan	1,710	3,408	2,985	2,328	84	449	2,620	1,201	NS	1,820	2,069
Number of age-0 Chinook within habitat types											
Glide	2,967	2,458	857	623	137	130	837	157	NS	3,231	1,931
Pool	13,468	21,814	12,131	11,294	1,755	2,553	11,454	5,933	NS	25,890	32,612
Riffle	8,531	12,616	6,698	6,197	2,525	3,699	5,392	4,626	NS	20,629	19,754
M. Chan	20,517	42,225	35,370	36,965	1,396	9,682	50,728	30,912	NS	64,866	80,576

APPENDIX C. Continued.

Habitat	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Proportion of total habitat available											
Glide	0.07	0.07	0.08	0.08	0.07	0.09	0.08	0.08	0.08	0.07	0.07
Pool	0.17	0.16	0.16	0.16	0.17	0.23	0.22	0.23	0.18	0.23	0.23
Riffle	0.49	0.50	0.47	0.47	0.47	0.51	0.54	0.53	0.57	0.53	0.53
M. Chan	0.26	0.27	0.29	0.30	0.29	0.17	0.15	0.16	0.17	0.17	0.17
Fraction of all age-0 Chinook within habitat types											
Glide	0.02	0.01	0.01	0.03	0.02	0.03	0.02	0.02	0.04	0.01	0.02
Pool	0.23	0.07	0.19	0.31	0.46	0.40	0.36	0.34	0.34	0.41	0.37
Riffle	0.15	0.14	0.07	0.12	0.12	0.11	0.11	0.11	0.19	0.15	0.13
M. Chan	0.60	0.77	0.73	0.54	0.40	0.45	0.51	0.53	0.43	0.43	0.48
Densities of age-0 Chinook within habitat types (fish/ha)											
Glide	200	58	49	237	113	238	230	286	526	173	321
Pool	951	155	492	1,240	1,211	1,210	1,453	1,436	1,805	1,360	1,890
Riffle	216	101	60	166	118	156	175	200	330	221	281
M. Chan	1,626	1,008	1,057	1,147	603	1,872	2,993	3,293	2,515	2,061	3,190
Number of age-0 Chinook within habitat types											
Glide	1,884	540	442	2,498	1,120	2,668	2,371	3,164	6,122	1,535	2,822
Pool	21,091	3,183	9,626	26,754	28,851	34,314	39,382	44,765	48,846	42,209	55,651
Riffle	13,783	6,501	3,367	10,753	7,809	9,773	11,558	14,446	27,883	15,418	19,619
M. Chan	54,519	34,952	36,196	46,580	25,409	38,275	55,607	69,609	61,944	44,779	73,057

APPENDIX C. Concluded.

Habitat	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean
Proportion of total habitat available											
Glide	0.07	0.07	0.06								**0.08**
Pool	0.22	0.24	0.24								**0.19**
Riffle	0.54	0.53	0.54								**0.53**
M. Chan	0.17	0.16	0.16								**0.20**
Fraction of all age-0 Chinook within habitat types											
Glide	0.01	0.01	0.01								**0.02**
Pool	0.37	0.31	0.35								**0.30**
Riffle	0.11	0.05	0.08								**0.13**
M. Chan	0.51	0.63	0.56								**0.55**
Densities of age-0 Chinook within habitat types (fish/ha)											
Glide	133	66	114								**169**
Pool	1,569	1,300	1,628								**1,079**
Riffle	190	98	168								**163**
M. Chan	2,957	3,768	3,789								**1,923**
Number of age-0 Chinook within habitat types											
Glide	1,120	518	931								**1,711**
Pool	44,321	34,993	49,103								**25,916**
Riffle	13,085	6,017	11,550								**10,926**
M. Chan	62,713	69,969	78,589								**46,893**

Appendix B

Fish Trapping at the Chiwawa and Wenatchee Rotary Smolt Traps during 2016

Monitoring Juvenile Salmonids in the Wenatchee River basin:

Activities in the Chiwawa River and Lower Wenatchee River during 2016

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February 13, 2017

Table of Contents

List of Figures

Page

List of Tables

Page

INTRODUCTION

Background

Monitoring and Evaluation

Productivity indicators in the freshwater environment provide data essential to inform evolving salmon and steelhead hatchery programs. In the Wenatchee River subbasin, the Juvenile Monitoring Component of the Monitoring and Evaluation Plan for PUD Hatchery Programs gather data directed at informing these productivity indicators (see Hillman et al. 2013). More specifically, this data directly addresses Objective 2 of the monitoring and evaluation framework:

"Determine if the proportion of hatchery fish on the spawning grounds affects the freshwater productivity of supplemented stocks."

Objectives

The Washington Department of Fish and Wildlife monitors juvenile salmonids in the Wenatchee River basin with the primary objective of estimating: natural productivity, migration timing, and age with size at migration. This has occurred at the tributary level (Chiwawa River since 1991) and population level (Wenatchee River since 1997). Target species include spring Chinook Salmon *Oncorhynchus tshawytscha* and summer steelhead *O. mykiss* in the Chiwawa River, and is expanded to include sockeye Salmon *O. nerka* and summer Chinook Salmon *O. tshawytscha* in the mainstem Wenatchee River.

Monitoring has primarily been conducted with rotary smolt traps that capture emigrating salmonids from spring through fall. In an effort to reduce biases in emigrant estimates, and to improve understanding of survival and movement during non-trapping periods (December through February), WDFW began remote sampling spring Chinook Salmon in the Chiwawa Basin in 2012.

Study Area

Chiwawa River

The Chiwawa River is a fourth-order river draining a 474-km^2 basin and has a mean annual discharge of 14.4 cubic meters per second (m^3/s); contributing about 15% of the mean annual discharge of the Wenatchee River. The Chiwawa basin is dominated by the snow melt cycle with peak discharge occurring May through July with occasional fall freshets (Figure 1). The Chiwawa River originates in the North Cascades and flows southeast for 60 km before joining the Wenatchee River. This confluence with the Wenatchee River is approximately 9km downstream of Lake Wenatchee and 76 km upstream of the Columbia River (Figure 2). The Chiwawa River basin is relatively natural, with 96% managed as part of the Wenatchee National Forest and the upper 32% designated wilderness.

Precipitation in the basin varies between 76 cm near the confluence and 356 cm at the peaks, while elevations range from 573 to 2,768 m. The river is dynamic with generally shallow pool riffle segments as it meanders through a U-shaped valley formed by ancient glaciers in the region. Gradients remain well under 1% for the majority of the river.

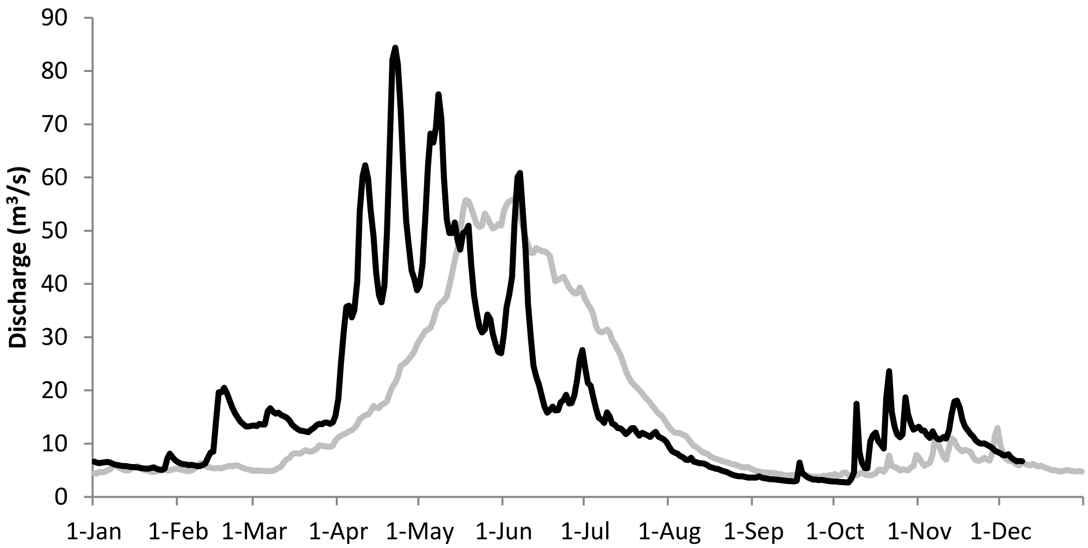

Figure 1. Discharge of the Chiwawa River at Plain, USGS gauge # 12456500. Black line represents 2016 discharge and grey line represents mean discharge from 1990-2015.

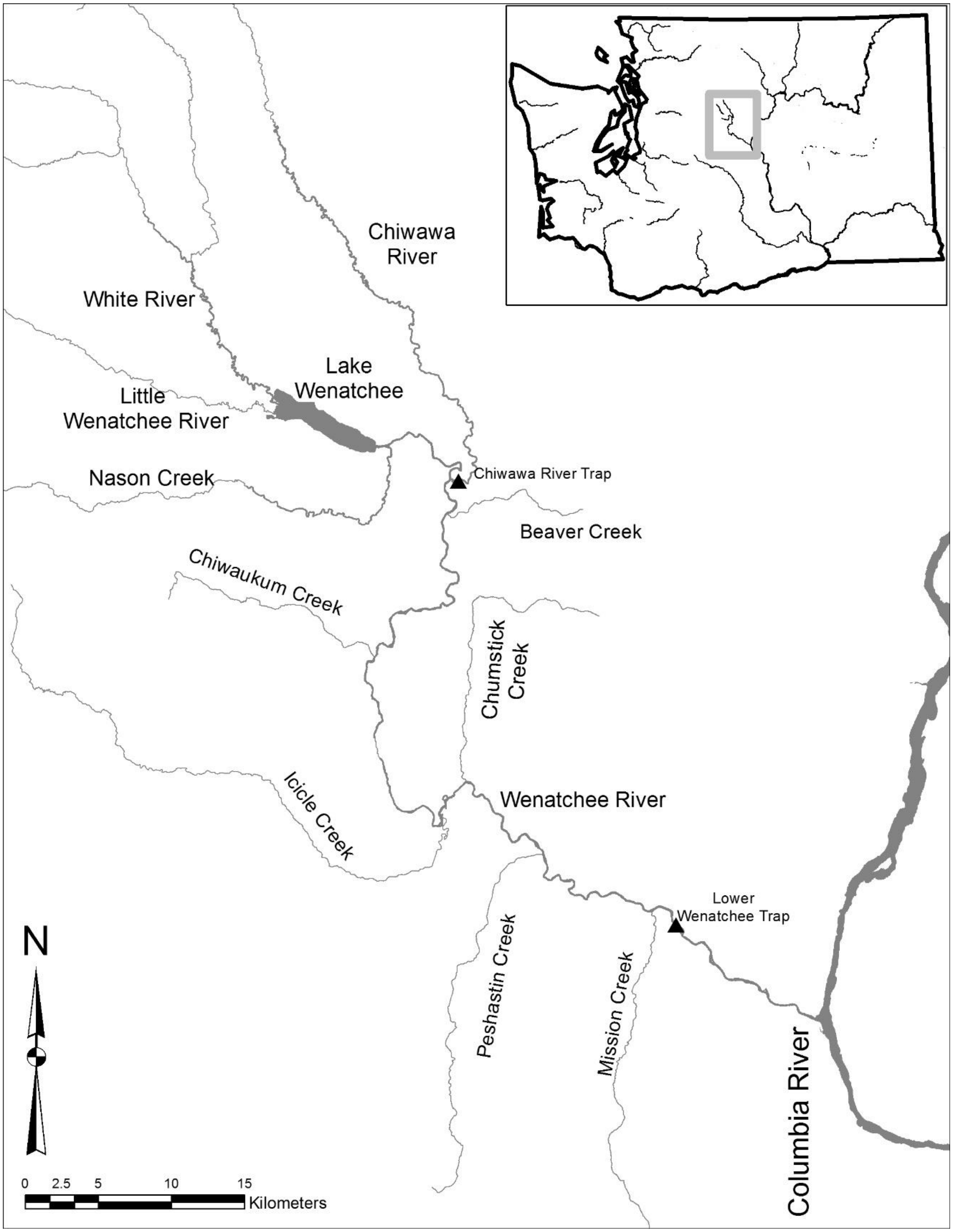

Figure 2. Wenatchee River basin (with rotary smolt trap locations).

Wenatchee River

The Wenatchee River is a fourth-order river draining a 3,437-km^2 basin and has a mean annual discharge of 91.4 m^3/s. The hydrograph is dominated by the snow melt cycle with peak discharge occurring May through July with occasional fall freshets (Figure 3). The mainstem originates at the outlet of Lake Wenatchee and flows southeast 84.5 km before joining the Columbia River, 753 km upstream of the Pacific Ocean (Figure 2). While most of the lowlands (17%) are private, the majority (83%) of basin is public land.

Precipitation in the basin varies from 22 cm near the Columbia River confluence to 381 cm at the crest of the Cascade Mountains with elevations ranging from 237 to 2,768 m. The Wenatchee River has a relatively low gradient except from rkm 40 – 64 where the river flows through a bedrock canyon (Tumwater Canyon) and has a gradient of approximately 9.8 meters per kilometer.

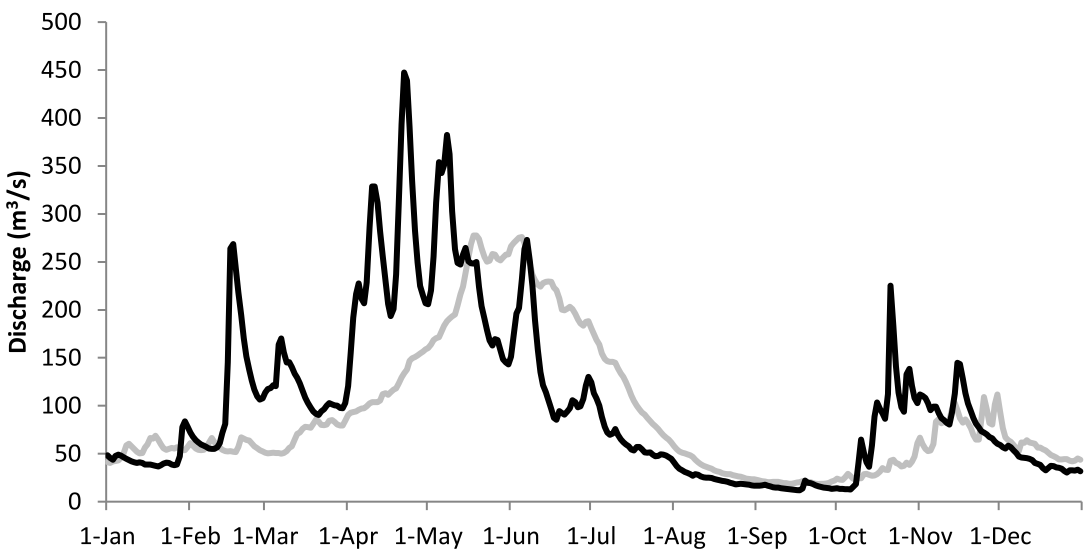

Figure 3. Discharge of the Wenatchee River at Monitor, USGS gauge # 12462500. Black line represents 2016 discharge and grey line represents mean discharge from 1990-2015.

METHODS

Rotary Smolt Traps

Trap Operations

The Chiwawa River trap consists of a single 2.4m cone and has been operating since 1991 at its current location, 0.6 km upstream from the confluence with the Wenatchee River. Trap operations usually begin in late February and continue until ice suspends operations in late fall. The Lower Wenatchee trap consists of two 2.4m cones and has been operating in its current location (rkm 12.5) since 2013. Trap operations usually begin in late January and continue until fall, when river conditions force its removal.

Operational procedures and techniques follow the standardized basin-wide monitoring plan developed by the Upper Columbia Regional Technical Team for the Upper Columbia Salmon Recovery Board (UCSRB; Hillman 2004), which was adapted from Murdoch and Petersen (2000). The traps remain in operation 24 hours a day unless environmental condition (high/low flow, extreme temperature, and high debris), hatchery releases, mechanical failure or human recreational activities halt operations. During periods of high recreational activities in the spring and summer the Lower Wenatchee trap is pulled during daylight hours to minimize human danger.

Fish Sampling

At a minimum of once a day, all fish collected at the traps were identified to genus or species, enumerated, weighed, and fork length (FL) measured. All salmonids were classified as hatchery, wild, or unknown and visually classified as fry, parr, transitional, or smolt. All hatchery salmonids in the basin are marked (adipose fin-clip, coded-wire tags, or Passive Integrated Transponder (PIT) with the exception of coho. Based on length subsamples of known hatchery coho at Leavenworth Fish Hatchery, all coho collected at the Lower Wenatchee rotary smolt trap were considered wild if < 80mm FL or unknown origin if ≥ 80mm FL. All coho collected in the Chiwawa River were considered wild. Target species (≥ 65 mm FL) were tagged using 12.5 mm FDX PIT tags and all PIT tagging information was uploaded to a reginal PIT tag database (PTAGIS) maintained by the Pacific States Marine Fisheries Commission.

A combination of length, time of year, and trap location was used to determine race (spring or summer) of captured juvenile Chinook Salmon. All Chinook Salmon captured in the Chiwawa River trap were considered spring Chinook, regardless of size since summer Chinook Salmon spawning has not been documented upstream of the trap. All yearling (age-1) Chinook captured at the Lower Wenatchee River trap during the spring migration period were considered spring Chinook Salmon because spring Chinook Salmon are yearling migrants and summer Chinook Salmon are typically subyearling migrants. All subyearling fry and parr (age-0) Chinook captured at the Lower Wenatchee River trap during spring were considered summer Chinook Salmon.

Mark–Recapture Trials

Groups of marked juveniles were released during a range of stream discharges in order to determine trapping efficiencies under the varied flow regime. Natural origin fish were marked with a PIT tag if ≥65mm FL or stained with Bismarck Brown dye if <65 mm FL and hatchery origin fish were marked using a caudal fin clip. All marked fish were released evenly upstream on both sides of the river between 1800 hours and 2000 hours. Marked fish from the Lower Wenatchee River trap were transported and released 14.5 km upstream of the trap site while fish from the Chiwawa River trap were released 2.6 km upstream. Each trial was conducted over a four-day (96 hour) period to allow time for passage or capture. Target mark group sizes were based on historical data, location and species, ranging from 100 to over 500 individual fish. See appendix D for mark-recapture trails.

Emigrant Estimates

All emigration estimates were calculated using estimated daily trap efficiency derived from the regression formula using trap efficiency (dependent variable) and discharge (independent variable). Trap efficiency models used a modified Bailey estimator (recaptures + 1) in the calculation of efficiency as a method of bias correction. If a significant relationship ($R^2 > 0.5$ and $P < 0.05$) could not be found a pooled trap efficiency estimate was used. Estimates of emigrating spring Chinook were calculated with and without fry (<50mm FL) due to the uncertainty that these fish were actively migrating to the ocean (UCRTT, 2001). See appendices A and B for detailed equations and information on how the point estimate, variance, and standard error were calculated.

During minor breaks in operation (less than seven days), the number of individual fish collected was estimated. This estimate was calculated using the mean number of fish captured two days prior and two days after the break in operation. For major breaks in operations (greater than seven days), an estimate based on historical run timing was developed. This estimate of daily capture was incorporated into the overall emigration estimate.

Egg-to-emigrant Survival

The estimated total egg deposition (d) was calculated by multiplying the mean fecundity (f) of the brood spawners by the total number of redds (r) found during surveys (Hillman et al. 2015). Egg-to-emigrant survival (s) was calculated by dividing total emigrants (e) by estimated egg deposition (d).

Backpack Electrofishing

Sampling Procedure

From 2012 to present, WDFW has had a goal of PIT tagging 3,000 juvenile spring Chinook Salmon each year. In order to representatively tag the population throughout all reaches, the number of fish tagged in each reach was based on the reach specific abundance encountered during snorkeling surveys in late summer. See Appendix C for further explanation.

Detections and Calculations

Detections occur at PIT tag interrogation sites in and out of the basin as well as rotary smolt traps downstream of the sampling reaches. Calculations of non-trapping emigrant estimates are based on a flow-detection efficiency regression developed using mark-groups previously released to test smolt trap efficiencies. The total number of tagged fish (t) divided by the estimated total parr abundance (p), as based off of standard snorkeling techniques (Hillman et al. 2013), resulted in an overall tag rate (t_i). See Appendix C for further explanation.

RESULTS

Rotary Smolt Traps – Chiwawa

Trap Operation

The Chiwawa trap operated between 2 March and 21 November 2016. During that time the trap was inoperable for 72 days as a result of low or high discharge, debris, hatchery fish releases, and mechanical issues. Forty seven of those days came during the fall when there was not enough discharge to operate the trap. Throughout the year the trap was operated in a single upper position.

Fish Sampling

A total of 27,172 individual fish were collected, with wild spring Chinook Salmon and steelhead comprising 71% and 6% of the total catch, respectively. Additionally, 2,525 hatchery spring Chinook, 1,518 hatchery steelhead, and 3 wild coho were collected. Throughout the sampling period 11,396 PIT tag were deployed into wild spring Chinook and steelhead (10,083 and 1,313 respectively). Spring Chinook mortality for the season totaled 4 yearling, 74 subyearling parr, and 15 fry (0.1%, 0.6%, and 0.4%, respectively). Mortality of steelhead throughout the season totaled 10 (0.6%). The mean fork length (SD) of captured yearling and subyearling spring Chinook Salmon (fry excluded) was 91 (8.5) mm and 71 (12.78) mm, respectively (Table 1).

Table 1. Mean fork length (mm) and weight (g) of spring Chinook Salmon captured in the Chiwawa rotary smolt trap during 2016.

	Yearling transitional/smolts			Subyearling parr		
	Mean	SD	*N*	Mean	SD	*N*
Fork length	91.3	8.5	2,789	71.1	12.8	12,198
Weight	8.3	3.1	2,784	4.7	2.2	10,947

Yearling Spring Chinook (Brood Year 2014)

Wild yearling spring Chinook Salmon were primarily captured between 2 March and 31 May (Figure. 4). A total of 2,807 yearling Chinook Salmon were captured and an estimated 3,414 would have been captured if the trap had operated without interruption. Six mark/recapture efficiency trials using PIT tags were conducted producing a mean trap efficiency of 9.4%. In 2016, mark/recapture trials were conducted at all desired discharge levels and a statistically significant flow-efficiency regression model was obtained (R^2 = 0.84, P < 0.028). The estimated number (95% C.I.) of yearling spring Chinook Salmon that emigrated from the Chiwawa River in 2015 was 37,170 (±6,524). Smolt survival (SE) to McNary of those tagged fish was 43% (5%) using the Cormack-Jolly-Seber estimator.

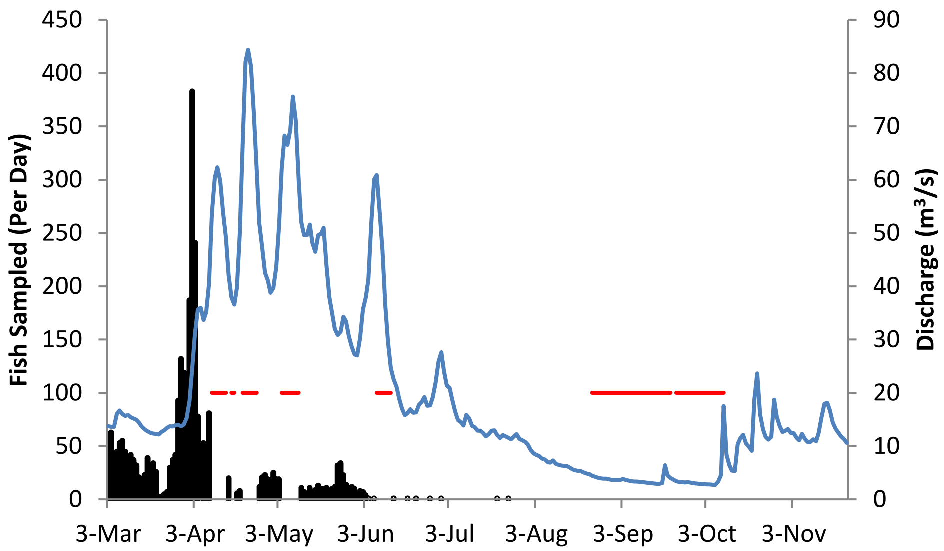

Figure 4. Daily catch of yearling spring Chinook Salmon at the Chiwawa rotary smolt trap. Blue line indicates river discharge and red horizontal line indicates non-trapping period.

Subyearling Spring Chinook (Brood Year 2015)

Wild subyearling spring Chinook Salmon were captured throughout the sampling period, with peak catches of parr in August, October, and November and fry occurring in March and April (Figures 5 and 6, respectively). A total of 12,429 subyearling parr and 3,835 fry were captured with an estimated 13,319 subyearling parr and 4,063 fry had the trap operated without interruption. Twelve mark/recapture efficiency trials were conducted (eight PIT tagged and four Bismarck Brown groups) with a mean trap efficiency of 19.1%. These 12 trials were used to develop a significant regression model for the trap (R^2 = 0.64, P < 0.002). In 2016, the estimated number of subyearling spring Chinook Salmon emigrating from the Chiwawa River during the sampling period was 80,543 (± 27,967) if you do not include fry or 145,971 (±48,393) if fry are included.

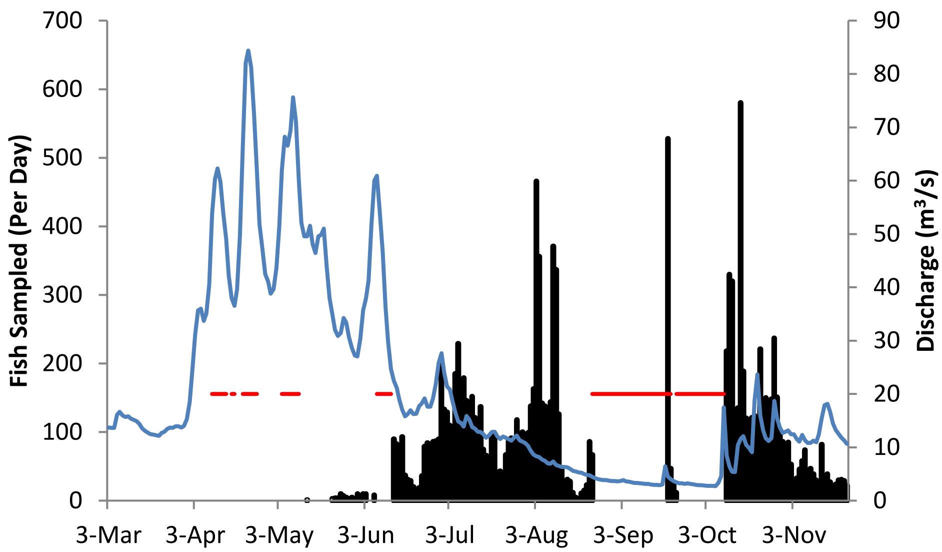

Figure 5. Daily catch of wild spring Chinook subyearling parr at the Chiwawa rotary smolt trap. Blue line indicates river discharge and red horizontal line indicates non-trapping period.

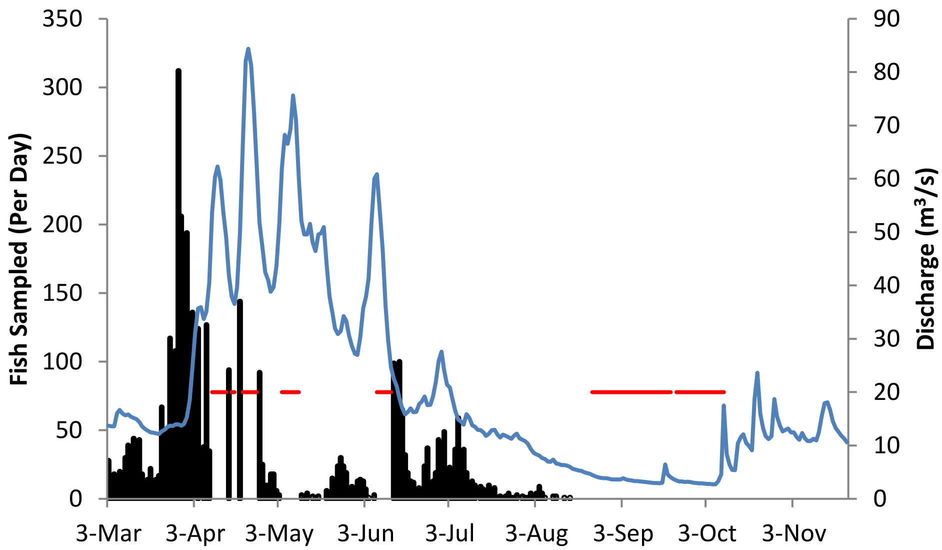

Figure 6. Daily catch of wild spring Chinook fry at the Chiwawa rotary smolt trap. Blue line indicates river discharge and red horizontal line indicates non-trapping period.

Summer Steelhead

During the trapping period, 195 steelhead transitional/smolts and 1,522 steelhead/rainbow parr and fry were captured. While collections occurred in moderate numbers throughout the year, peak collections occurred during September and October (Figure 7). The mean fork length (SD) of steelhead parr and transitional/smolts captured was 83.6 (23.1) and 146.7 (33.4) mm, respectively (Table 2).

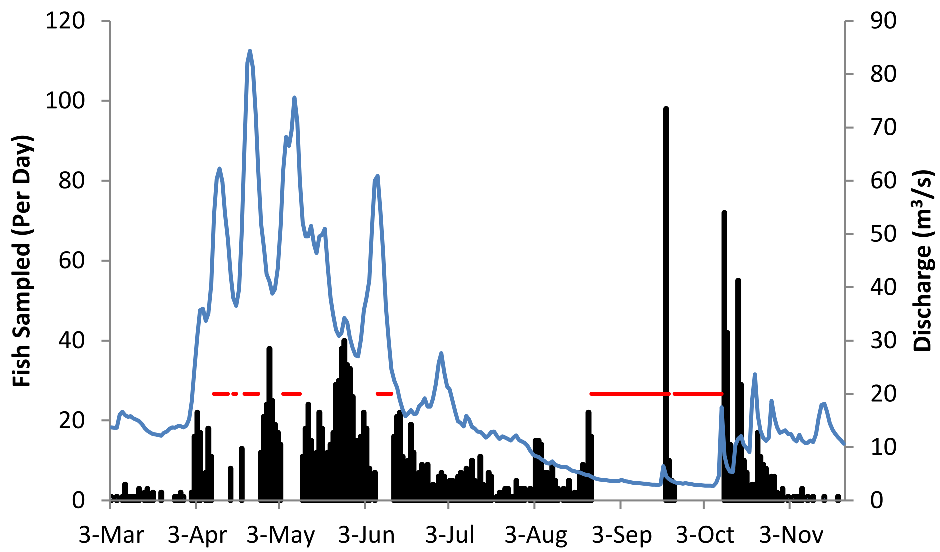

Figure 7. Daily catch of all wild steelhead at the Chiwawa rotary smolt trap. Blue line indicates river discharge and red horizontal line indicates non-trapping period.

Table 2. Mean fork length (mm) and weight (g) and of steelhead/rainbow captured in the Chiwawa rotary smolt trap during 2016.

	Transitional/smolts			Parr		
	Mean	SD	*N*	Mean	SD	*N*
Fork length	146.7	33.4	195	83.6	23.1	1,406
Weight	37.3	23.7	194	7.8	9.4	1,393

Egg-to-emigrant Survival

For BY 2014, 485 redds were counted in the Chiwawa River Basin with an estimated 1,961,825 eggs being deposited. A total of 114,680 emigrants were estimated resulting in an egg-to-emigrant survival of 5.8% (Table 3). This is up from a five year moving average of 3.8%.

Table 3. Estimated egg deposition and egg-to-emigrant survival rates for Chiwawa River spring Chinook Salmon.

Brood Year	Number of redds	Estimated egg deposition	Estimated number				Egg-to-emigrant survival (%)
			Sub-yearling	Non trapping	Yearling	Total emigrants	
1992	302	1,570,098	25,818		39,723	65,541	4.2
1993	106	556,394	14,036		8,662	22,698	4.1
1994	82	485,686	8,595		16,472	25,067	5.2
1995	13	66,248	2,121		3,830	5,951	9.0
1996	23	106,835	3,708		15,475	19,183	18.0
1997	82	374,740	16,228		28,334	44,562	11.9

Brood Year	Number of redds	Estimated egg deposition	Estimated number				Egg-to-emigrant survival (%)
			Sub-yearling	Non trapping	Yearling	Total emigrants	
1998	41	207,675	2,855		23,068	25,923	11.9
1999	34	166,090	4,988		10,661	15,649	9.4
2000	128	642,944	14,854		40,831	55,685	8.7
2001	1,078	4,836,704	459,784		86,482	546,266	11.0
2002	345	1,605,630	93,331		90,948	184,279	11.5
2003	111	648,684	16,881		16,755	33,637	5.2
2004	241	1,156,559	44,079		72,080	116,158	10.0
2005	333	1,436,564	108,595		69,064	177,659	12.3
2006	297	1,284,228	62,922		45,050	107,972	8.4
2007	283	1,241,521	60,196		25,809	86,006	6.9
2008	689	3,163,199	85,161		35,023	120,184	3.8
2009	421	1,925,233	30,996		30,959	61,955	3.2
2010[a]	502	2,165,628	53,619		47,511	101,130	4.7
2011[a]	492	2,157,420	67,982	3,665	37,185	108,832	5.0
2012[a]	880	3,716,240	49,774	25,305	34,334	109,413	2.9
2013[a]	714	3,367,224	73,695	NA	39,396	113,091	3.4
2014[a]	485	1,961,825	77,510	NA	37,170	114,680	5.8
2015[a]	312	1,372,800	80,543	--	--	--	--

[a]calculated with Bailey model

Non-target Taxa

Bull trout (*Salvelinus confluentus*) also comprised a large proportion of incidental species captured. During the trapping period 118 bull trout (15 ≥ 300 mm FL and 103 <300 mm FL) were captured. Additionally, 43 westslope cutthroat trout (*O. clarki lewisi*), and three Eastern brook trout (*S. fontinalis*) were collected. In all, 109 bull trout and 41 westslope cutthroat trout were released with PIT tags. Monthly and annual totals of all fish captured are presented in Appendix E and Appendix F, respectively.

Rotary Smolt Traps – Lower Wenatchee

Trap Operation

The Lower Wenatchee trap operated from 29 January through 26 July 2016. During this time the trap was inoperable for a total of 23 days due to high/low flows, high temperatures, heavy debris, major hatchery releases, and mechanical issues. Extreme river temperatures and low flows resulted in trapping operations being suspended for the season on 26 July. Throughout the season, the trap cones were operated in a single lower position.

Fish Sampling

A total of 43,685 individual fish were collected, with wild summer Chinook Salmon comprising 89% of the total catch. Additionally, 610 wild yearling spring Chinook Salmon, 7,701 hatchery yearling Chinook Salmon, 1,346 wild sockeye, 417 wild steelhead, and 259 hatchery steelhead were captured. Throughout the sampling period 567, 1,065, and 131 PIT tag were deployed into wild yearling spring Chinook, sockeye, and steelhead, respectively. Mortality for the season totaled 2 yearling spring Chinook, 184 subyearling summer Chinook, 63 sockeye, and 6 steelhead (0.3%, 0.7%, 4.7%, and 1.4%, respectively).

Wild Yearling Spring Chinook (Brood Year 2014)

Wild yearling spring Chinook Salmon were primarily captured in February and March (Figure 8). Throughout the trapping period 610 spring Chinook were collected and an estimated 708 would have been collected had the trap operated without interruption. A combination of 2013, 2014, and 2015 trials were used to develop a significant relationship between discharge and trap efficiency (R^2 = 0.62, P = 0.02). This model was used to calculate an emigrant estimate of 36,752 (±5,330). The mean fork length (SD) of captured yearling Chinook was 94 (9.4) mm (Table 4).

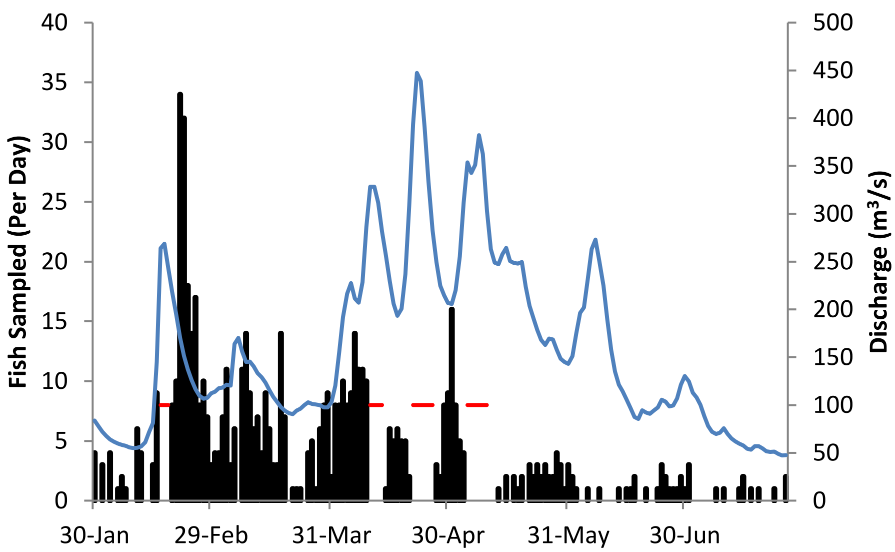

Figure 8. Daily capture of wild yearling Chinook Salmon at the Lower Wenatchee rotary smolt trap. Blue line indicates river discharge and red horizontal line indicates non-trapping period.

Table 4. Mean fork length (mm) and weight (g) for wild yearling spring Chinook Salmon sampled at the Lower Wenatchee rotary trap during 2016.

	Mean	SD	N
Fork length	94	9.4	600
Weight	9.0	2.9	598

Wild Subyearling Summer Chinook (Brood Year 2015)

Wild subyearling summer Chinook dominated the catch (63%) with 27,407 fish being processed, most being collected in April and May (Figure 9). An estimated 35,815 would have been captured had the trap operated without interruption. Over the season, four mark/recapture efficiency trials were carried out using Bismarck Brown dye. When combined with trials from 2014 and 2015 a significant discharge efficiency relationship was developed ($R^2 = 0.56$, $P <$ 0.001) and an emigrant estimate (95% C.I.) of 4,023,310 (±676,633) was calculated. The mean fork length (SD) for captured subyearling parr and fry summer Chinook was 64 (10.1) and 40 (3.7), respectively (Table 5). Over the sampling period 18 PIT tags were deployed in summer Chinook.

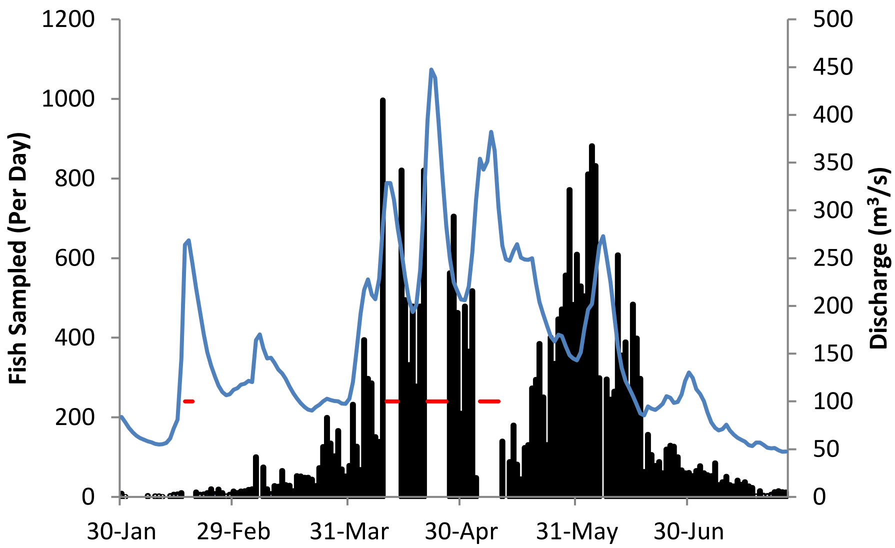

Figure 9. Daily capture of wild summer Chinook Salmon at the Lower Wenatchee rotary smolt trap. Blue line indicates river discharge and red horizontal line indicates non-trapping period.

Table 5. Mean fork length (mm) and weight (g) of subyearling summer Chinook Salmon sampled at the Lower Wenatchee rotary smolt trap.

	Transition / Smolt			Parr			Fry		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Fork length	82.8	7.3	216	64.1	10.1	2,799	40.9	3.7	3,143
Weight	6.4	1.8	216	3.1	1.6	2,778	0.6	0.3	3,005

Wild Sockeye

A total of 1,346 juvenile sockeye were collected in the 2016 season and an estimated 1,916 had the trap operated without interruption. Almost all of these fish (84%) were collected in April (Figure 10). No mark/recapture efficiency trials were carried out due to mechanical issues during the peak of the run. Mark/recapture efficiency trials from the 2013, 2014, and 2015 seasons created a significant discharge efficiency model ($R^2 = 0.52$, $P < 0.043$). This model produced a 2016 emigrant population estimate (95% C.I.) for juvenile sockeye at 208,250 (±29,447). Smolt survival (SE) to McNary of those tagged fish was 26% (5%) using the Cormack-Jolly-Seber estimator. In 2016, while most were Age 1+ (78%), we saw a large jump in Age 2+ (22%) when compared to 2014 and 2013 (Table 6). Mean fork length (SD) for captured sockeye was 81 (12.1) mm (Table 7).

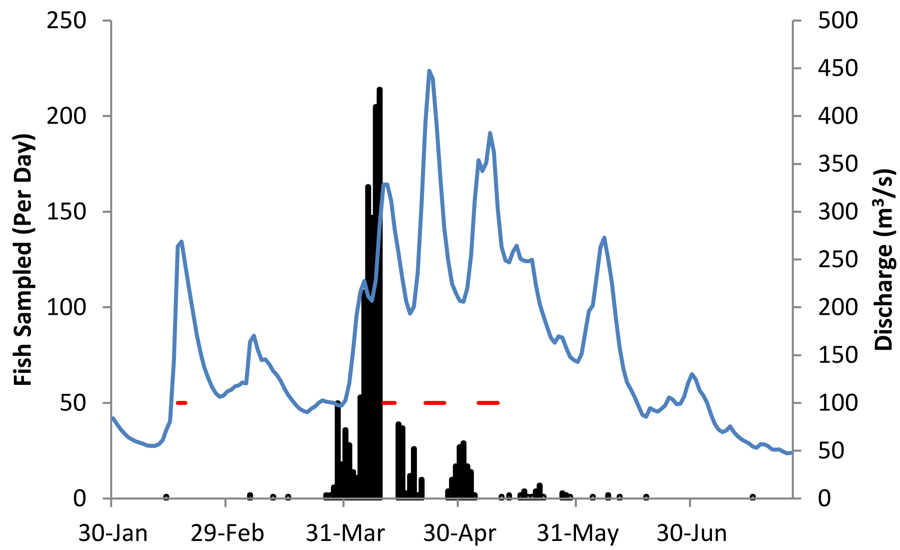

Figure 10. Daily capture of wild sockeye Salmon at the Lower Wenatchee rotary smolt trap. Blue line indicates river discharge and red horizontal line indicates non-trapping period.

Table 6. Age structure and estimated number of wild sockeye smolts that emigrated from Lake Wenatchee in 2013-2015.

Run year	Proportion of Wild Smolts			Total Wild Smolts
	Age 1+	Age 2+	Age 3+	
2013	0.932	0.068	0.00	873,096
2014	0.924	0.076	0.00	1,275,027
2015	0.780	0.220	0.00	1,065,614
2016	NA	NA	NA	208,250

Table 7. Mean fork length (mm) and weight (g) of wild sockeye Salmon smolts sampled at the Lower Wenatchee rotary smolt trap.

	Mean	SD	N
Fork length	81.0	12.1	1,164
Weight	4.7	2.9	1,147

Wild Summer Steelhead

Capture of wild steelhead at the Lower Wenatchee site for all life stages was low, totaling 417 fry, parr, and smolts combined and an estimated 505 collected had the trap operated without interruption. Peak catches of steelhead occurred in July (Figure 11). One mark/recapture trial was conducted using hatchery steelhead transitional/smolts in 2016. When combined with two trials using hatchery steelhead transitional/smolts 2014 a pooled efficiency of 0.028 was used to estimate (95% C.I.) the emigrant population (no fry) at 10,135 (±102,145) parr and smolt emigrant steelhead. If you include fry, the emigrant population was estimated at 18,400 (± 185,447). However, due to the low number of trials, small sample sizes, use of hatchery transitional/smolts surrogates and the relationship not being significant, caution should be used in the interpretation and use of the estimate. Mean length (SE) of transitional/smolts and parr was 159 (29.6) and 83 (24.0) mm, respectively (Table 8).

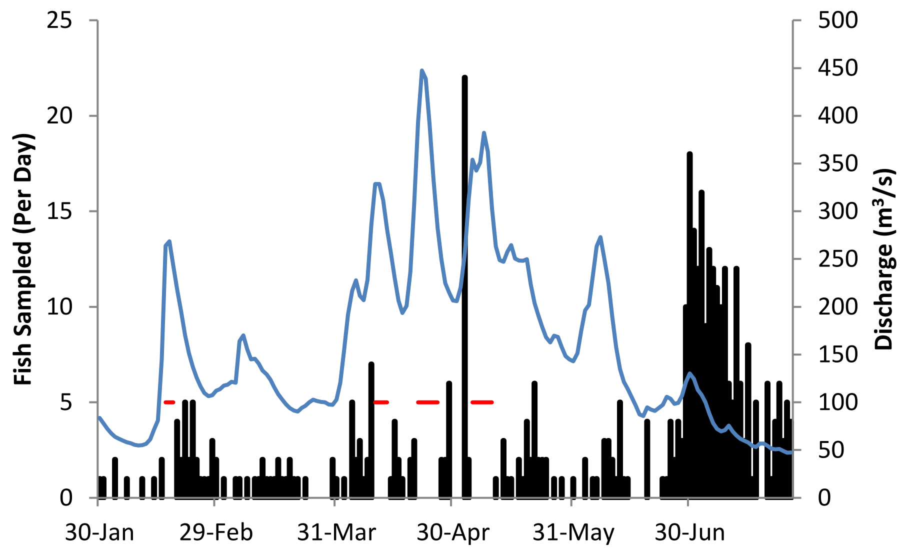

Figure 11. Daily capture of wild steelhead at the Lower Wenatchee rotary smolt trap. Blue line indicates river discharge and red horizontal line indicates non-trapping period.

Table 8. Mean fork length (mm) and weight (g) of wild steelhead sampled at the Lower Wenatchee rotary smolt trap.

	Transitional/Smolt			Parr		
	Mean	SD	N	Mean	SD	N
Fork length	159.4	29.6	66	83.1	24.0	102
Weight	45.7	27.4	66	7.7	6.6	99

Survival

For BY 2014, 885 spring Chinook Salmon redds were surveyed in the Wenatchee Basin producing an estimated 3,894,000 eggs. An estimate of 36,752 emigrants results in an estimated egg-to-emigrant survival of 0.94%. This is down from the last three year average of 1.45% (Table 9).

Table 9. Estimated egg deposition and egg-to-smolt survival rates for Wenatchee Basin spring

Chinook Salmon.

Brood Year	Number of redds	Estimated egg deposition	Estimated number	
			Total emigrants	Egg-to-emigrant survival (%)
2000	350	1,758,050	76,643	4.36
2001	1,876	8,674,624	243,516	2.81
2002	1,139	5,300,906	165,116	3.11
2003	323	1,887,612	70,738	3.75
2004	555	2,663,445	55,619	2.09
2005	829	3,587,083	302,116	8.42
2006	588	2,542,512	85,558	3.37
2007	466	2,069,506	60,219	2.91
2008	1,411	6,479,312	82,137	1.27
2009	--	--	--	--
2010	--	--	--	--
2011	872	3,823,720	89,917	2.35
2012	1,704	7,195,992	67,973	0.94
2013	1,159	5,512,204	58,595	1.06
2014	885	3,894,000	36,752	0.94

For BY 2015, 2,725 summer Chinook Salmon redds were surveyed in the Wenatchee Basin, 95.8% being upstream of the Lower Wenatchee smolt trap. After extrapolating by the proportion of redds above the trap a total emigrant population of 4,023,310 was estimated resulting in an egg-to-emigrant survival of 36.55%. This is down from the last three year average of 83.54% (Table 10).

Table 10. Estimated egg deposition and egg-to-emigrant survival rates for Wenatchee Basin summer Chinook Salmon.

Brood year	Peak total redd expansion	Estimated egg deposition	Redds above trap / total redds	Estimated number		
				Trap estimate	Total emigrants	Egg-to-emigrant survival (%)
1999	2,738	13,654,406	0.988	9,572,392	9,685,591	70.93
2000	2,540	13,820,140	0.983	1,299,476	1,322,383	9.57
2001	3,550	18,094,350	0.987	8,229,920	8,340,342	46.09
2002	6,836	37,488,624	0.977	13,167,855	13,475,368	35.95
2003	5,268	28,241,748	0.996	20,336,968	20,426,149	72.33
2004	4,874	26,207,498	0.989	14,764,141	14,935,745	56.99
2005	3,538	17,877,514	0.993	11,612,939	11,695,581	65.42
2006	8,896	45,663,168	0.979	9,397,044	9,595,512	21.01

Brood year	Peak total redd expansion	Estimated egg deposition	Redds above trap / total redds	Estimated number		
				Trap estimate	Total emigrants	Egg-to-emigrant survival (%)
2007	1,970	10,076,550	0.983	4,470,672	4,546,838	45.12
2008	2,800	14,302,400	0.978	4,309,496	4,405,473	30.8
2009	3,441	18,206,331	0.983	6,695,977	6,814,805	37.43
2010	3,261	16,184,343	0.957	--	--	--
2011	3,078	15,122,214	0.958	--	--	--
2012	2,504	12,021,704	0.93	9,333,214	10,034,508	83.47
2013	3,241	16,162,867	0.947	11,936,928	12,605,925	77.99
2014	3,458	16,556,904	0.959	14,157,778	14,763,064	89.17
2015	2,725	11,491,325	0.958	4,023,310	4,199,697	36.55

Non-target Taxa

No westslope cutthroat trout or bull trout where sampled at the Lower Wenatchee Trap. No PIT tags were applied to non-target taxa. Monthly and annual totals of all fish captured are presented in Appendix G and Appendix H, respectively.

Backpack Electrofishing

Fish Sampling

Between 19 October and 12 November 2015, WDFW personnel sampled the Chiwawa River for a total of 36,782 seconds. During this sampling, a total of 1,103 subyearling Chinook were collected of which 1,054 received a PIT tag. The greatest concentration of juvenile Chinook occurred between rkm 31 and 45 which had a mean sample rate of one Chinook collected for every 24 seconds of sampling. Over the sample period 20 Chinook died resulting in a mortality rate of 1.8%. Additionally, 63 juvenile bull trout were collected and 43 received a PIT tag. Highest catch rates for bull trout were around rkm 47. No mortality was observed for bull trout.

Detections and Calculations

Between the non-trapping season of 25 November 2015 through 1 March 2016, a total of three detections of remotely tagged Chinook were recorded at the lower Chiwawa antenna array. During the 2015 fall (19 October through 24 November) and 2016 spring trapping season (2 March and 30 June), the Chiwawa rotary smolt trap collected 29 and 26 remotely tagged Chinook, respectively. Due to relatively low sample size and poor detection rates at the Chiwawa antenna no emigrant estimate for the non-trapping period was calculated for the BY 2014.

DISCUSSION

Chiwawa River Rotary Smolt Trap

Over the last five years the Chiwawa River smolt trap has had an average installation date of 1 March. With a relatively normal winter the smolt trap was installed on 2 March. However the spring proved to be one of the warmest leading to a record high discharge for much of the spring and very low flows in the fall. In the spring the trap was pulled due to high flow/debris for 22 days and in the fall it was pulled for 47 days due to low flow.

Floods in the fall of 2015 – spring 2016 also caused the substrate to sift and altered the range of flows the Chiwawa River rotary smolt trap is considered operable. New discharge limits are estimated to be between 4.5 and 55.2 m^3/s. For the 2017 field season we will adjust our methodology to allow for sampling during low discharge levels by replacing our 2.4 m smolt trap with a 1.5 m smolt trap as needed.

Due to the assumed change in trap efficiencies associated with a single cone positions and altered substrate new trap efficiency models were developed for subyearling and yearling Chinook. However, a continued reliance upon historic mark/recapture trials for steelhead had to be used. This model will continue to be improved and updated as conditions allow. Historically, emigrant estimates were calculated using the Peterson estimator of abundance (Seber 1982), however more accurate estimates currently utilize a modified Bailey estimator (Murdoch et al. 2012).

The total production estimate for brood year 2014 was 114,680 and comprises estimates of subyearling emigrants in 2015 and yearling emigrants in 2016. Unfortunately, high flows, low antenna detections, and concerns related to spawning bull trout resulted in an abbreviated sampling window and prevented the completion of 2015 remote tagging efforts. This resulted in no estimate being calculated for the 2015 non-trapping season and a known underestimate of the total brood year production. Protocols and field sampling will be continually adapted to fit within environmental and permit constraints and estimates will be improved upon when possible.

Due to the large fall break in trapping historic run timing was used to extrapolate what the catch would have been had the trap been able to operate without interruption. It was estimated 6.5% of subyearling Chinook emigrated during this fall break in trapping so our subyearling Chinook emigrant estimate was adjusted accordingly.

The 2016 field season represented the first year the smolt trap operated with a single cone position. This allowed for a single model to be developed for each life stage and species regardless of when it emigrated, thus removing bias and improving our estimates for subyearling and yearling Chinook. In 2017 we will continue to develop and modify our mark/recapture models paying particular attention to improving our steelhead model.

Lower Wenatchee River Rotary Smolt Trap

Historically, the smolt trap on the mainstem Wenatchee River has moved location numerous times due to poor trap efficiencies of target species and environmental factors causing abbreviated trapping seasons. At the lower Wenatchee site, the smolt trap has been able to operate into September in 2013 and October in 2014. This marks a relatively large increase in operational length over the old site (located 2.5 km downstream) which had an average trap removal date of 14 August. However, since 2014 river discharge and water temperatures have hampered the trapping season for the Lower Wenatchee trap. At this site, the trap is considered operable between discharges of 36.8 and 283.2 m^3/s. In 2016, record high spring discharge resulted in the trap being pulled for 19 days, mostly in April and May. Complicating things further, river temperatures exceeded starting 20°C starting 27 July and trapping operations were again suspended. River temperatures remained elevated and low flow persisted through summer and on 19 August the decision was made to remove the smolt trap. Additionally, mechanical issues hindered catch totals and subsequent emigrant estimates. This was particularly evident when mechanical issues led to only one cone being operable for five days during the peak sockeye emigration. This caused a known underestimate of total catch and emigrant estimate. Overall however, river discharge and temperature continue to be the main issues that impact our trapping season. Adaptive management will be use to ensure maximum efficiency and number of days trapping.

Significant discharge efficiency models were obtained for three of the four target species at the Lower Wenatchee trap during the 2016 trapping season (wild spring and summer Chinook Salmon and sockeye Salmon). Collections of wild steelhead continue to be inadequate for conducting mark–recapture trials. In 2017, hatchery steelhead from the Chiwawa acclimation site will be used in mark/recapture trials in an effort to improve emigrant estimates of this target species. This approach requires the assumption that hatchery fish behave in a similar manner to wild fish, an assumption we will test over time as possible. While the new trap location has allowed for greater operational flexibility, it does require the development of new flow-efficiency models. While this can be accomplished relatively quickly with species that are relatively abundant (e.g., summer Chinook and sockeye), it may take several years for those in low abundance (e.g., steelhead). Fortunately, given similar operation parameters across time, we will be able to reexamine past abundance estimates when those models are fully developed.

Backpack Electrofishing

Remote sampling in the Chiwawa Basin started in 2012. Some success occurred early with PIT tag targets being met, however, there have been substantial obstacles since 2013. Permit restrictions limit field operations until bull trout spawning has concluded; which typically occurs early October. At this time, weather becomes increasingly unfavorable and elevated discharge along with cold air and water temperatures hinder sampling efforts. Since 2014, early high water events hindered sampling efforts and limited not only the area that was sampled, but also the number of fish that were processed. Future investigations will look into alternative sampling techniques and the allocation of personnel to maximize sampling efforts in the basin.

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APPENDICES

Appendix A. Peterson Population and Variance Equations.

Trap efficiency was calculated using the following formula:

$$\text{Trap efficiency} = E_i = R\ /\ Mi,$$

Where E_i is the trap efficiency during time period i; M_i is the number of marked fish released during time period i; and R_i is the number of marked fish recaptured during time period i. The number of fish captured was expanded by the estimated daily trap efficiency (e) to estimate the daily number of fish migrating past the trap using the following formula:

$$\text{Estimated daily migration} = \hat{N}_i = C_i / \hat{e}_i$$

where N_i is the estimated number of fish passing the trap during time period i; C_i is the number of unmarked fish captured during time period i; and e_i is the estimated trap efficiency for time period i based on the regression equation.

The variance for the total daily number of fish migrating past the trap was calculated using the following formulas:

$$\text{Variance of daily migration estimate} = \operatorname{var}\left[\hat{N}_i\right] = \hat{N}_i^2 \frac{\text{MSE}\left(1 + \frac{1}{n} + \frac{\left(X_i - \overline{X}\right)^2}{\left(n-1\right)s_X^2}\right)}{\hat{e}_i^2}$$

where X_i is the discharge for time period i, and n is the sample size. If a relationship between discharge and trap efficiency was not present (i.e., $P < 0.05$; r^2 □0.5), a pooled trap efficiency was used to estimate daily emigration:

$$\text{Pooled trap efficiency} = e_p = \sum R / \sum M$$

The daily emigration estimate was calculated using the formula:

$$\text{Daily emigration estimate} = \hat{N}_i = C_i / e_p$$

The variance for daily emigration estimates using the pooled trap efficiency was calculated using the formula:

Variance for daily emigration estimate = $\mathrm{var}\left[\hat{N}_i\right] = \hat{N}_i^2 \frac{e_p(1-e_p)/\sum M}{e_p^2}$

The total emigration estimate and confidence interval was calculated using the following formulas:

Total emigration estimate = $\sum \hat{N}_i$

95% confidence interval = $1.96 \times \sqrt{\sum \mathrm{var}}\left[\hat{N}_i\right]$

Appendix B. Bailey Population and Variance Equations.

Trap efficiency was calculated using the following formula:

Trap efficiency = $E_i = R+1 \;/\; Mi,$

Estimated daily emigration = $\hat{N}_i = \dfrac{C_i + 1}{\hat{e}_i}$

The variance of the total population abundance was calculated as follows:

$$Var\left(\sum_{i=1}^{n} \hat{N}_i\right) = \underbrace{\sum_i Var\left(\frac{(C_i + 1)}{\hat{e}_i}\right)}_{Part\ A} + \underbrace{\sum_i \sum_j Cov\left(\frac{(C_i + 1)}{\hat{e}_i}, \frac{(C_j + 1)}{\hat{e}_j}\right)}_{Part\ B}$$

Part A is the variance of the daily estimates where C_i is the number of fish caught in period *i*, e_i is the estimated trap efficiency for period *i*, and *Cov* is the between day covariance for days that the same linear model is used (part B). For a more details and derivation of Peterson and Bailey estimation methods see Murdoch et al. (2012).

Appendix C. Emigration during non-trapping periods.

A flow-efficiency regression model was developed for the lower Chiwawa River PIT tag interrogation site (CHL) using the same mark/recapture trials used for estimating efficiency at the smolt trap. This CHL model was used to calculate emigration outside of the trapping period by incorporating the tag rate into the Bailey estimator.

$$\text{Estimated daily emigration} = \left(\hat{N}_i = \frac{C_i + 1}{\hat{e}_i} \right) \Big/ t_i$$

$$\text{Where } t_i \text{ is equal to the tag rate} = t_i = \frac{t}{p}$$

Appendix D: Mark–recapture groups used to developing emigrant estimates. YCW = Yearling spring Chinook wild, YCH = Yearling spring Chinook hatchery, SKW = Sockeye wild, SUCH = summer Chinook wild, SBC = subyearling Chinook wild.

Species	Date	Position	Released	Recaptured	Efficiency (%)	Discharge (m^3/s)
			Lower Wenatchee River rotary smolt trap			
YCW	20-Mar-13	Low	223	5	2.24	88.2
YCW	05-Apr-13	Low	216	4	1.85	211.6
YCW	09-Apr-13	Low	186	3	1.61	187.2
YCW	13-Mar-14	Low	156	2	1.28	121.8
YCW	21-Mar-14	Low	243	4	1.65	102.8
YCW	31-Mar-14	Low	306	9	2.94	82.9
YCW	14-Apr-14	Low	165	4	2.42	127.6
YCH	17-Apr-15	Low	2,045	82	4.01	63.1
SKW	27-Apr-13	Low	565	6	1.06	141.6
SKW	31-Mar-14	Low	322	1	0.31	83.1
SKW	04-Apr-14	Low	599	2	0.33	81.7
SKW	07-Apr-14	Low	633	2	0.32	99.6
SKW	16-Apr-14	Low	591	3	0.51	126.2
SKW	19-Apr-14	Low	385	4	1.04	130.4
SKW	23-Apr-14	Low	504	2	0.40	125.5
SKW	12-Apr-15	Low	540	2	0.37	73.9
SUCH	14-May-14	Low	521	3	0.58	236.4
SUCH	20-May-14	Low	999	5	0.50	289.5
SUCH	27-May-14	Low	1,039	4	0.38	263.3
SUCH	31-May-14	Low	1,129	17	1.51	223.4
SUCH	05-Jun-14	Low	993	3	0.30	287.9
SUCH	08-Jun-14	Low	1,023	5	0.49	259.8
SUCH	16-Jun-14	Low	911	6	0.66	182.2
SUCH	19-Jun-14	Low	960	13	1.35	175.4
SUCH	07-Jul-14	Low	931	13	1.40	153.8
SUCH	11-Jul-14	Low	511	6	1.17	125.0
SUCH	17-Jul-14	Low	407	7	1.72	105.8
SUCH	20-Jul-14	Low	448	4	0.89	91.1
SUCH	24-Jul-14	Low	364	4	1.10	74.4
SUCH	03-Apr-15	Low	540	5	0.93	114.7
SUCH	07-Apr-15	Low	1,170	44	3.76	88.1
SUCH	10-Apr-15	Low	755	13	1.72	76.5

Species	Date	Position	Released	Recaptured	Efficiency (%)	Discharge (m^3/s)
SUCH	23-Apr-15	Low	1,035	17	1.64	99.4
SUCH	22-May-15	Low	974	12	1.23	159.5
SUCH	28-May-15	Low	1,109	3	0.27	164.6
SUCH	25-May-16	Low	1,051	10	0.95	171.5
SUCH	02-Jun-16	Low	1,071	22	2.05	167.6
SUCH	11-Jun-16	Low	685	11	1.61	85.1
		Chiwawa River rotary smolt trap				
YCW	06-Mar-16	Upper	132	15	11.36	14.7
YCW	09-Mar-16	Upper	106	12	11.32	15.8
YCW	12-Mar-16	Upper	126	14	11.11	15.1
YCW	02-Apr-16	Upper	178	11	6.18	22.7
YCW	04-Apr-16	Upper	240	13	5.42	34.4
SBC	16-Jun-16	Upper	265	21	7.92	17.6
SBC	26-Jun-16	Upper	241	32	13.28	17.7
SBC	01-Jul-16	Upper	326	34	10.43	24.9
SBC	07-Jul-16	Upper	246	34	13.82	14.5
SBC	11-Jul-16	Upper	80	13	16.25	14.0
SBC	27-Jul-16	Upper	101	22	21.78	12.1
SBC	04-Aug-16	Upper	209	96	45.93	8.2
SBC	10-Aug-16	Upper	162	51	31.48	6.5
SBC	12-Oct-16	Upper	199	73	36.68	5.7
SBC	17-Oct-16	Upper	185	37	20.00	10.9
SBC	28-Oct-16	Upper	200	22	11.00	16.8
SBC	04-Nov-16	Upper	156	17	10.90	11.8

Appendix E. Monthly collection information for the Chiwawa River rotary smolt trap.

	2016											
Species/Origin	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Total**
Chinook												
Wild												
Yearling	--	--	1,252	1,202	324	27	2	0	0	0	0	2,807
Subyearling	--	--	1,662	985	256	1,863	3,557	2,856	611	3,725	878	16,393
Hatchery	--	--	0	2,523	2	0	0	0	0	0	0	2,525
Steelhead												
Wild												
Smolt	--	--	8	56	46	44	8	16	16	1	0	195
Parr and fry	--	--	21	178	439	201	115	140	101	316	11	1,522
Hatchery	--	--	0	2	1,505	10	0	1	0	0	0	1,518
Coho												
Wild												
Smolt	--	--	0	0	0	0	0	0	0	0	0	0
Parr and fry	--	--	0	0	3	0	0	0	0	0	0	3
Hatchery	--	--	0	0	0	0	0	0	0	0	0	0
Bull trout												
Juvenile	--	--	0	3	2	1	0	4	9	71	13	103
Adult	--	--	1	0	0	2	1	0	7	4	0	15
Westslope cutthroat trout	--	--	0	0	5	13	6	14	4	1	0	43
Eastern brook trout	--	--	0	0	1	1	0	0	0	0	1	3
Rainbow trout	--	--	0	0	0	0	0	0	0	0	0	0
Mountain whitefish	--	--	14	1	6	6	211	570	6	25	44	883
Longnose dace	--	--	5	19	51	213	57	122	388	111	13	979
Northern pikeminnow	--	--	0	0	0	1	26	42	0	0	0	69
Sculpin spp.	--	--	7	5	12	16	21	15	4	9	5	94
Sucker spp.	--	--	0	0	0	0	1	1	0	1	0	3
Dace spp.	--	--	0	5	3	0	1	6	0	0	1	16
Yellow Perch	--	--	0	0	0	0	0	1	0	0	0	1
Redside shiner	--	--	0	0	0	0	0	0	0	0	0	0

Appendix F. Annual collection information from the Chiwawa River rotary smolt trap.

Species origin	2016	2015	2014	2013	2012	2011
Chinook						
Wild						
Yearling	2,807	6,350	5,419	3,199	7,626	4,848
Subyearling	16,393	31,152	23,755	27,621	14,831	20,561
Hatchery	2,525	7,162	5,293	15,909	30,751	25,620
Steelhead						
Wild						
Smolt	195	259	49	85	183	195
Parr and Fry	1,522	3,004	1,889	1,949	1,738	981
Hatchery	1,518	3,151	290	1,539	1,664	8,250
Coho						
Wild						
Smolt	0	0	0	1	1	3
Parr and fry	3	38	12	0	0	4
Hatchery	0	0	1	10	3	0
Bull trout						
Juvenile	103	266	260	310	488	351
Adult	15	32	75	51	31	7
Westslope cutthroat trout	43	72	59	86	60	38
Eastern brook trout	3	8	12	13	66	3
Mountain whitefish	883	5,544	2,970	2,108	3,291	990
Longnose dace	979	2,663	2,633	2,257	1,762	1,526
Northern pikeminnow	69	331	5	71	34	20
Sculpin spp.	94	225	131	91	157	129
Sucker spp.	3	30	4	6	0	0
Dace spp.	16	NA	NA	NA	NA	NA
Redside shiner	0	13	0	0	0	0
Yellow perch	1	0	0	0	0	0

Appendix G. Monthly collection information for the Lower Wenatchee River rotary smolt trap.

	2016											
Species/Origin	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Total**
Chinook												
Wild												
Yearling	4	194	166	141	69	23	13	--	--	--	--	610
Subyearling	10	148	1,752	8,338	7,612	8,677	870	--	--	--	--	27,407
Hatchery	1,858	3,197	37	2,538	69	2	0	--	--	--	--	7,701
Steelhead												
Wild												
Smolt	0	7	3	29	43	5	1	--	--	--	--	88
Parr and fry	2	28	20	15	11	62	191	--	--	--	--	329
Hatchery	0	0	0	101	146	12	0	--	--	--	--	259
Sockeye												
Wild	0	1	118	1,130	91	5	1	--	--	--	--	1,346
Coho												
Wild												
Smolt	0	7	2	0	0	1	0	--	--	--	--	10
Fry and parr	0	45	13	11	18	36	12	--	--	--	--	135
Hatchery	0	0	0	0	212	7	0	--	--	--	--	219
Unknown	0	0	5	1,776	829	17	3	--	--	--	--	2,630
Bull trout												
Juvenile	0	0	0	0	0	0	0	--	--	--	--	0
Adult	0	0	0	0	0	0	0	--	--	--	--	0
Westslope cutthroat trout	0	0	0	0	0	0	0	--	--	--	--	0
Mountain whitefish	0	0	2	7	3	3	0	--	--	--	--	15
Lamprey spp.	35	162	343	89	286	397	185	--	--	--	--	1,497
Longnose dace	1	23	11	28	17	39	44	--	--	--	--	163
Sculpin spp.	1	5	6	7	8	10	19	--	--	--	--	56
Sucker spp.	2	23	14	49	79	86	16	--	--	--	--	269
Dace spp.	1	3	20	25	32	37	15	--	--	--	--	133
Fathead minnow	0	0	0	3	5	0	1	--	--	--	--	9
Redside shiner	0	1	2	1	69	90	26	--	--	--	--	189
Stickleback (3-spined)	0	0	0	0	2	0	0	--	--	--	--	2
Northern pikeminnow	0	11	7	54	181	274	25	--	--	--	--	552
Chiselmouth	0	0	0	1	2	57	6	--	--	--	--	66
Peamouth	0	0	0	0	0	0	0	--	--	--	--	0

Appendix H. Annual collection information from the Lower Wenatchee River rotary smolt trap.

Species/Origin	2016	2015	2014	2013
Chinook				
Wild				
Yearling	610	1,559	1,700	1,854
Subyearling	27,407	252,293	81,445	52,652
Hatchery	7,701	9,920	31,290	13,979
Steelhead				
Wild				
Smolt	88	231	80	173
Parr	329	100	102	537
Hatchery	259	2,288	494	819
Sockeye				
Wild	1,346	4,178	7,678	4,520
Hatchery	0	0	0	72
Coho				
Wild				
Smolt	10	22	220	597
Fry and parr	135	4,972	393	923
Hatchery	219	6,566	16,908	12,960
Unknown	2,630	143	NA	NA
Bull trout				
Juvenile	0	0	3	6
Adult	0	0	0	0
Westslope cutthroat trout	0	1	3	0
Mountain whitefish	15	9	27	110
Lamprey spp.	1,497	283	292	762
Longnose dace	163	242	541	1,382
Sculpin spp.	56	52	128	242
Sucker spp.	269	51	134	240
Redside shiner	189	19	94	423
Stickleback (3-spined)	2	13	66	196
Dace spp.	133	NA	NA	NA
Fathead minnow	9	NA	NA	NA
Northern pikeminnow	552	12	37	39
Chiselmouth	66	6	69	10
Peamouth	0	3	9	10

Appendix C

Summary of PIT-Tagging Activities in the Wenatchee Basin, 2016

Appendix C. Numbers of fish captured, recaptured, PIT tagged, trap and hand mortality, shed tags, and total tags released in the Wenatchee River basin during January through November, 2016.

Sampling Location	Species and Life Stage	Number collected	Number of recaptures	Number tagged	Number died	Shed tags	Total tags released	Percent mortality
Chiwawa Trap	Wild Subyearling Chinook	16,393	89	7,355	82	1	7354	0.50
	Wild Yearling Chinook	2,807	79	2,729	4	3	2,729	0.14
	Wild Steelhead/Rainbow	1,717	18	1,323	10	10	1,313	0.58
	Hatchery Steelhead/Rainbow	1,518	0	1	0	0	1	0.00
	Wild Coho	3	0	0	0	0	0	0.00
	Total	22,438	186	11,408	96	14	11,397	0.43
Chiwawa Remote (Electrofishing)	Wild Subyearling Chinook	1,829	24	1,776	5	0	1,776	0.27
	Wild Yearling Chinook	0	0	0	0	0	0	0.00
	Wild Steelhead/Rainbow	0	0	0	0	0	0	0.00
	Hatchery Steelhead/Rainbow	0	0	0	0	0	0	0.00
	Wild Coho	0	0	0	0	0	0	0.00
	Total	1,829	24	1,776	5	0	1,776	0.27
Nason Creek Trap	Wild Subyearling Chinook	791	48	434	6	0	434	0.76
	Wild Yearling Chinook	61	4	61	0	0	61	0.00
	Wild Steelhead/Rainbow	1,007	6	531	1	1	530	0.10
	Hatchery Steelhead/Rainbow	98	7	0	0	0	0	0.00
	Wild Coho	6	0	6	0	0	6	0.00
	Total	1,963	65	1,032	7	1	1,031	0.36
Nason Creek Remote (Electrofishing)	Wild Subyearling Chinook	828	10	802	14	0	802	1.69
	Wild Yearling Chinook	0	0	0	0	0	0	0.00
	Wild Steelhead/Rainbow	0	0	0	0	0	0	0.00
	Hatchery Steelhead/Rainbow	0	0	0	0	0	0	0.00
	Wild Coho	0	0	0	0	0	0	0.00
	Total	828	10	802	14	0	802	1.69
White River Trap	Wild Subyearling Chinook	197	3	137	2	1	136	1.02
	Wild Yearling Chinook	3	0	3	0	0	3	0.00
	Wild Steelhead/Rainbow	5	0	5	0	0	5	0.00
	Hatchery Steelhead/Rainbow	0	0	0	0	0	0	0.00
	Wild Coho	0	0	0	0	0	0	0.00
	Total	205	0	145	2	1	144	0.98
Lower Wenatchee Trap	Wild Subyearling Chinook	27,407	38	18	184	0	18	0.67
	Wild Yearling Chinook	610	4	538	2	0	538	0.33
	Wild Steelhead/Rainbow	417	0	131	6	0	131	1.44
	Hatchery Steelhead/Rainbow	259	0	0	1	0	0	0.39
	Wild Coho	145	0	0	0	0	0	0.00
	Unknown Coho	2,630	0	2	3	0	2	0.11
	Wild Sockeye	1,346	1	1,065	64	0	1,065	4.75

Sampling Location	Species and Life Stage	Number collected	Number of recaptures	Number tagged	Number died	Shed tags	Total tags released	Percent mortality
	Total	32,814	43	1,754	260	0	1,754	0.79
Total:	**Wild Subyearling Chinook**	47,445	212	10,522	293	2	10,520	0.62
	Wild Yearling Chinook	3,481	87	3,331	6	3	3,331	0.17
	Wild Steelhead/Rainbow	3,146	24	1,990	17	11	1,979	0.51
	Hatchery Steelhead/Rainbow	1,875	7	1	1	0	1	0.05
	Wild Coho	154	0	6	0	0	6	0.00
	Unknown Coho	2,630	0	2	3	0	2	0.11
	Wild Sockeye	1,346	1	1,065	64	0	1,065	4.75
Grand Total:		60,077	331	16,917	384	16	16,904	0.64

Appendix D

Wenatchee Steelhead Spawning Escapement Estimates, 2016

Estimates of Wenatchee Steelhead Spawners in 2016

Kevin See

January 06, 2017

Introduction

Redd counts are an established method to provide an index of adult spawners (Gallagher et al. 2007). In the Wenatchee and Methow subbasins, index reaches are surveyed weekly during the steelhead spawning season (Mar 07, 2016 - May 26, 2016) and non-index reaches are surveyed once during the peak spawning period. The goal of this work is to:

- Predict observer net error, based on a model developed with data from steelhead redd surveys in the Methow, similar to that described in Murdoch et al. (2014).
- Use estimates of observer net error rates and the mean survey interval to estimate the number of redds in each index reach, using a Gaussian area under the curve (GAUC) technique described in Millar et al. (2012).
- Estimate the total number of redds in the non-index reaches by adjusting the observed counts with the estimated net error.
- Convert these estimates of redds in the mainstem areas (surveyed for redds) into estimates of spawners.
- Use PIT-tag based estimates of escapement for all tributaries in the Wenatchee, and combine those estimates with the redd-based estimates of spawners in the mainstem areas to estimate the total number of spawners in the Wenatchee.

Methods

Mainstem areas

The model for observer net error (observed redd counts / true number of redds) is a model averaging of the 2 best models that were fit to 43 data points in the Methow. Both models contained covariates of observed redd density (redds / m) and mean thalweg CV as a proxy for channel complexity. One model also contained discharge while the other also contained total redd survey experience as an additional covariate. Predictions were made using model averaged coefficients (based on AICc model weights) and the 2016 steelhead data. From these survey specific estimates of net error, a mean and standard error of net error was calculated for each reach. The standard deviation was calculated by taking the square root of the sum of the squared standard errors for all predictions within a reach.

Estimates of total redds were made for each index reach using the GAUC model described in Millar et al. (2012). The GAUC model was developed with spawner counts in mind. As it is usually infeasible to mark every individual spawner, only total spawner counts can be used, and an estimate of average stream life must be utilized to translate total spawner days to total unique spawners. However, in adapting this for redd surveys, two modification could be used. The first would fit GAUC models to data showing all visible redds at each survey, and use an estimate of redd life as the equivalent of spawner stream life. However, because conditions can lead to many redds not disappearing before the end of the survey season, the estimates of redd life can be biased low. The second method relies on the fact that individual redds can be marked, and therefore the GAUC model can be fit to new redds only. The equivalent of stream life thus became the mean and standard deviation of the survey interval. We utilized the second method for this analysis.

For non-index reaches, which were surveyed only once during peak spawning, the estimate of total redds was calculated by dividing the observed redds by the estimate of net error associated with that survey. This assumes that no redds were washed out before the non-index survey, and that no new redds appeared after that survey. As the number of redds observed in the non-index reaches ranged from 0 to 3, any violoation of this assumption should not affect the overall estimates very much. Based on the peak spawning time for the associated index reaches, the surveys in the non-index reaches were conducted either at peak spawning, or within 10 days after peak spawning (Figure 2}).

To convert estimates of total redds into estimates of natural and hatchery spawners, total redds were multiplied by a fish per redd (FpR) estimate and then by the proportion of hatchery or wild fish. The fish per redd estimate was based on PIT tags from the branching patch-occupany model (see below) observed to move into the lower or upper Wenatchee (below or above Tumwater dam). FpR was calculated as the ratio of male to female fish, plus 1. This was 1.65 above Tumwater dam, and 1.61 below Tumwater. Reaches W1 - W7 are below Tumwater, while reaches W8 - W10 are above Tumwater. Similarly, the proportion of hatchery and natural origin fish was calculated from the same group of PIT tags for areas above and below Tumwater. The proportion of hatchery origin fish was 0.45 above Tumwater dam, and 0.35 below Tumwater (Table 2).

Tributary areas

Esimates of escapement to various tributaries in the Wenatchee were made using a branching patch-occupancy model (Waterhouse, L. et al., *in prep*) based on PIT tag observations of fish tagged at Priest Rapids dam. All fish that escaped to the various tributaries were assumed to be spawners (i.e. pre-spawn mortality only occurs in the mainstem).

Total spawners

When summing spawner estimates from index reaches to obtain estimates of total spawners in the Wenatchee, an attempt was made to incorporate the fact that the reaches within a stream are not independent. Estimates of correlation between the reaches within a stream were made based on weekly observed redds. Because correlations are often quite high between reaches, this is a better alternative than to naively assume the standard errors between reaches are independent of one another. These estimates of correlation were combined with estimates of standard error for each index reach to calculate a covariance matrix for the Wenatchee index reaches (W6, W8, W9, W10), which was used when summing estimates of spawners to estimate the total standard error. Failure to incorporate the correlations between reaches would result in an underestimate of standard error at the population scale. Non-index reaches were only surveyed once, so it is impossible to estimate a correlation coefficient between non-index reaches and index reaches. Therefore, they were assumed to be independent from the index reachs when summing the estimates of spawners. Because the estimates of tributary spawners were made separately (see above), they were also treated as independent when summing spawner estimates. The uncertainty in each step was carried through the entire analysis via the delta method (Casella and Berger 2002).

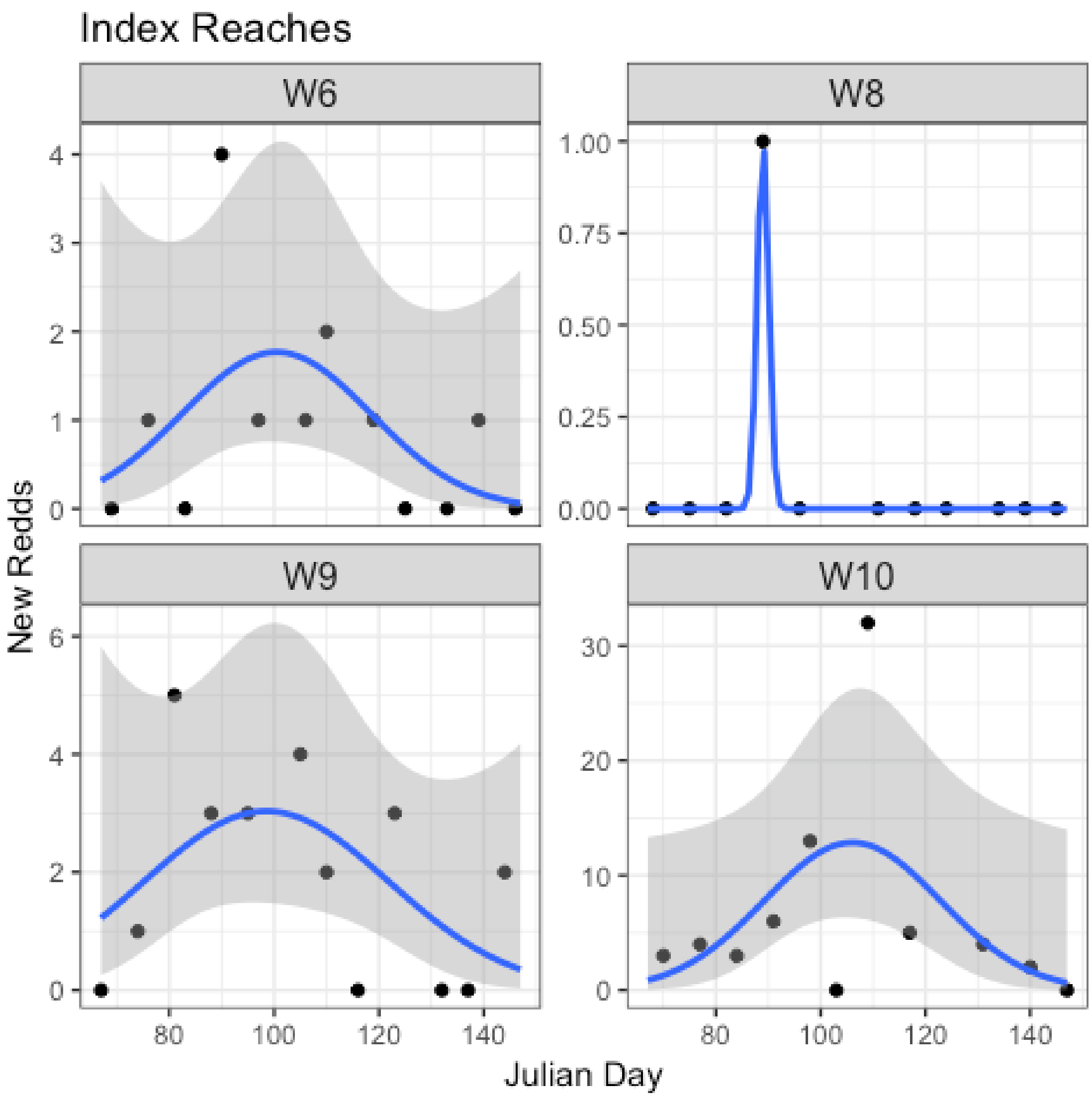
Results

Redd estimates

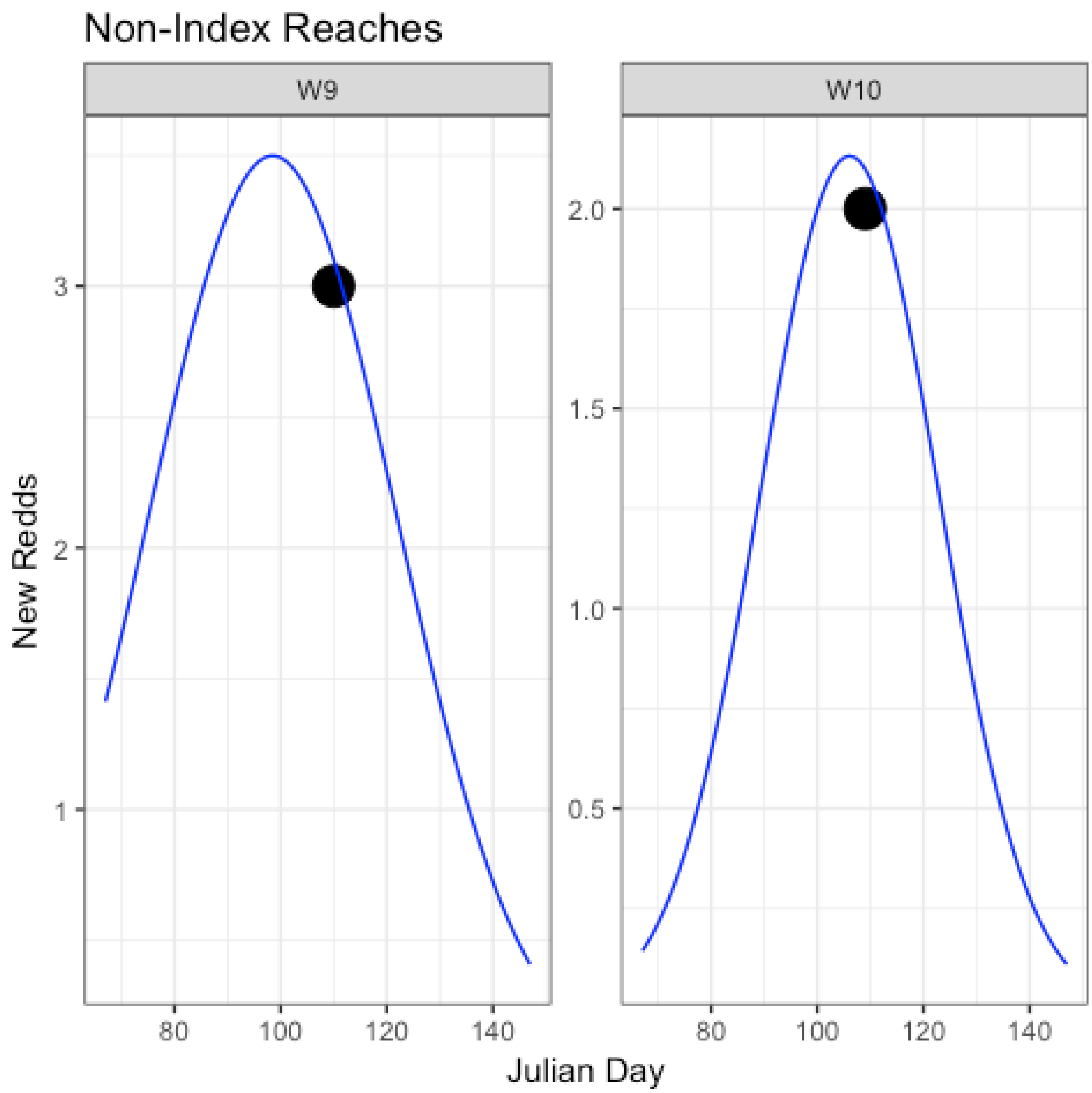
It should be noted that the GAUC parameters from index reaches were not used to estimate total redds in the associated non-index reaches. Figure 4 does illustrate that the non-index reach surveys were conducted close to the period of peak spawning (as determined by the associated index reaches), thus helping to validate the assumptions that go into estimating total redds in non-index reaches.

Table 1: Estimates of mean net error and total redds for each reach.

Reach	Type	Index.Reach	Net.Error	Net.Error.CV	Redds.Counted	Redds.Est	Redds.CV
C1	Index	-	NA	NA	0	0	NA
N1	Index	-	NA	NA	0	0	NA
P1	Index	-	NA	NA	0	0	NA
P1	Non-Index	NA	NA	NA	0	0	NA
W1	Non-Index	W2	NA	NA	0	0	NA
W2	Index	-	0.91	1.98	0	0	NA
W3	Non-Index	W2	NA	NA	0	0	NA
W4	Non-Index	W6	NA	NA	0	0	NA
W5	Non-Index	W6	NA	NA	0	0	NA
W6	Index	-	1.01	1.36	11	11	1.42
W6	Non-Index	W6	1.28	0.52	0	0	NA
W8	Index	-	0.85	1.47	1	1	0.59
W9	Index	-	0.93	1.46	23	26	1.48
W9	Non-Index	W9	0.99	0.42	3	3	0.42
W10	Index	-	0.84	1.31	72	82	1.39
W10	Non-Index	W10	0.66	0.34	2	3	0.34
Total	NA	NA	NA	NA	112	126	1.04



Plots of observed redd counts (black dots) through time for each index reach, and the fitted curve from the GAUC model (blue line) with associated uncertainty (gray).



Observed redd counts for non-index reaches with non-zero peak redd counts. The blue curve shows the GAUC estimated spawning curve, demonstrating how close to peak spawning the non-index surveys were conducted.

Spawner estimates

Table 2: Fish per redd and hatchery / natural origin proportion estimates.

Area	Fish/redd	FpR Std. Error	Prop. Hatchery	Prop Std. Error
Above TUF	1.652	0.070	0.447	0.036
Below TUF	1.613	0.084	0.347	0.043

Table 3: Estimates (CV) of spawners by area and origin.

