Yakima Steelhead VSP Project

Yakima River Steelhead Population Status and Trends Monitoring

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Executive Summary

This project expands research, monitoring, and evaluation (RM&E) activities conducted by the co-managers in the Yakima Basin (Yakama Nation and Washington Department of Fish and Wildlife-WDFW) to better evaluate viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity) for Yakima River steelhead (*Oncorhynchus mykiss*) populations. It was developed to fill critical monitoring gaps identified in the 2009 Columbia Basin monitoring strategy review and the FCRPS Biological Opinion reasonable and prudent alternative (RPA) review. Using information developed from this project (including the companion component monitoring resident/anadromous interactions) as well as the restoration and research, monitoring and evaluation work of several related projects (1995-063-25, 2008-458-00, 2007-401-00, 1997-051-00, 1996-035-01, and 1997-013-25), this report provides the latest status and trend information with respect to Yakima River Basin steelhead VSP metrics relative to data collected by the Yakama Nation.

The Yakima River steelhead major population group (MPG) is believed to consist of four individual, genetically unique populations spawning in the following areas: the Upper Yakima River consisting of the mainstem and all tributaries above the confluence with the Naches River; the Naches River system including Ahtanum Creek and Yakima Mainstem extending from the confluence of the Naches down to Toppenish Creek; Toppenish Creek; and Satus Creek. Adult population and productivity metrics for the Yakima River steelhead MPG are trending upwards. For the most recent five steelhead run years (June 30, 2013 to July 1, 2018) mean annual NOR abundance was 3,235 steelhead for the MPG (average abundance at Prosser Dam) and 341 steelhead for the proportion of the Upper Yakima population spawning above Roza Dam (average abundance at Roza Dam). This compares to average annual abundance estimates of about 2,870 steelhead for the MPG and 153 steelhead spawning above Roza Dam between 1994-2013. With an increasing proportion of Yakima River steelhead comprising the Bonneville Dam count, Yakima River MPG steelhead are potentially experiencing greater survival relative to other steelhead populations above Bonneville Dam due to improved freshwater rearing conditions within the Yakima basin. Habitat restoration actions in the Yakima River Basin (see 1997-051-00, 1996-035-01, and Yakima Basin Fish and Wildlife Recovery Board summary), the Yakima kelt reconditioning program (see 2008-458-00 and 2007-401-00), as well as ongoing efforts to improve fish passage (see Yakima River Basin Water Enhancement Project) and limiting factors in the Yakima Subbasin (see Yakima Basin Fish and Wildlife Recovery Board) may partially explain these results.

Juvenile abundance and productivity metrics are generally positive at the MPG level, but these metrics are not as reliable as adult metrics due to uncertainties and complexities involved with estimating total juvenile abundance from relatively small samples of juvenile outmigrants. Redd survey and passive integrated transponder (PIT) detection data indicate that steelhead are fairly broadly distributed spatially throughout most known steelhead streams in the Yakima River Basin. Evaluation of data from adult sampling at Prosser and Roza Dams demonstrate that, on average, about 70% of the adult steelhead returning to the Yakima Basin are female. The vast majority (about 95%) of MPG steelhead returning to the Yakima River Basin are in the "Group A" size management range (< 78cm fork length) which is used for fishery management purposes in the Columbia River Basin. We are still compiling and evaluating age-at-migration and age-at-return information; more complete presentations and analyses using these data will be available in subsequent annual reports.

Although annual adult abundance of Yakima River steelhead at the MPG level can be estimated fairly reliably using Prosser Dam counts, there is a need for spawner abundance estimates for individual populations. In accordance with RPA 50.6 (Improve Fish Population Status Monitoring), this project conducted a three year telemetry study that provided spawner abundance estimates for each Yakima MPG steelhead population for spawn years 2012-14. The 3-year study also tested the efficacy of other proposed adult abundance monitoring methods needed for long-term status and trends monitoring including genetic stock identification (GSI) and the installation, management, and performance of remote Instream PIT-tag detection arrays. This project is also working towards improving the sampling and analytical methods for estimating juvenile abundance for both individual populations and the Yakima MPG as a whole. As this project progresses and matures over time, more complete presentations and analyses using this new information will be provided in subsequent annual reports.

Introduction

This project expands research, monitoring, and evaluation (RM&E) activities conducted by the co-managers in the Yakima Basin (Yakama Nation and Washington Department of Fish and Wildlife-WDFW) to better evaluate viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity) for Yakima River steelhead (*Oncorhynchus mykiss*) populations. It was developed to fill critical monitoring gaps identified in the 2009 Columbia Basin monitoring strategy review and the FCRPS Biological Opinion reasonable and prudent alternative (RPA) review. Data from our research will be used to evaluate population status and trends, inform NOAA status reviews and implementation of the Federal Columbia River Power System (FCRPS) Biological Opinion, and address critical uncertainties (e.g., the relationship between resident and anadromous life histories in the Yakima River Basin), consistent with the Northwest Power and Conservation Council (NPCC) Fish and Wildlife program, Columbia Basin research plan (uncertainties 3.1, 7.1 & 7.3), NOAA mid-Columbia steelhead recovery plan, and Fish Accords. The improved understanding of steelhead population performance and dynamic interactions between anadromous and resident O. *mykiss* produced by this project will directly inform efforts to recover steelhead populations in the Yakima Basin.

This report presents fish population status and trend metrics for the Yakima River steelhead major population group (MPG). The Yakima River steelhead MPG is believed to consist of four individual, genetically unique populations spawning in the following areas: the Upper Yakima River consisting of the mainstem and all tributaries above the confluence with the Naches River; the Naches River system including Ahtanum Creek and Yakima Mainstem extending from the confluence of the Naches down to Toppenish Creek; Toppenish Creek; and Satus Creek (Loxterman and Young 2003). Another major research component of the project is monitoring resident/anadromous interactions; the latest results (Temple et al. 2018) from this project component are attached at the end of the report.

This work relies heavily on the infrastructure and staffing associated with the Yakima/Klickitat Fisheries Project (YKFP) and other related projects in the Yakima Basin. Status and trend metrics for spring Chinook (*O. tshawytscha*), summer/fall Chinook (*O. tshawytscha*), and coho (*O. kisutch*) RM&E work are reported under 1995-063-25. Related steelhead kelt reconditioning is reported under CRITFC projects 2008-458-00 and 2007-401-00.

YKFP-related habitat activities for the Yakima Subbasin are addressed under project 1997-051-00. Yakama reservation habitat and RM&E activities are addressed under project 1996-035-01. Hatchery Production Implementation (Operation and Maintenance) is addressed under project 1997-013-25. **Data and findings presented in this report should be considered preliminary until results are published in the peer-reviewed literature.**

Purpose and Need for Project

Annual adult abundance of Yakima River steelhead at the MPG level can be estimated fairly reliably using Prosser Dam counts, however, there is a need for spawner abundance estimates for individual populations. Prior to implementation of this project, stock status assessments used for recovery planning by the Interior Columbia Technical Review Team (ICTRT) relied on a combination of methods for apportioning Prosser Dam adult counts to individual populations. These include the use of a 1990-92 radio-tracking survey (Hockersmith et al. 1995), redd counts from Satus and Toppenish creeks, and Roza Dam counts.

In accordance with RPA 50.6 (Improve Fish Population Status Monitoring), one of the project objectives is to effectively generate annual spawner abundance estimates for each of the four Yakima River steelhead populations. The project also seeks to improve the monitoring capabilities and methods used to generate those estimates.

A 3-year study also tested and validated the efficacy of several proposed adult abundance monitoring methods to be used for long-term status and trends monitoring. The methods that were tested during the 3 year telemetry study included:

1) **The use of Genetic Stock Identification (GSI) -** The concept of using GSI techniques for stock partitioning used stratified genetic sampling taken from the adult steelhead run at large at Prosser Dam. The sampling was conducted across the entire adult run-timing beginning in September and extending into the early part of May. Population-of-origin assignments from individual fish were compared to actual spawning locations of those fish using information from the telemetry study.

2) **The use of Remote Instream Passive Integrated Transponder (PIT) detection Arrays-** Several instream arrays were placed adjacent to radio telemetry fixed sites in areas below known spawning distributions of the Satus and Toppenish Creek steelhead populations. The functionality, and performance of the arrays were evaluated simultaneously with the expanded spawner abundance estimates generated by the PIT-tag data. The number of unique PIT-tags detected by instream arrays was used to apportion the total Yakima River steelhead count (enumerated at Prosser Dam, RKM 75.6) into spawner escapement estimates for each of the four individual steelhead populations.

The Yakama Nation and WDFW have emphasized maintaining the natural genetic composition of Yakima Basin steelhead stocks. The last release of hatchery-origin juvenile steelhead in the Yakima Basin occurred in 1993. While no hatchery programs exist within the Yakima Basin, stray hatchery-origin fish from other basins make up approximately 3% of the total steelhead run into the basin. The VSP project's primary focus is monitoring natural-origin abundance at the population scale, but will also enumerate and report on the number of out-of-basin stray hatchery spawners that are observed within each of the four Yakima River steelhead populations.

This project initially expanded the flow entrainment study at Prosser Dam to include the estimation precision of total steelhead smolt production and known assignment bias using a fixed sampling rate of steelhead smolts at Chandler.

Due to low numbers of juvenile steelhead entrained and extended periods of holding time needed to provide adequate sample sizes for entrainment releases, the project has temporarily suspended the use of steelhead juveniles, and will continue to rely on spring Chinook as a surrogate until low sampling procedures of steelhead juveniles are resolved.

Steelhead have the most complex life history spectrum of all species of anadromous salmonids in the Columbia Basin. Our current understanding of life history and other population diversity traits within and among Yakima steelhead populations is limited because sufficient time and resources have not been dedicated to understanding the complexity of this task. A population's viability and long-term persistence strongly depends on its ability to withstand environmental perturbations and changes caused by either natural or anthropogenic induced factors. Diversity allows a species to use a wider array of environments than they could without it (McElhany et al. 2000), and populations exhibiting greater diversity are generally more resilient to these environmental changes in the short and long term (ICTRT 2007). A population's diversity comprises a broad range of phenotypic life history traits and underlying genetic diversity. Characterizing and understanding these traits within and among populations will provide necessary information for recovery planners to build more explicit recovery criteria for the diversity component of the VSP framework (YBFWRB 2009). Furthermore, this type of information should be considered essential for understanding temporal and spatial linkages between a population's life history traits, and the habitat types utilized by them.

The Yakima River steelhead VSP project will analyze biological data collected by three projects: Yakima River Monitoring and Evaluation-Yakima/Klickitat Fisheries Project (1995-063-25), Yakama reservation Watershed Project (1996-035-01), and this project. Life history information will contribute to assessing an overall risk rating for the spatial structure and diversity VSP parameters by providing data needed for assessing individual metrics in NOAA's hierarchical format as outlined in the document "Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs" (ICTRT 2007).

Study Area

The Yakima Subbasin is located in south-central Washington. It drains an area of 6,155 square miles and contains about 1,900 river miles of perennial streams (Figure 1). The Yakama Nation Reservation is located in the southwest corner of the subbasin just south of the city of Yakima. Major Yakima River tributaries contained within the Reservation include Satus and Toppenish watersheds. The Yakima River originates near the crest of the Cascade Range above Keechelus Lake at an elevation of 6,900 feet and flows 214 miles southeastward to its confluence with the Columbia (RM 335.2). Major tributaries outside the Yakama Nation Reservation include the Kachess, Cle Elum and Teanaway rivers in the northern part of the subbasin, and the Naches River in the west. Six major reservoirs are located in the subbasin. The Yakima River flows out of Keechelus Lake (157,800 acre feet), the Kachess River from Kachess Lake (239,000 acre feet), the Cle Elum River from Cle Elum Lake (436,900 acre feet), the Tieton from Rimrock Lake (198,000 acre feet), and the Bumping from Bumping Lake (33,700 acre feet). Topography in the subbasin is characterized by a series of thrust fault ridges extending eastward from the Cascades. These Ridges divide the Yakima River into several macro floodplain reaches, each unique to its own physical characteristics. Elevations in the subbasin range from about 7,000 feet in the Cascades to about 350 feet at the confluence of the Yakima and Columbia rivers.

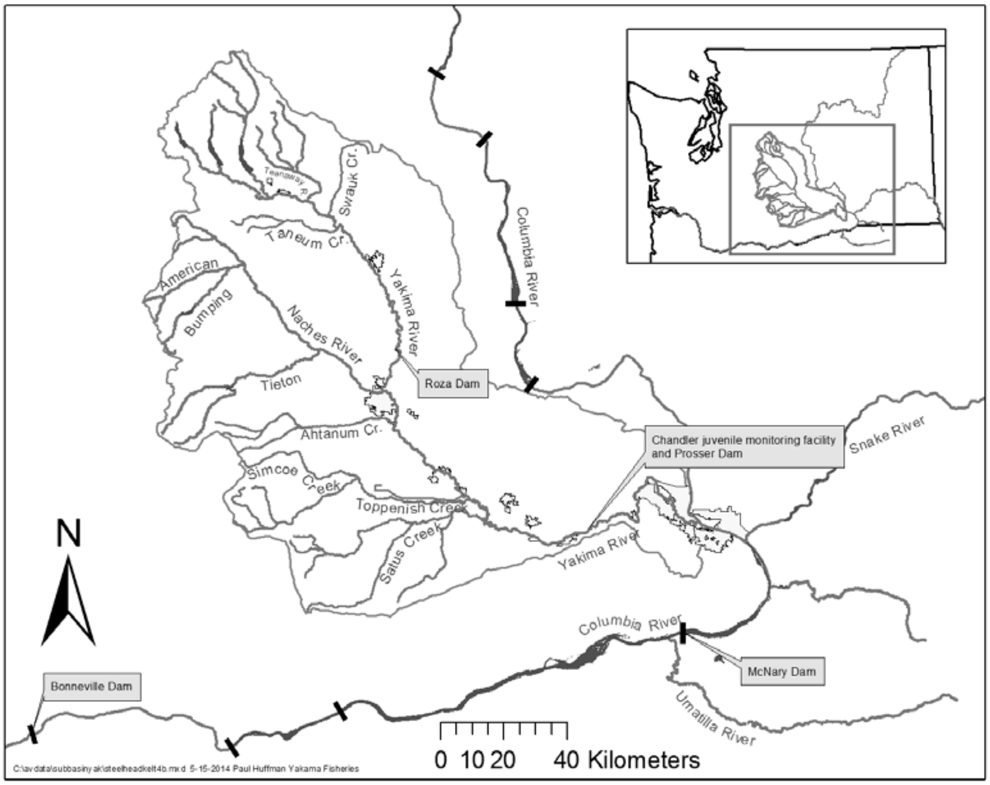

Figure 1. Yakima River Basin showing major steelhead streams and monitoring locations (map courtesy of Paul Huffman).

Project Map: *http://www.cbfish.org/Project.mvc/Map/2010-030-00*

Contract Map(s): *http://www.cbfish.org/Contract.mvc/Map/55510*

Status and Trend of Adult Fish Populations (Abundance)

Methods:

Summer-run steelhead in the Yakima River Basin are enumerated at Prosser and Roza Dams (Rkm 75.6 and Rkm 205.8 respectively) using video equipment installed in adult fish ladders (monitoringmethods.org methods 143, 144, 307, 418, 515). At both Prosser and Roza Dams, adult fish traps are also used on a seasonal basis for biological sampling and enumeration (monitoringmethods.org methods 135). When the Roza adult trap is not in operation, video equipment is also employed at the adult fish ladders there. However, camera placement and actual viewing area are limited; these combined with water clarity issues during certain river conditions all affect video enumeration at Roza Dam. Automatic Passive Integrated Transponder (PIT) tag detectors are also employed at all fish ladders at both dams (see sites RZF and PRO in ptagis.org). For the safety and protection of personnel and equipment, video and PIT-detection equipment are removed during periods of high river flow. In these instances, biologists attempt to extrapolate fish counts using data from before and after the high flow event. Although adult passage over spillways is believed to occur when flows are favorable, Prosser Dam counts are generally considered by Yakama Nation biologists to be within +/- 5% of actual fish passage. Roza Dam counts during trap operation (the entire spring steelhead counting period, February-June, and the forefront of the following run year, July-Oct) are considered virtually 100% accurate; however during the late fall and winter counting period when video equipment is used at least part of the time, accuracy may fall to only 50-75% of actual fish passage based on preliminary evaluation of PIT tag detection data. Fish are denoted as hatchery- or natural-origin based on presence or absence respectively, of observed external or internal marks (monitoringmethods.org method 342).

At Prosser Dam, time-lapse video recorders (VHS) and a video camera were used at viewing windows at each of the three fishways. Digital video recorders (DVR) and progressive scan cameras (to replace the VHS systems) were tested at each of the three Prosser fishways in 2007 and became fully operational in February of 2008. The new system functions very similarly to the VHS system but provides digital video data readily downloadable to the viewing stations in Toppenish. This new system also allows technicians in Toppenish to scan rapidly to images of fish giving a more timely and accurate fish count. The technicians review the images and record various types of data for each fish that migrates upstream via the ladders. These images and information are entered into a Microsoft Access database, and daily dam count reports are regularly posted to the ykfp.org and Data Access in Real-Time (DART) web sites. Similarly at Roza Dam, adult trap data are entered into a Microsoft Access database, and daily dam count reports (with video counts integrated) are regularly posted to the ykfp.org and DART web sites. Post-season, counts are reviewed and adjusted for any data gaps. Historical final counts are posted to the ykfp.org and DART web sites.

Population-specific spawner abundances have been estimated from 1984-2018 using two separate methods spanning different time stratas.

Results:

Table 1. Yakima Basin steelhead counts at Prosser and Roza Dams, 1983 – present.

Run Year[1]	Prosser Dam Wild	Prosser Dam Hatchery	Prosser Dam Total	Roza Dam Wild	Roza Dam Hatchery	Roza Dam Total
1983-84	911	229	1,140	15		15
1984-85	1,975	219	2,194	6		6
1985-86	2,012	223	2,235	3		3
1986-87	1,984	481	2,465	0		0
1987-88	2,470	370	2,840	0		0
1988-89	1,020	142	1,162	0		0
1989-90	686	128	814	0		0
1990-91	730	104	834	0		0
1991-92	2,012	251	2,263	107	9	116
1992-93	1,104	80	1,184	15	0	15
1993-94	540	14	554	28	0	28
1994-95	838	87	925	22	1	23
1995-96	451	54	505	90	2	92
1996-97	961	145	1,106	22	0	22
1997-98	948	165	1,113	51	0	51
1998-99	1,018	52	1,070	14	0	14
1999-00	1,571	40	1,611	14	0	14
2000-01	3,032	57	3,089	133	7	140
2001-02	4,491	34	4,525	232	5	237
2002-03	2,190	45	2,235	128	6	134
2003-04	2,739	16	2,755	212	2	214
2004-05	3,377	74	3,451	224	3	227
2005-06	1,995	10	2,005	120	2	122
2006-07	1,523	14	1,537	59	0	59
2007-08	3,025	285	3,310	171	5	176
2008-09	3,444	25	3,469	206	0	206
2009-10	6,602	194	6,796	311	15	326
2010-11	6,064	132	6,196	336	10	346
2011-12	6,206	153	6,359	398	6	404
2012-13	4,516	271	4,787	280	18	298
2013-14	4,083	60	4,143	372	4	376
2014-15	5,181	31	5,212	470	5	475
2015-16	3,938	15	3,953	470	3	473
Means:						
All Years	2,534	127	2,662	137	4	140
2006-16	4,458	118	4,576	307	7	314
2011-16	4,785	106	4,891	398	7	405

[1] July 1 to June 30 run year.

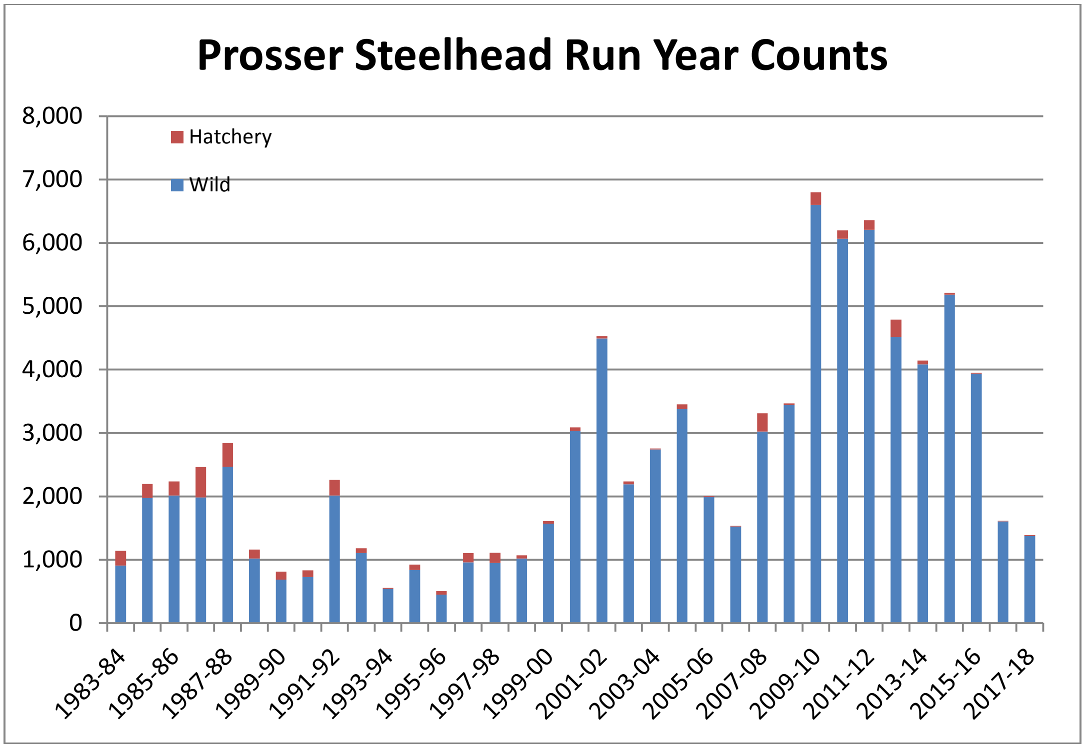

Figure 2. Estimated counts of wild and hatchery-origin steelhead at Prosser Dam, 1983-present.