Area	Type	Hatchery	Natural
Little Wenatchee	Trib	0 (--)	0 (--)
White River	Trib	0 (--)	8 (0.8)
C1	Index	0 (--)	0 (--)
Chiwaukum	Trib	11 (1)	64 (0.36)
Chiwawa	Trib	134 (0.35)	45 (0.44)
Chumstick	Trib	39 (0.37)	74 (0.27)
Icicle	Trib	18 (0.53)	72 (0.25)
Mission	Trib	13 (0.69)	33 (0.38)
N1	Index	0 (--)	0 (--)
Nason	Trib	94 (0.32)	57 (0.39)
P1	Index	0 (--)	0 (--)
P1	Non-Index	0 (--)	0 (--)
Peshastin	Trib	0 (--)	151 (0.19)
W1	Non-Index	0 (--)	0 (--)
W10	Index	61 (1.39)	75 (1.39)
W10	Non-Index	2 (0.35)	3 (0.35)
W2	Index	0 (--)	0 (--)
W3	Non-Index	0 (--)	0 (--)
W4	Non-Index	0 (--)	0 (--)
W5	Non-Index	0 (--)	0 (--)
W6	Index	6 (1.43)	12 (1.42)
W6	Non-Index	0 (--)	0 (--)
W8	Index	1 (0.6)	1 (0.6)
W9	Index	19 (1.48)	24 (1.48)
W9	Non-Index	2 (0.43)	3 (0.42)
Total		400 (0.31)	621 (0.25)

Discussion

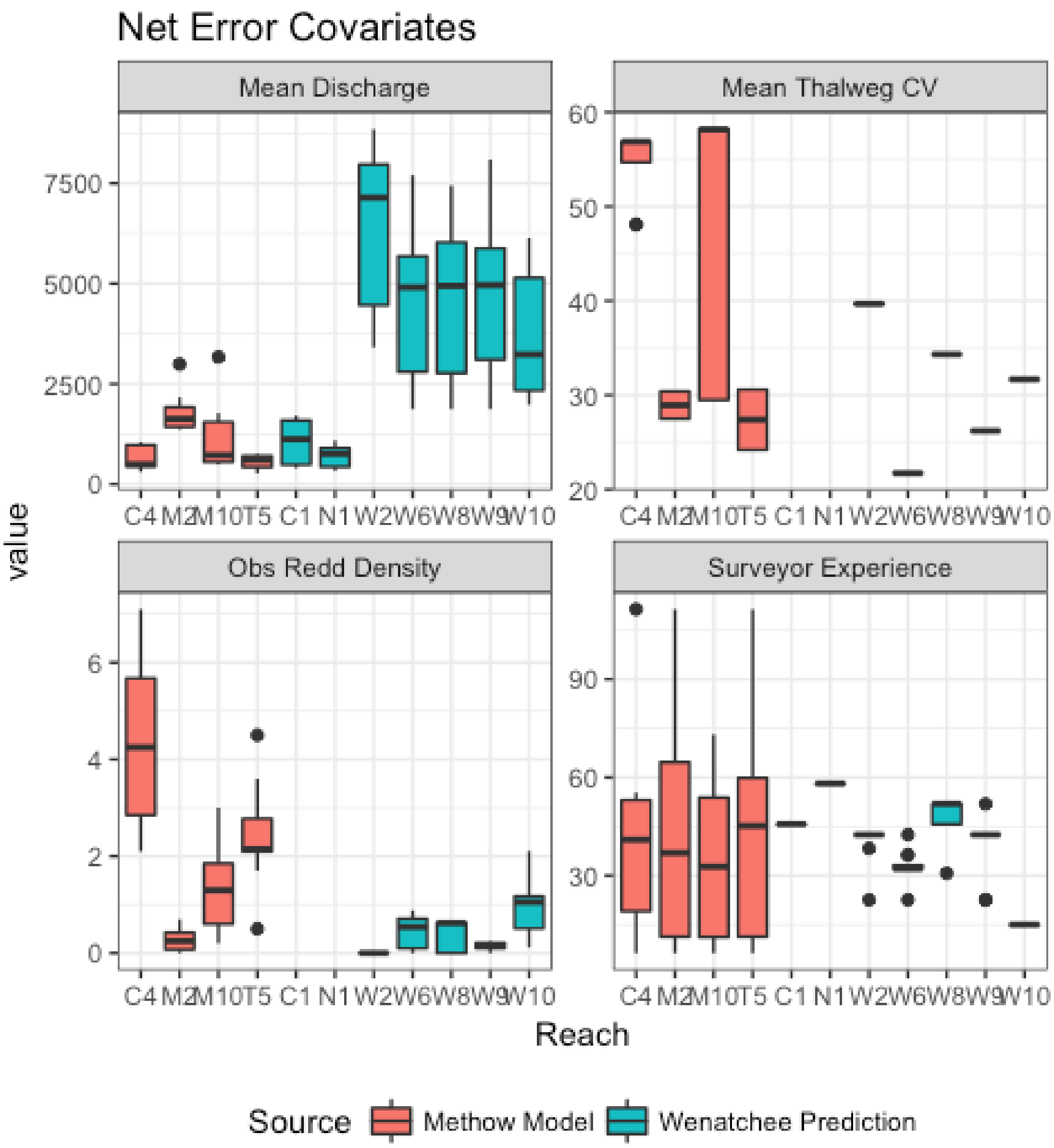
We have estimated the number of steelhead redds based on redd surveys, while incorporating potential observation error. After translating these to estimates of spawners by origin, we can then compare the spawner estimates to escapement estimates made using PIT tags, and estimate a pre-spawn mortality rate (Table 4). Taking the total PIT-tag based escapement estimate to the Wenatchee (after subtracting the 327 hatchery and 66 wild fish removed at Tumwater, as well as the 27 hatchery fish removed at Dryden, and the 56 and 8 deaths to hatchery and wild fish due to harvest), and subtracting the total estimate of spawners, including the tributaries, then dividing by the total escapement estimate provides an estimate of pre-spawn mortality across the entire Wenatchee population. We did this for natural and hatchery origin fish, and found that natural fish had a higher pre-spawn mortality rate this year.

Table 4: Wenatchee pre-spawn mortality rates.

Origin	**Pre-spawn_Mort**	**CV**
Natural	0.26	0.0009
Hatchery	0.09	0.0077

Caveats

The predictions of surveyor net error were made using a model that had been fit to data in the Methow. Most covariates in the Wenatchee were within the range of values in the Methow study, but mean discharge was higher in all reaches in the Wenatchee than in the modeled reaches in the Methow (Figure 3). The mean discharge in the Methow study was 1069.2, while it was 3837.5 in the Wenatchee reaches in 2016. That difference alone would change net error predictions by 0.5, not an insignificant amount. However, the observed covariate values in the Wenatchee did not lead to unrealistic estimates of net error. The ranges of net error estimates for the Methow study and the Wenatchee in 2016 were very similar.



Net error covariate values from the study in the Methow and the predicted reaches in the Wenatchee.

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Appendix E

Genetic Diversity of Wenatchee Summer Steelhead

Examining the Genetic Structure of Wenatchee Basin Steelhead and Evaluating the Effects of the Supplementation Program

Developed for

Chelan County PUD

and the

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17 January 2012

Table of Contents

Executive Summary

In 1997, Wenatchee River summer steelhead, as part of the upper Columbia River evolutionarily significant unit (ESU), were listed as threatened under the Endangered Species Act (ESA). To address concerns about effects of hatchery supplementation, the hatchery program for hatchery produced (HOR) summer steelhead to be planted in the Wenatchee River changed from using mixed ancestry broodstock collected in the Columbia River to using Wenatchee River broodstock collected in the Wenatchee River. Three monitoring and evaluation (M&E) indicators were developed to measure the genetic effects of hatchery production on wild fish populations. To address these indicators, temporal collections of tissue samples from Wenatchee River hatchery-produced (HOR) and natural origin (NOR) adults captured and sampled at Dryden and Tumwater dams and from NOR juveniles from three Wenatchee River tributaries and the Entiat River were surveyed for genetic variation with 132 genetic (SNPs) markers. Peshastin Creek (a Wenatchee River tributary) and the Entiat River served as no-hatchery-outplant controls, meaning they have stopped receiving HOR juvenile outplants. As per the M&E plan, we interrogated these data for the presence or absence of spatial and temporal trends in allele frequencies, genetic distances, and effective population size.

Allele frequencies – Changes to the summer steelhead hatchery supplementation program had no detectable effect on genetic diversity of wild populations. On average, HOR adults had higher minor allele frequencies (MAF) than NOR adults, which may simply reflect the mixed ancestry of HOR adults. Both HOR and NOR adults had MAF similar to juveniles collected in spawning tributaries and in the Entiat River. There was no temporal trend in allele frequencies or observed heterozygosity in adult or juvenile collections and allele frequencies in control populations were no different than those still receiving hatchery outplants. This suggests that the hatchery program has had little effect on allele frequencies since broodstock sources changed in 1998.

Genetic distances – As intended, interbreeding of Wenatchee River HOR and NOR adults reduced the genetic differences between Wells Hatchery HOR adults and Wenatchee River NOR adults observed in the first few years after changing the broodstock collection protocol. Though there were detectable genetic differences between HOR and HOR adults, the magnitude of that

difference declined over time. HOR adults were genetically quite different from NOR adults and juveniles based on pair-wise F_{ST} and principal components analysis (PCA), most likely because of the much smaller effective population size (N_b) in the hatchery population (see below). Pair-wise F_{ST} estimates and genetic distances between HOR and NOR adults collected the same year declined over time suggesting that the interbreeding of HOR and NOR adults in the hatchery (and presumably in the wild) is slowly homogenizing Wenatchee River summer steelhead. Analyses using brood year (the year fish were hatched, determined using scale-based age estimates) were inconclusive because of limitations of the data.

Effective population size (N_b) – Although the effective population size of the Wenatchee River hatchery summer steelhead program was consistently small, it does not appear to have caused a reduction in the effective population size of wild populations. On average, estimates of N_b were much lower and varied less for HOR adults than for NOR adults and juveniles. Estimates of N_b for HOR adults declined from the earliest brood years to a stable new low value after broodstock practices were changed in 1997. There was no indication that this had any effect on N_b in NOR adults and juveniles; N_b estimates for NOR adults and juveniles were, on average, higher and varied considerably over the time period covered by our dataset (1998 – 2010) and showed no temporal trend.

Introduction

The National Marine Fisheries Service (NMFS) recognizes 15 Evolutionary Significant Units (ESU) for west coast steelhead (*Oncorhynchus mykiss*). The Upper Columbia ESU, which contains steelhead in the Wenatchee Basin, was listed as endangered under the Endangered Species Act (ESA) in 1997. Included in this listing were the Wells hatchery steelhead (program initiated in the late 1960s) that originated from a mixed group of native steelhead and are considered to be genetically similar to natural spawning populations above Wells Dam. Juvenile steelhead from Wells Fish Hatchery was the primary stock released into the Wenatchee River (Murdoch et al. 2003). The 1998 steelhead status review identified several areas of concern for this ESU including the risk of genetic homogenization due to hatchery practices and the high proportion (65% for the Wenatchee River) of hatchery fish present on the spawning grounds (Good et al. 2005). The Biological Review Team (BRT) further identified the relationship between the resident and anadromous forms of *O. mykiss* and possible changes in the population structure ('genetic heritage of the naturally spawning fish') in the basin as two areas requiring additional study. Furthermore, the West Coast Steelhead BRT (2003) recommended that stocks in the Wenatchee, Entiat, and Methow rivers, within the Upper Columbia ESU, be managed as separate populations.

A review of the presence of resident *O. mykiss* in the Upper Columbia ESU (Good et al. 2005) shows that rainbow trout are relatively abundant in upper Columbia River tributaries currently accessible to steelhead as well as in upriver tributaries unavailable to anadromous access by Chief Joseph and Grand Coulee dams (Kostow 2003). U.S. Fish and Wildlife Service (USFWS) biologists surveyed the abundance of trout and steelhead juveniles in the Wenatchee, Entiat, and Methow river drainages in the mid-1980s and found adult trout (defined as those with fork length > 20 cm) in all basins (Mullan et al. 1992). The results also supported the hypothesis that resident *O. mykiss* are more abundant in tributary or mainstem areas upstream of the areas used by steelhead for rearing. No samples of rainbow trout from the Wenatchee were available for this study.

In addition to the mixed ancestry Wells Hatchery steelhead, Skamania Hatchery (Washougal River steelhead ancestry) steelhead were also released into the Wenatchee River basin for several years in the late 1980s (L. Brown, Washington Dept. of Fish and Wildlife [WDFW], personal communication). In 1996, broodstock for the Wenatchee River steelhead program were collected from Priest Rapids Dam and Dryden (rkm 24.9) and Tumwater (rkm 52.6) dams on the Wenatchee River. Because of the ESA listing, broodstock collection after 1996 was restricted to the Wenatchee River in an effort to develop a localized broodstock (Murdoch et al. 2003). Thus, starting in 1998, all juvenile steelhead released into the Wenatchee River and Wenatchee River tributaries were offspring of only Wenatchee River captured broodstock.

In response to the need for evaluation of the supplementation program, both a monitoring and evaluation plan (Murdoch and Peven 2005) and the associated analytical framework (Hays et al. 2006) were developed for the Habitat Conservation Plans Hatchery Committee through the joint effort of the fishery co-managers (Confederated Tribes of the Colville Reservation [CCT], NMFS, USFWS, WDFW, and Yakama Nation [YN]) and Chelan County, Douglas County, and Grant County Public Utility Districts (PUD). These reports outline 10 objectives to be applied to various species assessing the impacts of hatchery operations mitigating the operation of Rock Island and Rocky Reach Dams. This report pertains to Wenatchee River basin steelhead (*O. mykiss*) and the steelhead supplementation program as addressed by objective 3, specifically the first three evaluation indicators.

> **Objective 3:** Determine if genetic diversity, population structure, and effective population size have changed in natural spawning populations as a result of the hatchery program. Additionally, determine if hatchery programs have caused changes in phenotypic characteristics of natural populations.

3.1 Allele Frequency

3.2 Genetic Distances Between Populations

3.3 Effective Spawning Population

To address these evaluation indicators the WDFW Molecular Genetics Lab (MGL) obtained pertinent tissue collections and samples, surveyed genetic variation with SNP markers using our standard laboratory protocols, and calculated the relevant genetic metrics and statistics. We used collections from both the Entiat River and Wenatchee River basins. Both have received hatchery plants from non-local stocks [i.e. Entiat was stocked with both Wenatchee and Wells program juveniles averaging 12K and 18K respectively during 1995-2001, and Wenatchee received on average 177K juveniles from the Wells program during 1995-2001; (Good et al. 2005)], and both have all or some part of the basin designated as natural production "reference" drainage – no hatchery outplanting (i.e., the entire Entiat Basin, and Peshastin Creek in the Wenatchee River basin) (Good et al. 2005).

Materials and methods

Sample collections

To address objectives 3.1 through 3.3, we obtained samples from hatchery (HOR, adipose fin clipped) and natural origin (NOR, adipose fin intact) adult summer steelhead captured at Dryden or Tumwater diversion dams in the summer and fall of 1997 through 2009 (excepting 2004 and 2005; Table 1). All or some fraction of these fish was later used as hatchery broodstock the calendar year following the sampling year. In order to keep things simple we have reported years as the spawning year, i.e., the calendar year the fish were spawned, not the calendar year they were captured.

To address objective 3.2, it was necessary to have samples from natural origin fish from each of the spawning populations in the basin. It is difficult to obtain adult samples from known spawning populations due to the life history and behavior of steelhead, without tributary weirs or some other blocking method of collection. The NOR adult samples used as broodstock collected from Dryden and Tumwater Dams were a mixed collection representing all of the spawning populations located upstream. Therefore to determine population substructure within the basin we obtained collections of juvenile fish from smolt traps located within tributaries representing three major populations in the basin and from the Entiat River (Chiwawa River, Nason Creek, and Peshastin Creek; Table 2). We also obtained two collections of juvenile fish caught in a smolt trap in the lower Wenatchee River. These, like the NOR adult collections, were a mixed collection presumably representing all populations located upstream. Fin tissue was taken from each fish and preserved in 95% ethanol.

Sample processing

Fin tissue samples were processed for 1468 HOR and NOR adult steelhead broodstock (Table 1) and for 1542 juvenile *O. mykiss* from the Wenatchee and Entiat Rivers (Table 2). Samples were genotyped at 152 single nucleotide polymorphism loci (SNPs, Tables 3, 4). We originally proposed to use microsatellites, but WDFW MGL and other regional genetic laboratories (Columbia River Inter-Tribal Fish Commission [CRITFC], Idaho Fish and Game [IDFG], USFWS) are moving toward using SNPs and they provide the same kinds of information with faster processing. Twenty SNP loci were developed to discriminate among trout species; 14 distinguish *O. mykiss* from coastal cutthroat trout (*O. clarkii clarkii*) and westslope cutthroat (*O. clarkii lewisi*), and 6 distinguish steelhead and coastal cutthroat from westslope cutthroat (Table 4). The remaining 132 SNP loci were developed to be used for population structure, parentage assignment, or other population genetic studies of *O. mykiss* (Table 3). These markers comprised the current standard set of SNP markers used for genetic studies of *O. mykiss* at WDFW MGL.

We used Qiagen DNEasy ® kits (Qiagen Inc., Valencia, CA), following the recommended protocol for animal tissues, to extract and isolate DNA from fin tissue. SNP genotypes were obtained through PCR and visualization on Fluidigm EP1 integrated fluidic circuits (chips). Protocols followed Fluidigm's recommendations for TaqMan SNP assays as follows: Samples were pre-amplified by Specific Target Amplification (STA) following Fluidigm's recommended protocol with one modification. The 152 assays were pooled to a concentration of 0.2X and mixed with 2X Qiagen Multiplexing Kit (Qiagen, Inc., Valencia CA), instead of TaqMan PreAmp Master Mix (Applied Biosystems), to a volume of 3.75µl, to which 1.25µl of unquantified sample DNA was added for a total reaction volume of 5µl. Pre-amp PCR was conducted on a MJ Research or Applied Biosystems thermal cycler using the following profile: 95°C for 15 min followed by 14 cycles of 95°C for 15 sec and 60°C for 4 minutes. Post-PCR reactions were diluted with 20µl dH_2O to a final volume of 25µl.

Specific SNP locus PCRs were conducted on the Fluidigm chips. Assay loading mixture contained 1X Assay Loading Reagent (Fluidigm), 2.5X ROX Reference Dye (Invetrogen) and 10X custom TaqMan Assay (Applied Biosystems); sample loading mixture contains 1X TaqMan Universal PCR Master Mix (Applied Biosystems), 0.05X AmpliTaq Gold DNA polymerase (Applied Biosystems), 1X GT sampling loading reagent (Fluidigm) and 2.1 µL template DNA. Four µL assay loading mix and 5 µL sample loading mix were pipetted onto the chip and loaded by the IFC loader (Fluidigm). PCR was conducted on a Fluidigm thermal cycler using a two step profile. Initial mix thermal profile was 70°C for 30min, 25°C for 5 min, 52.3° for 10 sec, 50.1°C for 1 min 50sec, 98°C for 5 sec, 96°C for 9 min 55 sec, 96°C for 15 sec, 58.6°C for 8 sec, and 60.1°C for 43 sec. Amplification thermal profile was 40 cycles of 58.6°C for 10 sec, 96°C for 5 sec, 58.6°C for 8 sec and 60.1°C for 43 sec with a final hold at 20°C.

The SNP assays were visualized on the Fluidigm EP1 machine using the BioMark data collection software and analyzed using Fluidigm SNP genotyping analysis software. To ensure all SNP markers were being scored accurately and consistently, all data were scored by two researchers and scores of each researcher were compared. Disputed scores were called missing data (i.e., no genotype).

Evaluation of loci

A two-tailed exact test of Hardy–Weinberg equilibrium (HWE) was performed for each locus in each collection or population using the Markov Chain method implemented in GENEPOP v4.1 (dememorization number 1000, 100 batches, 1000 iterations per batch; Raymond and Rousset 1995; Rousset 2008). Significance of probability values was adjusted for multiple tests using false discovery rate (Verhoeven et al. 2005). F_{IS}, a measure of the fractional reduction in heterozygosity due to inbreeding in individuals within a subpopulation and an additional indicator of scoring issues, was calculated according to Weir and Cockerham (1984) using GENEPOP v4.1. Allele frequencies were calculated using CONVERT v1.0 (Glaubitz 2004). Expected and observed heterozygosities were calculated using GDA v1.1 (Lewis and Zaykin 2001).

Allele frequencies, genetic distances and population differentiation

To evaluate Q1 of Objective 3.1 and 3.2, we evaluated trends and patterns in allele frequencies, genetic distances and population differentiation. To test for temporal patterns in allele frequencies, we compared sample or spawn year to two diversity metrics, allele frequency and observed heterozygosity, from each adult and juvenile collection. Each SNP locus had only one or two alleles, so we used the minor allele frequency (MAF) of each SNP locus for each adult collection and averaged across loci. We also calculated the average observed heterozygosity (Ho) for each SNP locus within each adult and juvenile collection. We examined the presence or absence of a temporal trend in average allele frequency and observed heterozygosity with logistic regression analysis in R (R Development Core Team 2009).

To partition genetic variance into temporal, spatial (juvenile) and origin (adult) fractions, we performed hierarchical analysis of molecular variance (AMOVA) using ARLEQUIN v3.0 (Excoffier et al. 2005) with 1,000 permutations. We performed this analysis separately for juvenile and adult collections. Juveniles were grouped by sampling location (tributary) and adults were grouped by origin (HOR or NOR). To estimate the magnitude of genetic differences among temporal and spatial collections we calculated pairwise F_{ST} estimates among collections using FSTAT (Goudet 1995) with 1000 permutations. Statistical significance was adjusted using false discovery rate (Verhoeven et al. 2005).

To evaluate the temporal changes in genetic relationships, we compared spawn year to within spawn year pairwise F_{ST} estimates between NOR and NOR adults using beta regression (Simas and Rocha 2010). We used beta regression because the dependent variable was bound by zero and one but not binomial. Analysis was performed in R (package "betareg", Cribari-Neto and Zeileis 2010), with a loglog link.

We used principal component analyses (PCA) to explore the relationship between the covariation among the SNP loci within each collection and genetic differentiation between HOR and NOR collections, and to determine if the degree of differentiation has changed with time. Since each SNP is represented by only two alleles, only one allele per SNP is necessary to fully describe the covariation among all SNPs. We used MATLAB® scripts (2007a, The Mathworks, Natlick, MA) to calculate the principal components from SNP allele frequencies using only the major allele (1-MAF) for each SNP. We defined the major allele as the allele with the higher mean frequency across all collections, regardless of its status within any individual collection. We conducted three PCA analyses using: (1) all adult samples, aggregated based on origin (HOR versus NOR) and spawn year (i.e., the year the adult fish were used as broodstock) (N = 1437, 22 collections), (2) same as #1, but with the addition of all juvenile samples (N = 2938, 37 collections), and (3) only those adults samples with available age information (Mike Hughes, WDFW, personal communication) aggregated based on origin, and spawn year or brood year (i.e., the year the fish were hatched) (N = 1313, 20 spawn-year or 25 brood-year collections).

Molecular differentiation between HOR and NOR adults within a year was calculated based on principal component scores using Euclidian distances. We calculated pair-wise Euclidian distances between HOR and NOR fish within a spawn year or brood year using the first three principal components, and standardized each distance by subtracting from it the mean Euclidian distance calculated across all pair-wise distances. We used Mahalanobis distances to calculate the variation among HOR and NOR collections (calculated separately), again using the first three principal components. Here, we calculated Mahalanobis distances as the Euclidian distances between each collection and the centroid of all collections (HOR and NOR combined), but the Euclidian distances are scaled based on the dispersion of collections around the centroid (i.e., the variance). Euclidian and Mahalanobis distances were calculated using MATLAB scripts.

Effective spawning population

To evaluate Q1 of Objective 3.3, we estimated N_e using the single-sample linkage disequilibrium methods implemented in the program LDNE (Waples and Do 2008). This method requires that you input the P_{crit} value, the minimum frequency at which alleles were included in the analysis, since results can be biased depending on this setting (Waples and Do 2010). SNP markers typically have only one or two alleles; if one of two alleles is excluded based on its frequency in the collection it essentially excludes the locus, reducing the overall dataset. Therefore, we used P_{crit} values ranging from 0.1 to 0.001 to evaluate whether trends in N_e changed given which loci were used. Confidence intervals were calculated using a jackknife procedure.

We calculated an estimate of N_e for all adult and juvenile collections individually. However, the intention of an integrated hatchery program such as the Wenatchee River steelhead hatchery program is that HOR and NOR fish are integrated and progress as a single population through intentional interbreeding in the hatchery and presumed natural interbreeding in the wild. Thus, we also combined annual HOR and NOR collections to calculate an overall N_e estimate as has been done in other genetic monitoring and evaluation analyses (e.g., Small et al. 2007, [Chinook salmon, *O. tshawytscha*]).

Estimates of N_e from linkage refer to the generations that produced the sample. To calculate the ratio of effective population size to census size (N_e/N), we obtained the number of fish spawned in the hatchery (1993 through 2006, i.e., those that produced the adipose fin clipped adults that returned to spawn in the Wenatchee River 1998 through 2010) and the estimated escapement of fish spawning naturally (HOR and NOR separately) for the same time period. Estimates of census population size in spawning tributaries was obtained by multiplying the fraction of redds counted within tributaries (Chad Herring ,WDFW, unpublished data) by the total Wenatchee River census population estimate (Andrew Murdoch, WDFW, unpublished data). To calculate N_e/N, we performed two analyses. First, for adults, we assumed a five year generation time for natural origin adults and a four year generation time for hatchery origin adults and divided the N_e estimate by the census population estimate from four or five years earlier. For juveniles, we assumed an age at outmigration of two years and divided the N_e estimates by the estimate of census population size for the appropriate tributary. Second, we used available adult age data to parse individuals into cohorts originating in brood years (rather than spawn years) and then used LDNE to estimate N_e from cohort collections. We performed both analyses to make full use of all available data; age data were not available for many adults, and because of variable survival and sampling not all cohorts had sufficient numbers of HOR and NOR adults. According to Luikart et al. (2010), estimates produced using linkage disequilibrium should be interpreted as something between effective population size (N_e) and the effective number of breeders (N_b). Using cohorts, the estimate produced by LDNE is clearly an estimate of N_b rather than N_e. In order to keep things simple, we have referred to all estimates as N_b.

Results and Discussion

Collections and samples received

From 1468 samples from HOR and NOR adult steelhead broodstock, 1437 produced sufficient genetic data for further analysis (Table 1). From 1542 samples from NOR juvenile steelhead from Wenatchee River tributaries and the Entiat River, 1501 produced sufficient genetic data for further analysis and were genetically identified as *O. mykiss* (Table 2). Samples genetically identified as *O. clarki* (2 samples from the Chiwawa River, 1 from the Entiat River) or *O. clarki*/*O. mykiss* hybrids (4 – lower Wenatchee River, 4 – Nason Creek, 4 – Chiwawa River, and 1 – Entiat River) were omitted from further analysis.

Evaluation of loci

Three loci showed deviations from HWE in 10 or more of 37 Wenatchee steelhead collections before correcting for multiple tests (AOmy016, AOmy051, AOmy252, Table A1) indicating possible scoring issues. These loci were omitted from further analysis. Nine of the remaining loci were monomorphic or nearly monomorphic in all collections (average MAF < 0.1, AOmy023, AOmy028, AOmy123, AOmy129, AOmy132, AOmy209, AOmy229, AOmy270, AOmy271, Table A1) contributing little or nothing to analytical power. These loci were also omitted from further analysis. No genetic data was available for collection 10FD due to poor PCR amplification at locus AOmy213 for the entire collection. AOmy213 had a relatively low MAF in most collections so rather than re-processing this collection at this locus or running different sets of loci for different tests, we omitted this locus from further analysis. Only six tests of deviation from HWE were significant after correcting for 4348 tests using false discovery rate. Two of these tests were in loci already omitted. The remaining four tests were spread among the remaining loci, indicating no more loci needed to be omitted from further analysis.

Objective 3.1, 3.2 – Allele frequencies and Genetic distances

Allele frequencies

Average MAF of SNP loci ranged from 0.00 to 0.60 in HOR adult collections and from 0.00 to 0.61 in NOR adult collections (Table A1). Observed heterozygosity ranged from 0.00 to 0.75 in HOR adult collections and from 0.01 to 0.67 in NOR adult collections. Juvenile collections produced similar ranges of MAF and Ho (Table A1). Average MAF and Ho of HOR adult collections appeared to be greater than those of natural origin collections. However, logistic regression analysis indicated there was no significant temporal trend in either diversity statistic (Figure 1). Similarly, there was no consistent temporal trend in MAF or Ho of juvenile collections (Figure 2). Both the Chiwawa River and Nason Creek, the two tributaries that currently still receive hatchery juvenile outplants, both appeared to have declining allele frequencies, but neither was statistically significant ($P > 0.90$). However, the power to detect significant trends was limited by the small sample sizes (n = 3 sample years).

Analysis of Molecular Variance

Analysis of molecular variance (AMOVA) of adult collections (i.e., temporal and origin structure) indicated most of the genetic variance was among individuals or among individuals within populations (99.04%). Most of the remaining variance was temporal variation within hatchery and natural origin groups (0.61%) with the remaining variation from origin (0.35%). AMOVA of juvenile collections (i.e., spatial structure) indicated most of the genetic variance was among individuals (98.44%) or among individuals within populations (0.94%). Most of the remaining variance existed among temporal collections within tributary collections (0.37%) with the smallest fraction as among tributary variance (0.24%). Thus, overall, there was more variability among years than among tributaries or origins, but no trend in the temporal variability.

Pair-wise F_{ST} *estimates*

HOR adults were genetically different that NOR adults as estimated by F_{ST} (full pair-wise table in Table A2, all pair-wise F_{ST} estimates with P-values ≤ 0.05 before correcting for multiple tests were significantly different from zero after correcting for multiple tests using false discovery rate). On average, HOR adult collections were as different from one another (mean F_{ST} = 0.011) as they were from NOR adult collections among years (mean F_{ST} = 0.009) or from NOR adult collections within years (mean F_{ST} = 0.010). Among year comparisons of NOR adult collections were, on average, nearly an order of magnitude lower (mean = 0.002). These patterns held whether spawn year or brood year (data not shown) was used to group individuals. Over time, within spawn year pair-wise F_{ST} estimates between HOR and NOR adults declined over time (β = -0.014, P = 0.0185; Figure 3), suggesting that the integration of hatchery and wild fish is slowly genetically homogenizing the groups. That relationship disappeared when adults were grouped by brood year (i.e., comparing fish produced the same year) and all brood years were used (β = -0.009, P = 0.615, data not shown). However, when the dataset was restricted to just those brood years when all typical (age at maturation frequency among all years > 0.10) age classes were present in the dataset (HOR = age 3, 4; NOR = age 4, 5, 6; brood years 1996-1998, 2004-2005) a non-significant (P = 0.278) negative relationship (β = -0.12) of F_{ST} and brood year was apparent. When the data were further restricted to just the years after the hatchery program changed to only collecting broodstock in the Wenatchee River (brood years 1998, 2004-2005), the slope was also negative (β = -0.09), but the relationship was not statistically significant (P = 0.962).

Within tributary among sample year pair-wise comparisons of juvenile collections were, on average, only very slightly smaller than comparisons among tributaries (0.005 vs. 0.006, respectively, Table 5, all pair-wise F_{ST} estimates with P-values ≤ 0.05 before correcting for multiple tests were significantly different from zero after correcting for multiple tests using false discovery rate). Nason Creek and Peshastin Creek on average showed higher among sample year F_{ST} estimates (0.010 and 0.007, respectively) than the Chiwawa or Entiat Rivers (0.004 and 0.002, respectively). The pair-wise comparison of the two collections of lower Wenatchee River smolts, presumably a mix of Chiwawa, Nason, Peshastin smolts and smolts from other spawning tributaries, was an order of magnitude smaller (F_{ST} = 0.0002), and not significantly different than zero (Table 5). There was no temporal trend in pair-wise comparisons of juvenile collections. However with, at most, four annual collections, detecting any temporal trend was unlikely. We also had no collections from years prior to 1998 (the first year of new hatchery program broodstock collecting protocols) with which to compare contemporary data, nor could we find any reports or papers containing pre-hatchery-program-change genetic comparisons among Wenatchee River tributary populations, making it impossible to determine whether or not changing the hatchery program has had any effect at all on population structure. However, these data will be useful for future studies.

Principal Components

Each principal component analysis (Figures 4, 5) indicated that the genetic structure among HOR collections differed from that among NOR collections, and that this difference has decreased with time. When adult fish were aggregated based on origin and spawn-year, there was a clear differentiation between HOR and NOR adult collections along PC 1, and a separation among HOR collections, differentiating the early spawn-years (1998 – 2003) from the later spawn-years (2004 – 2010) along PC 2 and PC 3, respectively (Figure 4). The pair-wise genetic distances between HOR and NOR collections from the same spawn year (i.e., the HOR and NOR fish used as broodstock within the same year) decreased from the largest distance in 1998 to small distances in 2009 and 2010, although the smallest distance occurred in 2004 (Figure 4, top right). That is, within hatchery broodstock, the genetic difference between HOR and NOR fish decreased, on average, from 1998 to 2010, and the decrease appeared to be a mutual convergence of NOR fish shifting right along PC 1 and HOR fish shifting downward along PC 2 and PC 3. This increasing similarity in adult fish mirrored that seen in within year pair-wise F_{ST} estimates between HOR and NOR adults which also declined over time (Figure 3).

Overall, there was considerably more genetic variation among the HOR collections than there was among the NOR collections with average Mahalanobis distances (distance between each collection and the overall centroid [0,0,0]) among the HOR and NOR collections being 4.2 and 1.5, respectively. Since each NOR collection was generally composed of 3-4 brood-years, while HOR collections rarely were composed of more than two brood-years, we attributed the lower year-to-year genetic variability of the NOR broodstock to the greater homogenizing effect of including four or more brood-years compared with only two brood years for the HOR broodstock.

Including the 15 juvenile collections, along with the 22 adult collections, did not materially alter the principal component structure (Figure 6), although the total genetic variation accounted for by the three principal components decreased from 44% using only the adults to 33% when juveniles were included. For the most-part, the juvenile fish appeared intermediate between HOR and NOR fish, but there was greater overlap in principal component scores (and therefore greater genetic similarity) of the juvenile and NOR collections, than of the juvenile and HOR collections. The average Euclidian distance between the juvenile and HOR collections was 0.49, compared to 0.23 between the juvenile and NOR collections, which was no different than 0.23 and 0.22 for the within juvenile and NOR collections, respectively.

By using the available adult age data, we were able to compare the genetic differentiation among the same set of fish when they are aggregated by origin (hatchery versus natural) and brood-year (year fish were hatched) with aggregates based on origin and spawn-year (year adult fish were spawned). A brood-year analysis compares within a year the genetic diversity generated from hatchery broodstock with that naturally produced in the spawning grounds. A spawn-year analysis compares the HOR and NOR genetic diversity that was mixed among cohorts of the parental generations. The same basic pattern of genetic structure that we have seen in spawn-year analyses (Figure 4, Figure 6, and the right side of Figure 5) also occurred in the brood-year analysis (left side of Figure 5). That is, from Figure 5 we saw (1) that HOR and NOR fish were differentiated from each other; (2) there was considerably more genetic variation (temporal variation) among the hatchery-origin collections than there was among the natural-origin collections (for brood-year, Mahalanobis distances = 5.18 and 0.75, respectively; for spawn-year, Mahalanobis distances = 4.25 and 1.25, respectively), and (3) that the genetic distances between HOR and NOR collections were lower in the more recent brood- and spawn-years, than in the earlier brood- and spawn-years (Figure 7; $R^2 = 0.41$ or 41%, $P < 0.05$). This indicated that the HOR and NOR fish used as broodstock in 2010 were more similar to each other than they were at the inception of the new hatchery program.

The relationship between genetic distance and brood-year was not the same as the relationship between genetic distance and spawn-year. For brood-year, although the slope was negative (i.e., trending downward or decreased differentiation with time) and the two most-recent brood years (2005-2006) showed relatively small HOR and NOR adult differentiation, the negative slope was not significantly different from zero and the regression accounted for only 7% of the variation. This was likely the result of insufficient sampling of certain age classes from many brood years (especially from NOR adults) due to two un-processed sample years (2005 and 2006).

Objective 3.3 – Effective spawning population

There was no difference in the temporal trends in estimates of N_b with P_{crit} set from 0.1 to 0.001 (Figure 8, data not shown for all collections), so we have reported only results with $P_{crit} = 0.001$, i.e., the full genetic dataset. Using either spawn-year or brood year, estimates of NOR adult N_b were higher and varied more than those of HOR adults (Figures 9, 10), concordant with the PCA analysis. Estimates for HOR adults ranged from 17 to 174 (by spawn year, mean = 65) or from 6 to 130 (by brood year, mean = 39). Estimates for NOR adults ranged from 36 to 982 (by spawn year, mean = 405) or from 59 to 2966 (by brood year, mean = 645). Many N_b estimates for NOR adults had confidence intervals extending to infinity on the upper bound. This reflected the difficulty in obtaining precise estimates of N_b for large populations (Waples and Do 2010).

Estimates of N_b for HOR steelhead dropped by approximately half from 1994, when broodstock were still collected at Wells Hatchery, to 1998, when the program used Wenatchee River trapped adults only, suggesting an effect of changing broodstock collection practices, which began in 1997 (Figures 8, 9). Since 1997, the hatchery population N_b remained at a relatively stable lower level (Figures 8, 9, and 10). There was no obvious change in N_b for NOR steelhead since 1993; the N_b estimate for 1993 was the largest, however the confidence interval overlapped estimates from many other years. The temporal trend in N_b estimates from combined collections mirrored those of the HOR collections alone, though estimates using combined collections were slightly larger (Figure 11).

As with N_b estimates, estimates of the ratio of N_b/N for NOR adults varied more than those of HOR adults (Figures 12, 13). However, using spawn year, i.e., mixtures of cohorts, the average N_b/N ratio for HOR adults was equal to that of NOR adults (mean $N_b/N = 0.26$), whereas when using brood year, the average N_b/N ratio for NOR adults was double that of HOR adults (NOR average =0.40, HOR average = 0.20). This is likely a consequence of the homogenizing effect of mixed cohorts. Estimates of N_b for HOR adults using spawn year were close to those estimated using brood year because of the lower diversity in age at maturation, whereas for NOR, grouping by brood year produces different estimates than when grouping by spawn year because of higher diversity in age at maturation. Regardless of which estimate was used, there was no temporal trend in N_b/N for either NOR or HOR adults.

Summary

On average, HOR adults had higher minor allele frequencies (MAF) than NOR adults, and both had similar MAF as juveniles collected in spawning tributaries and in the Entiat River. There was no temporal trend in allele frequencies or observed heterozygosity in adult or juvenile collections and allele frequencies in control populations were no different than those still receiving hatchery outplants suggesting that the hatchery program has had little effect on allele frequencies since 1998.

HOR adults were genetically quite different from NOR adults and juveniles based on pair-wise F_{ST} and principal components analysis (PCA), most likely because of the much smaller effective population size (N_b) in the hatchery population. Pair-wise F_{ST} estimates and genetic distances between HOR and NOR adults collected the same year declined over time suggesting that the interbreeding of HOR and NOR adults in the hatchery (and presumably in the wild) is slowly homogenizing Wenatchee River summer steelhead. Analyses using brood year (the year fish were hatched, determined using scale-based age estimates) were inconclusive because of limitations of the data.

On average, estimates of N_b were much lower and varied less for HOR adults than for NOR adults and juveniles. Estimates of N_b for HOR adults declined from the earliest brood years to a stable new low value after broodstock practices were changed in 1997. There was no indication that this had any effect on N_b in NOR adults and juveniles; N_b estimates for NOR adults and juveniles were, on average, higher and varied considerably over the time period covered by our dataset (1998 – 2010) and showed no temporal trend. Small N_b sizes increase the risk of loss of genetic diversity due to inbreeding and random effects (genetic drift). The N_b of the hatchery component of the population may be increased by spawning more families, using specific mating designs, and minimizing variance in reproductive success. However, given the apparent lack of effects overall, changes to the hatchery protocol may not be necessary.

Overall, hatchery practices appear to have had little effect on natural origin Wenatchee summer steelhead neutral genetic diversity or N_b. We cannot accurately assess their effects on population structure at this time. However, it is interesting to note that when juvenile collections are analyzed separately from adult collections, Peshastin Creek, which has received fewer hatchery outplants in the past and is currently a refuge from hatchery outplants, is genetically different than other tributaries and the Entiat River (data not shown). On the other hand, the Entiat River, which is also a refuge from hatchery outplants and is not a tributary of the Wenatchee River, is genetically very similar to Nason Creek and the Chiwawa River, both Wenatchee River tributaries. This suggests, though it does not conclude, that within basin population structure may have existed before summer steelhead hatchery production began in the upper Columbia River and that the population structure was eliminated by hatchery influence long before 1998.

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Figures

Figure 1. Observed average minor allele frequencies (MAF) and observed heterozygosities (Ho) of 119 SNP loci from 11 annual collections of hatchery-produced (HOR) and natural origin (NOR) adult steelhead from the Wenatchee River. Trend lines are from a logistic regression. Note the X axis does not cross the Y axis at the origin. Neither the slopes nor the intercepts were statistically significant.

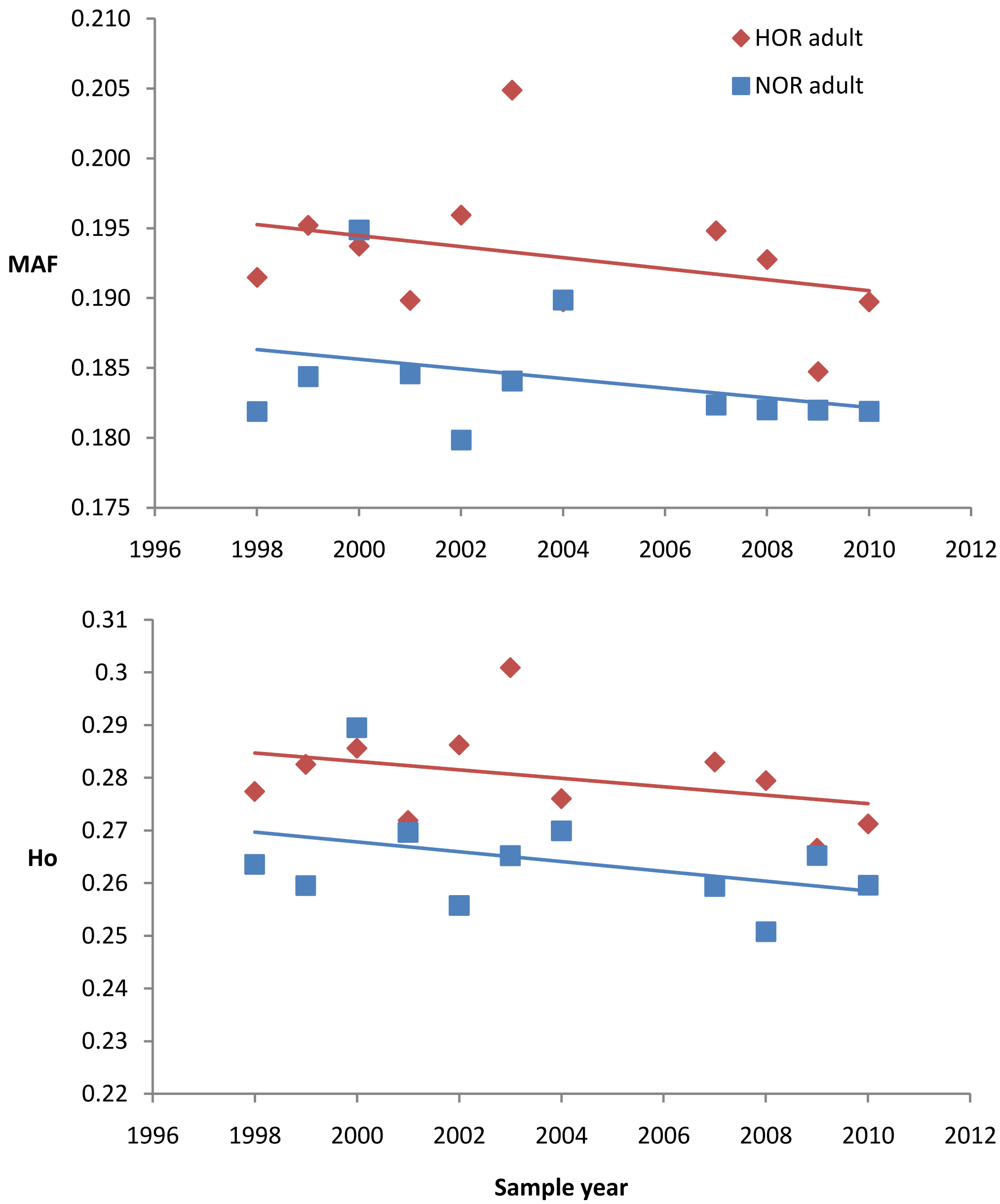


Figure 2. Observed average minor allele frequencies (MAF) and observed heterozygosities (Ho) of 119 SNP loci from 15 collections of natural origin juvenile steelhead from Wenatchee River tributaries, the lower Wenatchee River and the Entiat River. There were no consistent temporal trends in MAF or Ho in these collections.

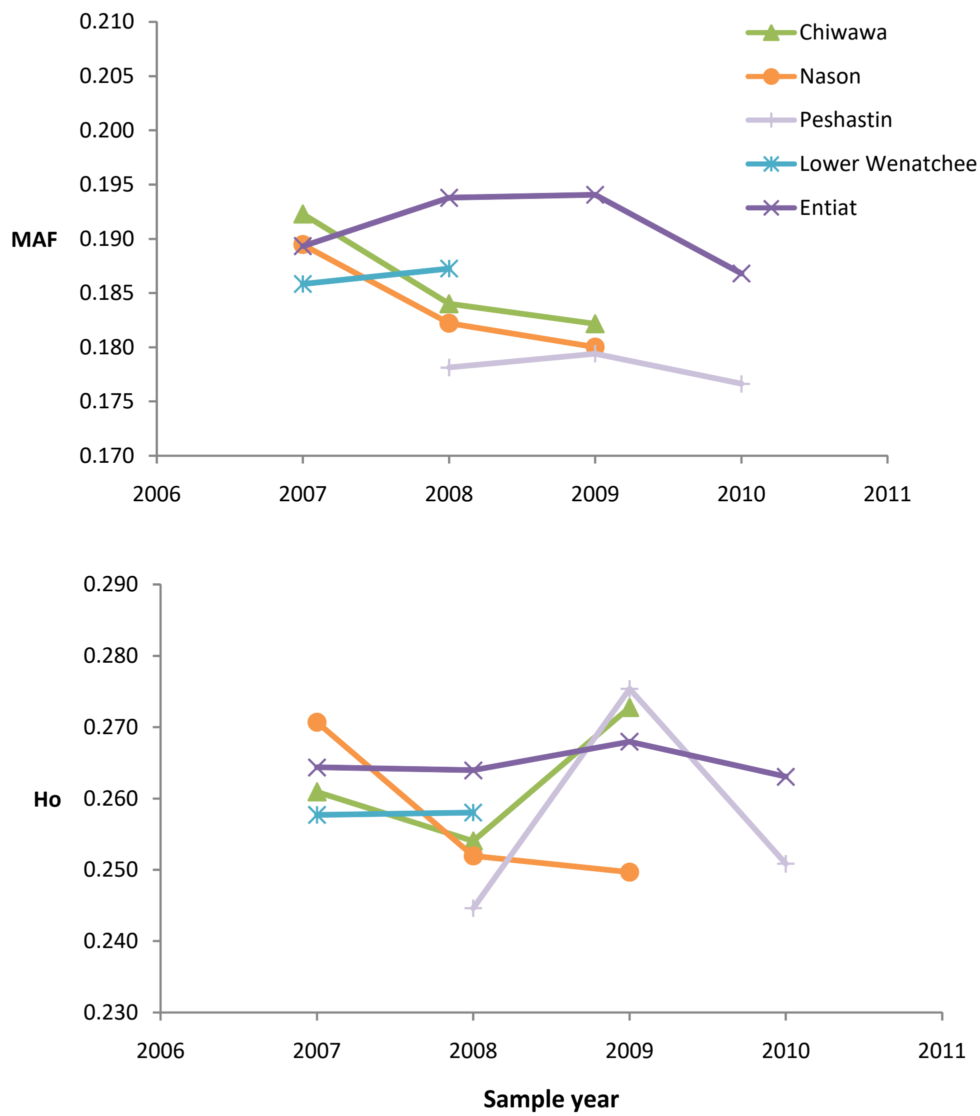


Figure 3. The relationship of time with pairwise F_{ST} estimates between hatchery-produced (adipose fin clipped) and natural origin (unclipped) adults of the same sample year. The line is the prediction based on beta regression.

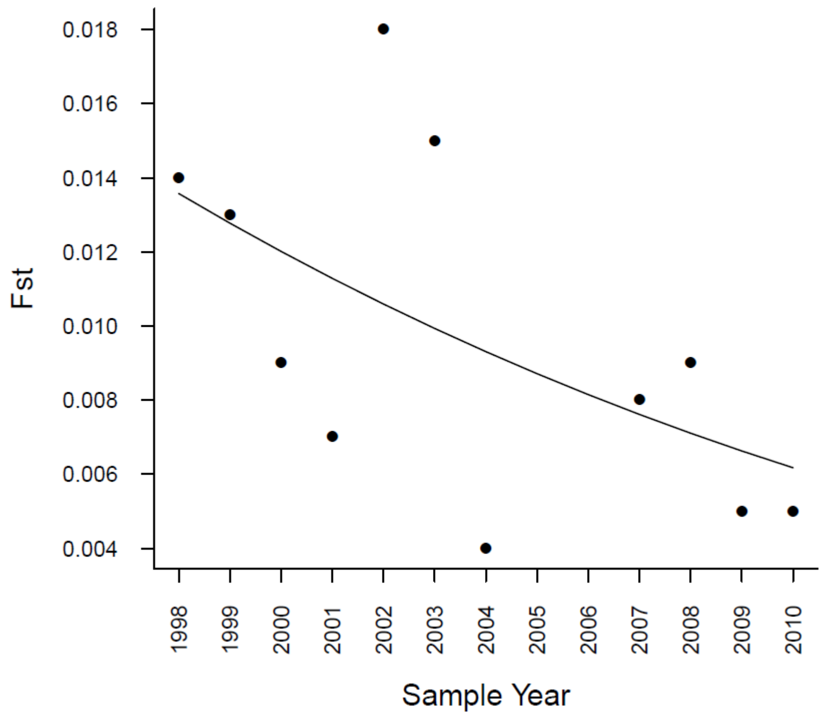


Figure 4. Principal component (PC) 1 versus 2 (top left), PC 1 versus 3 (bottom left), and PC 2 versus 3 (bottom right) based on an analysis using all adults aggregated into origin and spawn-year collections. Natural-origin spawn-years are shown in italicized typeface. The percentage within the label of each axis convey the percent of total genetic variance that is accounted for by that axis. Taken together, the three principal components account for 44% of the total SNP variation. Top right shows pairwise Euclidian distances versus spawn-year, with zero distance equal to average distance across all pairwise distances. Blue line is least-squares fit with $R^2 = 0.45$.

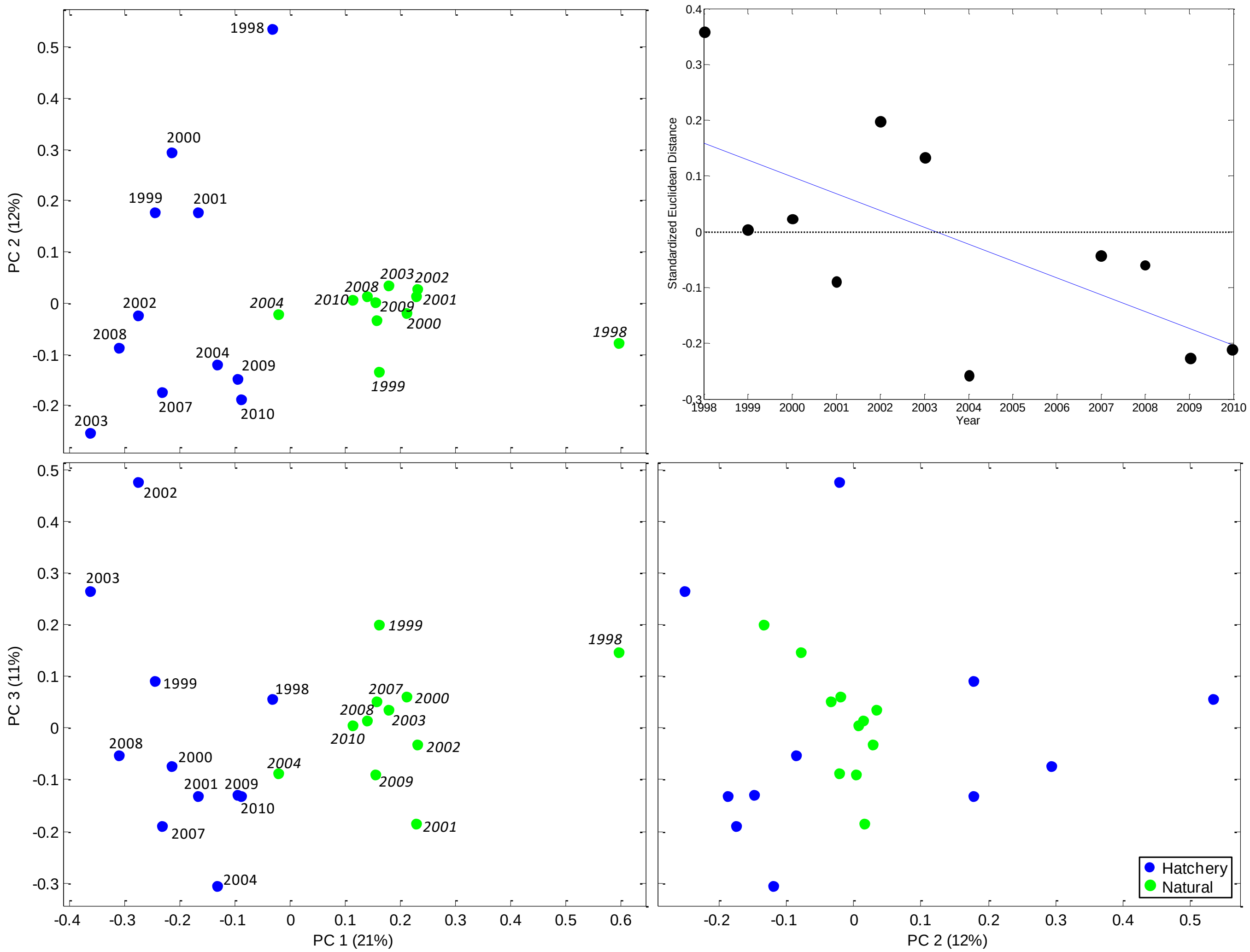


Figure 5. Principal components (PC) 1 versus 2 (top) and 3 (bottom) for adults aggregated into brood-year (BY; left) and spawn-year (SY; right). Spawn-year analysis is the same as in Figure x1, except fewer individuals per collection were included (see methods). Note that for the SY analysis here PC 2 and 3 are similar to PC 3 and 2, respectively, in Figure x1. Only BY1995 (earliest year with paired hatchery-natural data), BY2000 (extreme PC 1 score), and BY2006 (latest year with paired hatchery-natural data) are labeled. Hatchery- and natural-origin individuals from BY1995, BY2000, and BY2006, returned to spawn (spawn-year) in 1999 (hatchery)/1999-2001 (natural), 2003-2004 (hatchery)/2004 and 2007 (natural), and 2009-2010 (hatchery)/2010 (natural), respectively. These years are labeled in the upper right figure. Only 4 year-old BY 2006 natural-origin fish are represented in the SY 2010 collection.

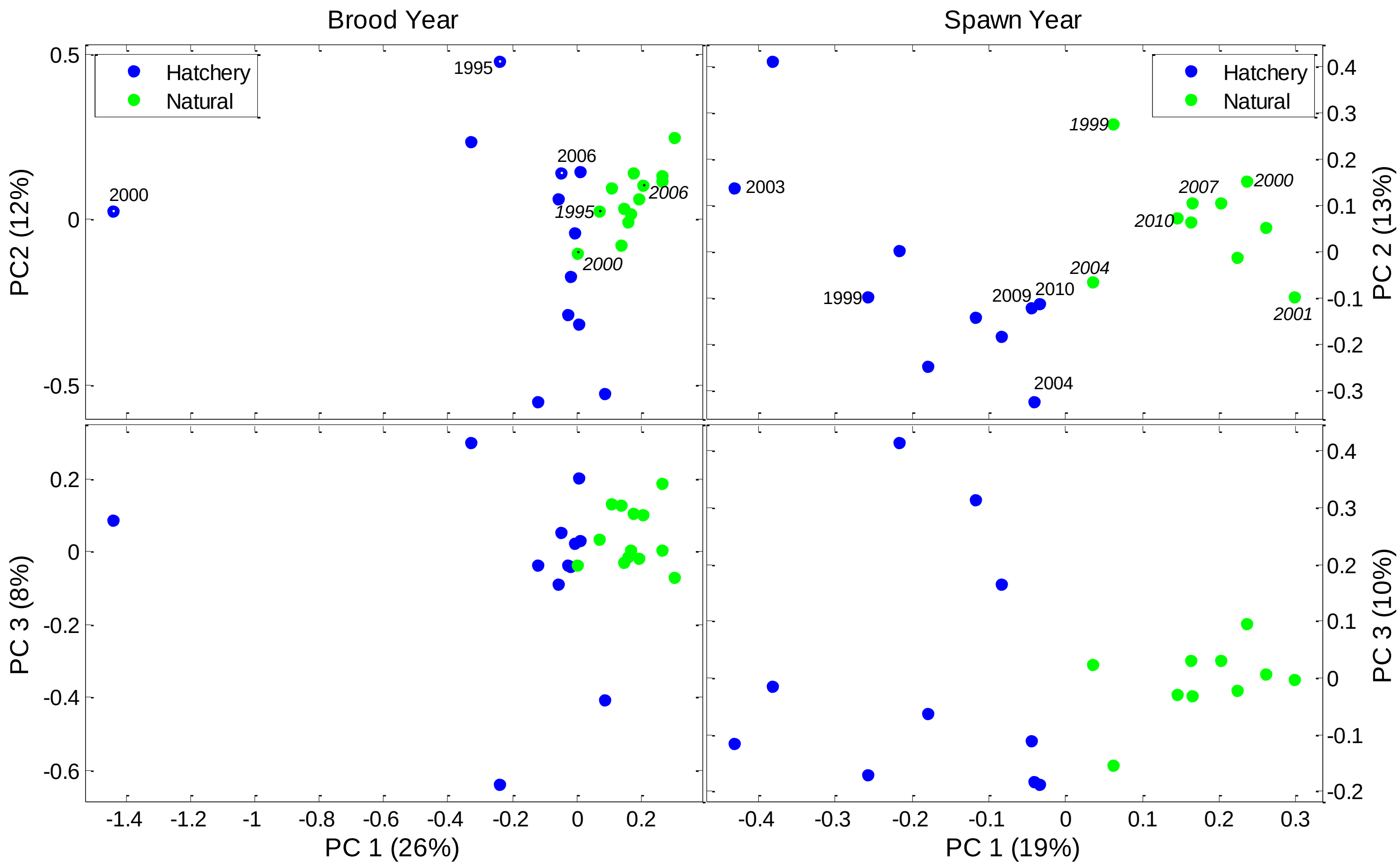


Figure 6. Principal component (PC) 1 versus 2 (top) and PC 1 versus 3 (bottom) based on an analysis using all adult and juvenile fish aggregated into age (juvenile versus adult), origin (hatchery versus adult) and spawn-year collections.

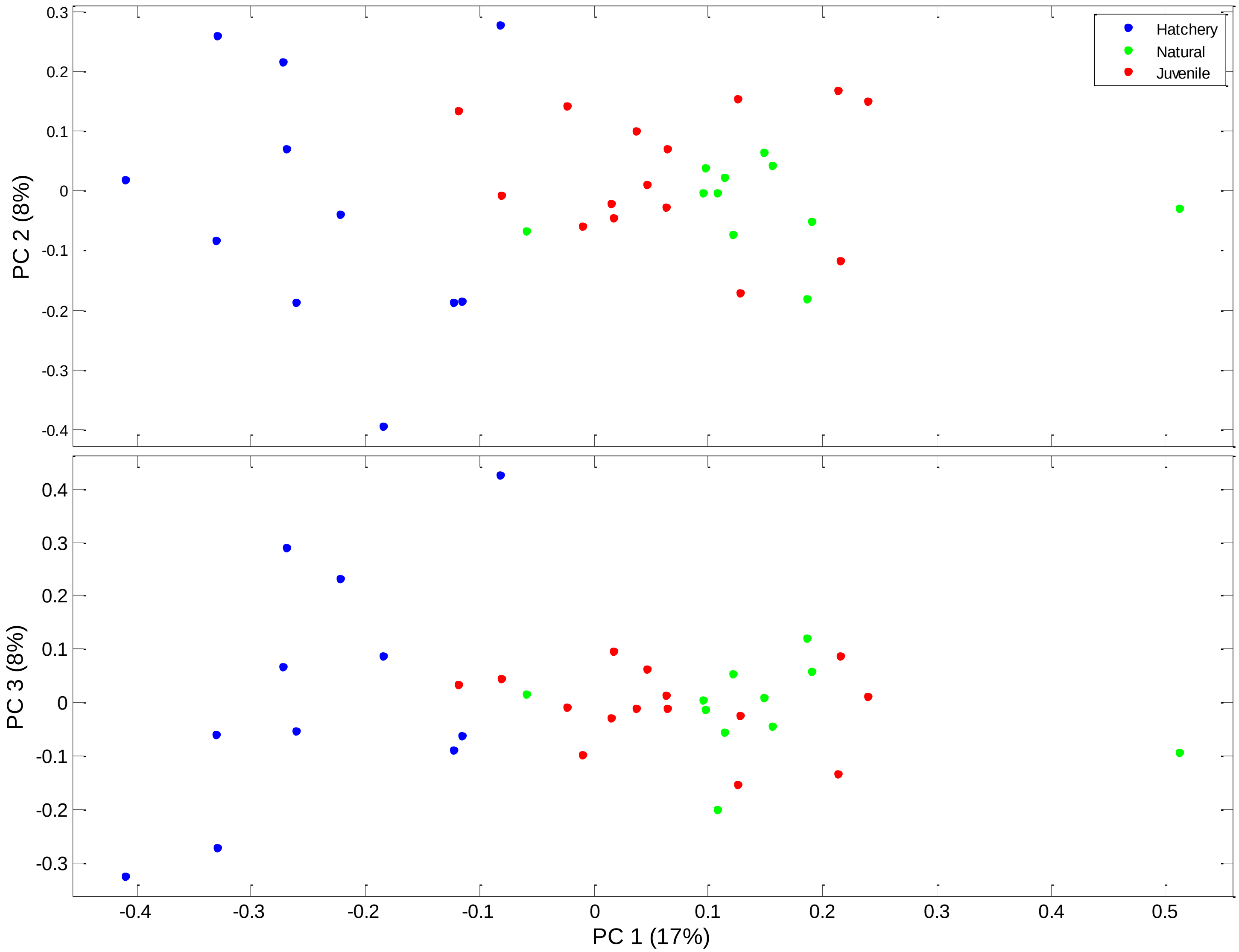


Figure 7. Pairwise Euclidian distances versus brood-year (top) and spawn-year (bottom), with zero distance equal to average distance across all pairwise distances. Blue lines are least-squares fits, which is not significant (slope = 0) for brood-year, but significant (slope > 0) for spawn-year.

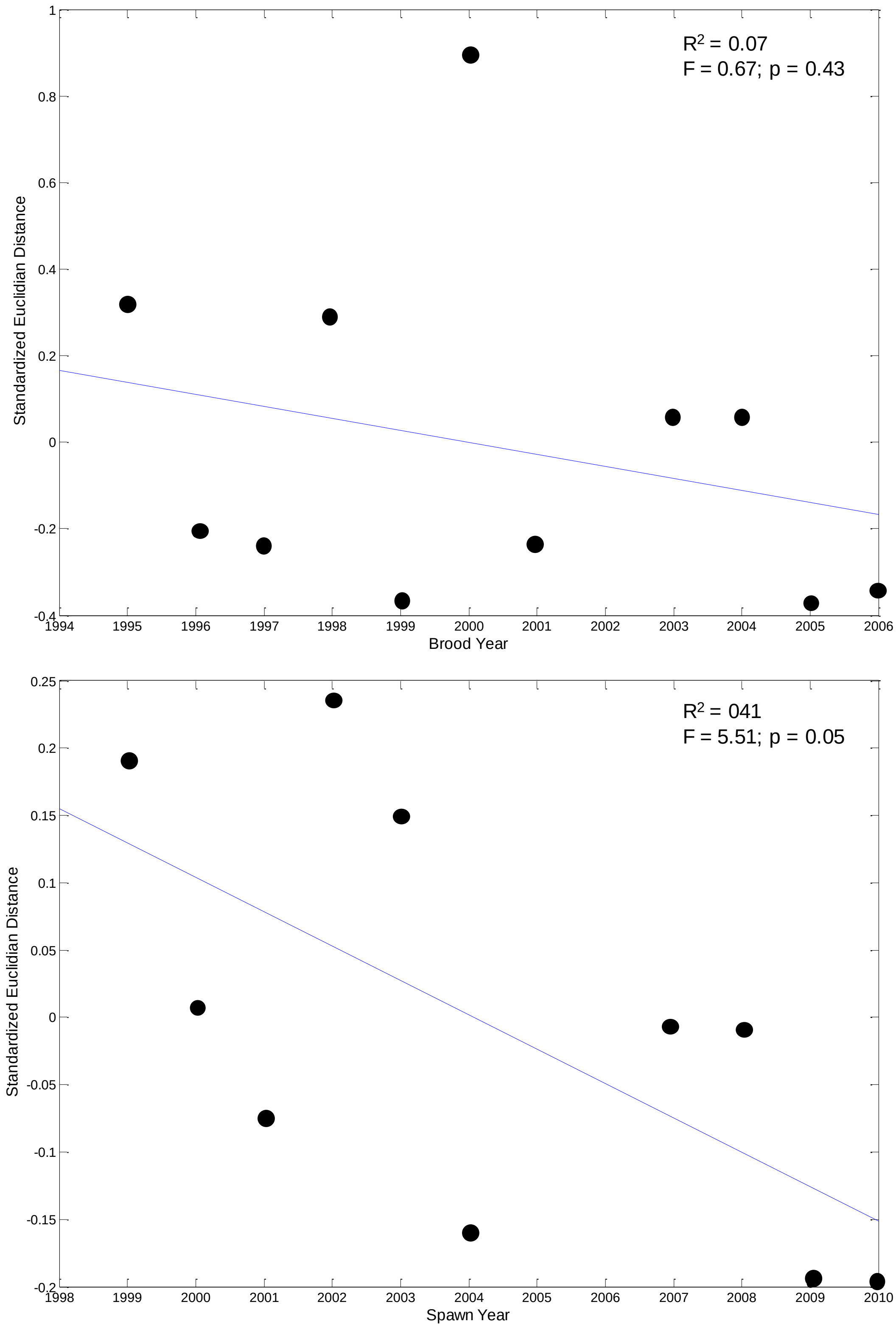


Figure 8. Effective population size estimates (N_b) from Wenatchee River adult hatchery-produced steelhead annual collections calculated using single sample methods implemented in the program LDNE (Waples and Do 2008). Each line connects annual estimates of N_b estimated with a different value of P_{crit}, the smallest allelic proportion allowed during analysis. With SNP data, omitting an allele omits the locus. Estimates of N_b changed very little when P_{crit} varied from 0.1 to 0.001. Setting P_{crit} = 0.001 forced the use of all available loci.

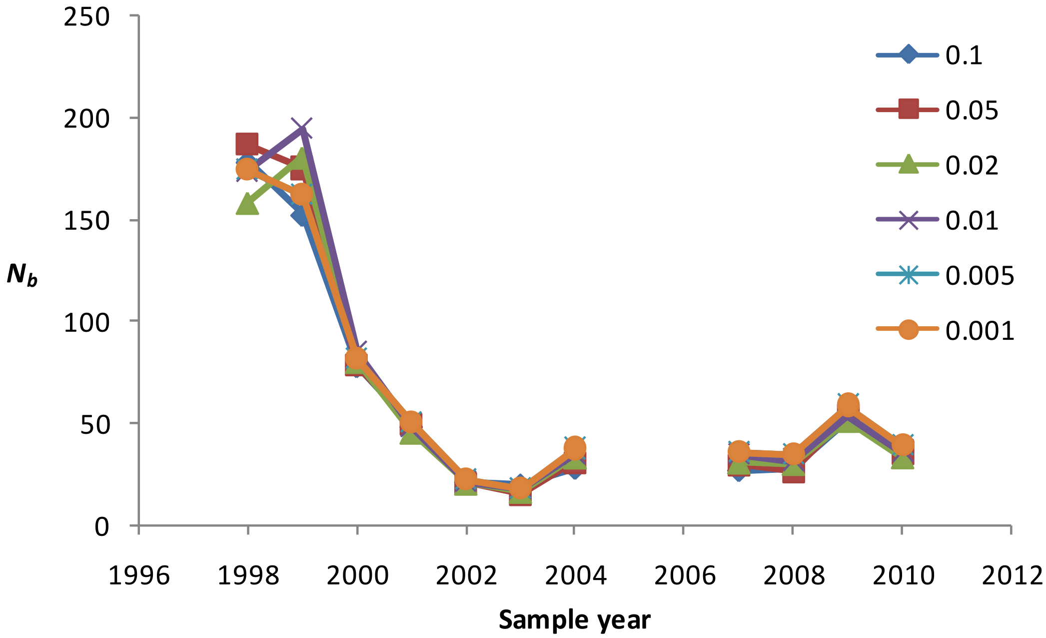


Figure 9. Estimates of Wenatchee River steelhead effective number of breeders (N_b) estimated using the single sample methods incorporated in the program LDNE (Waples and Do 2008). Estimates of N_b refer to parental (and even grantparental) generations. N_b data were plotted against their estimated parental brood year. We assumed a 5 year generation time for natural origin adults (NOR), a 4 year generation time for hatchery-produced adults (HOR) and an age of smolt outmigration of age 2 for smolt collections from Wenatchee River tributaries (Chiwawa River, Nason Creek, Peshastin Creek), the lower Wenatchee River, and the Entiat River. Bars represent the 95% confidence interval estimated by jackknife procedure. Bars that exceed the upper limit of the Y axis are labeled with the upper bound (Inf. = infinity).

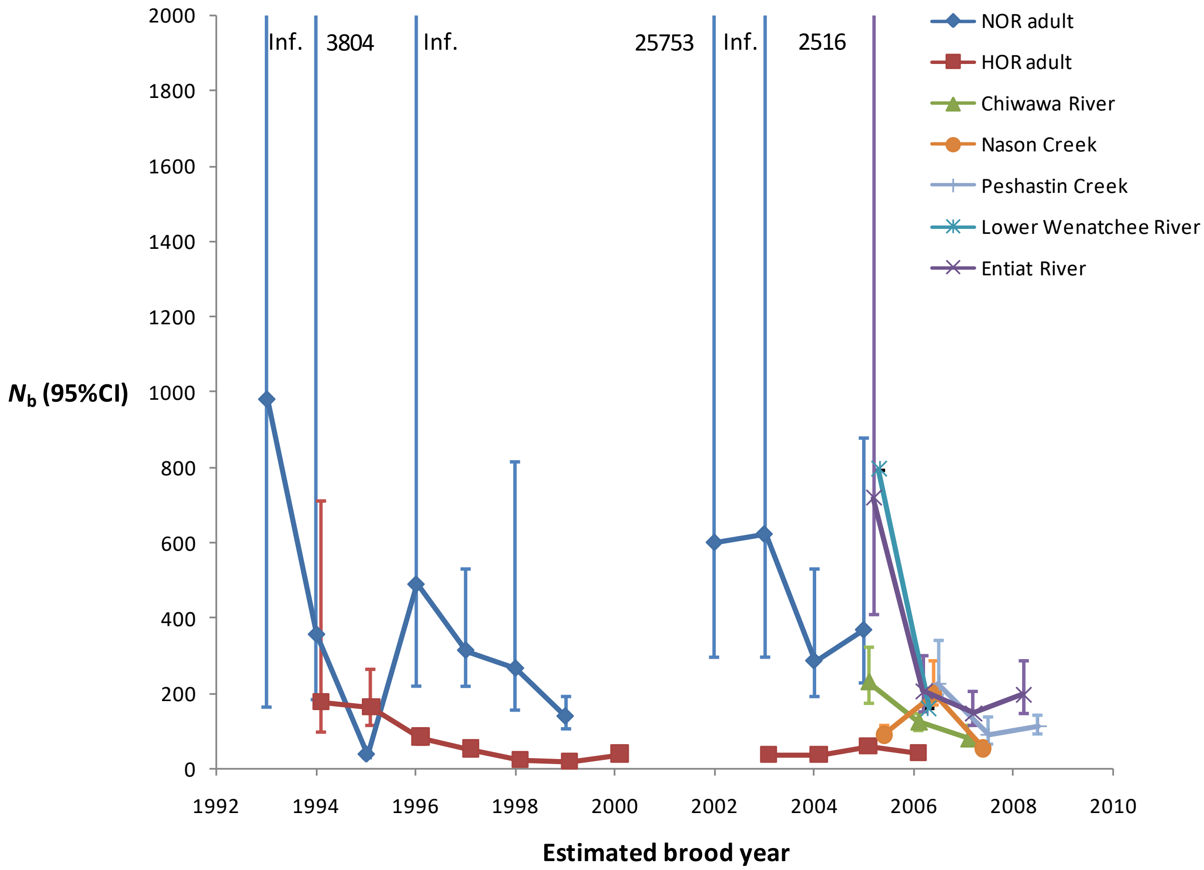


Figure 10. Estimates of N_b for collections of hatchery-produced (HOR) and natural origin (NOR) Wenatchee River summer steelhead grouped by brood year rather than spawn year. Brood year was estimated using scale-based age data. Error bars that extend past the top of the chart are all bounded by infinity.

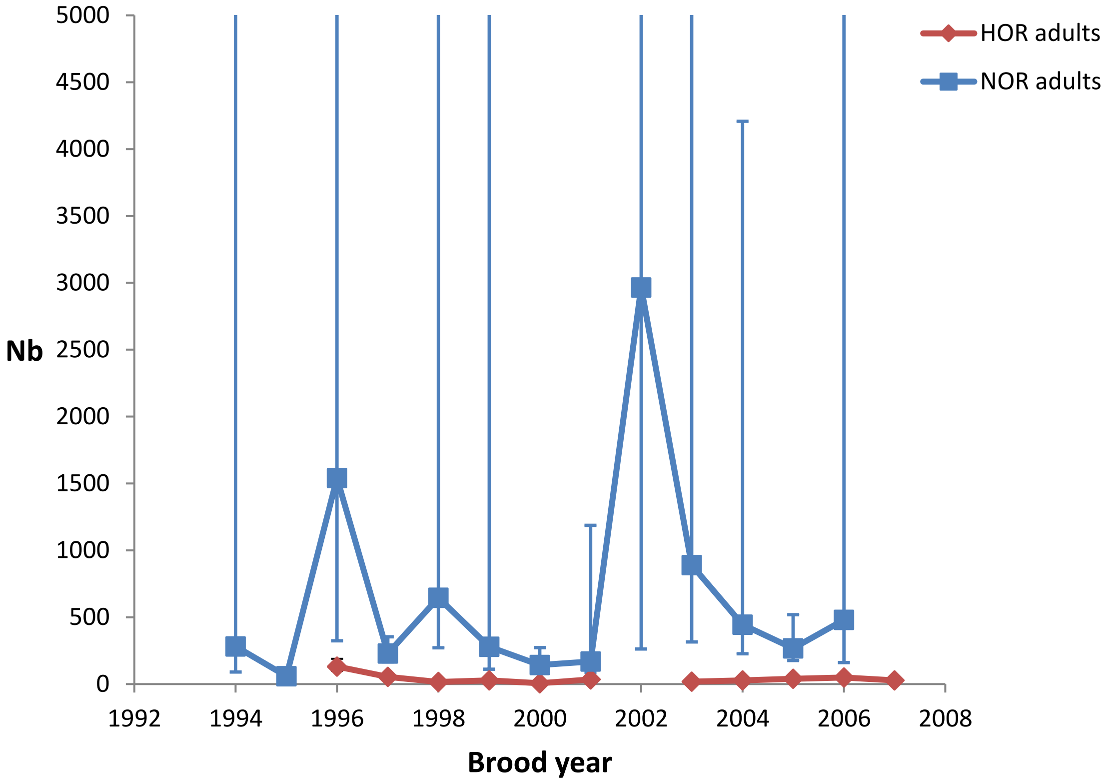


Figure 11. Estimates of N_b for combined annual adult hatchery-produced (HOR) and natural origin (NOR) steelhead and for HOR adults alone. The temporal patterns are similar, though estimates from combined collections are larger than those from HOR collections alone.

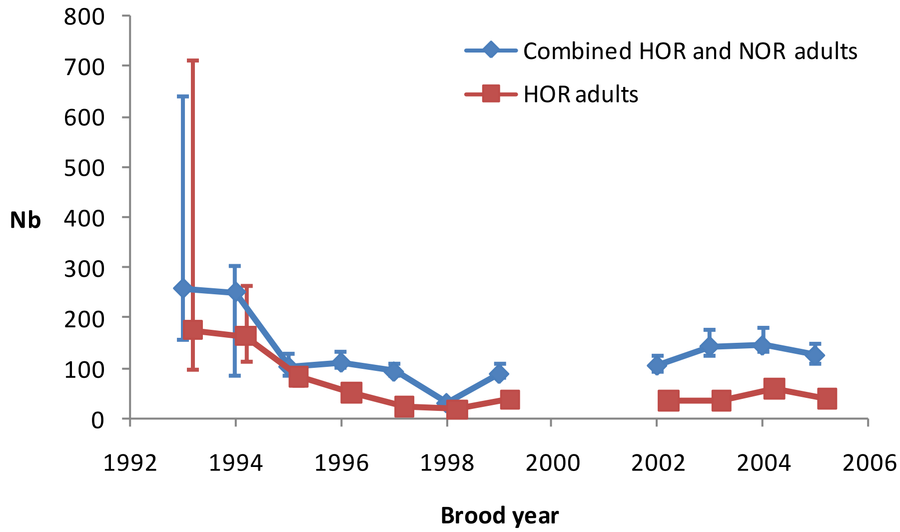


Figure 12. N_b/N ratios for hatchery-produced (HOR) and natural origin (NOR) adult Wenatchee River summer steelhead grouped by spawn year. The average N_b/N ratios are not different, though in later years NOR adults appear to have lower N_b/N ratios.

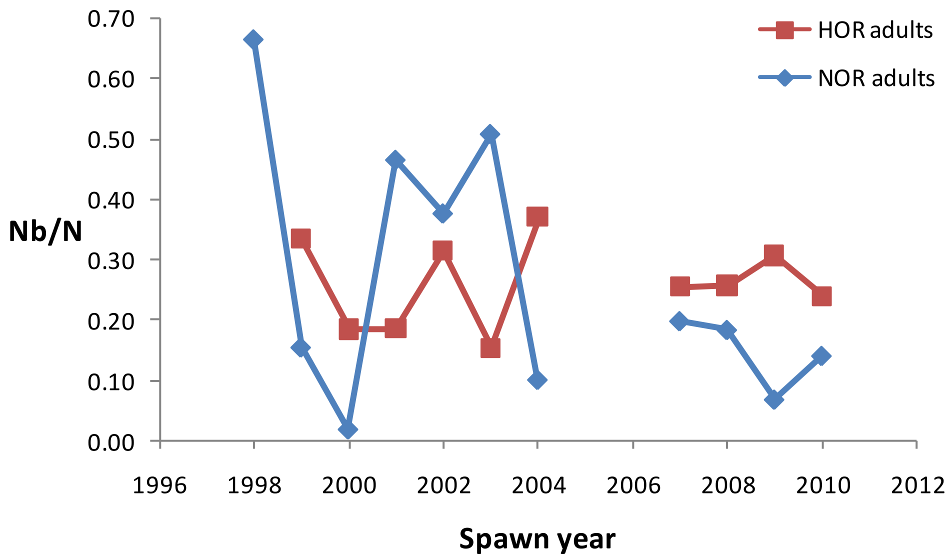
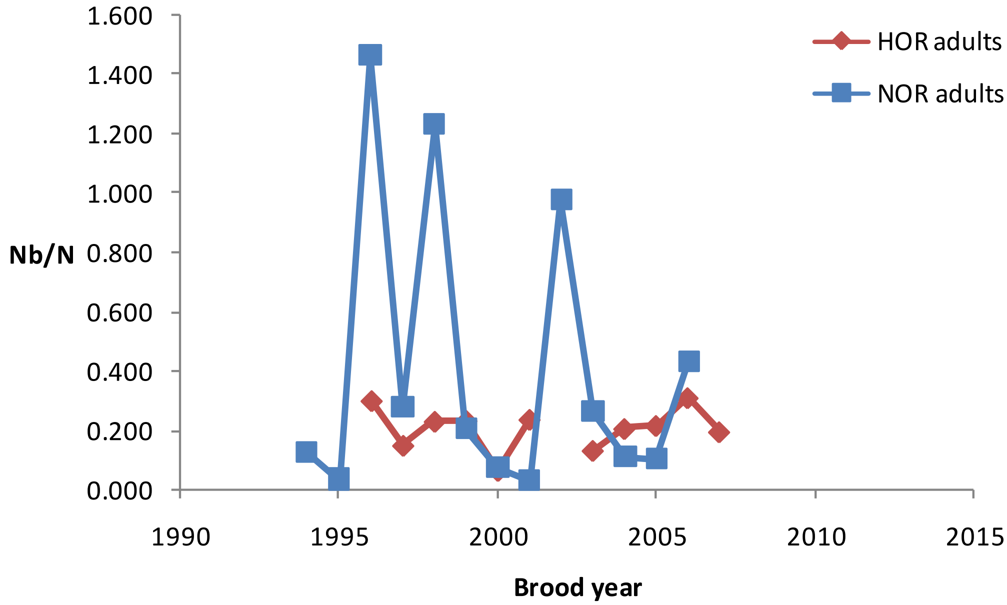


Figure 13. N_b/N ratios for hatchery-produced (HOR) and natural origin (NOR) adult Wenatchee River summer steelhead collections with individuals grouped in brood years rather than spawn years. Individual brood year was estimated using scale-based age data.



Tables

Table 1. Samples of adult steelhead collected for Wenatchee Program broodstock and used for genetic monitoring and evaluation.

Origin	Sampling Location	Year spawned	WDFW Collection code	Samples (N)	Unused Samples[a]
Hatchery	Dryden/Tumwater Dams	1998	98AE	32	4
		1999	98LJ	62	2
		2000	99NE	60	5
		2001	00DQ	99	1
		2002	01MS	64	
		2003	02NP	89	
		2004	03KW	61	
		2007	06CW	64	1
		2008	08AG	56	
		2009	09AV	74	
		2010	10FE	76	1
			Total	737	14
Natural	Dryden/Tumwater Dams	1998	98AF	30	5
		1999	99AA	51	1
		2000	99ND	33	3
		2001	00DP	50	
		2002	01MR	95	
		2003	02NO	50	
		2004	03KV	71	3
		2007	06CX	74	
		2008	08AF	74	1
		2009	09AU	82	2
		2010	10FD	90	2
			Total	700	17

[a]Samples were not used if they had incomplete (≤ 80% or 95 of 119 loci) or duplicate genotypes.

Table 2. Samples of natural origin juvenile steelhead and rainbow trout collected from four Wenatchee basin rivers or creeks and the Entiat River.

Sampling Location	Collection Year	WDFW Collection Code	Samples (N)	Unused samples[a]
Chiwawa River	2007	07AO	127	5
	2008	08CG	143	1
	2009	09NF	35	2
Entiat River	2007	07AL	134	4
	2008	08CI	82	4
	2009	09NC	74	1
	2010	10OX	82	1
Lower Wenatchee River	2007	07AM	139	5
	2008	08CE	98	2
Nason Creek	2007	07AN	81	4
	2008	08CF	133	6
	2009	09NG	103	2
Peshastin Creek	2008	08CH	142	2
	2009	09NE	34	1
	2010	10OY	94	1
		Total	1501	41

[a]Samples were not used if they were genetically identified as cutthroat trout or cutthroat/rainbow trout hybrids, or if they had incomplete (≤ 80% or 95 of 119 loci) or duplicate genotypes.

Table 3. List of 132 general use, diploid single nucleotide polymorphic (SNP) loci genotyped in Wenatchee River basin and Entiat River steelhead.

WDFW Name	Locus Name	Allele 1	Allele 2	Reference
AOmy005	Omy_aspAT-123	T	C	(Campbell et al. 2009)
AOmy014	Omy_e1-147	G	T	(Sprowles et al. 2006)
AOmy015	Omy_gdh-271	C	T	(Campbell et al. 2009)
AOmy016	Omy_GH1P1_2	C	T	(Aguilar and Garza 2008)
AOmy021	Omy_LDHB-2_e5	T	C	(Aguilar and Garza 2008)
AOmy023	Omy_MYC_2	T	C	(Aguilar and Garza 2008)
AOmy027	Omy_nkef-241	C	A	(Campbell et al. 2009)
AOmy028	Omy_nramp-146	G	A	(Campbell et al. 2009)
AOmy047	Omy_u07-79-166	G	T	WDFW - S. Young unpubl.
AOmy051	Omy_121713-115	T	A	(Abadía-Cardoso et al. 2011)
AOmy056	Omy_128693-455	T	C	(Abadía-Cardoso et al. 2011)
AOmy059	Omy_187760-385	A	T	(Abadía-Cardoso et al. 2011)
AOmy061	Omy_96222-125	T	C	(Abadía-Cardoso et al. 2011)
AOmy062	Omy_97077-73	T	A	(Abadía-Cardoso et al. 2011)
AOmy063	Omy_97660-230	C	G	(Abadía-Cardoso et al. 2011)
AOmy065	Omy_97954-618	C	T	(Abadía-Cardoso et al. 2011)
AOmy067	Omy_aromat-280	A	T	WSU - J. DeKoning unpubl.
AOmy068	Omy_arp-630	G	A	(Campbell et al. 2009)
AOmy071	Omy_cd59-206	C	T	WSU - J. DeKoning unpubl.
AOmy073	Omy_colla1-525	C	T	WSU - J. DeKoning unpubl.
AOmy079	Omy_g12-82	T	C	WSU - J. DeKoning unpubl.
AOmy081	Omy_gh-475	C	T	(Campbell et al. 2009)
AOmy082	Omy_gsdf-291	T	C	WSU - J. DeKoning unpubl.
AOmy089	Omy_hsp90BA-193	C	T	(Campbell and Narum 2009)
AOmy094	Omy_inos-97	C	A	WSU - J. DeKoning unpubl.
AOmy095	Omy_mapK3-103	A	T	CRITFC - N. Campbell unpubl.
AOmy096	Omy_mcsf-268	T	C	WSU - J. DeKoning unpubl.
AOmy100	Omy_nach-200	A	T	WSU - J. DeKoning unpubl.

AOmy107	Omy_Ots249-227	C	T	(Campbell et al. 2009)
AOmy108	Omy_oxct-85	A	T	WSU - J. DeKoning unpubl.
AOmy110	Omy_star-206	A	G	WSU - J. DeKoning unpubl.
AOmy111	Omy_stat3-273	G	Deletion	WSU - J. DeKoning unpubl.
AOmy113	Omy_tlr3-377	C	T	WSU - J. DeKoning unpubl.
AOmy117	Omy_u09-52-284	T	G	WDFW - S. Young unpubl.
AOmy118	Omy_u09-53-469	T	C	WDFW - S. Young unpubl.
AOmy120	Omy_u09-54.311	C	T	WDFW - S. Young unpubl.
AOmy123	Omy_u09-55-233	A	G	WDFW - S. Young unpubl.
AOmy125	Omy_u09-56-119	T	C	WDFW - S. Young unpubl.
AOmy129	Omy_BAMBI4.238	T	C	WDFW - S. Young unpubl.
AOmy132	Omy_G3PD_2.246	C	T	WDFW - S. Young unpubl.
AOmy134	Omy_Il-1b-028	T	C	WDFW - S. Young unpubl.
AOmy137	Omy_u09-61.043	A	T	WDFW - S. Young unpubl.
AOmy151	Omy_p53-262	T	A	CRITFC - N. Campbell unpubl.
AOmy173	BH2VHSVip10	C	T	Pascal & Hansen unpubl.
AOmy174	OMS00003	T	G	(Sánchez et al. 2009)
AOmy176	OMS00013	A	G	(Sánchez et al. 2009)
AOmy177	OMS00018	T	G	(Sánchez et al. 2009)
AOmy179	OMS00041	G	C	(Sánchez et al. 2009)
AOmy181	OMS00052	T	G	(Sánchez et al. 2009)
AOmy182	OMS00053	T	C	(Sánchez et al. 2009)
AOmy183	OMS00056	T	C	(Sánchez et al. 2009)
AOmy184	OMS00057	T	G	(Sánchez et al. 2009)
AOmy185	OMS00061	T	C	(Sánchez et al. 2009)
AOmy186	OMS00062	T	C	(Sánchez et al. 2009)
AOmy187	OMS00064	T	G	(Sánchez et al. 2009)
AOmy189	OMS00071	A	G	(Sánchez et al. 2009)
AOmy190	OMS00072	A	G	(Sánchez et al. 2009)
AOmy191	OMS00078	T	C	(Sánchez et al. 2009)
AOmy192	OMS00087	A	G	(Sánchez et al. 2009)

AOmy193	OMS00089	A	G	(Sánchez et al. 2009)
AOmy194	OMS00090	T	C	(Sánchez et al. 2009)
AOmy195	OMS00092	A	C	(Sánchez et al. 2009)
AOmy196	OMS00094	T	G	(Sánchez et al. 2009)
AOmy197	OMS00103	A	T	(Sánchez et al. 2009)
AOmy198	OMS00105	T	G	(Sánchez et al. 2009)
AOmy199	OMS00112	A	T	(Sánchez et al. 2009)
AOmy200	OMS00116	T	A	(Sánchez et al. 2009)
AOmy201	OMS00118	T	G	(Sánchez et al. 2009)
AOmy202	OMS00119	A	T	(Sánchez et al. 2009)
AOmy203	OMS00120	A	G	(Sánchez et al. 2009)
AOmy204	OMS00121	T	C	(Sánchez et al. 2009)
AOmy205	OMS00127	T	G	(Sánchez et al. 2009)
AOmy206	OMS00128	T	G	(Sánchez et al. 2009)
AOmy207	OMS00132	A	T	(Sánchez et al. 2009)
AOmy208	OMS00133	A	G	(Sánchez et al. 2009)
AOmy209	OMS00134	A	G	(Sánchez et al. 2009)
AOmy210	OMS00153	T	G	(Sánchez et al. 2009)
AOmy211	OMS00154	A	T	(Sánchez et al. 2009)
AOmy212	OMS00156	A	T	(Sánchez et al. 2009)
AOmy213	OMS00164	T	G	(Sánchez et al. 2009)
AOmy215	OMS00175	T	C	(Sánchez et al. 2009)
AOmy216	OMS00176	T	G	(Sánchez et al. 2009)
AOmy218	OMS00180	T	G	(Sánchez et al. 2009)
AOmy220	Omy_1004	A	T	(Hansen et al. 2011)
AOmy221	Omy_101554-306	T	C	(Abadía-Cardoso et al. 2011)
AOmy222	Omy_101832-195	A	C	(Abadía-Cardoso et al. 2011)
AOmy223	Omy_101993-189	A	T	(Abadía-Cardoso et al. 2011)
AOmy225	Omy_102505-102	A	G	(Abadía-Cardoso et al. 2011)
AOmy226	Omy_102867-443	T	G	(Abadía-Cardoso et al. 2011)
AOmy227	Omy_103705-558	T	C	(Abadía-Cardoso et al. 2011)

AOmy228	Omy_104519-624	T	C	(Abadía-Cardoso et al. 2011)
AOmy229	Omy_104569-114	A	C	(Abadía-Cardoso et al. 2011)
AOmy230	Omy_105075-162	T	G	(Abadía-Cardoso et al. 2011)
AOmy231	Omy_105385-406	T	C	(Abadía-Cardoso et al. 2011)
AOmy232	Omy_105714-265	C	T	(Abadía-Cardoso et al. 2011)
AOmy233	Omy_107031-704	C	T	(Abadía-Cardoso et al. 2011)
AOmy234	Omy_107285-69	C	G	(Abadía-Cardoso et al. 2011)
AOmy235	Omy_107336-170	C	G	(Abadía-Cardoso et al. 2011)
AOmy238	Omy_108007-193	A	G	(Abadía-Cardoso et al. 2011)
AOmy239	Omy_109243-222	A	C	(Abadía-Cardoso et al. 2011)
AOmy240	Omy_109525-403	A	G	(Abadía-Cardoso et al. 2011)
AOmy241	Omy_110064-419	T	G	(Abadía-Cardoso et al. 2011)
AOmy242	Omy_110078-294	A	G	(Abadía-Cardoso et al. 2011)
AOmy243	Omy_110362-585	G	A	(Abadía-Cardoso et al. 2011)
AOmy244	Omy_110689-148	A	C	(Abadía-Cardoso et al. 2011)
AOmy245	Omy_111005-159	C	T	(Abadía-Cardoso et al. 2011)
AOmy246	Omy_111084-526	A	C	(Abadía-Cardoso et al. 2011)
AOmy247	Omy_111383-51	C	T	(Abadía-Cardoso et al. 2011)
AOmy248	Omy_111666-301	T	A	(Abadía-Cardoso et al. 2011)
AOmy249	Omy_112301-202	T	G	(Abadía-Cardoso et al. 2011)
AOmy250	Omy_112820-82	G	A	(Abadía-Cardoso et al. 2011)
AOmy252	Omy_114976-223	T	G	(Abadía-Cardoso et al. 2011)
AOmy253	Omy_116733-349	C	T	(Abadía-Cardoso et al. 2011)
AOmy254	Omy_116938-264	A	G	(Abadía-Cardoso et al. 2011)
AOmy255	Omy_117259-96	T	C	(Abadía-Cardoso et al. 2011)
AOmy256	Omy_117286-374	A	T	(Abadía-Cardoso et al. 2011)
AOmy257	Omy_117370-400	A	G	(Abadía-Cardoso et al. 2011)
AOmy258	Omy_117540-259	T	G	(Abadía-Cardoso et al. 2011)
AOmy260	Omy_117815-81	C	T	(Abadía-Cardoso et al. 2011)
AOmy261	Omy_118175-396	T	A	(Abadía-Cardoso et al. 2011)
AOmy262	Omy_118205-116	A	G	(Abadía-Cardoso et al. 2011)

AOmy263	Omy_118654-91	A	G	(Abadía-Cardoso et al. 2011)
AOmy265	Omy_120255-332	A	T	(Abadía-Cardoso et al. 2011)
AOmy266	Omy_128996-481	T	G	(Abadía-Cardoso et al. 2011)
AOmy267	Omy_129870-756	C	T	(Abadía-Cardoso et al. 2011)
AOmy268	Omy_131460-646	C	T	(Abadía-Cardoso et al. 2011)
AOmy269	Omy_98683-165	A	C	(Abadía-Cardoso et al. 2011)
AOmy270	Omy_cyp17-153	C	T	WSU - J. DeKoning unpubl.
AOmy271	Omy_ftzf1-217	A	T	WSU - J. DeKoning unpubl.
AOmy272	Omy_GHSR-121	T	C	CRITFC - N. Campbell unpubl.
AOmy273	Omy_metA-161	T	G	CRITFC - N. Campbell unpubl.
AOmy274	Omy_UBA3b	A	T	(Hansen et al. 2011)

Primer and probe sequences for unpublished loci available by request.