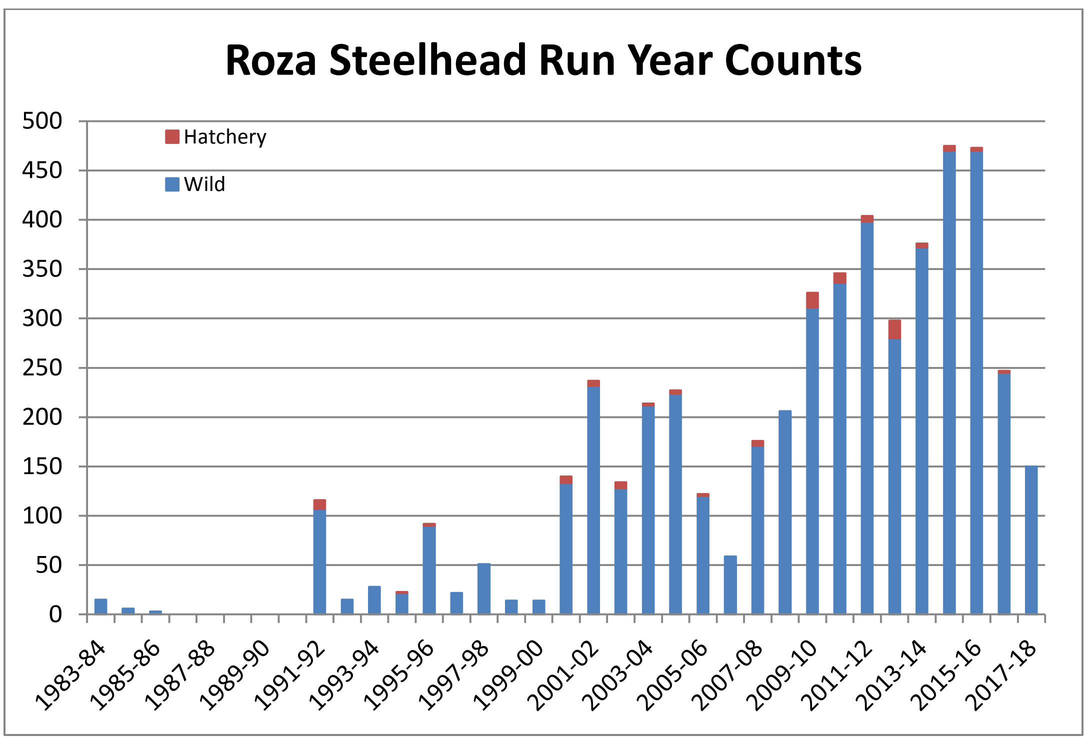

Figure 3. Estimated counts of wild and hatchery-origin steelhead at Roza Dam, 1983-present.

Table 2. Yakima River steelhead population spawner abundance estimates. Estimates through 2011 based on Hockersmith study, estimates from 2012-2018 based on Frederiksen study.

Spawn year	U Yakima	Satus	Toppenish	Naches
1984	70	351	91	285
1985	137	765	199	621
1986	140	779	203	634
1987	153	768	200	625
1988	177	957	249	778
1989	71	395	103	321
1990	48	256	41	256
1991	70	234	82	252
1992	98	940	260	452
1993	45	415	151	347
1994	32	191	82	174
1995	39	307	129	270
1996	60	138	56	143
1997	47	268	233	310
1998	61	348	131	304
1999	41	335	201	329
2000	59	397	434	507
2001	161	645	909	983
2002	260	1155	1129	1454
2003	133	646	460	709
2004	195	567	790	886
2005	223	890	801	1092
2006	123	746	260	646
2007	79	521	263	492
2008	190	946	585	976
2009	216	1044	693	1114
2010	367	2751	621	2138
2011	364	2274	799	1963
2012	475	1812	667	2203
2013	334	928	510	1683
2014	423	919	356	1506
2015	550	1093	504	1785
2016	528	1233	295	1409
2017	272	400	154	577
2018	160	341	131	492
Geomeans:				
Recent 10 yr Geomean:	346	1064	407	1340
Recent 5 yr Geomean:	351	701	255	1015

Discussion:

Trends in annual abundance of Yakima River MPG steelhead (Prosser Dam; Figure 2) and Upper Yakima steelhead (Roza Dam; Figure 3) had been increasing up through 2015 before experiencing declines over the last 2-3 years. For the most recent five steelhead run years (June 30, 2013 to July 1, 2018) mean annual abundance was 3,235 wild steelhead for the MPG and 341 wild steelhead for the portion of the Upper Yakima population spawning above Roza Dam (Table 1). This compares to average annual abundance estimates of about 1,400 steelhead for the MPG and fewer than 25 steelhead for the Upper Yakima population (proportion spawning above Roza Dam) in the 1980s and 1990s. The observed increases in annual abundance can be attributed to numerous factors including but not limited to; habitat restoration actions in the Yakima River Basin (see 1997-051-00, 1996-035-01, and Yakima Basin Fish and Wildlife Recovery Board summary), the Yakima kelt reconditioning program (Hatch et al. 2013), improved freshwater passage conditions, and improved marine survival. Notable droughts occurred during 2001 and 2005 which may have impacted adult returns.

From 1961 until 1986, an average of 63,500 hatchery steelhead smolts were released in the Yakima basin (Phelps 2000), originating primarily from the Skamania steelhead stock. From 1987-1994 steelhead releases ranged from 23,000-155,000, originating from native Yakima steelhead. No hatchery releases of steelhead have been made since 1994 in the Yakima Basin.

For the most recent 10 return years, both the aggregate MPG and the Upper Yakima population returns have averaged greater than 97% wild with some hatchery-origin strays from other Columbia River Basin tributaries (Table 1, Figures 2 and 3).

Steelhead counts at Prosser Dam represent total adult escapement for the Yakima River Major Population Group (MPG). The large geographic distribution of steelhead in the Yakima Basin results in diverse pre-spawning migration and holding patterns that influence the proportion of fish that survives to spawn. Historically, there have been no reliable means of estimating population-specific spawner abundances due to limited methods, enumeration points, and unknown pre-spawn mortality rates. This project conducted a 3 year radio telemetry study that estimated spawner escapement for the Yakima River steelhead populations including Satus Creek, Toppenish Creek, Naches River, and Upper Yakima River populations from 2012-2014. In addition to estimating spawner escapement for 3 consecutive years, data from the study was used to assess the potential long term monitoring methods including the use of GSI and Remote Instream PIT-tag detection Arrays for apportioning the total run at Prosser Dam. It was determined the Instream Arrays provided the best monitoring tool for estimating population level spawner abundance, the precision of those estimates, and other VSP metrics (Frederiksen 2014). Preliminary spawner escapement estimates for each of the four Yakima River steelhead populations are presented in Table 2 above.

Status and Trend of Adult Productivity

Methods:

An adult age-at-return database is being compiled for Yakima steelhead using scale and PIT sampling data from the Prosser denil adult sampling operation (monitoringmethods.org methods 1090, 3916). Available age data has been intermittent at best historically, so there are years that rely on the average age-at-return (from 1986-87, 1990-92, and 2002-2004) that are being used as part of the brood year cohort analysis (monitoring methods.org method 438). Adult-adult return rate estimates presented in Figures 4 and 5 are preliminary and derived from a single enumeration point (Prosser Dam). These estimates have not been adjusted for density dependent effects, harvest, or additional pre-spawn mortality factors. Therefore, these values should not be used to estimate the Intrinsic Productivity for the Yakima River steelhead MPG.

We also assessed the status of the Yakima steelhead MPG relative to the aggregate Bonneville Dam wild Group A population (all wild steelhead <78cm fork length destined to any tributary above Bonneville Dam) by simply dividing the Prosser wild steelhead count for a given steelhead run year (Table 1) by the Bonneville Dam "Group A" wild steelhead count for the same return year (ODFW/WDFW 2014).

Results:

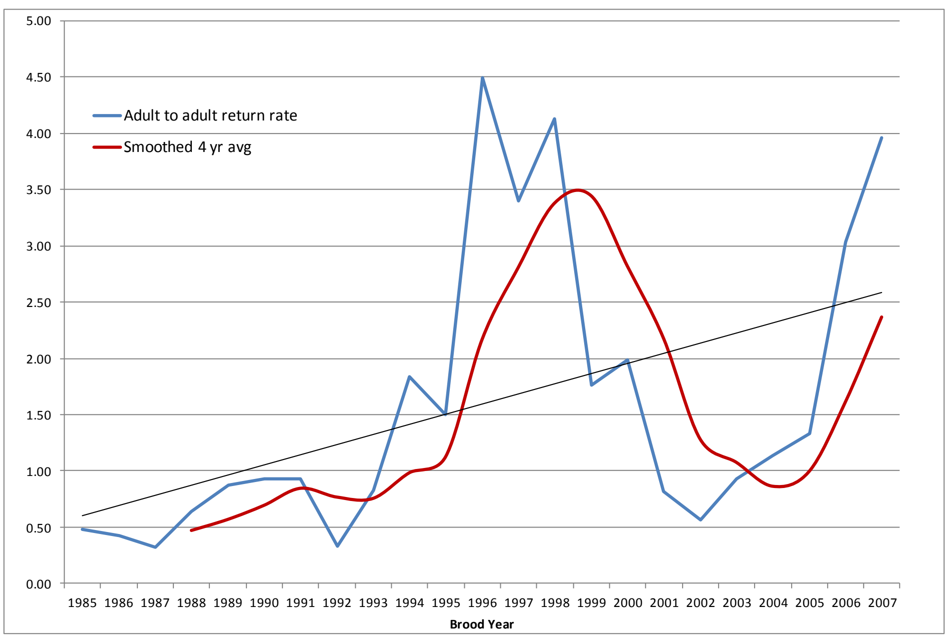

Figure 4. Surrogate adult-to-adult return rate indices for Yakima River MPG steelhead. The majority of age structures used for brood year cohorts rely on averages of age-at-return derived from 10 of 23 years, and are subject to revision when additional age data becomes available. The "smoothed" line represents a four-year running average.

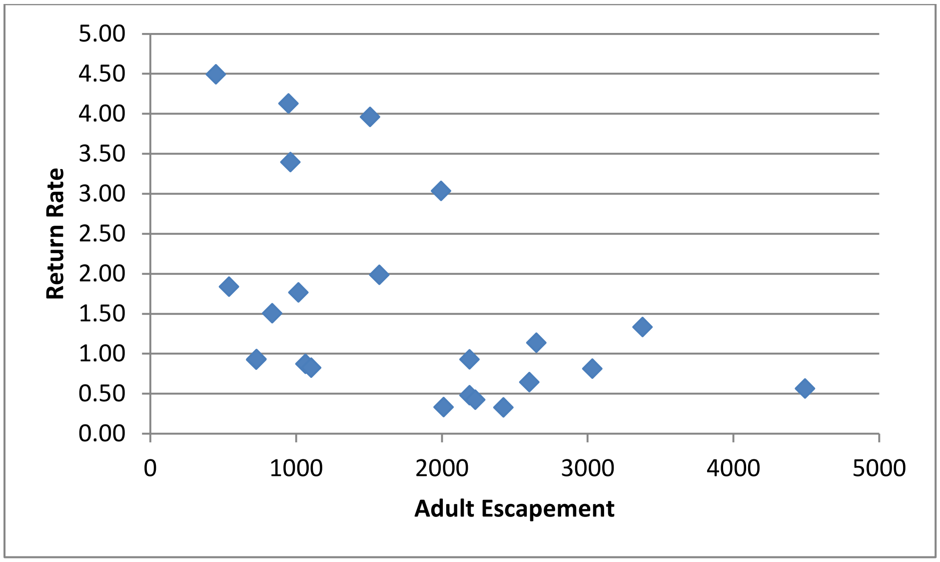

Figure 5. Yakima River MPG steelhead adult-to-adult return rate index.

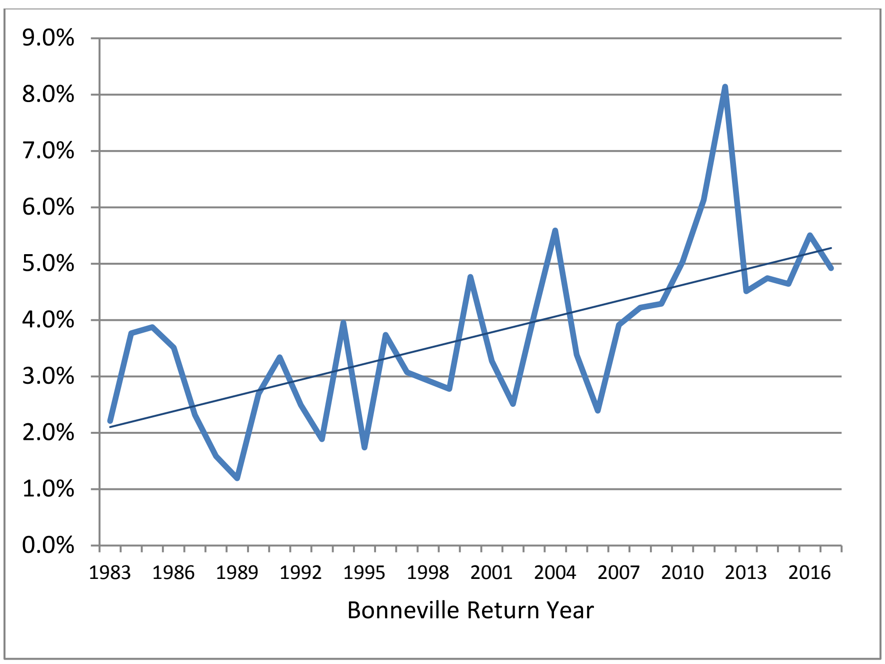

Figure 6. Yakima River MPG steelhead (Prosser wild abundance) as a percentage of Bonneville Dam wild Group A steelhead abundance, 1983 to present.

Discussion:

Since 2000, annual returns of specific adult salmon *Oncorhynchus spp.* runs to the Columbia River Basin have often reached numbers not observed in many decades, with different species doing better in different years. At Bonneville Dam (Figure 1), steelhead counts were especially high in 2001-2002 and 2009-2011 (ODFW/WDFW 2014). Ocean conditions have frequently been cited as one of the factors for the increased abundance (e.g., Williams et al. 2014).

Adult productivity indices for Yakima River MPG steelhead are presently trending upward (Figures 4 and 6). Under present conditions, productivity appears to peak at about 1,000 to 1,500 spawners and decline at higher spawner abundances (Figure 5). These data indicate that in some years, density-dependent limiting factors (see ISAB 2004) may be depressing natural productivity at fairly low population abundance in the Yakima River Basin. However, Figure 6 indicates that Yakima River MPG steelhead are experiencing improved survival relative to other steelhead streams above Bonneville Dam over and above survival increases due to common freshwater and marine conditions. Habitat restoration actions in the Yakima River Basin (see 1997-051-00, 1996-035-01, and Yakima Basin Fish and Wildlife Recovery Board summary), the Yakima kelt reconditioning program (Hatch et al. 2013), as well as ongoing efforts to improve fish passage (see Yakima River Basin Water Enhancement Project) and limiting factors in the Yakima Subbasin (see Yakima Basin Fish and Wildlife Recovery Board) may partially explain these results.

Status and Trend of Juvenile Abundance and Productivity

Methods:

This project initially expanded the flow entrainment study at Prosser Dam to include the estimation precision of total steelhead smolt production and known assignment bias using a fixed sampling rate of steelhead smolts at Chandler.

Due to low numbers of juvenile steelhead entrained and extended periods of holding time needed to provide adequate sample sizes for entrainment releases, the project has temporarily suspended the use of steelhead juveniles, and will continue to rely on spring Chinook as a surrogate until low sampling procedures of steelhead juveniles are resolved.

The spring chinook passage estimates themselves have proven unreliable in some years, probably due in part to fluctuations in migration paths over Prosser Dam. Other methods are being considered for smolt passage estimation such as the use of joint PIT-tag detections with downstream dams. This alternative method is facilitated by the fact that over 40,000 hatchery juvenile spring chinook are PIT-tagged each year in the upper Yakima River. The same passage estimation method could be employed for juvenile steelhead, although substantially fewer PIT-tagged steelhead are available. As part of this project, we will continue to explore and evaluate alternative methods for estimating juvenile abundance.

In addition to enumeration, biological data is being collected from a portion of salmonid outmigrants sampled at the CJMF on a daily basis and all PIT tagged fish were interrogated. Sampling methods were described in Busack et al. (1997) and were consistent with monitoringmethods.org methods 1562, 1563, 1595, and 1614.

As described earlier in this report, we are still in the process of compiling a comprehensive adult age-at-return database. Until such time as this database is available, we developed a surrogate smolt-to-adult return index from Prosser juvenile and adult abundance estimates assuming all smolts outmigrate at age-2 and all adults return at age-4.

Results:

Table 3. Yakima River MPG Natural-origin steelhead smolt (estimates at Prosser) by brood year and outmigration year. Returning natural-origin adults counted at Prosser 2 years after that smolt migration, and surrogate smolt-to-adult return (SAR) index, 1988-present. Note these data are preliminary and subject to change. DO NOT CITE.

Year	Steelhead Smolts[1]		Adults[2]		SARs	
	Brood Year	Outmigrant Year	Produced by Brood Year	Produced by Outmigrant Year	Brood Year Cohort	Outmigrant Year Cohort
1985	93,477	83,461	1,001	1,700	1.07%	1.89%
1986	86,944	96,639	917	1,877	1.05%	1.81%
1987	49,194	89,657	786	917	1.60%	0.95%
1988	41,009	61,338	1,672	879	4.08%	1.33%
1989	38,058	38,536	927	1,004	2.44%	2.42%
1990	45,864	31,206	673	1,549	1.47%	4.62%
1991	30,238	29,933	679	875	2.25%	2.72%
1992	25,875	50,104	667	624	2.58%	1.16%
1993	31837	24,529	907	687	2.85%	2.60%
1994	47,003	26,748	993	625	2.11%	2.17%
1995	86,760	26,331	1,261	932	1.45%	3.29%
1996	102,951	69,454	2,021	962	1.96%	1.29%
1997	72,490	117,771	3,263	1,229	4.50%	0.97%
1998	36602	70,297	3,914	1,994	10.69%	2.64%
1999	47,597	36,293	1,809	2,641	3.80%	6.77%
2000	33,168	45,127	3,191	4,661	9.62%	9.60%
2001	46,122	31,391	2,473	1,099	5.36%	3.26%
2002	39,044	42,522	2,544	3,570	6.52%	7.81%
2003	46,343	32,599	2,136	3,052	4.61%	8.71%
2004	43,427	37,915	3,163	1,806	7.28%	4.43%
2005	26,113	50,550	4,527	2,040	17.34%	3.75%
2006	22,083	18,265	6,054	3,175	27.41%	16.85%
2007	28,527	30,650	5,977	4,489	20.95%	14.07%
2008	45,380	26,251	N/A	6,227	N/A	23.65%
2009	68,098	28,754	N/A	5,908	N/A	20.55%
2010	N/A	57,948	N/A	N/A	N/A	N/A
2011	N/A	76,000	N/A	N/A	N/A	N/A
2012	N/A	83,000	N/A	N/A	N/A	N/A
Mean	49,368	50,474	2,242	2,181	6.22%	5.97%
Geomean	45,138	44,758	1,752	1,701	3.95%	3.77%

[1]Juvenile age data available from 1985-2007. 2008-09 Used average age structures from prior years.
[2]Adult age data available 1986-87, 1990-92, 2002-2005. All other years used averages from available years.

Discussion:

Still, there is much reason for caution in interpreting these results. Smolt accounting at Prosser Dam is based on statistical expansion of Chandler smolt trap sampling data using available flow data and estimated Chandler entrainment rates. Chandler smolt passage estimates are prepared primarily for the purpose of comparing relative marked versus unmarked passage estimates and not for making survival comparisons. While these Prosser smolt passage estimates represent the best available data, there may be a relatively high degree of error associated with these estimates due to inherent complexities, assumptions, and uncertainties in the statistical expansion process. Therefore, these estimates are subject to revision.