Table 4. List of 20 species identification single nucleotide polymorphic (SNP) loci genotyped in Wenatchee River basin and Entiat River steelhead.

		Expected genotype			
WDFW Name	Locus Name	*O. mykiss*	*O. clarkii clarkii*	*O. clarkii lewisi*	Reference
ASpI001	Ocl_Okerca	T	C	C	(McGlauflin et al. 2010)
ASpI002	Ocl_Oku202	A	C	C	(McGlauflin et al. 2010)
ASpI003	Ocl_Oku211	G	T	T	(McGlauflin et al. 2010)
ASpI004	Ocl_Oku216	C	C	A	(McGlauflin et al. 2010)
ASpI005	Ocl_Oku217	C	C	A	(McGlauflin et al. 2010)
ASpI006	Ocl_SsaHM5	A	A	G	(McGlauflin et al. 2010)
ASpI007	Ocl_u800	T	C	C	(McGlauflin et al. 2010)
ASpI008	Ocl_u801	A	T	T	(McGlauflin et al. 2010)
ASpI009	Ocl_u802	C	C	T	(McGlauflin et al. 2010)
ASpI010	Ocl_u803	C	T	T	(McGlauflin et al. 2010)
ASpI011	Ocl_u804	G	G	C	(McGlauflin et al. 2010)
ASpI012	Omy_B9_228	A	A	C	(Finger et al. 2009)
ASpI013	Omy_CTDL1_243	C	A	A	(Finger et al. 2009)
ASpI014	Omy_F5_136	C	G	G	(Finger et al. 2009)
ASpI016	Omy_myclarp404-111	T	G	G	CRITFC - S. Narum - unpubl.
ASpI017	Omy_myclgh1043-156	C	T	T	CRITFC - S. Narum - unpubl.
ASpI018	Omy_Omyclmk436-96	A	C	C	CRITFC - S. Narum - unpubl.
ASpI019	Omy_RAG11_280	T	A	A	(Sprowles et al. 2006)
ASpI020	Omy_URO_302	T	C	C	(Finger et al. 2009)
ASpI021	Omy_BAC-F5.238	C	G	G	WDFW - S. Young unpubl.

Primer and probe sequences for unpublished loci available by request.

Table 5. Pairwise F_{ST} estimates for collections from Wenatchee River tributaries and the Entiat River (below diagonal) and associated bootstrap estimated *P*-values (above diagonal).

		Chiwawa River			Nason Creek			Peshastin Creek			Lower Wenatchee River		Entiat River			
Population	Year	2007	2008	2009	2007	2008	2009	2008	2009	2010	2007	2008	2007	2008	2009	2010
Chiwawa	2007		**0.000**	**0.003**	**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.000**	**0.001**	**0.001**	**0.000**	**0.001**	**0.000**	**0.000**
River	2008	0.004		**0.004**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
	2009	0.004	0.003		**0.000**	**0.001**	0.061	**0.000**	**0.001**	**0.000**	0.086	**0.050**	**0.022**	0.108	**0.005**	**0.045**
Nason	2007	0.011	0.010	0.007		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Creek	2008	0.007	0.007	0.005	0.009		**0.003**	**0.000**	**0.002**	**0.000**	0.079	**0.000**	**0.001**	**0.000**	**0.000**	**0.000**
	2009	0.007	0.007	0.003	0.014	0.006		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Peshastin	2008	0.010	0.011	0.008	0.013	0.010	0.013		**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Creek	2009	0.005	0.005	0.006	0.010	0.007	0.008	0.003		**0.002**	**0.002**	**0.047**	**0.028**	**0.004**	**0.005**	**0.001**
	2010	0.010	0.011	0.008	0.015	0.008	0.011	0.003	0.003		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Lower Wenatchee	2007	0.003	0.003	0.000	0.005	0.008	0.007	0.009	0.010	0.008		0.112	**0.020**	**0.012**	**0.002**	**0.017**
River	2008	0.002	0.005	0.002	0.003	0.004	0.005	0.007	0.009	0.006	0.000		**0.049**	0.459	**0.047**	**0.002**
Entiat	2007	0.005	0.006	0.002	0.005	0.006	0.005	0.005	0.007	0.006	0.001	0.002		0.451	0.173	**0.000**
River	2008	0.004	0.004	0.000	0.007	0.005	0.007	0.008	0.009	0.011	0.002	0.001	0.000		0.644	**0.002**
	2009	0.005	0.006	0.002	0.003	-0.001	0.003	0.002	0.003	0.004	0.003	0.002	0.002	0.000		**0.028**
	2010	0.005	0.006	0.003	0.006	0.004	0.006	0.006	0.008	0.009	0.002	0.003	0.003	0.003	0.002	

P-values in bold were significant at $\alpha = 0.05$ after correcting for multiple tests using false discovery rate.

Appendix F

NPDES Hatchery Effluent Monitoring, 2016

NPDES MONITORING FOR WDFW FACILITIES

All WDFW hatcheries monitor their discharge in accordance with the National Pollutant Discharge Elimination System (NPDES) permit. This permit is administered in Washington by the Washington Department of Ecology under agreement with the United States Environmental Protection Agency. The previous permit was extended until March 31, 2016. The current permit was renewed effective April 1, 2016 and will expire March 31, 2021.

Facilities are exempted from sampling during any month that pounds of fish on hand fall below 20,000 lbs and pounds of feed used fall below 5,000 lbs, with the exception of offline settling basin discharges which are to be monitored once per month when ponds are in use and discharging to receiving waters. Inactive permitted facilities retain a permit but are not required to monitor discharges because the pounds of fish and pounds of feed remain below monitoring guideline set by the permit.

Sampling at permitted facilities includes the following parameters:

<FLOW	Measured in millions of gallons per day (MGD) discharge.
<SS EFF	Average net settleable solids in the hatchery effluent, measured in ml/L.
<TSS COMP	Average net total suspended solids, composite sample (6 x/day) of the hatchery effluent, measured in mg/L.
<TSS MAX	Maximum daily net total suspended solids, composite sample (6 x/day) of the hatchery effluent, measured in mg/L.
<SS PA	Maximum settleable solids discharge from the pollution abatement pond, measured in ml/L.
<SS %	Removal of settleable solids within the pollution abatement pond from inlet to outlet, measured as a percent. No longer required under permit effective June 1, 2000.
<TSS PA	Maximum total suspended solids effluent grab from the pollution abatement pond discharge, measured in mg/L.
<TSS %	Removal of suspended solids within the pollution abatement pond from inlet to outlet, measured as a percent. No longer required under permit effective June 1, 2000.
<SS DD	Settleable solids discharged during drawdown for fish release. One sample per pond drawdown, measured in ml/L.
<TRC	Total residual chlorine discharge after rearing vessel disinfection and after neutralization with sodium thiosulfate. One sample per disinfection, measured in ug/L.

In addition, at Similkameen Hatchery only, the following sampling was conducted at the request of Washington Department of Ecology, but is not required under NPDES permit:

<SS IW	Settleable solids influent grab taken as wastes are pumped into the pollution abatement pond, measured in mg/L. No longer monitored as of January 2008.
<TSS IW	Total suspended solids influent grab as wastes are pumped into the pollution abatement pond, measured in mg/L. No longer monitored as of January 2008.

Eastbank Hatchery

NPDES Permit Number WAG13-5011

		FLOW	SS EFF	TSS COMP	TSS MAX	FLOW PA	SS PA	SS %	TSS PA	TSS %	Lbs of Fish	Lbs of Feed
2016	JAN	29.72	0	0	0	5000	0.01		14.2		24405	6167
	FEB	29.72	0	0	0	7000	0.01		18		34129	6724
	MAR	31.02	0	0	0	15000	0		27.5		44129	7136
	APR	14.87	0	0.2	0.2	5000	0.01		6		34824	5588
	MAY	19.39	0	0.2	0.2	7500	0.01		13		28243	8931
	JUN	29.09	0	0.2	0.2	15000	0		14.4		36506	9347
	JUL	29.09	0	0.8	0.8	12000	0.01		30.2		42904	7331
	AUG	29.09	0	0.5	1	7500	0.01		12.6		38218	7227
	SEP	29.09	0	0	0	10000	0.01		19.8		35629	11396
	OCT	29.72	0	0.6	0.6	7000	0.6		21.2		46349	12083
	NOV	29.72	0	0	0	7000	0		17.2		46363	3241
	DEC	15.51	0	0	0	5000	0		27.3		18401	4101

Wells Hatchery

NPDES Permit Number WAG13-5009

		FLOW	SS EFF	TSS COMP	TSS MAX	FLOW PA	SS PA	SS %	TSS PA	TSS %	Lbs of Fish	Lbs of Feed
2016	JAN	17.38	0.01	0	0	**	**		**		68738	14203
	FEB	19.59	0.01	1.2	1.2	**	**		**		86459	18204
	MAR	24.67	0.01	1.4	1.4	**	**		**		102881	18878
	APR	6.62	0	-10.4	9.4	**	**		**		10038	286
	MAY	6.62	0	0.4	1.6	**	**		**		10708	1660
	JUN	6.62	-0.1	-0.2	8.4	**	**		**		15118	3432
	JUL	3.97	0.01	1	1	**	**		**		5613	2481
	AUG	4.19	0.01	0	0	**	**		**		9105	3393
	SEP	6.06	0	1.4	1.4	**	**		**		13849	4538
	OCT	7.39	0	0.8	0.8	9288	0.1		2.4		22216	5753
	NOV	8.61	0.03	3.4	3.4	15309	0.05		1.2		28056	9830
	DEC	8.68	0.02	1	1	17573	0.06		1.4		46313	13557

** PA pond - No discharge. PA pond system down during hatchery rebuild.

Chiwawa Ponds - Chiwawa River
NPDES Permit Number WAG13-5015

		FLOW	SS EFF	TSS COMP	TSS MAX	Lbs of Fish	Lbs of Feed	SS DD	TSS DD
2016	JAN	3.67	0	2	2	9716	353		
	FEB	2.87	0	-0.4	-0.4	9323	518		
	MAR	3.22	0	0	0	17838	2848	0.05	5.2
	APR	2.32	0	1	1	17477	1320	0.03	14.4
	MAY		No Monitoring			0	0		
	JUN		No Monitoring			0	0		
	JUL		No Monitoring			0	0		
	AUG		No Monitoring			0	0		
	SEP	4.6	0.03	-0.4	-0.4	6553	132		
	OCT	4.49	0	-2	-0.2	6553	619		
	NOV	4.22	0	0.4	0.4	7865	750		
	DEC	3.71	0	0.8	0.8	8288	241		

Chiwawa Ponds - Wenatchee River
NPDES Permit Number WAG13-5015

		FLOW	SS EFF	TSS COMP	TSS MAX	Lbs of Fish	Lbs of Feed	SS DD	TSS DD
2016	JAN	No Monitoring				0	0		
	FEB	No Monitoring				0	0		
	MAR	No Monitoring				0	0		
	APR	2.18	0	0.8	0.8	18309	2746		
	MAY	2.25	0			7500	0	0.05	50.6
	JUN		No Monitoring			0	0		
	JUL		No Monitoring			0	0		
	AUG		No Monitoring			0	0		
	SEP		No Monitoring			0	0		
	OCT		No Monitoring			0	0		
	NOV	3	0	-1.4	-1.4	11778	1316		
	DEC	6.91	0	0.2	0.2	14254	1150		

Methow Hatchery

NPDES Permit Number WAG13-5000

		FLOW	SS EFF	TSS COMP	TSS MAX	FLOW PA	SS PA	SS %	TSS PA	TSS %	Lbs of Fish	Lbs of Feed	SS DD	TSS DD
2016	JAN	7.98	0	0.2	0.2	14400	0.1		0.2		11800	850		
	FEB	7.98	0	0	0	14400	0.1		0		12400	925		
	MAR	6.4	0	0.5	1	14400	0.1		0.2		13000	970		
	APR	6.4	0	-1.6	-1.6	14400	0.1		0.2		15000	1000	0.1	7.6
	MAY	6.4	0	0	0	14400	0.1		0.2		16000	1100	0.1	1.2
	JUN	6.2	0	0.2	0.2	14400	0.1		0.4		4000	240		
	JUL	6.4	0	0	0	14400	0		0		4400	1700		
	AUG	6.4	0	0	0	14400	0		0.2		4900	2100		
	SEP	6.4	0	0.2	0.2	14400	0		0.4		6300	3150		
	OCT	5.83	0	0	0	14400	0		0		7200	1200		
	NOV	5.83	0	0	0	14400	0		0		9100	1560		
	DEC	9.86	0	0	0	14400	0		0		10300	1100		

Similkameen Hatchery

NPDES Permit Number WAG13-5007

		FLOW	SS EFF	TSS COMP	TSS MAX	FLOW PA	SS IW	TSS IW	Lbs of Fish	Lbs of Feed	SS DD	TSS DD
2016	JAN	6.62	0	-10.4	-10.4				10038	286		
	FEB	6.62	0	0.4	0.4				10708	1660		
	MAR	6.62	-0.1	-0.2	0.2				15118	3432		
	APR	6.62	0	-14.2	-14.2				17224	2322	0	13.8
	MAY		No Monitoring						0	0		
	JUN		No Monitoring						0	0		
	JUL		No Monitoring						0	0		
	AUG		No Monitoring						0	0		
	SEP		No Monitoring						0	0		
	OCT	6.48	0	-1	-1				5730	528		
	NOV	6.84	0	-1.6	-1.6				6624	1584		
	DEC	6.48	0	0.8	0.8				7548	0		

Chelan Hatchery

NPDES Permit Number WAG13-5006

		FLOW	SS EFF	TSS COMP	TSS MAX	FLOW PA	SS PA	SS %	TSS PA	TSS %	Lbs of Fish	Lbs of Feed
2016	JAN	5.2	0.05	0.4	0.4	68000	0.05		3.2		14000	5163
	FEB	7.2	0.05	0.2	0.2	68000	0.05		1		16000	7936
	MAR	7.2	0.05	1.2	1.2	68000	0.05		4.6		27000	6417
	APR	5.2	0.05	0.7	1	68000	0.05		2.6		10332	2324
	MAY	7.2	0.05	1.2	1.2	68000	0.05		7		5400	2076
	JUN	7.2	0.05	1.2	1.2	68000	0.05		2		4200	2105
	JUL	9.5	0.04	0.4	0.4	68000	0.05		2.8		4196	4137
	AUG	9.8	0.05	-0.8	-0.8	68000	0.05		2.2		5325	5766
	SEP	9.8	0.05	0.4	0.4	68000	0.05		1.8		9374	8256
	OCT	8.9	0.05	1.4	1.4	68000	0.05		2.8		32535	10733
	NOV	8.9	0.05	0	0	68000	0.05		1.8		20152	4236
	DEC	6.23	0.05	0.2	0.2	68000	0.05		1.6		9000	3420

Chelan Falls Hatchery

NPDES Permit Number WAG13-7019

		FLOW	SS EFF	TSS COMP	TSS MAX	FLOW PA	SS PA	SS %	TSS PA	TSS %	Lbs of Fish	Lbs of Feed
2016	JAN	12.8	0.05	-6.6	-6.6	857	0.05		0.8		23897	2475
	FEB	12.8	0.05	-2	-2	857	0.05		0.2		23595	1919
	MAR	12.8	0.05	-14	-14	857	0.05		0.8		24208	5895
	APR	12.8	0.05	-1.6	-1.6	857	0.05		1.2		27623	2409
	MAY		No Monitoring								0	0
	JUN		No Monitoring								0	0
	JUL		No Monitoring								0	0
	AUG		No Monitoring								0	0
	SEP		No Monitoring								0	0
	OCT		No Monitoring								0	0
	NOV	6.9	0.04	-0.6	-0.6	3000	0.05		0.6		25846	3779
	DEC	6.9	0.04	-0.4	-0.4	3000	0.05		1.4		28196	3344

Dryden Acclimation Pond

NPDES Permit Number WAG13-5014

		FLOW	SS EFF	TSS COMP	TSS MAX	Lbs of Fish	Lbs of Feed	SS DD	TSS DD
2016	JAN		No Monitoring			0	0		
	FEB		No Monitoring			0	0		
	MAR	14.2	0	0.2	0.2	35272	484		
	APR	14.08	0.01	-0.2	-0.2	43929	2024	-0.01	12.4
	MAY		No Monitoring			0	0		
	JUN		No Monitoring			0	0		
	JUL		No Monitoring			0	0		
	AUG		No Monitoring			0	0		
	SEP		No Monitoring			0	0		
	OCT		No Monitoring			0	0		
	NOV		No Monitoring			0	0		
	DEC		No Monitoring			0	0		

Priest Rapids

NPDES Permit Number WAG13-7013

		FLOW	SS EFF	TSS COMP	TSS MAX	FLOW PA	SS PA	TSS PA	Lbs of Fish	Lbs of Feed	SS DD	TSS DD
2016	JAN	22.8	0	0.9	1	**	**	**	5054	0		
	FEB	26.6	0	0.2	0.2	**	**	**	6759	539		
	MAR	40.73	0	-0.8	-0.8		0.01	55.2	15217	5674		
	APR	26.1	0	0.2	0.2		0	17	36203	21076		
	MAY	38.03	0	1.4	1.4		0	33.8	72648	33627		
	JUN	30.25	0	0.6	0.6		0	32	108095	37585	0	1.9
	JUL		No Monitoring						0	0		
	AUG		No Monitoring						0	0		
	SEP	57.24	0			**	**	**	3280	0		
	OCT	60.39	0			**	**	**	39030	0		
	NOV	62.67	0			**	**	**	25050	0		
	DEC	34.85	0	0.6	0.6	**	**	**	7062	0		

**PA pond - No discharge this month

Appendix G

Steelhead Stock Assessment at Priest Rapids Dam, 2014-2015

Priest Rapids Dam 2014-2015 Adult Upper Columbia River Steelhead Run-Cycle Stock Assessment Report

Introduction

Upper Columbia River (UCR) steelhead stock assessment sampling at Priest Rapids Dam (PRD) is authorized through the Endangered Species Act (ESA) Section 10 Permit 1395 (NMFS 2003). Permit authorizations include interception and biological sampling of up to 10 percent of the UCR steelhead passing PRD to determine upriver population size, estimate hatchery to wild ratios, determine age-class contribution and evaluate the need for managing hatchery steelhead consistent with ESA recovery objectives, which include fully seeding spawning habitat with naturally produced UCR steelhead supplemented with artificially propagated enhancement steelhead (NMFS 2003).

Stock Assessment

The 2014 steelhead sampling at Priest Rapids Dam began on 7 July and concluded 8 November. Sampling consisted of operating the Priest Rapids Off Ladder Fish Trap (OLAFT), located on the left-bank fishway at Priest Rapids Dam, 8 hours per day, up to three days per week, for a total of 53 sampling days. Steelhead were trapped, handled, and released in accordance with Section 2.1 and 2.2.1 of the National Marine Fisheries Service (NMFS) Biological Opinion for ESA Permit 1395 (NMFS 2003). The cumulative sample rate attained during 2014 totaled 17.3%.

The Washington Department of Fish and Wildlife (WDFW) sampled 3,428 steelhead of the 2014/2015 run-cycle passing PRD, totaling 19,766 steelhead, for an overall sampling rate of 17.3%. Of the 3,428 steelhead sampled, 2,262 (70.0%) were hatchery origin and 1,166 (30.0%) were wild origin. The estimated 2014-2015 run-cycle total wild steelhead return was 5,930 representing 207.2% of the 1986-2013 average and about 106.2% of the most recent 5-year average (Table 1).

Based on external marks and external and internal tags, 2,217 hatchery-origin steelhead were sampled at Priest Rapids Dam during the 2014 return cycle and included 30.4% Wenatchee hatchery-origin steelhead and 47.1% "above Wells Dam" hatchery-origin steelhead[1] (Table 2), while 11.0% of the hatchery-origin steelhead sampled could not be assigned to a specific hatchery program. Ringold FH origin steelhead represented about 11.5% of the hatchery sample (Table 2).

[1] Defined as "above Wells Dam" because hatchery origin, adipose-clipped steelhead released into the Methow and Okanogan rivers from the Wells FH and Winthrop NFH have the same marks and are indistinguishable from one another.

Table 1. Priest Rapids Dam adult steelhead returns and stock composition, 1974-2013.

Run-cycle[1/]	Hatchery	Wild	Wild percent	Total run
1974				2,950
1975				2,560
1976				9,490
1977				9,630
1978				4,510
1979				8,710
1980				8,290
1981				9,110
1982				10,770
1983				32,000
1984				26,200
1985				34,010
1986	20,022	2,342	10.5	22,364
1987	9,955	4,058	29.0	14,013
1988	7,530	2,670	26.2	10,200
1989	8,033	2,685	25.1	10,718
1990	6,252	1,585	20.2	7,837
1991	11,169	2,799	20.0	13,968
1992	12,102	1,618	11.8	13,720
1993	4,538	890	16.4	5,428
1994	5,880	855	12.7	6,735
1995	3,377	993	22.7	4,370
1996	7,757	843	9.8	8,600
1997	8,157	785	8.8	8,942
1998	4,919	928	15.9	5,847
1999	6,903	1,374	16.6	8,277
2000	9,023	2,341	20.6	11,364
2001	24,362	5,715	19.0	30,077
2002	12,884	2,983	18.8	15,867
2003	14,890	2,837	16.0	17,729
2004	15,670	2,985	16.0	18,655
2005	10,352	3,127	23.2	13,479
2006	8,738	1,677	16.1	10,415
2007	12,160	3,097	20.3	15,257
2008	13,528	3,030	18.3	16,558
2009	32,557	7,439	18.6	39,996
2010	18,784	7,647	28.9	26,431
2011	15,910	4,896	23.5	20,806
2012	13,908	3,284	19.1	17,192
2013	10,415	4,657	30.9	15,072
2014	13,836	5,930	30.0	19,766
1986-2013 average	**11,778**	**2,862**	**19.1**	**14,204**
2009-2013 average	**18,317**	**5,583**	**24.2**	**23,899**

[1/] A return cycle is the combined total of steelhead passing PRD from 1 June – 30 November during year (x), plus steelhead passing PRD between 15 April and 31 May on year (x+1).

Table 2. Origin classification of steelhead sampled at Priest Rapids Dam, 7 July – 8 November 2014.

Steelhead origin																					
Wild			Hatchery																		
Wild			Wenatchee						Above Wells				Ringold FH			Unk. Hat.					
Criteria			VIE						Criteria				Criteria			Criteria			Total	Total	Total
NS	NM	Total	LTGR	RTGR	RTOR	CWT	AD	Total	AD	Ped	LV	Total	AD	RV	Total	SD	NM	Total	Wild	Hatchery	Total
x	x	1,166	x					0	x			997	x	x	255	x	x	243	1,166	2,217	3,383
				x				0		x		11									
					x			0			x	36									
						x		141													
							x	534													
Total		**1,166**						**675**				**1,044**			**255**			**243**	**1,166**	**2,217**	**3,383**
% Hatchery								**30.4**				**47.1**			**11.5**			**11.0**		**100.0**	
% Total		**34.4**						**20.0**				**30.9**			**7.5**			**7.2**	**34.5**	**65.5**	**100.0**

Reconciliation of saltwater age of wild and hatchery steelhead sampled at Priest Rapids Dam during 2014 was accomplished through scale analysis. Salt-age analysis of the 2014 UCR steelhead run-cycle provides an estimated hatchery-origin return dominated by 1-salt and 2-salt age composition of 34.1% and 65.8%, respectively (Table 3). Natural-origin steelhead salt ages were 31.1% and 68.8% for salt ages-1 and 2, respectively. Three-salt age fish represented less than 0.1% of the combined hatchery/wild sample (Table 3).

Table 3. Salt-water age composition of 2014 – 2015 return cycle Upper Columbia River steelhead sampled at Priest Rapids Dam, corrected by scale age/origin determination.

	Origin					
	Hatchery		Wild		Combined	
Salt-age	***N***	**%**	***N***	**%**	***N***	**%**
1-salt	791	35.7	370	31.1	1161	34.1
2-salt	1,422	64.3	817	68.8	2239	65.8
3-salt	0	0.0	1	0.1	1	>0.1
4-salt	0	0.0	0	0.0	0	0.0
Total	**2,213**		**1,188**		**3,401**	

Freshwater residency of naturally produced Upper Columbia River steelhead present in the 2014-2015 run-cycle were dominated by age-2 freshwater fish (78.9%), and was only slightly lower than the 1986-2013 average of 74.2% (Table 4).

Table 4. 2014 return year freshwater age of wild Upper Columbia River steelhead sampled at Priest Rapids Dam during steelhead stock assessment activities, compared to July – November 1986-2013 average.

Freshwater age	**2014-2015 run cycle**		**1986-2013 proportion**	
	N	**%**	***N***	**%**
1.x	53	4.9	489	7.9
2.x	851	78.9	4,581	74.2
3.x	168	15.6	1,046	17.0
4.x	7	0.6	51	0.8
5.x	0	0.0	3	>0.1
Total	**1,079**		**6,170**	

Wild and hatchery-origin steelhead exhibited similar saltwater growth in the 2014 run-cycle. Wild 1and 2-salt adults were slightly larger than their hatchery cohorts (Table 5). Age-1 salt hatchery and age-1 and 2 salt wild steelhead observed in the 2014-2015 adult run-cycle return past PRD were comparable in size to the 1986-2013 run-cycle average (Table 5).

Table 5. Average fork length of 1-salt and 2-salt, Upper Columbia River steelhead sampled at Priest Rapids Dam during July – November 2014 and the period between 1986-2013.

	Average fork length (cm)			
	2014-2015 run cycle		1986-2013 run cycle	
Salt age	**Wild**	**Hatchery**	**Wild**	**Hatchery**
x.1	57.4	55.8	59.7	58.7
x.2	71.1	70.2	72.5	71.6

Appendix H

Wenatchee Sockeye Salmon Spawning Escapement, 2016

PUBLIC UTILITY DISTRICT NUMBER 1 OF CHELAN COUNTY
Natural Resource Division
Fish and Wildlife Department
327 N. Wenatchee Ave., Wenatchee WA 98801 (509) 663-8121

March 28, 2017

To: HCP Hatchery Committee

From: Catherine Willard and Scott Hopkins

Subject: 2016 Wenatchee Sockeye Mark/Recapture-Based Sockeye Escapement Estimates to Tributaries

Introduction

In 2016, the Chelan County Public Utility District (District) estimated sockeye escapement to tributaries based on mark-recapture methodology. The purpose of this document is to report the spawning escapement estimates for the Little Wenatchee and White River subbasins. This information is used to track and/or estimate viable salmonid population parameters (VSP): abundance, productivity, spatial structure, and diversity (McElhaney et al. 2000).

Methods

Mark-Recapture Method:

Detection efficiencies of the in-stream arrays were calculated for the Little Wenatchee River and White River in 2016. The in-stream arrays include a series of upstream and downstream coils (Figure 1). Combined, these coils represented the upstream and downstream detection arrays, respectively. Overall detection efficiency P_{all} of the arrays was calculated based on observed detection probabilities of individual arrays:

$$P_{all} = 1 - \left(1 - P_{array\ 1}\right)\left(1 - P_{array\ 2}\right)$$

where the probability of missing a fish on both the upstream P_{array1} and downstream P_{array2} arrays were combined for an overall efficiency P_{all} (Connolly et al. 2008).

Adult sockeye salmon were tagged at adult fishways within the Columbia River and at Tumwater Dam. Additionally, adult returns that were PIT tagged as juveniles were used in the analyses. Total passage of adult sockeye salmon through Tumwater Dam was obtained from Columbia River Data Access in Real Time (DART 2016). Resulting tag files were queried in PTAGIS (2016), providing detection histories for each study fish.

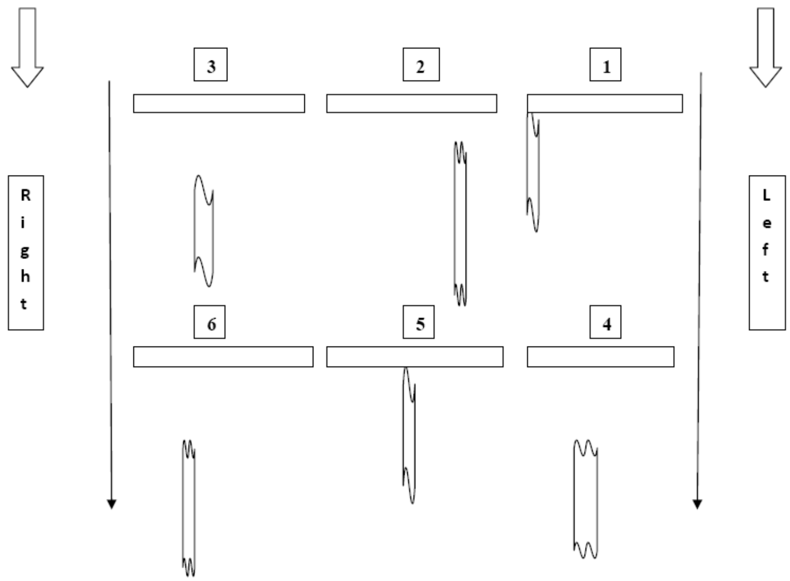


Figure 1. Schematic of a PIT array configuration.

Resulting data from passage at Tumwater Dam, mark and recapture using PIT tags, and detection efficiency estimates can provide estimation of escapement to spawning tributaries. Assumptions include: (1) the study population is "closed," i.e., no individuals die or emigrate between the initial mark and subsequent recaptures; (2) tags are not lost and detections are correctly identified; (3) all individuals have the same probability of being detected, and (4) the number of recapture events are proportional to the total population. Lastly, it was assumed that PIT-tagging efforts at Tumwater have negligible influence on fish behavior and tagged individuals behave similarly to untagged individuals. The resulting escapement rate, adjusted for detection efficiency, was then applied to the total population as such:

$$Escapement = \left(\frac{\left(\frac{Obs_{LWN}}{Eff_{LWN}} + \frac{Obs_{WTL}}{Eff_{WTL}} \right)}{PITs_{TUM}} \right) \times Counts_{TUM}$$

where the PIT tag detections (*Obs*) at the Little Wenatchee (*LWN*) and White River (WTL) were adjusted for detection efficiency (*Eff*), compared to the number released (*PITs*) at Tumwater Dam (*TUM*), and the resulting proportion was applied to the population observed (*Counts*) passing Tumwater Dam.

Results

Sockeye Salmon Mark-Recapture Method

Fishway enumeration at Tumwater Dam indicated that 73,697 adult sockeye salmon passed the facility during the 2016 migration, which was a sufficient return to open a recreational fishery in Lake Wenatchee for 2016. PIT tags were implanted in 790 fish at Tumwater and 630 fish were PIT-tagged before passing Tumwater; 130 fish were subsequently detected at the Little Wenatchee PIT tag array and 743 fish were subsequently detected at the White River PIT tag array (Table 1). Based on the recapture of PIT-tagged adult sockeye and assigned detection efficiency, total estimated escapement from Tumwater Dam to the Little Wenatchee River was 6,747 adult sockeye and 38,321 adult sockeye to the White River (Table 2).

Table 1. Number of adult sockeye salmon PIT-tagged, released, and detected upstream of Tumwater Dam in 2009 through 2016, and mark/recapture based tributary escapement estimates. Obs. = observed, D.E. = detection efficiency, Est = estimated (Obs./D.E.), and NA = not available.

Year	Number of PIT-tagged adults detected or tagged at Tumwater[1]	White River			Little Wenatchee River			Chiwawa River Obs.	Nason Creek Obs.
		Obs.	*D.E. (p_{all})*	*Est*	Obs.	*D.E. (p_{all})*	*Est*		
2009	1,085	381	0.406	*939*	38	0.971	*39*	37	7
2010	1,164	571	0.900[2]	*635*	67	1.000	*67*	3	1
2011	484	40	NA[3]	*NA*	84	--	*0*	0	0
2012	1,154	410	0.943	*435*	74	0.987	*75*	0	0
2013	719	152	NA[3]	*NA*	55	0.818	*67*	0	0
2014	1,729	848	0.999	*848*	76	1.000	*76*	0	3
2015[4]	950	371	0.999	*371*	50	1.000	*50*	69	4
2016	1,420	743	0.994	*738*	130	1.000	*130*	2	1

[1] Also includes fish detected downstream of release point (fallbacks).
[2] Detection efficiency p_{all} = 0.406 in 2009 was assigned from 2010 data.
[3] Technical difficulties with the White River PIT array prevented the calculation of detection efficiency and a mark-recapture based escapement estimate.
[4] In 2015, 45 sockeye salmon were detected in Chiwaukum Creek.

Table 2. Estimated escapement of adult sockeye salmon to Little Wenatchee and White rivers based on mark-recapture events, in-stream detection efficiency, and adult enumeration at Tumwater Dam, 2009-2016.

Year	Tumwater count	Recreational harvest	Little Wenatchee	White River	Combined	Escapement
2009	16,034	2,229	576	13,876	14,452	0.901
2010	35,821	4,129	2,062	19,542	21,604	0.603
2011[1]	18,634	0	2,431	14,582	17,013	0.913
2012	66,520	12,107	4,607	23,866	28,473	0.428
2013[1]	29,015	6,262	2,426	14,294	16,720	0.576
2014	99,898	16,281	4,319	49,021	53,340	0.534
2015	51,435	7,916	2,707	20,097	22,804	0.443
2016	73,697	14,630	6,747	38,321	45,068	0.612
Average	**48,882**	**7,944**	**3,234**	**24,200**	**27,434**	**0.626**

[1] Escapement was calculated using AUC counts for the Little Wenatchee River and a linear regression relationship to the Little Wenatchee River for the White River.

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Appendix I

Genetic Diversity of Wenatchee Sockeye Salmon

Assessing the Genetic Diversity of Lake Wenatchee Sockeye Salmon And Evaluating The Effectiveness Of Its Supportive Hatchery Supplementation Program

Developed for

Chelan County PUD

and the

Habitat Conservation Plan's Hatchery Committee

Developed by
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March 2008

Executive Summary

Nine spawning populations of sockeye (*Oncorhynchus nerka*) salmon have been identified in Washington, including stocks in the Lake Wenatchee basin (SaSI 5800) (Washington Department of Fisheries et al. 1993). Lake Wenatchee sockeye are classified as an Evolutionary Significant Unit (ESU), and consists of sockeye salmon that spawn primarily in tributaries above Lake Wenatchee (the White River, Napeequa River, and Little Wenatchee Rivers). Since 1990, the Wenatchee Sockeye Program has released juveniles into Lake Wenatchee to supplement natural production of sockeye salmon in the basin. The program's broodstock are predominantly natural-origin sockeye adults returning to the Wenatchee River captured at Tumwater Dam (Rkm 52.0), where a net-pen system is used to house both maturing adults and juveniles prior to release into Lake Wenatchee to over-winter.

Previous genetic studies have generally found a lack of concordance between population genetic relationships and their geographic distributions. These studies indicate that the nearest geographic neighbors of sockeye salmon populations are not necessarily the most genetically similar. Specifically for the Columbia River Basin, sockeye from Lake Wenatchee, Okanogan River, and Redfish Lake may be more closely related to a population from outside the Columbia River (depending on marker used) then to each other.

In this study we investigated the temporal and spatial genetic structure of Lake Wenatchee sockeye collections, without regard to sockeye populations outside of the Lake Wenatchee area. Our primary objective here was to determine if the Wenatchee Sockeye Program affected the natural Lake Wenatchee sockeye population. More specifically, we were tasked to determine if the genetic composition of Lake Wenatchee sockeye population had been altered by a supplementation program that was based on the artificial propagation of a small subset of that population. Using microsatellite DNA allele frequencies, we investigated population differentiation between temporally replicated collections of natural-origin Lake Wenatchee sockeye and program broodstock. We analyzed thirteen collections of Lake Wenatchee sockeye (Table 1), eight temporally replicated collections of natural-origin Lake Wenatchee sockeye (N=786) and five temporally replicated collections of Wenatchee Sockeye Program broodstock (N=248). Paired natural – broodstock collections were available from years 2000, 2001, 2004, 2006, and 2007.

Conclusions

We observed that allele frequency distributions were consistent over time, irrespective of collection origin, resulting in small and statistically insignificant measures of genetic differentiation among collections. We interpreted these results to indicate no year-to-year differences in allele frequencies among natural-origin or broodstock collections. Furthermore, there were no observed difference between pre- and post-supplementation collections. Therefore, we accepted our null hypothesis that the allele frequencies of the broodstock collections equaled the allele frequencies of the natural collections, which

equaled the allele frequency of the donor population. Given the small differences in genetic composition among collections, the genetic model for estimating N_e produced estimates with extremely large variances, preventing the observation of any trend in N_e.

Introduction

A report titled "Conceptual Approach to Monitoring and Evaluating the Chelan County Public Utility District Hatchery Programs" was prepared July 2005 by Andrew Murdoch and Chuck Peven for the Chelan PUD Habitat Conservation Plan's Hatchery Committee. This report outlined 10 objectives to be applied to various species assessing the impact (positive or negative) of hatchery operations mitigating the operation of Rock Island Dam. This current study pertains only to Lake Wenatchee sockeye and objective 3:

> *Determine if genetic diversity, population structure, and effective population size have changed in natural spawning populations as a result of the hatchery program. Additionally, determine if hatchery programs have caused changes in phenotypic characteristics of natural populations.*

In order to evaluate cause and effect of hatchery supplementation, WDFW Molecular Genetics Lab surveyed genetic variation of Lake Wenatchee sockeye. The conceptual approach for this project follows that of a parallel study regarding the Wenatchee River spring Chinook supplementation program (Blankenship et al. 2007). We determined the genetic diversity present in the Lake Wenatchee sockeye population by analyzing temporally replicated collections spanning 1989 – 2007, which included collections from before and following the inception of the Wenatchee Sockeye Program. Documenting the genetic composition of the Lake Wenatchee sockeye population is necessary to assess the effect of the hatchery program on the Lake Wenatchee population. In addition, this work provides a genetic baseline for future projects requiring genetic data. See study objectives below for specific details about how this project addresses Murdoch and Peven (2005) objective 3.

Lake Wenatchee Sockeye Salmon

Nine spawning populations of sockeye (*Oncorhynchus nerka*) salmon have been identified in Washington (Washington Department of Fisheries et al. 1993): 1) Baker

River, 2) Ozette Lake, 3) Lake Pleasant, 4) Quinault Lake, and 5) Okanogan River (classified as native stock); 6) Cedar River (classified as non-native stock); 7) Lake Wenatchee, classified as mixed stock); 8) Lake Washington/Lake Sammamish tributaries; and 9) Lake Washington beach spawners (classified as unknown origin). Chapman et al. (1995) listed four additional spawning aggregations of sockeye salmon that appear consistently in Columbia River tributaries: the Methow, Entiat, and Similkameen Rivers; and Icicle Creek in the Wenatchee River drainage.

Located in north central Washington, the Wenatchee River basin drains a portion of the eastern slope of the Cascade Mountains, including high mountainous regions of the Cascade crest. The headwater area of the Wenatchee River is Lake Wenatchee, a typical low productivity oligotrophic or ultra-oligotrophic sockeye salmon nursery lake (Allen and Meekin 1980, Mullan 1986, Chapman et al. 1995). Sockeye salmon bound for Lake Wenatchee enter the Columbia River in April and May and arrive at Lake Wenatchee in late July to early August (Chapman et al. 1995; Washington Department of Fisheries et al. 1993). The run timing of Lake Wenatchee sockeye salmon, classified as an Evolutionary Significant Unit (ESU), appears to have become earlier by 6 - 30 days during the past 70 years (Chapman et al. 1995; Quinn and Adams 1996). Additionally, scale pattern analysis suggests Wenatchee sockeye migrate past Bonneville Dam earlier than the sockeye bound for the Okanogan River (Fryer and Schwartzberg 1994). The Wenatchee population spawns from mid-September through October in the Little Wenatchee, White, and Napeequa Rivers above Lake Wenatchee (Washington Department of Fisheries et al. 1993), peaking in late September (Chapman et al. 1995). Limited beach spawning is believed to occur in Lake Wenatchee (L. Lavoy pers. com.; Mullan 1986), although Gangmark and Fulton (1952) reported two lakeshore seepage areas in Lake Wenatchee that were used by spawning sockeye salmon. Sockeye salmon fry enter Lake Wenatchee between March and May (Dawson et al. 1973), and typically rear in the lake for one year before leaving as smolts (Gustafson et al. 1997; Peven 1987).

Both the physical properties of the habitat and ecological/biological factors of the sockeye populations differ between the Lake Wenatchee ESU and the geographically proximate Okanogan ESU. For example: 1) Different limnology is encountered by sockeye salmon in Lakes Wenatchee and Osoyoos; 2) Lake Wenatchee sockeye predominantly return at ages four and five (a near absence of 3-year-olds), where a large percentage of 3-year-olds return to the Okanogan population; and 3) the apparent one month separation in juvenile outmigration-timing between Okanogan- and Wenatchee-origin fish (Gustafson et al. 1997 and references therein).

Sockeye Artificial Propagation In Lake Wenatchee

The construction of Grand Coulee Dam completely blocked fish passage to the upper Columbia River, and 85% of sockeye salmon passing Rock Island Dam between 1935 and 1936 were estimated to be from natural stocks bound for areas up-river to Grand Coulee Dam (Mullan 1986; Washington Department of Fisheries et al. 1938). To compensate for loss of habitat resulting from Grand Coulee Dam, the federal government initiated the Grand Coulee Fish-Maintenance Project (GCFMP) in 1939 to maintain fish runs in the Columbia River above Rock Island Dam. Between 1939 and 1943, all sockeye salmon entering the mid-Columbia River were trapped at Rock Island Dam, and over 32,000 mixed Lake Wenatchee, Okanogan River, and Arrow Lake adult sockeye salmon were released into Lake Wenatchee (Gustafson et al. 1997 Appendix Table D-2). In addition to adult relocation, between 1941 and 1969 over 52.8 million fry descended from original spawners collected at Rock Island and Bonneville Dams, were released into Lake Wenatchee (Gustafson et al. 1997 Appendix Table D-2).

No releases of artificially-reared sockeye salmon occurred in the Wenatchee watershed during the years 1970 to 1989 (Gustafson et al. 1997 Appendix Table D-2). Since 1990, the Wenatchee Sockeye Program has released juveniles into Lake Wenatchee to supplement natural production of sockeye salmon in the basin. Sockeye adults returning to the Wenatchee River are captured at Tumwater Dam (Rkm 52.0) and transferred to Lake Wenatchee net pens until mature. The Wenatchee Sockeye Program goals are 260 adults with an equal sex ratio, <10% hatchery-origin returns (identified by coded wire tags), and the adults removed for broodstock account for <10% of the run size. Fish are spawned at Lake Wenatchee and their gametes are taken to Rock Island Fish Hatchery

Complex (i.e., Eastbank) for fertilization and incubation. Fry are returned to the Lake Wenatchee net -pens after they are large enough to be coded wire tagged, and are housed in the pens until fall (one year after spawning), when they are liberated into the lake to over-winter. For brood years 1991 – 2004 an average of 218,683 (std. dev. = 71,090) pen-reared Lake Wenatchee-origin juvenile sockeye salmon have been released yearly into Lake Wenatchee.

Previous Genetic Studies

Protein (allozyme) variation – Surveying genetic variation at 12 allozyme loci, Utter et al. (1984) reported moderate population structure among 16 sockeye collections from southeast Alaska through the Columbia River Basin, including Okanogan and Wenatchee stocks, with an apparent genetic association between upper Fraser River and Columbia River sockeye salmon. Winans et al. (1996) surveyed variation at 55 allozyme loci for 25 sockeye salmon and two kokanee collections from 21 sites in Washington, Idaho, and British Columbia, and reported the lowest level of allozyme variability of any species of Pacific salmon and a highest level of inter-population differentiation. Furthermore, these authors reported that there was no clear relationship between geographic and genetic differentiation among the populations within there study. Other studies corroborate the results of Winans et al. (1996), finding a lack of discernible geographic patterning for sockeye salmon populations in British Columbia, Alaska, and Kamchatka (Varnavskaya et al. 1994, Wood et al. 1994, Wood 1995). These studies indicate that the nearest geographic neighbors of sockeye salmon populations are not necessarily the most genetically similar, which contrasts with the other Pacific salmon species that exhibit concordance between geographic and genetic differentiation (Utter et al. 1989, Winans et al. 1994, Shaklee et al. 1991). As part of the comprehensive status review of west coast sockeye salmon (Gustafson et al. 1997), NMFS biologists collected new allozyme genetic information for 17 sockeye salmon populations and one kokanee population in Washington and combined these data for analysis with the existing Pacific Northwest sockeye salmon and kokanee data from Winans et al. (1996). Results of the updated study were consistent with Winans et al. (1996), with no clear concordance between geographic and genetic distances. Sockeye salmon from Lake Wenatchee, Redfish Lake, Ozette Lake, and Lake Pleasant are very distinct from other collections in the study, and Columbia River populations were not necessarily most closely related to each other. Gustafson et al. (1997) also examined between-year variability within a collection location and found low levels of statistical significance among the five Lake Wenatchee collections included in the study (For 10 pair-wise comparisons using sum-G test, five were statistically significant). Lake Wenatchee brood year 1987 accounted for three of the significant comparisons, which were driven by unusually high frequencies of two allozyme alleles (ALAT*95 and ALAT*108) (Winans et al. 1996). Nevertheless, Gustafson et al. (1997) conclude that, in general, temporal variation at a locale was considerably less than between-locale variation.

Nucleic acid variation - Beacham et al. (1995) reported levels of variation in nuclear DNA of *O. nerka* using minisatellite probes. They analyzed 10 collections, including a sample from Lake Wenatchee. Cluster analysis showed the Lake Wenatchee sample was different from all the other collections, including those from the Columbia River. Using a similar molecular technique, Thorgaard et al. (1995) examined the use of multi-locus DNA fingerprinting (i.e., banding patterns) to discriminate among 14 sockeye salmon and kokanee populations. Dendrograms based on analysis of banding patterns produced different genetic affinity groups depending on the probes used. While none of the five DNA probes showed a close relationship between Lake Wenatchee and Okanogan River sockeye salmon, if information from all probes were combined, *O. nerka* from Redfish Lake, Wenatchee, and Okanogan were separate from kokanee of Oregon and Idaho and a sockeye salmon sample from the mid-Fraser River.

Study Objective

We documented temporal variation in genetic diversity (i.e., heterozygosity and allelic diversity), and investigated population differentiation between temporally replicated collections of natural-origin Lake Wenatchee sockeye and program broodstock, using microsatellite DNA allele frequencies. Temporally replicated collections from the same location can also be used to estimate effective population size (N_e). If populations are "ideal", the census size of a population is equal to the "genetic size" of the population.

Yet, numerous factors lower the "genetic size" below census, such as, non-equal sex ratios, changes in population size, and variance in the numbers of offspring produced from parent pairs. N_e is thought to be between 0.10 and 0.33 of the estimated census size (Bartley et al. 1992; RS Waples pers. comm.), although numerous observations differ from this general rule. N_e can be calculated directly from demographic data, or inferred from observed differences in genetic variance over time. Essentially, when calculated from genetic data, N_e is the estimated size of an "ideal" population that accounts for the genetic diversity changes observed, irrespective of abundance.

We will address the hypotheses associated with Objective 3 in Murdock and Peven (2005) using the following four specific tasks:

Task 1 - Document the observed genetic diversity.

Task 2 - Test for population differentiation among Lake Wenatchee collections and the associated supplementation program.

Task 2 was designed to address two hypotheses listed as part of Objective 3 in Murdoch and Peven (2005):

- Ho: Allele frequency $_{\text{Hatchery}}$ = Allele frequency $_{\text{Naturally produced}}$ = Allele frequency $_{\text{Donor pop}}$.
- Ho: Genetic distance between subpopulations $_{\text{Year x}}$ = Genetic distance between subpopulations $_{\text{Year y}}$

Murdoch and Peven (2005) proposed these two hypotheses to help evaluate supplementation programs through a "Conceptual Process" (Figure 5 in Murdoch and Peven 2005). There are two components to the first hypothesis, which must be considered separately for Lake Wenatchee sockeye. The first component involves comparisons between natural-origin populations from Lake Wenatchee to determine if there have been changes in allele frequencies through time starting with the donor population. Documenting a change does not necessarily indicate that the supplementation program has directly affected the natural-origin fish, as additional tests would be necessary to support that hypothesis. The intent of the second component is to determine if the hatchery produced populations have the same genetic composition as the naturally produced populations.

Task 3 - Calculate N_e using the temporal method for multiple samples from the same location to document trend.

Task 4 - Compare N_e estimates with trend in census size for Lake Wenatchee sockeye.

Methods and Materials

Sampling

Thirteen collections of Lake Wenatchee sockeye were analyzed, eight temporally replicated collections of natural Lake Wenatchee sockeye (N=786) and five temporally replicated collections of Wenatchee Sockeye Program broodstock (N=248) (Table 1). Paired natural – broodstock collections were available from years 2000, 2001, 2004, 2006, and 2007 (Table 1). All collections were made at Tumwater Dam on the Wenatchee River. Note that collections classified as broodstock were predominantly natural-origin sockeye. A majority of the genetic samples were from dried scales. The tissue collections from 2006 and 2007 were fin clips stored immediately in ethanol after collection. DNA was extracted from stored tissue using Nucleospin 96 Tissue following the manufacturer's standard protocol (Macherey-Nagel, Easton, PA, U.S.A.).

Laboratory Analysis

Polymerase chain reaction (PCR) amplification was performed using 17 fluorescently end-labeled microsatellite marker loci, *One* 2 (Scribner et al 1996) *One* 100, 101, 102, 105, 108, 110, 114, and 115 (Olsen et al. 2000), *Omm* 1130, 1135, 1139, 1142, 1070, and 1085 (Rexroad et al. 2001), *Ots* 3M (Banks et al. 1999) and *Ots* 103 (Small et al. 1998). PCR reaction volumes were 10 μL, with the reaction variables being 2 μL 5x PCR buffer (Promega), 0.6 μL $MgCl_2$ (1.5 mM) (Promega), 0.2 μL 10 mM dNTP mix (Promega), and 0.1 μL *Go Taq* DNA polymerase (Promega). Loci were amplified as part of multiplexed sets, so primer molarities and annealing temperatures varied. Multiplex one had an annealing temperature of 55°C, and used 0.09 Molar (M) *One* 108, 0.06 M *One* 110, and 0.11 M *One* 100. Multiplex two had an annealing temperature of 53°C, and used 0.08 M *One* 102, 0.1 M *One* 114, and 0.05 M *One* 115. Multiplex three had an annealing temperature of 55°C, and used 0.08 M *One* 105 and 0.07 M *Ots* 103. Multiplex four had an annealing temperature of 53°C, and used 0.09 M *Omm* 1135 and 0.08 M *Omm* 1139. Multiplex five had an annealing temperature of 60°C, and used 0.2 M *Omm* 1085, 0.09 M *Omm* 1070, and 0.05 M *Ots* 3M. Multiplex six had an annealing temperature of 48°C, and used 0.06 M *One* 2, 0.08 M *Omm* 1142, and 0.08 M *Omm* 1130. *One* 101 was run in isolation with a primer molarity of 0.06. Thermal cycling was conducted on either PTC200 (MJ Research) or GeneAmp 9700 thermal cyclers as follows: 94°C (2 min); 30 cycles of 94°C for 15 sec., 30 sec. annealing, and 72°C for 1 min.; a final 72°C extension and then a 10°C hold. PCR products were visualized by denaturing polyacrylamide gel electrophoresis on an ABI 3730 automated capillary analyzer (Applied Biosystems). Fragment analysis was completed using GeneMapper 3.7 (Applied Biosystems).

Genetic data analysis

Assessing within collection genetic diversity - Heterozygosity measurements were reported using Nei's (1987) unbiased gene diversity formula (i.e., expected heterozygosity) and Hedrick's (1983) formula for observed heterozygosity. Both tests were implemented using the microsatellite toolkit (Park 2001). For each locus and collection FSTAT version 2.9.3.2 (Goudet 1995) was used to assess Hardy-Weinberg equilibrium, where deviations from the neutral expectation of random associations among alleles were calculated using a randomization procedure. Alleles were randomized among individuals within collections (4160 randomizations for this dataset) and the F_{IS} (Weir and Cockerham 1984) calculated for the randomized datasets were compared to the observed F_{IS} to obtain an unbiased estimation of the probability that the null hypothesis was true. The 5% nominal level of statistical significance was adjusted for multiple tests (Rice 1989). Genotypic linkage disequilibrium was calculated following Weir (1979) using GENETIX version 4.05 (Belkhir et al. 1996). Statistical significance of linkage disequilibrium results was assessed using a permutation procedure implemented in GENETIX for each locus by locus combination within each collection.

Assessing among collection genetic differentiation - The temporal stability of allele frequencies was assessed by the randomization chi-square test implemented in FSTAT version 2.9.3.2 (Goudet 1995). Multi-locus genotypes were randomized between collections. The G-statistic for observed data was compared to G-statistic distributions from randomized datasets (i.e., null distribution of no differentiation between collections). Population differentiation was also investigated using pairwise estimates of F_{ST}. Multi-locus estimates of pairwise F_{ST}, estimated by a "weighted" analysis of variance (Weir and Cockerham, 1984), were calculated using GENETIX version 4.05 (Belkhir et al.1996). F_{ST} was used to quantify population structure, the deviation from statistical expectations (i.e., excess homozygosity) due to non-random mating between populations. To determine if the observed F_{ST} estimate was consistent with statistically expectations of no population structure, a permutation test was implemented in GENETIX (1000 permutations).

Effective population size (N_e) – Estimates of the effective population size were obtained using a multi-collection temporal method (Waples 1990a). The temporal method assumes that cohorts are used, but we did not decompose the collection year samples into their respective cohorts using age data. Therefore, N_e estimates that pertain to individual year classes of breeders are not valid; however the harmonic mean over all samples will estimate an N_e that pertains to the time period from which the collections are derived. Comparing samples from years *i* and *j*, Waples' (1990a) temporal method estimates the effective number of breeders ($\hat{N}_{b(i,j)}$) according to:

$$\hat{N}_{b(i,j)} = \frac{b}{2(\hat{F} - 1/\tilde{S}_{i,j})}$$

The standardized variance in allele frequency ($\hat{F}$) is calculated according to Pollack (1983). The parameter b is calculated analytically from age structure information and the number of years between samples (Tajima 1992). The age-at-maturity information required to calculate b was obtained from ecological data (Hillman et al. 2007). The harmonic mean of sample sizes from years *i* and *j* is $\tilde{S}_{i,j}$. The harmonic mean over all pairwise estimates of $\hat{N}_{b(i,j)}$ is $\tilde{N}_b$. SALMONNb (Waples et al. 2007) was used to calculate $\tilde{N}_b$.

Results and Discussion

In this section we combine our presentation and interpretations of the genetic analyses. Additionally, this section is organized based on the task list presented in the study plan.

Task 1 - Document the observed genetic diversity.

Substantial genetic diversity was observed over all Lake Wenatchee sockeye collections analyzed (Table 1), with heterozygosity estimates over all loci having a mean of 0.79. Genetic diversity was consistent with expected Hardy-Weinberg random mating genotypic proportions for all collections. The F_{IS} observed for each collection was not statistically significant given the distribution of F_{IS} generated using a randomization procedure. Additionally, there were no statistically significant associations observed between alleles across loci (i.e., linkage equilibrium) (data not shown). We concluded from these results that the genetic data from each collection was consistent with statistical expectations for random association of alleles within and between loci. In other words, each collection represents samples from a single gene pool (i.e., populations), and the genetic diversity observed has no detectable technical artifacts or evidence of natural selection.

Task 2 - Test for differentiation among Lake Wenatchee collections and the associated supplementation program.

We explicitly tested the hypothesis of no significant differentiation within natural-origin or broodstock collections from Lake Wenatchee using a randomization chi-square test. The null hypothesis for these tests was that the allele frequencies from two different populations were drawn from the same underlying distribution. We show the results for the pairwise comparisons among eight temporally replicated natural-origin collections from Lake Wenatchee (28 pairwise tests), and report all tests were non-significant (Table 2A). Similarly, for five temporally replicated broodstock collections, 10 of 10 pairwise tests were non-significant (Table 2B). We also tested if natural-origin and broodstock collections were differentiated from each other over time, and report that 40 of 40 tests were non-significant (Table 2C). The nominal level of statistical significance ($\alpha = 0.05$) was adjusted for multiple comparisons using strict Bonferroni correction (Rice 1989). Yet, there are perhaps slight differences between paired natural-broodstock collections. Note that the p-values for comparisons regarding 2006 and 2007 paired collections are lower than for comparisons regarding 2000, 2001, and 2004. The small sample sizes for broodstock collections in 2006 and 2007 may not have been random samples from the Lake Wenatchee sockeye population.

Given the consistencies observed for allele frequency distributions over time, metrics of population structure were expected to be small. This was the case, as the estimated F_{ST} over all thirteen collections was 0.0003. This observed value fell within the distribution of F_{ST} values expected if there were no population structure present (permutation test p-value 0.12). Analysis of the paired natural-broodstock collections corroborated this result. Pairwise estimates of F_{ST} were 0.000 for years 2000, 2001, 2004, and 2007, and 0.002 for 2006. All five estimates were non-significant. Essentially, all 13 sockeye collections could be considered samples from the same population. Given these results, it is valid to combine all collections for statistical analysis. Therefore, we did not calculate genetic distances among any collections, as it is inappropriate to estimate distances that are effectively zero.

Conclusions

We interpret these data to indicate that there appears to be no significant year-to-year differences in allele frequencies among natural-origin or broodstock collections, nor are there observed differences between collections pre- and post-supplementation. As a result, we accept the null hypothesis that the allele frequencies of the broodstock collections equal the allele frequencies of the natural collections, which equals the allele frequency of the donor population. Furthermore, the observed genetic variance that can be attributed to among collection differences was negligible.

Task 3 - Calculate N_e using the temporal method for multiple samples from the same location to document trend.

The fundamental parameter for inferring N_e using genetic data is the standardized variance in allele frequency ($\hat{F}$) (Pollack 1983). Methods estimate N_e from observed changes in $\hat{F}$ over temporally replicated collections from the same location. Yet, as previously shown, there were no statistically significant differences detected in allele frequencies. The underlying model for estimating N_e produced estimates with extremely large variances, given small temporal differences in $\hat{F}$, which rendered any trend in N_e unobservable. Table 3 shows N_e estimates calculated using temporally replicated natural collections.

Task 4 - Compare N_e estimates with trend in census size for Lake Wenatchee sockeye.

See Task 3

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Table 1 Lake Wenatchee sockeye collections analyzed. MNA is the mean number of alleles per locus, Hz is unbiased heterozygosity, Obs Hz is observed heterozygosity, and HW is the p-value of the null hypothesis of random association of alleles (i.e., Hardy – Weinberg equilibrium). For reference, the nominal level of statistical significance at $\alpha = 0.05$ is 0.0002 after correction for multiple tests.

Year	Collection Code	Tissue Type	Source	N	MNA	Hz	Obs Hz	HW
1989	89[1]	Scales	Natural	96	14.35	0.792	0.791	0.424
1990	90[1]	Scales	Natural	96	13.19	0.793	0.779	0.131
2000	00AAE	Scales	Broodstock	96	12.31	0.787	0.776	0.213
2000	00[1]	Scales	Natural	96	11.76	0.801	0.826	0.868
2001	01AAS	Scales	Broodstock	53	9.47	0.788	0.793	0.392
2001	01[1]	Scales	Natural	96	14.35	0.786	0.794	0.456
2002	02[1]	Scales	Natural	96	14.53	0.794	0.777	0.780
2004	04[1]	Scales	Natural	96	14.65	0.798	0.803	0.704
2004	04AAV	Scales	Broodstock	43	14.35	0.796	0.795	0.051
2006	06CN	Tissue	Broodstock	38	14.59	0.793	0.785	0.688
2006	06CO	Tissue	Natural	96	14.53	0.806	0.803	0.408
2007	07EE	Tissue	Broodstock	18	14.00	0.790	0.790	0.221
2007	07EF	Tissue	Natural	96	14.35	0.789	0.800	0.347

[1] Samples taken from scale cards provided by Jeff Fryer (CRITFC)

Table 2 Allelic differentiation for Lake Wenatchee sockeye collections. A single analysis tested (pairwise) the allelic differentiation between all thirteen collections; however p-values for G-statistics are partitioned in the table by A) natural-origin, B) broodstock, and C) natural versus broodstock. Underlined values are for paired natural-broodstock collections from the same year. For reference, the nominal level of statistical significance at α = 0.05 is 0.0006 after correction for multiple tests. No significant values were observed.

A) Natural-Origin Collections

	89	90	00	01	02	04	06CO	07EF
89		0.257	0.359	0.531	0.331	0.127	0.031	0.263
90			0.953	0.148	0.753	0.903	0.077	0.283
00				0.328	0.527	0.607	0.604	0.400
01					0.209	0.081	0.127	0.093
02						0.085	0.707	0.235
04							0.312	0.577
06CO								0.435
07EF								

B) Broodstock Collections

	00AAE	01AAS	04AAV	06CN	07EE
00AAE		0.189	0.090	0.008	0.058
01AAS			0.122	0.020	0.116
04AAV				0.008	0.031
06CN					0.326
07EE					

C) Natural vs. Broodstock

	89	90	00	01	02	04	06CO	07EF
00AAE	0.027	0.309	<u>0.572</u>	0.018	0.041	0.012	0.093	0.040
01AAS	0.115	0.471	0.160	<u>0.219</u>	0.519	0.049	0.654	0.133
04AAV	0.136	0.219	0.210	0.423	0.208	<u>0.328</u>	0.037	0.153
06CN	0.029	0.004	0.053	0.007	0.022	0.004	<u>0.019</u>	0.001
07EE	0.099	0.229	0.053	0.015	0.093	0.178	0.090	<u>0.037</u>

Table 3 Estimation of N_e for temporally replicated natural-original sockeye collections. Above the diagonal are pairwise estimates of N_e, where negative values mean sampling variance can account for genetic variance observed (i.e., genetic drift unnecessary). Below the diagonal are variances for pairwise estimates of N_e. Absent variance values (denoted by **-**) were too large for SalmonNb to display.

Collection	89	90	00	01	02	04	06CO	07EF
89		-3936.6	-1414	-2636.3	671.4	1871.1	1066.1	1951.2
90	2.59E+09		-1490.3	3649.1	-31144	-6808.4	817.6	93190.2
00	1.40E+09	4.45E+09		-592.2	-6842.2	-667.1	-1736.9	-1350.1
01	1.21E+09	1.47E+09	2.33E+09		977.1	6160.4	387.8	2531.5
02	1.91E+09	1.33E+09	1.16E+09	2.29E+09		1495.6	-848.5	3213.6
04	2.21E+09	3.62E+09	4.08E+09	1.27E+09	1.14E+09		896.6	2155.3
06CO	1.34E+09	1.39E+09	1.73E+09	**-**	4.51E+09	1.2E+09		3278.6
07EF	2.15E+09	1.51E+09	1.18E+09	1.68E+09	**-**	1.36E+09	2.65E+09	

Appendix J

Wenatchee Spring Chinook Redd Estimates, 2016

Spring Chinook Redd Estimates - 2016

Upper Wenatchee

Kevin See

December 22, 2016

Goals

Redd counts are an established method to provide an index of adult spawners (Gallagher et al. 2007). In the Wenatchee subbasin, spawning reaches are surveyed weekly during the spring Chinook spawning season (Jul 25, 2016 - Oct 03, 2016). The goals of this work are to:

- Estimate the true number of redds in each spawning reach with uncertainty.
- Summarize the number of redds at the tributary and population scale.

Methods

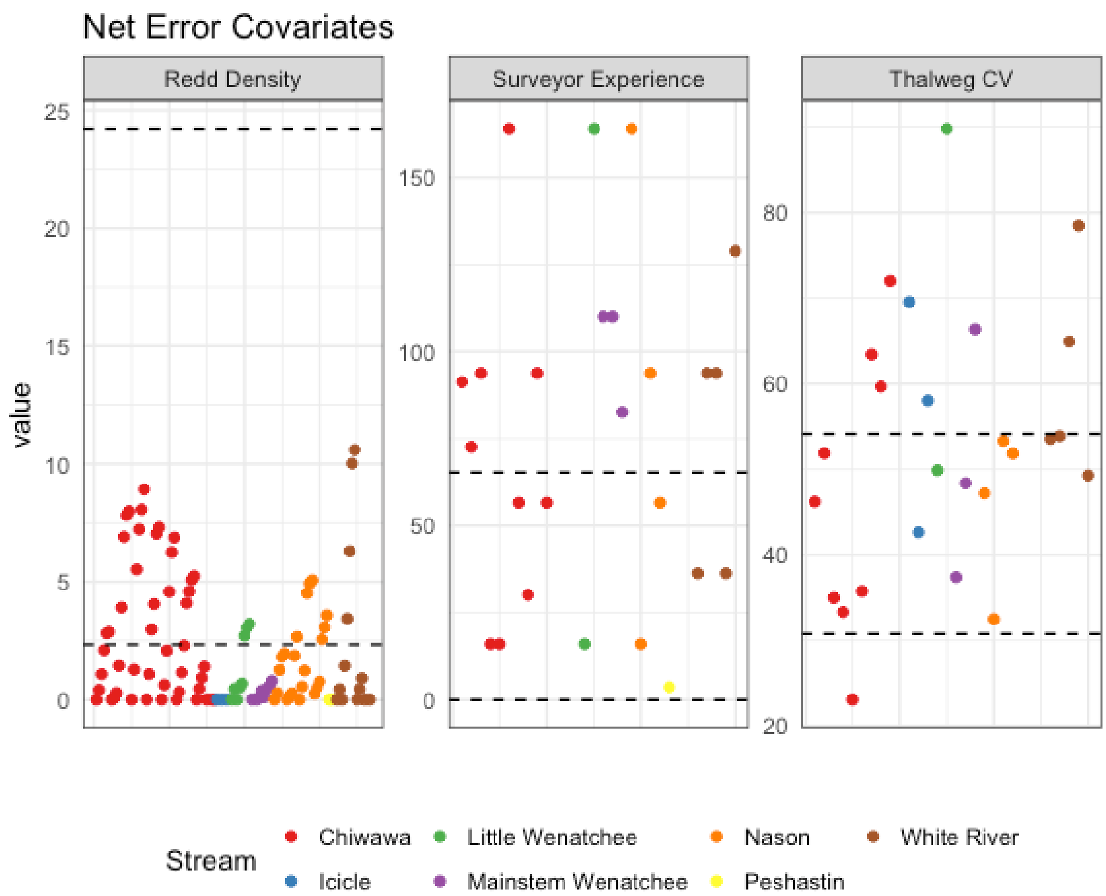
Data

Data were collected on the number of new redds during each survey (usually conducted about every week during the spawning season). Covariates such as surveyor experience, mean thalweg CV, and redd density (observed redds / km) were also collected on the reach scale to make predictions of surveyor error.

Surveyor Error

From the results of a previous study on spring Chinook, similar to the one outlined in Murdoch et al. (2014) for steelhead, we had a model that predicted surveyor net error (ratio of identified redds to true redds) based on covariates such as the surveyor's total experience with spawning ground surveys, the mean thalweg CV, and the observed redd density (redds/km). This model suggests that increasing experience and observed redd density lead to higher net error, while increasing the stream complexity (mean thalweg CV) leads to lower net error.

Because the net error model is a linear model, and therefore not constrained to be between 0 and 1 (less than 1 implies an underestimate of the number of redds, while net error greater than 1 implies an overestimate due to false identifications), we examined the values of the predictive covariates and compared them to the values used to fit the net error model. Several values were outside the range of the model dataset (See Figure 1). However, using those more extreme values did not result in absurd predictions of observer error, so we did not alter or constrain them.



Values of the covariates for the net surveyor error model, colored by stream. Dashed lines depict the range of values from the data set used to develop the net error model.

Total Redds

Estimates of total redds were made for each reach using the Gaussian area under the curve (GAUC) model described in Millar et al. (2012). The GAUC model was developed with spawner counts in mind. As it is usually infeasible to mark every individual spawner, only total spawner counts can be used, and an estimate of average stream life must be utilized to translate total spawner days to total unique spawners. However, in adapting this for redd surveys, individual redds can be marked, and therefore we fit the GAUC model to new redds only. The equivalent of stream life thus becomes the interval between surveys. However, this year surveys were unable to be conducted during several weeks coinciding with peak spawning in the Chiwawa. Therefore, to fit the GAUC model, we used survey number instead of Julian day, and set the survey interval to one. We fit these models to reach-scale data, which did pose several challenges for a few reaches. We did not make

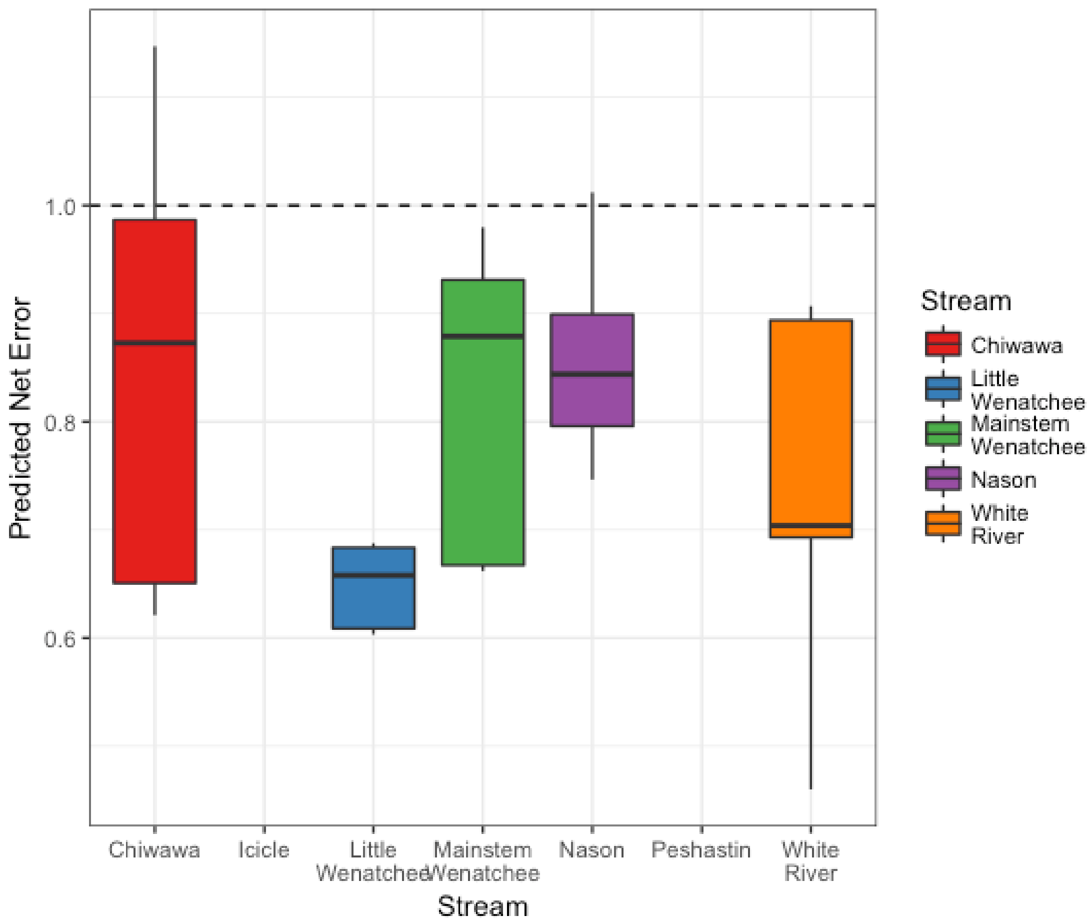
GAUC estimates for reaches that had fewer than 2 observed redds, or less than 3 weeks with at least one new redd observed.

When summing GAUC estimates at the reach-scale to obtain estimates at the stream scale, an attempt was made to incorporate the fact that the reaches within a stream are not independent. Estimates of correlation between the reaches within a stream were made based on weekly observed redds. This method may not be perfect, since spawners may use certain reaches preferentially at different times in the season, but it may be the best we can do. Because correlations are often quite high between reaches, this is a better alternative than to naively assume the standard errors between reaches are independent of one another. These estimates of correlation were combined with GAUC estimates of standard error for each reach to calculate a covariance matrix for the reaches within each stream, which was used when summing estimates of total redds to estimate the standard error at the stream-scale. Failure to incorporate the correlations between reaches would result in an underestimate of standard error at the stream scales. Different streams (and therefore reaches in different streams) were assumed to be independent.

Results

Surveyor Error

Predictions of net error are shown in Figure 2. Most predictions were less than one, implying some redds may have been missed. A few surveys had predictions of net error greater than one, implying some redds identified by surveyors were false redds.



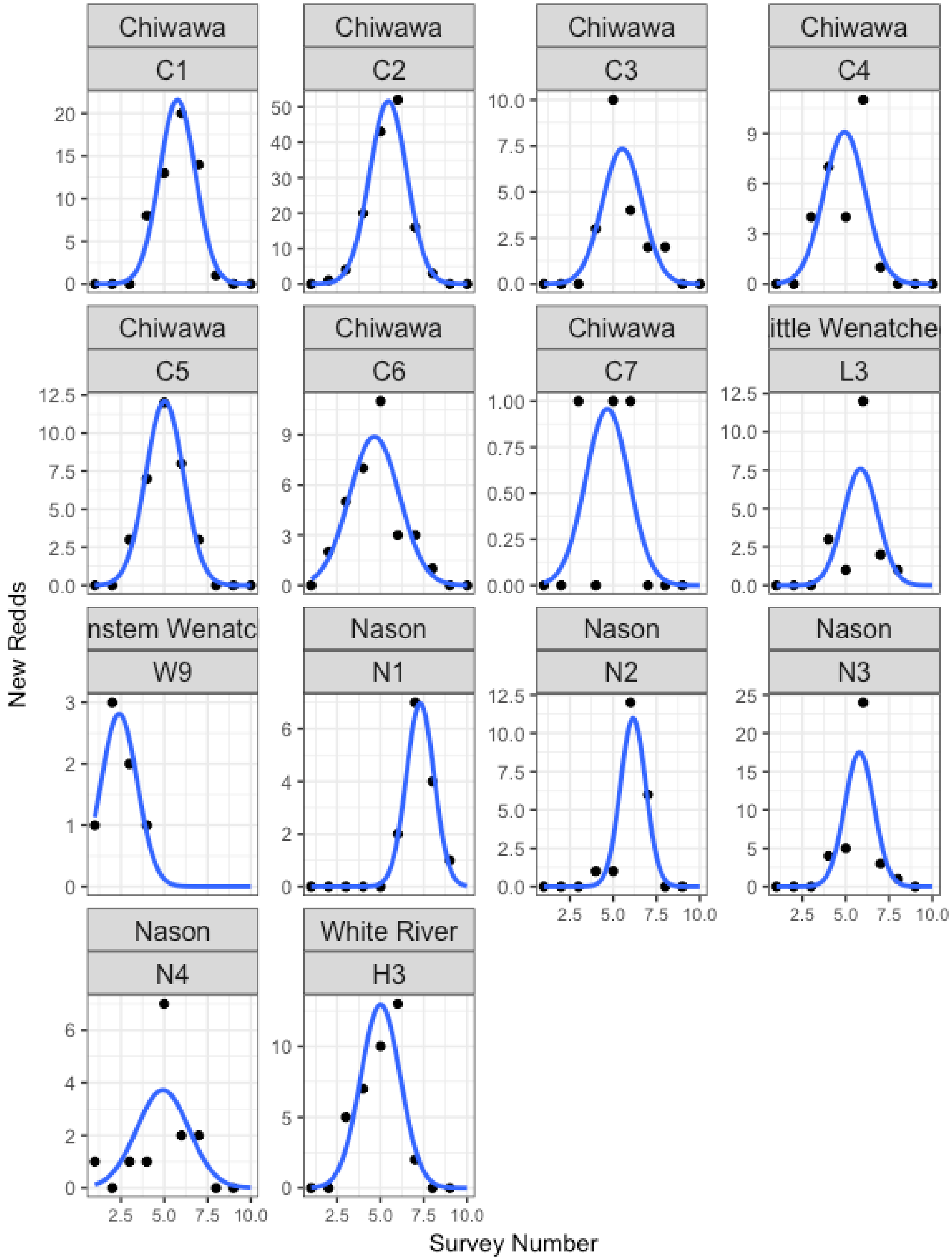
Boxplots showing predicted net error by stream. Dashed line shows no error.

Total Redds

Redds were estimated at the reach scale using the GAUC method whenever possible, and simply dividing the total number of observed redds by the predicted net error when not. For a few small tributary reaches, no estimates of observer error were made and instead the small number of observed redds was assumed to be observed without error. The estimates at the reach scale are displayed in Table 1. The curves that were fit in the GAUC process are shown in Figure 3. The results are summarized at the stream and population scale in Table 2.

Table 1: Estimates of total redds by reach.

Stream	Reach	Type	GAUC	Obs. Redds	Mean Net Error	Est. Redds	SE	CV
Chiwawa	C1	Major	Y	56	0.88	64	9.04	0.14
Chiwawa	C2	Major	Y	139	0.82	170	16.22	0.10
Chiwawa	C3	Major	Y	21	1.02	21	4.64	0.22
Chiwawa	C4	Major	Y	27	0.88	31	6.93	0.22
Chiwawa	C5	Major	Y	33	0.97	34	3.12	0.09
Chiwawa	C6	Major	Y	32	1.13	28	4.97	0.18
Chiwawa	C7	Major	Y	3	0.65	5	1.80	0.36
Chiwawa	K1	Minor	N	1	--	1	--	--
Chiwawa	R1	Minor	N	0	--	0	--	--
Chiwawa	S1	Minor	N	0	--	0	--	--
Icicle	I1	Minor	N	2	--	2	--	--
Icicle	I2	Minor	N	61	--	61	--	--
Icicle	I3	Minor	N	9	--	9	--	--
Little Wenatchee	L2	Major	N	3	0.69	4	1.33	0.33
Little Wenatchee	L3	Major	Y	19	0.61	31	13.43	0.43
Mainstem Wenatchee	A1	Minor	N	2	--	2	--	--
Mainstem Wenatchee	W10	Major	N	8	0.88	9	3.17	0.35
Mainstem Wenatchee	W9	Major	Y	7	0.67	11	2.30	0.21
Nason	N1	Major	Y	14	1.00	14	2.24	0.16
Nason	N2	Major	Y	20	0.85	23	5.94	0.26
Nason	N3	Major	Y	37	0.82	45	10.93	0.24
Nason	N4	Major	Y	14	0.76	18	7.17	0.40
Peshastin	D1	Minor	N	0	--	0	--	--
Peshastin	P1	Minor	N	0	--	0	--	--
Peshastin	P2	Minor	N	2	--	2	--	--
White River	H2	Major	N	4	0.69	6	1.86	0.31
White River	H3	Major	Y	37	0.85	43	8.14	0.19
White River	H4	Major	N	2	0.70	3	1.27	0.42
White River	Q1	Minor	N	1	--	1	--	--
White River	T1	Minor	N	0	--	0	--	--



Observed new redds by survey number and reach. Blue curve depicts the GAUC fitted curve.

Table 2: GAUC results at stream and population scale. Mean net error is the mean of net error estimates, weighted by the number of observed redds in each reach.

Stream	Obs. Redds	Mean Net Error	Est. Redds	Std. Err.	CV
Chiwawa	312	0.89	354	41.30	0.12
Icicle	72	--	72	0.00	0.00
Little Wenatchee	22	0.62	35	13.43	0.38
Mainstem Wenatchee	17	0.78	22	2.30	0.10
Nason	85	0.85	100	19.58	0.20
Peshastin	2	--	2	0.00	0.00
White River	44	0.83	53	8.14	0.15
Total	554	--	638	48.38	0.08

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Millar, R., S. McKechnie, and C. Jordan. 2012. Simple estimators of salmonid escapement and its variance using a new area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences 69:1002–1015.

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Appendix K

Genetic Diversity of Chiwawa River Spring Chinook Salmon

Assessing the Genetic Diversity of Natural Chiwawa River Spring Chinook Salmon and Evaluating the Effectiveness of its Supportive Hatchery Supplementation Program

Developed for

Chelan County PUD

and the

Habitat Conservation Plan's Hatchery Committee

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Table of Contents

Executive Summary

The main objective of this study was to determine the potential impacts of the Chiwawa River Supplementation Program on natural spring Chinook in the upper Wenatchee system. We did this by investigating population differentiation between temporally replicated Chiwawa River natural and hatchery samples from the Wenatchee River watershed using microsatellite DNA allele frequencies and the statistical assignment of individual fish to specific populations. Additionally, to assess the genetic effect of the hatchery program, we investigated the relationship between census and effective population sizes using collections obtained before and after the supplementation program. In this summary, we briefly describe the salient results contained within this report; however, each "Task" within the Results/Discussion section below contains extended coverage for each topic along with an expanded interpretation of each result.

Overall, we observed substantial genetic diversity within collections, with heterozygosities equal to roughly 80%, over thirteen microsatellite markers. Microsatellite allele frequencies among temporally replicated collections from the same population (i.e., location) were variable, resulting in significant genetic differentiation among these collections. However, these difference are likely the result of salmon life history in this area, as four-year-old Chinook comprise a majority of returns each year. That is, the genetic tests are detecting the differences of contributing parents from each cohort, rather than a hatchery effect.

Analysis of Chiwawa River Collections

To assess the multiple competing hypotheses regarding population differentiation within and among Chiwawa River collections, we found it necessary to organized the Chiwawa genetic data into three data sets: (1) fish origin (hatchery versus natural), (2) spawning location (hatchery broodstock versus in-river (natural) spawners), and (3) four "treatment" groups (1. hatchery-origin hatchery broodstock, 2. hatchery-origin natural spawner, 3. natural-origin natural spawner, and 4. natural-origin hatchery broodstock). We conducted separate analyses using each of the three data sets, with each analysis

touching on some aspect of the components necessary to move through the Conceptual Process outlined by Murdoch and Peven (2005).

Origin Dataset – We report that allele frequencies within and between natural- and hatchery-origin collections are significantly different, but there does not appear to be a robust signal indicating that the recent natural-origin collections have diverged greatly from the pre- or early post-supplementation collections. Genetic drift will occur in all populations, but does not appear to be a major factor affecting allele frequencies within the Chiwawa collections.

Spawning Location Dataset – There are significant allele frequency differences within and between hatchery broodstock and natural spawner collections. However, in recent years the allele frequency differences between the hatchery broodstock and natural spawner collections have declined. Furthermore, based on linkage disequilibrium, there is a genetic signal that is consistent with increasing homogenization of allele frequencies within hatchery broodstock collections, but a similar homogenization within the natural spawner collection is not apparent. These data suggest that there exists consistent year-to-year variation in allele frequencies among hatchery and natural spawning collections, but there is a trend toward homogenization of the allele frequencies of the natural- and hatchery-origin fish that compose the hatchery broodstock.

Four Treatment dataset – Although there are signals of allelic differentiation among Chiwawa River collections, there are no robust signs that these collections are substantially different from each other. We used two different analyses to measure the degree of genetic variation that exists among individuals and collections within the Chiwawa River. First, we conducted a principal component analysis using all Chiwawa samples with complete genotypes (i.e., no missing alleles from any locus). Although the first two principal component axes account for only 10.5% of the total molecular variance, a substantially greater portion of that variance is among individual fish, regardless of their identity, rather than among hatchery and natural collections. The variances in principal component scores among individuals are 11 and 13 times greater than the variance in scores among collections.

Secondly, using an Analysis of Molecular Variance (AMOVA), we were able to determine how best to group populations, with "best" being defined as that grouping that accounts for the greatest proportion of among group (i.e., population) variance. Furthermore, by partitioning molecular variance into different hierarchical components, we are able to determine what level accounts for the majority of the molecular variance. The AMOVA results clearly show that nearly all molecular variation, no matter how the data are organized, resides within a collection. The percentage of total molecular variance occurring within collections ranged from 99.68% to 99.74%. These results indicate that the significant differences among collections of Chiwawa fish account for less than one percent of the total molecular variance, and these differences cannot be attributed to fish origin or spawning location.

Effective Population Size (N_e)

The contemporary estimate of N_e calculated using genetic data combined for Chiwawa natural-origin spawners (NOS) and hatchery-origin spawners (HOS) Chinook is N_e=386.8, which is slightly larger than the pre-hatchery N_e we estimated using demographic data from 1989 – 1992. Additionally, the N_e /N ratio calculated using 386.8 for N_e and the arithmetic mean yearly census of NOS and HOS Chinook from 1989 – 2005 for N is 0.40. These results suggest the N_e has not declined during the period of Chiwawa Hatchery Supplementation Program operation.

Analysis Of Upper Wenatchee Tributary Collections

We compared genetic data for spring Chinook collected from the major spawning aggregates of the Wenatchee River. We observed significant differences in allele frequencies among temporally replicated collections within populations, and among populations within the upper Wenatchee. However, these differences account for a very small portion of the overall molecular variance, and these populations overall are very similar to each other. Of all the populations within the Wenatchee River, the White River appears to be the most distinct. Yet, this distinction is more a matter of detail than of large significance, as the median F_{ST} between White River collections and all other collections (except the Little Wenatchee collection; see Results/Discussion) is less than 1.5% among population variance. We consider the implications of these results in the Conclusion section that follows the Results/Discussion section. Additionally, there is no evidence that the Chiwawa River Supplementation Program has changed the allele frequencies in the Nason Creek and White River populations, despite the presence of hatchery-origin fish in both these systems.

Introduction

Murdoch and Peven (2005) outlined 10 objectives to assess the impact (positive or negative) of hatchery operations mitigating the operation of Rock Island Dam. Two objectives relate to monitoring the genetic integrity of populations:

Objective 3: Determine if genetic diversity, population structure, and effective population size have changed in natural spawning populations as a result of the hatchery program. Additionally, determine if hatchery programs have caused changes in phenotypic characteristics of natural populations.

Objective 5: Determine if the stray rate of hatchery fish is below the acceptable levels to maintain genetic variation between stocks.

This study addresses Objective 3 (above), and documents analyses and results WDFW completed for populations of spring Chinook (*Oncorhynchus tshawytscha*) in the Wenatchee River watershed. This study was not intended to specifically address Objective 5 (above); however, genetic data provide results relevant to Objective 5. The critical component of Objective 3 is to determine if hatchery supplementation has effected change. Furthermore, change in this context means altering census size and/or genetic marker allele frequencies; we did not attempt to measure changes in fitness. Perhaps a more meaningful rewording of Objective 3 is, "Did the hatchery supplementation program succeed at increasing the census size of a target population while leaving genetic integrity intact?" In order to evaluate cause and effect of hatchery supplementation, we surveyed and compared genetic variation in samples collected before and after potential effects from the Chiwawa Hatchery Supplementation Program. Samples were acquired from the primary spawning aggregates in the upper Wenatchee River watershed: Nason Creek, Little Wenatchee River, White River, and Chiwawa River. Hatchery samples were acquired from programs that could potentially affect genetic composition of Wenatchee stocks, the integrated Chiwawa River stock (local stock), Leavenworth National Fish Hatchery spring Chinook (Carson Stock – non local), and Entiat NFH (Carson Stock – non local). Additionally, the genetic markers used were the Genetic Analysis of Pacific Salmonids (GAPS) (Seeb et al. in review) standardized microsatellites, so all data from the Wenatchee study will be available for inclusion in the GAPS Chinook coastwide microsatellite baseline.