Given these complicating factors, Table 3 presents a surrogate smolt-to-adult survival index for Yakima River MPG steelhead. Because of the complexities noted above, these data are useful for analysis of trends but should not be used as direct citations of smolt-to-adult survival rates. The reader is encouraged to contact Yakama Nation technical staff to discuss these and other issues prior to any use of these data or any other estimation of Yakima Basin SARs that may be available through data obtained from public web sites such as RMPC, PTAGIS, DART, or other.

Status and Trend of Spatial Distribution

Methods:

Over the years the spatial distribution of Yakima River steelhead has been estimated and documented using several methods. Radio telemetry studies (Hockersmith and Frederiksen Studies) and redd surveys conducted at various scales have both contributed to spatial distribution information for all 4 Yakima River steelhead populations. Regular foot and/or boat redd surveys (monitoringmethods.org methods 30, 131, 285, 1508) have been conducted within the established geographic range for each species. For this method, redds were individually marked during each survey. The Yakama Nation conducted surveys in Satus, Toppenish, and Ahtanum Creeks. The U.S. Forest Service, WDFW, and other collaborators conducted surveys in the Naches River system. There are currently no organized efforts to conduct redd surveys within the geographic distribution of the upper Yakima population. River conditions vary from year to year and frequently preclude complete accounting due to issues such as water clarity, flow, and access.

Over the last 10 years, the spatial distribution of adult spawners has been well documented for the Satus and Toppenish Cr populations through redd surveys. Detailed results and maps illustrating the redd locations and spawner distribution for these populations can be viewed in reports provided by project 1996-035-01. The spawning distribution of the upper Yakima population has been estimated and documented from past radio telemetry efforts including a study spanning 1989-1993 (Hockersmith et al. 1995) and a study spanning 2002-2006 (Karp et al. 2009).

Results:

Table 4. Yakima Basin steelhead escapement and redd survey summary, 1987 – 2015.

Run Year[1]	Prosser Dam Count	Redd Counts by Survey Stream					Roza Dam Count
		Satus	Toppenish	Ahtanum	Naches	Total	
1987-88	2,840	445				445	
1988-89	1,162	404	45			449	
1989-90	814	289	26			315	
1990-91	834	125				125	
1991-92	2,263						116
1992-93	1,184	73				73	15
1993-94	554	114				114	28
1994-95	925	85				85	23
1995-96	505	148				148	92
1996-97	1,106	76	5			81	22
1997-98	1,113	190	13			203	51
1998-99	1,070	130	78			208	14
1999-00	1,611	169	185	11		365	14
2000-01	3,089	252	355	8		615	140
2001-02	4,525	295	111	13		419	237
2002-03	2,235	319	161	16		496	134
2003-04	2,755	117	56	12	94	279	214
2004-05	3,451	110	99	16	140	365	227
2005-06	2,005	60	21	1	19	101	122
2006-07	1,537	87	44	4	44	179	59
2007-08	3,310	110	68	8	11	129	176
2008-09	3,469	119	79	3	29	230	206
2009-10	6,796	465	105		116	686	326
2010-11	6,196	293	100	28	77	498	346
2011-12	6,359	152	46		60	258	404
2012-13	4,787	223	78	20	60	381	298
2013-14	4,143	267	134		40	441	376
2014-15	5,181	206	112		82	400	475
2015-16	3,953						473

Blank = no data available
All surveys were partial or affected by poor redd visibility due to spring conditions.
[1] July 1 to June 30 run year.

Status and Trend of Diversity Metrics

Methods:

Sampling methods for evaluating juvenile steelhead at the CJMF were consistent with monitoringmethods.org methods 1562, 1563, 1595, and 1614. At both Prosser and Roza Dams, adult fish traps were used on a seasonal basis for biological sampling and enumeration (monitoringmethods.org methods 454, 1454, 1548, 1549, 1551, 4008, 4041). Methods for sampling and enumerating downstream migrating kelt (post-spawned) steelhead were described in Hatch et al. (2013). We used these data to describe and evaluate migration timing of juveniles, adults, and downstream migrating kelts; and sex ratios and size distribution of returning adults at Prosser and Roza dams as well as downstream migrating kelts at Prosser (diverted into Chandler canal and the CJMF).

Results:

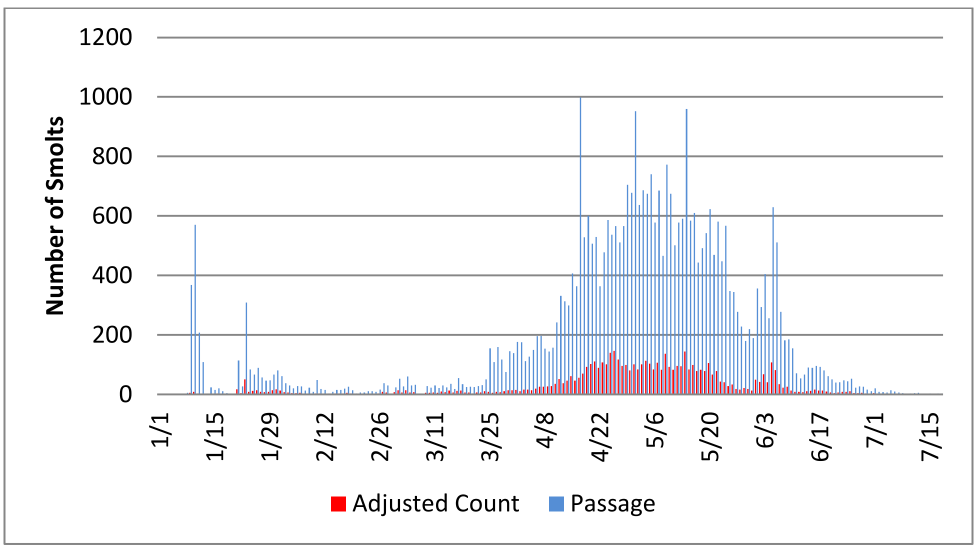

Figure 7. Distribution, average adjusted daily sample count, and estimated smolt passage of Yakima MPG Steelhead at Prosser Dam, 2000-2009.

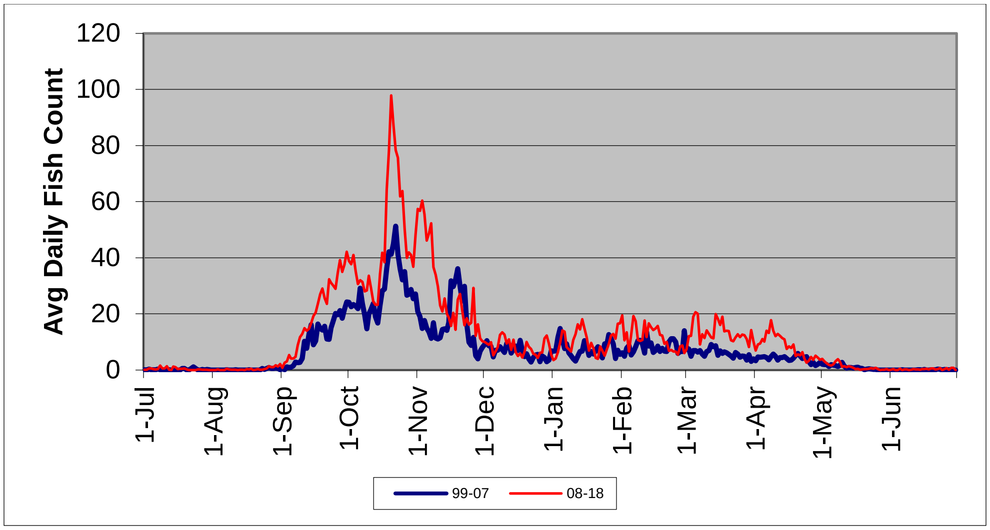

Figure 8. Average Adult Steelhead Run Timing at Prosser Dam, July 1, 1999 to June 30, 2008 compared to July 1, 2008 to June 30, 2018.

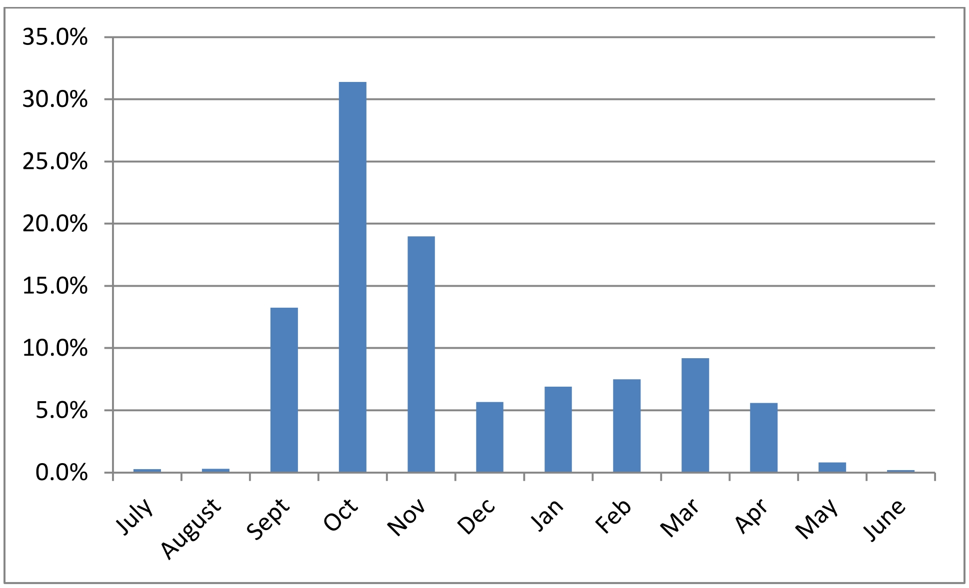

Figure 9. Recent 10-year Average Adult Steelhead Passage Proportions by Month at Prosser Dam.