History of Artificial Propagation

Artificial propagation in the upper Columbia River began in 1899 when hatcheries were constructed on the Wenatchee and Methow rivers (Mullan 1987). These initial operations were small, with the Tumwater Hatchery on the Wenatchee River releasing several hundred thousand fry, and the Methow River hatchery producing few Chinook salmon before it was closed in 1913 (Craig and Suomela 1941, Nelson and Bodle 1990). The Leavenworth State Hatchery operated in the Wenatchee River Basin between 1913 and 1931 using eggs from non-native stocks (Willamette River spring-run and lower Columbia Chinook hatchery fall-run). These early attempts at hatchery production were largely unsuccessful for spring-run Chinook (WDF 1934). Between 1931 and 1939, no Chinook salmon hatcheries were in operation above Rock Island Dam (Rkm 730).

In 1938, the last salmon was allowed to pass upstream through the uncompleted Grand Coulee Dam (Rkm 959). To mitigate the loss of habitat, adult Chinook salmon were trapped, under the auspices of the Grand Coulee Fish Maintenance Project (GCFMP), at Rock Island Dam beginning in May 1939, and relocated into three of the remaining accessible tributaries to the upper Columbia River: the Wenatchee, Entiat, and Methow Rivers. GCFMP transfers continued through the autumn of 1943. Spring- and summer/fall-run fish were differentiated at Rock Island Dam based on a 9 July cutoff date for Chinook arrivals at Rock Island Dam (Fish and Hanavan 1948). Spring-run adults collected at Rock Island Dam (pre 9 July fish) were either transported to Nason Creek on the Wenatchee River to spawn naturally (1939-43), or to the newly constructed Leavenworth NFH (1940) for holding and subsequent spawning (1940-43). Eggs were incubated on site or transferred to the Entiat NFH (1941) and Winthrop NFH (1941). In 1944 spring-run adults were allowed to freely pass Rock Island Dam. The GCFMP did not differentiate among late-run stocks (post 9 July fish) passing Rock Island Dam. Late-run offspring reared at the Leavenworth NFH, Entiat NFH, and Winthrop NFHs were an amalgamation of summer and fall upper Columbia River populations (Fish and Hanavan 1948). Late-run fish were transplanted into the upper and lower Wenatchee, Methow, and Entiat Rivers.

After 1943, the Winthrop NFH continued to use local spring-run Chinook for hatchery production, while the other NFHs largely focused on summer-run Chinook salmon. Renewed emphasis on spring run production in the mid-1970s saw the inclusion of local and non-local eggs (Carson NFH stock, Klickitat River stock, and Cowlitz River stock) to the NFHs. In the early 1980s, imports of non-native eggs were reduced significantly, and thereafter the Leavenworth, Entiat, and Winthrop NFHs have relied on adults returning to their facilities for their egg needs (Chapman et al. 1995). Regarding late-run Chinook, due to the variety of methods employed to collect broodstock at dams, hatcheries, or the result of juvenile introductions into various areas, Chinook populations and runs (i.e., summer and fall) have been mixed considerably in the upper Columbia system over the past five decades (reviewed in Chapman et al. 1994).

Washington Department of Fish and Wildlife (WDFW) operates two facilities producing spring-run Chinook, the Methow Fish Hatchery (MFH) owned by Douglas County PUD that began operation in 1992 and Eastbank Fish Hatchery (EFH) owned by Chelan County PUD that began operation in 1989. Both programs were designed to implement supplementation (supportive breeding) programs for naturally spawning populations on the Methow and Wenatchee Rivers, respectively (Chapman et al. 1995). As part of the Rock Island Mitigation Agreement between Chelan County Public Utility District and the fishery management parties (RISPA 1989), a supplementation (supportive breeding) program was initiated in 1989 on the Chiwawa River to mitigate smolt mortality resulting from the operation of Rock Island Hydroelectric Project. EFH uses broodstock collected at a weir on the Chiwawa River, although in recent years hatchery fish have been collected at Tumwater Dam. Similarly, the MFHC uses returning adults collected at weirs on the Methow River and its tributaries, the Twisp and Chewuch Rivers (Chapman et al. 1995; Bugert 1998). Although low run size and trap efficiency has resulted in most broodstock being collected from the hatchery outfall or in some years Wells Dam, progeny produced from these programs are reared at and released from satellite sites on the tributaries where the adults were collected. Numerous other facilities have reared spring-run Chinook salmon on an intermittent basis.

Previous Genetic Studies – Population differentiation

Waples et al. (1991a) examined 21 polymorphic allozyme loci in samples from 44 populations of Chinook salmon in the Columbia River Basin. These authors reported three major clusters of Columbia River Basin Chinook salmon: 1) Snake River spring- and summer-run Chinook salmon, and mid and upper Columbia River spring-run Chinook salmon, 2) Willamette River spring-run Chinook salmon, 3) mid and upper Columbia River fall- and summer-run Chinook salmon, Snake River fall-run Chinook salmon, and lower Columbia River fall- and spring-run Chinook salmon. Utter et al. (1995) examined allele frequency variability at 36 allozyme loci in samples of 16 upper Columbia River Chinook populations. Utter et al. (1995) indicated that spring-run populations were distinct from summer- and fall-run populations, where the average genetic distance between spring-run and late-run Chinook were about eight times the average of genetic distances between samples within each group. Additionally, allele frequency differences among spring-run populations were considerably greater than that among summer- and fall-run populations in the upper Columbia River. Utter et al. (1995) also reported hatchery populations of spring-run Chinook salmon were genetically distinct from natural spring-run populations, but hatchery populations of fall-run Chinook salmon were not genetically distinct from natural fall-run populations.

As part of an evaluation of the relative reproductive success for the Chiwawa River supplementation program, Murdoch et al. (2006), used eleven microsatellite loci to assess population differentiation among spring Chinook salmon population samples in the upper Wenatchee River. Murdoch et al. (2006) reported a >99% accuracy of correctly identifying spring-run and fall-run Chinook from the Wenatchee River. They also reported slight, but significantly different genetic variation among wild spring populations and between wild and hatchery stocks. Yet, since the spring-run populations are genetically similar, identifying individuals genetically from the upper tributaries of the Wenatchee River was difficult. This result is exemplified in their individual assignment results, where < 8% of spring-run individuals, hatchery or wild, were correctly assigned using their criterion of an LOD (log of odds) score greater than 2. Murdoch et al. (2006) also reported contemporary natural spring Chinook show heterozygote deficit and low linkage disequilibrium (LD), while contemporary hatchery spring Chinook show heterozygote excess and high LD.

Williamson et al. (submitted) have continued the work of Murdoch et al. (2006) by analyzing Chiwawa River demographic data from 1989 – 2005 to estimate the proportions of recruits that were produced by Chinook with hatchery or wild origin. In an "ideal" population, the genetic size (i.e., effective size or N_e) and the census size are equal; however various demographic factors such as unequal sex ratios and variance in reproductive success among individuals reduces the genetic size below the census size. It is generally thought that the genetic size is approximately 10-33% the census size (Bartley et al. 1992; RS Waples pers. comm.), although values have been reported outside this range (Araki et al. 2007; Arden and Kapuscinski 2003; Heath et al. 2002). Despite being difficult to estimate, the effective population size in many respects is a more important parameter to know than census size, because N_e determines how genetic diversity is distributed within populations and how the forces of evolution (i.e., forces that change genetic diversity over time) will affect the genetic variation present.

Williamson et al. (submitted) used demographic data to 1) investigate the effect of unequal sex ratio on genetic diversity, 2) investigate the effect of variation in reproductive success on genetic diversity, 3) investigate the effect of fluctuations in population size on genetic diversity, and 4) estimate the effective population size, using the inbreeding method (Ryman and Laikre 1991). Most importantly, they use demographic data from 1989 – 2000 to assess the impact of the Chiwawa Hatchery Supplementation Program on the effective population size of natural-origin Chiwawa River spring Chinook. They estimate that the N_e of naturally spawning Chiwawa Chinook (i.e., both hatchery- and wild-origin fish on the spawning grounds) from 1989 –

1992 was N_e = 2683 and in 1997 – 2000 was N_e = 989. They compare spawning ground N_e to estimates calculated from combined broodstock and naturally spawning Chinook demographic data. The combined inbreeding N_e estimate from 1989 – 1992 was N_e = 147 and in 1997 – 2000 was N_e = 490. Williamson et al. (submitted) argue that since the combined N_e estimate is lower than the naturally spawning estimate, the supplementation program has had a negative impact on the Chiwawa River N_e.

Williamson et al. (submitted) also present genetic data for Chinook recovered on spawning grounds in upper Wenatchee River tributaries in 2004 and 2005. These genetic data are derived from the Murdoch et al. (2006) study. They compare samples collected from Chiwawa River (i.e., hatchery and wild), White River, Nason Creek, and Leavenworth Hatchery. Additionally, they include a 1994 Chiwawa River wild smolt sample for comparison with the 2004 brood year. Williamson et al. (submitted) report statistically significant genetic differentiation among Chiwawa River, White River and Nason Creek. Additionally, they report that the 1994 and 2004 Chiwawa River wild samples are not statistically different, but the 2004 Chiwawa wild and hatchery collections are statistically different.

Study Objectives

This study investigated within and among population genetic diversity to assess the effect of the Chiwawa Hatchery's supplemental program on the natural Chiwawa River spring Chinook population. Differences among temporal population samples, the census size, heterozygosity, and allelic diversity were documented. We investigated population differentiation between the Chiwawa River natural and hatchery samples, and among all temporally replicated samples from the Wenatchee River watershed using microsatellite DNA allele frequencies and the statistical assignment of individual fish to specific populations. To assess the genetic effect of the hatchery program, correlation between census and effective population sizes were investigated using temporally replicated samples obtained before and after the supplementation program operation. To address the hypotheses associated with Objective 3 in Murdock and Peven (2005) we developed eleven specific "Tasks" (Blankenship and Murdoch 2006), to which we analyzed specific genetic data. We present the results from these analyses specific to each individual Task.

Methods and Materials

Tissue collection and DNA extraction

We analyzed thirty-two population collections of adult spring Chinook salmon (*Oncorhynchus tshawytscha*) obtained from the Wenatchee River between 1989 and 2006 (Table 1). Nine collections of natural Chinook adults from the Chiwawa River (n=501), and nine collections of Chiwawa Hatchery Chinook (n=595) were collected at a weir located in the lower Chiwawa River. The 1993 and 1994 Chiwawa Hatchery samples are smolt samples from the 1991 and 1992 hatchery brood years, respectively. Additional samples were collected from upper Wenatchee River tributaries, White River, Little Wenatchee River, and Nason Creek. Six collections of natural White River Chinook (n=179), one collection from the Little Wenatchee (n=19), and six collections from Nason Creek (n=268) were obtained. Single collections were obtained for Chinook spawning in the mainstem Wenatchee River and Leavenworth National Fish Hatchery. An additional out-of-basin collection from Entiat River was also included in the analysis. Samples collected in 1992 or earlier are scale samples. All other samples were either fin clips or operculum punches, stored immediately in ethanol after collection. DNA was extracted from stored tissue using Nucleospin 96 Tissue following the manufacturer's standard protocol (Macherey-Nagel, Easton, PA, U.S.A.).

Laboratory analysis

We performed polymerase chain reaction (PCR) amplification on each fish sample using the 13 fluorescently end-labeled microsatellite marker loci standardized as part of the GAPS project (Seeb et al. in review). GAPS genetic loci are: *Ogo*2, *Ogo*4 (Olsen et al. 1998); *Oki*100 (unpublished); *Omm*1080 (Rexroad et al. 2001); *Ots*201b (unpublished); *Ots*208b, *Ots*211, *Ots*212, and *Ots*213 (Grieg et al. 2003); *Ots*3M, *Ots*9 (Banks et al.

1999); *Ots*G474 (Williamson et al. 2002); *Ssa*408 (Cairney et al. 2000). PCR reaction volumes were 10 µL, and contained 1 µL 10x PCR buffer (Promega), 1.0 µL MgCl2 (1.5 mM final) (Promega), 0.2 µL 10 mM dNTP mix (Promega), and 0.1 units/mL Taq DNA polymerase (Promega). Loci were amplified as part of multiplexed sets, so primer molarities and annealing temperatures varied. Multiplex one had an annealing temperature of 50°C, and used 0.37 Molar (M) *Oki*100, 0.35 M *Ots*201b, and 0.20 M *Ots*208b, and 0.20 M *Ssa*408. Multiplex two had an annealing temperature of 63°C, and used 0.10 M *Ogo*2, and 0.25 M of a non-GAPS locus (*Ssa* 197). Multiplex three had an annealing temperature of 56°C, and used 0.18 M *Ogo*4, 0.18 M *Ots*213, and 0.16 M *Ots*G474. Multiplex four had an annealing temperature of 53°C, and used 0.26 M *Omm*1080, and 0.12 M *Ots*3M. Multiplex five had an annealing temperature of 60°C, and used 0.30 M *Ots*212, 0.20 M *Ots*211, and 0.10 M *Ots*9. Thermal cycling was conducted on either a PTC200 thermal cycler (MJ Research) or GeneAmp 9700 (Applied Biosystems) as follows: 95°C (2 min); 30 cycles of 95°C for 30 sec., 30 sec. annealing, and 72°C for 30 sec.; a final 72°C extension and then a 10°C hold. PCR products were visualized by electrophoresis on an ABI 3730 automated capillary analyzer (Applied Biosystems). Fragment analysis was completed using GeneMapper 3.7 (Applied Biosystems). Standardization of genetic data to GAPS allele standards was conducted following Seeb et al. (in review).

Genetic data analysis

Assessing within population genetic diversity - Heterozygosity measurements are reported using Nei's (1987) unbiased gene diversity formula (i.e., expected heterozygosity) and Hedrick's (1983) formula for observed heterozygosity. Both tests are implemented using the microsatellite toolkit (Park 2001). We used GENEPOP version 3.4 (Raymond and Rousset 1995) to assess Hardy-Weinberg equilibrium (HWE), where deviations from the neutral expectation of random associations among alleles are calculated using a Markov chain method (5000 iterations in this study) to obtain unbiased estimates of Fisher's exact test. Global estimates of F_{IS} according to Weir and Cockerham (1984) were calculated using GENEPOP version 3.4. Genotypic linkage disequilibrium was calculated following Weir (1979) using GENEPOP version 3.4.

Linkage results for population collections are reported as the proportion of pairwise (locus by locus) tests that are significant (alpha = 0.01). Linkage disequilibrium is considered statistically significant if more than 5% of the pairwise tests based on permutation are significant for a collection.

Within- and among-population genetic differentiation – The temporal stability of allele frequencies within populations, and pairwise differences in allele frequencies among populations were assessed using several different procedures. First, we tested for differences in allele frequencies among populations defined in Table 1 using a randomization chi-square test implemented in GENEPOP version 3.4 (Raymond and Rousset 1995). This procedure tests for differences between pairs of populations where alleles are randomized between the populations (i.e., genic test). The null hypothesis for this test is that the allele frequency distributions between two populations are the same. A low p-value should be interpreted as the allele frequency distributions being compared are unlikely to be samples drawn from the same underlying distribution.

Second, to graphically describe allele frequency differences among populations we conducted a nonmetric multidimensional scaling analysis using allele-sharing distance matrices from two different data sets. Pairwise allele-sharing distances are calculated as 1 – (mean over all loci of the sums of the minima of the relative frequencies of each allele common to a pair of populations). To calculate the allele-sharing distances for each pair of populations we used PowerMarker v3.25 (Liu and Muse 2005). Nonmetric multidimensional scaling is a technique designed to construct an n-dimensional "map" of populations, given a set of pairwise distances between populations (Manly 1986). The output from this analysis is a set of coordinates along n-axes, with the coordinates specific to the number of n-dimensions selected. To simplify our analysis we selected a 2-dimensional analysis to represent the relative positions of each population in a typical bivariate plot. The goodness of fit between the original allele-sharing distances and the pairwise distances between all populations along the 2-dimensional plot is measured by a "stress" statistic. Kruskal (in Rohlf 2002) developed a five-tier guide for evaluating stress levels, ranging from a perfect fit (stress=0) to a poor fit (stress=0.40). We conducted the nonmetric multidimensional scaling analysis for one data set containing Chiwawa natural- and hatchery-origin collections, and another data set containing Chiwawa broodstock and in-river spawner collections. We used the mdscale module in MATLAB R2006b (The Mathworks 2006) to generate the nonmetric multidimensional scaling coordinates.

We examined the geographic and temporal structure of populations in the upper Wenatchee (Chiwawa River, Nason Creek, and White River, only) using a series of analyses of molecular variance (AMOVAs). Here, we defined an AMOVA as an analysis of variance of allele frequencies, as originally designed by Cockerham (1969), but implemented in Arlequin v2.1 (Schneider et al. 2000). These analyses permit populations to be aggregated into groups, and molecular variance is then partitioned into within collections, among collections, but within groups, and among group components. With this approach, we were able to determine how best to group populations, with "best" being defined as that grouping that accounts for the greatest proportion of among group variance. Furthermore, by partitioning molecular variance into three different hierarchical components, we are able to determine what level accounts for the majority of the molecular variance.

Finally, we explored the partitioning of molecular variance between among-individuals and among-populations using a principal component analysis and multi-locus estimates of pairwise F_{ST}, estimated by a "weighted" analysis of variance (Weir and Cockerham, 1984). Principal component analysis is a data-reduction technique whereby the correlation structure among variables can be used to combine variables into a series of multivariate components, with each original variable receiving a weighted value for each component based on its correlation with that component. Here, we used a program written by Warheit in MATLAB R2006b (The Mathworks 2006) that treats each allele for each locus as a single variable (13 loci = 26 alleles or variables), and these 26 "variables" were arranged into 26 components, with each component accounting for a decreasing amount of molecular variance. Estimates of F_{ST} were calculated using GENETIX version 4.05 (Belkhir et al.1996). To determine if the F_{ST} estimates were statistically different from random (i.e., no structure), 1000 permutations were implemented in GENETIX version 4.05 (Belkhir et al.1996).

Effective population size (N_e) – Estimates of the effective population size were obtained using two methods, a multi-collection temporal method (Waples 1990), and a single-collection method (Waples 2006) using linkage disequilibrium data. The temporal method assumes that cohorts are used, but we did not decompose the collection year samples into their respective cohorts using age data. Therefore, N_e estimates that pertain to individual year classes of breeders are not valid; however the harmonic mean over all samples will estimate the contemporary N_e. Comparing samples from years *i* and *j*, Waples' (1990) temporal method estimates the effective number of breeders ($\hat{N}_{b(i,j)}$) according to:

$$\hat{N}_{b(i,j)} = \frac{b}{2(\hat{F} - 1/\hat{S}_{i,j})}$$

The standardized variance in allele frequency ($\hat{F}$) is calculated according to Pollack (1983). The parameter b is calculated analytically from age structure information and the number of years between samples (Tajima 1992). The age-at-maturity information required to calculate b was obtained from Murdoch et al. (2006) for this analysis. They observed for Chiwawa Hatchery Chinook that 8.6% matured at age 2, 4% at age 3, 87% at age 4, and 0.4% at age 5. For Chiwawa natural Chinook, Murdoch et al. (2006) observed that 1.8% matured at age 3, 81.6% at age 4, and 16.7% at age 5. The harmonic mean of sample sizes from years *i* and *j* is $\tilde{S}_{i,j}$. Over all pairwise comparisons the harmonic mean of all $\hat{N}_{b(i,j)}$ is $\tilde{N}_b$, the contemporary estimate of the effective population size (N_e). SALMONNb (Waples et al. 2007) was used to calculate $\tilde{N}_b$. As suggested by authors, alleles with a frequency below 0.05 were excluded from the analysis to reduce potential bias.

The method of Waples (2006) uses linkage disequilibrium (i.e., mean squared correlation of allele frequencies at different gene loci) as a means of estimating effective population size (N_e) from a single sample. While this method is biased in some cases where N_e /N ratio is less the 0.1 and the sample size is less than the true N_e, it has been shown to produce comparable results to the temporal method. Burrows' delta method is used to estimate LD, and a bias corrected estimate of N_e is calculated after eliminating alleles with frequency less than 0.05. This test was implemented using LDN$_e$ (Do and Waples unpublished). In age-structured species, N_e estimates based on LD are best interpreted as the effective number of breeders (N_b) that produced the sample (Waples 2006). N_b should be multiplied by the mean generation length (i.e., 4 in this case) to obtain an overall estimate of N_e based on an N_b estimate. We analyzed collections categorized by spawning location (i.e., hatchery broodstock or in-river) and did not analyze collections categorized by origin (i.e., hatchery or natural). Waples' (2006) method estimates N_e from observed LD, therefore the corresponding N_e estimates for the hatchery collections would be low and the estimates for the natural collections would be high. Yet, since the supplementation program is integrated, and hatchery fish can spawn naturally, we feel it inappropriate to analyze the hatchery and natural samples as if they were separate, which would essentially partition all the LD into the hatchery samples.

Each collection has an N_b estimate and an associated confidence interval. If the confidence interval includes infinity, it means that sampling error accounts for all the LD observed (i.e., empirical LD is less than expected LD). The usual interpretation is that there is no evidence for any disequilibrium caused by genetic drift in a finite number of parents. Since the LD method estimates the number of breeders that contributed to the sample being analyzed, in order to calculate an N_e /N ratio, the appropriate census size must be used. The census size used to derive a ratio was the estimate four years prior to the collection analyzed using LD, which assumed a strict four-year-old lifecycle, although the observed proportion of four-year-olds was approximately 85% each year. The census numbers (Table 2) used to calculate the ratios for Chiwawa broodstock and in-river spawners were combined NOS (natural-origin spawners) and HOS (hatchery-origin spawners) census estimates.

Individual assignment – A population baseline file was constructed containing all 1704 individual Chinook from 34 population collections (Table 1; Chiwawa origin data set plus all samples from other populations). All individuals in the baseline had geneotypes that included nine or more loci. Individual Chinook were assigned to their most likely population of origin based on the partial Bayesian criteria of Rannala and Mountain (1997), using a "jack-knife" procedure, where each individual to be assigned was removed from the baseline prior to the calculation of population likelihoods. This procedure was implemented in a program written by Warheit in MATLAB R2006b (The Mathworks 2006). Two assignment criteria were used, 1) the population with the largest posterior probability for an individual was the "most-likely" population of origin (i.e., all individuals assigned to a collection), and 2) an assignment was consider valid only if the posterior probability was greater than or equal to 0.9. Please note that while the analysis used 34 population collections to assign Rannala and Mountain likelihoods for each individual, these likelihoods were aggregated based on "population" (i.e., Chiwawa, Nason, White, and so on) and posterior probabilities were calculated for population location, rather than individual collections.

Results and Discussion

In this section we combine our presentation and interpretations of the genetic analyses. Additionally, this section will be organized based on the task list presented in the study plan. Overall conclusions are provided following this section.

<u>Task 1:</u> Determine trend in census size for Chiwawa River spring Chinook.

Census data from 1989 – 2005 are provided in Table 2 for the Chiwawa Hatchery broodstock and spring Chinook present in the Chiwawa River. The demographic data for naturally spawning Chinook are based on redd sampling and carcass surveys, while broodstock data are based on Chiwawa hatchery records. As the supplementation program is integrated by design, we also present the proportion of natural-origin broodstock (pNOB) incorporated into the hatchery, in addition to the number of natural-origin (NOS) and hatchery-origin (HOS) spawners present in Chiwawa River. The census size fluctuated yearly, and a general reduction in census size was observed in the mid to late 1990's. This trend was apparent in both the broodstock and in the river. The arithmetic mean census size from 1989 – 2005 for the Chiwawa Hatchery (i.e., broodstock) was N=87.5 per year. The arithmetic mean census size from 1989 – 2005 for the Chiwawa River (i.e., NOS and HOS combined) was N=961.9 per year. For collection years when adult Chiwawa hatchery-origin fish would have been absent in the Chiwawa River (1989 – 1992), the arithmetic mean of natural Chiwawa Chinook census size is N=962.7. We will use this number as the baseline census size to assess if census size has changed. We used two different values for the contemporary census size in the Chiwawa River, NOS only and NOS + HOS. Additionally, we used collection years 2002 – 2005 for the contemporary NOS and HOS estimates, as these are the most recent data and the number of years included for estimation is the same as the pre-hatchery estimate above (i.e., four years). For NOS only, the arithmetic mean census size from 2002 – 2005 was N=536.0. For total census size (i.e., NOS and HOS combined), the arithmetic mean census size from 2002 – 2005 was N=1324.0. For the demographic data presented here, the contemporary census size is larger than the census estimate derived from the years prior to hatchery operation.

<u>Task 2:</u> Document the observed genetic diversity.

Genetic Diversity Categorized By Origin

For Chiwawa River collections categorized by origin (Table 1A), substantial genetic diversity was observed, with heterozygosity estimates over all loci, having a mean of 0.80. Genetic diversity was consistent with expected Hardy-Weinberg random mating genotypic proportions for ten of the eighteen collections. Eight of the nine Chiwawa natural collections were consistent with HWE, and two of nine Chiwawa Hatchery collections were consistent with HWE. F_{IS} is observed to be slight for all Chiwawa population collections, suggesting individuals within collections do not show excessive homozygosity.

The deviations from HWE observed were generally associated with hatchery collections. The two smolt collections (i.e., 1993 and 1994) showed significant deviations from HWE, which may be a function of non-random hatchery practices involving the contributing natural-origin parental broodstocks (i.e., 1991 and 1992 cohort). Deviations from HWE in the remaining hatchery collections may be the result of few individuals being represented in the broodstock (see below).

Additionally, linkage disequilibrium (LD) was also common for Chiwawa hatchery-origin collections and minimal for Chiwawa natural-origin collections. The random association of alleles between loci (i.e., linkage equilibrium) is expected under ideal conditions. LD is observed when particular genotypes are encountered more than expected by chance. Laboratory artifacts (e.g. null alleles) or physical linkage of loci on the same chromosome can cause LD, but the LD we observed was not associated with certain locus combinations, which you would expect if either artifacts or physical linkage were the cause of LD. LD was observed for seven of the nine hatchery-origin collections. As with the deviations from HWE, the high LD in the 1993 and 1994 hatchery-origin collections may be a result of non-random hatchery practices. The substantial LD observed in the hatchery-origin adult collections (collection years 2000, 2001, 2004, and 2006) might be the result of small parental broodstock sizes contributing to those returning adults. During the mid 1990's, the Chiwawa broodstock size was low, with zero individuals collected in 1995 and 1999; so fewer individuals would be contributing to the hatchery adult returns than the natural. This idea is corroborated by the lower LD observed for the 2005 hatchery-origin collection, which had a contributing parental broodstock size in 2001 (i.e., the major contributing parental generation) approximately eight times as large as the previous few collection years (Table 2). LD reappears in the 2006 Chiwawa hatchery-origin collection, which had a contributing parental broodstock size (i.e., for the most-part, the 2002 hatchery brood year) five times lower (Table 2) than that of the 2005 collection.

While seven of nine hatchery-origin collections showed significant LD, only one natural origin collection showed LD, and for this collection, only 10% of the loci-pairs were in disequilibrium (Table 1). The fact that LD predominated in the hatchery samples, suggests that variance in reproductive success (i.e., overrepresentation of particular parents) is higher in the hatchery-origin than in natural-origin collections.

Genetic Diversity Categorized By Spawning Location

For upper Wenatchee River collections categorized by spawning location (Table 1B), substantial genetic diversity was observed, with heterozygosity estimates over all loci, having a mean of 0.79 and ranging from a low of 0.69 (1993 White River) to 0.85 (1993 Little Wenatchee). Genetic diversity was consistent with HWE for nineteen of twenty-nine population collections. For the collections that departed from HWE, seven were from the Chiwawa River, one was from Leavenworth Hatchery, one was the Wenatchee mainstem collection of hatchery-origin – naturally spawning fish, and one was from the White River. F_{IS} is observed to be slight for all population collections except the 1993 White River collection (10% heterozygote deficit) (Table 1B). Collections deviating with HWE generally correlated with collections having high LD. Twelve population collections showed a proportion of pairwise linkage disequilibrium tests (across all loci) greater than 5% (Table 1B), eight of which were Chiwawa collections.

Starting in 1996, spawning location collections are composed of both natural- and hatchery-origin samples. The LD seen in the later spawning location collections may be caused by an admixing effect (i.e., mixing two populations), where random mating has not had the chance to freely associate alleles into genotypes. Interestingly, there appears to be a trend of reducing LD through time within the broodstock collections (Table 1B), which suggests that a "homogenizing" effect is taking place within the Chiwawa River. This observation is discussed more fully in Task 3 below.

<u>Task 3:</u> Test for population differentiation among collections within the Chiwawa River and associated supplementation program.

Introduction

Task 3 was designed to address two hypotheses listed as part of Objective 3 in Murdoch and Peven (2005):

- Ho: Allele frequency $_{\text{Hatchery}}$ = Allele frequency $_{\text{Naturally produced}}$ = Allele frequency $_{\text{Donor pop}}$.
- Ho: Genetic distance between subpopulations $_{\text{Year x}}$ = Genetic distance between subpopulations $_{\text{Year y}}$

Murdoch and Peven (2005) proposed these two hypotheses to help evaluate the Chiwawa supplementation program through the "Conceptual Process" (Figure 5 in Murdoch and Peven 2005; repeated here as Figure 1). There are two components to the first hypothesis, which must be considered separately. The first component involves comparisons between natural-origin populations in the Chiwawa to determine if there have been changes in allele frequencies or genetic distances, through time starting with the donor population. Documenting a change does not necessarily indicate that the supplementation program has directly affected the natural origin fish, as additional tests would be necessary to support that hypothesis. The intent of the second component is to determine if the hatchery produced populations have the same genetic composition as the naturally produced populations.

Although on the surface these two components and their associated comparisons may appear simple, from a hypothesis-testing perspective the analyses are complicated by the fact that natural-origin fish may have had hatchery-origin parents, and hatchery-origin fish may have had natural-origin parents. As such, we organized the Chiwawa genetic data into three data sets: (1) fish origin (hatchery versus natural), (2) spawning location (hatchery broodstock versus in-river (natural) spawners), and (3) four "treatment" groups (1. hatchery-origin hatchery broodstock, 2. hatchery-origin natural spawner, 3. natural-origin natural spawner, and 4. natural-origin hatchery broodstock). We conducted separate analyses using each of the three data sets, with each analysis touching on some aspect of the components necessary to move through the Conceptual Process (Figure 1).

Hatchery- Versus Natural-Origin

We address the following questions with the origin data set:

1. Are there changes in allele frequencies and allele sharing distances in the natural-origin collections from pre-supplementation to today?
2. Are there changes in allele frequencies and allele sharing distances in the hatchery-origin collections from early supplementation to today?
3. Are there significant differences in allele frequencies and large allele sharing distances between hatchery- and natural-origin adults from a collection year, and has this pattern changed through time?

Genic Differentiation Tests – We explicitly tested the hypothesis of no significant differentiation within natural- or hatchery-origin collections from the Chiwawa River using a randomization chi-square test. We show the results for the pairwise comparisons among natural-origin collections from the Chiwawa River populations in the first block of the second page of Table 3. Ten of the 36 (28%) pairwise comparisons have highly significant allele frequency differences, while only 12 of the 36 comparisons (33%) showed no significant differences. Eight of these 12 comparisons involved the 1996 collection, which included only eight samples and therefore provided little power to differentiate allele frequencies. If we exclude the 1996 collection, only 14% of the pairwise comparisons showed no significant differences, and here all but one of these comparisons involved the 1989 collection. The 1989 collection appeared to be the least differentiated collection in the natural-origin data set in that all pairwise comparisons were either not significant, or only mildly significant at the nominal critical value. No comparisons involving the 1989 collection were significant using a Bonferroni-corrected critical value, and 1989 is the only natural-origin collection in our data set that can be classified as "pre-supplementation."

We can interpret these results to indicate that although there appears to be significant year-to-year differences in allele frequencies among post-supplementation collections, the allele frequencies between each post-supplementation collection and the 1989 pre-supplementation collection are not greatly different. However, the level of differentiation does increase from the early post-supplementation years to the more recent years (2001, 2004-2006), although the statistical level of this significance never exceeds the Bonferroni-corrected critical value. Finally, sample sizes were also small for the 1989 collection (n = 36) and we cannot eliminate a reduction in power as a contributing factor for the lack of significance for these tests.

As with the hatchery-origin collections, most pairwise comparisons of allele frequencies between hatchery-origin samples were significant (Table 3, first page, upper block). Out of the 36 pairwise comparisons, all but three are significant at some level, and most comparisons are highly significant. Similar to the natural-origin analysis, the non-significant results were limited to comparisons involving the 1996, which included only eight samples.

As a result of this analysis *we reject the hypothesis that there was no significant differentiation among natural- or hatchery-origin collections from the Chiwawa River*. Furthermore, the allele frequencies of the hatchery-origin collections are significantly different from those of natural-origin collections (Table 3, first page, second block). For those fish collected in the same year, allele frequencies are significantly different between hatchery- and natural-origin collections, although in 2005 the level of significance was below the Bonferroni critical value (Table 3). The next step is to examine the pattern of allelic differentiation to discover first if there is a trend among the data, and second, if this trend suggests that the allele frequency differences among Chiwawa River natural-origin fish collections has been affected by the hatchery-origin fish.

Allele-sharing and Nonmetric Multidimensional Scaling – We constructed a pairwise allele-sharing distance matrix for all hatchery- and natural-origin collections from the Chiwawa River and subjected this matrix to a nonmetric multidimensional scaling analysis, restricting the analysis to two dimensions (Figure 2). The stress statistic for this analysis is 0.09, a value Kruskal (in Rohlf 2002) listed as a good to excellent fit between the actual allele-sharing distances and the Euclidean (straight-line) distances in the plot.

In other words, Figure 2 is a good visual representation of the allele sharing distance matrix; collections with a high percentage of alleles shared will be closer to each other than collections with a lower percentage of alleles shared.

With the exception of the two outlier years (1996 and 1998) the Chiwawa natural-origin collections form a tight cluster indicating an overall common set of shared alleles among these collections. Even if we ignore the 1996 and 1998 hatchery-origin collections, there appears to be a greater variance in shared alleles among the Chiwawa hatchery-origin collections than the natural-origin collections (Figure 2). In fact, the median percentage of alleles shared among the Chiwawa natural-origin collections is 76% compared with 69% alleles shared among the Chiwawa hatchery-origin collections.

Also, there appears to be a convergence in allele sharing distances (i.e., a decrease in allele frequency differences) between the hatchery- and natural-origin fish from the late 1980s/early 1990s to 2006. The series of red arrows in Figure 2 represent the progression of change in hatchery-origin allele sharing distances from 1996 (first adult hatchery origin fish in our analysis) to 2006 and this progression is decidedly in the direction of the natural-origin cluster. However, the most recent natural-origin collections (2001, 2004-2006) appear to have pulled closer to the hatchery-origin collections, compared with the 1989 natural-origin collection (note the close proximity of the 2000 and 1989 natural-origin collections). Nevertheless, the cluster of natural-origin collections adjacent to the hatchery-origin collections in Figure 2 also includes the 1993 natural-origin collection. Qualitatively, it appears that the initial hatchery-origin and natural-origin collections were more different from each other in terms of the percentage of shared alleles than are the most recent hatchery- and natural-origin collections. This may have been a result of a non-random sample of natural-origin fish that was used as broodstock in the initial years of the supplementation program (see discussion in Task 2 concerning deviations from HWE and linkage disequilibrium).

That being said, we do need to emphasize that Figure 2 is dominated by five outlier collections (two each from the 1996 and 1998 collections, and the 1994 smolt collection).

The 1996 and 1998 collections are characterized by small samples sizes, and the 1994 smolt collection has nearly all pairs of loci in linkage disequilibrium (Table 1). If we eliminate these five outlier groups, both the hatchery- and natural-origin collections form a relatively tight cluster. Excluding the five outliers, the median percentage of shared alleles among all pairwise combinations of Chiwawa hatchery versus Chiwawa natural collections is 76%. This compares with a median pairwise percentage of 79% among only Chiwawa natural-origin collections. That is, there are nearly as many alleles shared between the hatchery-origin and natural-origin collections as there are among the natural-origin collections themselves. There is also a narrowing of differences between natural- and hatchery-origin fish from the same collection years from 1993 (76% shared alleles) through 2006 (83% shared alleles).

If allelic differentiation among collections is a function of genetic drift, we would expect a positive correlation between the number of years between two collections and the allele sharing distance. That is, if genetic drift is the primary cause of allele frequency differences between two collections, the greater the number of years between the two collections the larger the allele-sharing distance. For both the natural- and hatchery-origin collections we examined the relationship between the number of years between a pair of collections and the collections' allele-sharing distance (Figure 3). Although the relationship between time interval and allele distance appears to be a positive function in the natural collections, the slope of the regression line is 0.0017, and is not significantly different from zero. Furthermore, the correlation coefficient (r^2) equals 0.1068, which means that the time interval between collections accounts for only 10% of the pairwise differences in allelic distance. The hatchery-origin collections do show a significantly positive slope (0.0037; $p = 0.0254$) and a regression coefficient nearly three times greater than that for the natural-origin collections. However, the correlation coefficient is still relatively small ($r^2 = 0.3290$), indicating that the time interval between collections accounts for one-third of the pairwise differences in allelic distance. The results suggest that if genetic drift is a factor in allelic differentiation between collections, it is only a minor factor, and appears to have affected the hatchery-origin collections more than the natural-origin collections.

If four-year-old fish dominate each collection year, we would expect a closer relationship among collections that are spaced at intervals of four years. The average percentage of alleles shared between two natural-origin collections that are separated by four years or a multiple of four years is 81%, compared with 78% for natural-origin collections separated by years that are not divisible by four. Likewise, for hatchery-origin collections the average percentage of alleles shared is 80% and 75% for collections separated by years divisible and not divisible by four, respectively. Although the percent differences described above are relatively small, they are consistent with the idea that allelic differences between collections are a function of year-to-year variability among different cohorts of four year-old fish.

Summary – The allele frequencies within and between natural- and hatchery-origin collections are significantly different, but there does not appear to be a robust signal indicating that the recent natural-origin collections have diverged greatly from the pre- or early post-supplementation collections. Genetic drift will occur in all populations, but does not appear to be a major factor with the Chiwawa collections. We propose that the differences among collections are a function of differences in allele frequencies among cohorts of the four year-old fish that dominate each collection.

Hatchery Broodstock Versus Natural (In-River) Spawners

We address the following questions with the spawner data set:

1. Are there changes in allele frequencies and allele sharing distances in the natural spawning collections from pre-supplementation to today?
2. Are there changes in allele frequencies and allele sharing distances in the hatchery broodstock collections from early supplementation to today?
3. Are there significant differences in allele frequencies and large allele sharing distances between hatchery and natural spawning adults from a collection year, and has this pattern changed through time?

Genic Differentiation Tests – For the most part there are significant differences in allele frequencies among collections for both the hatchery broodstock and natural spawners (Table 4), and these differences are consistent with the origin data set (Table 3). There are four collection years with paired samples (2001, 2004-2006) where we can compare allele frequency differences between the hatchery broodstock and natural spawners, within the same year. The 2001 hatchery broodstock and natural spawner collections have significantly different allele frequencies, but the level of significance decreased from 2001 to 2004, and become non-significant in 2005 and 2006 (Table 4). This indicates that by 2005, the hatchery broodstock and natural spawners collections were effectively sampling from the same population of fish. Additionally, the percentage of alleles shared between the hatchery broodstock and the natural spawners increased from 76% in 2001 to 86% in 2006 (allele sharing distance matrix, not shown). From this analysis, we conclude that although there are year-to-year differences in allele frequencies within the natural and hatchery spawner collections, *there appears to be a convergence of allele frequencies within collection-year, between the natural and hatchery spawner populations*.

Linkage Disequilibrium – Linkage disequilibrium is the correlation of alleles between two loci, and can occur for several reasons. If two loci are physically linked on the same chromosome, than alleles from each of these loci should be correlated. However, linkage between two loci can occur as a result of population bottlenecks, small population sizes, and natural selection. If any of these conditions had occurred or were occurring within the Chiwawa River system, we would expect to find substantial linkage disequilibrium in many or perhaps all Chiwawa collections. However, many Chiwawa collections, especially the natural-origin collections, do not show linkage disequilibrium (Table 1), and it would appear that the linkage disequilibrium within certain Chiwawa collections is not a function of the processes listed above. Linkage disequilibrium can also result if the collection is composed of an admixture. That is, if two or more reproductively isolated populations are combined into a single collection, the collection will show linkage disequilibrium. Each broodstock and natural spawning collection is composed of natural- and hatchery-origin fish. If these hatchery- and natural-origin fish are drawn from the same population, the spawning collections should not show substantial linkage disequilibrium. However, if the hatchery- and natural-origin fish are from different populations (i.e., full hatchery – natural integration has not been achieved), the spawning collections should show substantial linkage disequilibrium.

There are only three Chiwawa spawning collections that are not composed of both hatchery- and natural-origin samples: 1989 (natural-origin, natural spawner), 1993 (natural-origin, hatchery broodstock), and 2001 (natural-origin, natural spawner). Of the 10 spawning collections with both hatchery- and natural-origin fish, seven show significant linkage disequilibrium. Two of the three collections that did not show linkage disequilibrium are the 1996 and 1998 hatchery broodstock collections, which are composed of only seven natural- and six hatchery-origin fish, and two natural- and 19 hatchery-origin fish, respectively. Within the hatchery broodstock collections with linkage disequilibrium, the percent of loci pairs showing linkage decreased from 32% in 2000 to 13% in 2001 and 2004, to only 1% and 5% in 2005 and 2006, respectively (Table 1). If the homogenization of allele frequencies of natural- and hatchery-origin fish was increasing from 2000 to 2006, we would expect a decrease in linkage disequilibrium among the broodstock collections. This is what occurred within the hatchery broodstock collections, but did not occur within the natural spawner collections, where the percent of loci pairs showing linkage was 18% in 2004, 6% in 2005, and 10% in 2006 (Table 1). Furthermore, the 2001 natural spawner collection, with no hatchery-origin component showed linkage disequilibrium with 9% of loci pairs.

There is no correlation between percent of loci pairs showing linkage disequilibrium and percent of broodstock composed of hatchery-origin fish ($r^2 = 0.0045$). Furthermore, the natural spawner and hatchery broodstock collections were each composed of roughly the same average percentage of hatchery-origin fish (57% and 53%, respectively). If the decrease in linkage disequilibrium among the hatchery broodstock collections from 2000 to 2006 was a result of a homogenization of allele frequencies of natural- and hatchery-origin fish in the broodstock, the same degree of homogenization did not occur within the natural spawner collections. This would occur if natural- and hatchery-origin fish spawning within the river remain segregated, either by habitat or by fish behavior.

Summary – As with the origin data set, there are significant allele frequency differences within and between hatchery broodstock and natural spawner collections. However, in recent years the allele frequency differences between the hatchery broodstock and natural spawner collections has declined. Furthermore, based on linkage disequilibrium, there is a genetic signal that is consistent with increasing homogenization of allele frequencies within hatchery broodstock collections, but a similar homogenization within the natural spawner collection is not apparent. These data suggest that there exists consistent year-to-year variation in allele frequencies among hatchery and natural spawning collections, but there is a trend toward homogenization of the allele frequencies of the natural- and hatchery-origin fish that compose the hatchery broodstock.

Four Treatment Groups

Analyses of genetic differences between hatchery (broodstock) and natural spawner collections is confounded by the fact that each these two groups are composed of fish of natural- and hatchery-origin. To understand the effects of hatchery supplementation on *natural-origin fish that spawn naturally*, we needed to divide the Chiwawa data set into four mutually exclusive groups: (1) hatchery-origin hatchery broodstock, (2) hatchery-origin natural spawner, (3) natural-origin hatchery broodstock, and (4) natural-origin natural spawner, with each group consisting of multiple collection years, for a total of 25 different groups.

Allele-sharing and Nonmetric Multidimensional Scaling –As with previous analyses discussed above, we constructed a pairwise allele-sharing distance matrix for all collections from each of these treatment groups and subjected this matrix to a nonmetric multidimensional scaling analysis, restricting the analysis to two dimensions. Figure 4 shows that five outlier groups dominate the allele-sharing distances within this data set. These outlier groups are also present in Figure 2, as discussed above, and Figure 2 and 4 resemble each other because the same fish are included in each analysis. The difference between Figures 2 and 4 is that in Figure 4 the fish are grouped into collection year and the four treatment groups, rather than collection year and two treatment groups (hatchery- versus natural-origin).

Figure 4 does not provide useful resolution of the groups within the polygon, because the outlier groups dominate the allele sharing distances. We removed the five outlier groups from Figure 4, recalculated the allele sharing distances and subjected this new matrix to a multidimensional scaling analysis (Figure 5). Figure 5 shows separation among the 2001, 2004-2006 collections, but this separation does not necessarily indicate that within-year collections are more similar to each other than any collection is to a collection from another year. For example, the 2006 natural-origin natural spawner and the 2005 natural-origin hatchery broodstock collections share 81% alleles, while the 2006 natural-origin natural spawner and 2006 hatchery-origin hatchery broodstock collections share 75% alleles. There does not appear to be any discernable pattern of change in allele-sharing distance among the collections relevant to pre- or post-supplementation. Although the 1989 pre-supplementation natural-origin collection appears distinct (Figure 5), the 1993 natural-origin hatchery broodstock collection appears quite similar to the 2005 and 2006 natural-origin collections (Figure 5). The 1993 natural-origin hatchery broodstock collection, although not technically pre-supplementation, is composed of fish whose ancestry cannot be traced to any Chiwawa hatchery fish. Therefore, there is no clear pattern of allele sharing change from pre-supplementation to recent collections.

There does appear to be some change in the average percentage of alleles shared within the 2001 to 2006 collections, with an increase from 74% in 2001 and 2004 to 78% and 79% in 2005 and 2006, respectively. The results provided by this analysis are consistent with the results presented in the origin and spawner data sets. That is, there are allele frequency and allele sharing differences among the collections, but analyses do not strongly suggest that these differences are a function of the supplementation program. Furthermore, there is also a weak signal that the hatchery and natural collections within the most recent years are more similar to each other than in the previous years.

Overall Genetic Variance – Although there are signals of allelic differentiation among Chiwawa River collections, there are no robust signs that these collections are substantially different from each other. We used two different analyses to measure the degree of genetic variation that exists among individuals and collections within the Chiwawa River. First, we conducted a principal component analysis using all Chiwawa samples with complete genotypes (i.e., no missing alleles from any locus). Although the first two principal component axes account for only 10.5% of the total molecular variance, a substantially greater portion of that variance is among individual fish, regardless of their identity, rather than among hatchery and natural collections (Figure 6). The variances in principal component scores among individuals are 11 and 13 times greater than the variance in scores among collections, along the first and second axes, respectively.

Second, we conducted a series of analyses of molecular variance (AMOVA) to ascertain the percentage of molecular variance that could be attributed to differences among collections. We organized these analyses to test also for differences in the hierarchical structure of the data. That is, we tested for differences among collections using the following framework:

- No organizational structure – all 25 origin-spawner collections considered separately
- Origin-spawner collections organized into 10 collection year groups
- Origin-spawner collections organized into 2 breeding location groups (hatchery versus natural)
- Origin-spawner collections organized into 2 origin groups (hatchery versus natural)
- Origin-spawner collections organized into the 4 origin-spawner groups

It is clear from this analysis that nearly all molecular variation, no matter how the data are organized, resides within a collection (Table 5). The percentage of total molecular variance occurring within collections ranged from 99.68% to 99.74%. The among group variance component was limited to less than 0.26% and in all organizational structures, except “no structure,” the among group percentage was not significantly greater than zero. Furthermore, none of the organizational structures provided better resolution than “no structure” in terms of accounting for molecular variance within the data set. *These results indicate that if there are significant differences among collections of Chiwawa fish, these differences account for less than one percent of the total molecular variance, and these differences cannot be attributed to fish origin or spawning location.*

Summary and Conclusions

We reject the null hypothesis that the allele frequencies of the hatchery collections equal the allele frequencies of the natural collections, which equals the allele frequency of the donor population. Furthermore, because the allele-sharing distances are not consistent within and among collections years, we also reject the second stated hypothesis discussed above. However, there is an extremely small amount of genetic variance that can be attributed to among collection differences. The allelic differentiation that does exist among collections does not appear to be a function of fish origin, spawning location, genetic drift, or collection year. Figure 5 and related statistics does suggest that hatchery and natural collections in 2005 and 2006 are more similar to each other than previous years’ collections, and this would be expected in a successful integrated hatchery supplementation program.

Since each of these collection years are generally composed of four-year-old fish, the differentiation among these collections for the most part is differentiation among specific cohorts. The slightly greater percentage of alleles shared among collections that are separated in time by multiples of four years, compared with collections that are not separated in time as such, suggests that cohort differences may be the most important factor accounting for differences in allele frequencies among collections.

<u>Task 4:</u> Develop a model of genetic drift.

See Task 3

<u>Task 5:</u> Analyze spring Chinook population samples from the Chiwawa River and Chiwawa Hatchery from multiple generations.

See Task 3

<u>Task 6:</u> Analyze among population differences for upper Wenatchee spring Chinook.

Supplementation of the Chiwawa River spring Chinook population may affect populations within the Wenatchee River watershed other than the Chiwawa River stock. If the stray rate for Chiwawa hatchery-origin fish is greater than that for natural-origin fish, an increase in gene flow from the Chiwawa population into other populations may result. If this gene flow is high enough, Chiwawa River fish may alter the genetic structure of these other populations. Records from field observations indicate that hatchery-origin fish are present in all major spawning aggregates (A.R Murdoch, unpublished data), and these fish are successfully reproducing (Blankenship et al 2006). The intent of this task is to investigate if there have been changes to the genetic structure of the spring Chinook stocks within upper Wenatchee tributaries during the past 15-20 years, and if changes have occurred, are they a function of the Chiwawa River Supplementation Program? Therefore, we ask the following two questions:

1. Are allele frequencies within populations in the upper Wenatchee stable through time? That is, is there significant allelic differentiation among collections within upper Wenatchee populations?
2. Are the recent collections from the upper Wenatchee populations more similar to the Chiwawa population than earlier collections from the same populations?

For this task we analyzed natural spawning collections from the White River (natural-origin), Little Wenatchee River (natural-origin), Nason Creek (natural-origin), and

Wenatchee mainstem (hatchery-origin), and hatchery collections from Leavenworth NFH and Entiat River NFH (Table 1). We also included in the analysis the natural- and hatchery-origin collections from the Chiwawa River. There are no repeated collections from Leavenworth, Entiat, Little Wenatchee, and Wenatchee mainstem (Table 1), so for many of the analyses we have limited our discussion to the Chiwawa River, White River, and Nason Creek collections. Furthermore, genetic structure of the Little Wenatchee collection, which consisted of only 19 samples, was unexpectedly quite different from the other collections. For example, the F_{ST} statistic measures the percent of total molecular variation that can be attributed to differences between populations. The median F_{ST} for all pairwise combinations of collections from all populations, except Little Wenatchee (33 populations, 528 individual F_{ST} statistics) equals 0.010 (1%), with a range of 0.000 to 0.037 (Table 6). The median F_{ST} for the Little Wenatchee paired with all other collections (33 individual F_{ST} statistics) equals 0.106 (10.6%), with a range of 0.074 to 0.121. The ten-fold increase in the F_{ST} statistic indicates that either the Little Wenatchee spring Chinook is unique among the upper Wenatchee River stocks, or this 1993 collection is somehow aberrant. Therefore, we exclude the Little Wenatchee collection from many other analyses.

Population Differentiation – Table 3 provides the levels of significance for all pairwise genic differentiation tests. Most between-collection comparisons are highly significant, with no pattern of increasing or decreasing differentiation with time, and no differences when comparisons are made with Chiwawa hatchery- versus Chiwawa natural-origin fish. For example, excluding the outlier 1996 and 1998 Chiwawa hatchery- and natural-origin collections, Nason Creek showed highly significant allele frequency differences between the Chiwawa hatchery- and natural-origin collections at 100% and 86% of the comparisons, respectively. The same comparisons with the White River produced 100% and 93% highly significant allele frequency comparisons, respectively. Allele frequencies between Nason Creek and White River were likewise differentiated from each other.

The collection allele frequencies within the upper Wenatchee system are significantly different, and these differences do not appear to change as a function of time (Table 3). Nason Creek shows greater within-population year-to-year variation in allele frequencies than does the White River, with 47% of the pairwise comparisons showing highly significant differences, compared with only 13% for the White River. However, the 2005 and 2006 collections from the White River appear to be somewhat more differentiated from not only each other, but from the earlier collections from the White River.

Despite the high degree of temporal and spatial structure suggested by the genic differentiation tests, as described above for within-Chiwawa analysis (Task 3), most of the genetic variation within this data set occurs within populations, rather than between populations (Table 6). The F_{ST} values for most population comparisons are between 0.01 and 0.02, indicating 1% to 2% among-population variance, with the remaining 98% to 99% variance occurring within populations. The White River shows the highest median F_{ST} among the natural-origin collections, equal to 0.014, compared with 0.009 for both the Nason Creek and Chiwawa natural-origin collections. The median F_{ST} for the Chiwawa hatchery-origin collections (0.012) was higher than that for the Chiwawa natural-origin collections.

Table 7 summarizes the information from the F_{ST} analyses, under five different temporal and spatial scenarios. Under all scenarios, over 99% of the molecular variance is within populations. There is significantly greater spatial structure among populations ("Origin") in 2005 and 2006 than from 1989 to 1996. That is, there appears to be more spatial structure among the Chiwawa hatchery-origin, Chiwawa natural-origin, White River, and Nason Creek now, than in 1989 to 1996, despite the potential homogenizing and cumulative effect of hatchery strays. However, we stress that the amount of molecular variance associated with the among population differences, despite being significantly greater than 0.00%, is limited to only 0.43%.

Allele-sharing and Nonmetric Multidimensional Scaling – As in the Chiwawa River data discussed above, we constructed an allele-sharing distance matrix and then subjected that matrix to a multidimensional scaling analysis (Figure 7). Consistent with all previously discussed multidimensional scaling analyses, the 1996 and 1998 adult, and the 1994 smolt collections are outliers. There is clear separation between the White River collections and all other natural-origin and Chiwawa hatchery-origin collections, indicating that there are more alleles shared among the Nason Creek and Chiwawa collections, than with the White River collections. Furthermore, there is a slight separation between the Chiwawa natural-origin natural spawner collections and Nason Creek collections, suggesting different groups of shared alleles between these populations. There is more variation in the allele-sharing distances among collections involved with the Chiwawa hatchery (origin or broodstock) than any of the natural-origin collections, even if we exclude the 1994, 1996, and 1998 collections. This suggests that there is more year-to-year variation in the composition of hatchery-origin and hatchery broodstock than within natural-origin populations throughout the upper Wenatchee. All Wenatchee mainstem fish are hatchery-origin, and if these fish are from the Chiwawa Supplementation Program (rather than from Leavenworth), it is not unexpected that this collection would be plotted within the Chiwawa polygon (Figure 7).

Assignment of Individual to Populations – Finally, we conducted individual assignment tests whereby we assigned each individual fish to a population, based on a procedure developed by Rannala and Mountain (1997) (Table 8 and 9). Individual fish may be correctly assigned to the population from which they were collected, or incorrectly assigned to a different population. Incorrect assignments may occur if the fish is an actual migrant (i.e., source population different from population where collected), or because the genotype for that fish matches more closely with a population different from its source. If there are many individuals from a population incorrectly assigned to populations other than its source population, that original population is either unreal (i.e., an admixture), or there is considerable gene flow between that population and other populations. Furthermore, in assigning individuals to populations, we can either accept the assignment with the highest probability, regardless of how low that probability may be, or we can establish a more stringent criterion, such as to not accept an assignment unless the posterior probability is equal to or greater than 0.90. This value is roughly equal to having the likelihood of the most-likely population equal to 10 times that of the second most-likely population.

We provide a summary of the assignments in Tables 8 and 9. On average, nearly 50% of the fish are assigned incorrectly if we accept all assignments (Table 8), but the incorrect assignment rate drops to roughly 10% when we accept only those assignments with probabilities greater than 0.90. However, with this more stringent criterion, nearly 64% of the fish go unassigned. These results indicate that the allele frequency distributions for these populations are very similar, and it would be very difficult to assign an individual fish of unknown origin to the correct population. If all fish are assigned, there is a 50% chance, overall, of a correct assignment. If you accept only those assignment with the 0.90 criterion, nearly two-thirds of the fish would be unassigned, but there is a 90% chance of correctly assigning those fish that are indeed assigned.

Of all the populations in the data set, there are fewer errors associated with assigning fish to the White River. If all fish are assigned (Table 8), 72% of those fish assigned to the White River, are actually from the White River (115 fish out of a total of 159 fish assigned to the White River). This compares to a rate of only 52% and 53% for Nason Creek and Chiwawa natural-origin, respectively, and 60% for the Chiwawa hatchery-origin collections. With the 0.90 criterion (Table 9), 89% of the fish assigned to the White River, are actually from the White River, compared with 70% and 65% for Nason Creek and Chiwawa natural origin, respectively, and 81% for the Chiwawa hatchery origin.

When all fish are assigned, most of the incorrectly assigned fish from Nason Creek and White River are assigned to Chiwawa River, at roughly equal frequencies to the hatchery- and natural-origin populations. Incorrectly assigned fish to other populations occur at a slightly higher rate in Nason Creek than in the White River. However, when only those fish meeting the 0.90 criterion are assigned (Table 9), incorrectly assigned fish from Nason Creek are distributed among White and Chiwawa Rivers, as well as Leavenworth NFH, and the Entiat NFH. Mis-assignment to the Chiwawa hatchery-origin was the highest among the Nason Creek collections, equal to nearly 14%. This contrasts with the White River where mis-assignments do not exceed 7% anywhere, and there is a roughly even distribution of mis-assignments among Nason Creek and Chiwawa River collections.

Summary and Conclusions – There is little geographic or temporal structure among populations within the upper Wenatchee systems. Among population molecular variance is limited to 1% or less. The little variance that can be attributed to among populations indicates that the White River is more differentiated from the Chiwawa and Nason populations than these populations are from each other. Furthermore, although we cannot rule out a hatchery effect on the Nason Creek and White River populations, there is no indication there has been any temporal changes in allele frequencies within these populations that can be attributed directly to the Chiwawa River Supplementation Program. In fact, Table 7 weakly suggests that there is more differentiation among these populations now, than there was before or at the early stages of Chiwawa supplementation.

Therefore, returning to our two original questions, there are significant differences in allele frequencies among collections within populations, and among populations within the upper Wenatchee spring Chinook stocks. However, these differences account for a very small portion of the overall molecular variance, and these populations overall are very similar to each other. There is no evidence that the Chiwawa River Supplementation Program has changed the allele frequencies in the Nason Creek and White River populations, despite the presence of hatchery-origin fish in both these systems. Finally, of all the populations within the Wenatchee River, the White River appears to be the most distinct. Yet, this distinction is more a matter of detail than of large significance, as the median F_{ST} between White River collections and all other collections (except the Little Wenatchee) is less than 1.5% among population variance.

<u>Task 7:</u> Calculate the inbreeding effective population size using demographic data for each sample year, and document the ratio of census to effective size.

This analysis was completed by Williamson et al. (submitted).

<u>Task 8:</u> Calculate LD N_b using genetic data for each sample year, and document the ratio of census to effective size.

We report N_e estimated for the Chiwawa River collections based on the bias correction method of Waples (2006) implemented in LDNe (Do and Waples unpublished). N_e estimates based on LD are best interpreted as the effective number of breeders (N_b) that produced the sample (Waples 2006).

For collections categorized by spawning location (i.e., hatchery broodstock or natural), estimates of N_b are shown in Table 10. Considering the hatchery broodstock, N_b estimates range from 30.4 (1996) to 274.3 (2005). To obtain N_e /N ratios, the N_b estimate is multiplied by four (i.e., mean generation length) and divided by the total in river (i.e., NOS [natural-origin spawners] plus HOS [hatchery-origin spawners]) census data from four years prior (i.e., major cohort; see Table 2). The observed N_e /N ratios for the broodstock collections range from 11% to 54% of the census estimate, excluding the 2000 collection which is 106%. A ratio greater than one is possible under special circumstances, and certain artificial mating schemes within hatcheries can inflate N_e above N; yet, it is unknown if this is the case for this collection. While no direct comparisons are possible, the N_b estimates reported by Williamson et al. (submitted) for Chiwawa broodstock collections from 2000 – 2003 are similar in magnitude to our estimates. For Chiwawa natural spawner collections, the N_b estimates range from 5.2 (1989) to 231.5 (2005), with observed N_e /N ratios of 22% - 48% of the census estimate.

<u>Task 9:</u> Calculate N_b using the temporal method for multiple samples from the same location.

Estimates of effective number of breeders (N_b) derived from Waples' (1990) temporal method are shown in Tables 11-13. Eight collection years were used for the Chiwawa broodstock collections (Table 11). The harmonic mean of all pairwise estimates of N_b ($\tilde{N}_b$) was 269.4. This estimate is the contemporary N_e for Chiwawa broodstock collections. For the five collection years of Chiwawa in-river spawners (Table 12), the estimated $\tilde{N}_b$ = 224.2. This estimate is the contemporary N_e for Chiwawa River natural spawner collections. Since the Chiwawa Supplementation Program is integrated by design, we also performed another estimation of N_e using composite hatchery and natural samples. There are paired samples from 2004-2006. We combined genetic data for hatchery (HOS) and natural (NOS) origin fish from 2004 – 2006 to create a single Chiwawa River natural spawner sample for each year. The three composite samples from 2004 – 2006 were then analyzed using the temporal method (Table 13), resulting in a $\tilde{N}_b$ = 386.8. This estimate is the contemporary N_e for Chiwawa River.

Williamson et al. (submitted) estimated N_e using Waples' (1990) temporal method for Chinook captured in 2004 and 2005, and used age data to decompose brood years into consecutive cohorts from 2000 – 2003. They report for Chiwawa broodstock a $\tilde{N}_b$ = 50.4. This estimate is not similar to our Chiwawa broodstock estimate. However, if we analyze the hatchery-origin Chinook only, our estimate is $\tilde{N}_b$ = 80.1 for collection years 1989 – 2006 (data not shown). Williamson et al. (submitted) report for Chiwawa naturally spawning Chinook a $\tilde{N}_b$ = 242.7, which is slightly higher than our estimate for in-river spawners from 1989 – 2006, but lower than our estimate from combined NOS and HOS Chinook from 2004 – 2006 collection years.

<u>Task 10:</u> Use available data and the Ryman-Laikre and Wang-Ryman models to determine the expected change of N_e for natural spring Chinook salmon in the Wenatchee River due to hatchery operation.

N_e is generally thought to be between 0.10 and 0.33 of the estimated census size (Bartley et al. 1992; RS Waples pers. comm.). We used this range to generate an estimate of N_e for Chiwawa natural spawners prior to hatchery operation. For brood years 1989 – 1992, the arithmetic mean census size was N=962.7 (Table 2), resulting in an estimated N_e ranging from 96.3 – 317.7. The contemporary estimate of N_e calculated using genetic data for the Chiwawa in-river spawners is N_e=224.2 (Table 12), falling in the middle of the pre-hatchery range. The N_e /N ratio calculated using 224.2 and the arithmetic census of NOS Chinook from 1989 – 2005 is 0.42. A more appropriate contemporary N_e to compare with the pre-hatchery estimate (i.e., 96.3 – 317.7) is the combined NOS and HOS estimate from natural spawners, since the supplementation program is integrated. As discussed above, the contemporary estimate of N_e calculated using genetic data for Chiwawa NOS and HOS Chinook is N_e=386.8 (Table 13), which is slightly larger than the pre-hatchery range, suggesting the N_e has not declined during the period of hatchery operation. The N_e /N ratio calculated using 386.8 and the arithmetic census of NOS and HOS Chinook from 1989 – 2005 is 0.40. These results suggest the Chiwawa Hatchery Supplementation Program has not resulted in a smaller N_e for the natural spawners from the Chiwawa River.

Williamson et al. (submitted) argued that since their combined (i.e., broodstock and natural) N_e estimate was lower than the naturally spawning estimate, the supplementation program likely had a negative impact on the Chiwawa River N_e. We disagree with this interpretation of these data. Since the natural spawning component is mixed hatchery and natural ancestry, the N_e estimates from natural spawning data are the results that bear on possible hatchery impacts. The census data show the population declined in the mid 1990's and rebounded by 2000 (Table 2). This trend is reflected in the N_e results, as shown above, and Williamson et al. (submitted) clearly show in their Table 4 the N_e was lower in 2000 (N_e = 989) than it was in 1992 (N_e = 2683). Yet, the important comparison they make in our view was the natural spawning N_e versus the natural only component N_e (i.e., hypothetically excluding hatchery program). Williamson et al. (submitted) report the 1989 – 1992 N_e estimated from naturally spawning Chinook (i.e., NOS and HOS integrated) was essentially the same as the natural only component estimate, 2683 and 2776, respectively. This result is not surprising since no HOS fish were present between 1989 – 1992. They also report that the 1997 – 2000 N_e estimated from naturally spawning Chinook (i.e., NOS and HOS integrated) was N_e =989, while the natural-origin estimate of N_e in 1997 – 2000 was N_e = 629. Since the natural-origin estimate of 629 is lower than 989, the N_e estimate from all in-river spawners, we argue that their analysis of demographic data show the N_e estimated from naturally spawning Chinook (i.e., NOS and HOS integrated) is larger only if the hatchery Chinook in the river are ignored.

Task 11: Use individual assignment methods to determine the power of self-assignment for upper Wenatchee River tributaries.

See "Assignment of Individual to Populations" in Task 6

Conclusions

Has the Chiwawa Hatchery Supplementation Program succeeded at increasing the census size of the target population while leaving genetic integrity intact? This is an important question, as hatcheries can impact natural populations by reducing overall genetic diversity (Ryman and Laikre 1991), reducing the fitness of the natural populations through relaxation of selection or inadvertent positive selection of traits advantageous in the hatchery (Ford 2002; Lynch and O'Hely 2001), and by reducing the reproductive success of natural populations (McLean et al. 2003). The census data presented here show that the current natural spawning census size is similar to the pre-supplementation census size. Despite large numbers of hatchery-origin fish on the Chiwawa River spawning grounds, the genetic diversity of the natural-origin collections appear unaffected by the supplementation program; heterozygosities are high, and contemporary N_e is similar (perhaps slightly higher) than pre-supplementation N_e. We did find significant year-to-year differences in allele frequencies in both the origin and spawner datasets, but these differences do not appear to be related to fish origin, spawning area, or genetic drift. However, we do suggest that cohort differences may be the most important factor accounting for differences in allele frequencies among collections.

The main objective of this study was to determine the potential impacts of the hatchery program on natural spring Chinook in the upper Wenatchee system. We did this by analyzing temporally replicated collections from the Chiwawa River, and by comparing genetic diversity prior to the presumed effect of the Chiwawa Hatchery Supplementation Program, with contemporary collections. We report that the genetic diversity present in the Chiwawa River is unchanged (allowing for differences among cohorts) from 1989 – 2006, and the contemporary estimate of the effective population size (N_e) using genetic data is approximately the same as the N_e estimate extrapolated from 1989 – 1992 census data (i.e., pre-hatchery collection years). We observed substantial genetic diversity, with heterozygosities ~80% over thirteen microsatellite markers. Yet, temporal variation in allele frequencies was the norm among temporal collections from the same populations (i.e., location). The genetic differentiation of replicated collections from the same population is likely the result of salmon life history in this area, as four-year-old Chinook comprise a majority of returns each year. The genetic tests are detecting the differences of contributing parents for each cohort. An important point related to the temporal variation, is that the hatchery broodstock is composed in part of the natural origin Chinook from the Chiwawa River. When we compared the genetic data (within a collection year) for Chinook brought into the hatchery as broodstock with the Chinook that remained in the river (years 2001, 2004 – 2006), there was a trend of decreasing statistical differences in allele frequencies from 2001 to 2004, and no differences were detected for 2005 and 2006. While the replicated collections may have detectable differences in allele frequencies, those differences reflect actual differences in cohorts, not the result of hatchery operations, and the hatchery broodstock collection method captures the differences in returning Chiwawa River spring adults each year. We conclude from these results that the genetic diversity of natural spring Chiwawa Chinook has been maintained during the Chiwawa Hatchery Supplementation Program.

We observe slight, but statistically significant population differentiation between Chiwawa River, White River, and Nason Creek collections. Murdoch et al (2006) and Williamson et al. (submitted) also observed population differentiation between Chiwawa River, White River, and Nason Creek collections. Yet, 99.3% of the genetic variation observed was within samples, very little variance could be attributed to population differences (i.e., population structure). The AMOVA analysis and poor individual assignment results suggest the occurrence of gene flow among Wenatchee River locations or a very recent divergence of these groups. While Murdoch et al. 2006 did not perform an AMOVA analysis, their F_{ST} results provide comparable data to our among-population results. Murdoch et al. 2006 report F_{ST} ranging from 2%-3% for pairwise comparisons between of Chiwawa, White, and Nason River collections. Since F_{ST} is an estimate of among-sample variance, these results also imply a majority of the genetic variance (i.e., 97%-98%) resides within collections. To provide further context for the magnitude of these variance estimates, we present the among-group data from Murdoch et al. 2006 comparing summer-run and spring-run Chinook from the Wenatchee River. They report that approximately 91% of observed genetic variance is within-collection for comparisons between collections of summer- and spring-run Chinook. Ultimately, the information provided by this and other reports will be incorporated into the management process for Wenatchee River Chinook. However, we would like to emphasize that the application of these genetic data to management is more about the goals related to the distribution of genetic diversity in the future than specific data values reported. If Chinook are collected at Tumwater Dam instead of within the upper Wenatchee River tributaries, a vast majority of the genetic variation present in the basin would be captured, although any differences among tributaries would be mixed. Alternatively, management policies could be crafted to promote and maintain the among-group genetic diversity that genetic studies consistently observe to be non-zero within the Wenatchee River.

We agree with Murdoch et al. (2006) that it appears hatchery Chinook are not contributing to reproduction in proportion to their abundance. Additionally, if the total census size (i.e., NOS and HOS combined) within the Chiwawa River does not continue to increase, genetic diversity may decline within this system, given the smaller N_e within the hatchery-origin collections compared with the natural-origin collections.

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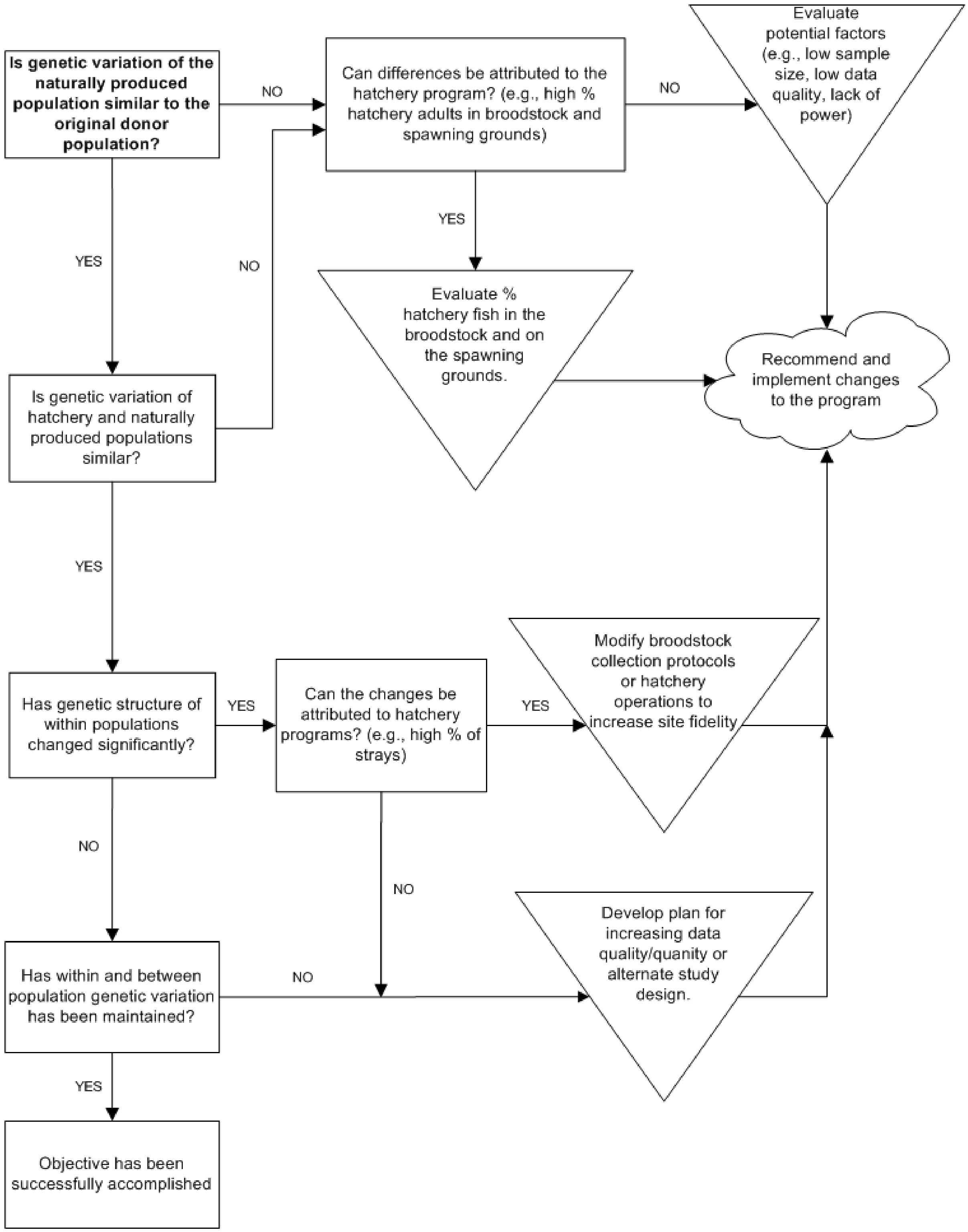

Figure 1. Conceptual process for evaluating potential changes in genetic variation in the Chiwawa naturally produced populations as a result of the supplementation hatchery programs (From Murdoch and Peven 2005).

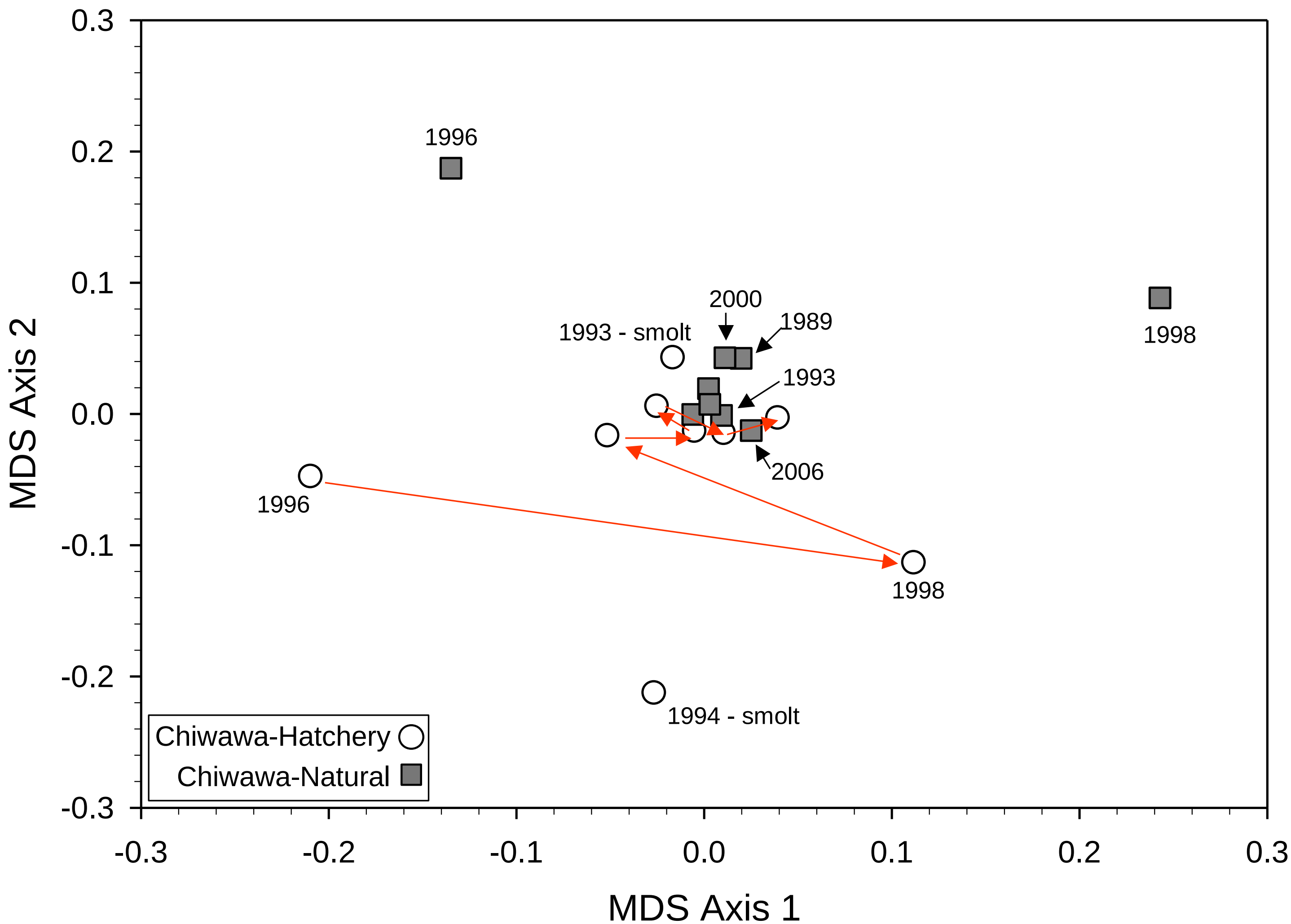

Figure 2. Multidimensional scaling plot from an allele-sharing distance matrix calculated from the Chiwawa data set organized by fish origin (i.e., hatchery versus natural). The red arrows connect consecutive hatchery-origin collections starting with the first adult collection (1996) and ending with the 2006 collection (see Table 1 for collection years).

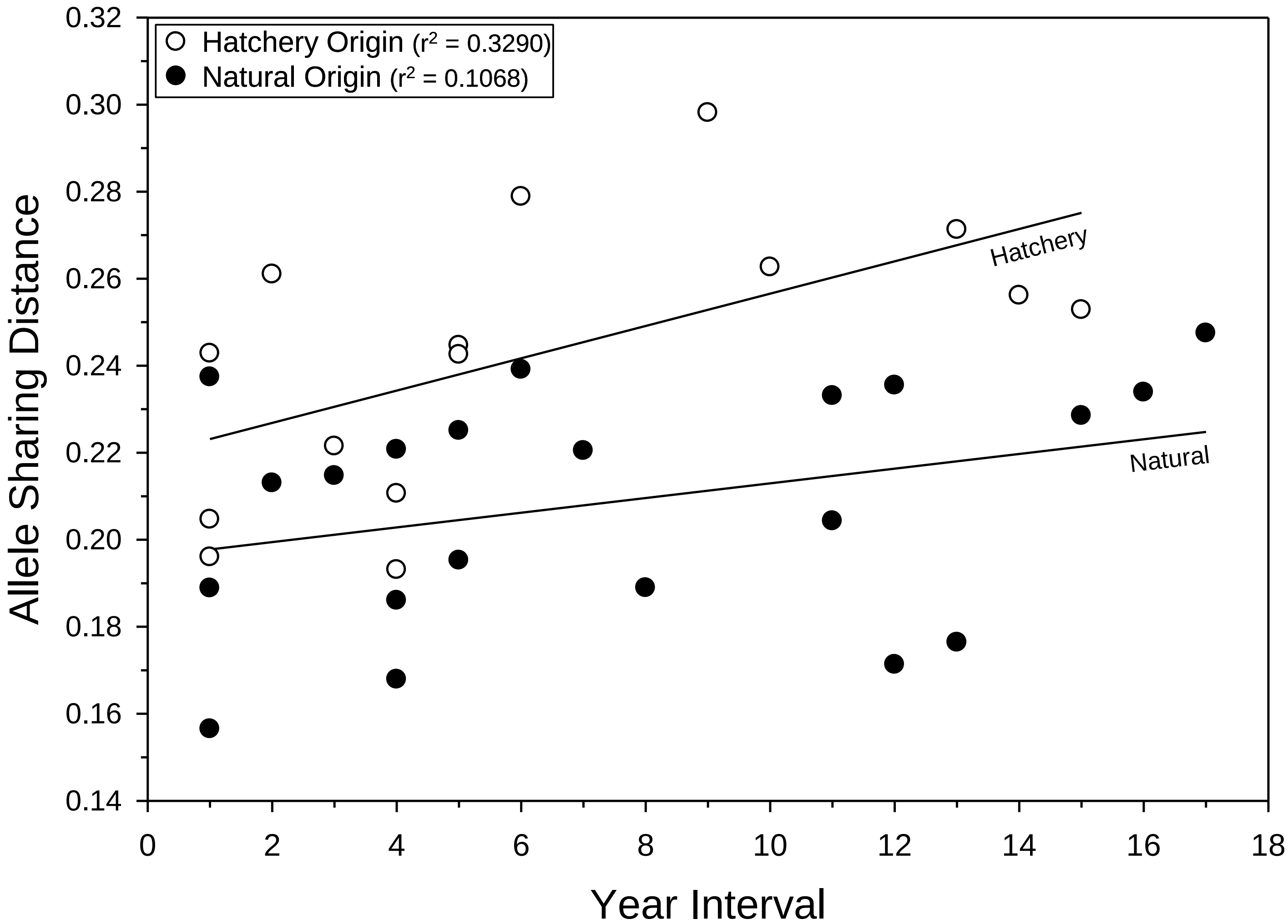

Figure 3. Relationships between the time interval in years and allele sharing distances, with each circle representing the pairwise relationship between two Chiwawa collections. Separate regression lines for the natural- and hatchery-origin collections. The slope for the natural-origin collection is not significantly different from zero (p=0.1483), while the slope for hatchery-origin collection is significantly greater than zero (p=0.0254) indicating a positive relationship between time interval and allele sharing distance.

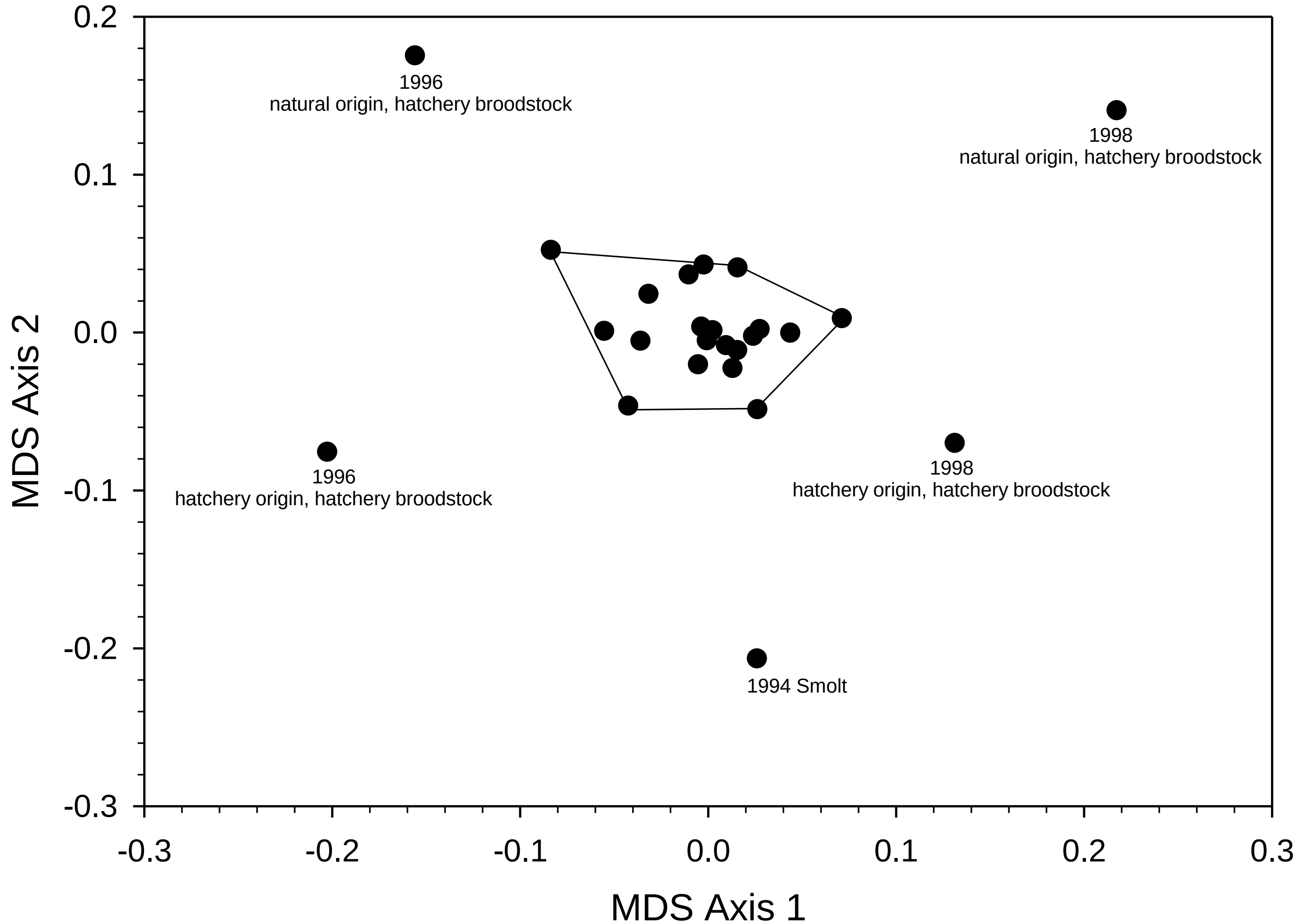

Figure 4. Multidimensional scaling plot from an allele-sharing distance matrix calculated from the Chiwawa data set organized by four treatment groups, as discussed in the text. Each circle represents a single collection within each of the four treatment groups, and the polygon encloses all groups that are not outliers. Each outlier group is specifically labeled.

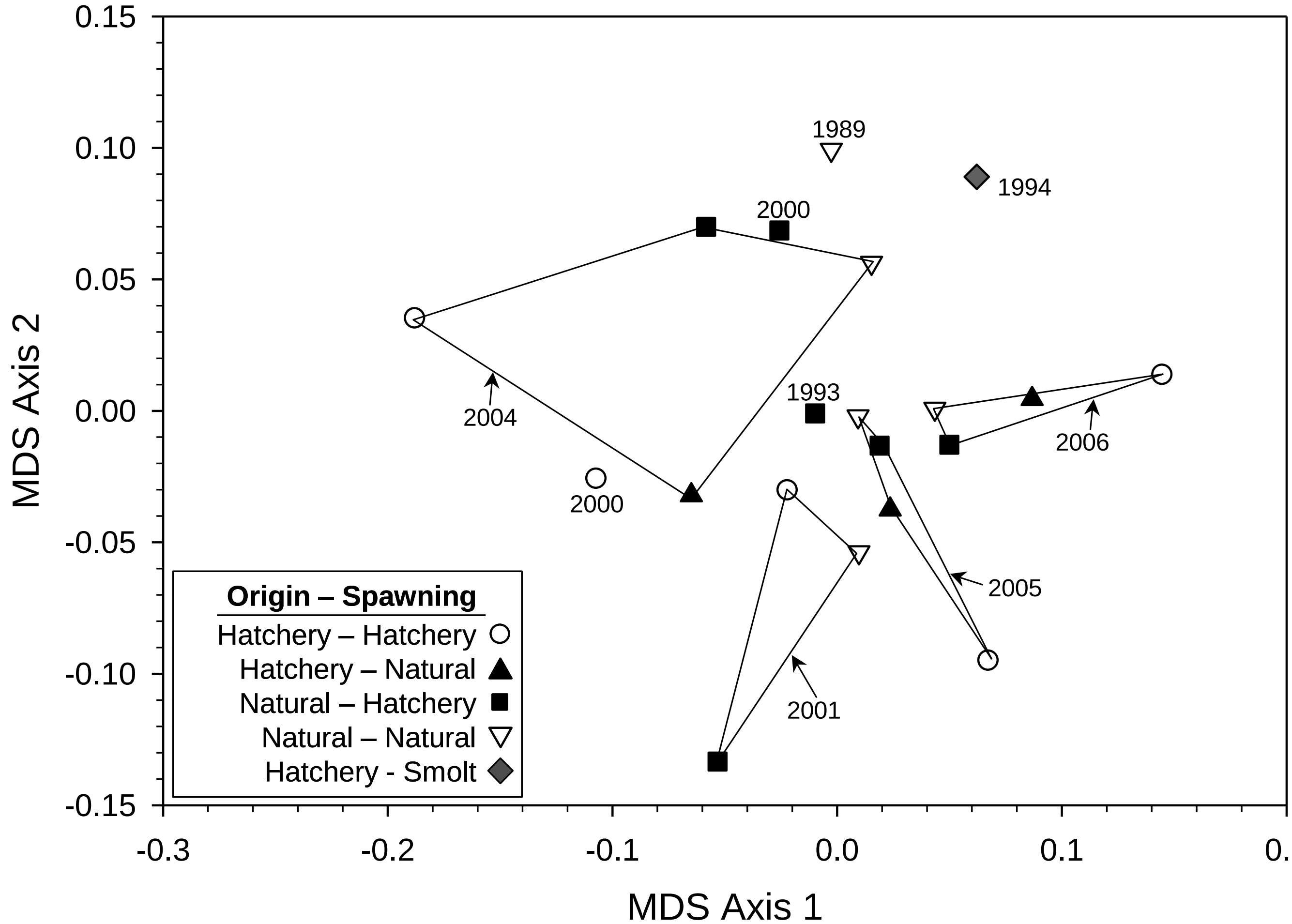

Figure 5. As in Figure 4, but allele-sharing distance matrix recalculated without the five outlier groups shown in Figure 4. Polygons group together treatment groups from the same collection year. Dates associated with symbols also refer to collection year. Collection years 2004-2006 included all four treatment groups, while collection year 2001 did not include a hatchery-origin natural spawner group. Legend is read as follows: Open circles refer to hatchery-origin hatchery spawner group, while filled box refers to natural-origin hatchery spawner group, and so on.