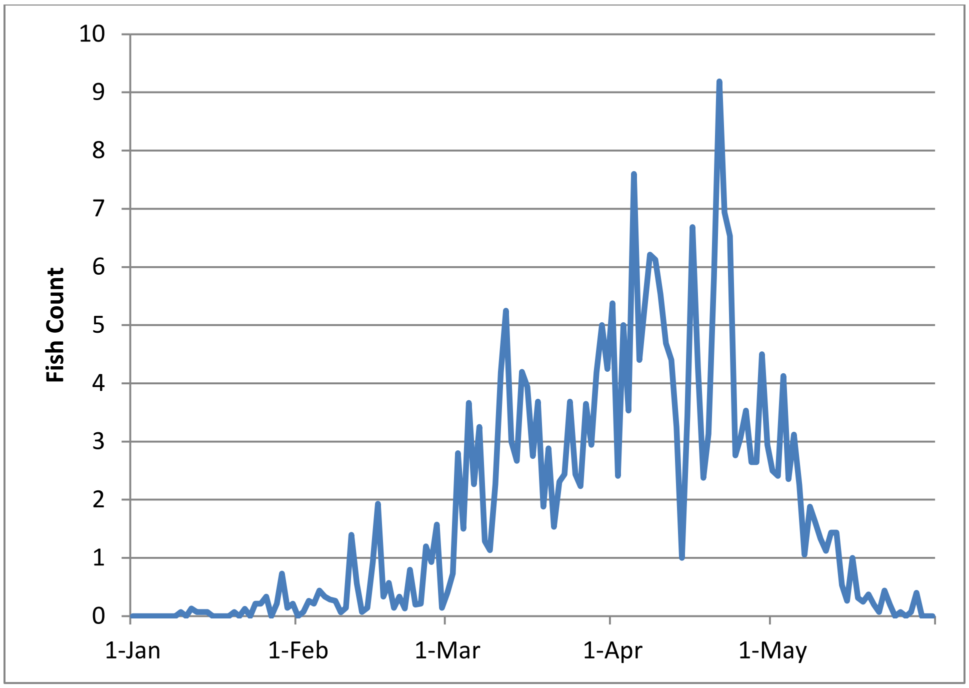

Figure 10. Average Daily Adult Steelhead Passage at Roza Dam, 2001 – 2018.

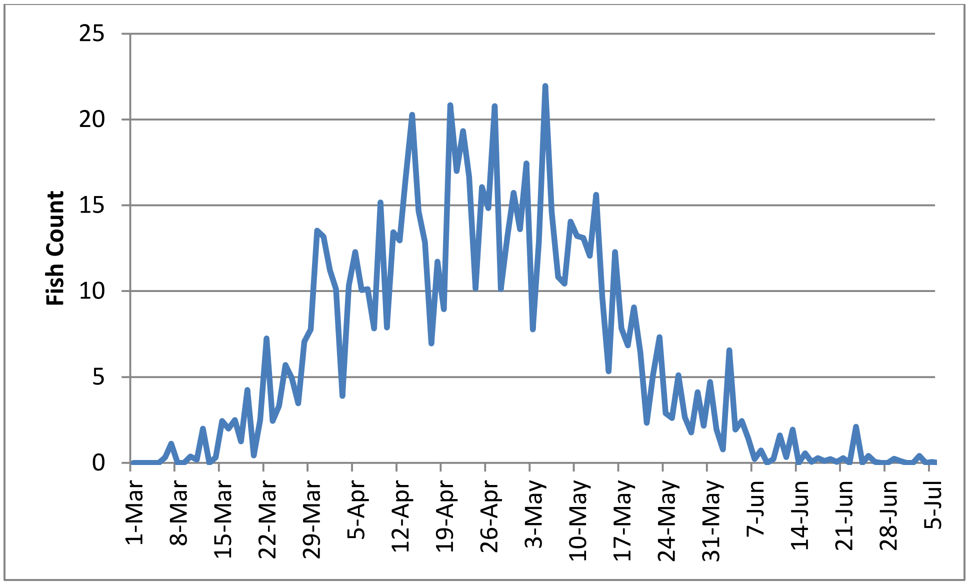

Figure 11. Average arrival timing of downstream migrating, post-spawned kelt steelhead at the Chandler Fish Monitoring Facility (Prosser Dam), 2001-2018.

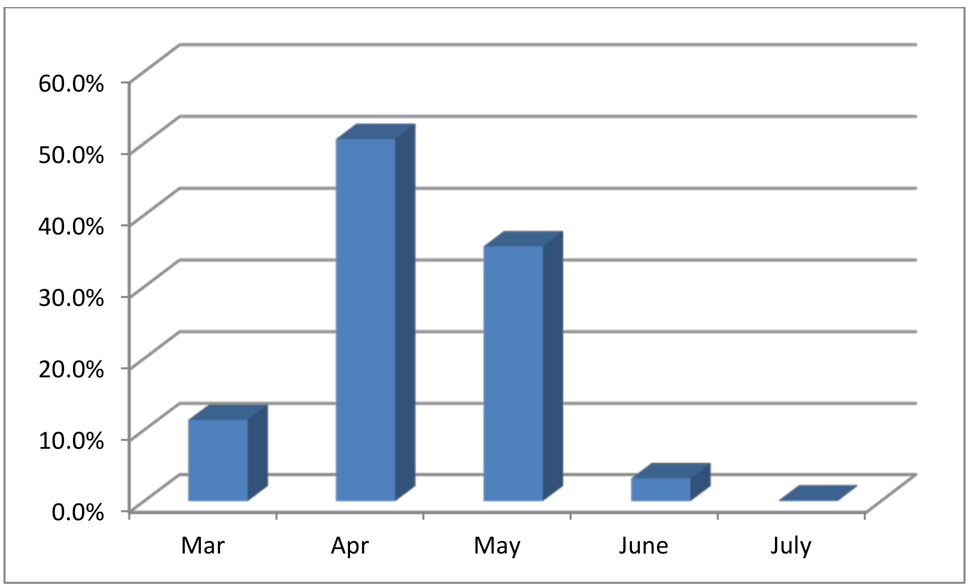

Figure 12. Average Kelt Steelhead Passage Proportions by Month at Chandler, 2001-2018.

Table 5. Sex ratio of upstream migrating wild steelhead sampled at the Prosser Dam right bank denil ladder and fish trap[1], July 1, 2002 to June 30, 2018.

Run Year	Sample Size F	M	Female%	Sample Date Range First	Last
2002-03	144	29	83.2%	09/09/02	11/25/02
2003-04	388	185	67.7%	09/11/03	11/24/03
2004-05	617	356	63.4%	09/06/04	12/02/04
2005-06	274	81	77.2%	09/11/05	11/20/05
2006-07	152	40	79.2%	09/14/06	11/20/06
2007-08	205	67	75.4%	09/11/07	11/20/07
2008-09	165	76	68.5%	09/10/08	12/07/08
2009-10	473	289	62.1%	09/08/09	03/18/10
2010-11	247	109	69.4%	09/08/10	11/17/10
2011-12	455	231	66.3%	09/14/11	05/08/12
2012-13	553	272	67.0%	09/07/12	04/25/13
2013-14	647	279	69.9%	09/16/13	05/01/14
2014-15	556	298	65.1%	09/04/14	04/29/15
2015-16	534	206	72.2%	09/09/15	04/01/16
		Mean	70.5%		

[1] July 1-June 30 run year. Excludes any fish with a previously-inserted PIT tag to exclude reconditioned kelts which would skew sex ratios even further toward females.

Table 6. Sample size (N), mean fork and mid-eye to hypural plate (MEH) lengths (cm), and weights (pounds) of upstream migrating wild steelhead sampled at the Prosser Dam right bank denil ladder and fish trap[1], July 1, 2002 to June 30, 2018.

Run	Females				Males			
Year	N	Fork	MEH	Weight	N	Fork	MEH	Weight
2002-03	143	68.0	56.1	6.9	29	67.2	53.9	6.6
2003-04	388	60.0	49.4	4.8	185	60.3	48.8	4.8
2004-05	617	62.3	52.1	5.2	356	61.0	50.1	4.7
2005-06	274	65.9	54.6	6.3	81	66.0	54.0	6.2
2006-07	152	64.0	53.0	5.9	40	66.7	54.9	6.4
2007-08	205	61.1	48.7	5.1	67	63.3	49.2	5.3
2008-09	164	64.0	52.2	6.4	76	62.6	51.2	6.0
2009-10	473	62.9	48.7	5.4	289	63.3	48.2	5.7
2010-11	247	65.0	52.1	6.3	109	64.4	50.4	6.0
2011-12	455	65.8	54.3	5.9	230	64.9	52.3	5.6
2012-13	553	65.8	52.2	6.1	272	65.7	51.2	6.0
2013-14	646	62.4	50.5	5.1	279	62.4	50.1	4.9
2014-15	556	65.2	52.8	5.9	298	64.3	51.1	5.6
2015-16	534	64.6	52.1	5.6	206	66.4	52.7	5.9
Mean		64.1	52.1	5.8		64.2	51.3	5.7

[1] July 1-June 30 run year. Excludes any fish with a previously-inserted PIT tag to exclude reconditioned kelts which could skew means.

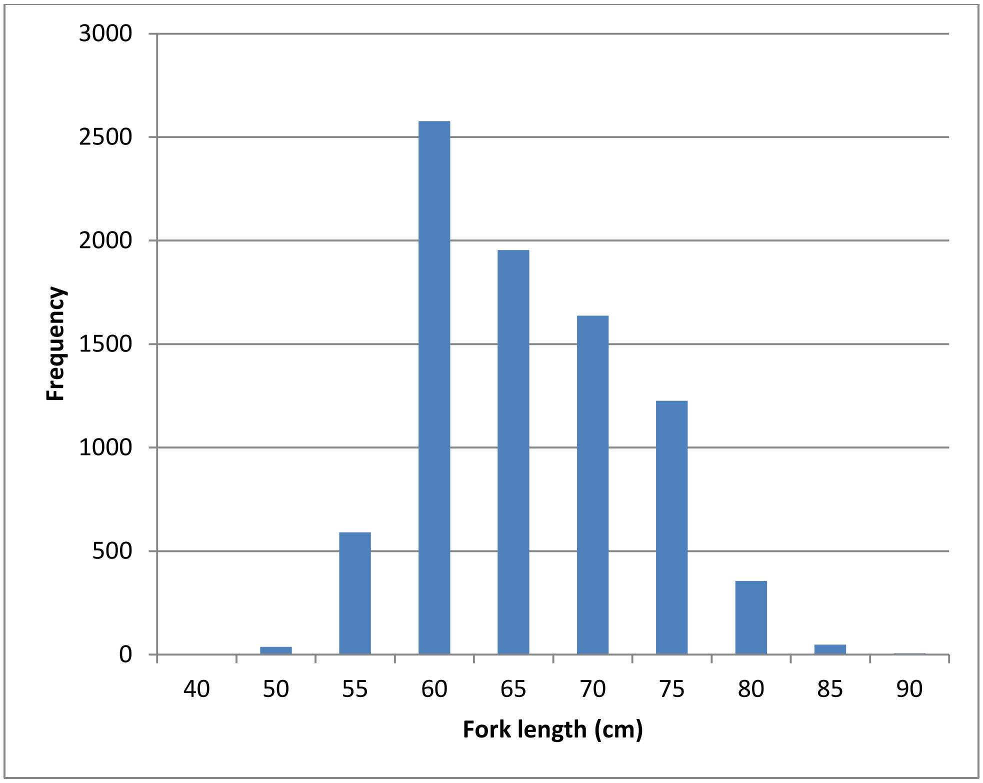

Figure 13. Frequency histogram of fork lengths (cm) for all upstream migrating wild steelhead sampled at the Prosser Dam right bank denil ladder and fish trap, July 1, 2002 to June 30, 2018 (n=8438). Excludes any fish with a previously-inserted PIT tag to exclude reconditioned kelts which could skew the data.