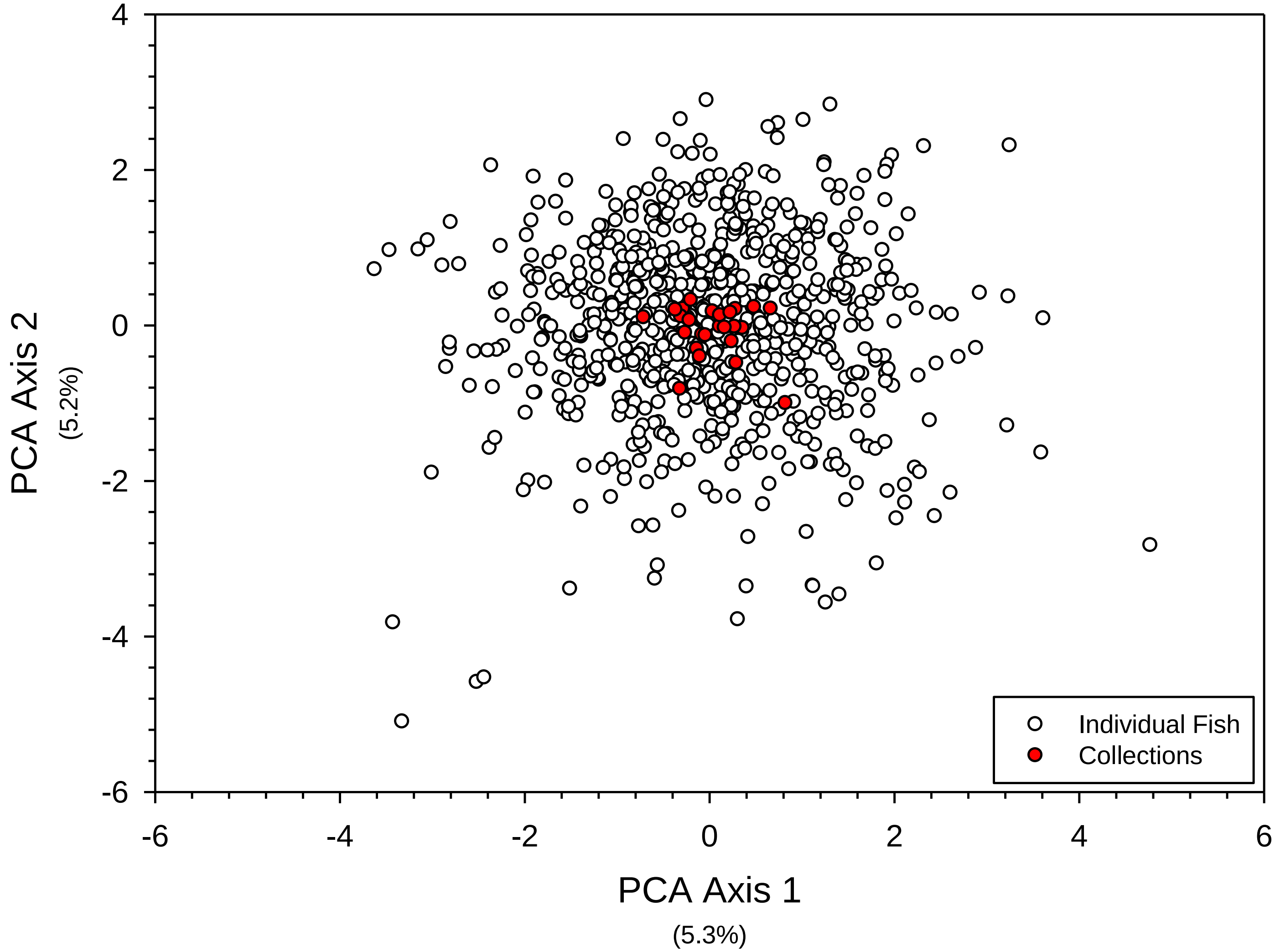

Figure 6. Principal component (PC) analysis of individual fish from the Chiwawa River. Only fish with complete microsatellite genotypes were included in the analysis (n = 757). Open circles are the PC scores for individual fish, and the filled circles are the centroids (bivariate means) for each of the 25 groups discussed in the text. PC axes 1 and 2 account for only 10.5% of the total molecular variance.

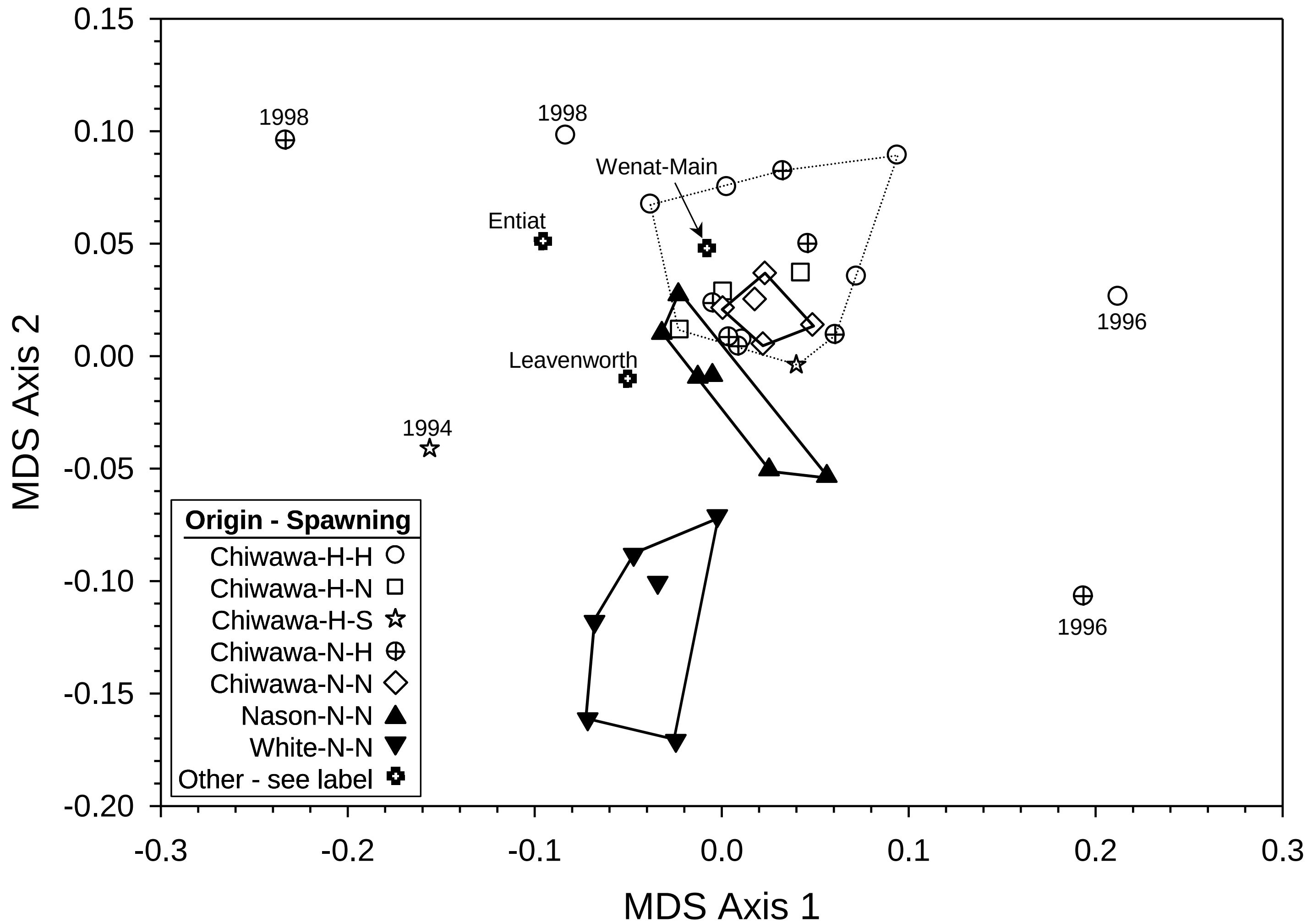

Figure 7. Multidimensional scaling plot from an allele-sharing distance matrix calculated from the Chiwawa origin data set and all other non-Chiwawa collections, except Little Wenatchee River. Legend is read with abbreviations beginning with origin and then spawning location. H=hatchery, N=natural, and S=smolts. Polygons with solid lines enclose the natural-origin natural spawner collections from each population (i.e., river). The polygon with the dotted lines enclose all Chiwawa collections, except for the five outlier collections, as discussed in text.

Table 1 Summary of within population genetic data. Chiwawa collection data are summarized in A) by origin of the sample (i.e., clipped vs. non-clipped). All collection data are summarized in B) by spawning location (i.e., hatchery broodstock or on spawning grounds). Hz is heterozygosity, HWE is the statistical significance of deviations from Hardy-Weinberg expectations (* = 0.05, ** = 0.01, and *** = 0.001), LD is the proportion of pairwise locus tests (across all populations) exhibiting linkage disequilibrium (bolded values are statistically significant), and the last column is mean number of alleles per locus.

Collection	Sample size	Gene Diversity	Observed Hz	HWE	F_{IS}	LD	Mean # Alleles
A) Origin							
1993 Chiwawa Hatchery	95	0.77	0.79	***	-0.02	**0.86**	14.00
1994 Chiwawa Hatchery	95	0.76	0.77	***	-0.01	**0.91**	11.38
1996 Chiwawa Hatchery	8	0.75	0.81	-	-0.01	0.00	8.23
1998 Chiwawa Hatchery	27	0.81	0.82	-	0.00	0.04	12.62
2000 Chiwawa Hatchery	43	0.75	0.78	***	-0.01	**0.19**	12.46
2001 Chiwawa Hatchery	69	0.77	0.80	***	-0.02	**0.14**	15.31
2004 Chiwawa Hatchery	72	0.77	0.77	***	0.01	**0.45**	15.92
2005 Chiwawa Hatchery	91	0.79	0.82	*	-0.03	**0.05**	16.15
2006 Chiwawa Hatchery	95	0.80	0.84	***	-0.05	**0.49**	15.85
1989 Chiwawa Natural	36	0.76	0.78	-	0.01	0.00	12.77
1993 Chiwawa Natural	62	0.78	0.81	-	-0.02	0.04	15.85
1996 Chiwawa Natural	8	0.72	0.78	-	-0.02	0.00	7.54
1998 Chiwawa Natural	10	0.78	0.84	-	0.00	0.00	8.23
2000 Chiwawa Natural	39	0.78	0.79	***	0.00	**0.10**	14.00
2001 Chiwawa Natural	75	0.78	0.80	-	-0.03	0.03	15.31
2004 Chiwawa Natural	85	0.78	0.77	-	0.02	0.01	15.77
2005 Chiwawa Natural	90	0.79	0.79	-	0.01	0.01	16.15
2006 Chiwawa Natural	96	0.80	0.81	-	-0.01	0.01	16.46

Table 1 Within population genetic data analysis summary continued.

Collection	Sample size	Gene Diversity	Observed Hz	HW	F_{IS}	LD	Mean # Alleles
B) Spawning Location							
1993 Chiwawa Broodstock	62	0.78	0.81	-	-0.02	0.00	15.85
1996 Chiwawa Broodstock	16	0.75	0.79	-	-0.02	0.00	10.92
1998 Chiwawa Broodstock	37	0.82	0.83	-	0.00	0.01	14.38
2000 Chiwawa Broodstock	82	0.78	0.78	***	0.00	**0.32**	15.62
2001 Chiwawa Broodstock	89	0.78	0.80	*	-0.02	**0.13**	15.77
2004 Chiwawa Broodstock	61	0.77	0.76	*	0.02	**0.13**	14.92
2005 Chiwawa Broodstock	75	0.79	0.78	*	0.02	0.01	15.85
2006 Chiwawa Broodstock	89	0.80	0.83	-	-0.03	**0.05**	16.46
1989 Chiwawa River	36	0.76	0.78	-	0.01	0.00	12.77
2001 Chiwawa River	55	0.78	0.80	-	-0.02	**0.09**	14.00
2004 Chiwawa River	96	0.78	0.78	*	0.01	**0.18**	17.23
2005 Chiwawa River	106	0.79	0.82	*	-0.02	**0.06**	16.69
2006 Chiwawa River	102	0.80	0.83	***	-0.03	**0.10**	16.77
1989 White River	48	0.75	0.75	-	0.01	0.01	12.85
1991 White River	19	0.76	0.76	-	0.03	0.00	10.92
1992 White River	22	0.75	0.79	-	-0.02	0.01	11.00
1993 White River	21	0.75	0.69	*	0.10	0.00	10.15
2005 White River	29	0.75	0.77	-	-0.01	0.03	12.23
2006 White River	40	0.76	0.76	-	0.01	0.04	13.38

Table 1 Within population genetic data analysis summary continued.

Collection	Sample size	Gene Diversity	Observed Hz	HW	F_{IS}	LD	Mean # Alleles
1993 Little Wenatchee R.	19	0.84	0.85	-	0.02	0.00	11.23
1993 Nason Creek	45	0.78	0.80	-	-0.01	0.01	13.77
2000 Nason Creek	51	0.76	0.78	-	-0.02	**0.13**	13.92
2001 Nason Creek	41	0.79	0.81	-	-0.01	**0.08**	14.23
2004 Nason Creek	38	0.76	0.76	-	0.02	0.03	13.23
2005 Nason Creek	45	0.78	0.82	-	-0.04	0.03	14.92
2006 Nason Creek	48	0.80	0.82	-	-0.01	0.00	15.77
2001 Wenatchee River	32	0.79	0.80	*	0.00	0.04	12.85
2000 Leavenworth NFH	73	0.80	0.82	*	-0.02	**0.15**	16.23
1997 Entiat NFH	37	0.81	0.83	-	-0.01	**0.06**	14.38

Table 2 Demographic data for Chiwawa Hatchery and Chiwawa natural spring Chinook salmon. BS is census size of hatchery broodstock, pNOB is the proportion of hatchery broodstock of natural origin, NOS is the census size of natural-origin spawners present in Chiwawa River, HOS is the census size of hatchery-origin spawners present in Chiwawa River, Total is NOS and HOS combined, and pNOS is the proportion of spawners present in Chiwawa River of natural origin.

	Hatchery		In River			
Brood Year	BS	pNOB	NOS	HOS	Total	pNOS
1989	28	1	1392	0	1392	1.00
1990	18	1	775	0	775	1.00
1991	32	1	585	0	585	1.00
1992	78	1	1099	0	1099	1.00
1993	94	1	677	491	1168	0.58
1994	11	0.64	190	90	280	0.68
1995	0	0	8	50	58	0.14
1996	18	0.44	131	51	182	0.72
1997	111	0.29	210	179	389	0.54
1998	47	0.28	134	45	178	0.75
1999	0	0	119	13	132	0.90
2000	30	0.3	378	310	688	0.55
2001	371	0.3	1280	2850	4130	0.31
2002	71	0.28	694	919	1613	0.43
2003	94	0.44	380	223	603	0.63
2004	215	0.39	820	788	1608	0.51
2005	270	0.33	250	1222	1472	0.17

Table 3 Levels of significance for pairwise tests of genic differentiation among all hatchery- and natural-origin collections used in this analysis. HS = highly significant ($P < 0.000095$; the Bonferroni corrected p-value for an alpha = 0.05); * = $P < 0.05$ (nominal critical value for most statistical test); - = $P > 0.05$ (not significant). A significant result between pairs of populations indicates that the allele frequencies between the pair are significantly different. Results are read by comparing the collections along the rows to collections along columns. The top block for each section is a symmetric matrix, as it compares collections within the same group.

		Chiwawa – Hatchery Origin								
		1993	**1994**	**1996**	**1998**	**2000**	**2001**	**2004**	**2005**	**2006**
Chiwawa – Hat. Origin	**1993**		HS	*	HS	HS	HS	HS	HS	HS
	1994	HS		HS	HS	HS	HS	HS	HS	HS
	1996	*	HS		*	-	*	-	-	*
	1998	HS	HS	*		HS	HS	HS	HS	HS
	2000	HS	HS	-	HS		HS	*	HS	HS
	2001	HS	HS	*	HS	HS		HS	*	HS
	2004	HS	HS	-	HS	*	HS		HS	HS
	2005	HS	HS	-	HS	HS	*	HS		HS
	2006	HS	HS	*	HS	HS	HS	HS	HS	
Chiwawa – Natural Origin	**1989**	HS	HS	-	HS	HS	*	HS	HS	HS
	1993	HS	HS	-	HS	HS	-	HS	*	HS
	1996	*	HS	-	*	-	-	-	-	-
	1998	HS	HS	-	-	HS	*	*	*	-
	2000	HS	HS	-	HS	HS	HS	*	HS	HS
	2001	HS	HS	-	HS	HS	HS	HS	*	HS
	2004	HS	HS	-	HS	HS	HS	HS	HS	HS
	2005	HS	HS	-	HS	HS	*	HS	*	HS
	2006	HS	HS	-	*	HS	HS	HS	HS	HS
Nason	**1996**	HS	HS	-	HS	HS	HS	HS	HS	HS
	2000	HS	HS	*	HS	HS	HS	HS	HS	HS
	2001	HS	HS	-	HS	HS	HS	HS	HS	HS
	2004	HS	HS	-	HS	HS	HS	HS	HS	HS
	2005	HS	HS	-	HS	HS	HS	HS	HS	HS
	2006	HS	HS	-	*	HS	HS	HS	HS	HS
White	**1989**	HS	HS	HS	HS	HS	HS	HS	HS	HS
	1991	HS	HS	-	HS	HS	HS	HS	HS	HS
	1992	HS	HS	*	HS	HS	HS	HS	HS	HS
	1993	HS	HS	*	HS	HS	HS	HS	HS	HS
	2005	HS	HS	-	HS	HS	HS	HS	HS	HS
	2006	HS	HS	HS	HS	HS	HS	HS	HS	HS
Other	**Wen-M**	HS	HS	*	HS	HS	*	*	-	HS
	Leaven	HS	HS	*	HS	HS	HS	HS	HS	HS
	Entiat	HS	HS	*	HS	HS	HS	HS	HS	HS

Table 3 (con't)

		Chiwawa – Natural Origin								
		1989	**1993**	**1996**	**1998**	**2000**	**2001**	**2004**	**2005**	**2006**
Chiwawa – Natural Origin	**1989**		-	-	-	-	*	*	*	*
	1993	-		-	*	*	*	HS	*	HS
	1996	-	-		-	-	-	-	-	-
	1998	-	*	-		*	*	HS	*	*
	2000	-	*	-	*		HS	-	HS	HS
	2001	*	*	-	*	HS		HS	*	HS
	2004	*	HS	-	HS	-	HS		HS	HS
	2005	*	*	-	*	HS	*	HS		*
	2006	*	HS	-	*	HS	HS	HS	*	
Nason	**1996**	*	*	-	*	*	HS	HS	HS	HS
	2000	HS	HS	HS	HS	HS	HS	HS	HS	HS
	2001	HS	*	-	*	HS	HS	HS	HS	HS
	2004	HS	HS	-	HS	HS	HS	HS	HS	HS
	2005	*	*	-	*	HS	HS	HS	HS	HS
	2006	HS	HS	-	-	HS	HS	HS	HS	HS
White	**1989**	HS	HS	*	HS	HS	HS	HS	HS	HS
	1991	HS	HS	*	-	HS	HS	HS	HS	HS
	1992	HS	HS	-	*	HS	HS	HS	HS	HS
	1993	HS	*	-	*	HS	HS	HS	HS	HS
	2005	HS	*	*	*	HS	HS	HS	*	HS
	2006	HS	HS	*	HS	HS	HS	HS	HS	HS
Other	**Wen-M**	*	-	-	-	*	*	HS	*	*
	Leaven	HS	HS	*	*	HS	HS	HS	HS	HS
	Entiat	HS	HS	*	HS	HS	HS	HS	HS	HS

Table 3 (con't)

		Nason					
		1996	2000	2001	2004	2005	2006
Nason	1996		HS	-	HS	-	*
	2000	HS		HS	HS	HS	HS
	2001	-	HS		*	-	*
	2004	HS	HS	*		*	HS
	2005	-	HS	-	*		-
	2006	*	HS	*	HS	-	
White	1989	HS	HS	HS	HS	HS	HS
	1991	*	HS	HS	HS	*	*
	1992	HS	HS	HS	HS	HS	HS
	1993	*	HS	HS	HS	HS	HS
	2005	*	HS	HS	HS	HS	HS
	2006	HS	HS	HS	HS	HS	HS
Other	Wen-M	HS	HS	HS	HS	*	HS
	Leaven	HS	HS	HS	HS	HS	HS
	Entiat	HS	HS	HS	HS	HS	HS

Table 3 (con't)

		White						Other		
		1989	1991	1992	1993	2005	2006	Wen-M 2001	Leaven 2000	Entiat 1997
White	1989		-	*	-	HS	HS	HS	HS	HS
	1991	-		-	-	*	*	*	HS	HS
	1992	*	-		-	*	*	HS	HS	HS
	1993	-	-	-		*	*	HS	HS	HS
	2005	HS	*	*	*		*	HS	HS	HS
	2006	HS	*	*	*	*		HS	HS	HS
Other	Wen-M	HS	*	HS	HS	HS	HS		HS	HS
	Leaven	HS	HS	HS	HS	HS	HS	HS		HS
	Entiat	HS	HS	HS	HS	HS	HS	HS	HS	

Table 4 Probabilities (above diagonal) and levels of significance (below diagonal) for pairwise tests of genic differentiation among all Chiwawa hatchery broodstock and Chiwawa natural spawner collections used in this analysis. HS = highly significant (P < 0.000476; the Bonferroni corrected p-value for an alpha = 0.05); * = P < 0.05 (nominal critical value for most statistical test); - = P > 0.05 (considered not significant). A significant result between pairs of populations indicates that the allele frequencies between the pair are significantly different. Pairwise comparisons between the hatchery broodstock and natural spawner collections from 2001, 2004, 2005, and 2006, respectively, are highlighted.

		Smolt		Hatchery Broodstock								Natural Spawners				
		1993	1994	1993	1996	1998	2000	2001	2004	2005	2006	1989	2001	2004	2005	2006
Smolt	1993		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	1994	HS		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hatchery Broodstock	1993	HS	HS		0.9155	0.0000	0.0073	0.3647	0.0003	0.0694	0.0000	0.2220	0.0039	0.0008	0.0095	0.0000
	1996	HS	HS	-		0.0151	0.8388	0.0452	0.4916	0.3189	0.0716	0.5591	0.0759	0.8101	0.2364	0.0786
	1998	HS	HS	HS	*		0.0000	0.0000	0.0000	0.0000	0.0043	0.0000	0.0000	0.0000	0.0000	0.0005
	2000	HS	HS	*	-	HS		0.0000	0.4720	0.0000	0.0000	0.0036	0.0000	0.0712	0.0000	0.0000
	2001	HS	HS	-	*	HS	HS		0.0000	0.0059	0.0000	0.0003	0.0000	0.0000	0.0126	0.0000
	2004	HS	HS	*	-	HS	-	HS		0.0000	0.0000	0.0001	0.0000	0.0012	0.0000	0.0000
	2005	HS	HS	-	-	HS	HS	*	HS		0.0005	0.0024	0.0137	0.0025	0.7782	0.0018
	2006	HS	HS	HS	-	*	HS	HS	HS	*		0.0000	0.0000	0.0000	0.0000	0.5770
Natural Spawners	1989	HS	HS	-	-	HS	*	*	HS	*	HS		0.0023	0.0317	0.0000	0.0003
	2001	HS	HS	*	-	HS	HS	HS	HS	*	HS	*		0.0000	0.2641	0.0000
	2004	HS	HS	*	-	HS	-	HS	*	*	HS	*	HS		0.0000	0.0000
	2005	HS	HS	*	-	HS	HS	*	HS	-	HS	HS	-	HS		0.0000
	2006	HS	HS	HS	-	*	HS	HS	HS	*	-	*	HS	HS	HS	

Table 5 Analysis of molecular variance (AMOVA) for the Chiwawa collections, showing the partition of molecular variance into (1) within collections, (2) among collections but within group, and (3) among group components. Each column in the table represents a separate analysis testing for differences under a different spatial or temporal hypothesis. The different analyses are grouped together in a single table for comparisons. The values within the table are percentages and the parenthetical values are P-values, or probabilities, associated with that percentage. P-values greater than 0.05 indicate that the percentage is not significantly different from zero. For example, when collections are organized by hatchery- versus natural-origin ("Origin" – fourth column), 0.11% of the molecular variance is attributed to among group (i.e., hatchery- versus natural-origin), which is not significantly different from zero. No collections (first column) indicates no organization or grouping among all collections, and the among-group percentage is equal to the F_{ST} for the entire data set.

	No Structure	Collection Year	Spawning Location	Origin	Origin-Spawning Location
Among Groups	0.26 (0.00)	0.20 (0.43)	0.05 (0.48)	0.11 (0.15)	0.11 (0.06)
Among collections - Within groups	-	0.08 (0.003)	0.24 (0.00)	0.21 (0.00)	0.18 (0.06)
Within collections	99.74 (0.00)	99.72 (0.00)	99.71 (0.00)	99.68 (0.00)	99.71 (0.00)

Table 6 F_{ST} values for all pairwise combinations of populations. Each F_{ST} is the median value for all pairwise combinations of collections within each population (the number of collections within each population is shown parenthetically next to each population name on each row). For example, the F_{ST} for the Chiwawa hatchery versus the White River (0.019) is the median value of 54 pairwise comparisons. The bold values along the center diagonal are the median F_{ST} values within each collection. For those populations with only one collection, the diagonal value was set at 0.000.

	Chiwawa-Hatchery	Chiwawa-Natural	Entiat	Leaven-worth	Nason	Wenatchee-main	White	Little Wenatchee
Chiwawa-Hatchery (9)	**0.013**	0.008	0.016	0.012	0.011	0.005	0.019	0.111
Chiwawa-Natural (9)		**0.003**	0.012	0.011	0.007	0.003	0.014	0.105
Entiat (1)			**0.000**	0.005	0.010	0.008	0.019	0.078
Leavenworth (1)				**0.000**	0.007	0.008	0.014	0.092
Nason (6)					**0.006**	0.008	0.015	0.099
Wenatchee-main (1)						**0.000**	0.012	0.098
White (6)							**0.005**	0.113
Little Wenatchee (1)								**0.000**

Table 7 As in Table 5, except data includes Chiwawa hatchery- and natural-origin, Nason Creek, and White River collections

	All Years	All Years	1989-1996	2005-2006	2005-2006
	No Structure	Origin	Origin	Origin	Collection Year
Among Groups	0.28 (0.00)	0.33 (0.00)	-0.07 (0.67)	0.43 (0.01)	-0.06 (0.57)
Among Collections - Within groups	-	0.04 (0.00)	0.22 (0.00)	0.25 (0.00)	0.64 (0.00)
Within Collections	99.72	99.63	99.85	99.32	99.41

Table 8 Individual assignment results reported are the numbers of individuals assigned to each population using the partial Bayesian criteria of Rannala and Mountain (1997) and a "jack-knife" procedure (see Methods). The population with the highest posterior probability is considered the stock of origin (i.e., no unassigned individuals). Individuals from each population are assigned to specific populations (along rows). Bold values indicate correct assignment back to population of origin. Individuals assigned to a population are read down columns. For example, of the 595 individuals from Chiwawa hatchery origin, 134 individuals were assigned to Chiwawa natural origin (reading across). Of the 511 individuals assigned to Chiwawa natural origin (reading down), 60 were from Nason Creek.

Population	Total	Unassigned	1	2	3	4	5	6	7	8
1) Chiwawa Hatchery	595	0	**371**	134	2	16	0	45	15	12
2) Chiwawa Natural	501	0	156	**269**	4	5	0	42	9	16
3) Entiat	37	0	4	5	**13**	8	0	6	1	0
4) Leavenworth	73	0	9	8	3	**33**	0	17	0	3
5) Little Wenatchee	19	0	0	0	0	0	**19**	0	0	0
6) Nason	268	0	49	60	5	11	0	**131**	1	11
7) Wenatchee Mainstem	32	0	12	9	0	1	0	2	**6**	2
8) White	179	0	22	26	0	2	0	13	1	**115**
TOTAL	1704	0	623	511	27	76	19	256	33	159

Table 9 As in Table 8, except the posterior probability from the partial Bayesian criteria of Rannala and Mountain (1997) must be 0.90 or greater, to be assigned to a population. Those individuals with posterior probabilities less than 0.90 are unassigned.

Aggregate	**Total**	**Unassigned**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1) Chiwawa Hatchery	595	332	**214**	31	1	4	0	10	3	0
2) Chiwawa Natural	501	375	30	**82**	0	1	0	5	2	6
3) Entiat	37	24	1	1	**5**	4	0	2	0	0
4) Leavenworth	73	51	0	1	1	**19**	0	1	0	0
5) Little Wenatchee	19	2	0	0	0	0	**17**	0	0	0
6) Nason	268	188	11	6	2	5	0	**53**	0	3
7) Wenatchee Mainstem	32	23	4	3	0	0	0	0	**2**	0
8) White	179	92	4	3	0	1	0	5	1	**73**
TOTAL	1704	1087	264	127	9	34	17	76	8	82

Table 10 Estimates of N_e based on bias correction method of Waples (2006) implemented in LDNe (Do and Waples unpublished). Collections are categorized by spawning location. Sample size is the harmonic mean of the sample size, 95% CI is the confidence interval calculated using Waples' (2006) equation 12, and Major Cohort assumes that each collection is 100% four-year-olds.

	Sample size	Estimated N_b	95% CI	Major Cohort	Census	N_e/N
1993 Chiwawa Broodstock	58.4	103.1	77.0 - 149.7	1989	1392	0.30
1996 Chiwawa Broodstock	15.5	30.4	19.6 - 58.1	1992	1099	0.11
1998 Chiwawa Broodstock	33.4	37.7	29.8 - 49.7	1994	280	0.54
2000 Chiwawa Broodstock	77.8	48.4	41.4 - 57.2	1996	182	1.06
2001 Chiwawa Broodstock	80.4	49.6	42.2 - 59.2	1997	389	0.51
2004 Chiwawa Broodstock	56.6	48.1	39.0 - 60.9	2000	688	0.28
2005 Chiwawa Broodstock	73	274.3	148.9 - 1131.8	2001	4130	0.27
2006 Chiwawa Broodstock	88.4	198.3	136.1 - 340.5	2002	1613	0.49
1989 Chiwawa River	26.6	5.2	3.9 - 6.3	1985		
2001 Chiwawa River	46.7	38.6	31.0 - 49.3	1997	389	0.40
2004 Chiwawa River	88.5	82.6	67.3 - 104.4	2000	688	0.48
2005 Chiwawa River	104.2	231.5	161.8 - 382.7	2001	4130	0.22
2006 Chiwawa River	101.1	107.3	87.2 - 136	2002	1613	0.27

Table 11 Summary of output from program SALMONNb and data for eight Chiwawa broodstock collections from Wenatchee River. For each pairwise comparison of samples *i* and *j*, $\tilde{S}$ is the harmonic mean sample size, *n* is the number of independent alleles used in the comparison, $\hat{N}_{b(i,j)}$ are the pairwise estimates of N_b, and Var [$\hat{N}_{b(i,j)}$] is the variance of $\hat{N}_{b(i,j)}$. $\tilde{N}_b$ is the harmonic mean of the $\hat{N}_{b(i,j)}$. Alleles with a frequency below 0.05 were excluded from the analysis to reduce potential bias.

Year	1993	1996	1998	2000	2001	2004	2005	2006
Pairwise $\tilde{S}$ (above diagonal) and *n* (below diagonal):								
1993	-	24.5	42.5	66.4	67.2	57.2	64.6	70.3
1996	82	-	21.2	25.8	26.0	24.4	25.6	26.4
1998	80	81	-	46.7	47.2	42.0	45.8	48.4
2000	80	82	84	-	78.6	65.2	75.1	82.7
2001	73	77	81	76	-	66.0	76.2	84.2
2004	77	81	75	76	78	-	63.5	69.0
2005	71	75	82	73	73	69	-	80.0
2006	81	80	84	75	74	75	72	-
Pairwise $\hat{N}_{b(i,j)}$ (above diagonal) and Var [$\hat{N}_{b(i,j)}$] (below diagonal):								
1993	-	-742.7	406.9	1240.8	-5432.0	829.8	808.9	729.0
1996	22491.2	-	110.4	-1786.5	765.9	162.8	824.7	382.7
1998	10910.4	67299.1	-	101.8	237.1	69.6	307.0	140.0
2000	6910.0	742895.8	19122.7	-	490.6	1498.2	706.9	201.6
2001	49318.3	21402.8	9754.2	6126.6	-	307.8	82.0	362.5
2004	8338.4	257267.7	24283.0	145043.4	7095.7	-	269.7	140.1
2005	31511.8	22242.5	10015.8	6596.6	114931.1	8240.4	-	599.6
2006	6223.8	43935.2	73518.7	10152.5	5885.3	12827.0	6370.8	-

$\tilde{N}_b$ = 269.4

Table 12 Summary of output from program SALMONNb and data for five Chiwawa in-river spawner collections from Wenatchee River. For each pairwise comparison of samples *i* and *j*, $\tilde{S}$ is the harmonic mean sample size, *n* is the number of independent alleles used in the comparison, $\hat{N}_{b(i,j)}$ are the pairwise estimates of N_b, and Var [$\hat{N}_{b(i,j)}$] is the variance of $\hat{N}_{b(i,j)}$. $\tilde{N}_b$ is the harmonic mean of the $\hat{N}_{b(i,j)}$. Alleles with a frequency below 0.05 were excluded from the analysis to reduce potential bias.

Year	1989	2001	2004	2005	2006
Pairwise $\tilde{S}$ (above diagonal) and *n* (below diagonal):					
1989	-	33.3	40.2	41.7	42.2
2001	72	-	60.5	63.9	63.3
2004	72	77	-	95.3	94.0
2005	69	72	75	-	102.5
2006	76	76	77	78	-
Pairwise $\hat{N}_{b(i,j)}$ (above diagonal) and Var [$\hat{N}_{b(i,j)}$] (below diagonal):					
1989	-	118.4	299.0	143.3	165.3
2001	40378.8	-	181.7	-1537.3	153.5
2004	10455.2	7265.5	-	387.1	329.4
2005	20923.6	68660.6	5040.7	-	356.8
2006	16227.2	8886.9	3802.0	4522.8	-

$\tilde{N}_b = 224.2$

Table 13 Summary of output from program SALMONNb and data for three brood years that combined Chiwawa natural- and hatchery-origin samples from Wenatchee River. For each pairwise comparison of samples *i* and *j*, $\tilde{S}$ is the harmonic mean sample size, *n* is the number of independent alleles used in the comparison, $\hat{N}_{b(i,j)}$ are the pairwise estimates of N_b, and Var [$\hat{N}_{b(i,j)}$] is the variance of $\hat{N}_{b(i,j)}$. $\tilde{N}_b$ is the harmonic mean of the $\hat{N}_{b(i,j)}$. Alleles with a frequency below 0.05 were excluded from the analysis to reduce potential bias.

Year	2004	2005	2006
Pairwise $\tilde{S}$ (above diagonal) and *n* (below diagonal):			
2004	-	162	164.3
2005	77	-	188.2
2006	76	75	-
Pairwise $\hat{N}_{b(i,j)}$ (above diagonal) and Var [$\hat{N}_{b(i,j)}$] (below diagonal):			
2004	-	611.3	210.8
2005	9351.5	-	727.5
2006	14965.5	8673.9	-
$\tilde{N}_b$ = 386.8			

Appendix L

Fish Trapping at the Nason Creek Smolt Trap 2016

Population Estimates for Juvenile Salmonids in Nason Creek, WA

2016 Annual Report

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ABSTRACT

In 2016, Yakama Nation Fisheries Resource Management (YNFRM) monitored emigration of Endangered Species Act (ESA) listed Upper Columbia River (UCR) spring Chinook salmon and summer steelhead as well as naturally spawned juvenile coho salmon in Nason Creek. This report summarizes juvenile abundance and freshwater survival estimates for each of these species. Fish were captured using a 1.5m rotary smolt trap between March 1 and November 30, 2016. We collected 852 spring Chinook salmon, 672 summer steelhead, 1 bull trout, and 6 coho; all of natural origin and varying age classes. Daily fish abundances for spring Chinook, steelhead, and coho were expanded by stream discharge-to-trap efficiency regression or pooled estimates. All estimates were made with a 95% confidence interval (CI) with total emigration estimates for BY2014 spring Chinook juveniles and coho juveniles of 8,694 (± 5,207) and 223 (± 514), respectively. We estimated the total BY2013 summer steelhead emigration at the trap to be 13,417 (± 3,733). Egg-to-emigrant survival rates for BY2014 spring Chinook and BY2013 summer steelhead were both 1.7%. Productivity, as measured by emigrants-per-redd, for spring Chinook and summer steelhead, was 76 and 99, respectively.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This project is part of a basin-wide monitoring program requiring close coordination between multiple agencies and contractors. We greatly appreciate the hard work of the Yakama Nation Fisheries Resource Management (YNFRM) crew members including Matthew Clubb, Jamie Hallman, Arlene Heemsah, Tim Jeffris, and Kevin Swager who maintained and operated the trap during all hours including nights/weekends and through challenging weather conditions. We would like to also thank the Wenatchee River Ranger District (U.S. Forest Service) and Mr. Duane Bolser for providing use of the trapping site and accommodating the needs of this project as well as to Peter Graf (Grant County PUD) for administering contracting and funding. Finally, thank you to Mike Hughes, Mclain Johnson, Andrew Murdoch, Ben Truscott, and Joshua Williams (Washington Department of Fish and Wildlife), and Tracy Hillman (Bio Analysts, Inc.) for shared data and smolt trap methodologies.

1.0 INTRODUCTION

Beginning in the fall of 2004, Yakama Nation Fisheries Resource Management (YNFRM) began operating a rotary smolt trap in Nason Creek for nine months per year. Prior to 2004, the smolt trap was operated on a limited basis solely for hatchery coho predation studies. This project is a cost share between the YNFRM's Mid-Columbia Coho Reintroduction Program (MCCRP) and Grant County PUD's Hatchery Monitoring Plan. Trap operations were conducted in compliance with ESA consultation specifically to address abundance and productivity of spring Chinook, steelhead trout, and coho salmon in Nason Creek.

Within this document we will report:

1) Juvenile abundance and productivity of spring Chinook salmon (tkwínat) *Oncorhynchus tshawytscha*, steelhead trout (shúshaynsh) *Oncorhynchus mykiss* and coho salmon (súnx) *Oncorhynchus kisutch* in Nason Creek.

2) Emigration timing of spring Chinook salmon, steelhead trout and coho salmon emigrating from Nason Creek.

The data presented will be directly used to address Objective 2 in the Monitoring and Evaluation Plan for PUD Hatchery Programs (Hillman et al. 2015) on a 5-year analytic cycle:

Objective 2: Determine if the proportion of hatchery fish on the spawning grounds affects the freshwater productivity of supplemented stocks (Hillman et al. 2013).

1.1 Watershed Description

The Nason Creek watershed drains 26,547 ha of alpine glaciated landscape where high precipitation and moderate rain on snow recurrence controls the hydrology and aquatic communities. Nason Creek originates near the Cascade crest at Stevens Pass and flows east for approximately 37 river kilometers (rkm) until joining the Wenatchee River at rkm 86.3 just below Lake Wenatchee. Both smolt trap locations employed in 2014 (see section 2.1 Trapping Equipment and Operations) were downstream from the majority of spring Chinook and steelhead spawning grounds (Figure 1). There are 26.4 rkm along the mainstem accessible to anadromous fish in Nason Creek. Private land ownership comprises 21,165 ha (79.7%) of the watershed while 5,180 ha (19.5%) are federal and 194 ha (0.1%) are state owned (USFS et al. 1996).

The channel morphology of the lower 25 rkm of Nason Creek has been impacted by development of highways, railroads, power lines, and residential development resulting in channel confinement and reduced side-channel habitat. The present condition is a low gradient (< 1.1%), low sinuosity (1:2 to 2:0 channel-to-valley length ratio) and depositional channel (USFS et al. 1996). Peak runoff typically occurs in May and June with occasional high water produced by rain on snow events in October and November.

In 2016, mean daily discharge for Nason Creek was 11.1 m^3/s (392 cfs; Figure 2). The onset of spring freshets was unseasonable early in 2016, with peak flows occurring approximately one month earlier than the 12-year mean. Accordingly, this resulted in a prolonged summer base-flow period, as snowpack was deminished at a much faster rate than normal. Fall freshets began in mid-October with a significant spike in flow, followed by normal levels of discharge. Water temperature data for 2016 was not available through Washington State Deportment of Ecology (WDOE).

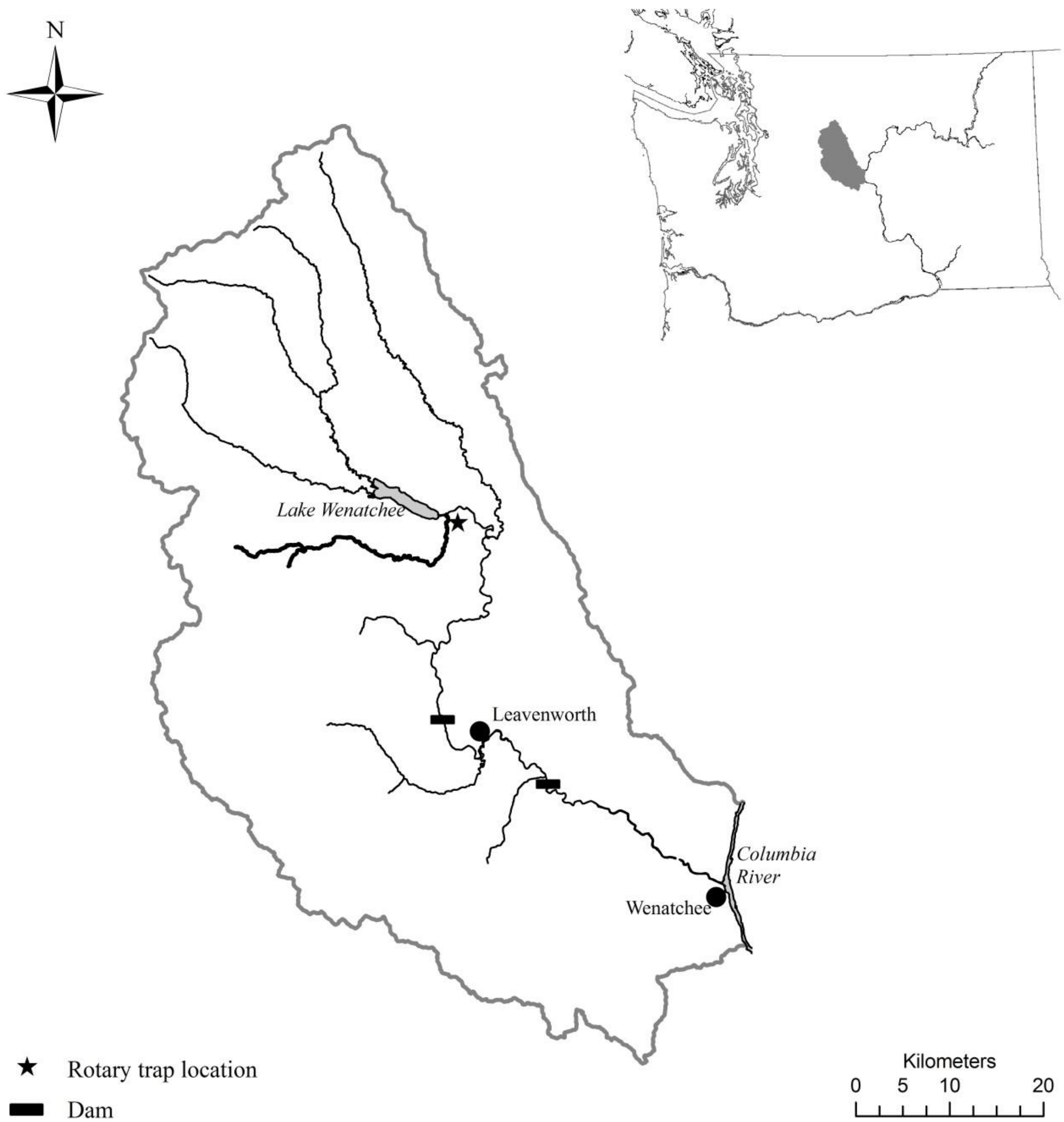


Figure 1. Map of Wenatchee River Subbasin with the Nason Creek rotary trap location.

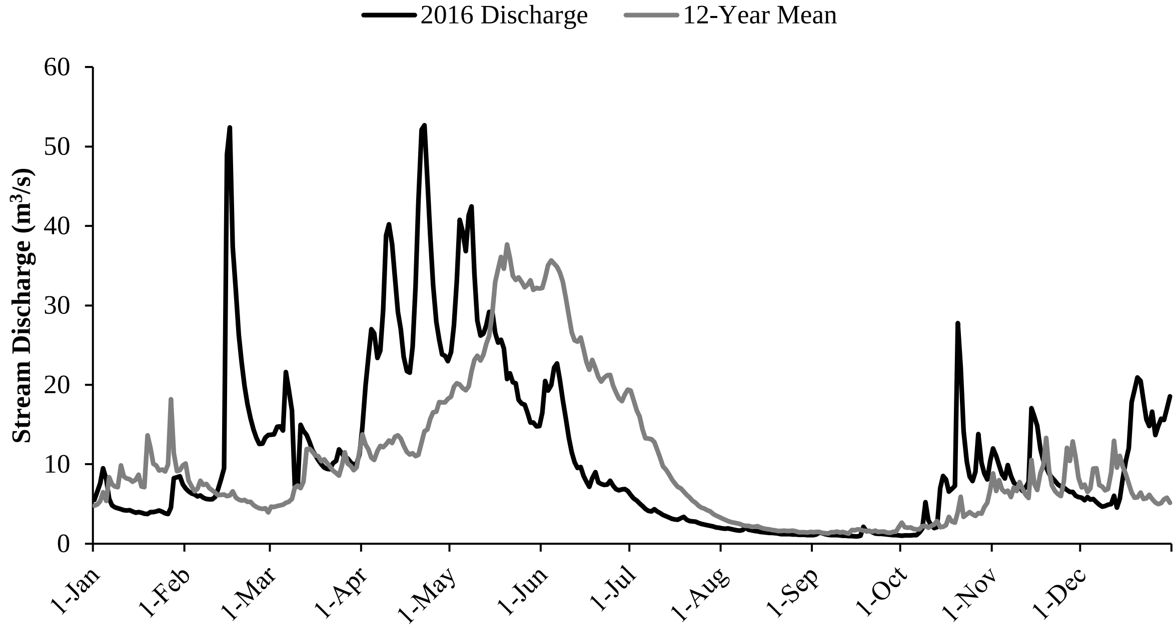


Figure 2. Mean daily stream discharge at the Nason Creek WDOE stream monitoring station in 2016.

2.0 METHODS

2.1 Trapping Equipment and Operation

The smolt trap was operated continually 24 hours per day, 7 days per week when conditions permitted. During spring snowmelt, operations occurred only during hours of darkness in order to minimize trap damage and capture mortality, while retaining the ability to sample during periods of peak fish movement. Without the threat of vandalism posed during periods of peak use at the previously-used campground location, summer operations at the Bolser location were not modified (daytime suspension).

On a daily basis, fish were removed from the primary collection box and retained in separate shore-anchored holding boxes until removed for efficiencies trials. A rotating drum-screen constantly removed small debris from the live box to avoid fish injury. All changes/modifications to the trap as well as periods of stoppage were noted.

2.2 Biological Sampling

Trap operating procedures and techniques followed a standardized basin-wide monitoring plan developed by the Upper Columbia Regional Technical Team (RTT) for the Upper Columbia

Salmon Recovery Board (UCSRB; Hillman 2004), which was adapted from Murdoch and Petersen (2000).

All fish were enumerated by species and size class. Fish to be sampled were anesthetized in a solution of MS-222, weighed with an electronic scale and measured in a wetted trough-type measuring board. Anesthetized fish received air through aquarium bubblers and were allowed to fully recover before being either released downstream of the trap or used in efficiency trials. Fork length (FL) and weight were recorded for all fish except when large numbers of fry or non-target species were collected; a sub-sample of 25 fish were measured and weighed while the remaining fish were tallied. Weight was measured to the nearest 0.1 gram and FL to the nearest millimeter. We used these data to calculate a Fulton-type condition factor (K-factor) using the formula:

$$K = (W/L^3) \times 100{,}000$$

where K = Fulton-type condition metric;
W = weight in grams;
L = fork length in millimeters;
And 100,000 is a scaling constant.

Scale samples were collected from steelhead measuring ≥ 60 mm FL so that age and brood year could be assigned. Samples were collected according to the needs and protocols set by Washington Department of Fish and Wildlife (WDFW), who conducted the analysis and provided YNFRM with results. Tissue samples were collected from spring Chinook and steelhead for DNA analysis. Samples from spring Chinook and steelhead were retained for reproductive success analyses conducted by WDFW and National Marine Fisheries Service (NMFS). All target salmonids were classified as either natural or hatchery origin by physical appearance, presence/absence of coded wire tags (CWTs), or post-orbital elastomer tags. Developmental stages were visually classified as fry, parr, transitional, or smolt. Fry were defined as newly emerged fish with or without a visible yolk sac and a FL measuring < 50 mm. Age-0 coho and spring Chinook salmon captured before July 1 were considered 'fry' and were excluded from subyearling population estimates because of the uncertainty that these fish were actively migrating (UCRTT, 2001).

2.3 PIT Tagging

All natural origin Chinook, steelhead and coho measuring ≥ 60 mm were PIT tagged. Once anesthetized, each fish was examined for external wounds or descaling, then scanned for the presence of a previously implanted PIT tag. If a tag was not detected, a pre-loaded 12mm Digital Angel 134.2 kHz type TX 1411ST PIT tag was inserted into the body cavity using a Biomark MK-25 Rapid Implant Gun. Each unique tag code was electronically recorded along with date of tag implantation, date of fish release, tagging personnel, FL, weight, and anesthetic bath temperature. Data were entered using P3 software and submitted to the PIT Tag Information System (PTAGIS). PIT tagging methods were consistent with methodologies described in the PIT Tag Marking Procedures Manual (CBFWA 1999) as well as in 2008 ISEMP protocols (Tussing 2008).

After marking and sampling, fish were held for a minimum of 24-hours in holding boxes at the trap to; a) ensure complete recovery, b) assess tagging mortality, and c) determine a PIT tag shed rate. Mark groups were released by hand 0.8 rkm above the trap at nautical twilight. At each release, fish were distributed evenly along river-left, and river-right banks in pools and other protected areas. Fish that were not used in mark-recapture trials were released downstream from the trap.

2.4 Mark-Recapture Trials

Groups of marked juveniles were released during a range of stream discharges in order to determine the trapping efficiency. PIT tags were the only method of marking used in 2016. These releases followed the protocols described in Hillman (2004), in which the author suggests a minimum sample size of 100 fish for each mark-recapture trial. Although 100 fish/trial represented the ideal mark group, low abundance of fish often required mark-recapture trials be completed with smaller sample sizes. To achieve the largest marked group possible, we combined catch over a maximum of 72 hours. Fish being held for mark-recapture trials were kept in auxiliary live boxes attached to the end of each pontoon or floating holding boxed anchored to the stream bank. A pre-season, minimum mark group size for each species/life stage was initially determined based on past regression models. In light of high abundance, minimum trial sizes could be raised to a more robust mark group with the intention of strengthening existing regression models.

Each mark-recapture trial was conducted over a three-day (72 hour) period to allow time for passage or capture. Completed trials were only considered invalid if an interruption to trapping occurred or proper pre-release procedures were not followed. Trials resulting in zero recaptures were included in the efficiency regression (if determined valid once vetted through release/recapture protocols) as allowed by the new method of observed trap efficiency calculation. The model used (Bailey) employs use of recaptures +1 in the calculation of efficiency as a mode of bias correction. As a result, even trials yeilding no recaptures can be included in regression modeling (See equation 3 in **2.5.1 Estimate of Abundance**).

In the event that low juvenile abundaces could not provide any opportunities for efficiency trials, releases were performed to allow for a pooled estimate. These releases did not have a minimum size and were released at equal intervals across the migratory period. Pooled estimates at the Nason Creek trap were utilized as an alternative method of estimation prior to the development of a viable regression model.

2.5 Data Analysis

2.5.1 Estimate of Abundance During Smolt Trapping

Seasonal juvenile migration, N, was estimated as the sum of daily migrations, N_i, i.e., $N = \sum_i N_i$, and daily migration was calculated from catch and efficiency:

$$\hat{N}_i = \frac{C_i}{\hat{e}_i}, \quad \textbf{(1)}$$

where C_i = number of fish caught in period *I*;

$\hat{e}_i$ = trap efficiency estimated from the flow-efficiency relationship, $\sin^2(b_0 + b_1 flow_i)$,

where b_0 is estimated intercept and b_1 is the estimated slope of the regression.

The regression parameters b_0 and b_1 are estimated using linear regression for the model:

$$\arcsin\left(\sqrt{e_k^{obs}}\right) = \beta_0 + \beta_1 flow_k + \varepsilon, \quad \textbf{(2)}$$

where e_k^{obs} = observed trap efficiency of Eq. 2 for trapping period *k*;

β_0 = intercept of the regression model;

β_1 = slope parameter;

ε = error with mean 0 and variance σ^2.

In Equation 2, the observed trap efficiency, e_k^{obs}, is calculated as follows,

$$e_k^{obs} = \frac{r_k + 1}{m}. \quad \textbf{(3)}$$

The estimated variance of seasonal migration is calculated from daily estimates as:

$$Var\left(\sum_{i=1}^{n} \hat{N}_i\right) = \underbrace{\sum_i Var(N_i)}_{Part\ A} + \underbrace{\sum_i \sum_j Cov(N_i, N_j)}_{Part\ B},$$

or,

$$Var\left(\sum_{i=1}^{n} \hat{N}_i\right) = \underbrace{\sum_i Var\left(\frac{(C_i + 1)}{\hat{e}_i}\right)}_{Part\ A} + \underbrace{\sum_i \sum_j Cov\left(\frac{(C_i + 1)}{\hat{e}_i}, \frac{(C_j + 1)}{\hat{e}_j}\right)}_{Part\ B}. \quad \textbf{(4)}$$

Part A of equation 4 is the variance of daily estimates. Part B is the between-day covariance. Note that the between-day covariance exists only for days that use the same trap efficiency model. If, for example, day 1 is estimated with one trap efficiency model, and day 2 estimated from a different model, then there is no covariance between day 1 and day 2. The full expression for the estimated variance:

$$\hat{Var}\left(\sum_{i=1}^{n}\hat{N}_i\right)=\underbrace{\sum_i \hat{N}_i^2\left(\frac{N_i\hat{e}_i(1-\hat{e}_i)}{(C_i+1)^2}+\frac{4(1-\hat{e}_i)}{\hat{e}_i}\hat{Var}(b_0+b_1\,flow_i)\right)}_{PartA}+$$
$$\underbrace{\sum_i\sum_j 4\left(\hat{N}_i(1-\hat{e}_i)\right)\left(\hat{N}_j(1-\hat{e}_j)\right)\cdot\left[\hat{V}ar(b_0)+flow_i\,flow_j\hat{V}ar(b_1)\right]}_{PartB}$$

where $\hat{Var}(b_0+b_1\,flow_i)=M\hat{S}E\left(1+\frac{1}{n}+\frac{(flow_i-\overline{flow})^2}{(n-1)s_{flow}^2}\right)$, and $\hat{V}ar(b_0)$ and $\hat{V}ar(b_1)$ are

obtained from regression results. In Excel, the standard error (SE) of the coefficients is provided. The variance is calculated as the square of the standard error, SE^2.

In cases when there was no significant flow-efficiency relationship (i.e., low correlation), then a pooled, or average trap efficiency will suffice for the stratum. The estimator is calculated as follows:

$$\hat{\hat{e}}=\frac{\sum_{j=1}^{k}r_j}{\sum_{j=1}^{k}m_j}$$

where $\hat{\hat{e}}$ = the average or pooled trap efficiency for the stratum;
m_j = the number of smolts marked and released in efficiency trial j for the stratum;
r_j = the number of smolts recaptured out of m_j marked fish in efficiency trial j.

Abundance for a trapping period is estimated as:

$$\hat{N}_i^{pooled}=\frac{C_i}{\hat{\hat{e}}},$$

,and total stratum abundance is:

$$N^{pooled}=\sum_i \hat{N}_i^{pooled}.$$

The variance of seasonal abundance takes into account the variability in catch numbers that are a result of binomial sampling (Part A), the pooled variance of trap efficiency, $\hat{\hat{e}}$ (Part B), and the covariance in daily estimates that arises from using a common estimate of efficiency across all trapping days (Part C):

$$V\hat{a}r\left(\sum_{i=1}^{n}\hat{N}_i^{pooled}\right)=\underbrace{\left(\sum_i \frac{\hat{N}_i\left(1-\hat{\bar{e}}\right)}{\hat{\bar{e}}}\right)}_{PartA}+\underbrace{\frac{Var\left(\hat{\bar{e}}\right)}{\hat{\bar{e}}^2}\sum_i \hat{N}_i^2}_{PartB}+\underbrace{\frac{Var\left(\hat{\bar{e}}\right)}{\hat{\bar{e}}^2}\sum_i\sum_j \hat{N}_i\hat{N}_j}_{PartC}.$$

The Part B and Part C terms are combined in the calculation as a new Part B:

$$V\hat{a}r\left(\sum_{i=1}^{n}\hat{N}_i^{pooled}\right)=\underbrace{\left(\sum_i \frac{\hat{N}_i\left(1-\hat{\bar{e}}\right)}{\hat{\bar{e}}}\right)}_{PartA}+\underbrace{\frac{Var\left(\hat{\bar{e}}\right)}{\hat{\bar{e}}^2}\left[\sum_i \hat{N}_i^2+\sum_i\sum_j \hat{N}_i\hat{N}_j\right]}_{PartB}.$$

The variance of $\hat{\bar{e}}$ is calculated as:

$$V\hat{a}r\left(\hat{\bar{e}}\right)=V\hat{a}r\left(\frac{\sum_{k=1}^{n} r_k}{\sum_{k=1}^{n} m_k}\right)=\frac{\sum_{k=1}^{n}\left(r_k-\hat{\bar{e}}_k m_k\right)^2}{\overline{m}^2 n(n-1)}$$

where $\overline{m}$ is the average release size across all efficiency trial, $\frac{\sum_{k=1}^{n} m_k}{n}$.

Confidence intervals were calculated using the following formulas:

95% confidence interval = $1.96\times\sqrt{\sum \mathrm{var}\left[\hat{N}_i\right]}$

The single M-R estimator of abundance carries a set of well documented assumptions (Everhart and Youngs 1981; Seber 1982),

1. The population is closed to mortality.
2. The probability of capturing a marked or unmarked fish is equal.
3. Marked fish were randomly dispersed in the population prior to recapture.
4. Marking does not affect probabilities of capture.
5. Marks were not lost between the time of release and recapture.
6. All marks are reported upon recapture.
7. The number of fish in the trap, C, is fully enumerated and known without error.

2.5.2 Estimate of Abundace During Trap Stoppages and Suspended Operations

Daily catch during stoppages of seven days or less was estimated by averaging catch three days prior to, and after the discreet non-trapping event and then applying that value to the consecutive days without operation. This method had been used consistently in the past given the duration of the stoppage is limited, and is applied to all target species.

For periods of suspended trapping longer than seven days, a methodology developed and currently employed by local WDFW smolt trap operators was used (J. Williams, personal communication, March 8, 2017). This method uses historic run-timing to determine the proportion of the entire emigrant estimate missed during the period of suspended trapping. Once determined, the estimated percentage can be used with in-year data to extrapolate how many fish were missed. This method is used exclusively during the fall migratory period, when low summer flows commonly result in extended stoppages. Because steelhead are considered non-migratory during this period, this type of estimate was only applied to spring Chinook subyearlings.

2.5.3 Estimate of Abundance During The Winter Non-Trapping Period

An estimate of spring Chinook emmigration during the non-trapping period (December 1 through February 28) was calculated using remote-tagged spring chinook parr and the lower Nason Creek PIT tag array (NAL). A flow-detection efficiency regression was developed using mark-groups previously released to test the efficiency of the smolt trap. Daily spring Chinook detections at the NAL array and the developed regression were then applied to the Bailey estimator, as was peformed with daily trap abundance data (See equation **2.5.1 Estimate of Abundance**). Tag rate determined at the Nason Creek smolt trap was used to account for unmarked emmigrants passing the NAL array.

Tag rate, t_i, was calculated as:

$$t_i = \frac{t}{p}$$

where t = total smolt trap recaptures subsequent to the tagging effort;
p = total catch at the smolt trap.

Daily abundace during the non-trapping period is calculated as:

$$\hat{N}_i = \left(\frac{C_i}{\hat{e}_i}\right) \Big/ t_i \,,$$

where C_i = number of fish caught in period I;
$\hat{e}_i$ = trap efficiency estimated from the flow-efficiency relationship, $\sin^2(b_0 + b_1 flow_i)$;
t_i = tag rate.

2.5.4 Production and Survival

Production estimates by age class were summed to produce a total emigration estimate. For spring Chinook and coho, estimates of fall migrant parr were added to subsequent spring smolt estimates to generate a single brood year estimate. For steelhead, a single brood year may require up to three years for emigration from Nason Creek to occur. Pending scale analysis, steelhead captured in 2016 were aged via an age-length histogram built upon previously analyzed scale samples. For all three species, egg-to-emigrant estimates were calculated by dividing estimated emigrants by approximated egg deposition during a spawning brood (average fecundity used to determine egg deposition derived from WDFW Chiwawa broodstock spawning). The number of emigrants-per-redd for each brood year was calculated by dividing the total emigrant estimate by the number of redds counted during spawning ground surveys.

3.0 RESULTS

3.1 Dates of Operation

The Nason Creek smolt trap was installed on February 25, and operated in its fixed position for the entirety of the trapping season (March 1 to November 30). Removal of the trap occurred on December 5. We attempted to run the trap continuously 24 hours a day, 7 days per week. Intentional suspension of trapping activities occurred for two periods in the summer-early fall due to base flows (July 31 – August 8 and August 10 - October 9; Table 1). Pulling of the trap also occurred on October 21 as a precautionary measure during a high-water event.

Table 1. Summary of Nason Creek rotary trap operation.

Date of Trap Operations	Trap Status	Description	Days
March 1 to June 30	Operating	Continuous data collection	120
	Interrupted	Interrupted by debris	2
	Pulled	Intentionally pulled due to high flow, low flow, or heavy debris load	0
July 1 to November 30	Operating	Continuous data collection	76
	Interrupted	Interrupted by debris	6
	Pulled	Intentionally pulled due to high flow, low flow, or heavy debris load	71

3.2 Daily Captures and Biological Sampling

3.2.1 Spring Chinook Yearlings (BY2014)

Between March 1 and June 30, a total of 61 wild Chinook yearlings were captured at the trap (Figure 3). A peak catch of 12 yearling smolts coincided with a secondary spike in discharge occurring in early April. Following this peak, catch dropped substantially with the last emigrating Chinook yearling captured on April 8. Mean FL and weight for Chinook yearlings was 96 mm (*n* = 61; *SD* = 5.5) and 9.0 g (*n* = 61; *SD* = 1.7; Table 2), respectively. Tissue samples were collected from 61 fish for an ongoing, parental-based DNA analysis by WDFW. There were no wild spring Chinook mortalities.

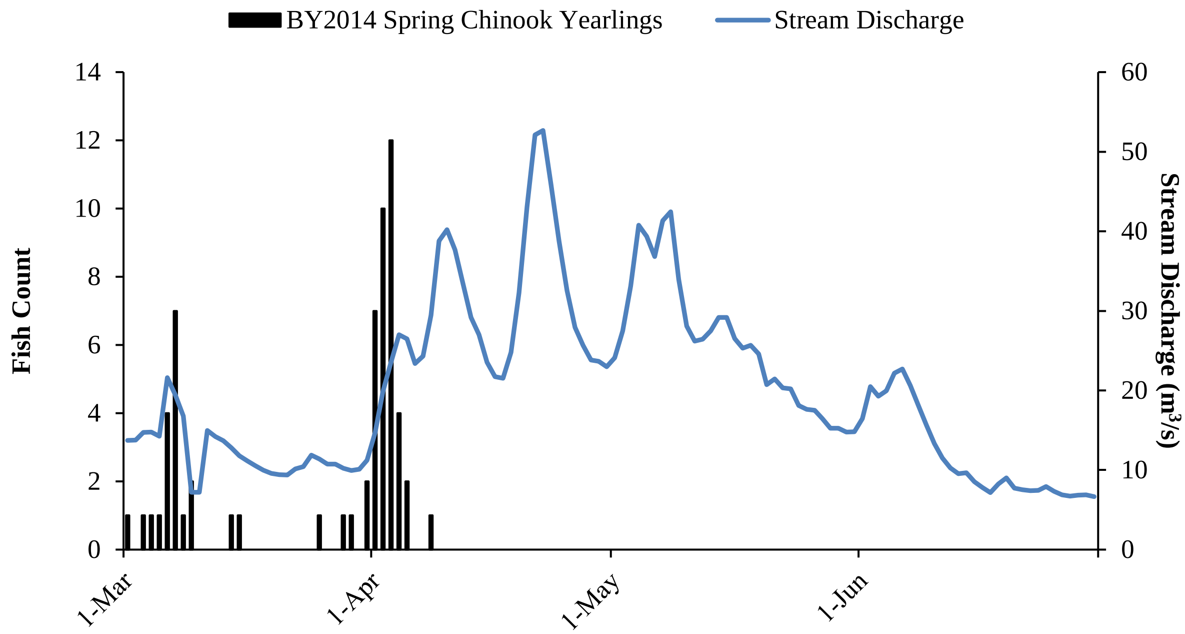


Figure 3. Daily catch of BY2014 spring Chinook yearlings with mean daily stream discharge at the Nason Creek rotary trap, March 1 to June 30, 2016.

Table 2. Summary of length and weight sampling of juvenile spring Chinook captured at the Nason Creek rotary trap in 2016.

Brood Year	Origin/Species/Stage	Fork Length (mm) Mean	*n*	SD	Weight (g) Mean	*n*	SD	K-Factor
2014	Wild Spring Chinook Yearling Smolt	96	61	5.5	9.0	61	1.7	1.01
2015	Wild Spring Chinook Subyearling Fry	38	285	3.0	0.5	285	0.2	0.78
2015	Wild Spring Chinook Subyearling Parr	85	491	12.7	6.9	490	2.5	1.07
2014	Hatchery Spring Chinook Yearling Smolt	119	87	13.5	19.6	87	7.6	1.09

3.2.2 Spring Chinook Subyearlings (BY2015)

A total of 491 wild spring Chinook subyearling parr (FL ≥ 50 mm) and 300 subyearling fry (FL < 50 mm) were captured in 2016 (Figure 4). The majority of parr movement was documented in late October following the first fall freshets. Mean FL and weight among subyearling parr was 85 mm (*n* = 491; *SD* = 12.7) and 6.9 g (*n* = 490; *SD* = 2.5), respectively. We estimate that an additional 20 Chinook subyearling parr would have been captured during short stoppages (≤7 days) had the trap run without interruption. Daily catch estimates were not made during the two periods of suspended trapping; total emmigrant estimates for these two periods will be included in section 3.4.2. Tissue samples were collected from 431 fish for an ongoing, parental-based DNA analysis by WDFW. Six subyearling Chinook (four fry and two parr) mortalities occurred in 2016. All deaths were attributed to trapping.

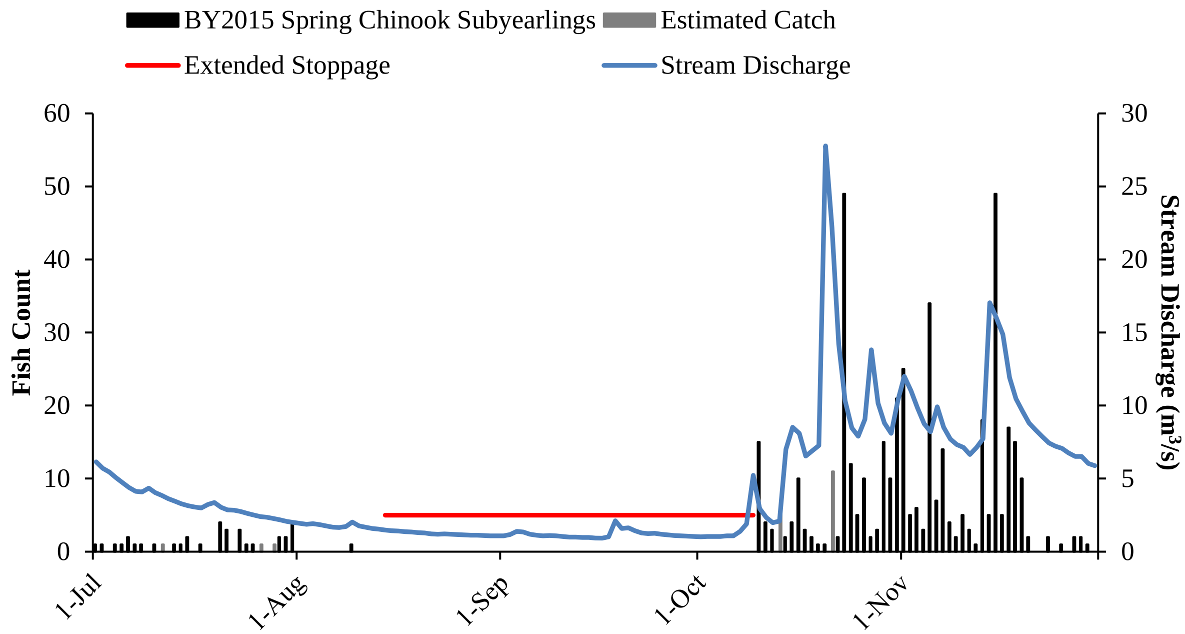


Figure 4. Daily catch of BY2015 spring Chinook subyearlings with mean daily stream discharge at the Nason Creek rotary trap, July 1 to November 30, 2016.

3.2.3 Hatchery Spring Chinook Smolts (BY2014)

In the spring of 2016, 31,651 hatchery spring Chinook smolts were released into Nason Creek. All hatchery spring Chinook were released directly from the Grant County Public Utility District (GCPUD) Nason Creek Acclimation Facility located at rkm17.3. Subsequently, a total of 124 smolts were captured with a mean FL and weight of 119 mm (*n* =87; *SD* = 13.5) and 19.6 g (*n* = 87; *SD* = 7.6), respectively (Figure 5). Hatchery spring Chinook were not captured at the smolt trap beyond June 3. There were no mortalities incurred.

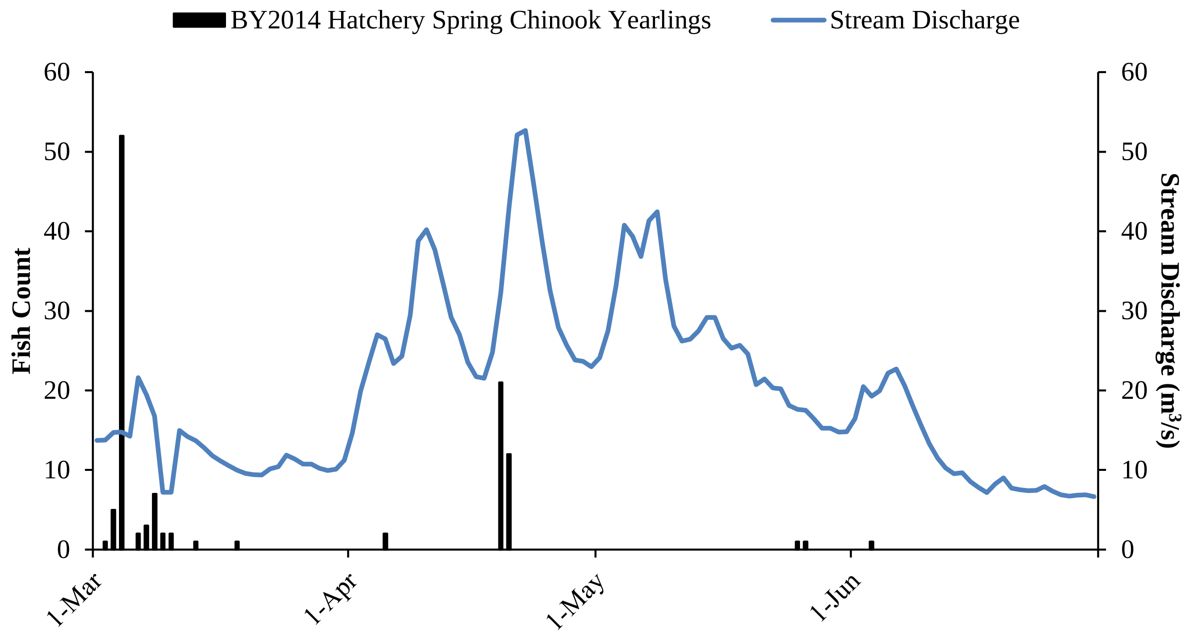


Figure 5. Daily catch of BY2014 hatchery spring Chinook smolts with mean daily stream discharge at the Nason Creek rotary trap, March 1 to June 30, 2016.

3.2.4 Summer Steelhead

A total of 1,007 wild summer steelhead juveniles were captured throughout the season from March 1 to November 30, with a peak catch of 79 juveniles on August 9 (Figs. 6&7). We estimated that an additional 6 age-1 juveniles would have been captured had there been no interruptions to trapping during the migratory period (Mar 1 to July 31). Histogram analysis of known steelhead ages sampled from 2005 to 2014 allowed us to estimate ages of fish captured in 2016 using FL. We estimate that of the total steelhead captured, 702 were young-of-the-year, 285 were age-1, 19 were age-2, and 1 was age-3. Subyearling steelhead had a mean FL of 56mm (n = 674; SD = 16.4), and a mean weight of 2.4 (n = 617; SD = 1.8). The majority of steelhead juveniles captured were age-1 parr emigrating past the trap in spring. Mean FL and weight of age-1 fish was 87 mm (n = 278; SD = 21.5; Table 3) and 8.3 g (n = 278; SD = 5.9), respectively. Age-2 steelhead were caught primarily in the spring, with only two fish being captured after July 31. Mean FL and weight of age-2 fish was 143 mm (n = 19; SD = 17.4) and 31.1 g (n = 19; SD = 9.6), respectively. A single age-3 fish with a FL of 202 mm and weight of 90.1 g was also captured. Scales were taken from a sub-sample (n = 141) to be used for future age analyses. One mortality was incurred (See **3.6 ESA Compliance**).

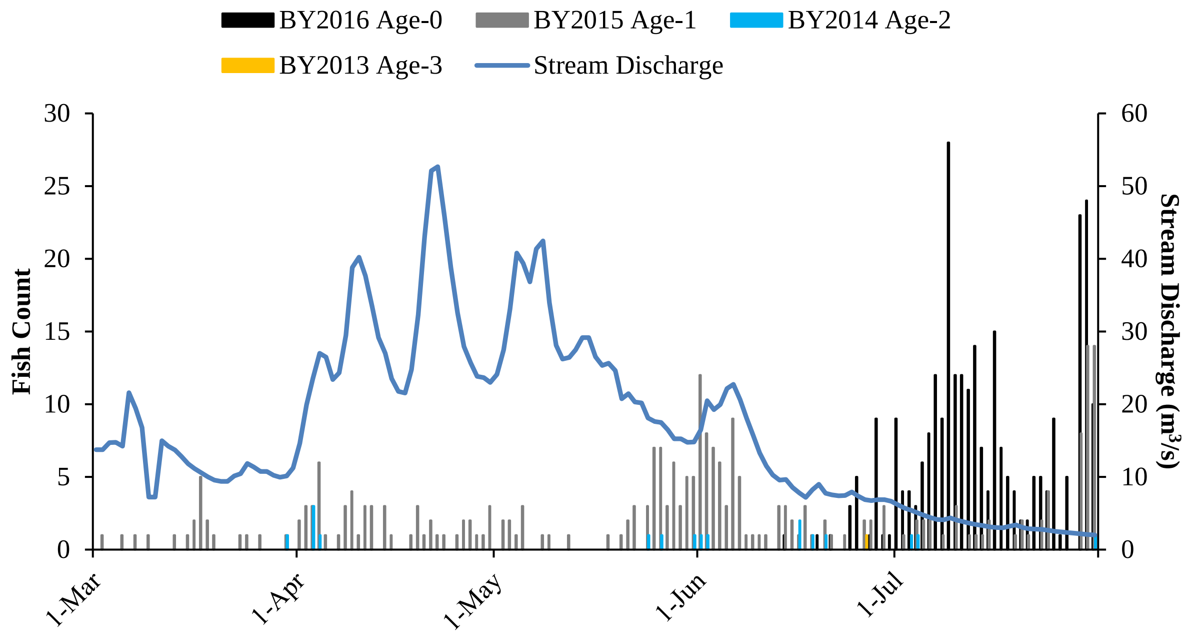


Figure 6. Daily catch of wild summer steelhead with mean daily stream discharge at the Nason Creek rotary trap, March 1 to July 31, 2016. Estimates of fish passage during trap interruptions are not depicted.

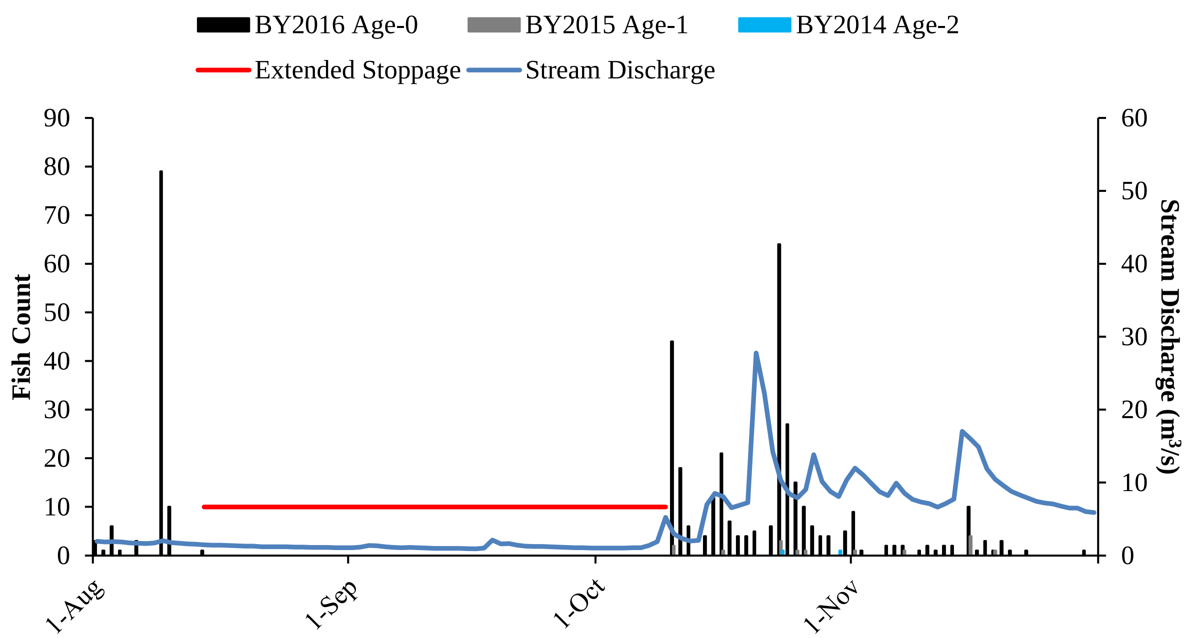


Figure 7. Daily catch of wild summer steelhead with mean daily stream discharge at the Nason Creek rotary trap, August 1 to November 30, 2016. Estimates of fish passage during trap interruptions are not depicted.

Table 3. Summary of length, weight and condition factor by age class of wild summer steelhead emigrants and hatchery steelhead captured at the Nason Creek rotary trap.

Brood Year	Origin/Species/Stage	Fork Length (mm)			Weight (g)			K-Factor
		Mean	*n*	SD	Mean	*n*	SD	
2016	Wild Summer Steelhead (Age-0)	56	674	16.4	2.4	617	1.8	1.02
2015	Wild Summer Steelhead (Age-1)	87	278	21.5	8.3	278	5.9	1.05
2014	Wild Summer Steelhead (Age-2)	143	19	17.4	31.1	19	9.6	1.04
2013	Wild Summer Steelhead (Age-3)	202	1	—	90.1	1	—	1.09
2015	Hatch. Summer Steelhead Smolt	175	95	15.5	55.1	95	16.2	0.99

3.2.5 Hatchery Steelhead Smolts (BY2015)

During April and May, WDFW directly planted a total of 55,105 hatchery summer steelhead smolts into Nason Creek above the smolt trap (M. Babiar, personal communication, February 8, 2017). Subsequently, a total of 98 hatchery steelhead were captured at the smolt trap with a mean FL and weight of 175 mm (n =95; SD = 15.5) and 55.1 g (n = 95; SD = 16.2), respectively (Figure 8). The last hatchery smolt was caught on June 14. Hatchery origin was determined by the presence of coded wire tags (CWT). There were no hatchery-origin steelhead smolt mortalities.

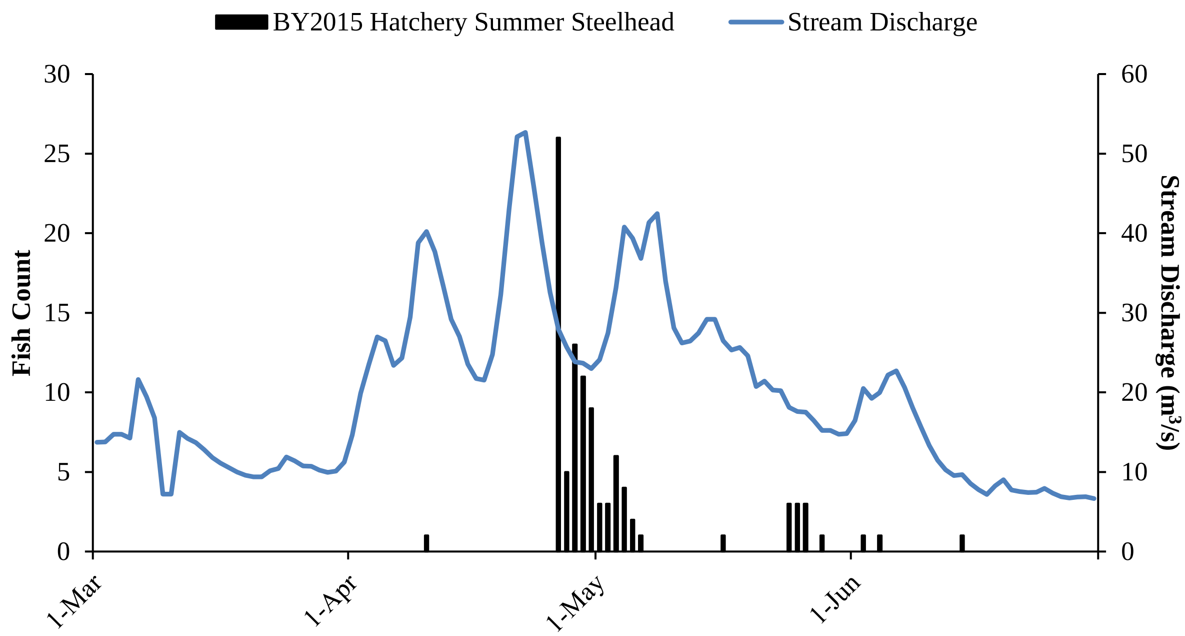


Figure 8. Daily catch of BY2015 hatchery steelhead smolt with mean daily stream discharge at the Nason Creek rotary trap, March 1 to June 30, 2016.

3.2.6 Bull Trout

Bull trout presence at the trap in 2016 was limited to a single fish with a FL of 199 mm and weight of 70.0 g. The bull trout was released immediately after morphometric measurements were taken. No other sampling/tagging activities were performed.

3.2.7 Coho Yearlings (BY2014)

Six naturally-produced coho yearlings were captured during spring emigration between March 1 and June 30 (Figure 9). Their mean FL and weight was 100 mm (n = 6; SD = 15.8) and 11.1 g (n = 6; SD = 5.5), respectively (Table 4). Scale and tissue samples were not taken from naturally-produced coho smolts in 2016. There were no coho yearling mortalities.

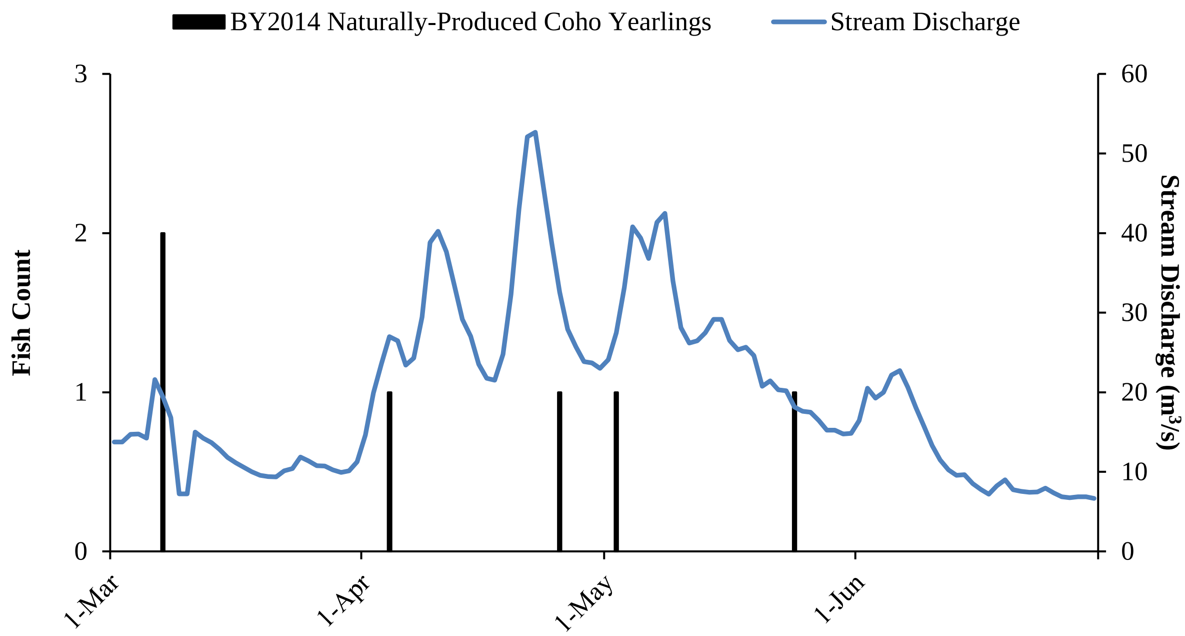


Figure 9. Daily catch of BY2014 naturally-produced coho yearlings with mean daily stream discharge at the Nason Creek rotary trap, March 1 to June 30, 2016.

Table 4. Summary of length and weight sampling of juvenile coho salmon captured at the Nason Creek rotary trap in 2016.

Brood Year	Origin/Species/Stage	Fork Length (mm)			Weight (g)			K-Factor
		Mean	*n*	SD	Mean	*n*	SD	
2013	Naturally Produced Coho Yearling Smolt	100	6	15.8	11.1	6	5.5	1.03
2013	Hatchery Coho Yearling Smolt	134	302	8.4	24.8	301	5.0	1.02

3.2.8 Coho Subyearlings (BY2015)

There were no BY2015 naturally-produced coho fry or parr captured at the Nason Creek smolt trap in 2016.

3.2.9 Hatchery Coho Smolts (BY2014)

A total of 276,063 hatchery coho were released into Nason Creek above the trap in spring of 2016. All hatchery coho released were acclimated in natural ponds adjacent to Nason Creek and reared to smolt stage prior to volitional release. Between March 1 and June 30, a total of 343 hatchery coho were captured at the trap (Figure 10). Mean FL was 134 mm (*n* = 302; *SD* = 8.4) and mean weight was 24.8 g (*n* = 301; *SD* = 5.0; Table 2). A peak daily catch of 45 hatchery coho smolts occurred on April 29 following volitional release into Nason Creek. Two trapping mortalities were incurred. Hatchery coho emigration data at the Nason Creek trap assists the MCCRP by providing size-at-emigration, emigration timing and duration of residence in Nason Creek.

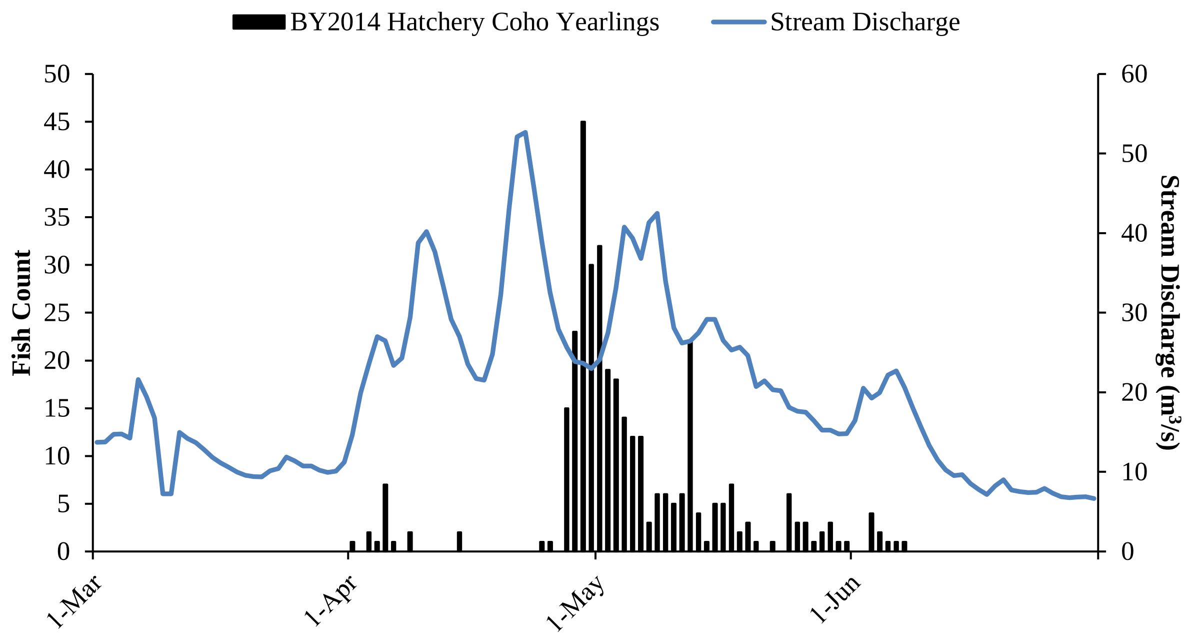


Figure 10. Daily catch of BY2014 hatchery coho smolt with mean daily stream discharge at the Nason Creek rotary trap, March 1 to June 30, 2016.

3.3 Remote Parr Tagging (BY2014 Spring Chinook)

YNFRM and WDFW personnel PIT tagged and released a total of 1,214 BY2014 spring Chinook parr between September 23 and October 15, 2015. The total surveyed area included Nason Creek from rkm 0.8 to 26.1. All collections were performed via backpack electrofisher. Equal capture effort (measured in electrofisher seconds used) was applied across all reaches.

Between October 1 and March 30, a total of 100 re-sights of the remote tagged spring Chinook were documented at the NAL array (Figure 11). Of these detections, only two were during the winter non-trapping period. High flows in November caused significant damages to the NAL array, resulting in antennas 1, 5, and 6 being inoperable throughout the non-trapping period (J. Deason Personal Communication, February 10, 2016).

Subsequent to the remote tagging effort, five remote-tagged BY2014 spring Chinook were recaptured at the Nason Creek smolt trap. Total spring Chinook catch at the smolt trap was 255 emigrants during the same period. The pooled tag rate for remote-tagged spring Chinook captured at the Nason smolt trap was 2.0%.

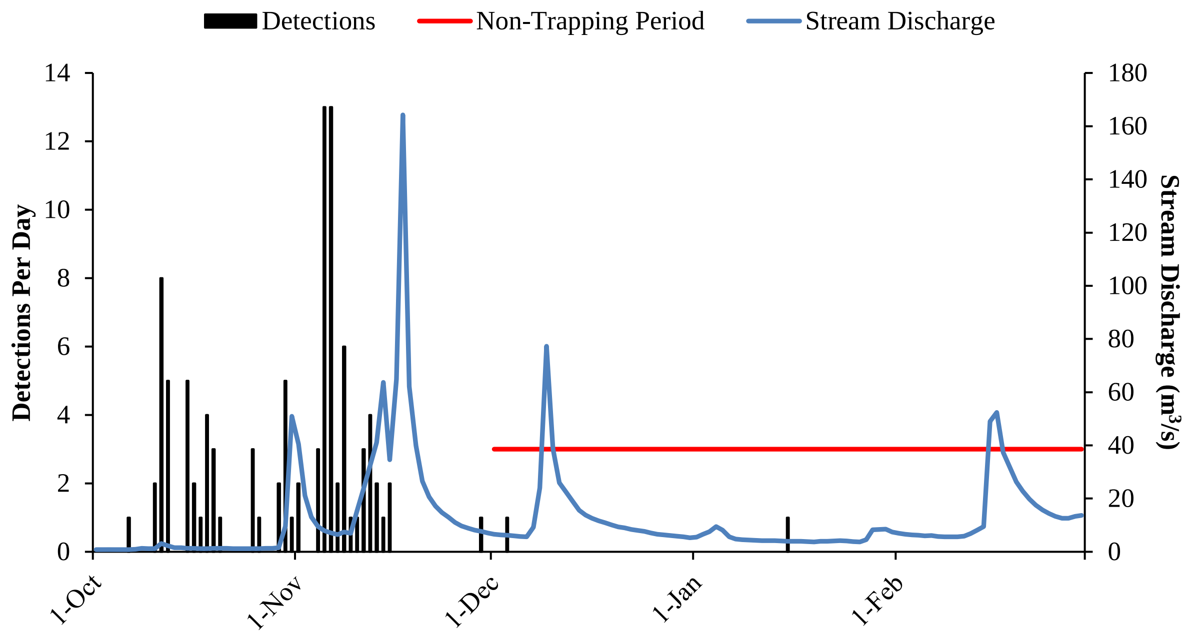


Figure 11. Daily detections of remote-tagged BY2014 spring Chinook at the lower Nason Creek PIT tag antenna array (NAL) between October 2015 and March 2016.

3.4 Trap Efficiency Calibration and Population Estimates

3.4.1 Spring Chinook Yearlings (BY2014)

Infrequent releases, low abundance, and a lack of recaptures did not allow a flow-efficiency model to be used on BY2014 yearling emigrants. In order to produce an estimate, a pooled efficiency (6.6%) composed of spring Chinook yearling releases in 2016 was used (Table 5). We recognize the sub-optimal nature of this estimation methodology, and will recalculate the estimates using linear regression analysis as soon as feasible. We estimated a total of 930 (± 5,083; 95% CI) BY2014 spring Chinook yearlings emigrated in spring of 2016 (Table 6). Parr emmigration during the non-trapping period was estimated using a flow-efficiency regression ($r^2 = 0.38$; $p = 0.007$) based on detections at the NAL pit tag array. This antenna efficiency is solely based on detections made on the three antennas that were functional during winter of 2016. We estimated that 1,442 (± 1,297; 95% CI) BY2013 spring Chinook emigrated out of Nason Creek during the non-trapping period. Combined with a recalculated BY2014 subyearling estimate of 8,694 (± 5,207; 95% CI), we estimated that a total of 7,280 (± 5,197; 95% CI) BY2014 spring Chinook juveniles emigrated from Nason Creek.

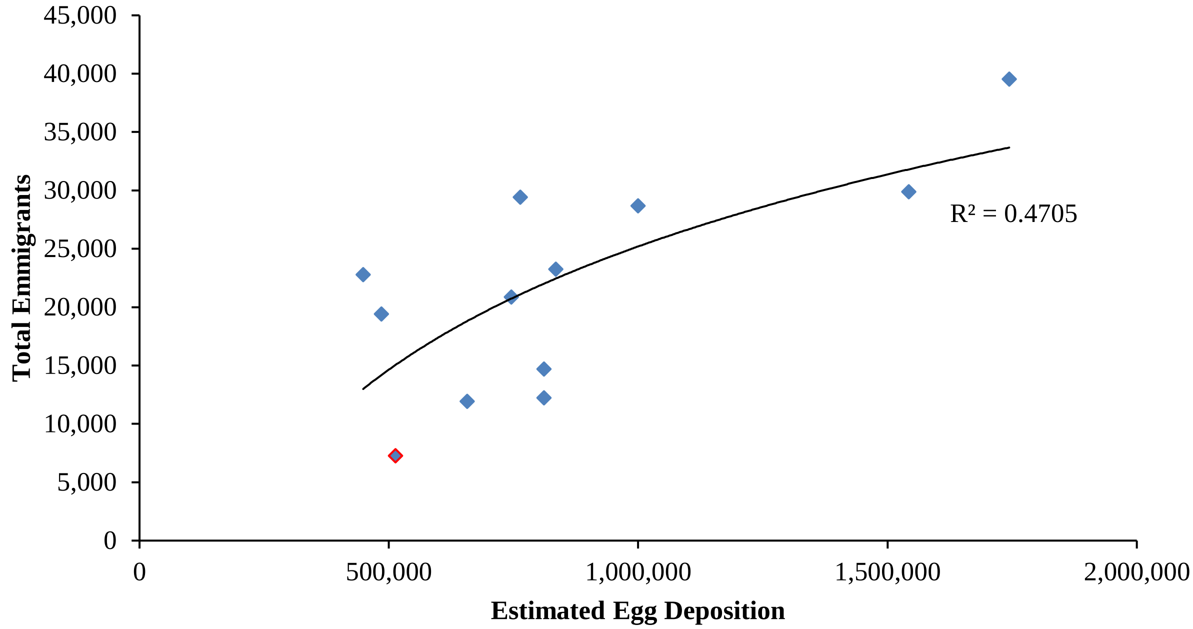
Table 5. Trap efficiency trials conducted with BY2014 wild spring Chinook yearlings and hatchery-origin coho yearling surrogates.

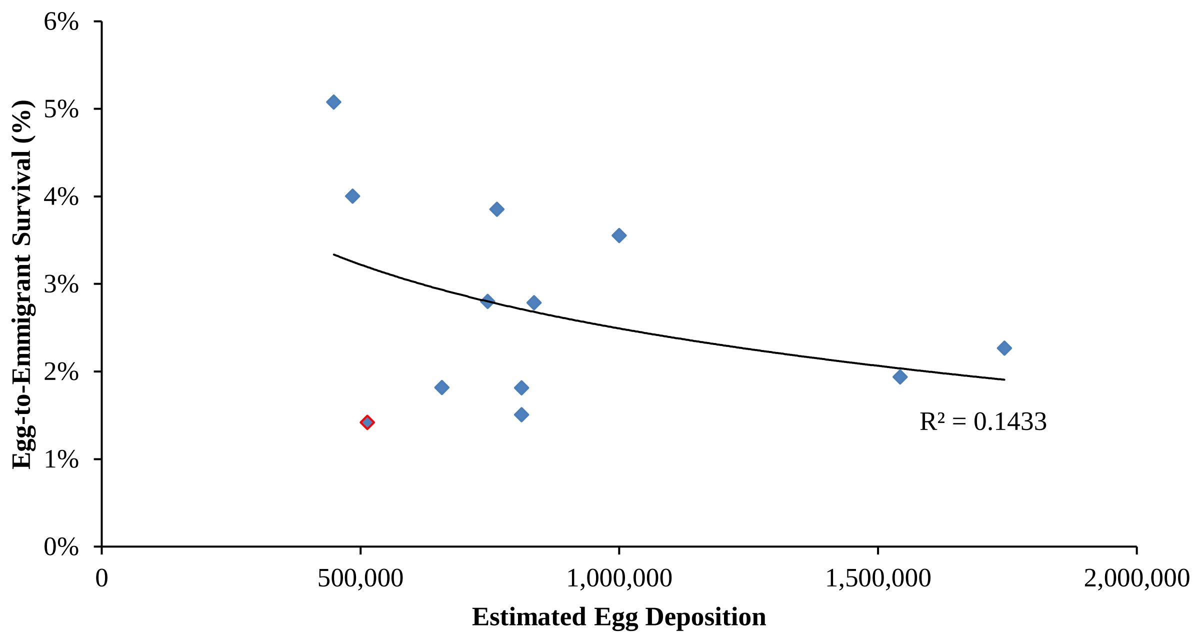
Origin/Species/Stage	Age	Date	Marked	Recaptured	Discharge (m^3/s)
Wild Chinook Yearlings	1+	3/4/2016	3	0	14.0
Wild Chinook Yearlings	1+	3/8/2016	12	4	15.9
Wild Chinook Yearlings	1+	3/12/2016	3	0	13.5
Wild Chinook Yearlings	1+	3/16/2016	2	0	10.5
Wild Chinook Yearlings	1+	3/28/2016	2	0	9.7
Wild Chinook Yearlings	1+	4/1/2016	10	0	13.9
Wild Chinook Yearlings	1+	4/5/2016	28	0	25.3
Wild Chinook Yearlings	1+	4/9/2016	1	0	37.7
Total			**61**	**4**	

Table 6. Estimated egg-to-emigrant survival and smolts-per-redd production for Nason Creek spring Chinook salmon.

Brood Year	No. Redds	Fecundity[a]	Est. Egg Deposition	No. of Emigrants				Egg-to-Emigrant	Emigrants per Redd
				Age-0[b]	Non Trap[d]	Age-1	Total ± 95% CI		
2002	294	4,654	1,368,276	—	—	4,683	—	—	—
2003	83	5,844	485,052	13,067	—	6,358	19,425 ± 1,993	4.0%	234
2004	169	4,799	811,031	12,111	—	2,597	14,708 ± 2,938	1.8%	87
2005	193	4,327	835,111	14,565	—	8,696	23,261 ± 5,440	2.8%	121
2006	152	4,324	657,248	4,144	—	7,798	11,942 ± 1,744	1.8%	79
2007	101	4,441	448,541	17,097	—	5,679	22,776 ± 2,983	5.1%	226
2008	336	4,592	1,542,912	26,284	—	3,611	29,895 ± 7,244	1.9%	89
2009	167	4,573	763,691	27,720	—	1,705	29,425 ± 12,777	3.9%	176
2010	188	4,314	811,032	8,685	—	3,535	12,220 ± 1,972	1.5%	65
2011	170	4,385	745,450	18,457	—	2,422	20,879 ± 3,887	2.8%	123
2012	413	4,223	1,744,099	34,961	—	4,561	39,522 ± 6,395	2.3%	96
2013	212	4,716	999,792	21,697	6,822	6,992[e]	35,511 ± 34,195	3.6%	168
2014	115	4,467	513,705	6,321	1,442	930[e]	8,694 ± 5,207	1.7%	76
2015	85	5,132	436,220	6,813	—	—	—	—	—
Avg.[c]	192	4,584	863,139	17,092	—	4,574	21,799	2.76%	128

[a] Data provided by Hillman et al. 2015.
[b] Does not include subyearling fry prior to July 1.
[c] 12-year average of complete brood data, BY2003-2014.
[d] Estimated emigration during the winter non-trapping period (December 1 – February 28).
[e] Pooled estimate


45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Total Emmigrants
R² = 0.4705
0
500,000
1,000,000
1,500,000
2,000,000
Estimated Egg Deposition


6%
5%
4%
3%
2%
1%
0%
Egg-to-Emmigrant Survival (%)
R² = 0.1433
0
500,000
1,000,000
1,500,000
2,000,000
Estimated Egg Deposition

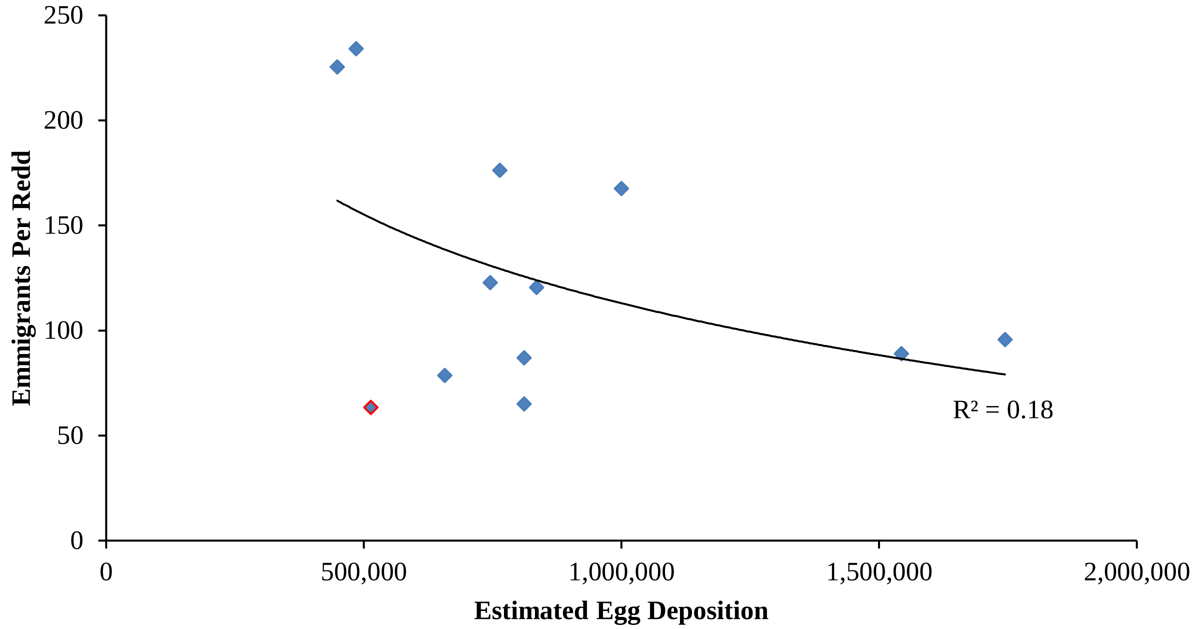


Figure 12. Relationships between estimated egg deposition and total emigrants produced, egg-to-emigrant survival, and emigrants per redd for Nason Creek spring Chinook, BY 2003 to 2014. *2014 brood (denoted by red border) does not include non-trapping estimate.

3.4.2 Spring Chinook Subyearlings (BY2015)

A linear regression model was developed using subyearling mark groups released in the fall of 2014 and 2016. The resulting regression (r^2 = 0.60; p = 0.005) was based on individual mark groups of ≥ 50 Chinook subyearlings only. Using this model we estimated that a total of 3,813 (± 1,116; 95% CI) BY2015 spring Chinook emigrated past the trap in the fall of 2016 (Table 6).

Table 7. Trap efficiency trials conducted with BY2015 wild spring Chinook subyearlings.

Origin/Species/Stage	Age	Date	Marked	Recaptured	Discharge (m^3/s)
Wild Chinook Subyearlings	0	7/2/2016	2	0	5.2
Wild Chinook Subyearlings	0	7/6/2016	4	0	3.9
Wild Chinook Subyearlings	0	7/14/2016	1	0	2.9
Wild Chinook Subyearlings	0	7/18/2016	2	0	2.9
Wild Chinook Subyearlings	0	7/22/2016	3	0	2.5
Wild Chinook Subyearlings	0	8/3/2016	1	0	1.7
Wild Chinook Subyearlings	0	10/24/2016	59	6	8.0
Wild Chinook Subyearlings	0	11/1/2016	68	8	10.6
Wild Chinook Subyearlings	0	11/6/2016	49	6	9.6
Wild Chinook Subyearlings	0	11/15/2016	69	11	15.3
Wild Chinook Subyearlings	0	11/20/2016	32	3	8.2
Total			**290**	**34**	

3.4.3 Summer Steelhead

Low abundance of summer steelhead emigrants in the spring of 2016 required a pooled estimate be used in light of the inability to meet minimum mark-group sizes (n = 50) for regression analysis. Releases of PIT-tagged steelhead were subsequently released every four days upstream at the established release location (Table 8). In a total of 31 separate trials, 216 wild summer steelhead were released upstream with 3 recaptures (1.4%). Estimates of age-0 fry and parr were not made due to insufficient evidence that active migration is occurring at this young age. Previous attempts at the old location to build a model based on young-of-the-year steelhead parr in the fall have yielded weak flow-efficiency relationships; further suggesting that age-0 parr catch is the result of displacement rather than active migration. We estimated that 19,872 (± 69,909; 95% CI) BY2015 age-1, 1,124 (± 4,437; 95% CI) BY2014 age-2, and 72 (± 294; 95% CI) BY2013 age-3 steelhead emigrated past the trap in 2016 (Table 9). We estimate that total (age 1-3) BY2013 emigration to be 13,417(± 9,133; 95% CI). All pooled estimates will be recalculated upon development of a species-specific flow-efficiency model.

Table 8. Efficiency trials conducted with wild summer steelhead juveniles.

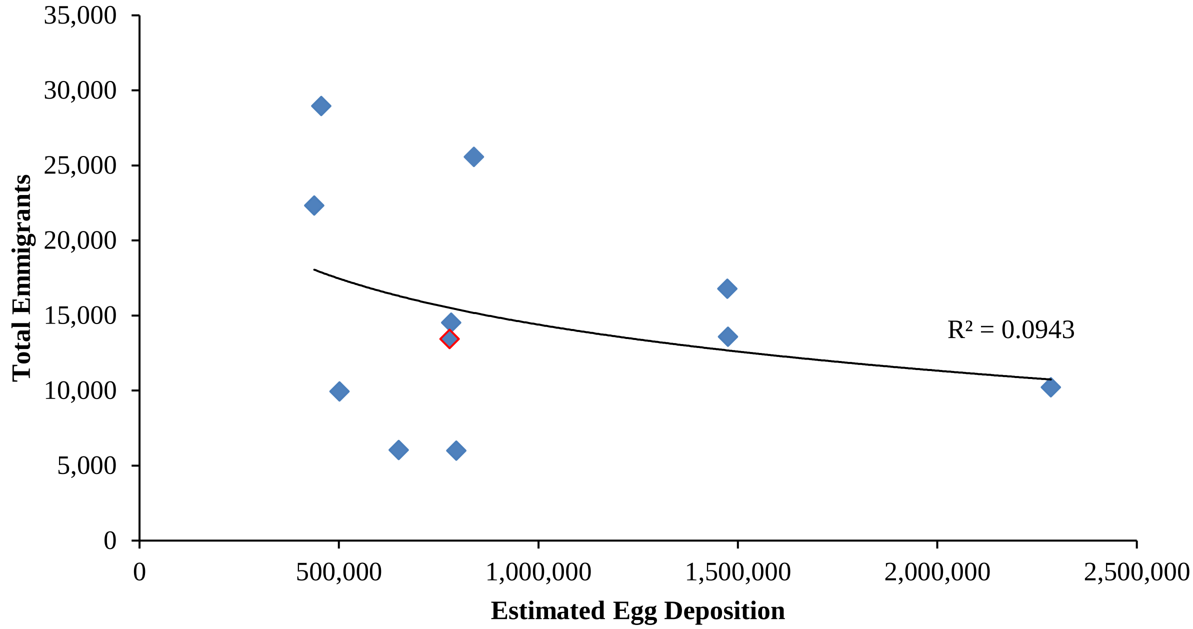
Origin/Species/Stage	Date	Marked	Recaptured	Discharge (m^3/s)
Wild Steelhead Parr/Smolt	3/4/2016	1	0	14.8
Wild Steelhead Parr/Smolt	3/8/2016	2	0	15.9
Wild Steelhead Parr/Smolt	3/12/2016	1	0	13.5
Wild Steelhead Parr/Smolt	3/16/2016	4	0	10.5
Wild Steelhead Parr/Smolt	3/20/2016	8	0	8.9
Wild Steelhead Parr/Smolt	3/24/2016	2	0	11.2
Wild Steelhead Parr/Smolt	4/1/2016	4	0	13.9
Wild Steelhead Parr/Smolt	4/5/2016	16	0	25.3
Wild Steelhead Parr/Smolt	4/9/2016	4	0	37.7
Wild Steelhead Parr/Smolt	4/13/2016	7	0	28.2
Wild Steelhead Parr/Smolt	4/17/2016	3	0	20.7
Wild Steelhead Parr/Smolt	4/21/2016	7	0	52.4
Wild Steelhead Parr/Smolt	4/25/2016	3	0	32.0
Wild Steelhead Parr/Smolt	4/29/2016	6	0	23.0
Wild Steelhead Parr/Smolt	5/3/2016	7	0	32.6
Wild Steelhead Parr/Smolt	5/7/2016	3	0	41.3
Wild Steelhead Parr/Smolt	5/11/2016	2	0	25.6
Wild Steelhead Parr/Smolt	5/23/2016	6	0	19.6
Wild Steelhead Parr/Smolt	5/27/2016	20	2	16.3
Wild Steelhead Parr/Smolt	5/31/2016	16	0	13.9
Wild Steelhead Parr/Smolt	6/4/2016	35	0	17.4
Wild Steelhead Parr/Smolt	6/8/2016	17	0	17.0
Wild Steelhead Parr/Smolt	6/12/2016	3	0	9.5
Wild Steelhead Parr/Smolt	6/16/2016	10	1	7.2
Wild Steelhead Parr/Smolt	6/20/2016	7	0	7.0

Origin/Species/Stage	Date	Marked	Recaptured	Discharge (m^3/s)
Wild Steelhead Parr/Smolt	6/24/2016	2	0	7.2
Wild Steelhead Parr/Smolt	6/28/2016	5	0	6.2
Wild Steelhead Parr/Smolt	7/2/2016	4	0	5.2
Wild Steelhead Parr/Smolt	7/6/2016	8	0	3.9
Wild Steelhead Parr/Smolt	7/10/2016	2	0	3.6
Wild Steelhead Parr/Smolt	7/14/2016	1	0	2.9
Total		**216**	**3**	

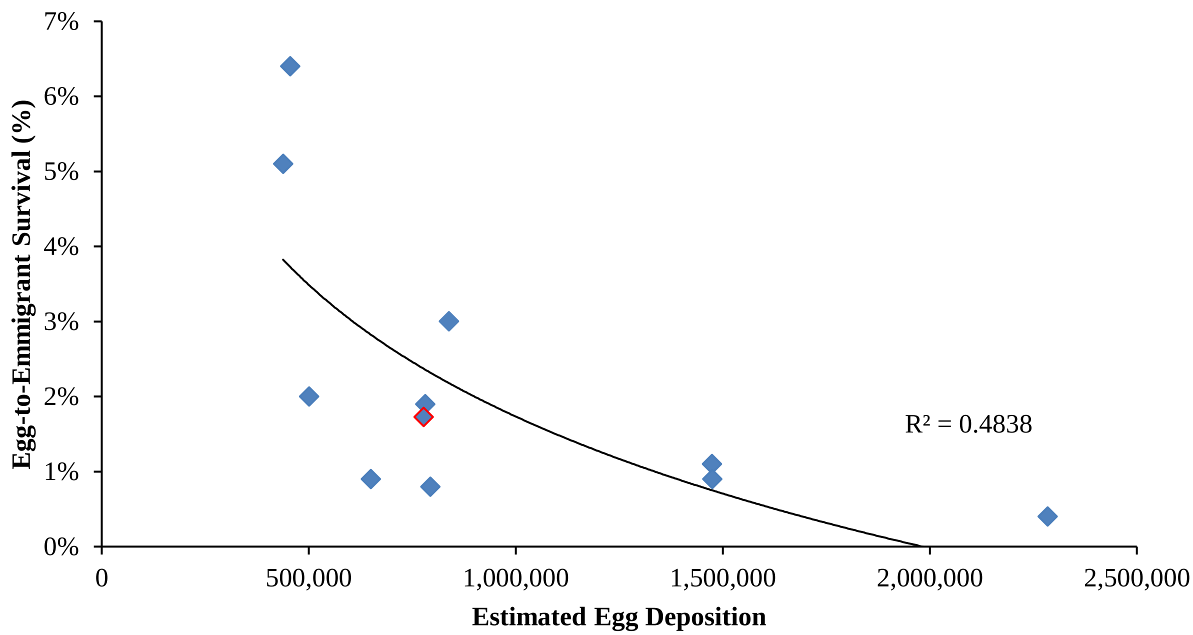
Table 9. Estimated egg-to-emigrant survival and emigrants-per-redd production for Nason Creek summer steelhead.

Brood Year	No. of Redds	Fecundity[a]	Est. Egg Deposition	No. of Emigrants				Egg-to-Emigrant	Emigrants per Redd
				1+	2+	3+	Total ± 95%CI		
2001	27	5,951	160,677	DNOT	DNOT	846	—	—	—
2002	80	5,776	462,080	DNOT	2,475	0	—	—	—
2003	121	6,561	793,881	4,906	1,054	27	5,987 ± 1,193	0.80%	49
2004	127	5,118	649,986	5,107	906	22	6,035 ± 885	0.90%	48
2005	412	5,545	2,284,540	7,416	2,502	298	10,216 ± 2,147	0.40%	25
2006	77	5,688	437,976	19,609	2,673	37	22,319 ± 5,722	5.10%	290
2007	78	5,840	455,520	26,518	2,325	117	28,960 ± 7,739	6.40%	371
2008	88	5,693	500,984	8,782	1,164	0	9,946 ± 2,382	2.00%	113
2009	126	6,199	781,074	13,606	608	312	14,526 ± 2,868	1.90%	115
2010	270	5,458	1,473,660	12,767	3,999	0	16,776 ± 3,885	1.10%	62
2011	235	6,276	1,474,860	13,109	482	0	13,591 ± 3,525	0.90%	58
2012	158	5,309	838,822	24,637	813	116[c]	25,566 ± 6,020	3.00%	162
2013	135	5,749	777,735	11,837	1,508[c]	72[c]	13,417 ± 9,133	1.73%	99
2014	198	5,831	1,154,538	22,504[c]	1,224[c]	—	—	—	—
2015	171	6,220	1,063,620	19,872[c]	—	—	—	—	—
Avg[b]	166	5,767	951,731	13,481	1,639	91	15,213	2.20%	127

[a] Data provided by Hillman et al. 2015
[b] 11-year average of complete brood estimates, BY2003-2013
[c] Pooled estimate



35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Total Emmigrants
R² = 0.0943
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
Estimated Egg Deposition



7%
6%
5%
4%
3%
2%
1%
0%
Egg-to-Emmigrant Survival (%)
R² = 0.4838
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
Estimated Egg Deposition

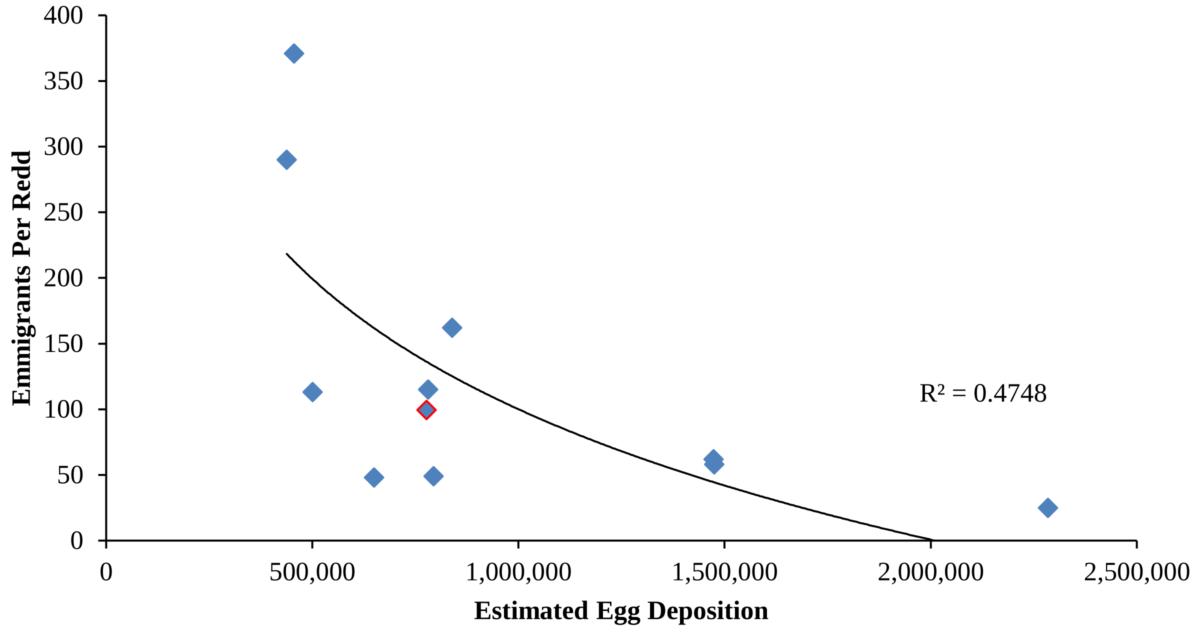


Figure 13. Relationships between estimated egg deposition and total emigrants produced, egg-to-emigrant survival, and emigrants per redd for Nason Creek summer Steelhead, BY 2003 to 2013. *2013 brood denoted by red border.

3.4.4 Coho Yearlings (BY2014)

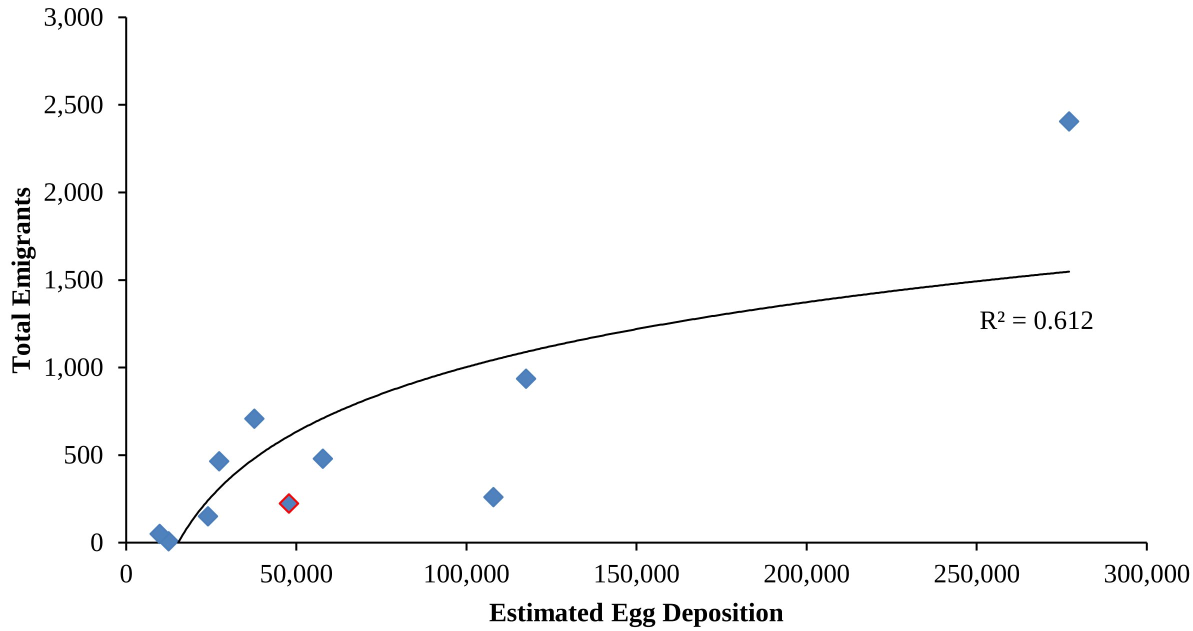
Limited abundance of BY2014 coho yearlings did not provide any opportunities to perform any efficiency trials in the spring of 2016. In lieu of a species-specific model, a pooled efficiency based on yearling spring Chinook releases was applied to wild coho smolts. In the spring of 2016, we estimated that 92 (± 504; 95% CI) emigrated past the trap (Table 10). Combined with a subyearling estimate of 131 (± 96; 95% CI),this gave us a total BY2014 emigrant estimate of 223 (± 514; 95% CI).

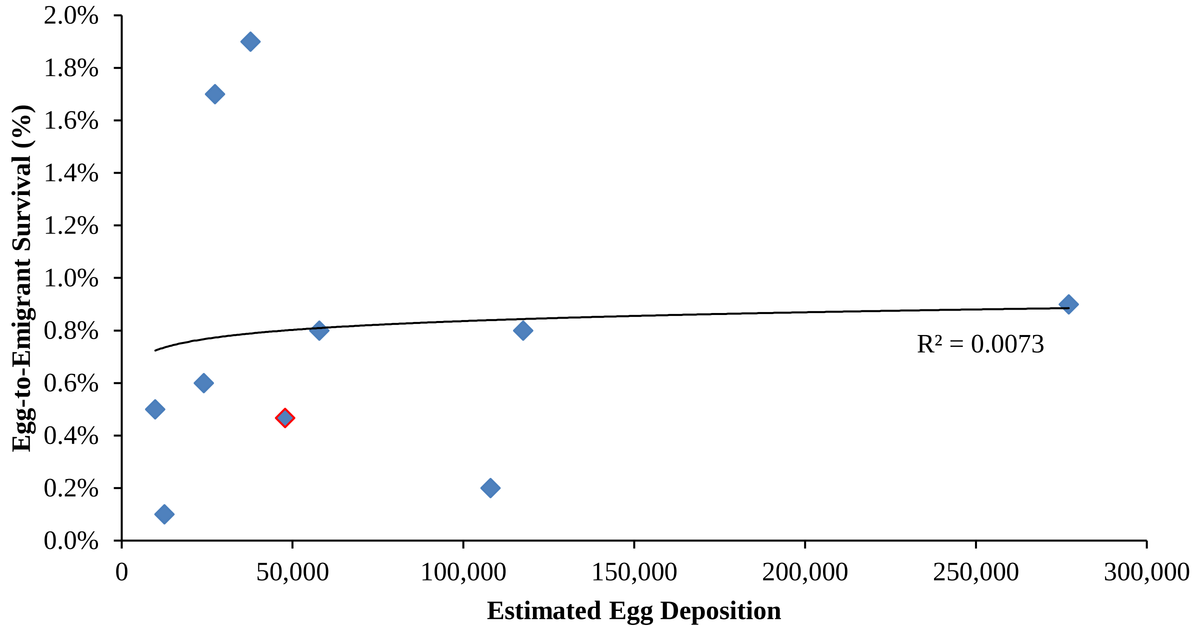
Table 10. Estimated egg-to-emigrant survival and smolts-per-redd production for Nason Creek coho salmon.

Brood Year	No. of Redds	Fecundity	Est. Egg Deposition	No. of Emigrants			Egg-to-Emigrant	Emigrants per Redd
				Age-0[a]	Age-1	Total ± 95% CI		
2003	6	2,458	14,748	DNOT	394	—	—	—
2004	35	3,084	107,940	204	56	260 ± 155	0.20%	7
2005	41	2,866	117,506	27	910	937 ± 347	0.80%	23
2006	4	3,126	12,504	7	0	7 ± 10	0.10%	2
2007	10	2,406	24,060	14	136	150 ± 104	0.60%	15
2008	3	3,275	9,825	50	0	50 ± 57	0.50%	17
2009	14	2,691	37,674	471	237	708 ± 478	1.90%	51
2010	8	3,411	27,288	27	437	464 ± 231	1.70%	58
2011	89	3,114	277,146	1,018	1,387	2,405 ± 612	0.90%	27
2012	21	2,752	57,792	46	434	480 ± 237	0.80%	23

Brood Year	No. of Redds	Fecundity	Est. Egg Deposition	No. of Emigrants			Egg-to-Emigrant	Emigrants per Redd
				Age-0[a]	Age-1	Total ± 95% CI		
2013	0	—	—	91	91[c]	182 ± 714	—	—
2014	16	2,992	47,872	131[c]	92[c]	223 ± 514	0.47%	14
2015	0	—	—	0	—	—	—	—
Avg.[b]	24	2,972	71,961	190	344	533	0.80%	24

[a] Does not include subyearling fry prior to July 1.
[b] 10-year average of complete brood data, BY2004-2014.
[c] Pooled estimate





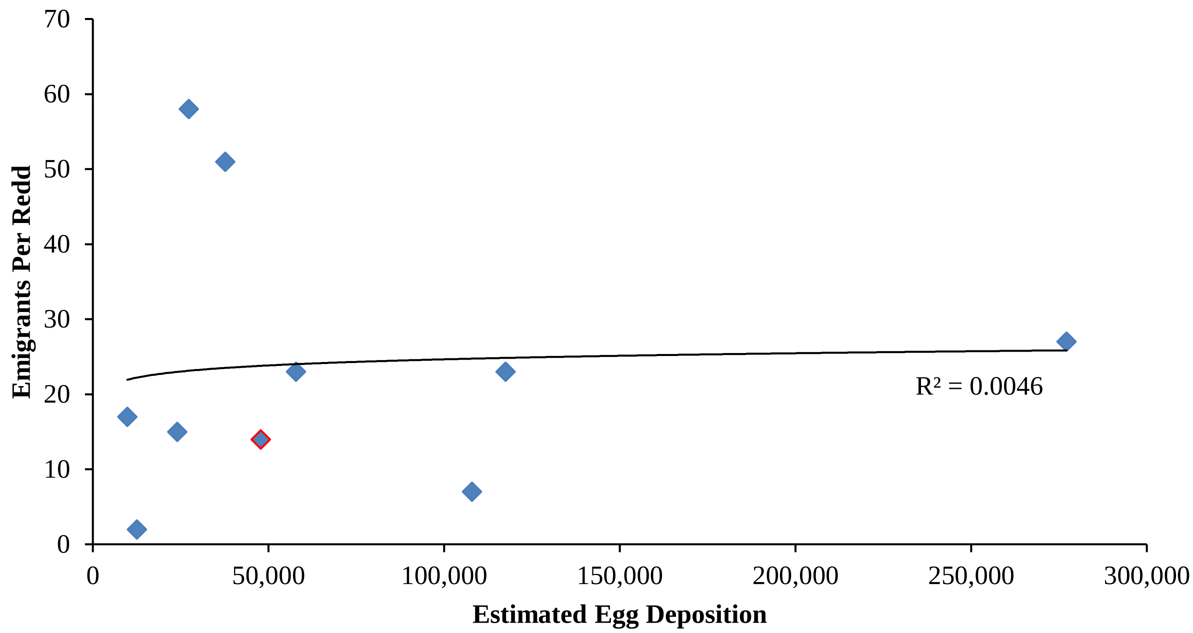


Figure 14. Relationships between estimated egg deposition and total emigrants produced, egg-to-emigrant survival, and emigrants per redd for Nason Creek natural-produced coho, BY 2003 to 2014. *2014 brood (denoted by red border).

3.4.5 Coho Subyearlings (BY2015)

Due to lack of BY2015 naturally-produced coho catch, we concluded that there were no emigrants from Nason in 2016.

3.5 PIT Tagging

During the 2016 trapping season, we PIT tagged 495 wild spring Chinook, 531 steelhead, and 6 naturally produced coho (Table 11). All tagging files were submitted to the PTAGIS database. One shed PIT tag (implanted in steelhead parr) was recovered in a holding box where fish had been held for 24-72 hours after tagging. During remote tagging efforts in the fall of 2015, 1,214 spring Chinook were PIT tagged by YNFRM and WDFW personnel.

Table 11. Number of PIT tagged coho, Chinook, and steelhead with shed rates at the Nason Creek rotary trap in 2016.

Species/Stage	Year-to-date Catch	Year-to-date PIT Tagged	No. of Shed Tags	Percent Shed Tags
Chinook Yearling Smolt	61	61	0	0.0%
Chinook Subyearling Parr (Mar 1 to June 30)	44	21	0	0.0%
Chinook Subyearling Parr (July 1 to Nov 30)	447	413	0	0.0%
Steelhead Parr	663	522	1	0.2%
Steelhead Smolt	9	9	0	0.0%
Coho Yearling Smolt	6	6	0	0.0%
Coho Subyearling Parr	0	0	—	—

* Counts do not include fish with FL<50mm (fry).

3.6 Incidental Species

Along with wild spring Chinook, wild steelhead/rainbow trout, and naturally produced coho, other resident fish species captured at the Nason Creek rotary trap and included in Table 12 are: bull trout *Salvelinus* confluentus, cutthroat trout *Oncorhynchus clarki*, flathead minnow *Pimephales promelas*, longnose dace *Rhinichthys cataractae*, northern pikeminnow *Ptychocheilus oregonensis*, redside shiner *Richardsonius balteatus*, sculpin *Cottus sp.*, sucker *Catostomus sp.*, and mountain whitefish *Prosopium williamsoni*.

Table 12. Summary of length and weight sampling of incidental species captured at the Nason Creek rotary trap in 2016.

Species	Total Count	Length (mm)			Weight (g)		
		Mean	N	SD	Mean	N	SD
Bull Trout	1	199	1	—	70.0	1	—
Cutthroat Trout	1	140	1	—	25.2	1	—
Fathead Minnow	4	52	4	3.7	1.7	4	0.3
Longnose Dace	230	52	230	19.2	2.5	228	4.1
Northern Pikeminnow	18	91	18	23.1	9.6	18	6.1
Redside Shiner	99	41	99	17.6	1.5	84	2.2
Sculpin	84	64	83	35.5	7.9	76	11.7
Sucker	319	58	319	23.4	3.8	317	18.7
Whitefish	81	58	81	39.8	4.8	79	25.8

3.7 ESA Compliance

The Nason Creek smolt trap was operated under consultation with NMFS and USFWS. Total numbers of UCR spring Chinook and UCR summer steelhead that were captured or handled (indirect take) at the trap were less than the maximum permitted (20%) for each species. Lethal take was well below the allowable level of 2% for all ESA-listed species (Table 13). Stream temperatures did not exceed 18˚C at any time in which fish were being handled.

Table 13. Summary of ESA species and coho salmon mortality at the Nason Creek rotary trap.

Species/Stage/Brood Year	Total Collected	Total Mortality	% Mortality
Spring Chinook Yearling (BY2014)	61	0	0.0%
Spring Chinook Subyearling (BY 2015)	791	6	0.8%
Total Wild Spring Chinook	**852**	**6**	**0.7%**
Total Hatchery Spring Chinook	**124**	**0**	**0.0%**
Steelhead Age-0 (BY2016)	702	1	0.1%
Steelhead Age-1 (BY2015)	285	0	0.0%
Steelhead Age-2 (BY2014)	19	0	0.0%
Steelhead Age-3 (BY2013)	1	0	0.0%
Total Wild Summer Steelhead	**1,007**	**1**	**0.1%**
Total Hatchery Summer Steelhead	**98**	**0**	**0.0%**
Total Bull Trout	**1**	**0**	**0.0%**
Coho Yearling (BY2014)	6	0	0.0%
Coho Subyearling (BY2015)	0	0	—
Total Naturally-Produced Coho	**6**	**0**	**0.0%**

4.0 DISCUSSION

Operation of the Nason Creek smolt trap in 2016 was, as in 2015, affected by an unseasonably early and warm spring that caused a quickly diminished snowpack. The resulting prolonged base-flow period meant that the trap could not be operated for much (70 d) of the mid to late summer due to insufficient water velocity. Aside from issues associated with the summer low flow period, inactivity due to other environmental conditions and mechanical issues was minimized. The critical assumptions noted in section 2.5.1, upon which the mark-recapture methodology was predicated, were not violated insofar as we could determine from measuring tag retention/tagging mortality, examining the health of all fish in mark groups prior to release, and ensuring that all fish encountered were thoroughly scanned for PIT tags post-release. All prudent measures were taken to ensure that fish used in mark groups avoided predation between point of release and the trap e.g., release into shallow water refugia.

Since establishment in the summer of 2014, smolt trap operations at the Bolser site have occurred largely under a prolonged period of El Niño spanning from approximately October 2014 through June 2016 (NOAA 2016). Oceanic Niño Index (ONI) levels for this period were especially high (≥ 2.0), with similar conditions not experienced since warming events in 1982/1983 and 1997/1998. Inland manifestations of this most recent El Niño included variable flow and temperature regimes, often deviating greatly from normal trends in both timing and magnitude (Figure 15). Comparison to the 12-year mean discharge and observed flows shows that high water events occurred early, and in periods in which cold temperature normally limit discharge. Quickly diminished snowpack caused by the high, early winter flows subsequently lead to early spring runoff and prolonged base-flow periods in the summer months.

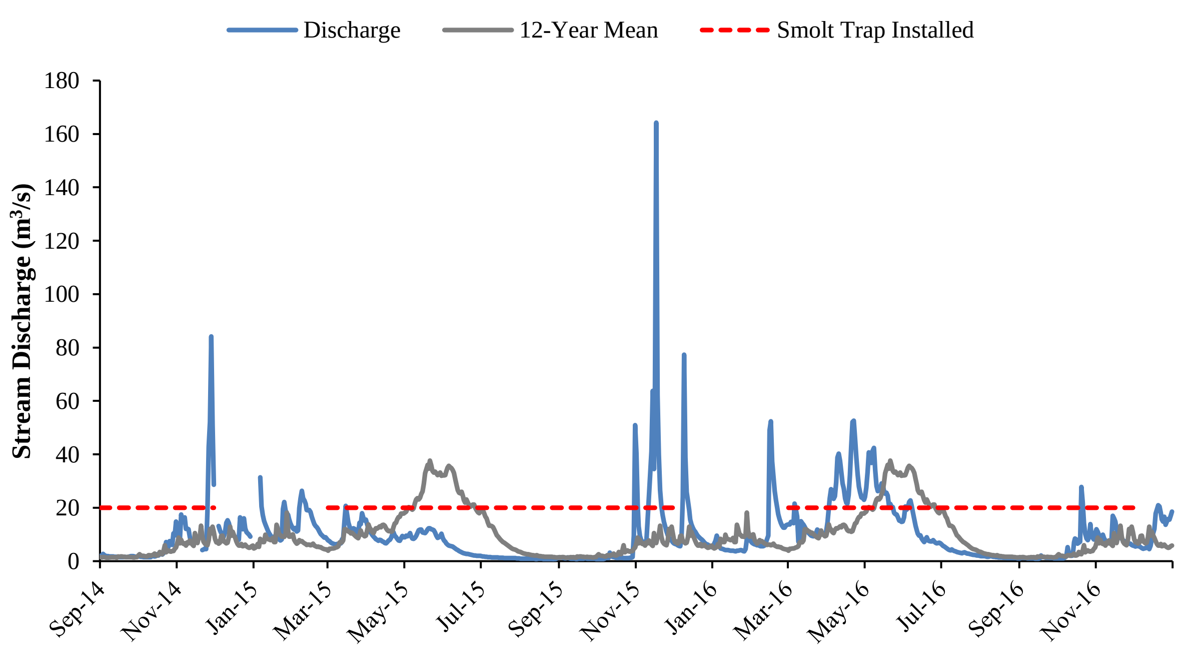


Figure 15. Nason Creek daily discharge from September 2014 through December 2016, with corresponding 12-year mean Nason Creek discharge.

Spring Chinook

The 2014 wild spring Chinook brood at Nason Creek yielded the smallest total emigrant estimate on record at the trap. Egg-to-emigrant survival in comparison to the nearby White River and Chiwawa River showed that Nason Creek was the only monitored tributary in the Wenatchee basin to demonstrate a decrease in in-stream survival between the 2013 and 2014 broods despite similar trends in redd deposition (Figure 17). Comparison of egg-to-emigrant survival and estimated egg deposition suggested that between the three tributaries, Nason Creek produced the most marked outlier (Figure 18). The degree to which Nason Creek deviated from the trends seen in the other tributaries may be due to the comparative effect that the El Niño event had on the individual watershed. The smallest, lowest elevation, and warmest of the three tributaries compared, Nason Creek saw the greatest physical impact of the warming phenomenon.

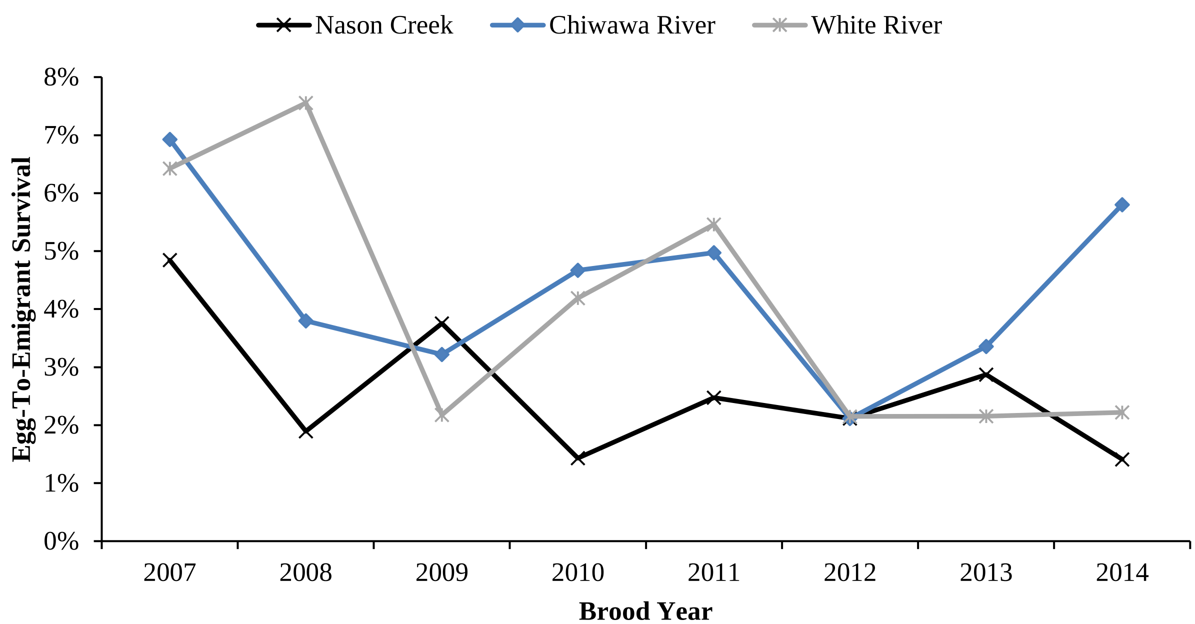


Figure 16. Comparison of wild spring Chinook abundance estimates (BY2007-2014) made at the White River, Nason Creek, and Chiwawa River smolt traps. *Non-trapping estimates not included.

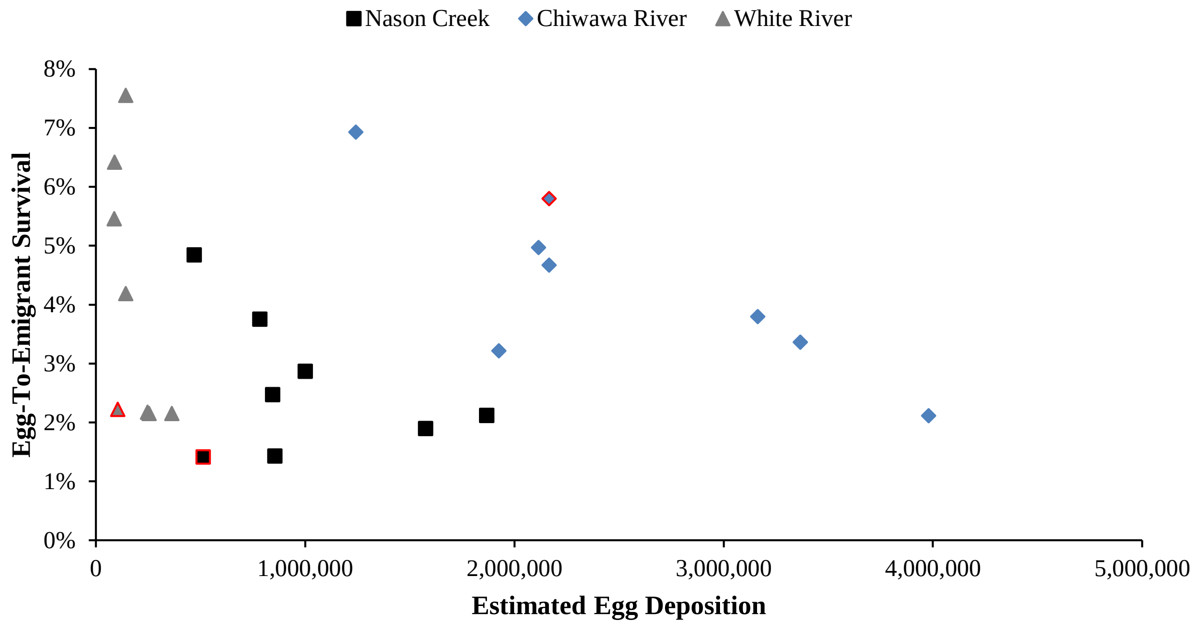


Figure 17. Comparison of egg-to-emigrant survival (BY 2007-2014) and egg deposition for Nason Creek, Chiwawa River, and White River spring Chinook. *Non-trapping estimates not included.

The low comparative survival of BY2014 Chinook was likely due in-apart to decreased survival associated with the anomalous flow and temperature regimes caused by El Niño. Redd scour and sedimentation brought on by irregularly high flows has been shown to increase in-gravel mortality (Montgomery et al. 1996 & Lotspeich and Everest 1981). Although difficult to quantify the exact influence of scour and sedimentation on our estimates, we assume that the strong negative correlation between juvenile survival and peak flow during incubation demonstrated in other tributaries had some negative influence in Nason Creek (Seiler et al. 2002). Some elevated level of increased mortality was also likely incurred as a result of warm water temperatures, decreased habitat available, and elevated competition for resources during the prolonged base flow period in the summer of 2015. Identified in normal years as an impaired watershed due to regular exceedance of 303(d) criteria, Nason Creek saw three consecutive months in 2015 (June-August) in which maximum temperatures exceeded 22ºC (Cristea and Pelletier 2005). Marine and Cech (2004) showed that between three laboratory-based rearing temperature regimes (13-16ºC, 17-20ºC, and 21-24ºC), higher water temperatures significantly decreased growth rates, smoltification indices, and predator avoidance capability. Though Marine and Cech did not see any increased mortality associated with higher rearing temperatures, we assume that effects noted in the study would have an impact on survival in-situ.

BY2014 spring Chinook parr that survived the summer months in Nason Creek were then met with extremely high discharges in the month of November 2015. Flows during this high-water event were large enough to cause a major reconfiguration of log jams and channel morphology in sections. During this period in which we presume a large proportion of the remaining Chinook in Nason Creek were involuntarily pushed out of the system, the trap was unable to run due to water high velocity and debris load. During this event, remote-tagged Chinook were also pushed from the system when the PIT tag arrays were the least effective. We suspect that along with a higher incidence of in-stream mortality, much of the BY2014 brood left Nason Creek when estimation methodologies were unavailable or ineffective.

A total of only 85 redds in Nason Creek in 2015 was the lowest on record since 2003. The extent to which high winter flows of 2015/2016 affected the BY2015 emigration estimate will potentially be determined upon completion of the outmigration in the summer of 2017. Impact on this brood may be great in that much of the winter flooding occurred pre-emergence; a period of high vulnerability to both scour and sedimentation. The estimated survival of this brood will hopefully indicate the ability of Nason Creek spring Chinook to endure such in-gravel conditions.

Summer Steelhead

The 2013 Nason summer steelhead brood estimate did not reflect the low survival seen in BY2014 Chinook concluding their outmigration at the same time. Although BY2013 steelhead abundance and survival both fell below their 11-year averages, they were not outliers. This is presumably due to the fact that the overwhelming majority (88%) of BY2013 steelhead emigrants left during the spring of 2014; a period not characterized by irregularly high flows or preceded by adverse rearing conditions. The BY2013 age-2 and age-3 emigrant estimates are based on pooled efficiencies, and will be recalculated upon establishment of a viable multi-year regression. Recalculation of these estimates based on a flow-efficiency regression will most likely result in a slightly lower total estimate due to the pooled estimates use of low fixed efficiencies (0.86% and 1.34%). However, because age-2 & 3 steelhead emigrants comprise a relatively small proportion of the total outmigration, recalculation may not change in-stream survival to a great extent.

Potential effects of the El Niño period on developing (BY2014 and BY2015) estimates are still unclear due to the use of pooled estimates employing the aforementioned low fixed efficiencies. BY2014 and BY2015 estimates thus far have produced age-1 estimates that are markedly higher than the 11-year mean. Completion of both emigrant estimates as well as recalculation with a viable flow-efficiency regression will determine if this high abundance is accurate, and in stark contrast to the poor survival calculated in cohabitating spring Chinook.

Coho

Despite a relatively large Wenatchee basin spawner escapement in 2014, only 16 redds were documented in Nason Creek; below the 11-year mean of 24 redds. The resulting total emigrant estimate was also below the 11-year mean, and in the absence of a flow-efficiency regression, calculated with a pooled estimate. As with similar methodologies used to calculate other species abundances in the absence of a flow-efficiency relationship, we suspect that these pooled estimated are likely overestimated due to low efficiencies used. BY2014 coho were likely affected by the El Niño weather trend similarly to BY2014 spring Chinook, given similar in-stream residence times.

A poor adult coho return in 2015 required exhaustive broodstock retention at Tumwater dam to meet hatchery production goals. As a result, no coho were documented in Nason Creek. This is reflected in the complete lack of BY2015 subyearlings at the trap during the 2016 trap year. Given little coho passage above Tumwater dam, and a very small likelihood that any spawning activity occurred in Nason Creek in 2015, we suspect that yearling emigrants will be absent completely for this brood as well.

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APPENDIX A. Daily Stream Discharge

Date	Stream Discharge (m^3/s)
1/1/2016	5.5
1/2/2016	6.6
1/3/2016	7.6
1/4/2016	9.5
1/5/2016	8.1
1/6/2016	5.7
1/7/2016	4.8
1/8/2016	4.6
1/9/2016	4.5
1/10/2016	4.3
1/11/2016	4.2
1/12/2016	4.2
1/13/2016	4.2
1/14/2016	4.0
1/15/2016	3.9
1/16/2016	4.0
1/17/2016	3.9
1/18/2016	3.8
1/19/2016	3.7
1/20/2016	
1/21/2016	
1/22/2016	4.1
1/23/2016	4.2
1/24/2016	4.0
1/25/2016	3.8
1/26/2016	3.7
1/27/2016	4.5
1/28/2016	8.2
1/29/2016	
1/30/2016	8.5
1/31/2016	7.5
2/1/2016	7.0
2/2/2016	6.6
2/3/2016	6.3
2/4/2016	6.2
2/5/2016	6.0
2/6/2016	6.1
2/7/2016	5.8
2/8/2016	5.6
2/9/2016	5.6
2/10/2016	5.6
2/11/2016	5.9
2/12/2016	6.9
2/13/2016	
2/14/2016	9.5
2/15/2016	49.0
2/16/2016	52.4
2/17/2016	37.4
2/18/2016	31.7
2/19/2016	26.3
2/20/2016	22.8
2/21/2016	19.9
2/22/2016	17.6
2/23/2016	15.7
2/24/2016	14.4
2/25/2016	13.3
2/26/2016	12.6
2/27/2016	12.6
2/28/2016	13.4
2/29/2016	13.7
3/1/2016	
3/2/2016	13.8
3/3/2016	14.7
3/4/2016	14.8
3/5/2016	14.2
3/6/2016	21.6
3/7/2016	19.4
3/8/2016	16.8
3/9/2016	7.2
3/10/2016	7.2
3/11/2016	15.0
3/12/2016	14.2
3/13/2016	13.7
3/14/2016	12.8
3/15/2016	11.8
3/16/2016	11.1
3/17/2016	10.6
3/18/2016	10.0
3/19/2016	9.6
3/20/2016	9.4
3/21/2016	9.4
3/22/2016	10.1
3/23/2016	10.4
3/24/2016	11.9

3/25/2016	11.4	5/9/2016	34.0
3/26/2016	10.8	5/10/2016	28.1
3/27/2016	10.7	5/11/2016	26.2
3/28/2016	10.2	5/12/2016	26.4
3/29/2016	9.9	5/13/2016	27.5
3/30/2016	10.1	5/14/2016	29.2
3/31/2016	11.2	5/15/2016	29.2
4/1/2016	14.6	5/16/2016	26.5
4/2/2016	19.9	5/17/2016	25.3
4/3/2016	23.6	5/18/2016	25.7
4/4/2016	27.0	5/19/2016	24.6
4/5/2016	26.5	5/20/2016	20.7
4/6/2016	23.4	5/21/2016	21.4
4/7/2016	24.3	5/22/2016	20.3
4/8/2016	29.4	5/23/2016	20.2
4/9/2016	38.8	5/24/2016	18.1
4/10/2016	40.2	5/25/2016	17.6
4/11/2016	37.7	5/26/2016	17.5
4/12/2016	33.4	5/27/2016	16.5
4/13/2016	29.2	5/28/2016	15.2
4/14/2016	27.0	5/29/2016	15.2
4/15/2016	23.5	5/30/2016	14.8
4/16/2016	21.7	5/31/2016	14.8
4/17/2016	21.5	6/1/2016	16.5
4/18/2016	24.8	6/2/2016	20.5
4/19/2016	32.3	6/3/2016	19.3
4/20/2016	43.0	6/4/2016	20.0
4/21/2016	52.1	6/5/2016	22.2
4/22/2016	52.7	6/6/2016	22.7
4/23/2016	45.9	6/7/2016	20.6
4/24/2016	38.8	6/8/2016	18.1
4/25/2016	32.6	6/9/2016	15.7
4/26/2016	27.9	6/10/2016	13.3
4/27/2016	25.7	6/11/2016	11.5
4/28/2016	23.8	6/12/2016	10.3
4/29/2016	23.7	6/13/2016	9.5
4/30/2016	23.0	6/14/2016	9.7
5/1/2016	24.1	6/15/2016	8.5
5/2/2016	27.5	6/16/2016	7.8
5/3/2016	33.1	6/17/2016	7.2
5/4/2016	40.8	6/18/2016	8.2
5/5/2016	39.4	6/19/2016	9.0
5/6/2016	36.8	6/20/2016	7.7
5/7/2016	41.3	6/21/2016	7.5
5/8/2016	42.5	6/22/2016	7.4

6/23/2016	7.4	8/7/2016	1.6
6/24/2016	7.9	8/8/2016	1.7
6/25/2016	7.3	8/9/2016	2.0
6/26/2016	6.9	8/10/2016	1.8
6/27/2016	6.7	8/11/2016	1.7
6/28/2016	6.9	8/12/2016	1.6
6/29/2016	6.9	8/13/2016	1.5
6/30/2016	6.7	8/14/2016	1.5
7/1/2016	6.1	8/15/2016	1.4
7/2/2016	5.7	8/16/2016	1.4
7/3/2016	5.4	8/17/2016	1.4
7/4/2016	5.1	8/18/2016	1.3
7/5/2016	4.7	8/19/2016	1.3
7/6/2016	4.4	8/20/2016	1.3
7/7/2016	4.1	8/21/2016	1.2
7/8/2016	4.1	8/22/2016	1.2
7/9/2016	4.4	8/23/2016	1.2
7/10/2016	4.0	8/24/2016	1.2
7/11/2016	3.9	8/25/2016	1.2
7/12/2016	3.6	8/26/2016	1.2
7/13/2016	3.5	8/27/2016	1.1
7/14/2016	3.3	8/28/2016	1.1
7/15/2016	3.1	8/29/2016	1.1
7/16/2016	3.1	8/30/2016	1.1
7/17/2016	3.0	8/31/2016	1.1
7/18/2016	3.2	9/1/2016	1.1
7/19/2016	3.4	9/2/2016	1.2
7/20/2016	3.0	9/3/2016	1.4
7/21/2016	2.9	9/4/2016	1.3
7/22/2016	2.8	9/5/2016	1.2
7/23/2016	2.8	9/6/2016	1.1
7/24/2016	2.6	9/7/2016	1.1
7/25/2016	2.5	9/8/2016	1.1
7/26/2016	2.4	9/9/2016	1.1
7/27/2016	2.4	9/10/2016	1.0
7/28/2016	2.3	9/11/2016	1.0
7/29/2016	2.2	9/12/2016	1.0
7/30/2016	2.1	9/13/2016	1.0
7/31/2016	2.0	9/14/2016	1.0
8/1/2016	1.9	9/15/2016	0.9
8/2/2016	1.9	9/16/2016	0.9
8/3/2016	1.9	9/17/2016	1.0
8/4/2016	1.8	9/18/2016	2.1
8/5/2016	1.8	9/19/2016	1.6
8/6/2016	1.7	9/20/2016	1.6

9/21/2016	1.4	11/3/2016	9.9
9/22/2016	1.3	11/4/2016	8.7
9/23/2016	1.2	11/5/2016	8.2
9/24/2016	1.3	11/6/2016	9.9
9/25/2016	1.2	11/7/2016	8.5
9/26/2016	1.2	11/8/2016	7.7
9/27/2016	1.1	11/9/2016	7.3
9/28/2016	1.1	11/10/2016	7.1
9/29/2016	1.1	11/11/2016	6.7
9/30/2016	1.0	11/12/2016	7.1
10/1/2016	1.0	11/13/2016	7.7
10/2/2016	1.0	11/14/2016	17.0
10/3/2016	1.0	11/15/2016	16.0
10/4/2016	1.0	11/16/2016	14.9
10/5/2016	1.1	11/17/2016	11.9
10/6/2016	1.1	11/18/2016	10.5
10/7/2016	1.4	11/19/2016	9.6
10/8/2016	1.9	11/20/2016	8.8
10/9/2016	5.2	11/21/2016	8.3
10/10/2016	2.9	11/22/2016	7.9
10/11/2016	2.3	11/23/2016	7.4
10/12/2016	2.0	11/24/2016	7.2
10/13/2016	2.1	11/25/2016	7.1
10/14/2016	7.0	11/26/2016	6.8
10/15/2016	8.5	11/27/2016	6.5
10/16/2016	8.1	11/28/2016	6.5
10/17/2016	6.5	11/29/2016	6.0
10/18/2016		11/30/2016	5.9
10/19/2016	7.3	12/1/2016	5.8
10/20/2016	27.8	12/2/2016	5.5
10/21/2016	22.2	12/3/2016	5.9
10/22/2016	14.2	12/4/2016	
10/23/2016	10.3	12/5/2016	5.6
10/24/2016	8.5	12/6/2016	5.2
10/25/2016	7.9	12/7/2016	4.9
10/26/2016	9.1	12/8/2016	4.7
10/27/2016	13.8	12/9/2016	4.7
10/28/2016	10.2	12/10/2016	4.9
10/29/2016	8.8	12/11/2016	5.0
10/30/2016	8.1	12/12/2016	6.0
10/31/2016	10.4	12/13/2016	4.6
11/1/2016	12.0	12/14/2016	5.7
11/2/2016	11.0	12/15/2016	8.2
12/16/2016	10.4		

12/17/2016	12.0
12/18/2016	17.8
12/19/2016	19.4
12/20/2016	20.9
12/21/2016	20.5
12/22/2016	18.0
12/23/2016	15.7
12/24/2016	14.8
12/25/2016	16.6
12/26/2016	13.7
12/27/2016	14.8
12/28/2016	15.7
12/29/2016	15.6
12/30/2016	17.0
12/31/2016	18.5

APPENDIX B. Daily Trap Operation

Date	Trap Status	Comments
3/1/2016	Op.	
3/2/2016	Op.	
3/3/2016	Op.	
3/4/2016	Op.	
3/5/2016	Op.	
3/6/2016	Op.	
3/7/2016	Op.	
3/8/2016	Op.	
3/9/2016	Op.	
3/10/2016	Op.	
3/11/2016	Op.	
3/12/2016	Op.	
3/13/2016	Op.	
3/14/2016	Op.	
3/15/2016	Op.	
3/16/2016	Op.	
3/17/2016	Op.	
3/18/2016	Op.	
3/19/2016	Op.	
3/20/2016	Op.	
3/21/2016	Op.	
3/22/2016	Op.	
3/23/2016	Op.	
3/24/2016	Op.	
3/25/2016	Op.	
3/26/2016	Op.	
3/27/2016	Op.	
3/28/2016	Op.	
3/29/2016	Op.	
3/30/2016	Op.	
3/31/2016	Op.	
4/1/2016	Op.	
4/2/2016	Op.	
4/3/2016	Op.	
4/4/2016	Op.	
4/5/2016	Op.	
4/6/2016	Op.	
4/7/2016	Op.	
4/8/2016	Op.	
4/9/2016	Op.	
4/10/2016	Op.	
4/11/2016	Op.	
4/12/2016	Op.	
4/13/2016	Op.	
4/14/2016	Op.	
4/15/2016	Op.	
4/16/2016	Op.	
4/17/2016	Op.	
4/18/2016	Op.	
4/19/2016	Op.	
4/20/2016	Op.	
4/21/2016	Op.	
4/22/2016	Op.	
4/23/2016	Op.	
4/24/2016	Op.	
4/25/2016	Op.	
4/26/2016	Op.	
4/27/2016	Op.	
4/28/2016	Op.	
4/29/2016	Op.	
4/30/2016	Op.	
5/1/2016	Op.	
5/2/2016	Op.	
5/3/2016	Op.	
5/4/2016	Op.	
5/5/2016	Op.	
5/6/2016	Op.	
5/7/2016	Op.	
5/8/2016	Op.	
5/9/2016	Op.	
5/10/2016	Op.	
5/11/2016	Op.	
5/12/2016	Op.	
5/13/2016	Op.	
5/14/2016	Op.	
5/15/2016	Op.	
5/16/2016	Op.	
5/17/2016	Op.	
5/18/2016	Op.	

5/19/2016	Op.		7/1/2016	Op.	
5/20/2016	Op.		7/2/2016	Op.	
5/21/2016	Op.		7/3/2016	Op.	
5/22/2016	Op.		7/4/2016	Op.	
5/23/2016	Op.		7/5/2016	Op.	
5/24/2016	Op.		7/6/2016	Op.	
5/25/2016	Op.		7/7/2016	Op.	
5/26/2016	Op.		7/8/2016	Op.	
5/27/2016	Op.		7/9/2016	Op.	
5/28/2016	Op.		7/10/2016	Op.	
5/29/2016	Op.		7/11/2016	No Op.	Stopped - low flow
5/30/2016	Op.		7/12/2016	Op.	
5/31/2016	Op.		7/13/2016	Op.	
6/1/2016	Op.		7/14/2016	Op.	
6/2/2016	Op.		7/15/2016	Op.	
6/3/2016	Op.		7/16/2016	Op.	
6/4/2016	Op.		7/17/2016	Op.	
6/5/2016	No Op.	Stopped by debris	7/18/2016	Op.	
6/6/2016	Op.		7/19/2016	Op.	
6/7/2016	Op.		7/20/2016	Op.	
6/8/2016	Op.		7/21/2016	Op.	
6/9/2016	Op.		7/22/2016	Op.	
6/10/2016	Op.		7/23/2016	Op.	
6/11/2016	Op.		7/24/2016	Op.	
6/12/2016	Op.		7/25/2016	Op.	
6/13/2016	Op.		7/26/2016	No Op.	Stopped - low flow
6/14/2016	Op.		7/27/2016	Op.	
6/15/2016	Op.		7/28/2016	No Op.	Stopped - low flow
6/16/2016	Op.		7/29/2016	Op.	
6/17/2016	Op.		7/30/2016	Op.	
6/18/2016	Op.		7/31/2016	No Op.	Stopped - low flow
6/19/2016	Op.		8/1/2016	No Op.	Stopped - low flow
6/20/2016	Op.		8/2/2016	Op.	
6/21/2016	Op.		8/3/2016	No Op.	Stopped - low flow
6/22/2016	Op.		8/4/2016	No Op.	Stopped - low flow
6/23/2016	Op.		8/5/2016	No Op.	Stopped - low flow
6/24/2016	Op.		8/6/2016	No Op.	Stopped - low flow
6/25/2016	Op.		8/7/2016	No Op.	Stopped - low flow
6/26/2016	Op.		8/8/2016	No Op.	Pulled - low flow
6/27/2016	Op.		8/9/2016	Op.	
6/28/2016	Op.		8/10/2016	No Op.	Pulled - low flow
6/29/2016	Op.		8/11/2016	No Op.	Pulled - low flow
6/30/2016	No Op.	Stopped - debris	8/12/2016	No Op.	Pulled - low flow

8/13/2016	No Op.	Pulled - low flow
8/14/2016	No Op.	Pulled - low flow
8/15/2016	No Op.	Pulled - low flow
8/16/2016	No Op.	Pulled - low flow
8/17/2016	No Op.	Pulled - low flow
8/18/2016	No Op.	Pulled - low flow
8/19/2016	No Op.	Pulled - low flow
8/20/2016	No Op.	Pulled - low flow
8/21/2016	No Op.	Pulled - low flow
8/22/2016	No Op.	Pulled - low flow
8/23/2016	No Op.	Pulled - low flow
8/24/2016	No Op.	Pulled - low flow
8/25/2016	No Op.	Pulled - low flow
8/26/2016	No Op.	Pulled - low flow
8/27/2016	No Op.	Pulled - low flow
8/28/2016	No Op.	Pulled - low flow
8/29/2016	No Op.	Pulled - low flow
8/30/2016	No Op.	Pulled - low flow
8/31/2016	No Op.	Pulled - low flow
9/1/2016	No Op.	Pulled - low flow
9/2/2016	No Op.	Pulled - low flow
9/3/2016	No Op.	Pulled - low flow
9/4/2016	No Op.	Pulled - low flow
9/5/2016	No Op.	Pulled - low flow
9/6/2016	No Op.	Pulled - low flow
9/7/2016	No Op.	Pulled - low flow
9/8/2016	No Op.	Pulled - low flow
9/9/2016	No Op.	Pulled - low flow
9/10/2016	No Op.	Pulled - low flow
9/11/2016	No Op.	Pulled - low flow
9/12/2016	No Op.	Pulled - low flow
9/13/2016	No Op.	Stopped - low flow
9/14/2016	No Op.	Pulled - low flow
9/15/2016	No Op.	Pulled - low flow
9/16/2016	No Op.	Pulled - low flow
9/17/2016	No Op.	Pulled - low flow
9/18/2016	No Op.	Pulled - low flow
9/19/2016	No Op.	Pulled - low flow
9/20/2016	No Op.	Pulled - low flow
9/21/2016	No Op.	Pulled - low flow
9/22/2016	No Op.	Pulled - low flow
9/23/2016	No Op.	Pulled - low flow
9/24/2016	No Op.	Pulled - low flow
9/25/2016	No Op.	Pulled - low flow
9/26/2016	No Op.	Pulled - low flow
9/27/2016	No Op.	Pulled - low flow
9/28/2016	No Op.	Pulled - low flow
9/29/2016	No Op.	Pulled - low flow
9/30/2016	No Op.	Pulled - low flow
10/1/2016	No Op.	Pulled - low flow
10/2/2016	No Op.	Pulled - low flow
10/3/2016	No Op.	Pulled - low flow
10/4/2016	No Op.	Pulled - low flow
10/5/2016	No Op.	Pulled - low flow
10/6/2016	No Op.	Pulled - low flow
10/7/2016	No Op.	Pulled - low flow
10/8/2016	No Op.	Pulled - low flow
10/9/2016	No Op.	Pulled - low flow
10/10/2016	Op.	
10/11/2016	Op.	
10/12/2016	Op.	
10/13/2016	No Op.	Stopped - low flow
10/14/2016	Op.	
10/15/2016	No Op.	Stopped - debris
10/16/2016	Op.	
10/17/2016	Op.	
10/18/2016	Op.	
10/19/2016	Op.	
10/20/2016	Op.	
10/21/2016	No Op.	Pulled - high flow
10/22/2016	No Op.	Stopped - debris
10/23/2016	Op.	
10/24/2016	Op.	
10/25/2016	Op.	
10/26/2016	Op.	
10/27/2016	Op.	

10/28/2016	Op.	
10/29/2016	Op.	
10/30/2016	Op.	
10/31/2016	Op.	
11/1/2016	Op.	
11/2/2016	Op.	
11/3/2016	Op.	
11/4/2016	Op.	
11/5/2016	Op.	
11/6/2016	Op.	
11/7/2016	Op.	
11/8/2016	Op.	
11/9/2016	Op.	
11/10/2016	Op.	
11/11/2016	Op.	
11/12/2016	Op.	
11/13/2016	Op.	
11/14/2016	Op.	
11/15/2016	Op.	
11/16/2016	Op.	
11/17/2016	Op.	
11/18/2016	Op.	
11/19/2016	Op.	
11/20/2016	Op.	
11/21/2016	Op.	
11/22/2016	Op.	
11/23/2016	Op.	
11/24/2016	Op.	
11/25/2016	Op.	
11/26/2016	Op.	
11/27/2016	Op.	
11/28/2016	Op.	
11/29/2016	Op.	
11/30/2016	Op.	End Trapping

APPENDIX C. Regression Models

Model: Chinook Yearlings (Spring '06-'14) Back Position, (r^2 = 0.15; p = 0.03)

Origin/Species/Stage	Age	Date	Trap Position	Mark	Recap	Trap Efficiency (R+1) / M	ASIN Transform	Discharge (m^3/s)
Wild Chinook Smolt	1+	3/31/2007	Back	40	2	0.08	0.28	24.6
Wild Chinook Smolt	1+	4/6/2006	Back	42	9	0.24	0.51	7.5
Wild Chinook Smolt	1+	4/14/2010	Back	42	4	0.12	0.35	4.9
Wild Chinook Smolt	1+	3/31/2012	Back	43	5	0.14	0.38	7.1
Wild Chinook Smolt	1+	4/3/2007	Back	46	1	0.04	0.21	18.6
Wild Chinook Smolt	1+	4/19/2012	Back	48	7	0.17	0.42	12.3
Wild Chinook Smolt	1+	4/10/2007	Back	53	4	0.09	0.31	27.4
Wild Chinook Smolt	1+	4/21/2009	Back	53	0	0.02	0.14	20.7
Wild Chinook Smolt	1+	4/13/2012	Back	53	4	0.09	0.31	10.1
Wild Chinook Smolt	1+	4/16/2012	Back	53	7	0.15	0.40	12.5
Wild Chinook Smolt	1+	4/24/2008	Back	57	8	0.16	0.41	5.9
Wild Chinook Smolt	1+	4/23/2012	Back	58	1	0.03	0.19	39.1
Wild Chinook Smolt	1+	4/24/2006	Back	59	3	0.07	0.26	10.4
Wild Chinook Smolt	1+	3/23/2007	Back	59	7	0.14	0.38	24.8
Wild Chinook Smolt	1+	3/17/2007	Back	64	7	0.13	0.36	26.5
Wild Chinook Smolt	1+	4/18/2010	Back	67	2	0.05	0.21	9.3
Wild Chinook Smolt	1+	4/17/2008	Back	72	13	0.19	0.46	7.8
Wild Chinook Smolt	1+	4/3/2006	Back	81	10	0.14	0.38	5.3
Wild Chinook Smolt	1+	3/20/2007	Back	91	13	0.15	0.40	34.8
Wild Chinook Smolt	1+	5/1/2008	Back	102	16	0.17	0.42	8.9
Wild Chinook Smolt	1+	4/28/2008	Back	127	19	0.16	0.41	7.7
Wild Chinook Smolt	1+	4/14/2008	Back	195	40	0.21	0.48	9.3
Wild Chinook Smolt	1+	3/9/2014	Back	65	4	0.08	0.28	27.1
Wild Chinook Smolt	1+	3/13/2014	Back	67	9	0.15	0.40	16.0

Model: Chinook Subyearling (Fall '06-'13) Back Position, (r^2 = 0.55; p = 0.001)

Origin/Species/Stage	Age	Date	Trap Position	Mark	Recap	Trap Efficiency (R+1) / M	ASIN Transform	Discharge (m^3/s)
Wild Chinook Parr	0	10/26/2006	Back	183	50	0.28	0.56	1.4
Wild Chinook Parr	0	10/30/2006	Back	168	52	0.32	0.60	1.8
Wild Chinook Parr	0	11/1/2010	Back	254	42	0.17	0.42	5.6
Wild Chinook Parr	0	11/4/2010	Back	287	49	0.17	0.43	6.1
Wild Chinook Parr	0	11/7/2010	Back	168	32	0.20	0.46	6.8
Wild Chinook Parr	0	11/13/2010	Back	185	35	0.19	0.46	3.7
Wild Chinook Parr	0	11/3/2012	Back	201	25	0.13	0.37	11.4

Wild Chinook Parr	0	11/7/2012	Back	233	27	0.12	0.35	11.2
Wild Chinook Parr	0	11/11/2012	Back	328	87	0.27	0.54	6.1
Wild Chinook Parr	0	11/15/2012	Back	195	34	0.18	0.44	6.0
Wild Chinook Parr	0	9/30/2013	Back	171	12	0.08	0.28	15.3
Wild Chinook Parr	0	10/2/2013	Back	213	43	0.21	0.47	9.3
Wild Chinook Parr	0	10/3/2013	Back	181	41	0.23	0.50	8.4
Wild Chinook Parr	0	10/7/2013	Back	242	31	0.13	0.37	6.6
Wild Chinook Parr	0	10/9/2013	Back	203	40	0.20	0.47	8.6
Wild Chinook Parr	0	11/27/2013	Back	241	55	0.23	0.50	5.2

Model: Chinook Subyearling (Fall ’06-’13) Forward Position, (r^2 = 0.16; p = 0.02)

Origin/Species/Stage	Age	Date	Trap Position	Mark	Recap	Trap Efficiency (R+1) / M	ASIN Transform	Discharge (m^3/s)
Wild Chinook Parr	0	7/13/2006	Back	52	8	0.17	0.43	4.8
Wild Chinook Parr	0	7/17/2006	Back	138	15	0.12	0.35	3.7
Wild Chinook Parr	0	7/20/2006	Back	74	5	0.08	0.29	3.2
Wild Chinook Parr	0	7/28/2006	Back	54	5	0.11	0.34	2.6
Wild Chinook Parr	0	7/31/2006	Back	99	7	0.08	0.29	2.2
Wild Chinook Parr	0	9/18/2006	Back	55	10	0.20	0.46	1.3
Wild Chinook Parr	0	7/31/2008	Back	60	15	0.27	0.54	3.4
Wild Chinook Parr	0	8/12/2008	Back	103	2	0.03	0.17	2.4
Wild Chinook Parr	0	8/22/2008	Back	75	11	0.16	0.41	2.7
Wild Chinook Parr	0	8/28/2008	Back	72	7	0.11	0.34	2.3
Wild Chinook Parr	0	10/9/2008	Back	110	22	0.21	0.48	1.8
Wild Chinook Parr	0	10/27/2008	Back	51	12	0.26	0.53	1.6
Wild Chinook Parr	0	10/30/2008	Back	84	15	0.19	0.45	1.5
Wild Chinook Parr	0	11/6/2008	Back	78	8	0.12	0.35	2.2
Wild Chinook Parr	0	11/10/2008	Back	88	0	0.01	0.11	8.7
Wild Chinook Parr	0	7/14/2009	Back	86	2	0.04	0.19	5.5
Wild Chinook Parr	0	7/15/2009	Back	105	4	0.05	0.22	5.1
Wild Chinook Parr	0	7/17/2009	Back	122	8	0.07	0.28	4.4
Wild Chinook Parr	0	7/20/2009	Back	89	2	0.03	0.19	3.8
Wild Chinook Parr	0	8/17/2009	Back	73	1	0.03	0.17	1.6
Wild Chinook Parr	0	9/10/2009	Back	56	7	0.14	0.39	1.7
Wild Chinook Parr	0	8/8/2010	Back	58	1	0.03	0.19	2.4
Wild Chinook Parr	0	8/11/2010	Back	114	8	0.08	0.29	2.2
Wild Chinook Parr	0	9/11/2010	Back	68	9	0.15	0.39	2.1
Wild Chinook Parr	0	10/12/2010	Back	216	42	0.20	0.46	3.6
Wild Chinook Parr	0	10/15/2010	Back	192	37	0.20	0.46	2.7
Wild Chinook Parr	0	10/18/2010	Back	193	36	0.19	0.45	2.3

Wild Chinook Parr	0	10/22/2010	Back	92	18	0.21	0.47	2.0
Wild Chinook Parr	0	10/25/2010	Back	60	7	0.13	0.37	2.2
Wild Chinook Parr	0	10/29/2010	Back	127	0	0.01	0.09	2.7
Wild Chinook Parr	0	8/19/2011	Back	106	5	0.06	0.24	3.5

Model: Chinook Subyearling (Fall ’14-’16) Bolser Site (r^2 = 0.60; p = 0.005)

Origin/Species/Stage	Age	Date	Trap Position	Mark	Recap	Trap Efficiency (R+1)/M	ASIN Transform	Discharge (m^3/s)
Wild Chinook Parr	0	7/14/2014	1	89	7	0.09	0.30	6.8
Wild Chinook Parr	0	7/21/2014	1	74	4	0.07	0.26	4.3
Wild Chinook Parr	0	7/27/2014	1	72	4	0.07	0.27	3.3
Wild Chinook Parr	0	10/24/2014	1	53	4	0.09	0.31	5.0
Wild Chinook Parr	0	10/27/2014	1	71	3	0.06	0.24	5.4
Wild Chinook Parr	0	10/30/2014	1	70	5	0.09	0.30	8.4
Wild Chinook Parr	0	11/1/2014	1	96	6	0.07	0.27	9.6
Wild Chinook Parr	0	10/24/2016	1	59	6	0.12	0.35	8.0
Wild Chinook Parr	0	11/1/2016	1	68	8	0.13	0.37	10.6
Wild Chinook Parr	0	11/15/2016	1	69	11	0.17	0.43	15.3

Model: Summer Steelhead Back Position (’07-’14), (r^2 = 0.35; p = 2.90E-05)

Origin/Species/Stage	Age	Date	Trap Position	Mark	Recap	Trap Efficiency (R+1) / M	ASIN Transform	Discharge (m^3/s)
Wild Steelhead Parr/Smolt	1+	3/20/2007	Back	55	1	0.04	0.19	34.8
Wild Steelhead Parr/Smolt	1+	3/31/2007	Back	56	4	0.09	0.30	24.6
Wild Steelhead Parr/Smolt	1+	4/10/2007	Back	60	8	0.15	0.40	27.4
Wild Steelhead Parr/Smolt	1+	5/1/2007	Back	52	2	0.06	0.24	22.2
Wild Steelhead Parr/Smolt	1+	6/9/2007	Back	71	9	0.14	0.38	23.8
Wild Steelhead Parr/Smolt	1+	6/12/2007	Back	65	8	0.14	0.38	19.9
Wild Steelhead Parr/Smolt	1+	6/14/2007	Back	61	5	0.10	0.32	19.5
Wild Steelhead Parr/Smolt	1+	6/21/2007	Back	67	4	0.07	0.28	21.3
Wild Steelhead Parr/Smolt	1+	4/14/2008	Back	149	46	0.32	0.60	9.3
Wild Steelhead Parr/Smolt	1+	4/17/2008	Back	75	3	0.05	0.23	7.8
Wild Steelhead Parr/Smolt	1+	4/28/2008	Back	74	11	0.16	0.41	7.7
Wild Steelhead Parr/Smolt	1+	5/1/2008	Back	176	29	0.17	0.43	8.9
Wild Steelhead Parr/Smolt	1+	5/12/2008	Back	55	8	0.16	0.42	18.8
Wild Steelhead Parr/Smolt	1+	5/15/2008	Back	57	1	0.04	0.19	39.4
Wild Steelhead Parr/Smolt	1+	6/9/2008	Back	142	20	0.15	0.39	26.6
Wild Steelhead Parr/Smolt	1+	6/12/2008	Back	83	10	0.13	0.37	23.3

Wild Steelhead Parr/Smolt	1+	6/16/2008	Back	81	8	0.11	0.34	32.3
Wild Steelhead Parr/Smolt	1+	4/20/2010	Back	121	11	0.10	0.32	19.1
Wild Steelhead Parr/Smolt	1+	4/22/2010	Back	121	10	0.09	0.31	20.6
Wild Steelhead Parr/Smolt	1+	6/20/2010	Back	128	11	0.09	0.31	26.2
Wild Steelhead Parr/Smolt	1+	4/5/2011	Back	52	1	0.04	0.20	21.5
Wild Steelhead Parr/Smolt	1+	5/22/2011	Back	84	3	0.05	0.22	43.6
Wild Steelhead Parr/Smolt	1+	6/12/2012	Back	69	5	0.09	0.30	33.1
Wild Steelhead Parr/Smolt	1+	7/26/2012	Back	63	4	0.08	0.29	7.9
Wild Steelhead Parr/Smolt	1+	4/22/2013	Back	66	6	0.11	0.33	14.7
Wild Steelhead Parr/Smolt	1+	4/26/2013	Back	50	2	0.06	0.25	18.2
Wild Steelhead Parr/Smolt	1+	4/30/2013	Back	54	2	0.06	0.24	22.0
Wild Steelhead Parr/Smolt	1+	5/8/2013	Back	62	0	0.02	0.13	61.4
Wild Steelhead Parr/Smolt	1+	5/19/2013	Back	122	15	0.13	0.37	32.0
Wild Steelhead Parr/Smolt	1+	5/22/2013	Back	58	4	0.09	0.30	30.6
Wild Steelhead Parr/Smolt	1+	5/26/2013	Back	79	3	0.05	0.23	20.5
Wild Steelhead Parr/Smolt	1+	5/30/2013	Back	92	7	0.09	0.30	24.0
Wild Steelhead Parr/Smolt	1+	6/3/2013	Back	71	6	0.10	0.32	27.2
Wild Steelhead Parr/Smolt	1+	6/7/2013	Back	94	4	0.05	0.23	40.2
Wild Steelhead Parr/Smolt	1+	6/13/2013	Back	64	2	0.05	0.22	21.1
Wild Steelhead Parr/Smolt	1+	6/17/2013	Back	115	5	0.05	0.23	25.0
Wild Steelhead Parr/Smolt	1+	6/29/2013	Back	60	12	0.22	0.48	20.7
Wild Steelhead Parr/Smolt	1+	7/7/2013	Back	75	9	0.13	0.37	9.2
Wild Steelhead Parr/Smolt	1+	5/5/2014	Back	55	3	0.07	0.27	35.7
Wild Steelhead Parr/Smolt	1+	5/20/2014	Back	57	0	0.02	0.13	42.2
Wild Steelhead Parr/Smolt	1+	6/3/2014	Back	75	1	0.03	0.16	45.6

Model: 2013 Summer Steelhead Back Position (In-yr.), (r^2 = 0.15; p = 0.05)

Origin/Species/Stage	Age	Date	Trap Position	Mark	Recap	Trap Efficiency (R+1) / M	ASIN Transform	Discharge (m^3/s)
Wild Chinook Smolt	1+	3/31/2007	Back	40	2	0.08	0.28	24.6
Wild Chinook Smolt	1+	4/6/2006	Back	42	9	0.24	0.51	7.5
Wild Chinook Smolt	1+	4/14/2010	Back	42	4	0.12	0.35	4.9
Wild Chinook Smolt	1+	3/31/2012	Back	43	5	0.14	0.38	7.1
Wild Chinook Smolt	1+	4/3/2007	Back	46	1	0.04	0.21	18.6
Wild Chinook Smolt	1+	4/19/2012	Back	48	7	0.17	0.42	12.3
Wild Chinook Smolt	1+	4/10/2007	Back	53	4	0.09	0.31	27.4
Wild Chinook Smolt	1+	4/21/2009	Back	53	0	0.02	0.14	20.7
Wild Chinook Smolt	1+	4/13/2012	Back	53	4	0.09	0.31	10.1
Wild Chinook Smolt	1+	4/16/2012	Back	53	7	0.15	0.40	12.5
Wild Chinook Smolt	1+	4/24/2008	Back	57	8	0.16	0.41	5.9