Table 7. Sex ratio of upstream migrating steelhead sampled at the Roza Dam adult fish trap[1], July 1, 2001-June 30, 2018.

Run	Sample Size			Sample Date Range	
Year	F	M	Female%	First	Last
2001-02	155	59	72.4%	01/10/02	05/15/02
2002-03	109	20	84.5%	11/18/02	05/13/03
2003-04	148	55	72.9%	07/24/03	06/24/04
2004-05	159	39	80.3%	01/24/05	06/02/05
2005-06	76	38	66.7%	01/13/06	05/15/06
2006-07	42	16	72.4%	02/13/07	05/14/07
2007-08	123	46	72.8%	09/13/07	05/16/08
2008-09	147	44	77.0%	02/25/09	06/03/09
2009-10	220	84	72.4%	07/25/09	06/29/10
2010-11	259	74	77.8%	07/10/10	05/23/11
2011-12	282	72	79.7%	07/10/11	06/19/12
2012-13	151	69	68.6%	09/07/12	05/14/13
2013-14	205	83	71.2%	09/16/13	06/21/14
2014-15	277	88	75.9%	07/09/14	05/20/15
2015-16	281	85	76.8%	08/24/15	05/28/16
		Mean	74.8%		

[1] July 1-June 30 run year. Excludes any fish with a previously-inserted PIT tag to exclude reconditioned kelts which would skew sex ratios even further toward females.

Table 8. Sample size (N), mean fork and post-eye to hypural plate (POH) lengths (cm), and weights (pounds) of upstream migrating steelhead sampled at the Roza Dam adult fish trap[1], July 1, 2001-June 30, 2018.

Run	Females				Males			
Year	N	Fork	POH	Weight	N	Fork	POH	Weight
2001-02	155	65.5	53.8	6.2	59	66.6	53.5	6.3
2002-03	109	69.3	57.1	7.4	20	71.3	57.0	7.6
2003-04	148	60.9	50.0	5.1	55	62.7	49.7	5.2
2004-05	159	66.9	55.4	6.4	39	68.9	55.5	6.7
2005-06	76	66.3	55.0	6.3	38	70.8	57.5	7.4
2006-07	42	64.4	53.6	4.1	16	67.2	54.2	4.7
2007-08	123	61.9	51.5	5.4	46	64.3	51.9	5.6
2008-09	147	65.3	54.1	6.2	44	66.2	53.3	6.2
2009-10	220	62.1	51.6	5.1	84	62.7	50.5	5.1
2010-11	259	66.3	55.3	6.3	74	67.5	54.5	6.5
2011-12	282	63.3	52.9	6.3	72	63.5	51.8	6.3
2012-13	151	63.6	53.3	6.4	69	64.9	52.7	6.8
2013-14	205	60.9	51.4	5.5	83	60.6	49.7	5.2
2014-15	277	63.1	53.2	5.5	88	62.0	50.9	5.0
2015-16	281	64.0	53.7	7.4	85	66.8	55.0	8.2
Mean		64.3	53.5	6.0		65.7	53.2	6.2

[1] July 1-June 30 run year. Excludes any fish with a previously-inserted PIT tag to exclude reconditioned kelts which could skew means.

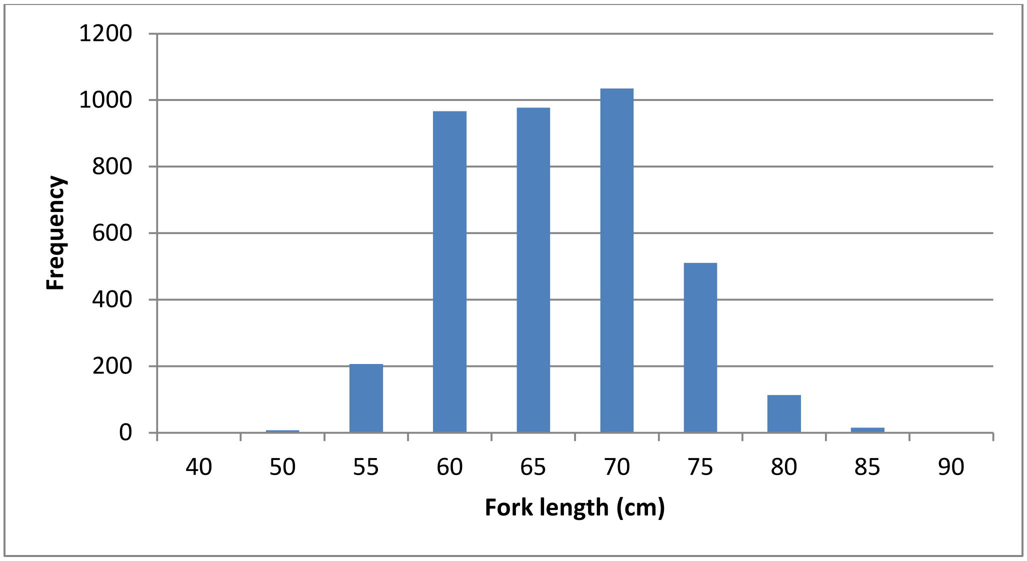

Figure 14. Frequency histogram of fork lengths (cm) for all upstream migrating steelhead sampled at the Roza Dam adult fish trap, July 1, 2001-June 30, 2018 (n=3833). Excludes any fish with a previously-inserted PIT tag to exclude reconditioned kelts which could skew the data.

Table 9. Sex ratio of downstream migrating kelt steelhead sampled at the Chandler juvenile fish monitoring facility, Jan. 1, 2001-June 30, 2018.

Kelt Year	Sample Size F	M	Female%	Sample Date Range First	Last
2001	525	29	94.8%	03/12/01	06/20/01
2002	1012	116	89.7%	03/11/02	06/13/02
2003	774	51	93.8%	03/12/03	06/21/03
2004	874	121	87.8%	03/15/04	06/21/04
2005	750	79	90.5%	03/01/05	06/23/05
2006	489	44	91.7%	01/25/06	06/08/06
2007	507	74	87.3%	03/26/07	05/31/07
2008	756	97	88.6%	03/21/08	06/23/08
2009	567	49	92.0%	04/09/09	06/03/09
2010	1437	218	86.8%	03/19/10	06/23/10
2011	880	110	88.9%	03/17/11	06/15/11
2012	604	71	89.5%	03/16/12	06/29/12
2013	609	74	89.2%	03/15/13	06/25/13
2014	469	104	81.8%	03/21/14	06/26/14
2015	1158	130	89.9%	03/17/15	06/05/15
2016	495	82	85.8%	03/16/16	06/25/16
		Mean	89.3%		

Table 10. Sample size (N), mean fork and post-eye to hypural plate (POH) lengths (cm), and weights (pounds) of downstream migrating kelt steelhead sampled at the Chandler juvenile fish monitoring facility, Jan. 1, 2001-June 30, 2018.

Kelt Year	Females N	Fork	POH	Weight	Males N	Fork	POH	Weight
2001	511	64.9	52.6	4.5	25	60.4	48.6	3.9
2002	987	63.3	51.0	4.4	101	61.2	48.0	4.0
2003	774	68.8	56.4	5.6	51	63.1	50.1	4.4
2004	874	60.5	49.6	3.7	121	58.6	46.7	3.5
2005	750	63.6	53.0	4.2	79	59.2	47.7	3.6
2006	489	66.7	56.1	4.8	44	63.5	52.0	4.4
2007	509	64.4	54.0	4.6	76	61.8	50.4	4.1
2008	756	62.1	51.8	4.1	97	61.2	49.8	3.9
2009	568	64.6	54.1	4.6	51	60.6	49.7	3.9
2010	1437	62.2	52.3	4.0	218	60.7	50.2	3.8
2011	880	64.7	54.8	4.7	110	59.6	49.0	3.7
2012	604	64.0	54.3	4.6	72	59.1	48.8	3.8
2013	609	64.7	54.7	4.7	74	58.8	48.7	3.7
2014	469	60.8	51.0	3.5	104	57.8	47.1	3.0
2015	1158	63.5	53.5	4.0	130	57.2	47.1	3.0
2016	495	63.8	53.8	4.3	82	60.4	49.7	3.7
Mean		63.9	53.3	4.4		60.2	49.0	3.8

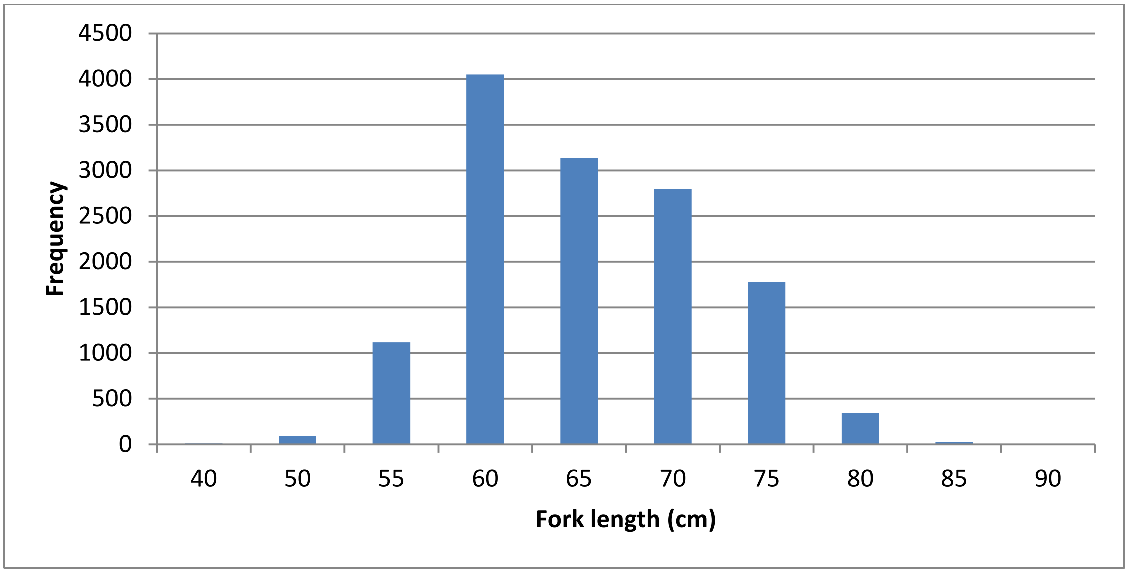

Figure 15. Frequency histogram of fork lengths (cm) for all downstream migrating steelhead sampled at the Chandler juvenile fish monitoring facility, Jan. 1, 2001-June 30, 2018 (n=13738).