Wild Chinook Smolt	1+	4/23/2012	Back	58	1	0.03	0.19	39.1
Wild Chinook Smolt	1+	4/24/2006	Back	59	3	0.07	0.26	10.4
Wild Chinook Smolt	1+	3/23/2007	Back	59	7	0.14	0.38	24.8
Wild Chinook Smolt	1+	3/17/2007	Back	64	7	0.13	0.36	26.5
Wild Chinook Smolt	1+	4/18/2010	Back	67	2	0.05	0.21	9.3
Wild Chinook Smolt	1+	4/17/2008	Back	72	13	0.19	0.46	7.8
Wild Chinook Smolt	1+	4/3/2006	Back	81	10	0.14	0.38	5.3
Wild Chinook Smolt	1+	3/20/2007	Back	91	13	0.15	0.40	34.8
Wild Chinook Smolt	1+	5/1/2008	Back	102	16	0.17	0.42	8.9
Wild Chinook Smolt	1+	4/28/2008	Back	127	19	0.16	0.41	7.7
Wild Chinook Smolt	1+	4/14/2008	Back	195	40	0.21	0.48	9.3
Wild Chinook Smolt	1+	3/9/2014	Back	65	4	0.08	0.28	27.1
Wild Chinook Smolt	1+	3/13/2014	Back	67	9	0.15	0.40	16.0

Model: Spring Chinook 2010-2014 Non-Trapping Period Array (NAL) – Full Antenna Function, (r^2 = 0.61; p = 0.0002)

Origin/Species/Stage	Age	Date	Mark	Detections	Trap Efficiency (R+1) / M	ASIN Transform	Discharge (m^3/s)
Wild Chinook Parr	0	11/4/2010	254	95	0.38	0.66	6.3
Wild Chinook Parr	0	11/7/2010	287	70	0.25	0.52	7.0
Wild Chinook Parr	0	11/10/2010	168	74	0.45	0.73	4.8
Wild Chinook Parr	0	11/13/2010	74	41	0.57	0.85	4.0
Wild Chinook Parr	0	11/18/2010	185	22	0.12	0.36	7.9
Wild Chinook Parr	0	11/3/2012	201	21	0.11	0.34	10.9
Wild Chinook Parr	0	11/7/2012	233	31	0.14	0.38	10.7
Wild Chinook Parr	0	11/11/2012	328	66	0.20	0.47	6.3
Wild Chinook Parr	0	11/15/2012	195	68	0.35	0.64	6.2
Wild Chinook Parr	0	11/4/2013	130	51	0.40	0.68	3.7
Wild Chinook Parr	0	11/8/2013	106	39	0.38	0.66	4.2
Wild Chinook Parr	0	3/9/2014	65	4	0.08	0.28	24.9
Wild Chinook Parr	0	3/13/2014	67	5	0.09	0.30	15.3
Wild Chinook Parr	0	11/4/2014	114	5	0.05	0.23	10.5
Wild Chinook Parr	0	11/1/2014	96	5	0.06	0.25	16.5
Wild Chinook Parr	0	11/10/2014	78	8	0.12	0.35	11.3

Model: Spring Chinook 2010-2014 Non-Trapping Period Array (NAL) – Partial Antenna Function, (r^2 = 0.38; p = 0.007)

Origin/Species/Stage	Age	Date	Mark	Detections	Discharge

					Trap Efficiency (R+1)/M	ASIN Transform	
Wild Chinook Parr	0	11/4/2010	254	39	0.16	0.41	6.3
Wild Chinook Parr	0	11/7/2010	287	16	0.06	0.25	7.0
Wild Chinook Parr	0	11/10/2010	168	34	0.21	0.47	4.8
Wild Chinook Parr	0	11/13/2010	74	17	0.24	0.52	4.0
Wild Chinook Parr	0	11/18/2010	185	8	0.05	0.22	7.9
Wild Chinook Parr	0	11/3/2012	201	7	0.04	0.20	10.9
Wild Chinook Parr	0	11/7/2012	233	8	0.04	0.20	10.7
Wild Chinook Parr	0	11/11/2012	328	24	0.08	0.28	6.3
Wild Chinook Parr	0	11/15/2012	195	30	0.16	0.41	6.2
Wild Chinook Parr	0	11/4/2013	130	40	0.32	0.60	3.7
Wild Chinook Parr	0	11/8/2013	106	30	0.29	0.57	4.2
Wild Chinook Parr	0	3/9/2014	65	1	0.03	0.18	24.9
Wild Chinook Parr	0	3/13/2014	67	5	0.09	0.30	15.3
Wild Chinook Parr	0	11/1/2014	96	1	0.02	0.15	10.5
Wild Chinook Parr	0	11/4/2014	114	4	0.04	0.21	16.5
Wild Chinook Parr	0	11/10/2014	78	3	0.05	0.23	11.3

APPENDIX D. Historical Morphometric Data

Spring Chinook (2004-2016)

Trap Year	Brood Year	Origin/Species/Stage	Fork Length (mm)			Weight (g)			K-factor
			Mean	n	SD	Mean	n	SD	
2004	2002	Wild Chinook Yearling Smolt	93.4	336	12.4	9	337	5	1.1
2004	2003	Wild Chinook Subyearling Fry	39.5	82	5.1	0.6	79	0.3	1
2004	2003	Wild Chinook Subyearling Parr	82.4	792	7.9	6.1	702	2.7	1.1
2005	2003	Wild Chinook Yearling Smolt	93.6	278	7.9	8.7	276	2.1	1.1
2005	2004	Wild Chinook Subyearling Fry	42.1	107	5.6	0.7	102	0.4	0.9
2005	2004	Wild Chinook Subyearling Parr	75.9	924	9.6	4.9	890	3.8	1.1
2006	2004	Wild Chinook Yearling Smolt	91.2	363	7.1	7.5	362	1.8	1
2006	2005	Wild Chinook Subyearling Fry	—	—	—	—	—	—	—
2006	2005	Wild Chinook Subyearling Parr	72.9	1,428	9.6	3.9	1,428	2.3	1
2007	2005	Wild Chinook Yearling Smolt	89	676	8.2	8	675	6.1	1.1
2007	2006	Wild Chinook Subyearling Fry	39	24	3.7	0.6	24	0.5	1
2007	2006	Wild Chinook Subyearling Parr	79.5	686	13.8	6.1	685	2.6	1.2
2008	2006	Wild Chinook Yearling Smolt	96.1	904	6.6	9.5	904	2.1	1.1
2008	2007	Wild Chinook Subyearling Fry	42.8	127	4.6	0.8	127	0.4	1
2008	2007	Wild Chinook Subyearling Parr	75.8	2,049	12.5	5.2	2,049	2.4	1.2
2009	2007	Wild Chinook Yearling Smolt	94.4	198	8.9	9.2	198	2.5	1.1
2009	2008	Wild Chinook Subyearling Fry	44.8	82	4.8	0.9	82	0.6	1
2009	2008	Wild Chinook Subyearling Parr	70.1	2,333	12	4.2	2,333	2	1.2
2010	2008	Wild Chinook Yearling Smolt	96.9	366	7.3	10.2	366	2.3	1.1
2010	2009	Wild Chinook Subyearling Fry	41.8	30	5	1.3	8	0.2	1.8
2010	2009	Wild Chinook Subyearling Parr	80.7	3,021	10.7	6.2	3,021	2.3	1.2
2011	2009	Wild Chinook Yearling Smolt	89.1	152	9.9	7.7	152	1.8	1.1
2011	2010	Wild Chinook Subyearling Fry	39.8	217	6.6	0.6	217	0.5	1
2011	2010	Wild Chinook Subyearling Parr	73.4	1,046	13.1	4.9	1,046	2.5	1.2
2012	2010	Wild Chinook Yearling Smolt	93.3	368	7	9.2	368	2.2	1.1
2012	2011	Wild Chinook Subyearling Fry	42.7	48	9.1	0.9	48	0.6	1.2
2012	2011	Wild Chinook Subyearling Parr	77.9	2,160	10.7	5.3	2,160	1.9	1.1
2013	2011	Wild Chinook Yearling Smolt	90.6	239	75	7.9	239	2.1	1.1
2013	2012	Wild Chinook Subyearling Fry	45.6	1,824	6.8	1	1,803	0.6	1.1
2013	2012	Wild Chinook Subyearling Parr	70	4,422	11.4	3.8	4,409	1.7	1.1
2014	2012	Wild Chinook Yearling Smolt	89.5	464	6.9	7.5	464	1.8	1
2014	2013	Wild Chinook Subyearling Fry	40.1	677	5.2	0.9	221	0.5	1.4
2014	2013	Wild Chinook Subyearling Parr	69.1	1,549	12.3	3.8	1,547	2.3	1.2
2015	2013	Wild Chinook Yearling Smolt	93	152	7	8.4	152	2.2	1
2015	2014	Wild Chinook Subyearling Fry	45	338	9.9	1	338	0.9	0.9

2015	2014	Wild Chinook Subyearling Parr	84	210	8	6.5	209	1.7	1.1
2015	2013	Hatchery Chinook Yearling Smolt	136	284	12.3	29.5	284	8.8	1.1
2016	2014	Wild Chinook Yearling Smolt	96	61	5.5	9.0	61	1.7	1.01
2016	2015	Wild Chinook Subyearling Fry	38	285	3.0	0.5	285	0.2	0.78
2016	2015	Wild Chinook Subyearling Parr	85	491	12.7	6.9	490	2.5	1.07
2016	2014	Hatchery Chinook Yearling Smolt	119	87	13.5	19.6	87	7.6	1.09

Summer Steelhead (2004-2016)

Trap Year	Brood Year	Age	Origin/Species	Fork Length (mm)			Weight (g)			K-factor
				Mean	n	SD	Mean	n	SD	
2004	2004	0	Wild Summer Steelhead	67	358	10	3.5	279	1.5	1.2
2004	2003	1	Wild Summer Steelhead	101.7	394	23.2	13.2	366	27.3	1.3
2004	2002	2	Wild Summer Steelhead	161.6	146	19.8	43.4	141	15.5	1
2004	2001	3	Wild Summer Steelhead	201.6	43	11.2	76	43	21.2	0.9
2004	2003	1	Hat. Summer Steelhead	182.8	523	22.4	62.1	497	21.2	1
2005	2005	0	Wild Summer Steelhead	54.1	649	15.7	2.2	616	3.2	1.4
2005	2004	1	Wild Summer Steelhead	93.6	585	25.6	10.8	575	10.1	1.3
2005	2003	2	Wild Summer Steelhead	153.5	103	21.2	38.1	102	16.4	1.1
2005	2002	3	Wild Summer Steelhead	144	1	—	43.2	1	—	1.4
2005	2004	1	Hat. Summer Steelhead	188.2	343	21.2	66	343	24	1
2006	2006	0	Wild Summer Steelhead	66.3	180	5.8	2.5	180	1	0.9
2006	2005	1	Wild Summer Steelhead	85.2	877	18.7	6.7	877	6.6	1.1
2006	2004	2	Wild Summer Steelhead	155.9	106	26.8	36.1	105	13.5	1
2006	2003	3	Wild Summer Steelhead	197	2	—	73.5	2	—	1
2006	2005	1	Hat. Summer Steelhead	—	—	—	—	—	—	—
2007	2007	0	Wild Summer Steelhead	54.2	329	11.7	2	328	1.4	1.3
2007	2006	1	Wild Summer Steelhead	82.7	1,330	16.8	7.2	1,329	6.3	1.3
2007	2005	2	Wild Summer Steelhead	143.8	102	20.6	31.4	102	11.9	1.1
2007	2004	3	Wild Summer Steelhead	143	1	—	26.8	1	—	0.9
2007	2006	1	Hat. Summer Steelhead	149.3	3	47	33.1	3	29.1	1
2008	2008	0	Wild Summer Steelhead	52.9	930	11.1	1.7	930	1.2	1.1
2008	2007	1	Wild Summer Steelhead	84.5	1,876	17.1	7.4	1,874	6.6	1.2
2008	2006	2	Wild Summer Steelhead	149.9	122	22.9	36	122	15.5	1.1
2008	2005	3	Wild Summer Steelhead	180.3	13	18.9	57.4	13	16.4	1
2008	2007	1	Hat. Summer Steelhead	179.4	389	16.5	55.9	388	14.8	1
2009	2009	0	Wild Summer Steelhead	55.6	843	10.5	2.2	688	1.1	1.3
2009	2008	1	Wild Summer Steelhead	82.6	452	18.6	7.1	447	5.5	1.3
2009	2007	2	Wild Summer Steelhead	156.9	72	22	40.9	72	15.5	1.1

2009	2006	3	Wild Summer Steelhead	195	3	5	73	3	6.7	1
2009	2008	1	Hat. Summer Steelhead	183.1	280	16.7	60.8	280	18.2	1
2010	2010	0	Wild Summer Steelhead	55	1,287	11.1	2.5	917	1.3	1.5
2010	2009	1	Wild Summer Steelhead	89.8	1,079	19.1	9	1,072	7.1	1.2
2010	2008	2	Wild Summer Steelhead	144.9	87	25.1	35	87	17.4	1.2
2010	2007	3	Wild Summer Steelhead	184	8	12.2	61.9	8	10.2	1
2010	2009	1	Hat. Summer Steelhead	183.5	531	19.5	61.3	526	19.6	1
2011	2011	0	Wild Summer Steelhead	43.5	1,093	10.1	1.1	783	0.9	1.3
2011	2010	1	Wild Summer Steelhead	75.7	818	18.5	5.5	811	5.7	1.3
2011	2009	2	Wild Summer Steelhead	144.8	27	41.3	42.1	27	62.1	1.4
2011	2008	3	Wild Summer Steelhead	—	—	—	—	—	—	—
2011	2010	1	Hat. Summer Steelhead	180.7	464	17	59.1	464	17.6	1
2012	2012	0	Wild Summer Steelhead	55.1	589	14.2	2.6	402	1.2	1.6
2012	2011	1	Wild Summer Steelhead	84.7	747	17.4	7.6	741	5.7	1.3
2012	2010	2	Wild Summer Steelhead	127.1	132	27	23.7	132	14.5	1.2
2012	2009	3	Wild Summer Steelhead	161	4	32	40.5	4	15.6	1
2012	2011	1	Hat. Summer Steelhead	154.8	318	20.9	37.7	318	14	1
2013	2013	0	Wild Summer Steelhead	56.1	878	11.3	2.1	777	1.1	1.2
2013	2012	1	Wild Summer Steelhead	44.5	1,777	14.7	5.4	1,772	4.2	1.2
2013	2011	2	Wild Summer Steelhead	144.7	21	15.7	36.1	21	10.2	1
2013	2010	3	Wild Summer Steelhead	—	—	—	—	—	—	—
2013	2012	1	Hat. Summer Steelhead	166.2	365	21.4	49.2	363	18.2	1.1
2014	2014	0	Wild Summer Steelhead	49.6	490	12.8	1.7	389	1.1	1.4
2014	2013	1	Wild Summer Steelhead	82.2	745	13.6	6.3	745	3.5	1.1
2014	2012	2	Wild Summer Steelhead	145.1	30	16.5	33	30	13.4	1.1
2014	2011	3	Wild Summer Steelhead	—	—	—	—	—	—	—
2014	2013	1	Hat. Summer Steelhead	173.4	632	18.7	52.6	633	15.9	1
2015	2015	0	Wild Summer Steelhead	70	182	15.5	4.3	176	2	1.1
2015	2014	1	Wild Summer Steelhead	88	233	20.2	8.3	233	6.7	1
2015	2013	2	Wild Summer Steelhead	149	14	13.5	33.7	14	8.2	1
2015	2012	3	Wild Summer Steelhead	191	1	—	73.8	1	—	1.1
2015	2014	1	Hat. Summer Steelhead	175	273	15.2	51.3	273	12.5	0.9
2016	2016	0	Wild Summer Steelhead	56	674	16.4	2.4	617	1.8	1.0
2016	2015	1	Wild Summer Steelhead	87	278	21.5	8.3	278	5.9	1.1
2016	2014	2	Wild Summer Steelhead	143	19	17.4	31.1	19	9.6	1.0
2016	2013	3	Wild Summer Steelhead	202	1	—	90.1	1	—	1.1
2016	2015	1	Hat. Summer Steelhead	175	95	15.5	55.1	95	16.2	1.0

Coho (2007-2016)

Trap Year	Brood Year	Origin/Species/Stage	Fork Length (mm)			Weight (g)			K-factor
			Mean	n	SD	Mean	n	SD	
2004	2002	Nat. Or. Coho Yearling Smolt	—	—	—	—	—	—	—
2004	2003	Nat. Or. Coho Subyearling Fry	—	—	—	—	—	—	—
2004	2003	Nat. Or. Coho Subyearling Parr	—	—	—	—	—	—	—
2004	2002	Hatchery Coho Yearling Smolt	136.6	847	12.8	27.4	820	7.5	1.1
2005	2003	Nat. Or. Coho Yearling Smolt	114.4	17	8.8	16.2	17	3.6	1.1
2005	2004	Nat. Or. Coho Subyearling Fry	49.1	9	10.4	1.3	9	0.8	1.1
2005	2004	Nat. Or. Coho Subyearling Parr	76.7	9	12.8	4.9	9	2.7	1.1
2005	2003	Hatchery Coho Yearling Smolt	137.3	689	11.3	28.6	690	7.2	1.1
2006	2004	Nat. Or. Coho Yearling Smolt	—	—	—	—	—	—	—
2006	2005	Nat. Or. Coho Subyearling Fry	—	—	—	—	—	—	—
2006	2005	Nat. Or. Coho Subyearling Parr	71	4	13.6	3.8	4	2.9	1.1
2006	2004	Hatchery Coho Yearling Smolt	—	—	—	—	—	—	—
2007	2005	Nat. Or. Coho Yearling Smolt	92.9	36	12.5	8.7	36	4	1.1
2007	2006	Nat. Or. Coho Subyearling Fry	—	—	—	—	—	—	—
2007	2006	Nat. Or. Coho Subyearling Parr	83	1	—	6.2	1	—	1.1
2007	2005	Hatchery Coho Yearling Smolt	116	2	—	16.8	2	—	1.1
2008	2006	Nat. Or. Coho Yearling Smolt	—	—	—	—	—	—	—
2008	2007	Nat. Or. Coho Subyearling Fry	—	—	—	—	—	—	—
2008	2007	Nat. Or. Coho Subyearling Parr	87	1	—	6.4	1	—	1
2008	2006	Hatchery Coho Yearling Smolt	130.2	843	10.4	23.6	843	6.2	1.1
2009	2007	Nat. Or. Coho Yearling Smolt	103	4	9.7	11.7	4	3.4	1.1
2009	2008	Nat. Or. Coho Subyearling Fry	—	—	—	—	—	—	—
2009	2008	Nat. Or. Coho Subyearling Parr	79.6	5	20.1	6.6	5	4.8	1.3
2009	2007	Hatchery Coho Yearling Smolt	135.3	625	8.9	26.2	579	5.2	1.1
2010	2008	Nat. Or. Coho Yearling Smolt	—	—	—	—	—	—	—
2010	2009	Nat. Or. Coho Subyearling Fry	48	2	—	1.3	2	—	1.2
2010	2009	Nat. Or. Coho Subyearling Parr	83.6	27	8.6	6.7	27	2.4	1.1
2010	2008	Hatchery Coho Yearling Smolt	130	1,051	10.1	23.8	1,049	5.3	1.1
2011	2009	Nat. Or. Coho Yearling Smolt	100.2	14	12.7	11.3	14	3.9	1.1
2011	2010	Nat. Or. Coho Subyearling Fry	—	—	—	—	—	—	—
2011	2010	Nat. Or. Coho Subyearling Parr	64.7	3	10.8	3	3	1.5	1.1
2011	2009	Hatchery Coho Yearling Smolt	124.6	969	8.6	21	969	4.8	1.1
2012	2010	Nat. Or. Coho Yearling Smolt	102.1	17	9.1	11.9	17	3	1.1
2012	2011	Nat. Or. Coho Subyearling Fry	36	1	—	—	—	—	—
2012	2011	Nat. Or. Coho Subyearling Parr	78.4	84	9.3	5	84	2.1	1
2012	2010	Hatchery Coho Yearling Smolt	126.2	1,684	7.6	21.5	1,684	5.5	1.1
2013	2011	Nat. Or. Coho Yearling Smolt	97	81	10	10	81	3.1	1.1
2013	2012	Nat. Or. Coho Subyearling Fry	47.3	3	1	1	3	1	0.9
2013	2012	Nat. Or. Coho Subyearling Parr	87.8	4	3.8	6.6	4	1	1

2013	2011	Hatchery Coho Yearling Smolt	130.1	982	8.5	23.3	977	4.9	1.1
2014	2012	Nat. Or. Coho Yearling Smolt	96.3	20	9.8	9.9	20	3	1.1
2014	2013	Nat. Or. Coho Subyearling Fry	36	1	—	—	—	—	—
2014	2013	Nat. Or. Coho Subyearling Parr	73	3	22.5	5.9	3	4.7	1.5
2014	2012	Hatchery Coho Yearling Smolt	127	1,203	9.7	21.7	1,207	5.0	1.1
2015	2013	Nat. Or. Coho Yearling Smolt	109	2	4.9	12.0	2	0.1	0.9
2015	2014	Nat. Or. Coho Subyearling Fry	47	7	13.7	1.4	7	1.5	0.9
2015	2014	Nat. Or. Coho Subyearling Parr	69	3	7	4.0	3	1.3	1.2
2015	2013	Hatchery Coho Yearling Smolt	131	952	9.9	23.3	952	4.8	1.0
2016	2014	Nat. Or. Coho Yearling Smolt	100	6	15.8	11.1	6	5.5	1.0
2016	2015	Nat. Or. Coho Subyearling Fry	—	—	—	—	—	—	—
2016	2015	Nat. Or. Coho Subyearling Parr	—	—	—	—	—	—	—
2016	2014	Hatchery Coho Yearling Smolt	134	302	8.4	24.8	301	5.0	1.0

Appendix M

Fish Trapping at the White River Smolt Trap during 2016

Population Estimates for Juvenile Spring Chinook Salmon in White River, WA

2016 Annual Report

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ABSTRACT

In 2007, Yakama Nation Fisheries Resource Management began monitoring emigration of Endangered Species Act (ESA) listed Upper Columbia River (UCR) spring Chinook salmon in the White River to provide abundance and freshwater survival estimates. This report summarizes data collected between March 1 and November 30, 2016. We used a 1.5 m rotary screw trap to collect 200 juvenile spring Chinook; 50 fry, 147 subyearling parr, and 3 yearling smolts. Daily counts at the trap were expanded via regression analysis derived from mark and recapture trials. We estimated that 386 (± 701; 95% CI) BY2014 wild spring Chinook smolts and 2,430 (± 723; 95% CI) BY2015 wild spring Chinook parr emigrated past the White River trap in 2016. Combined with data collected in 2015, this gives us a total estimate of 2,336 (± 807; 95% CI) BY2014 emigrants. Using spring Chinook spawning ground data collected by Washington Department of Fish and Wildlife (WDFW) in 2014, we estimated egg-to-emigrant survival of BY2014 spring Chinook to be 2.2% (90 smolts-per-redd).

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This project is part of a basin-wide monitoring program requiring close coordination between multiple agencies and contractors. We greatly appreciate the hard work of the Yakama Nation FRM crew members including Matthew Clubb, Jamie Hallman, Tim Jeffris and Kevin Swager who maintained and operated the trap during all hours including nights/weekends and inclement weather conditions. Also thank you to Peter Graf (Grant County PUD) for administering contracting and funding as well as Mike Hughes, Mclain Johnson, Andrew Murdoch, and Josh Williams (WDFW) for data sharing and collaboration on smolt trap methodologies.

1.0 INTRODUCTION

White River spring Chinook salmon (tkwínat) *Oncorhynchus tshawytscha* are part of the Upper Columbia River (UCR) spring Chinook salmon Evolutionarily Significant Unit (ESU), which was listed as endangered under the Endangered Species Act (ESA) in 1999. Due to critically low abundance, a captive broodstock program was operated in the White River between 1997 and 2015 as a risk aversion measure. Determining freshwater productivity of spring Chinook salmon in the White River is an essential component to overall population monitoring, and will help contribute to the body of knowledge needed to evaluate if further supplementation in the White River is warranted.

In the fall of 2005, Washington State Department of Fish and Wildlife (WDFW) began smolt trapping in the lower White River in order to provide an estimate of juvenile spring Chinook salmon production. No trapping was conducted in 2006 as there was a transition between trap operators. In 2007, Public Utility District No. 2 of Grant County (GCPUD) contracted with Yakama Nation Fisheries (YNF) to operate a rotary trap in the White River. This document reports data collected between March 1 and November 30, 2016, and provides emigration estimates for spring Chinook salmon yearlings (BY2014) and subyearlings (BY2015) during that time period. Fish trap operations were conducted in compliance with ESA consultation specifically to address abundance and productivity of spring Chinook salmon in the White River.

Within this document, we will report:

1) Juvenile abundance and productivity of spring Chinook salmon in the White River.

2) Emigration timing of spring Chinook salmon emigrating from the White River.

1.1 Watershed Description

The White River drainage encompasses 40,451 ha originating in alpine glaciers and perennial snow fields (Figure 1; USFS 2004). Elevation within the drainage varies from 569 m at the surface of Lake Wenatchee to 2,614 m at Clark Mountain (Andonaegui 2001). As one of two primary tributaries to Lake Wenatchee, the White River flows in a south-easterly direction for 42.9 rkm before emptying into the lake. Precipitation ranges from 79 cm at the mouth to more than 356 cm in the head waters (Andonaegui 2001). Due to its glacial origins, peak runoff for the White River typically occurs between April and July with occasional high

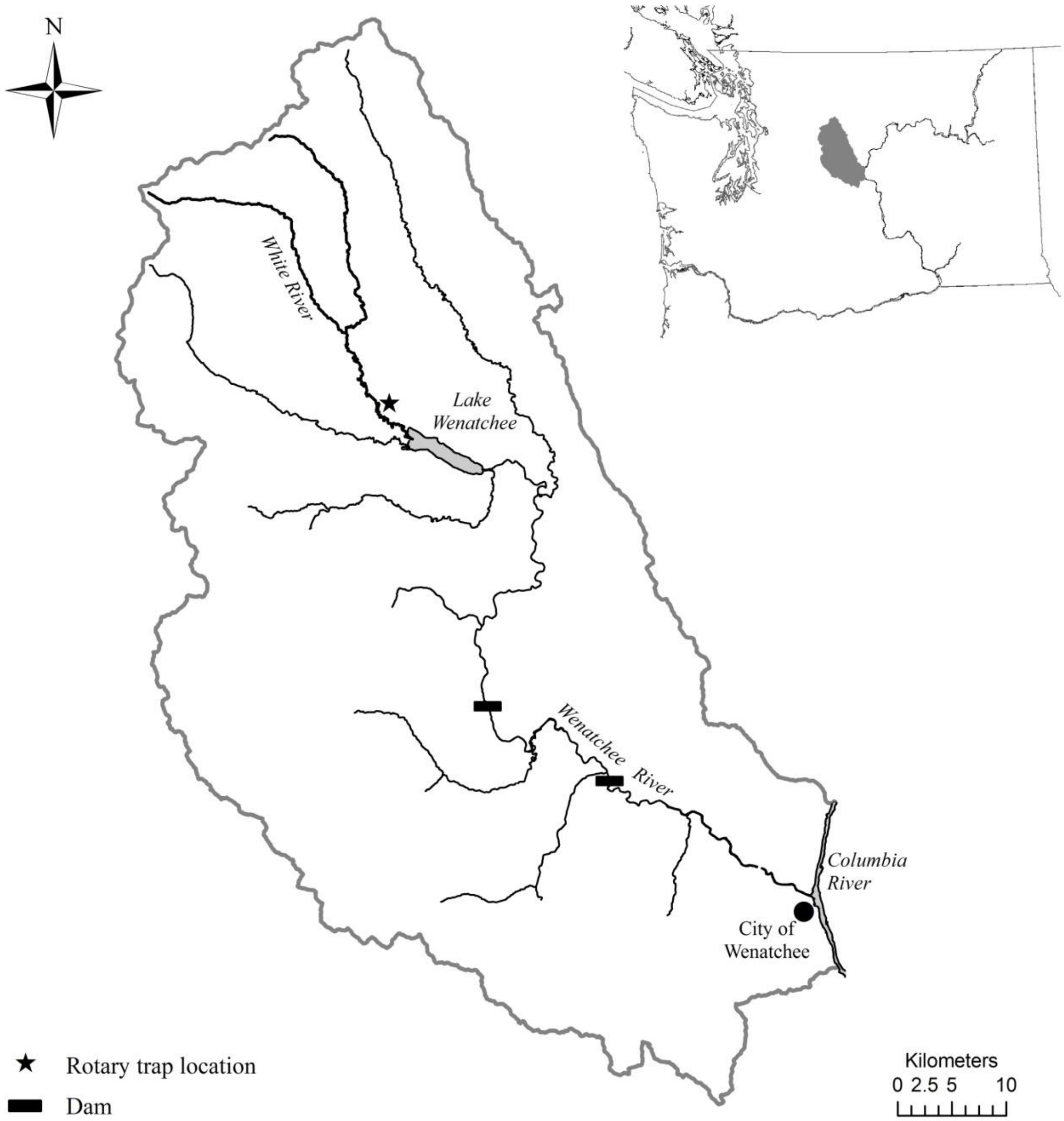


Figure 1. Map of the Wenatchee River subbasin with White River rotary trap location.

flows caused by rain-on-snow events in the fall and winter months. Water temperatures in this watershed tend to be cooler than other tributaries to the upper Wenatchee River subbasin. As of September 2002, Washington State Department of Ecology (WDOE) began operating a stream monitoring station at rkm 9.9. Operation of this station by WDOE is currently maintained with funding provided by GCPUD. In 2016, daily mean stream discharge ranged from 2.5 m^3/s (87 cfs) to 120 m^3/s (4,420 cfs) while mean daily stream temperatures ranged from 0.0°C to 14.6°C (Figs. 2 & 3). Discharge and temperature data provided by WDOE should be considered provisional and are presented in **Appendix A**.

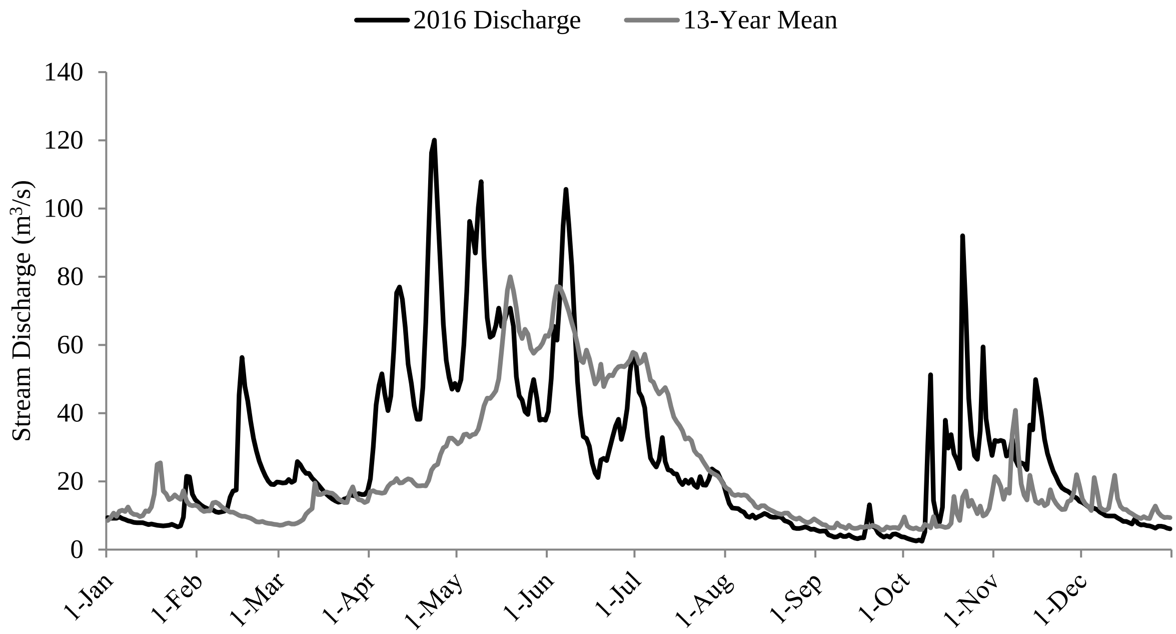


Figure 2. Mean daily stream discharge at the White River DOE stream monitoring station at Sears Creek Bridge, 2016.

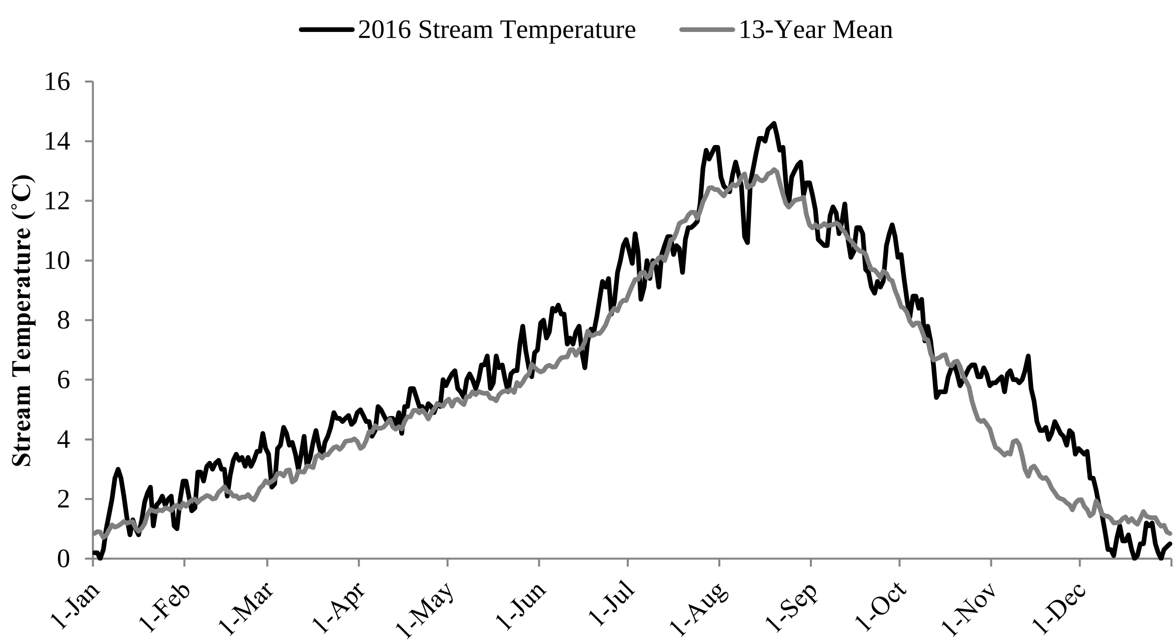


Figure 3. Mean daily water temperatures at the White River DOE stream monitoring station at Sears Creek Bridge, 2016.

The White River drainage has had minimal riparian harvest from the 1950's to the present on federally owned land. Turn of the century settlement and land clearing have impacted the riparian reserve network up to the Napeequa confluence, yet, riparian areas in the mainstem below Panther Creek remain in fair condition (USFS 2004). In the remainder of the watershed, woody debris recruitment, shade, aquatic habitat connectivity, and riparian vegetation appear to be in good condition. Current habitat concerns pertaining to the development of homes and vacation retreats on private lands do exist. Rip-rapping, channel constriction, and stream degradation are considered minor in the watershed. Public ownership comprises 78% of the drainage area; more than half of public land is located within the Glacier Peak Wilderness. The remaining 22% of the drainage is in private ownership (USFS 2004).

Downstream of White River Falls are key spawning grounds for spring Chinook salmon (tkwínat) *Oncorhynchus tshawytscha*, sockeye salmon (kálux) *O. nerka*, and bull trout *Salvelinus confluentus*. Two large tributaries to the White River, Napeequa River and Panther Creek, are also known to support populations of anadromous salmonids (Mullen et al. 1992). For a complete list of known fish species encountered in the White River see (**3.4 Incidental Species**).

2.0 METHODS

2.1 Trapping Equipment and Operation

In 2016, a 1.5m diameter cone rotary trap was operated in a single position at all discharge levels. This revised trapping regime was implemented in 2013 to simplify data analysis by eliminating obsolete trap positions that generated very little data. Past attempts at developing a high flow position generated very few efficiency trials resulting in limited trap efficiency data. Operating season-long at a single position, the trap was suspended from a river-spanning cable from which its position could be adjusted perpendicular to stream flow by hand powered winches anchored on a tree on the river-right bank.

The trap was operated 24 hours per day, seven days per week for the majority of the season. During spring snowmelt, operations only occurred during hours of darkness to minimize trap damage and subsequent capture mortality; still enabling sampling during the hours of peak fish movement. When trap operations were suspended, the cone was raised to avoid damage by debris.

During all ranges of river discharge, fish were removed daily. Additional trap checks were necessary during periods of high discharge in the spring, and in the autumn due to increased leaf litter. Debris in the live-box was removed continually by a rotating drum screen located at the rear of the holding box and hydraulically powered by the cone. A record of daily trap operations is provided in **Appendix B**.

2.2 Biological Sampling

Trap operating procedures and techniques followed a standardized, basin-wide monitoring plan developed by the Upper Columbia Regional Technical Team (UCRTT) for the Upper Columbia Salmon Recovery Board (UCSRB; Hillman 2004), which was adapted from Murdoch & Petersen (2000).

Captured fish were transferred from the rotary trap's live box using covered five-gallon plastic buckets to a stream-side portable sampling station. Fish were anesthetized in a solution of tricaine methanesulfonate (MS-222) to facilitate sampling and reduce handling stress. Fork length (FL) and weight were recorded for all fish, except large numbers of sockeye fry. For these fish, a daily subsample of 25 individuals was measured while the remaining fish were enumerated and released. Weight was measured to the nearest 0.1g with a portable digital scale while FL was recorded to the nearest 1.0 mm using a trough-type measuring board. These data were used to calculate a Fulton-type condition factor (K-factor) for each target species using the formula:

$$K = (W/L^3) \times 100{,}000$$

where K = Fulton-type condition metric;
W = weight in grams;
L = fork length in millimeters;
And 100,000 is a scaling constant.

Portable aerators were used to oxygenate holding water during sampling. All fish were allowed to fully recover from anesthesia before being released. Spring Chinook salmon were classified as either natural or hatchery origin by the presence/absence of coded wire tags (CWT's). Developmental stages (fry, parr, transitional or smolt) were visually identified and assigned to each individual sampled. Transitional juveniles were identified as having both parr and smolt characteristics; visible parr marks, semi-transparent fin coloration along with silvery coloration throughout body. Smolts were identified by a strong silvery coloration over entire body and faint or absent parr marks. Fry were defined as newly emerged fish with or without a visible yolk sac and a FL measuring < 50 mm. Age-0 spring Chinook salmon captured before July 1 were considered 'fry' and excluded from population estimates due to the inconclusive nature of their movement (i.e. active emigration or local distribution in-stream). Age-0 spring Chinook salmon captured after 1 July were considered subyearling emigrants and included in the population estimate (UCRTT, 2001).

Tissue samples (caudal clip) were taken from spring Chinook salmon and applied to blotter sheets. Samples were provided to WDFW for reproductive success analysis. Scale samples were also collected from all steelhead captured. Scale samples were submitted to WDFW for age analysis. Bull trout tissue or scale samples were not collected in 2016.

During periods when the trap operations were suspended (e.g. - high discharge, high debris and/or mechanical problems), passage estimates were generated to account for emigrants during these time periods. This estimate was calculated using the average number of fish captured three days prior and three days after the break in operation (Hillman et al., 2013; Snow et al., 2013).

2.3 Mark-Recapture Trials

Groups of marked spring Chinook salmon were used for trap efficiency trials. Fish were marked by insertion of a passive integrated transponder (PIT) tag into the abdominal cavity. Ideally, marked groups of fish would be released over a broad range of stream discharges in order to determine a trap efficiency-discharge relationship. (See **2.4 Data Analysis**). However, due to low abundance and limited holding time of ESA-listed species (reducing the ability to meet trials size requirements on a more consistent basis), marked groups were released whenever the minimum sample size (≥ 20) was obtained. Mark-recapture (M-R) trials followed the protocol described in Hillman (2004). Although the protocol suggests a minimum sample size of 100 fish for each mark-group, the limited abundance of juvenile emigrants from the White River required that efficiency trials be completed with much smaller sample sizes. YN's continued goal is to increase individual mark-group sizes, when possible, to meet the standard described above.

Number of wild fish included in a marked group was maximized by combining catches from three days of trapping. Fish were held up to 72 hours prior to release in holding boxes located on the river-left bank. Fish to be used in efficiency trials were then transported in five gallon buckets ~1.0 rkm upstream to the release location at Sears Creek Bridge (rkm 10.3). All mark groups are released by hand at nautical twilight.

Each M-R trial was conducted over a three-day (72 hour) period to allow time for passage or capture. Completed trials were only considered invalid if an interruption to trapping occurred or proper pre-release procedures were not followed. Trials resulting in zero recaptures were included in the efficiency regression as allowed by the new method of observed trap efficiency calculation (See equation 3 in **2.5.1 Estimate of Abundance**).

2.3.1 Marking and PIT tagging

All spring Chinook and summer steelhead juveniles with FL ≥ 60mm were PIT tagged unless the health of a specimen was in question. Once anesthetized, each fish was examined for external wounds or descaling and scanned for the presence of a previously implanted PIT tag. If a tag was not detected, a pre-loaded 12mm Digital Angel 134.2 kHz type TX 1411ST PIT tag was inserted into the body cavity using a Biomark MK-25 Rapid Implant Gun. Each unique tag code was electronically recorded with an appropriate tagging date, release date, tagging personnel and biological data. These data were entered into P3 and submitted to the PIT Tag Information System (PTAGIS) at the end of each month. Tagging methods were consistent with methodology described in the PIT Tag Marking Procedures Manual (CBFWA 1999) as well as with 2008 ISEMP protocols (Tussing 2008).

After marking and/or PIT tagging, fish were held for a minimum of 24-hours to a) ensure complete recovery, b) assess tagging mortality and c) determine tag-shed rate. Fish that were not to be used in an efficiency trial were released downstream of the smolt trap.

2.4 Data Analysis

2.4.1 Estimate of Abundance

Seasonal juvenile migration, N, was estimated as the sum of daily migrations, N_i, i.e., $N = \sum_i N_i$, and daily migration was calculated from catch and efficiency:

$$\hat{N}_i = \frac{C_i}{\hat{e}_i}, \qquad \textbf{(1)}$$

where C_i = number of fish caught in period *I*;

$\hat{e}_i$ = trap efficiency estimated from the flow-efficiency relationship, $\sin^2\left(b_0 + b_1 flow_i\right)$, where b_0 is estimated intercept and b_1 is the estimated slope of the regression.

The regression parameters b_0 and b_1 are estimated using linear regression for the model:

$$\arcsin\left(\sqrt{e_k^{obs}}\right) = \beta_0 + \beta_1 flow_k + \varepsilon, \qquad \textbf{(2)}$$

where e_k^{obs} = observed trap efficiency of Eq. 2 for trapping period k;

β_0 = intercept of the regression model;

β_1 = slope parameter;

ε = error with mean 0 and variance σ^2.

In Equation 2, the observed trap efficiency, e_k^{obs}, is calculated as follows,

$$e_k^{obs} = \frac{r_k + 1}{m}. \qquad \textbf{(3)}$$

The estimated variance of seasonal migration is calculated from daily estimates as:

$$Var\left(\sum_{i=1}^{n} \hat{N}_i\right) = \underbrace{\sum_i Var(N_i)}_{Part\ A} + \underbrace{\sum_i \sum_j Cov(N_i, N_j)}_{Part\ B},$$

or,

$$Var\left(\sum_{i=1}^{n} \hat{N}_i\right) = \underbrace{\sum_i Var\left(\frac{(C_i + 1)}{\hat{e}_i}\right)}_{Part\ A} + \underbrace{\sum_i \sum_j Cov\left(\frac{(C_i + 1)}{\hat{e}_i}, \frac{(C_j + 1)}{\hat{e}_j}\right)}_{Part\ B}. \qquad \textbf{(4)}$$

Part A of equation 4 is the variance of daily estimates. Part B is the between-day covariance. Note that the between-day covariance exists only for days that use the same trap efficiency model. If, for example, day 1 is estimated with one trap efficiency model, and day 2 estimated from a different model, then there is no covariance between day 1 and day 2. The full expression for the estimated variance:

$$\hat{Var}\left(\sum_{i=1}^{n}\hat{N}_i\right)=\underbrace{\sum_i \hat{N}_i^2\left(\frac{N_i\hat{e}_i(1-\hat{e}_i)}{(C_i+1)^2}+\frac{4(1-\hat{e}_i)}{\hat{e}_i}\hat{Var}(b_0+b_1 flow_i)\right)}_{PartA}+$$

$$\underbrace{\sum_i\sum_j 4\left(\hat{N}_i(1-\hat{e}_i)\right)\left(\hat{N}_j(1-\hat{e}_j)\right)\cdot\left[\hat{Var}(b_0)+flow_i\, flow_j\hat{Var}(b_1)\right]}_{PartB}$$

where $\hat{Var}(b_0+b_1 flow_i)=M\hat{S}E\left(1+\frac{1}{n}+\frac{\left(flow_i-\overline{flow}\right)^2}{(n-1)s_{flow}^2}\right)$, and $\hat{Var}(b_0)$ and $\hat{Var}(b_1)$ are

obtained from regression results. In Excel, the standard error (SE) of the coefficients is provided. The variance is calculated as the square of the standard error, SE^2.

In cases when there was no significant flow-efficiency relationship (i.e., low correlation), then a pooled, or average trap efficiency will suffice for the stratum. The estimator is calculated as follows:

$$\hat{\hat{e}}=\frac{\sum_{j=1}^{k}r_j}{\sum_{j=1}^{k}m_j}$$

where $\hat{\hat{e}}$ = the average or pooled trap efficiency for the stratum;

m_j = the number of smolts marked and released in efficiency trial j for the stratum;

r_j = the number of smolts recaptured out of m_j marked fish in efficiency trial j.

Abundance for a trapping period is estimated as:

$$\hat{N}_i^{pooled}=\frac{C_i}{\hat{\hat{e}}},$$

,and total stratum abundance is:

$$N^{pooled}=\sum_i\hat{N}_i^{pooled}.$$

The variance of seasonal abundance takes into account the variability in catch numbers that are a result of binomial sampling (Part A), the pooled variance of trap efficiency, $\hat{\hat{e}}$ (Part B), and the covariance in daily estimates that arises from using a common estimate of efficiency across all trapping days (Part C):

$$V\hat{a}r\left(\sum_{i=1}^{n}\hat{N}_i^{pooled}\right)=\underbrace{\left(\sum_i\frac{\hat{N}_i\left(1-\hat{\hat{e}}\right)}{\hat{\hat{e}}}\right)}_{PartA}+\underbrace{\frac{Var\left(\hat{\hat{e}}\right)}{\hat{\hat{e}}^2}\sum_i\hat{N}_i^2}_{PartB}+\underbrace{\frac{Var\left(\hat{\hat{e}}\right)}{\hat{\hat{e}}^2}\sum_i\sum_j\hat{N}_i\hat{N}_j}_{PartC}.$$

The Part B and Part C terms are combined in the calculation as a new Part B:

$$V\hat{a}r\left(\sum_{i=1}^{n}\hat{N}_i^{pooled}\right)=\underbrace{\left(\sum_i\frac{\hat{N}_i\left(1-\hat{\hat{e}}\right)}{\hat{\hat{e}}}\right)}_{PartA}+\underbrace{\frac{Var\left(\hat{\hat{e}}\right)}{\hat{\hat{e}}^2}\left[\sum_i\hat{N}_i^2+\sum_i\sum_j\hat{N}_i\hat{N}_j\right]}_{PartB}.$$

The variance of $\hat{\hat{e}}$ is calculated as:

$$V\hat{a}r\left(\hat{\hat{e}}\right)=V\hat{a}r\left(\frac{\sum_{k=1}^{n}r_k}{\sum_{k=1}^{n}m_k}\right)=\frac{\sum_{k=1}^{n}\left(r_k-\hat{\hat{e}}_k m_k\right)^2}{\overline{m}^2 n(n-1)}$$

where $\overline{m}$ is the average release size across all efficiency trial, $\frac{\sum_{k=1}^{n}m_k}{n}$.

Confidence intervals were calculated using the following formulas:

95% confidence interval = $1.96\times\sqrt{\sum\mathrm{var}\left[\hat{N}_i\right]}$

The single M-R estimator of abundance carries a set of well documented assumptions (Everhart and Youngs 1981; Seber 1982),

1. The population is closed to mortality.
2. The probability of capturing a marked or unmarked fish is equal.
3. Marked fish were randomly dispersed in the population prior to recapture.

4. Marking does not affect probabilities of capture.
5. Marks were not lost between the time of release and recapture.
6. All marks are reported upon recapture.
7. The number of fish in the trap, C, is fully enumerated and known without error.

3.0 RESULTS

3.1 Dates of Operation

In 2016, YNF operated a 1.5m rotary trap between March 1 and November 30. During this period, the trap operated 24 hours per day, 7 days per week barring inoperable environmental conditions (i.e. heavy debris loads or high discharge). Trapping was interrupted a total of 29 days (Table 1).

Table 1. Summary of White River smolt trap operation, 2016.

Trap Status	Description	Days
Operating	Continuous data collection	246
Interrupted	Unexpected interruption by debris, etc.	29
Pulled	Intentionally pulled to protect the trap during high flows	0

3.2 Daily Captures and Biological Sampling

3.2.1 Wild Spring Chinook Yearlings (BY2014)

Three wild yearling Chinook smolts were collected between March 1 and June 30 (Figure 4). Mean fork-length (FL) was 106 mm (n = 3; SD = 1.5) and mean weight was 12.4 g (n = 3; SD = 0.3; Table 2). All spring Chinook smolts were implanted with PIT tags and sampled for genetics. There were no BY2014 spring Chinook mortalities incurred (See **3.4 ESA Compliance**).

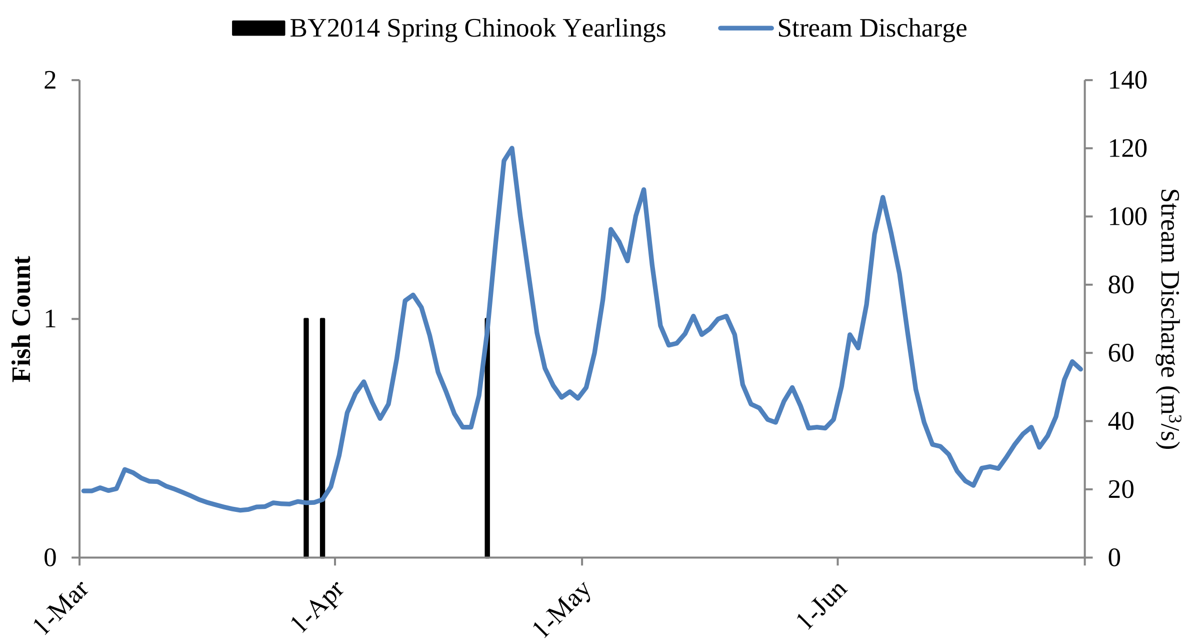


Figure 4. Daily catch of yearling spring Chinook smolt with mean daily stream discharge at the White River rotary trap, March 1 to June 30, 2016.

3.2.2 Wild Spring Chinook Subyearlings (BY2015)

Spring Chinook fry were captured at the trap between March 7 and June 22 (*n* = 49). During this period there were no fry trapping mortalities incurred. One additional subyearling Chinook with FL<50 mm was captured after June 30. Because this fish is considered a "fry" it was excluded from the parr estimate. A total of 147 wild subyearling Chinook parr were collected between May 25 and November 30, with peak catch occurring on August 25 (*n* = 14; Figure 5). The mean FL for subyearling parr was 89 mm (*n* = 147; *SD* = 10.7) and the mean weight was 8.3 g (*n* = 147; *SD* = 2.8); see Table 2. Four of the spring Chinook parr were captured prior to July 1. Because these were therefore considered "fry" they were excluded from the parr estimate. PIT tags were implanted into a total of 137 subyearling Chinook parr. One tag was shed during the 24hr holding period (Table 4). Genetic samples were taken from 137 parr. There were two BY2015 spring Chinook mortalities during the 2016 trapping season (See **3.4 ESA Compliance**).

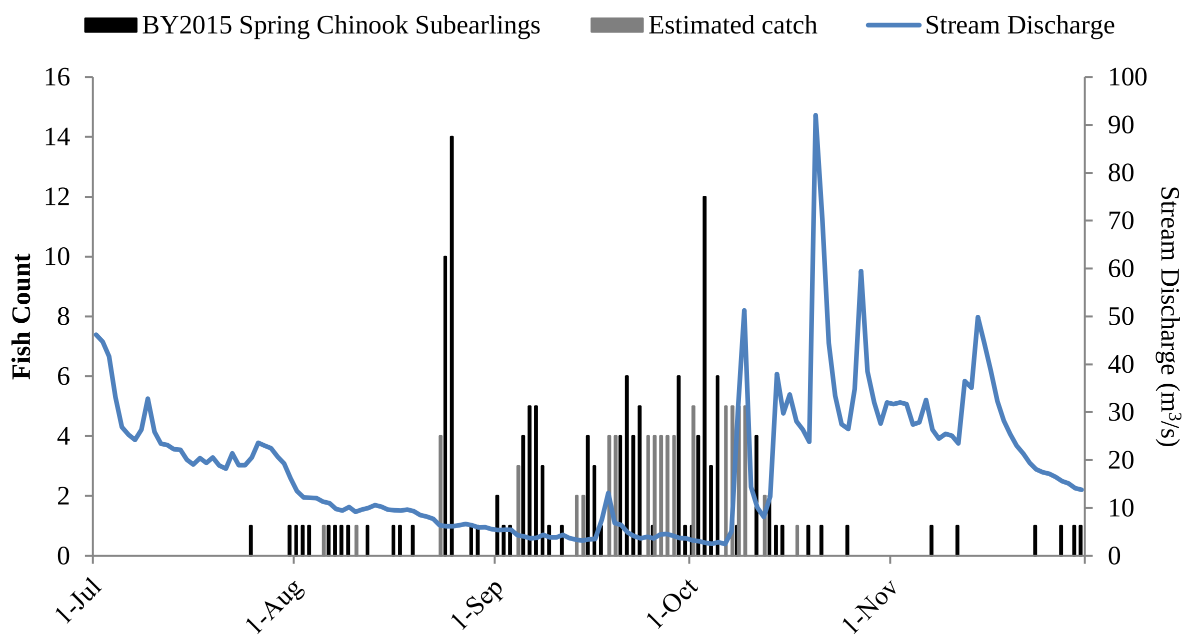


Figure 5. Daily catch of wild subyearling spring Chinook with mean daily stream discharge at the White River rotary trap, July 1 to November 30, 2016.

Table 2. Summary of length and weight sampling of juvenile spring Chinook captured at the White River rotary trap, 2016.

Brood Year	Origin/Species/Stage	Fork Length (mm)			Weight (g)			K-factor
		Mean	n	SD	Mean	n	SD	
2014	Wild Yearling Smolt	106	3	1.5	12.4	3	0.3	1.05
2015	Wild Subyearling Fry	38	50	3.0	0.5	49	0.3	0.82
2015	Wild Subyearling Parr	89	147	10.7	8.3	147	2.8	1.13

3.3 Trap Efficiency Calibration and Population Estimates

3.3.1 Wild Spring Chinook Yearlings (BY 2014)

Due to low abundance, no BY2014 wild yearling Chinook efficiency trials were performed in 2016. A composite regression model using previous year's (2008-2012) efficiency trials showed statistically significant ($r^2 = 0.57$; $p = 0.001$) flow-efficiency relationship, and was used to calculate yearling abundance. Use of a single spring trapping position allowed this regression to be applied to all yearling Chinook captured in 2016. Weighting of this regression via an R script (provided by WDFW) did not affect calculation parameters greatly and yielded the same r-square and *p*-values. In the fall of 2015, we estimated that 1,950 (± 400; 95% CI) BY2014 subyearlings emigrated past the trap. In the spring of 2016, we estimated that 386 (± 701; 95% CI) emigrated past the trap. Combining the two estimates, total BY2014 wild spring Chinook emigrants was 2,336 (± 807; 95% CI; Table 3).

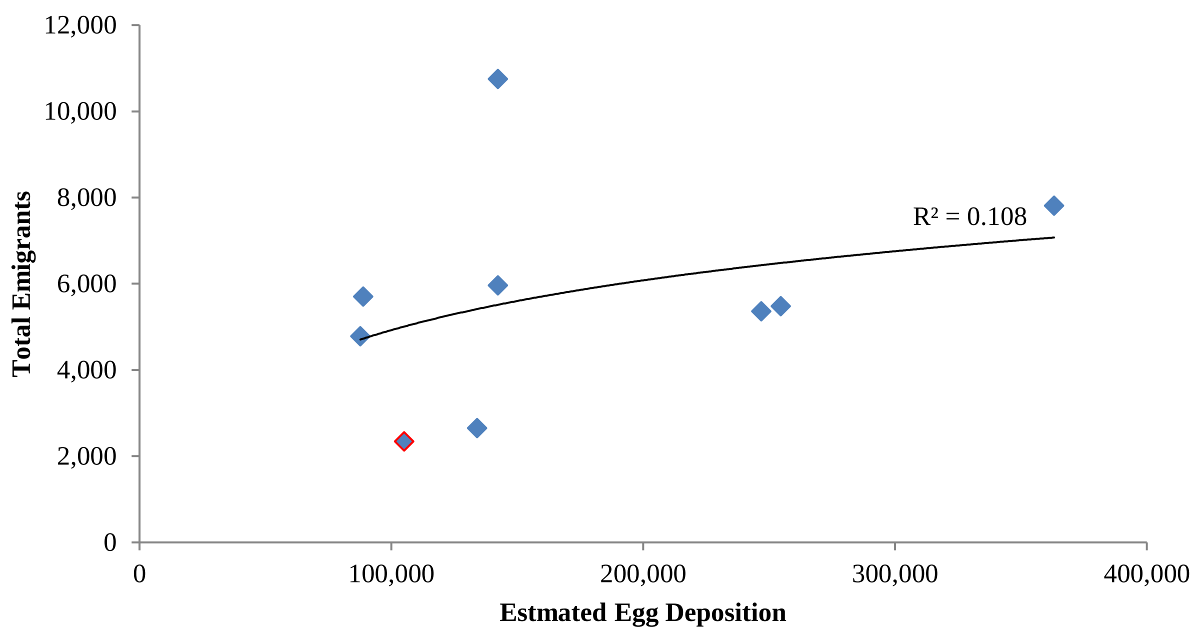
3.3.2 Wild Spring Chinook Subyearling (BY 2015)

Due to low abundance, no BY2015 wild yearling Chinook efficiency trials were performed in 2016. Instead, a composite regression based on previous year's data (2009-2015) was used to expand daily catch. This regression was comprised of all trails conducted fulfilling the minimum number marked ($n \geq 20$) including efforts in which zero recaptured were made (Appendix C). Mark-groups in which validity of the trial could be called into question (suspected trap stoppage or improper pre-release handling of the mark group) were removed. The weighted regression was not significant ($r^2 = 0.12$; $p = 0.086$) at our accepted limit ($\alpha = 0.05$). However, after comparison with a pooled method and considerations of the pooled estimate limitations, we decided to use the regression model despite its slightly higher *p*-value. This single regression was the only model required to estimate total subyearling migration due to the fact only one fall trapping position was used in 2015. We estimated that in 2016, 2,430 (± 723; 95% CI) spring Chinook subyearling parr moved past the trap (Table 3).

Table 3. Estimated egg-to-emigrant survival and emigrants per redd for White River spring Chinook

Brood Year	No. of Redds[a]	Fecundity[b]	No. of Eggs	No. of Emigrants			Egg-to Emigrant	Emigrants per Redd
				Age-0[c]	Age-1	Total ± 95% CI		
2005	86	4,327	372,122	DNOT[d]	4,856	—		—
2006	31	4,324	134,044	652	2,004	2,656 ± 1,597	2.0%	86
2007	20	4,441	88,820	2,309	3,395	5,704 ± 2,201	6.4%	285
2008	31	4,592	142,352	5,560	5,193	10,753 ± 3,783	7.6%	347
2009	54	4,573	246,942	2,428	2,939	5,367 ± 2,497	2.2%	99
2010	33	4,314	142,362	1,859	4,103	5,962 ± 3,448	4.2%	181
2011	20	4,385	87,700	3,128	1,659	4,787 ± 2,022	5.5%	239
2012	86	4,223	363,178	3,816	3,995	7,811 ± 3,847	2.2%	91
2013	54	4,716	254,664	2,461	3,023	5,484 ± 2,836	2.2%	102
2014	26	4,045	105,170	1,950	386	2,336 ± 807	2.2%	90
2015	70	4,847	339,290	2,430	—	—	—	—
Avg	39	4,401	173,915	2,685	2,966	5,651	3.8%	169

[a] Number of complete redds in White River (Hillman et al. 2015)
[b] Mean annual fecundity of spring Chinook broodstock at Chiwawa River Hatchery
[c] Estimate is based on capture of parr collected during summer/fall and does not include fry captured prior to July1
[d] Did not operate trap; no production estimates were made



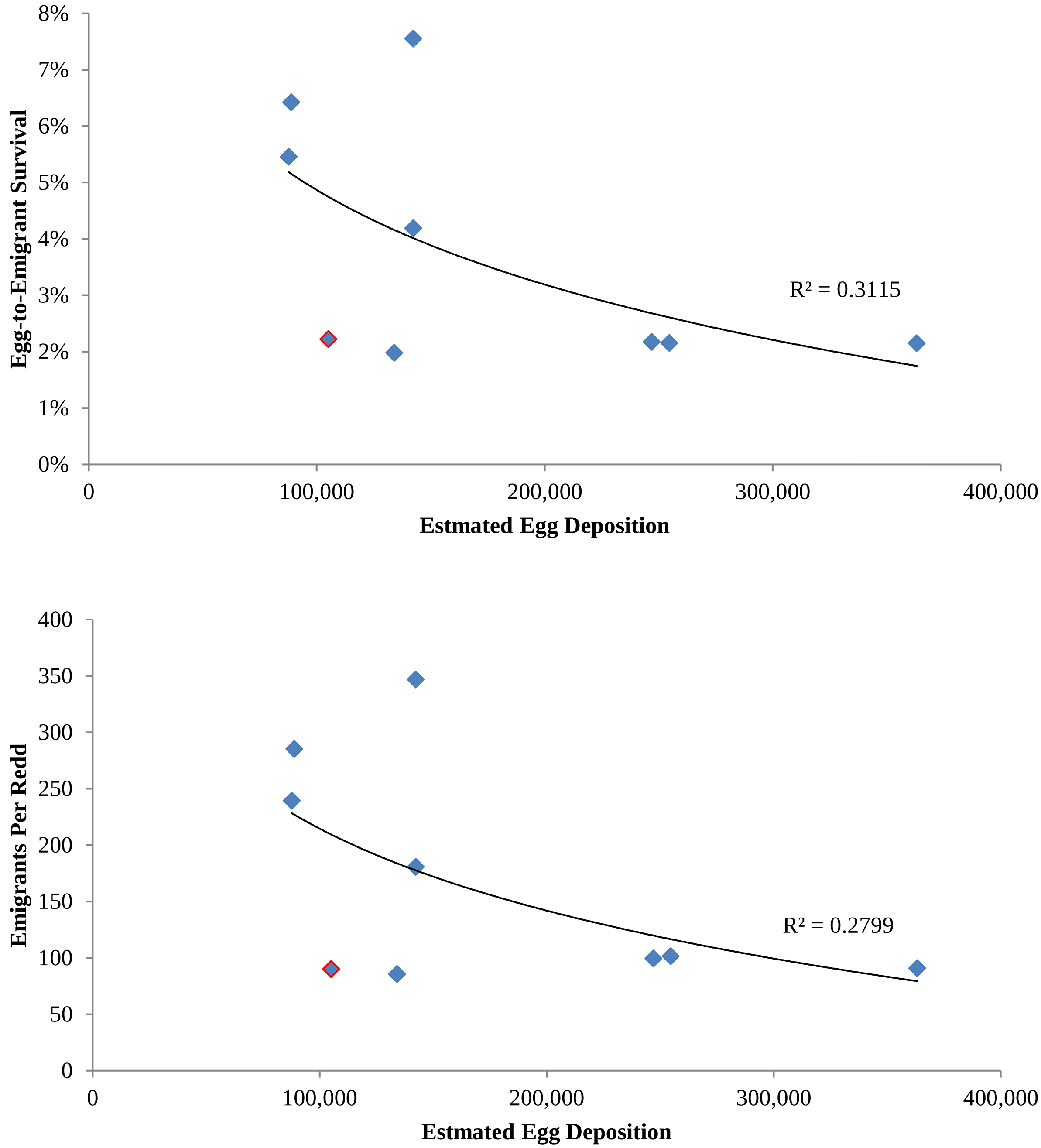


Figure 6. Relationships between estimated egg deposition and total emigrants produced, egg-to-emigrant survival, and emigrants per redd for White River spring Chinook, BY 2007 to 2014. *BY2014 values denoted by red border.

3.4 PIT Tagging

In 2016, a total of 140 spring Chinook and 5 steelhead were PIT tagged at the trap. PIT tag retention after 24 hours of observation yielded only one shed tag (wild spring Chinook parr; Table 4). There no tagging mortalities (Table 6).

Table 4. Number of PIT tagged spring Chinook and steelhead with shed rates at the White River rotary trap, 2016.

Brood Year	Species/Stage	Total Catch	Total PIT Tagged	Percent Tagged	Percent Tags Shed
2014	Yearling Chinook Smolt	3	3	100.0%	0.0%
2015	Subyearling Chinook Parr	147	137	93.2%	0.7%
*	Steelhead Parr	5	5	100.0%	0.0%

* Brood year unknown

3.5 Incidental Species

Incidental species were enumerated and sampled for length and weight (Table 5). Incidental species included: bull trout, longnose dace *Rhinichthys cataractae*, mountain whitefish *Prosopium williamsoni*, northern pikeminnow *Ptychocheilus oregonensis*, steelhead/rainbow trout (shúshaynsh) *Oncorhynchus mykiss*, redside shiner *Richardsonius balteatus*, sculpin *Cottus sp.*, sockeye salmon, sucker *Catostomus sp.*, and westslope cutthroat *Oncorhynchus clarkii lewisi*.

Table 5. Summary of length and weight sampling of incidental species captured at the White River rotary trap, 2016.

Species	Total Count	Fork Length (mm)			Weight (g)		
		Mean	*n*	SD	Mean	*n*	SD
Bull Trout Parr	5	341	5	220.5	98.9	3	89.5
Longnose Dace	4	73	4	24.5	5.9	4	4.7
Mountain Whitefish	93	64	93	29.7	6.2	83	19.6
Northern Pikeminnow	5	211	5	142.8	51.7	4	77.6
Rainbow Trout/Steelhead Parr	5	10	5	23.1	5.6	0	158.8
Redside Shiner	25	67	25	13.8	5.5	25	5.0
Sculpin	60	61	60	16.5	3.1	57	2.4
Sockeye Fry	1,784	27	864	1.1	—	—	—
Sockeye Parr	1	68	1	—	3.1	1	—
Sucker	20	213	20	76.9	159.0	20	109.3
Westslope Cutthroat	6	229	6	75.2	90.3	5	46.8

3.6 ESA Compliance

ESA-listed species mortalities incurred in 2016 included two subyearling Chinook parr (Table 6). At no point during the trapping season did the lethal take of wild spring Chinook exceed the maximum allowed 2%. All fish handled were inspected prior to tagging or further sampling with any sign of injury or stress warranting immediate release.

Table 6. Summary of White River ESA listed species catch and mortality, 2016.

Species/Stage	Total Catch	Total Mortality	Total % Mortality
Yearling Chinook Smolt	3	0	0.0%
Subyearling Chinook Parr	147	2	1.4%
Subyearling Chinook Fry	50	0	0.0%
Total Wild Spring Chinook	**200**	**2**	**1.0%**
Bull Trout	5	0	0.0%
Steelhead/Rainbow Trout	5	0	0.0%

4.0 DISCUSSION

Previously, below-average spring Chinook spawner escapements at the White River have resulted in elevated egg-to-emigrant survival estimates for their respective juveniles produced. Conversely, above-average spawner escapements have trended toward comparatively lowered rates of in-stream survival. Although replication at the highest escapement levels is limited, the trend thus far suggests that density-dependent constraints are influencing in-stream survival in the White River spring Chinook population. An estimated egg deposition in 2014 that fell well-below the White River average failed to produce the expected response of an elevated egg-to-emigrant survival. Instead, the BY2014 egg-to-emigrant survival rate of 2.2% showed no change over the two preceding broods, which had markedly higher estimated egg depositions. Potential explanations of this unexpected result are twofold: 1) the survival estimated is in fact a reflection of decreased survival, and contrary to the density-dependent trend previously noted, and/or 2) catch at the trap during the BY2014 migration did not effectively capture a representative sample of the outmigration. The likelihoods of both of these influences were exacerbated by the strong El Niño occurring during the majority of BY2014's in-stream rearing period (NOAA 2016).

Oceanic Niño Index (ONI) values were particularly high in 2015 and 2016, with levels not experienced since strong El Niño events in 1982/1983 and 1997/1998 (NOAA 2016). Inland manifestations of this oceanic phenomenon at the White River included high fall and winter discharges (Figure 7). High, irregular flows were likely to have produced some degree of increased mortality prior to gravel emergence as a result of redd scouring and sedimentation (Montgomery et al. 1996 & Lotspeich and Everest 1981). Flood events in November 2014 and 2015 were both great (>170 m^3/s [6,000cfs]), and included significant movement of bedload, suspended sediments, and large woody debris (LWD). Though difficult to quantify the impact of this flooding on incubating eggs, a strong negative correlation between egg-to-emigrant survival and peak flow during incubation has been shown in other tributaries (Seiler et al. 2002). Also, low snowpack and early snowmelt brought on by mild winter temperatures caused prolonged periods of summer base flows in 2015 and 2016. Though stream temperatures did not reach levels in which mass die-off was incurred (Max = 17.6ºC), prolonged low stream levels presumably resulted in a higher than average competition for critical resources.

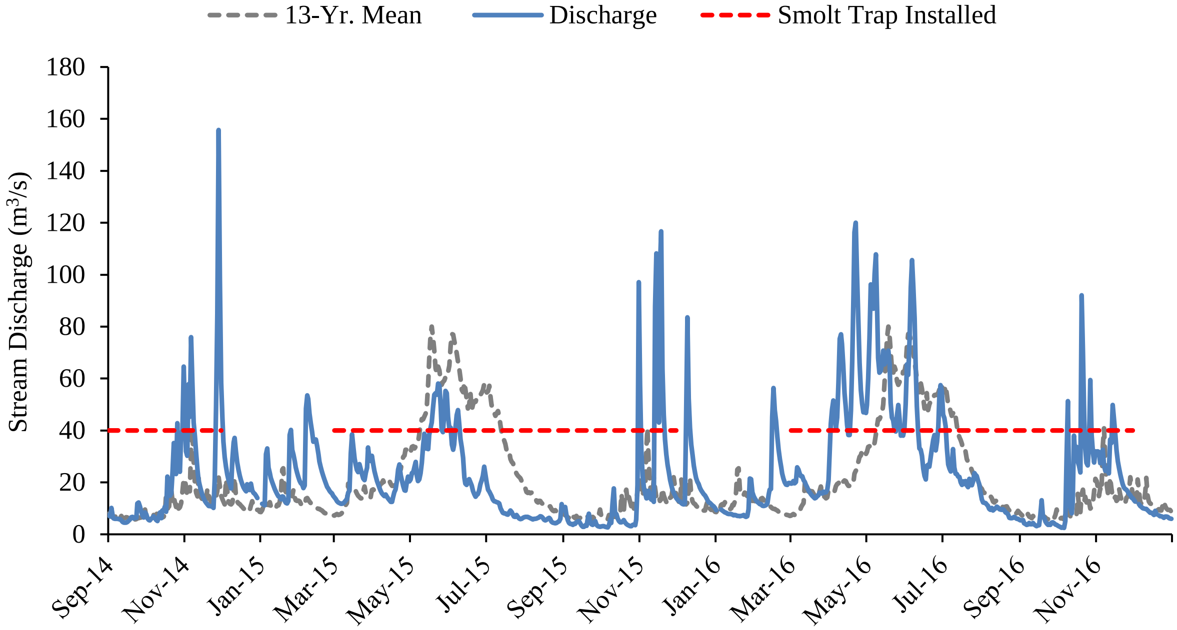


Figure 7. White River daily mean and 13-year mean discharge during strong El Niño, 2014-2016.

In addition to direct decreases to survival, we suspect that irregular weather patterns attributed to El Niño resulted in a potentially large portion of the BY2014 juvenile population being prematurely displaced during periods of low trap efficiency (high discharge), and/or early outmigration during the non-trapping period (December through February). While some displacement below the trap may be a simple function of pre-migratory fish being unable to maintain positioning during high-water events, Chinook populations elsewhere have displayed early migratory behavior in years with early snowmelt and warm water temperatures (Quinn 2005 & Achord et al. 2007). Early outmigration has also been associated with elevated growth, with larger fish tending to emigrate earlier (Achord et al. 2007). BY2014 subyearling parr had the highest average FL of any brood recorded. Given fulfillment of both conditions (warm water temperature and rapid-growth), BY2014 yearlings may have actively emigrated from the White River earlier than in previous years with typical temperature and flow regimes. If the bulk of movement was initiated prior to the start of trapping (March 1), spring operations may have captured a smaller than average proportion of the total outmigration i.e., only the tail-end of the downstream movement.

A comparison of egg-to-emigrant survival rates in the White River, Chiwawa River, and Nason Creek shows that BY2014 survivals deviated markedly from each other in comparison to the preceding two broods (Figure 8). We suspect that this may be explained in-part by differing felt effects of El Niño on each tributary, and capability of each trap to measure outmigration in light of high flows and early migratory behavior. Stronger influence of El Niño on a tributary would therefore cause a lowered estimated survival rate via the aforementioned effects on both survival and smolt trap efficacy. All three tributaries saw smaller spawner escapements in 2014. Based on previous data, all should have in-turn responded with elevated rates of egg-to-emigrant survival. We suspect that although the Chiwawa River did experience some adverse environmental effects, influence of El Niño on the Chiwawa BY2014 emigrant estimate was the least affected of the three tributaries. Nason Creek showed potentially the greatest negative response to El Niño, with a decrease in survival. The smallest of the three tributaries, Nason Creek is listed as impaired due to water temperatures exceeding 303(d) criteria (Cristea and Pelletier 2005). Survival in Nason Creek may have been impacted by the prolonged, extremely warm temperatures to a higher degree than the Whiter River and Chiwawa River; two tributaries with much cooler summer water temperatures. Like Nason Creek, the White River failed to show an increase in survival in-light of a smaller adult return. However, given the assumption that a potentially significant proportion of the run was missed producing an underestimate of abundance, we assume that BY2014 survival did in fact increase over the previous brood, as did the Chiwawa River population.

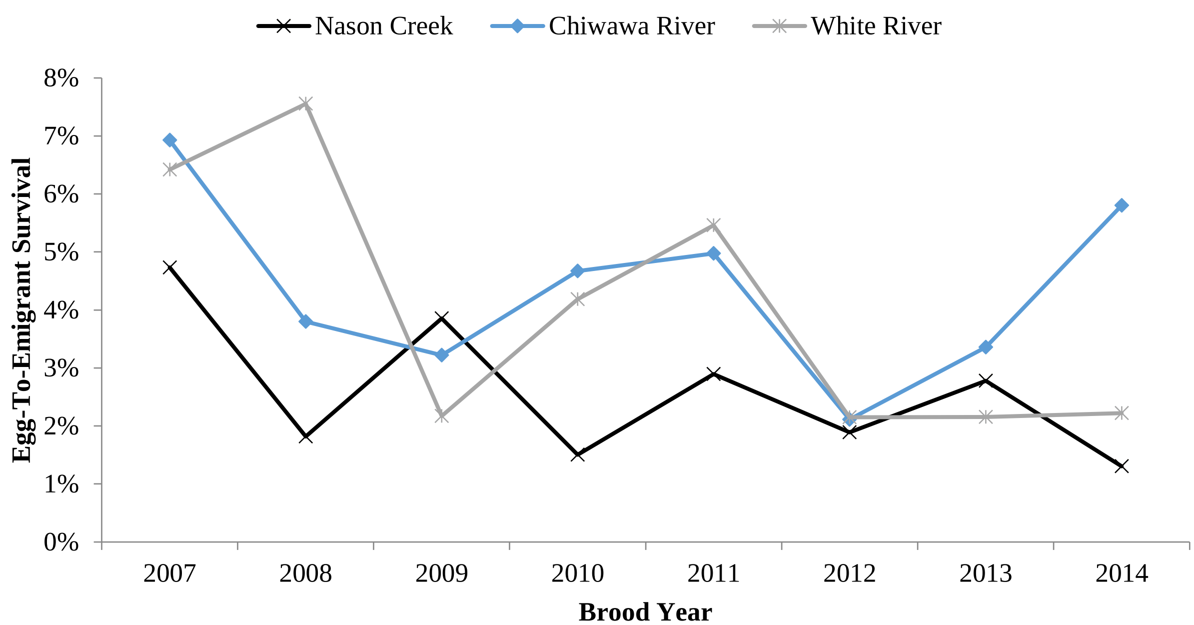


Figure 8. Comparison of wild spring Chinook abundance estimates (BY2007-2014) made at the White R., Nason Cr., and Chiwawa R. smolt traps. Chiwawa R. data provided by Hillman et al. (2015).

The 2015 White River spring Chinook brood in-stream rearing period also coincided partially with the El Niño event. The initial subyearling estimate is below the nine-year mean despite high estimated egg deposition; potentially the result of decreased survival and/or shifts in movement to low-efficiency or suspended periods of trapping. Completion of the migratory period in the spring of 2017 will help to determine the cumulative effect of the anomalous weather trends on the brood estimate. Given a change to cooler conditions associated with non-El Niño periods, we anticipate that the majority of BY2015 smolt emigration will occur after the smolt trap has been installed.

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APPENDIX A: White River Temperature and Discharge Data

Date	Stream Discharge (m^3/s)	Water Temperature (˚C)
3/1/2016	20	2.4
3/2/2016	20	2.5
3/3/2016	21	3.7
3/4/2016	20	3.8
3/5/2016	20	4.4
3/6/2016	26	4.2
3/7/2016	25	3.8
3/8/2016	23	3.9
3/9/2016	22	3.5
3/10/2016	22	3.0
3/11/2016	21	3.5
3/12/2016	20	4.1
3/13/2016	19	3.1
3/14/2016	18	3.4
3/15/2016	17	3.9
3/16/2016	16	4.3
3/17/2016	16	3.8
3/18/2016	15	3.4
3/19/2016	14	3.9
3/20/2016	14	4.1
3/21/2016	14	4.4
3/22/2016	15	4.9
3/23/2016	15	4.7
3/24/2016	16	4.7
3/25/2016	16	4.6
3/26/2016	16	4.7
3/27/2016	16	4.8
3/28/2016	16	4.5
3/29/2016	16	4.6
3/30/2016	17	4.9
3/31/2016	21	5.0
4/1/2016	30	4.8
4/2/2016	42	4.6
4/3/2016	48	4.6
4/4/2016	52	4.1
4/5/2016	46	4.3
4/6/2016	41	5.1
4/7/2016	45	5.0
4/8/2016	58	4.8
4/9/2016	75	4.6
4/10/2016	77	4.7
4/11/2016	73	4.7
4/12/2016	65	4.4
4/13/2016	54	4.9
4/14/2016	49	4.2
4/15/2016	42	5.1
4/16/2016	38	5.1
4/17/2016	38	5.7
4/18/2016	48	5.7
4/19/2016	67	5.4
4/20/2016	92	5.1
4/21/2016	116	5.1
4/22/2016	120	4.9
4/23/2016	100	5.2
4/24/2016	83	5.1
4/25/2016	66	4.9
4/26/2016	56	5.2
4/27/2016	50	5.1
4/28/2016	47	6.0
4/29/2016	49	5.8
4/30/2016	47	6.0
5/1/2016	50	6.2
5/2/2016	60	6.3
5/3/2016	76	5.7
5/4/2016	96	5.6
5/5/2016	93	5.4
5/6/2016	87	6.0
5/7/2016	100	6.2
5/8/2016	108	6.0
5/9/2016	86	5.7
5/10/2016	68	6.0
5/11/2016	62	6.5
5/12/2016	63	6.5
5/13/2016	66	6.8
5/14/2016	71	5.7

5/15/2016	65	5.9	6/29/2016	57	10.7
5/16/2016	67	6.8	6/30/2016	55	10.3
5/17/2016	70	6.4	7/1/2016	46	9.9
5/18/2016	71	6.5	7/2/2016	45	10.9
5/19/2016	65	6.0	7/3/2016	42	10.3
5/20/2016	51	5.6	7/4/2016	33	8.7
5/21/2016	45	6.2	7/5/2016	27	9.1
5/22/2016	44	6.3	7/6/2016	25	10.0
5/23/2016	40	6.3	7/7/2016	24	9.4
5/24/2016	40	7.2	7/8/2016	26	10.0
5/25/2016	46	7.8	7/9/2016	33	9.8
5/26/2016	50	7.0	7/10/2016	26	9.1
5/27/2016	44	6.4	7/11/2016	23	10.2
5/28/2016	38	6.1	7/12/2016	23	10.5
5/29/2016	38	6.9	7/13/2016	22	10.8
5/30/2016	38	7.0	7/14/2016	22	10.8
5/31/2016	40	7.9	7/15/2016	20	10.2
6/1/2016	50	8.0	7/16/2016	19	10.5
6/2/2016	65	7.4	7/17/2016	20	10.4
6/3/2016	61	7.6	7/18/2016	19	9.6
6/4/2016	74	8.4	7/19/2016	21	10.7
6/5/2016	95	8.3	7/20/2016	19	11.1
6/6/2016	106	8.5	7/21/2016	18	11.1
6/7/2016	95	8.2	7/22/2016	21	11.2
6/8/2016	83	8.2	7/23/2016	19	11.3
6/9/2016	66	7.2	7/24/2016	19	11.9
6/10/2016	49	7.4	7/25/2016	21	13.1
6/11/2016	40	7.2	7/26/2016	24	13.7
6/12/2016	33	7.6	7/27/2016	23	13.4
6/13/2016	33	7.8	7/28/2016	23	13.6
6/14/2016	30	6.9	7/29/2016	21	13.8
6/15/2016	25	6.4	7/30/2016	19	13.8
6/16/2016	22	7.3	7/31/2016	16	12.8
6/17/2016	21	7.7	8/1/2016	14	12.5
6/18/2016	26	7.6	8/2/2016	12	12.4
6/19/2016	27	8.1	8/3/2016	12	12.3
6/20/2016	26	8.7	8/4/2016	12	12.9
6/21/2016	29	9.3	8/5/2016	11	13.3
6/22/2016	33	9.1	8/6/2016	11	12.9
6/23/2016	36	9.4	8/7/2016	10	12.5
6/24/2016	38	8.2	8/8/2016	9	10.8
6/25/2016	32	8.6	8/9/2016	10	10.6
6/26/2016	36	9.6	8/10/2016	9	12.6
6/27/2016	41	10.0	8/11/2016	10	13.1
6/28/2016	52	10.5	8/12/2016	10	13.6

8/13/2016	11	14.1
8/14/2016	10	14.1
8/15/2016	10	14.0
8/16/2016	10	14.4
8/17/2016	9	14.5
8/18/2016	10	14.6
8/19/2016	9	14.2
8/20/2016	8	13.7
8/21/2016	8	13.8
8/22/2016	8	12.6
8/23/2016	6	11.9
8/24/2016	6	12.8
8/25/2016	6	13.0
8/26/2016	6	13.2
8/27/2016	7	13.3
8/28/2016	6	12.2
8/29/2016	6	12.6
8/30/2016	6	12.6
8/31/2016	6	12.2
9/1/2016	5	11.7
9/2/2016	5	10.7
9/3/2016	5	10.6
9/4/2016	4	10.5
9/5/2016	4	10.5
9/6/2016	4	11.5
9/7/2016	4	11.8
9/8/2016	4	11.6
9/9/2016	4	10.9
9/10/2016	4	11.3
9/11/2016	4	11.9
9/12/2016	4	10.7
9/13/2016	3	10.1
9/14/2016	3	10.3
9/15/2016	3	11.1
9/16/2016	4	11.1
9/17/2016	8	10.9
9/18/2016	13	9.7
9/19/2016	7	9.6
9/20/2016	6	9.1
9/21/2016	5	8.9
9/22/2016	4	9.3
9/23/2016	4	9.1
9/24/2016	4	9.3
9/25/2016	4	10.5
9/26/2016	4	10.9

9/27/2016	5	11.2
9/28/2016	4	10.8
9/29/2016	4	10.1
9/30/2016	4	10.2
10/1/2016	3	9.4
10/2/2016	3	8.7
10/3/2016	3	8.1
10/4/2016	3	8.8
10/5/2016	3	8.8
10/6/2016	2	8.4
10/7/2016	5	8.7
10/8/2016	30	7.3
10/9/2016	51	7.8
10/10/2016	14	7.3
10/11/2016	10	6.5
10/12/2016	8	5.4
10/13/2016	12	5.6
10/14/2016	38	5.6
10/15/2016	30	5.6
10/16/2016	34	6.1
10/17/2016	28	6.4
10/18/2016	26	6.5
10/19/2016	24	6.2
10/20/2016	92	5.8
10/21/2016	70	6.0
10/22/2016	44	6.2
10/23/2016	33	6.4
10/24/2016	27	6.5
10/25/2016	27	6.5
10/26/2016	35	6.1
10/27/2016	59	6.1
10/28/2016	39	6.4
10/29/2016	32	6.2
10/30/2016	28	5.8
10/31/2016	32	5.9
11/1/2016	32	5.9
11/2/2016	32	6.0
11/3/2016	32	6.1
11/4/2016	27	5.6
11/5/2016	28	6.2
11/6/2016	33	6.3
11/7/2016	26	6.0
11/8/2016	24	6.0
11/9/2016	25	5.9
11/10/2016	25	6.0

11/11/2016	23	6.3
11/12/2016	37	6.8
11/13/2016	35	5.7
11/14/2016	50	5.3
11/15/2016	44	4.6
11/16/2016	39	4.3
11/17/2016	32	4.3
11/18/2016	28	4.4
11/19/2016	25	4.0
11/20/2016	23	4.2
11/21/2016	21	4.6
11/22/2016	19	4.4
11/23/2016	18	4.2
11/24/2016	17	4.1
11/25/2016	17	3.8
11/26/2016	16	4.3
11/27/2016	16	4.2
11/28/2016	15	3.5
11/29/2016	14	3.7
11/30/2016	14	3.6

APPENDIX B: Daily Trap Operation Status

Date	Trap Status	Comments
3/1/2016	Op.	
3/2/2016	Op.	
3/3/2016	Op.	
3/4/2016	Op.	
3/5/2016	Op.	
3/6/2016	Op.	
3/7/2016	Op.	
3/8/2016	Op.	
3/9/2016	Op.	
3/10/2016	Op.	
3/11/2016	Op.	
3/12/2016	Op.	
3/13/2016	Op.	
3/14/2016	Op.	
3/15/2016	Op.	
3/16/2016	Op.	
3/17/2016	Op.	
3/18/2016	Op.	
3/19/2016	Op.	
3/20/2016	Op.	
3/21/2016	Op.	
3/22/2016	Op.	
3/23/2016	Op.	
3/24/2016	Op.	
3/25/2016	Op.	
3/26/2016	Op.	
3/27/2016	Op.	
3/28/2016	Op.	
3/29/2016	Op.	
3/30/2016	Op.	
3/31/2016	Op.	
4/1/2016	Op.	
4/2/2016	Op.	
4/3/2016	Op.	
4/4/2016	Op.	
4/5/2016	Op.	
4/6/2016	Op.	
4/7/2016	Op.	
4/8/2016	Op.	
4/9/2016	Op.	
4/10/2016	Op.	
4/11/2016	Op.	
4/12/2016	Op.	
4/13/2016	Op.	
4/14/2016	Op.	
4/15/2016	Op.	
4/16/2016	Op.	
4/17/2016	Op.	
4/18/2016	Op.	
4/19/2016	Op.	
4/20/2016	No Op.	Stopped-debris
4/21/2016	No Op.	Stopped-debris
4/22/2016	Op.	
4/23/2016	Op.	
4/24/2016	Op.	
4/25/2016	Op.	
4/26/2016	Op.	
4/27/2016	Op.	
4/28/2016	Op.	
4/29/2016	Op.	
4/30/2016	Op.	
5/1/2016	Op.	
5/2/2016	Op.	
5/3/2016	Op.	
5/4/2016	No Op.	Stopped-debris
5/5/2016	Op.	
5/6/2016	Op.	
5/7/2016	Op.	
5/8/2016	Op.	
5/9/2016	Op.	
5/10/2016	Op.	
5/11/2016	Op.	
5/12/2016	Op.	
5/13/2016	Op.	
5/14/2016	Op.	
5/15/2016	Op.	
5/16/2016	Op.	
5/17/2016	Op.	
5/18/2016	Op.	
5/19/2016	Op.	
5/20/2016	Op.	
5/21/2016	Op.	
5/22/2016	Op.	
5/23/2016	Op.	
5/24/2016	Op.	
5/25/2016	Op.	
5/26/2016	Op.	
5/27/2016	Op.	
5/28/2016	Op.	
5/29/2016	Op.	

5/30/2016	Op.	
5/31/2016	Op.	
6/1/2016	Op.	
6/2/2016	Op.	
6/3/2016	Op.	
6/4/2016	Op.	
6/5/2016	Op.	
6/6/2016	Op.	
6/7/2016	Op.	
6/8/2016	Op.	
6/9/2016	Op.	
6/10/2016	Op.	
6/11/2016	Op.	
6/12/2016	Op.	
6/13/2016	Op.	
6/14/2016	Op.	
6/15/2016	Op.	
6/16/2016	Op.	
6/17/2016	Op.	
6/18/2016	Op.	
6/19/2016	Op.	
6/20/2016	Op.	
6/21/2016	Op.	
6/22/2016	Op.	
6/23/2016	Op.	
6/24/2016	Op.	
6/25/2016	Op.	
6/26/2016	Op.	
6/27/2016	Op.	
6/28/2016	Op.	
6/29/2016	Op.	
6/30/2016	Op.	
7/1/2016	Op.	
7/2/2016	Op.	
7/3/2016	Op.	
7/4/2016	Op.	
7/5/2016	Op.	
7/6/2016	Op.	
7/7/2016	Op.	
7/8/2016	Op.	
7/9/2016	Op.	
7/10/2016	Op.	
7/11/2016	Op.	
7/12/2016	Op.	
7/13/2016	Op.	
7/14/2016	Op.	
7/15/2016	Op.	
7/16/2016	Op.	
7/17/2016	Op.	
7/18/2016	Op.	
7/19/2016	Op.	
7/20/2016	Op.	
7/21/2016	Op.	
7/22/2016	Op.	
7/23/2016	Op.	
7/24/2016	Op.	
7/25/2016	Op.	
7/26/2016	Op.	
7/27/2016	Op.	
7/28/2016	Op.	
7/29/2016	Op.	
7/30/2016	Op.	
7/31/2016	Op.	
8/1/2016	Op.	
8/2/2016	Op.	
8/3/2016	Op.	
8/4/2016	Op.	
8/5/2016	No Op.	Stopped-debris
8/6/2016	Op.	
8/7/2016	Op.	
8/8/2016	Op.	
8/9/2016	Op.	
8/10/2016	No Op.	Stopped-debris
8/11/2016	Op.	
8/12/2016	Op.	
8/13/2016	Op.	
8/14/2016	Op.	
8/15/2016	Op.	
8/16/2016	Op.	
8/17/2016	Op.	
8/18/2016	Op.	
8/19/2016	Op.	
8/20/2016	Op.	
8/21/2016	Op.	
8/22/2016	Op.	
8/23/2016	No Op.	Stopped-out of pos.
8/24/2016	Op.	
8/25/2016	Op.	
8/26/2016	Op.	
8/27/2016	Op.	
8/28/2016	Op.	
8/29/2016	Op.	
8/30/2016	Op.	
8/31/2016	Op.	
9/1/2016	Op.	
9/2/2016	Op.	
9/3/2016	Op.	
9/4/2016	No Op.	Stopped-debris
9/5/2016	Op.	
9/6/2016	Op.	

9/7/2016	Op.		10/20/2016	Op.	
9/8/2016	Op.		10/21/2016	No Op.	Stopped-debris
9/9/2016	Op.		10/22/2016	Op.	
9/10/2016	Op.		10/23/2016	No Op.	Stopped-debris
9/11/2016	Op.		10/24/2016	Op.	
9/12/2016	Op.		10/25/2016	No Op.	Stopped-debris
9/13/2016	No Op.	Stopped-debris	10/26/2016	No Op.	Stopped-debris
9/14/2016	No Op.	Stopped-debris	10/27/2016	No Op.	Stopped-debris
9/15/2016	Op.		10/28/2016	Op.	
9/16/2016	Op.		10/29/2016	Op.	
9/17/2016	Op.		10/30/2016	Op.	
9/18/2016	No Op.	Stopped-debris	10/31/2016	Op.	
9/19/2016	No Op.	Stopped-debris	11/1/2016	Op.	
9/20/2016	Op.		11/2/2016	Op.	
9/21/2016	Op.		11/3/2016	Op.	
9/22/2016	Op.		11/4/2016	Op.	
9/23/2016	Op.		11/5/2016	Op.	
9/24/2016	No Op.	Stopped-debris	11/6/2016	Op.	
9/25/2016	No Op.	Stopped-debris	11/7/2016	Op.	
9/26/2016	No Op.	Stopped-debris	11/8/2016	Op.	
9/27/2016	No Op.	Stopped-debris	11/9/2016	No Op.	Stopped-debris
9/28/2016	No Op.	Stopped-debris	11/10/2016	Op.	
9/29/2016	Op.		11/11/2016	Op.	
9/30/2016	Op.		11/12/2016	Op.	
10/1/2016	No Op.	Stopped-debris	11/13/2016	Op.	
10/2/2016	Op.		11/14/2016	Op.	
10/3/2016	Op.		11/15/2016	Op.	
10/4/2016	Op.		11/16/2016	Op.	
10/5/2016	Op.		11/17/2016	Op.	
10/6/2016	No Op.	Stopped-debris	11/18/2016	Op.	
10/7/2016	No Op.	Stopped-debris	11/19/2016	Op.	
10/8/2016	No Op.	Stopped-debris	11/20/2016	Op.	
10/9/2016	No Op.	Stopped-debris	11/21/2016	Op.	
10/10/2016	Op.		11/22/2016	Op.	
10/11/2016	Op.		11/23/2016	Op.	
10/12/2016	No Op.	Stopped-debris	11/24/2016	Op.	
10/13/2016	Op.		11/25/2016	Op.	
10/14/2016	Op.		11/26/2016	Op.	
10/15/2016	Op.		11/27/2016	Op.	
10/16/2016	Op.		11/28/2016	Op.	
10/17/2016	No Op.	Stopped-debris	11/29/2016	Op.	
10/18/2016	Op.		11/30/2016	Op.	
10/19/2016	Op.				

APPENDIX C: Regression Models

Model: Chinook Yearlings (Spring '08-'15) Back Position, (r^2=0.569; p = 0.001)

Origin/Species/Stage	Date	Marked	Recaptured	Trap Efficiency	ASIN Transform	Discharge (m^3/s)
Wild Chinook Yearlings	4/10/2008	25	2	0.12	0.354	6
Wild Chinook Yearlings	3/26/2009	24	5	0.25	0.524	5
Wild Chinook Yearlings	3/30/2009	34	4	0.147	0.394	5
Wild Chinook Yearlings	4/2/2009	37	10	0.297	0.577	6
Wild Chinook Yearlings	4/5/2009	59	15	0.271	0.548	6
Wild Chinook Yearlings	4/10/2009	36	3	0.111	0.34	11
Wild Chinook Yearlings	3/12/2010	25	1	0.08	0.287	8
Wild Chinook Yearlings	3/16/2010	30	5	0.2	0.464	8
Wild Chinook Yearlings	3/20/2010	21	1	0.095	0.314	8
Wild Chinook Yearlings	4/5/2010	37	1	0.054	0.235	10
Wild Chinook Yearlings	4/9/2010	31	4	0.161	0.413	9
Wild Chinook Yearlings	4/12/2010	58	4	0.086	0.298	8
Wild Chinook Yearlings	4/16/2010	73	2	0.041	0.204	11
Wild Chinook Yearlings	4/14/2012	48	1	0.042	0.206	15

Model: Chinook Subyearlings (Fall '09-'15) Back Position, (r^2=0.130; p = 0.086)

Origin/Species/Stage	Date	Marked	Recaptured	Trap Efficiency	ASIN Transform	Discharge (m^3/s)
Wild Chinook Subyearlings	8/20/2009	20	2	15.00%	0.398	9
Wild Chinook Subyearlings	8/29/2009	34	4	14.71%	0.394	6
Wild Chinook Subyearlings	10/7/2009	22	2	13.64%	0.378	3
Wild Chinook Subyearlings	10/16/2009	34	6	20.59%	0.471	4
Wild Chinook Subyearlings	11/17/2009	35	3	11.43%	0.345	11
Wild Chinook Subyearlings	11/23/2009	21	0	4.76%	0.22	9
Wild Chinook Subyearlings	11/21/2011	39	2	7.69%	0.281	5
Wild Chinook Subyearlings	10/4/2012	33	5	18.18%	0.441	4
Wild Chinook Subyearlings	10/24/2012	87	6	8.05%	0.288	8
Wild Chinook Subyearlings	10/28/2012	36	1	5.56%	0.238	20
Wild Chinook Subyearlings	10/31/2013	46	7	17.39%	0.43	7
Wild Chinook Subyearlings	11/6/2013	38	9	26.32%	0.539	7
Wild Chinook Subyearlings	11/9/2013	40	6	17.50%	0.432	7
Wild Chinook Subyearlings	11/13/2013	29	2	10.34%	0.327	12
Wild Chinook Subyearlings	11/23/2013	25	3	16.00%	0.412	11
Wild Chinook Subyearlings	11/27/2013	24	0	4.17%	0.206	9
Wild Chinook Subyearlings	9/17/2015	39	4	12.82%	0.366	3

Appendix D. Historical Morphometric Data

Spring Chinook (2007-2016)

Trap Year	Brood Year	Origin/Species/Stage	Fork Length (mm)			Weight (g)			K-factor
			Mean	n	SD	Mean	n	SD	
2007	2005	Wild Yearling Smolt	93	173	8.5	8.6	173	2.2	1.1
2007	2005	Wild Yearling Precocial Parr	123	4	7.2	22.2	4	5.8	1.2
2007	2005	Hatchery Yearling Smolt*	76	208	17.9	5.4	203	4.2	1.2
2007	2005	Hatchery Yearling Precocial Parr	98	20	8.7	11.1	19	2.2	1.2
2007	2006	Wild Subyearling Fry	35	7	1.6	—	—	—	—
2007	2006	Wild Subyearling Parr	95	33	12.4	9.8	33	4.1	1.1
2008	2006	Wild Yearling Smolt	100	105	12.3	12.5	105	13.5	1.2
2008	2006	Wild Yearling Precocial Parr	126	9	8.4	22.8	9	4.1	1.1
2008	2006	Hatchery Yearling Smolt	117	229	12.7	18.7	228	9.8	1.2
2008	2006	Hatchery Yearling Precocial Parr	155	2	15.6	47.6	2	12.6	1.3
2008	2007	Wild Subyearling Fry	41	10	4.4	—	—	—	—
2008	2007	Wild Subyearling Parr	95	202	9.1	9.4	202	2.5	1.1
2009	2007	Wild Yearling Smolt	104	275	6.4	12.5	274	2.6	1.1
2009	2007	Wild Yearling Precocial Parr	134	5	7.0	28.5	2	2.7	1.2
2009	2007	Hatchery Yearling Precocial Parr	188	2	17.7	81.9	2	27.1	1.2
2009	2008	Wild Subyearling Fry	38	13	2.1	—	—	—	—
2009	2008	Wild Subyearling Parr	85	507	11.8	7.2	499	2.7	1.2
2010	2008	Wild Yearling Smolt	96	345	7.1	11.2	345	2.4	1.3
2010	2008	Wild Yearling Precocial Parr	130	15	10.3	26.4	15	6.6	1.2
2010	2009	Wild Subyearling Fry	40	31	3.6	—	—	—	—
2010	2009	Wild Subyearling Parr	87	166	12.6	7.7	166	3.0	1.2
2011	2009	Wild Yearling Smolt	99	64	7.7	11.3	64	2.8	1.2
2011	2009	Wild Yearling Precocial Parr	137	1	—	32.3	1	—	1.3
2011	2009	Hatchery Yearling Smolt	127	46	10.6	24.3	46	6.5	1.2
2011	2010	Wild Subyearling Fry	37	26	2.5	—	—	—	—
2011	2010	Wild Subyearling Parr	91	159	13.0	9.2	159	7.1	1.2
2012	2010	Wild Yearling Smolt	98	182	7.9	10.9	179	2.8	1.2
2012	2010	Wild Yearling Precocial Parr	123	13	12.7	22.4	13	6.5	1.2
2012	2011	Hatchery Subyearling Fry	84	29	4.4	6.5	2	2.3	1.1
2012	2011	Hatchery Subyearling Parr	110	25	7.4	14.6	25	3.3	1.1
2012	2011	Wild Subyearling Fry	35	18	2.7	—	—	—	—
2012	2011	Wild Subyearling Parr	91	315	10.1	8.8	288	2.8	1.2
2013	2011	Wild Yearling Smolt	103	20	7.0	12.3	20	3.0	1.1
2013	2011	Wild Yearling Precocial Parr	111	2	0.7	13.5	2	3.0	1.0
2013	2011	Hatchery Yearling Precocial Parr	155	4	17.4	43.4	4	17.8	1.2
2013	2012	Wild Subyearling Fry	40	77	8.1	—	—	—	—
2013	2012	Wild Subyearling Parr	84	445	12.3	6.7	444	4.7	1.1

2014	2012	Wild Yearling Smolt	94	43	7.0	9.4	43	2.2	1.1
2014	2012	Wild Yearling Precocial Parr	127	7	13.0	23.2	7	7.4	1.1
2014	2013	Wild Subyearling Fry	40	22	3.8	—	—	—	—
2014	2013	Wild Subyearling Parr	86	185	14.1	7.5	185	3.3	1.2
2015	2013	Wild Yearling Smolt	103	32	6.8	13.0	31	2.8	1.1
2015	2013	Wild Yearling Precocial Parr	145	2	13.4	35.2	2	11.4	1.1
2015	2014	Wild Subyearling Fry	38	11	3.3	0.5	10	0.2	0.9
2015	2014	Wild Subyearling Parr	96	151	7.5	10.4	148	6.3	1.2
2016	2014	Wild Yearling Smolt	106	3	1.5	12.4	3	0.3	1.1
2016	2015	Wild Subyearling Fry	38	50	3.0	0.46	49	0.3	0.8
2016	2015	Wild Subyearling Parr	89	147	10.7	8.29	147	2.8	1.1

[a] Includes residualized non-precocial smolts caught after June 30
[b] "Fry" classification based on age despite FL ≥ 50mm

Appendix N

Genetic Diversity of Upper Columbia River Summer Chinook Salmon

Genetic Structure of upper Columbia River Summer Chinook and Evaluation of the Effects of Supplementation Programs

by

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Abstract

We investigated genetic relationships among temporally replicated collections of summer Chinook from the Wenatchee River, Methow River, and Okanogan River in the upper Columbia River basin. Samples from the Eastbank Hatchery – Wenatchee stock, Eastbank Hatchery – MEOK stock, and Wells Hatchery were also included in the analysis. Samples of natural- and hatchery-origin summer Chinook were analyzed and compared to determine if the supplementation program has had any impacts to the genetic structure of these populations. We also calculated the effective number of breeders for collection locations of natural- and hatchery-origin summer Chinook from 1993 and 2008. In general, population differentiation was not observed among the temporally replicated collection locations. A single collection from the Okanogan River (1993) was the only collection showing statistically significant differences. The effective number of breeders was not statistically different from the early collection in 1993 in comparison to the late collection in 2008. Overall, these analyses revealed a lack of differentiation among the temporal replicates from the same locations and among the collection from different locations, suggesting the populations have been homogenized or that there has been substantial gene flow among populations. Additional comparisons among summer-run and fall-run Chinook populations in the upper Columbia River were conducted to determine if there was any differentiation between Chinook with different run timing. These analyses revealed pairwise F_{ST} values that were less than 0.01 for the collections of summer Chinook to collections of fall Chinook from Hanford Reach, lower Yakima River, Priest Rapids, and Umatilla. Collections of fall Chinook from Crab Creek, Lyons Ferry Hatchery, Marion Drain, and Snake River had pairwise F_{ST} values that were higher in comparison to the collections of summer Chinook. The consensus clustering analysis did not provide good statistical support to the groupings, but did show relationships among collections based on geographic proximity. Overall the summer and fall run Chinook that have historically been

spawned together were not differentiated while fall Chinook from greater geographic distances were differentiated.

Introduction

The National Marine Fisheries Service (NMFS) recognizes 15 Evolutionary Significant Units (ESU) for Chinook salmon (*Oncorhynchus tshawytscha*) (Myers et al. 1998). The summer Chinook from the upper Columbia River are included in the Upper Columbia River Summer- and Fall-Run ESU, which encompasses all late-run (summer and fall), ocean-type Chinook salmon from the mainstem Columbia River and its tributaries (excluding the Snake River) between Chief Joseph and McNary Dams (Waknitz et al. 1995). Waknitz et al. (1995) concluded that due to high total abundance this ESU was not likely to become at risk from extinction. Yet, a majority of natural spawning activity was in the vicinity of Hanford Reach, and it was unclear whether natural production was self-sustaining given the vast summer Chinook artificial propagation efforts (Waknitz et al. 1995). Additionally, the Biological Review Team expressed concern about potential consequences to genetic and life-history traits from an increasing contribution of hatchery fish to total spawning escapement (Waknitz et al. 1995).

Artificial propagation of ocean-type Chinook from the middle/upper Columbia has been continuous since the implementation of the Grand Coulee Fish Maintenance Project (GCFMP) in 1939 (Myers et al. 1998). The US Fish and Wildlife Service established three hatchery programs for summer/fall Chinook during the GCFMP, Leavenworth NFH, Entiat NFH, and Winthrop NFH. The Washington Department of Fisheries (now Washington Department of Fish and Wildlife) followed with hatchery programs at Rocky Reach (1964), Wells Dam (1967), Priest Rapids (1974), and Eastbank (1990) facilities. Currently, only Leavenworth NFH and Winthrop NFH are not producing summer/fall Chinook. Entiat NFH has resumed production of summer/fall Chinook (Wells FH Stock) in 2009 and released their first yearling summer Chinook smolts in 2010. Since

1941, over 200 million ocean-type Chinook salmon have been released into the middle Columbia River Basin (Myers et al. 1998). Initially, the hatchery programs differentiated between early returning fish (i.e., stream-type) and later returning fish (i.e., ocean-type), but no distinction was made regarding the “summer” and “fall” components of the ocean-type stocks (Waknitz et al. 1995). Therefore, all Chinook salmon now migrating above Rock Island Dam descend from not only a mixture between different stocks from the basin, but also a mixture between the endemic summer and fall life histories. While hatchery protocols have been modified of late to maintain discreet summer and fall Chinook hatchery stocks (Utter et al. 1995; see also HGMP), physical evidence and genetic data suggests that summer and fall Chinook may have become homogenized. During the 1970’s and 80’s, given coded-wire tag recoveries, summer-run Chinook originating from above Rock Island Dam were believed to have spawned extensively with Hanford Reach and Priest Rapids Hatchery fish (Chapman 1994). Stuehrenberg et al. (1995) reported that 10% of their radio tagged summer Chinook were occupying typical fall-run spawning habitat on the mainstem Columbia river, and 25% of fall fish released from Priest Rapids were recovered as summers at (or above) Wells Hatchery. Genetic data reported by Marshall et al. (1995) and Waknitz et al. (1995) corroborate these observations, as genetic distances observed between summer and fall Chinook within the Upper Columbia River Summer- and Fall-Run ESU were essentially zero.

In response to the need for evaluation of the supplementation hatchery programs, both a monitoring and evaluation plan (DCPUD 2005; Murdoch and Peven 2005) and the associated analytical framework (Hays et al. 2006) were developed for the Habitat Conservation Plan’s Hatchery Committee through the joint effort of the fishery co-managers (CCT, NMFS, USFWS, WDFW, and YN) and Chelan County and Douglas County PUDs. These reports outline 10 objectives to be applied to various species assessing the impacts of hatchery operations mitigating the operation of Wells, Rocky Reach, and Rock Island hydroelectric projects. The present monitoring and evaluation study plan differs in scope from previous monitoring and evaluation projects proposed by WDFW Molecular Genetics Lab, in that it does not investigate a single watershed, but instead will encompass all summer Chinook stocks from the upper Columbia River including the three supplementation (Wenatchee, Methow, and Okanogan) and the harvest augmentation program (Wells summer Chinook). The objectives of this study were to determine if genetic diversity, population structure, and effective population size have changed in natural spawning populations as a result of the hatchery programs.

Materials and Methods

Collections

A total of 2,416 summer Chinook were collected from tributaries in the upper Columbia River basin and were analyzed (Table 1). Two collections of natural-origin summer Chinook from 1993 (prior to the supplementation program) were taken from the Wenatchee River Basin and were compared to collections of hatchery and natural-origin from 2006 and 2008 that were post-supplementation. Two pre-supplementation collections from the Methow River (1991 and 1993) were compared to post-supplementation collections from 2006 and 2008. Three pre-supplementation collections from the Okanogan River Basin (1991, 1992, and 1993) were compared with post-supplementation collections from 2006 and 2008. A collection of natural-origin summer Chinook from the Chelan River was also analyzed. Additionally, hatchery collections from Eastbank Hatchery (Wenatchee and MEOK stock) and Wells Hatchery were analyzed and compared to the in-river collections. Summer Chinook data (provided by the USFWS) from the Entiat River was also used for comparison. Lastly, data from eight collections of fall Chinook was compared to the collections of summer Chinook.

Laboratory Analyses

All laboratory analyses were conducted at the WDFW Genetics Laboratory in Olympia, Washington. Genomic DNA was extracted by digesting a small piece of fin tissue using the nucleospin tissue kits obtained from Macherey-Nagel following the recommended conditions in the user manual. Extracted DNA was eluted with a final volume of 100 µL.

Genotype information was generated using thirteen microsatellite markers following standard laboratory protocols and analysis methods. Descriptions of the loci assessed in this study and polymerase chain reaction (PCR) conditions are given in Table 2. PCR reactions were run with a thermal profile consisting of: denaturation at 95^{o}C for 3 min, denaturation at 95^{o}C for 15 sec, anneal for 30 sec at the appropriate temperature for each locus (Table 2), extension at 72^{o}C for 1 min, repeat cycle (steps 2-4), final extension at 72^{o}C for 30 minutes. PCR products were then processed with an ABI-3730 DNA Analyzer. Genotypes were visualized with a known size standard (GS500LIZ 3730) using GENEMAPPER 3.7 software. Alleles were binned in GENEMAPPER using the standardized allele sizes established for the Chinook GAPS dataset (Seeb et al. 2007).

Within-collection Statistical Analyses

Allele frequencies were calculated with CONVERT (version 1.3, Glaubitz 2003). Hardy-Weinberg proportions for all loci within each collection were calculated using GENEPOP (version 3.4, Raymond and Rousset 1995). Heterozygosity (observed and expected) was computed for each collection group using GDA (Lewis and Zaykin 2001).

Allelic richness and F_{IS} (Weir and Cockerham 1984) inbreeding coefficient were calculated using FSTAT (version 2.9.3.2, Goudet 2001). Linkage disequilibrium for each pair of loci in each collection was calculated using GENEPOP v 3.4 (10,000 dememorizations, 100 batches, and 5,000 iterations per batch). Pairwise estimates of genetic differentiation between collection groups were calculated using GENEPOP (version 3.4, Raymond and Rousset 1995). Statistical significance for the tests of Hardy-Weinberg proportions, linkage disequilibrium, and genotypic differentiation was evaluated using a Bonferroni correction of p-values to account for multiple, simultaneous tests (Rice 1989).

Between-collection Statistical Analyses

Pairwise F_{ST} estimates were computed to examine population structure among collections using GENETIX (version 4.03, Belkhir et al. 2001). This estimate uses allelic frequency data and departures from expected heterozygosity to assess differences between pairs of populations.

We used PHYLIP (version 3.5c, Felsenstein 1993) to calculate Cavalli-Sforza and Edwards (1967) pairwise chord distances between collections. Bootstrap calculations were performed using SEQBOOT followed by calculations of genetic distance using GENDIST. The NEIGHBOR-JOINING method of Saitou and Nei (1987) was used to generate the dendrograms and CONSENSE to generate a final consensus tree from the 1,000 replicates. The dendrogram generated in PHYLIP was plotted as an unrooted radial tree using TREEVIEW (version 1.6.6, Page 1996).

Effective Number of Breeders

The effective number of breeders (N_b) was estimated for pre- and post-supplementation program collections (where possible) to investigate whether hatchery programs had affected that genetic metric over the operational period. Wang (2009) derived an equation for effective size (N_e) as a function of the frequency of nested full-sib and half-sib families in a random collection of individuals.

$$\frac{1}{N_e} = \frac{1+3\alpha}{4}(Q_1 + Q_2 + 2Q_3) - \frac{\alpha}{2}\left(\frac{1}{N_1} + \frac{1}{N_2}\right) \quad \text{(equation 10)}$$

Where α is a measure of the deviation of genotype frequencies from Hardy-Weinberg expectation (equivalent to Wright's (1969) F_{IS}), Q_i are the probabilities that a pair of offspring are paternal half sibs, maternal half sibs, or full sibs, respectively, and N_1 and N_2 are the number of male and female parents that generation, respectively. Genetic parameters (i.e., sibship distributions) were estimated for summer Chinook collections using algorithms implemented in COLONY (Jones and Wang 2009). To be clear, Wang's (2009) method as implemented here will estimate N_b, given multi-locus genotypes from each collection were partitioned by brood year for this analysis. To obtain an estimate of N_e each N_b value must be multiplied by the mean generation time of that population.

Results

Collections

A total of 2,350 individuals from 32 collections of temporally replicated samples (six locations) were analyzed (Table 1). Temporally replicated collections of hatchery and natural-origin samples were from the Wenatchee, Methow, and Okanogan Rivers. Temporally replicated hatchery-origin summer Chinook were from Wells Hatchery, Eastbank Hatchery - Wenatchee stock, and Eastbank Hatchery - Methow/Okanogan (MEOK) stock. A total of 232 of those individuals were excluded from any analyses because they failed to amplify at nine or more loci. Data for remaining 2,118 individuals were analyzed to assess differences between temporally replicated natural- and hatchery-origin summer Chinook for each location and to compare the differences among the different collection locations. Summer Chinook data from the temporally replicated collection locations were then combined and compared to fall Chinook data from the GAPS v.3.0 dataset.

Statistical Analyses

The population statistics (Hardy-Weinberg equilibrium and F_{IS}) calculated for each of the 32 temporally replicated collection locations were consistent with neutral expectations (i.e., no associations among alleles). Three collections did have a single locus that did not meet expectations (Wenatchee hatchery-origin 2006, Wells hatchery 2006, and Okanogan hatchery-origin 2009). Based on these results we suggest the collections represented randomly breeding groups and were not comprised of mixtures of individuals from different genetic source populations.

Population differentiation was assessed for each of the temporally replicated collections from within each location (Table 3). This analysis revealed the only significant difference observed within a collection location pertained to the collection from 1993 Okanogan River natural-origin samples. Because of the significant difference of this collection to the other temporal replicates it was not included in further analyses.

Given the absence of genetic differentiation observed among the temporally replicated collections, the 32 collections from the Wenatchee, Methow, and Okanogan River were combined to form three location-specific collections for analysis. Population differentiation metrics were compared among the composite Wenatchee, Methow, and Okanogan collections and eight other location-specific collections (11 locations total). Comparing all collections, there were a total of 39 significant genic test comparisons out of a total 496 (Table 4). Thirty-eight of the 39 statistically significant pairwise differences pertained to the Okanogan River and 2006 Wells Hatchery collections (Table 4). F_{ST} results are described further below.

Within-collection genetic metrics were estimated for the 11 location-specific collections of summer Chinook from the upper Columbia River, in addition to eight collections of fall Chinook (Table 1). The population statistics (Hardy-Weinberg equilibrium and F_{IS}) calculated for these collections of summer and fall

Chinook were also consistent with neutral expectations. The collection from Lyons Ferry Hatchery had one locus that did not meet expectations and the collections from Crab Creek and Marion Drain both had three loci that did not meet expectations.

The hatchery collections in general had a higher percentage of significantly linked loci; however the observed genetic diversity were similar for the natural and hatchery-origin collections. Analysis of allelic richness was based on 11 individuals per collection, the minimum number of individuals across all collections with complete multilocus genotypes. The largest number of linked loci occurred in the Crab Creek, Entiat River, and Okanogan natural-origin collections. Allelic richness was on average lower in the collections of summer Chinook (10.7) collections in comparison to the collections of fall Chinook (11.0).

Pairwise F_{ST} (Table 4) estimates revealed low levels of differentiation, where all observed F_{ST} values between the collections of summer Chinook were lower than 0.0096. There were 15 out of 28 comparisons between collections of summer Chinook that were significantly different from zero and occurred primarily from comparisons of the Okanogan River (hatchery and natural-origin) and Wells Hatchery to all other collections. The collection of Eastbank Hatchery – MEOK stock was differentiated from the Wenatchee River natural-origin and Entiat River collections. The collection from the Chelan River had a small sample size of 23 individuals and only differentiated from the Eastbank Hatchery – MEOK stock. F_{ST} estimates regarding pairwise comparisons between each of four fall Chinook collection locations (Crab Creek, Lyons Ferry Hatchery, Marion Drain, and Snake River) to all other collections were significantly different from zero (Table 5). Pairwise comparisons for three other fall Chinook collections (Hanford Reach, lower Yakima River, and Umatilla River) to the collections of summer Chinook were significantly different from zero (Table 6). The only fall Chinook collection that was not significantly differentiated from all of the summer Chinook was Priest Rapids.

The relative genetic relationships among the test groups were assessed using the consensus clustering analysis (Figure 1). Statistical support for the dendrogram topology (i.e., tree shape) was low regarding the branching that separated the collections of summer Chinook from the upper Columbia River. The collections of fall Chinook; however were supported with bootstrap support over 76% with the exception of three collections (lower Yakima River, Crab Creek, and Umatilla River). In other words, 760 of the 1000 bootstrap replicates supported the placement of the node separating summer and fall collections. The collection from the Chelan River had bootstrap support of 68%; however the sample size for that collections was small (N = 23). Even though the bootstrap support was low among the collections of summer Chinook there was concordance between geography and genetic distance.

Where comparisons were possible between pre- and post-supplementation program collections, the effective number of breeders (N_b) estimated to have comprised those collections were slightly lower for contemporary (2008) collections; however in all cases the 95% confidence intervals overlapped between historical and contemporary collections, suggesting statistical equivalency. Regarding Wenatchee River collections, the point estimates of N_b ranged from 134 (08FU) to 190 (93DD), where all collections had overlapping confidence intervals (Table 7). The upper bound of the 1989 brood year for collection 93DD was very large, suggesting the sample size was insufficient for properly inferring the sibship distribution within the collection. Comparing the Okanogan natural collections 93ED and 08GA, the estimated N_b were 142 (CI 102 – 203) and 127 (CI 92 – 180), respectively. For the Eastbank Hatchery MEOK stock comparisons, the N_b estimated for the 93DF collection was 171 (CI 129 – 229), as compared to the 166 (CI 126 – 226) estimated for collection 08MO. In all cases, the estimated N_b can be converted to effective population size (N_e) by multiplying the estimate by the mean generation time.

Discussion

The collections of summer Chinook populations from the upper Columbia River are of interest because census sizes are reduced below historic levels and are the subject of mitigation and supplementation hatchery programs. Concern over the impacts of hatchery supplementation programs on the genetic integrity of natural-origin populations led to our primary objective, which was to evaluate genetic metrics for temporally replicated collections of summer Chinook in the upper Columbia River pre and post hatchery supplementation. A similar analysis by Kassler and Dean (2010) was conducted on spring Chinook in the Tucannon River to evaluate the effects of a supplementation and captive brood program on natural-origin stocks. Additionally, upper Columbia River spring Chinook supplementation programs (Blankenship et al. 2007; Small et al. 2007), spring and fall Chinook populations in the Yakima Basin (Kassler et al. 2008), and a potentially unique population of fall Chinook in Crab Creek (Small et al. 2010) have been evaluated. In the present analysis of summer Chinook populations, collections of pre- and post- supplementation summer Chinook were collected from the Wenatchee River, Methow River, and Okanogan River Basins and analyzed to determine if the genetic profile has changed as a result of the supplementation program. Analysis was then conducted on the collections of summer run to compare the fall run Chinook collections in the upper Columbia River basin.

Allozyme analyses of these three summer run Chinook stocks in the upper Columbia River have identified that each stock was distinct, with a closer relationship detected between the Wenatchee and Methow Rivers (WDF and WDW 1993, Marshall 2002). Wenatchee summer Chinook are thought to be a mixture of native summer Chinook and Chinook from the Grand Coulee Fish Maintenance Project (GCFMP). The goal of the GCFMP project between 1939 and 1943 was to trap migrating Chinook salmon at Rock Island dam (75 miles below Grand Coulee) and homogenize the populations, which reduced the genetic uniqueness of the distinct tributary populations present in the upper Columbia River.

We found allele frequencies for individual temporally replicated hatchery- and natural-origin collection locations of adult summer Chinook were not significantly different from that expected of a single underlying population, except for one collection (1993 Okanogan natural-origin; Table 3). This collection was differentiated to the Okanogan collections in 2006 and 2008; however it was not differentiated from the collection in 1992. The Okanogan collection from 1992 was also not differentiated to any other collection; therefore the difference in the collection from Okanogan 1993 was likely not an indication of genetic change from pre supplementation to post supplementation. The collection was however dropped from further analyses so as to not confuse interpretation of results. The lack of allelic differentiation observed among the temporally replicated collections was interpreted as the genetic metrics from each location in the early 1990's did not differ from the samples collected in 2008. Spanning a few generations, allele frequencies are not expected to change for large populations at genetic equilibrium. In contrast, changes in allele frequencies of small populations may occur due to the stochastic sampling of genes from one generation to the next (i.e., genetic drift).

A second round of analyses was conducted to evaluate the genetic relationships of the summer run collections (temporal collections were combined) with data from the Entiat River, Chelan River, and eight collections of fall Chinook. Assessment of the relationship between the summer run collections in comparison to each other provided very little evidence of genetic differentiation between these collections. While population differentiation did show some significant differences between the Okanogan River and Wells Hatchery collections, all of the pairwise F_{ST} values were below 0.003. Meaning that a very small proportion of the observed genetic variation could be attributed to restrictions in gene flow (i.e., population structure)

The comparison of the hatchery-origin collections revealed a lack of differentiation between the Eastbank Hatchery – Wenatchee stock, Eastbank Hatchery – MEOK stock, and the Wells Hatchery (with exception of the 2006 collection). The genetic similarity or low level of genetic differentiation among these stocks suggests that there has been an integration of natural- and hatchery-origin summer Chinook in the upper Columbia River or a lack of ancestral genetic difference. The difference of the 2006 Wells Hatchery collection to the other collections is most likely a result of sampling effect because of the lack of differentiation among the stocks in the basin. If the 2006 collection had been mixed from different sources of summer Chinook there would not be a detectable level of differentiation as was seen with the 2006 sample.

The analyses to compare summer and fall Chinook collections provided some understanding on the genetic relationships of Chinook with different run timings in the upper Columbia River basin. Historically, the hatchery programs in the upper Columbia River were separated into groups of the early returning fish (i.e., stream-type) and later returning fish (i.e., ocean-type), but the programs did not sort individuals identified as "summer" or "fall" stocks (Waknitz et al. 1995). Now all Chinook salmon that are migrating above Rock Island Dam descend from a mixture of different stocks from the upper Columbia River basin, but also a mixture between the endemic summer and fall life histories.

Small et al. (2010) conducted an analysis on summer run and fall run Chinook in the upper Columbia River and concluded that Crab Creek Chinook in the upper Columbia River were genetically distinct to all other fall and summer run Chinook stocks that were analyzed. They did note a departure from Hardy Weinberg expectation as a result of a null allele at the microsatellite locus *Ogo-4* and a higher linkage disequilibrium value due to the inclusion of family groups in one of their samples. Kassler et al. (2008) found differentiation among spring and fall Chinook populations in the Yakima River.

The tests of pairwise F_{ST} indicated a very low level of genetic differentiation (less than one percent difference) between collections of summer-run Chinook and fall-run Chinook. The range of pairwise F_{ST} values for comparisons between the summer run and fall run collections was 0.0016 – 0.0248. The larger values from the range were associated to the collections from Crab Creek, Lyons Ferry Hatchery, and Marion Drain. Studies by Kassler et al. (2008) and Small et al. (2010) have documented differences among the populations of these collections to others within the upper Columbia River basin. The low pairwise F_{ST} values between Priest Rapids and Hanford Reach collections and the summer run collections were not surprising because summer-run Chinook originating from above Rock Island Dam were believed to have spawned extensively with Hanford Reach and Priest Rapids Hatchery fish during the 1970's and 80's (Chapman 1994). The lack of differentiation among the summer and fall stocks in the Columbia River was also identified by Utter et al. (1995) and the HGMP where they state physical evidence and genetic data suggests that summer and fall Chinook may have become homogenized.

Despite low levels of statistical bootstrap support for dendrogram topology (i.e., tree shape), there was concordance observed between geographic location and the genetic relationships among the summer and fall Chinook populations. The collections from the Okanogan (hatchery and natural-origin) did separate out with collections from Wells Dam Hatchery, Entiat River, and Eastbank Hatchery – MEOK stock, and were next to a group of the Methow and Wenatchee collections. The fall Chinook populations are also separated to the summer collections and the position of all but three of these collections (lower Yakima River, Crab Creek, and Umatilla River) were statistically supported. The geographic proximity of the fall collections seemed to follow the observed pattern in this dendrogram. The relationship of the Snake River and Lyons Ferry Hatchery in proximity to the collection from Marion Drain was not surprising while the relationship between Priest Rapids and Hanford Reach was easily a result of the stocking practices of fall Chinook in the 1970 and 1980's.

A secondary objective of this study was to determine if the effective population size of upper Columbia River summer Chinook populations had changed over time due to supplementation efforts. We observed that the number of effective breeders in the collections from 1993 and 2008 has not changed thus providing reason to believe that the genetic diversity of summer Chinook in the upper Columbia River has not been altered through the supplementation program.

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Table 1. Samples of adult hatchery- and natural-origin summer and fall Chinook that were analyzed from the upper Columbia River. Total number of individuals that were analyzed / individuals with data for 9 or more loci that were included in the analysis. Collection statistics (allelic richness, linkage disequilibrium (before and after Bonferroni correction), F_{IS}, heterozygosity (H_O and H_E)) and p-values for deviations from Hardy-Weinberg equilibrium (HWE). P-values were defined as significant after implementation of Bonferroni correction for multiple tests (Rice 1989).

WDFW GSI code[a]	Collection location	N =	Allelic Richness[b]	Linkage Disequilibrium[c]	F_{IS} (p-value)[d]	H_O	H_E
93DD	Wenatchee River upstream of Tumwater Dam - natural origin	51 / 45					
93DE	Wenatchee River downstream of Tumwater Dam - natural origin	88 / 88					
06CQ	Wenatchee River upstream of Tumwater Dam - natural origin	95 / 86					
06CR	Wenatchee River downstream of Tumwater Dam - natural origin	95 / 82					
08FV	Wenatchee River upstream of Tumwater Dam - natural origin	95 / 82					
08FW	Wenatchee River downstream of Tumwater Dam - natural origin	95 / 87					
	Wenatchee River - Natural origin combined	**519 / 470**	**10.7**	**17 / 4**	**0.001 (0.403)**	**0.8504**	**0.8513**
06CP	Wenatchee River - hatchery origin	95 / 70					
08FU	Wenatchee River - hatchery origin	95 / 83					
	Wenatchee River - Hatchery origin combined	**190 / 153**	**10.6**	**18 / 6**	**0.018 (0.013)**	**0.8409**	**0.8561**
93EC	Methow River - natural origin	27 / 27					
06CT	Methow River - natural origin	95 / 90					
08FY	Methow River - natural origin	95 / 88					
09CO	Methow River - natural origin	91 / 80					
	Methow River - Natural origin combined	**308 / 285**	**10.7**	**4 / 1**	**0.006 (0.160)**	**0.8506**	**0.8554**
06CS	Methow River - hatchery origin	14 / 8					
08FX	Methow River - hatchery origin	21 / 18					
09CP	Methow River - hatchery origin	19 / 18					
	Methow River - Hatchery origin combined	**54 / 44**	**10.8**	**11 / 2**	**-0.003 (0.593)**	**0.8553**	**0.8523**

Table 1 continued.

92FM	Okanogan River - natural origin	49 / 46					
93ED*	Okanogan River - natural origin	103 / 87					
06CV	Okanogan River - natural origin	95 / 88					
08GA	Okanogan River - natural origin	95 / 92					
09CN	Okanogan River - natural origin	133 / 126					
	Okanogan River - Natural origin combined	**475 / 439**	**10.8**	**9 / 4**	**0.003 (0.304)**	**0.8563**	**0.8596**
* - not included in the combined dataset							
06CU	Okanogan River - hatchery origin	58 / 49					
08FZ	Okanogan River - hatchery origin	19 / 18					
09CM	Okanogan River - hatchery origin	117 / 107					
	Okanogan River - hatchery origin combined	**194 / 174**	**10.8**	**31 / 10**	**-0.011 (0.920)**	**0.8678**	**0.8586**
91FL	Wells Hatchery	68 / 42					
92FK	Wells Hatchery	25 / 23					
93DG	Wells Hatchery	11 / 9					
06DM	Wells Hatchery	95 / 91					
08HY	Wells Hatchery	95 / 91					
	Wells Hatchery combined	**294 / 256**	**10.7**	**8 / 3**	**-0.001 (0.529)**	**0.8670**	**0.8665**
08MN	**Eastbank Hatchery - Wenatchee River stock**	**95 / 90**	**10.7**	**6 / 1**	**0.020 (0.024)**	**0.8326**	**0.8498**
92FO	Eastbank Hatchery - Methow / Okanogan (MEOK) stock	36 / 33					
93DF	Eastbank Hatchery - Methow / Okanogan (MEOK) stock	90 / 86					
08MO	Eastbank Hatchery - Methow / Okanogan (MEOK) stock	95 / 88					
	Eastbank Hatchery - MEOK stock combined	**221 / 207**	**10.7**	**2 / 0**	**-0.005 (0.782)**	**0.8647**	**0.8604**
		2,350 / 2,118					

Table 1 continued.

06KN	**Chelan River**	**70 / 23**	**10.3**	**11 / 0**	**0.027 (0.118)**	**0.8334**	**0.8556**
Data provided by USFWS							
	Entiat River - summer Chinook	**190**	**10.9**	**33 / 10**	**0.008 (0.119)**	**0.8553**	**0.8625**
Data from Small et al. (2010)							
08EH	Crab Creek	108					
09AZ	Crab Creek	291					
	Crab Creek	**399**	**10.5**	**35 / 14**	**0.018 (0.000)**	**0.8519**	**0.8676**
GAPS v.3.0 data							
	Priest Rapids Hatchery - fall Chinook	**81**	**11.1**	**3 / 2**	**0.015 (0.079)**	**0.8591**	**0.8723**
	Hanford Reach - fall Chinook	**220**	**11.3**	**4 / 0**	**0.010 (0.068)**	**0.8661**	**0.8746**
	Umatilla - fall Chinook	**96**	**11.2**	**17 / 6**	**-0.003 (0.623)**	**0.8719**	**0.8693**
	lower Yakima River - fall Chinook	**103**	**11.0**	**3 / 1**	**0.000 (0.511)**	**0.8724**	**0.8721**
	Marion Drain - fall Chinook	**190**	**10.8**	**9 / 4**	**0.022 (0.001)**	**0.8586**	**0.8782**
	Lyons Ferry Hatchery - fall Chinook	**186**	**10.6**	**7 / 4**	**0.013 (0.033)**	**0.8527**	**0.8641**
	Snake River - fall Chinook	**521**	**11.1**	**0 / 0**	**-0.001 (0.634)**	**0.8720**	**0.8708**
		NA / 2,009					

[a] - Year that samples were collected is identifed by the two numbers in the WDFW GSI code

[b] - based on a minimum of 11 diploid individuals

[c] - adjusted alpha p-value = 0.0006

[d] - adjusted alpha p-value = 0.0002

Table 2. PCR conditions and microsatellite locus information (number alleles/locus and allele size range) for multiplexed loci used for the analysis of Chinook. Also included are the observed and expected heterozygosity (H_o and H_e) for each locus.

PCR Conditions			Locus statistics		Heterozygosity		
Poolplex	Locus	Dye Label	# Alleles/ Locus	Allele Size Range (bp)	H_o	H_e	References
Ots-M	*Ots-201b*	blue	49	137 - 334	0.9474	0.9544	Unpublished
	Ots-208b	yellow	56	154 - 378	0.9523	0.9672	Greig et al. 2003
	Ssa-408	red	32	184 - 308	0.9177	0.9214	Cairney et al. 2000
Ots-N	*Ogo-2*	red	22	206 - 260	0.8526	0.8673	Olsen et al. 1998
Ots-O	*Ogo-4*	blue	20	128 - 170	0.6694	0.7028	Olsen et al. 1998
	Ots-213	yellow	45	178 - 370	0.9430	0.9525	Greig et al. 2003
	Ots-G474	red	16	152 - 212	0.6816	0.6838	Williamson et al. 2002
Ots-R	*Ots-3M*	blue	15	128 - 158	0.7854	0.7938	Banks et al. 1999
	Omm-1080	green	54	162 - 374	0.9517	0.9670	Rexroad et al. 2001
Ots-S	*Ots-9*	red	9	99 - 115	0.6531	0.6543	Banks et al. 1999
	Ots-212	blue	33	123 - 251	0.9205	0.9360	Greig et al. 2003
Ots-T	*Oki-100*	blue	50	164 - 361	0.9500	0.9567	Unpublished
	Ots-211	red	34	188 - 327	0.9325	0.9414	Greig et al. 2003

Table 3. Tests of population differentiation for temporal collections of summer Chinook from natural and hatchery-origin populations in the upper Columbia River. P-values that are highlighted grey are significantly different after Bonferroni correction (Rice 1989). Adjusted alpha p-value was 0.0001 . The H and W in the collection identifier is for wild or hatchery-origin and the two digit number identifes the year samples were collected.

Wenatchee River

	WenW93U	WenW93D	WenH06	WenW06U	WenW06D	WenH08	WenW08U	WenW08D
WenW93U	****							
WenW93D	0.0162	****						
WenH06	0.0033	0.0102	****					
WenW06U	0.3039	0.1642	0.4795	****				
WenW06D	0.0261	0.0160	0.0678	0.5300	****			
WenH08	0.1126	0.0708	0.0073	0.4359	0.0893	****		
WenW08U	0.2115	0.1148	0.4191	0.7243	0.3830	0.8856	****	
WenW08D	0.1915	0.0014	0.7047	0.4928	0.1671	0.7755	0.7665	****

D - collection was downstream of Tumwater Dam; U - collection was upstream of Tumwater Dam

Methow River

	MetW93	MetH06	MetW06	MetH08	MetW08	MetW09	MetH09
MetW93	****						
MetH06	0.3962	****					
MetW06	0.5481	0.4688	****				
MetH08	0.1408	0.1192	0.2052	****			
MetW08	0.8219	0.8937	0.6156	0.3779	****		
MetW09	0.2564	0.4282	0.2502	0.0328	0.7309	****	
MetH09	0.1543	0.5678	0.0547	0.0017	0.0098	0.0073	****

Okanogan River

	OkanW92	OkanW93	OkanH06	OkanW06	OkanH08	OkanW08	OkanH09	OkanW09
OkanW92	****							
OkanW93	0.0066	****						
OkanH06	0.0193	0.0000	****					
OkanW06	0.2843	0.0082	0.0031	****				
OkanH08	0.1290	0.1106	0.0652	0.7329	****			
OkanW08	0.0106	0.0029	0.0082	0.4075	0.7396	****		
OkanH09	0.0187	0.0001	0.0094	0.0551	0.2214	0.0281	****	
OkanW09	0.0527	0.0000	0.0024	0.7130	0.0262	0.0065	0.0002	****

Table 3 continued.

Wells Dam Hatchery

	Wells91	Wells92	Wells93	Wells06	Wells08
Wells91	****				
Wells92	0.5863	****			
Wells93	0.0490	0.0784	****		
Wells06	0.0089	0.0100	0.0542	****	
Wells08	0.0819	0.1088	0.2552	0.0256	****

Eastbank Hatchery - Wenatchee and MEOK stocks

	EBHWen08	EBHME92	EBHME93	EBHME08
EBHWen08	****			
EBHME92	0.8681	****		
EBHME93	0.0251	0.8661	****	
EBHME08	0.0086	0.9563	0.1895	****

Table 4. F_{ST} pairwise comparisons and genotypic tests of differentiation for hatchery- and natural-origin summer Chinook from the upper Columbia River. Above the diagonol are the F_{ST} values and below are p-values for the test of genotypic differentiation. Non-significant p-values for the result of the genotypic differentiation test are in bold type and F_{ST} values that are not significantly different from zero are in bold type.

	Wenatchee Hatchery	Wenatchee Natural	Methow Hatchery	Methow Natural	Okanogan Hatchery	Okanogan Natural	Wells Hatchery	Eastbank Wenatchee stock	Eastbank MEOK stock	Entiat River	Chelan River
Wenatchee Hatchery	****	**0.0000**	**0.0011**	**0.0000**	**0.0013**	**0.0010**	0.0015	**0.0004**	**0.0007**	**0.0004**	**0.0072**
Wenatchee Natural	**0.4351**	****	**0.0016**	**0.0000**	0.0014	0.0016	0.0024	**0.0006**	0.0012	0.0009	**0.0068**
Methow Hatchery	**0.3800**	**0.0205**	****	**0.0012**	0.0029	**0.0008**	**0.0027**	**0.0014**	**0.0022**	**0.0019**	**0.0078**
Methow Natural	**0.2237**	**0.6566**	**0.1502**	****	**0.0011**	0.0011	0.0013	**0.0007**	**0.0007**	**0.0008**	**0.0053**
Okanogan Hatchery	0.0001	0.0000	**0.0364**	**0.0008**	****	**0.0010**	**0.0014**	0.0029	**0.0000**	**0.0007**	**0.0055**
Okanogan Natural	0.0000	0.0000	**0.1755**	0.0000	**0.0003**	****	0.0016	0.0023	**0.0005**	**0.0008**	**0.0049**
Wells Hatchery	0.0000	0.0000	**0.0129**	0.0000	0.0000	0.0000	****	0.0036	**0.0006**	**0.0008**	**0.0041**
Eastbank Wenatchee	**0.5261**	**0.4102**	**0.1215**	**0.8404**	**0.0015**	0.0000	0.0000	****	**0.0018**	0.0030	0.0096
Eastbank MEOK stock	**0.0485**	0.0000	**0.4246**	**0.0009**	**0.5786**	**0.0051**	0.0000	**0.0065**	****	**0.0005**	**0.0039**
Entiat River	**0.0565**	0.0000	**0.1795**	**0.0044**	**0.0005**	0.0000	**0.0032**	**0.0039**	**0.0042**	****	**0.0052**
Chelan River	**0.0091**	**0.0026**	**0.0182**	**0.0156**	**0.0048**	**0.0030**	**0.0066**	**0.0059**	**0.0493**	**0.0617**	****

Table 5. F_{ST} pairwise comparisons and genotypic tests of differentiation for fall Chinook. Above the diagonol are the F_{ST} values and below are p-values for the test of genotypic differentiation. Non-significant p-values for the result of the genotypic differentiation test are in bold type and F_{ST} values that are not significantly different from zero are in bold type.

	Crab Creek	Hanford Reach Fall	Lyons Ferry Hatchery Fall	lower Yakima River Fall	Marion Drain Fall	Priest Rapids Fall	Umatilla River Fall	Snake River Fall
Crab Creek	****	0.0087	0.0134	0.0079	0.0143	0.0107	0.0073	0.0097
Hanford Reach Fall	0.0000	****	0.0077	**0.0000**	0.0064	**0.0000**	**0.0000**	0.0022
Lyons Ferry Hatchery Fall	0.0000	0.0000	****	0.0063	0.0074	0.0092	0.0062	0.0029
lower Yakima River Fall	0.0000	**0.4140**	0.0000	****	0.0054	**0.0000**	**0.0000**	0.0018
Marion Drain Fall	0.0000	0.0000	0.0000	0.0000	****	0.0067	0.0061	0.0060
Priest Rapids Fall	0.0000	**0.0695**	0.0000	**0.0083**	0.0000	****	**0.0000**	0.0027
Umatilla River Fall	0.0000	**0.4879**	0.0000	**0.4896**	0.0000	**0.2539**	****	0.0011
Snake River Fall	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	****

Table 6. F_{ST} pairwise comparisons and genotypic tests of differentiation for hatchery- and natural-origin summer Chinook from the upper Columbia River and fall Chinook. Above the diagonol are the F_{ST} values and below are p-values for the test of genotypic differentiation. Non-significant p-values for the result of the genotypic differentiation test are in bold type and F_{ST} values that are not significantly different from zero are in bold type.

Population Differentiation

	Wenatchee Hatchery	Wenatchee Natural	Methow Hatchery	Methow Natural	Okanogan Hatchery	Okanogan Natural	Wells Hatchery	Eastbank Wenatchee stock	Eastbank MEOK stock	Entiat River	Chelan River
Crab Creek	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hanford Reach Fall	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0349**
Lyons Ferry Hatchery Fall	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
lower Yakima River Fall	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0074**
Marion Drain Fall	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Priest Rapids Fall	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0642**
Umatilla River Fall	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0579**
Snake River Fall	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 6 continued.

Pairwise F_{ST}

	Crab Creek	Hanford Reach Fall	Ferry Hatchery	Yakima River	Marion Drain Fall	Priest Rapids Fall	Umatilla River Fall	Snake River Fall
Wenatchee Hatchery	0.0158	0.0054	0.0180	0.0056	0.0153	**0.0025**	0.0053	0.0103
Wenatchee Natural	0.0162	0.0059	0.0185	0.0063	0.0157	0.0030	0.0059	0.0102
Methow Hatchery	0.0191	0.0104	0.0248	0.0095	0.0220	0.0069	0.0107	0.0165
Methow Natural	0.0148	0.0057	0.0182	0.0051	0.0148	0.0033	0.0055	0.0101
Okanogan Hatchery	0.0146	0.0041	0.0166	0.0042	0.0151	**0.0016**	0.0041	0.0082
Okanogan Natural	0.0163	0.0064	0.0187	0.0062	0.0170	0.0035	0.0068	0.0113
Wells Hatchery	0.0120	0.0051	0.0135	0.0044	0.0120	0.0028	0.0046	0.0077
Wenatchee stock	0.0184	0.0073	0.0203	0.0074	0.0167	0.0047	0.0084	0.0128
Eastbank MEOK stock	0.0128	0.0036	0.0143	0.0038	0.0135	**0.0019**	0.0038	0.0079
Entiat River	0.0147	0.0059	0.0176	0.0057	0.0156	0.0028	0.0056	0.0100
Chelan River	0.0074	**0.0046**	0.0110	**0.0040**	0.0160	**0.0047**	**0.0035**	0.0072

Table 7. Effective number of breeders per brood year with the largest number of samples of summer Chinook in the upper Columbia River. Brood years with sample size less than 19 individuals (shown in bold type) were not analyzed with exception of the 2008 Wells Hatchery collection. A comparison could not be made between an early and late collection from Wells Hatchery.

WDFW Code	Collection Location	Sample Size	Nb =	CI95(L) =	CI95(U) =
93DD[A]	Wenatchee Natural - upstream	23 / 19	152 / 190	77 / 87	616 / 2,147,483,647
08FV	Wenatchee Natural - upstream	56	162	112	249
93DE[A]	Wenatchee Natural - downstream	39 / 34	145 / 152	94 / 95	256 / 302
08FW	Wenatchee Natural - downstream	67	140	105	199
08FU	Wenatchee Hatchery	60	134	90	213
93EC[A]	Methow Natural	**10 / 15**	---	---	---
08FY	Methow Natural	62	150	106	218
08FX	Methow Hatchery	**9**	---	---	---
93ED	Okanogan Natural	69	142	102	203
08GA	Okanogan Natural	59	127	92	180
08FZ	Okanogan Hatchery	**16**	---	---	---
93DG	Wells Hatchery	**6**	---	---	---
08HY[B]	Wells Hatchery	24 / 39	---	---	---
08MN	Eastbank Hatchery - Wenatchee	88	190	144	263
93DF	Eastbank Hatchery - MEOK	84	171	129	229
08MO	Eastbank Hatchery - MEOK	88	166	126	226

[A] - calculations were made for samples from brood year 1988 / brood year 1989

[B] - samples were collected from brood year 2003 / brood year 2004

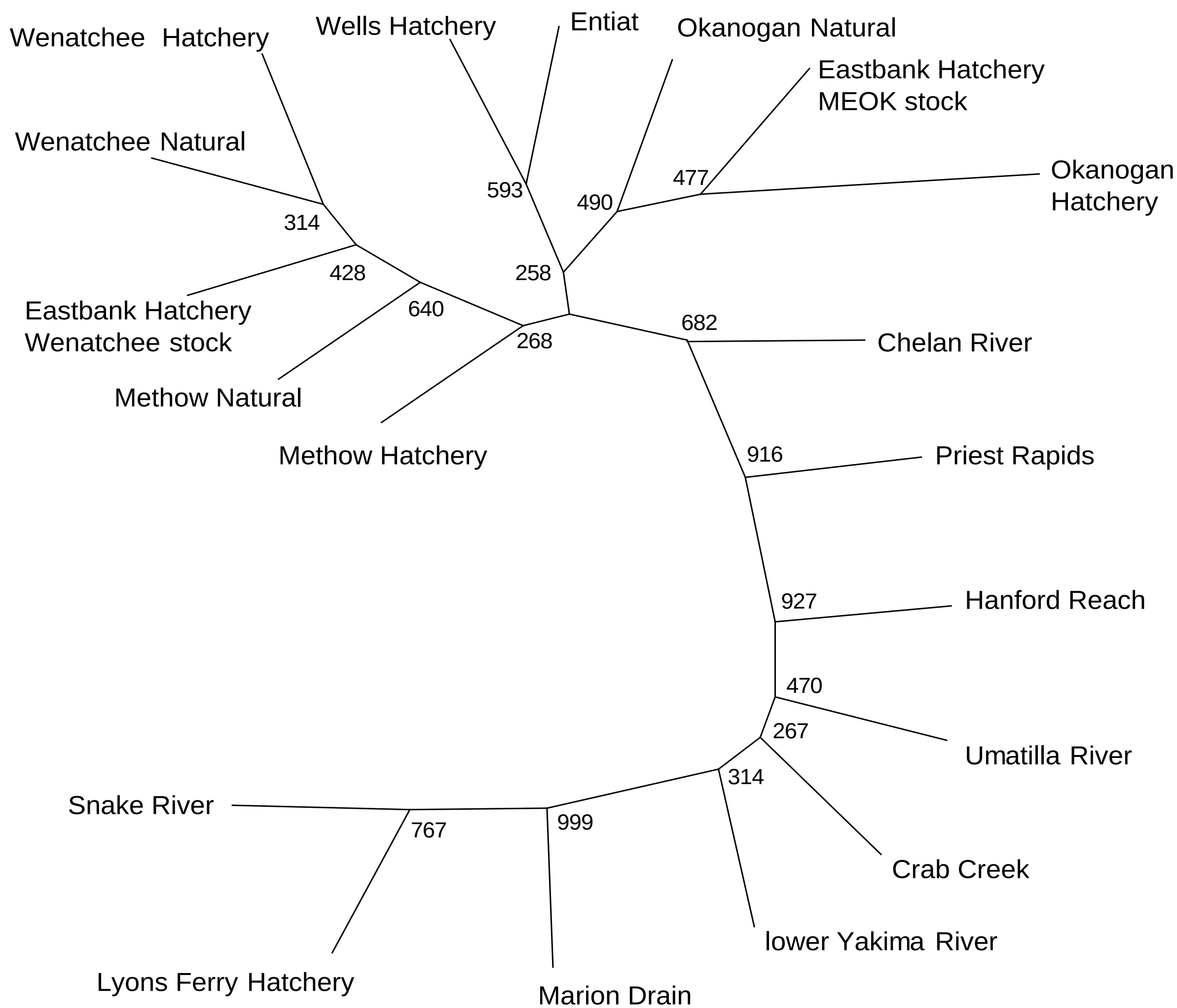

Figure 1. Relationship of natural- and hatchery-origin Chinook collections from the upper Columbia River basin using Cavalli-Sforza and Edwards (1967) chord distance. Bootstrap values are shown at each node.

Appendix O

Summer Chinook Spawning Ground Surveys in the Methow River Basin and Chelan River, 2016

BioAnalysts, Inc.℠
4725 North Cloverdale Road, Ste. 102
Boise ID 83713

March 10, 2017

To: Chelan and Grant Public Utility Districts

From: Denny Snyder and Mark Miller

Re: 2016 Summer Chinook Spawning Ground Surveys in the Methow Basin and Chelan River.

The purpose of this memo is to provide information on the supplemented natural spawning population of summer Chinook in the Methow and Chelan River basins. This work is part of a larger effort focused on monitoring and evaluating Grant and Chelan PUDs' hatchery supplementation programs. The tasks and objectives associated with implementing Grant and Chelan PUDs' Hatchery M&E Plan for 2016 are outlined in Hillman et al. (2013). In 2016, The Okanogan Basin was surveyed by the Colville Confederated Tribes (CCT).

METHODS

Spawning ground surveys were conducted by foot and raft beginning the third week of September and ending late-November. We did not use aerial surveys on the Methow River because past work has demonstrated that ground counts were more accurate than aerial surveys (Miller and Hillman 1997). Ground surveys were used to provide more accurate counts and a complete census of Chinook redds within their spawning distribution. Observers floated or walked through sampling reaches and recorded the location and numbers of redds each week (see Figures 1 and 2). Observers recorded the date, water temperature, river mile, and prepared a drawing of the area where redds were located. A different symbol was used each week to record the number of new and incomplete redds.

To maintain consistency, at least one observer surveyed the same stream reach on successive dates. In areas where numerous summer Chinook spawn, we constructed detailed maps of the river and used the cell-area-method (Hamilton and Bergersen 1984) to identify the number of redds within each cell. Cells were bound by noticeable landmarks along the banks (e.g., bridges or trees) or at stream habitat boundaries (e.g., transitions between pools and riffles). The number of redds were then recorded in the corresponding grid on the map. When possible, observers estimated the number of redds in a large disturbed area by counting females that defended redds. We assumed that the area or territory defended by a female was one redd.

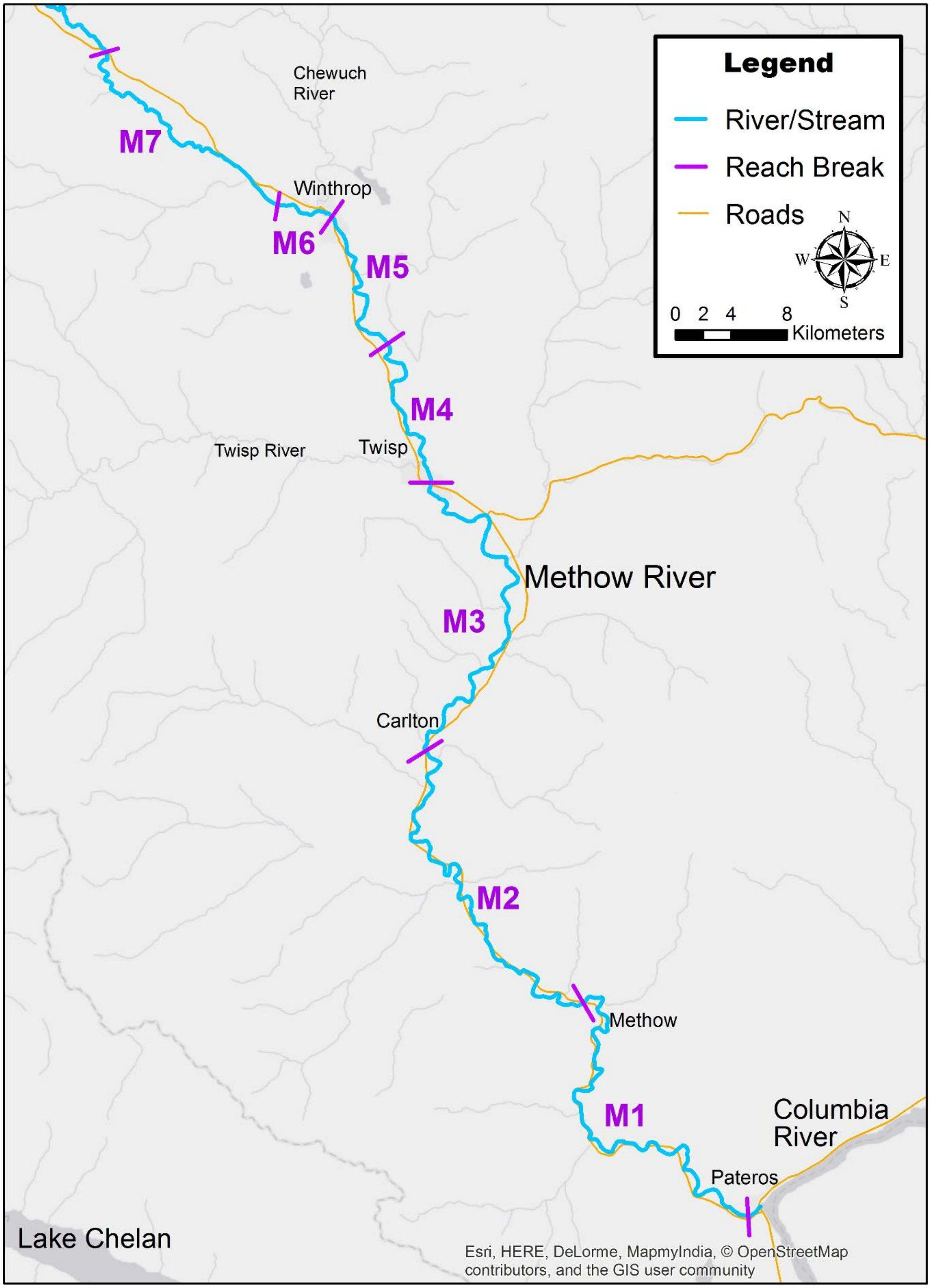

Figure 1. Summer Chinook survey reaches on the Methow River, 2016,

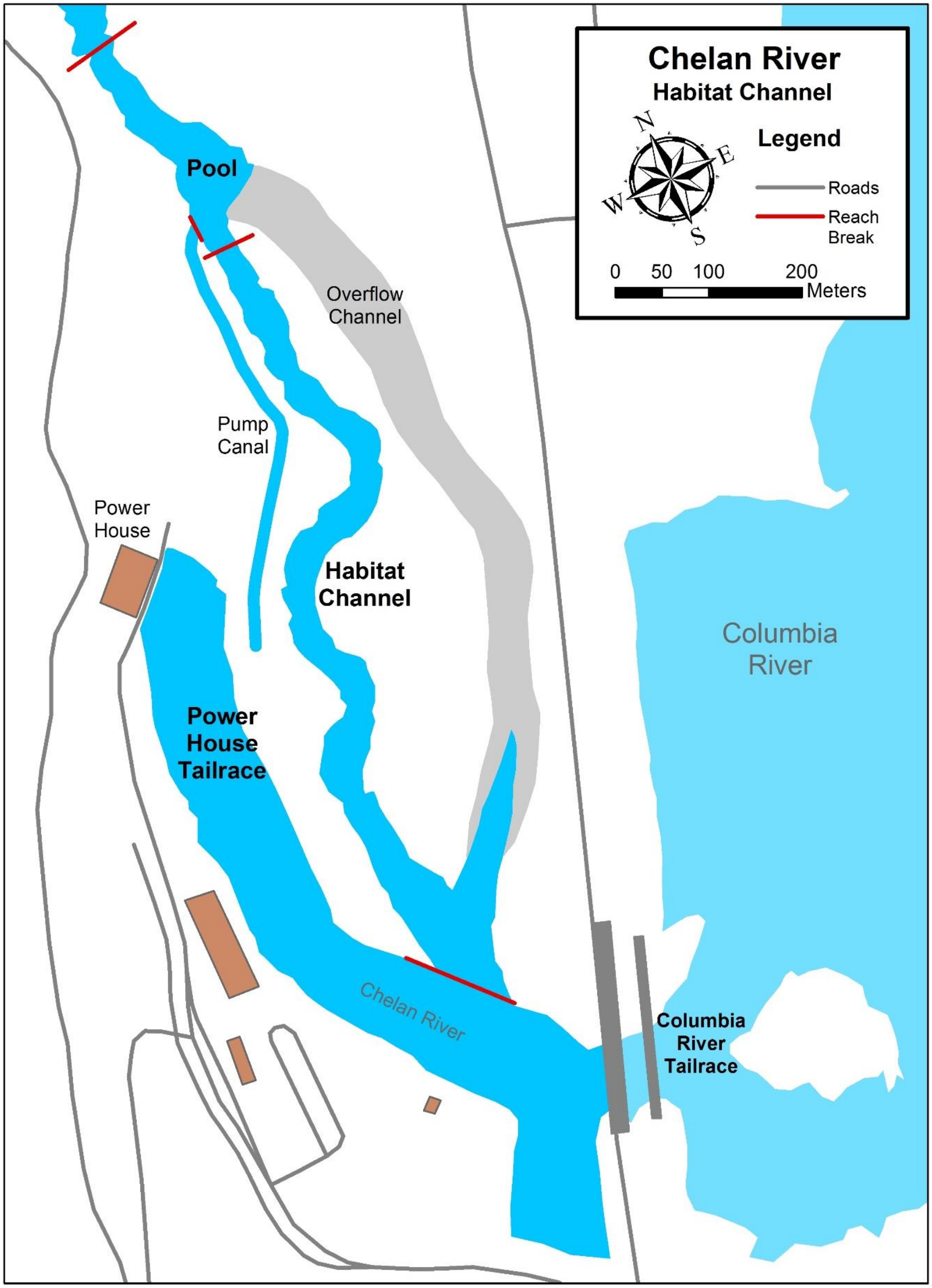

Figure 2. Summer Chinook survey areas on the Chelan River, 2016.

Spawning escapement was estimated as the number of redds times the sex ratio observed at Wells Dam during broodstock collection. In 2016, reach M1 experienced some clarity issues during spawning surveys. Turbidity noticeably increased during rainstorm events and was probably influenced by the Carlton Complex Fires and landslides that occurred in 2014.

Carcasses of summer Chinook were sampled to describe the spawning population. Biological data collection included: scale samples for age analysis, length measurements (POH and FKL), sex, egg voidance, marks, and presence of PIT tags. These data will be used to assess length-at-age, size-at-age, egg voidance, origin (hatchery or naturally produced), and stray rates. No DNA samples were collected on summer Chinook this year. In this report, we only report the number of redds counted in the Okanogan Basin.

RESULTS

Methow

There were 1,115 summer Chinook redds counted within seven reaches on the Methow River (Table 1). Most redds (81%) were located in reaches from the mouth to the town of Twisp (M1-M3). Estimated escapement based on expansion of redd counts from the sex-ratio observed at Wells Dam during broodstock collection indicates that 2,241 summer Chinook (1,115 redds x 2.01 fish/redd) spawned in the Methow River.

Table 1. Number of summer Chinook redds observed each week within the Methow River, 2016. Dashes (--) indicate that no survey occurred.

Reach	Location (Rkm)	Sep		Oct				Nov				Dec	Total	Percent
		18-24	25-1	2-8	9-15	16-22	23-29	30-5	6-12	13-19	20-26	27-3		
		39	40	41	42	43	44	45	46	47	48	49		
M1	0.0-23.8	--	0	3	47	13	54	42	22	1	0	--	182	16
M2	23.8-43.8	--	5	71	146	64	11	8	4	0	--	--	309	28
M3	43.8-63.7	--	6	131	208	48	16	1	--	--	--	--	410	37
M4	63.7-72.3	--	0	12	31	14	0	--	--	--	--	--	57	5
M5	72.3-80.1	--	0	51	70	26	0	--	--	--	--	--	147	13
M6	80.1-83.0	--	0	0	1	0	--	--	--	--	--	--	1	0
M7	83.0-96.1	--	4	5	0	0	0	--	--	--	--	--	9	1
Total:		**--**	**15**	**273**	**503**	**165**	**81**	**51**	**26**	**1**	**0**	**--**	**1,115**	**100**

Time of spawning was assessed as the number of new redds counted each week in the Methow River. Spawning began the last week of September, peaked in early October, and ended the third week of November (Figure 3). Stream temperatures in the Methow River varied from 10.5-11.0°C in September when spawning began. Spawning peaked the first week of October in Reach M7, while peak spawning occurred in reaches M2-M6 the second week of October. Spawning peaked the fourth week of October in reach M1 (Table 1). This was the sixth highest redd count observed in the last 26 years for the Methow River (Appendix A).

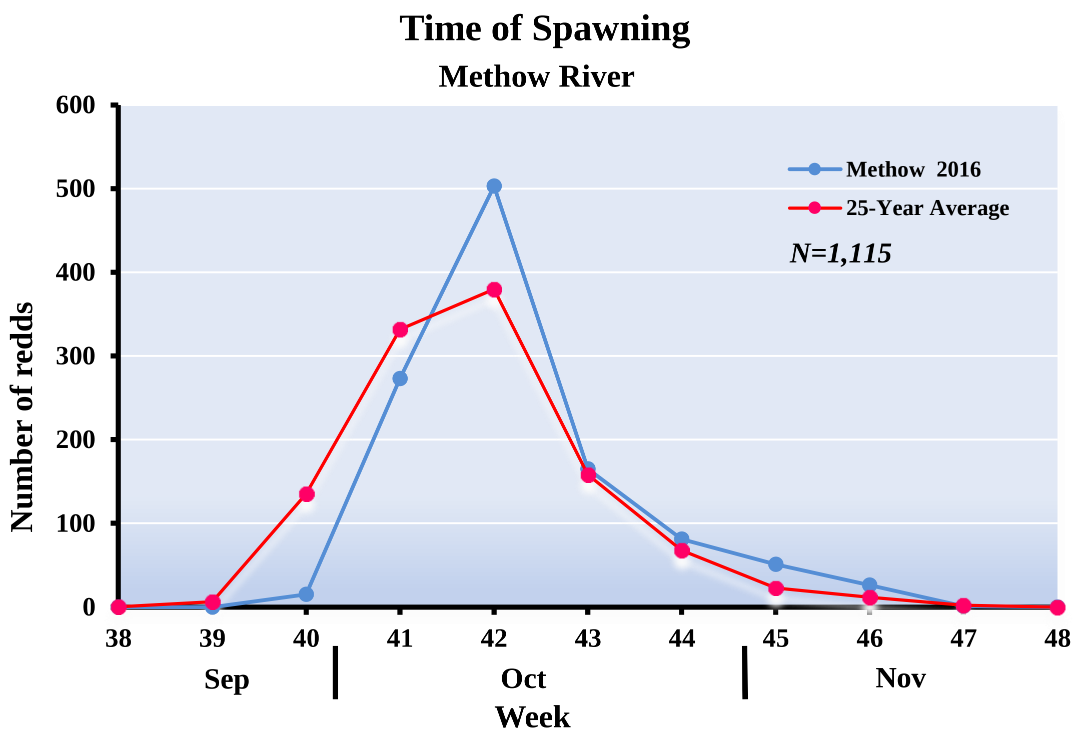

Figure 3. Number of new redds counted each week from late September to late-November in the Methow River, 2016. The figure shows the beginning, peak, and end of spawning for summer Chinook in the Methow River compared to a 25-year average (1991-2015).

There were 587 summer Chinook salmon carcasses sampled within the seven reaches on the Methow River (Table 2). The presence or absence of an adipose fin could not be determined on one fish. Twenty-six percent of the fish returning to the Methow River were sampled based on the estimated escapement of 2,241 summer Chinook. Ad-clipped hatchery fish made up 32% and naturally produced fish (adipose fin present) made up 68% of the fish sampled (Table 2).

Table 2. Number and percent of hatchery (ad-clipped) and naturally produced (ad-present) summer Chinook sampled in the Methow River, 2016.

Reach	Location (Rkm)	Ad-Clipped Hatchery				Naturally Produced				Reach Total
		Male	Female	Total	Percent	Male	Female	Total	Percent	
M1	0.0-23.8	15	14	29	35	26	27	53	65	**82**[1]
M2	23.8-43.8	40	17	57	34	64	47	111	66	**168**
M3	43.8-63.7	12	70	82	38	44	90	134	62	**216**
M4	63.7-72.3	5	6	11	25	20	13	33	75	**44**
M5	72.3-80.1	0	7	7	10	15	48	63	90	**70**
M6	80.1-83.0	0	0	0	0	0	1	1	100	**1**
M7	83.0-96.1	0	0	0	0	3	2	5	100	**5**
Total		**72**	**114**	**186**	**32**	**172**	**228**	**400**	**68**	**586**

[1] **Origin of one female carcass in Reach 1 could not be determined.**

Most (90%) of the ad-clipped hatchery fish were located in reaches M1-M3, while naturally produced fish were sampled within all survey reaches (Figure 4). Naturally produced fish made up 100% of the fish sampled in upper reaches (M6 and M7). Female summer Chinook accounted for 58% of the fish sampled in 2016 (Table 2).

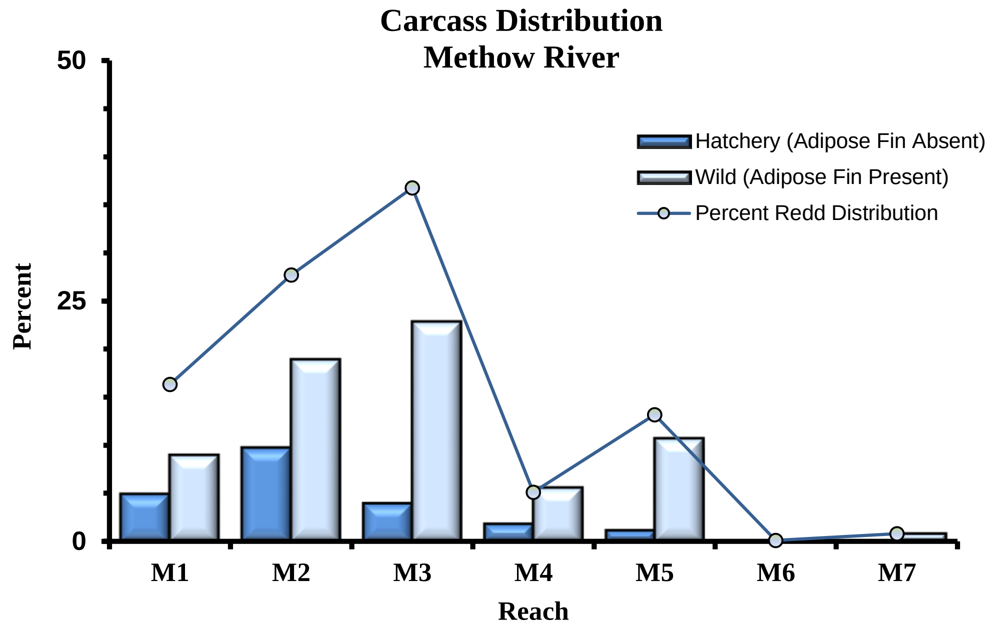

Figure 4. Percent distribution of ad-clipped hatchery and naturally produced fish plotted against the percent distribution of redds observed in reaches on the Methow River, 2016.

Egg voidance was assessed by sampling spawned-out female carcasses. Based on 343 sampled female carcasses, average egg voidance was 98%. Four females (1%) died before spawning (i.e., they retained all their eggs).

Chelan River

There were 448 redds counted in the Chelan River. This is the second highest redd count observed for summer Chinook in the Chelan River since 2000. The majority of spawning occurred in the powerhouse tailrace (46%), habitat channel (24%), and in the Columbia River tailrace (16%) (Table 3). Estimated escapement based on expansion of counts from the sex-ratio observed at Wells Dam during broodstock collection indicates that 900 summer Chinook (448 redds x 2.01 fish/redd) spawned in the Chelan River.

Table 3. Number of summer Chinook redds observed each week within the Chelan and Columbia rivers, 2016. Dashes (--) indicate that no survey occurred.

Reach	Location (Rkm)	Sep		Oct				Nov				Dec	Total	Percent
		18-24	25-1	2-8	9-15	16-22	23-29	30-5	6-12	13-19	20-26	27-3		
		39	40	41	42	43	44	45	46	47	48	49		
Powerhouse Tailrace		--	0	2	28	85	62	21	8	1	0	0	207	46
Columbia R. Tailrace		--	0	0	1	30	31	10	2	0	0	0	74	16
Pool		--	0	1	22	16	14	5	2	1	0	0	61	14
Habitat Channel		--	0	2	21	38	30	11	3	1	0	0	106	24
Total:		**--**	**0**	**5**	**72**	**169**	**137**	**47**	**15**	**3**	**0**	**0**	**448**	**100**

Time of spawning was assessed as the number of new redds counted each week in the Chelan River. Spawning activity began the first week of October and peaked two weeks later (Figure 5). Spawning ended the third week of November. An exceptionally high redd count in 2013 (792 redds) and late spawning in 2014 currently influence the average time of spawning. As more years of information are collected, average time of spawning will likely not appear bimodal.

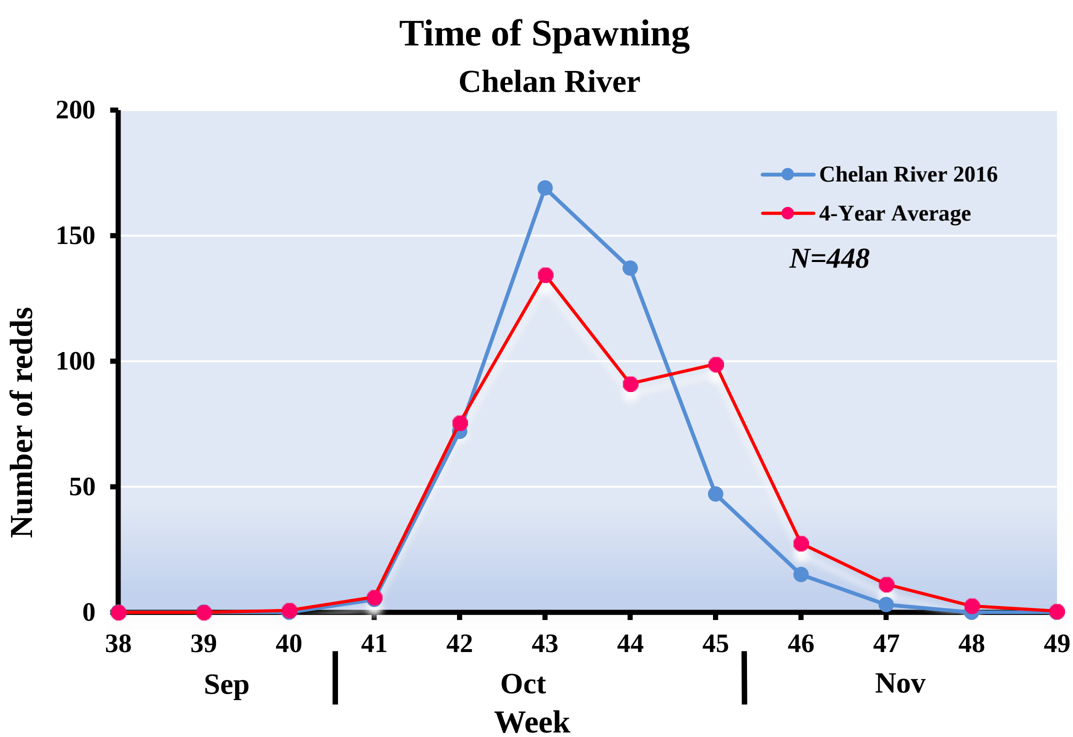

Figure 5. Number of new summer Chinook redds counted each week in the Chelan River from late September to mid-November. The figure displays the beginning, peak, and end of spawning for summer Chinook in the Chelan River in 2016 compared to a 4-year average (2012-2015).

There were 253 summer Chinook carcasses sampled in the Chelan River (Table 4). Twenty-eight percent of the summer Chinook returning to the Chelan River were sampled based on the estimated spawning escapement of 900 fish. Based on the absence of their adipose fin, hatchery fish made up 52% and naturally produced (ad-present) fish made up 48% of the fish examined. Females made up 73% of the carcasses examined (Table 4).

Table 4. Number and percent of hatchery (ad-clipped) and naturally produced (ad-present) summer Chinook collected in the Chelan River, 2016. The origin of one fish sampled could not be determined in the Chelan River.

Reach	Location (Rkm)	Ad-Clipped Hatchery				Naturally Produced				Reach Total
		Male	Female	Total	Percent	Male	Female	Total	Percent	
Powerhouse Tailrace		0	8	8	30	4	15	19	70	**27**
Columbia R. Tailrace		21	43	64	50	12	52	64	50	**128**
Pool		10	15	25	73	3	6	9	27	**34**
Habitat Channel		9	26	35	56	9	19	28	44	**63[1]**
Total		**40**	**92**	**132**	**52**	**28**	**92**	**120**	**48**	**253**

[1] **Origin of one female carcass in habitat channel could not be assigned.**

The distribution of ad-clipped hatchery fish and naturally produced fish varied within the Chelan River (Figure 6). A disproportionate number of fish (compared to redds counts) were sampled in the Columbia River tailrace. This likely occurred because carcasses drifted from upstream spawning areas and settle in the Columbia River tailrace. More hatchery fish were sampled in the habitat channel and pool upstream. Conversely, more wild fish were sampled in the powerhouse tailrace than hatchery summer Chinook.

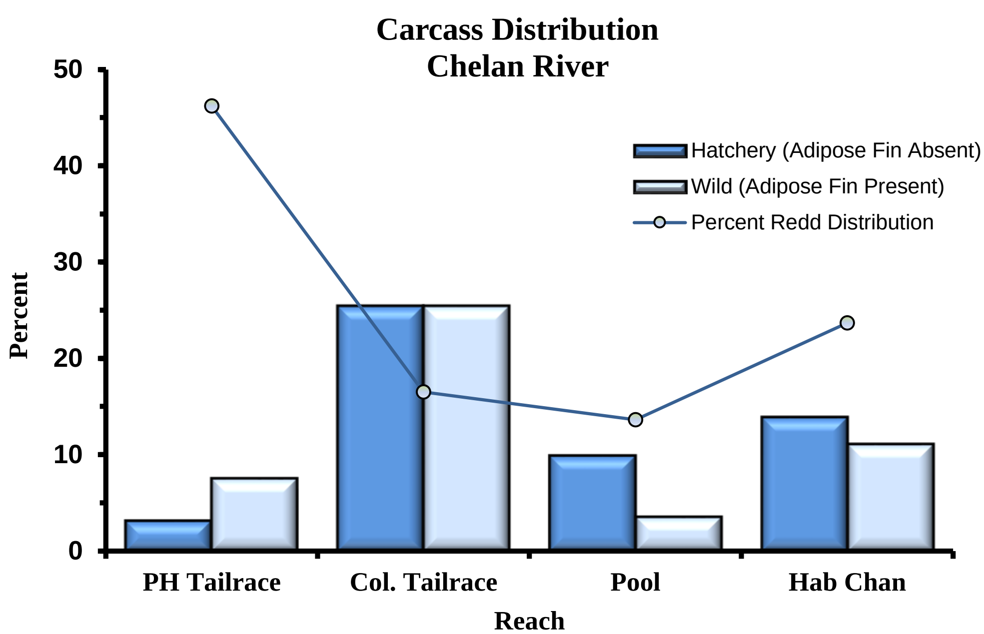

Figure 6. Percent distribution of ad-clipped hatchery and naturally produced fish plotted against the percent distribution of redds observed in reaches on the Chelan River, 2016.

In 2016, about 50 summer Chinook were collected as broodstock from the pool area upstream from the habitat channel.

Mean egg voidance assessed from 181 female carcasses was 81%. Egg voidance from four females could not be determined and seventeen females (17%) died before spawning. No Coho were sampled in 2016.

Okanogan Basin

In 2016, CCT conducted summer Chinook surveys in the Okanogan River basin. A total of 5,276 redds were counted in the Okanogan Basin (Personal Communication, Andrea Pearl, CCT).

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Appendix A. Historical aerial and ground redd counts of summer Chinook in the Methow, Chelan, Okanogan, and Similkameen rivers, 1956-2016.

Year	Methow		Okanogan		Similkameen		Chelan	
	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground
1956	109	--	37	--	30	--	--	--
1957	451	--	53	--	30	--	--	--
1958	335	--	94	--	31	--	--	--
1959	130	--	50	--	23	--	--	--
1960	194	--	29	--	--	--	--	--
1961	120	--	--	--	--	--	--	--
1962	678	--	--	--	17	--	--	--
1963	298	--	9	--	51	--	--	--
1964	795	--	112	--	67	--	--	--
1965	562	--	109	--	154	--	--	--
1966	1,275	--	389	--	77	--	--	--
1967	733	--	149	--	107	--	--	--
1968	659	--	232	--	83	--	--	--
1969	329	--	103	--	357	--	--	--
1970	705	--	656	--	210	--	--	--
1971	562	--	310	--	55	--	--	--
1972	325	--	182	--	64	--	--	--
1973	366	--	138	--	130	--	--	--
1974	223	--	112	--	201	--	--	--
1975	432	--	273	--	184	--	--	--
1976	191	--	107	--	139	--	--	--
1977	365	--	276	--	268	--	--	--
1978	507	--	195	--	268	--	--	--
1979	622	--	173	--	138	--	--	--
1980	345	--	118	--	172	--	--	--
1981	195	--	55	--	121	--	--	--
1982	142	--	23	--	56	--	--	--
1983	65	--	36	--	57	--	--	--
1984	162	--	235	--	301	--	--	--
1985	164	--	138	--	309	--	--	--
1986	169	--	197	--	300	--	--	--
1987	211	--	201	--	164	--	--	--
1988	123	--	113	--	191	--	--	--
1989	126	--	134	--	221	370	--	--
1990	229	--	88	47	94	147	--	--
1991	--	153	55	64	68	91	--	--
1992	--	107	35	53	48	57	--	--
1993	--	154	144	162	152	288	--	--
1994	--	310	372	375	463	777	--	--
1995	--	357	260	267	337	616	--	--

Year	Methow		Okanogan		Similkameen		Chelan	
	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground
1996	--	181	100	116	252	419	--	--
1997	--	205	149	158	297	486	--	--
1998	--	225	75	88	238	276	--	--
1999	--	448	222	369	903	1,275	--	--
2000	--	500	384	549	549	993	--	196
2001	--	675	883	1,108	865	1,540	--	240
2002	--	2,013	1,958	2,667	2,000	3,358	--	253
2003	--	1,624	1,099	1,035	103	378	--	173
2004	--	973	1,310	1,327	2,127	1,660	--	185
2005	--	874	1,084	1,611	1,111	1,423	--	179
2006	--	1,353	1,857	2,592	1,337	1,666	--	208
2007	--	620	1,265	1,301	523	707	--	86
2008	--	599	1,019	1,146	673	1,000	--	153
2009	--	692	1,109	1,672	907	1,298	--	246
2010	--	887	688	1,011	642	1,107	--	398
2011	--	941	1,203	1,714	1,047	1,409	--	413
2012	--	960	1,170	1,613	762	1,066	--	426
2013	--	1,551	NA	2,267	NA	1,280	--	729
2014	--	591	NA	2,231	NA	2,022	--	400
2015	--	1,231	NA	4,276[1]	NA	--	--	448
2016	--	1,115	729	2757	141	1649		448

1. The redd count is for the entire Okanogan Basin (Similkameen + Okanogan rivers).