Discussion:

Steelhead residing in the Yakima Basin are classified as summer-run based on their July-September run timing at Bonneville Dam (ODFW/WDFW 2014). Adult run timing into the Yakima Basin typically begins in late August or early September, and extends into May of the following year (Figures 10 and 11). After crossing Prosser Dam, the majority of fall migrants overwinter in mainstem areas near the tributary mouths of Satus and Toppenish Creeks. Part of the run will continue upstream, and overwinter in mainstem areas extending up to, and above Roza Dam. Steelhead will typically move upriver and into tributaries when spawning begins the following spring (Figure 12; tributary array PIT detection data). Post-spawned (kelt) and juvenile steelhead downstream passage at Prosser Dam is similar, generally occurring from March-June (Figures 9, 13, and 14). Adult steelhead migrants to the Yakima River Basin are predominantly female, with mean annual percentage female rates ranging from 62.1-83.2% (pooled mean 70.5%) at Prosser Dam (Table 5) and from 66.7-84.5% (pooled mean 74.8%) at Roza Dam (Table 7) for steelhead sampled from July 1, 2002 (2001 for Roza) to June 30, 2016. Downstream migrating kelt steelhead in the Yakima River Basin are even more skewed towards females, with mean annual percentage female rates ranging from 81.8-94.8% (pooled mean 89.3%) at the CJMF (Table 9) for kelt steelhead sampled from March 1, 2001 to June 30, 2016. Postspawn survival in steelhead has been reported to be higher for females than for males (Keefer et al. 2008; Seamons and Quinn 2010; Hatch et al. 2013).

Mean annual fork lengths of wild adult steelhead sampled at Prosser Dam ranged from about 60-68 centimeters (cm) from July 1, 2002 to June 30, 2016 and averaged 64.1 cm for females and 64.2 cm for males (Table 6). Nearly 90% of all wild steelhead sampled at Prosser Dam from July 1, 2002 to June 30, 2016 were between 55.1cm and 75.0cm fork length (Figure 15; range 32-89cm, median 62 cm). Mean annual fork lengths of adult steelhead sampled at Roza Dam from July 1, 2001 to June 30, 2016 ranged from about 61-71 centimeters (cm) and averaged 64.3 cm for females and 65.7 cm for males (Table 8). Over 91% of all wild steelhead sampled at Roza Dam from July 1, 2001 to June 30, 2016 were between 55.1cm and 75.0cm fork length (Figure 16; range 38-86 cm, median 64 cm). Thus, the vast majority (about 95%) of MPG steelhead returning to the Yakima River Basin are in the “Group A” size management range (< 78cm fork length) which is used for fishery management purposes in the Columbia River Basin (ODFW/WDFW 2014). Mean annual fork lengths of downstream migrating kelt steelhead sampled at the CJMF from Jan. 1, 2001 to June 30, 2016 ranged from about 58-69 centimeters (cm) and averaged 63.9 cm for females and 60.2 cm for males (Table 10). Nearly 89% of all kelt steelhead sampled at the CJMF from Jan. 1, 2001 to June 30, 2016 were between 55.1cm and 75.0cm fork length (Figure 17; range 22-87 cm, median 62 cm).

Adaptive Management and Lessons Learned

One of the primary objectives of the project is to develop long term methods for estimating population specific abundances. Radio Telemetry has become a well-established and common tool used for monitoring adult Salmonid life history traits. In many instances, such as for this study, radio telemetry has been used to estimate spawner escapement of one or more populations tagged within a run at large, and containing unknown stock proportions. Direct estimates were made for each of the populations spanning spawn years 2012-2014 with a 3-year telemetry study. The study also tested the efficacy of other proposed adult abundance monitoring methods for long-term status and trends monitoring, including the use of remote instream PIT-tag detection arrays and Genetic Stock Identification (GSI). The preliminary results for all three methods are summarized in past annual reports.

Thus far, we have been pleased with the monitoring capabilities demonstrated by the Yakima Basin PIT-tag detection arrays. Not only have they proven useful for the VSP project, they have contributed valuable data to sister projects like the Kelt reconditioning program. Due to a greater PIT-tag sampling rate (compared to the # of fish radio-tagged each year), the spawner escapement estimates generated from the Instream PIT-tag arrays might actually be more accurate, and with a higher level of precision, than those generated by the radio telemetry data. Not only are the Instream-arrays capable of being used for generating population abundance estimates, they’ve also proven useful for collecting additional life history data critical for estimating the productivity and diversity parameters needed for population viability analysis. The productivity metric is an important VSP parameter

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Appendix A: Use of Data & Products

All data and findings should be considered preliminary until results are published in the peer-reviewed literature.

Where will you post or publish the data your project generates?

Fish Passage Center
Yakama Nation Fisheries website
DART - Data Access in Real Time
RMIS - Regional Mark Information System
Yakima-Klickitat Fisheries Project website
BPA Pisces
StreamNet Database
BPA Fish and Wildlife publication page
PTAGIS Website

Describe the accessibility of the data and what the requirements are to access them?

- Automated integration of Prosser and Roza dam daily count data with Data Access in Real-Time (DART)
- Integration of PIT and CWT release and recovery data with PTAGIS, RMIS, and Fish Passage Center databases
- Production and support of data bases necessary to support BPA quarterly and annual reports (available via PISCES and BPA reports web site)
- Production and support of data bases necessary to support NPCC project proposals (available via CBfish.org)

Additional data for Yakima River steelhead is available on the ykfp.org web site and by email contact through Bill Bosch (bbosch@yakama.com) or Chris Frederiksen (chrisf@yakama.com). Project data managers participated in the Coordinated Assessments process to develop pilot exchange templates for adult and juvenile abundance and productivity parameters. However, as documented in a letter from Phil Rigdon, Director of Natural Resources for the Yakama Nation to Phil Anderson Director of the Washington Department of Fish and Wildlife, dated 7 Nov 2012, the Yakama Nation would like to see the region develop strong, enforceable data sharing agreements before we can support broad population and unlimited use of, and access to these regional databases with data from YN/YKFP projects. We remain concerned about the potential for misuse of project data obtained from existing regional databases.

Yakima Steelhead VSP Project:

Resident/Anadromous *O. mykiss* Status and Trends Monitoring

BPA Project # 2010-030-00

Report covers work performed under BPA contract #(s) 75719 and 74314(REL31)

Report was completed under BPA contract #(s) 74314(REL31)

1/1/2018 - 12/31/2018

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Executive Summary

The steelhead trout *Oncorhynchus mykiss* exhibit some of the most diverse life histories of any Pacific salmonid. Included in the diversity of this species is the variable expression of anadromous and resident life histories. The anadromous form may smolt and migrate to the ocean after one or more years of freshwater residency and return to its natal stream after spending one or more years in the ocean. In contrast, the resident life history form, also known as Rainbow Trout, spends its entire life in freshwater. Our understanding of this species is complicated by the fact that both forms can interbreed and produce offspring of the opposite type. It is unclear how this interaction between life history forms influences the recovery of the anadromous form (steelhead trout) as mandated under the Endangered Species Act (ESA). Our project provides information on the Viable Salmonid Population (VSP) metrics for the upper Yakima *O. mykiss* population while generating status and trend monitoring information for the resident and anadromous life history forms. Overall, the *O. mykiss* population in the upper Yakima appears to be gradually increasing and although our recovery targets for the anadromous life history have not yet been achieved, this trend appears unique relative to other regions throughout the Columbia Basin. Upper Yakima tributary streams continue to produce anadromous smolts with the greatest number originating in the mid-elevation tributaries. Preliminary comparisons of productivity indices suggest the Teanaway Basin tributaries maintain high anadromous smolt productivity relative to low elevation tributaries and the main stem Yakima River. In addition, preliminary modeling results suggest that a combination of *O. mykiss* density and a suite of environmental variables influenced our index of productivity over the time period of our evaluation. These results could help validate future habitat actions intended to benefit fish populations, but also specifically for *O. mykiss*. Finally, we continue to upgrade our instream PIT tag detection infrastructure that should improve our detection capabilities and produce an increasingly robust monitoring framework for VSP metric data collection.

Introduction

The steelhead trout *Oncorhynchus mykiss* exhibit some of the most diverse life histories of any Pacific salmonid. Included in the diversity of this species is the variable expression of anadromous and resident life histories. The anadromous form may smolt and migrate to the ocean after one, two, three, or more years of residency in freshwater and the return to its natal stream after spending one or more years in the ocean. In contrast, the resident life history form, also known as Rainbow Trout, spends its entire life in freshwater. Our understanding of this species is further complicated by the fact that both forms can interbreed and produce offspring of the opposite type. While steelhead in the Yakima Basin (mid-Columbia Distinct Population Segment) are currently listed as threatened under the Endangered Species Act (ESA), the resident form, Rainbow Trout, currently provide one of the best wild trout fisheries in Washington State (Krause 1991; Probasco 1994). Despite the fact that both forms can interbreed when in sympatry, they are managed separately, and the diversity in life history expression complicates effective management of either form (Satterthwaite et al. 2009). The anadromous form affords federal protection under the ESA due to depressed abundance and poor adult returns. Management of the resident form is under the jurisdiction of Washington State in the Yakima River and is currently managed as a popular sport fishery. Catch and release fishing regulations for Rainbow Trout have been in effect for the main stem of the Yakima River (upstream from Roza Dam) since 1990 although Rainbow Trout in many tributaries to the Yakima River are open to lawful harvest under Washington State fishing regulations (currently 2 fish over 8 inches in total length can be harvested daily). The flexibility in life history expression is thought to provide significant resiliency in unstable environments, although it substantially complicates our ability to manage them and further complicates the recovery of the anadromous form which is mandated under the ESA.

The Yakima Basin Sub-basin Plan (Conley et al. 2009) identified several key uncertainties and prioritized research needs consistent with steelhead recovery in the Yakima Basin. In 2009, the Yakima Steelhead Recovery Plan was developed that addressed key uncertainties associated with steelhead recovery in the Yakima Major Population Group (MPG; Conley et al. 2009). The Yakima Steelhead Recovery Plan was adopted by the National Marine

Fisheries Service and was included in the Middle Columbia River Steelhead Distinct Population Segment ESA Recovery Plan (NMFS 2009). One key uncertainty identified for the upper Yakima steelhead population is the relationship between resident and anadromous life histories present in the basin. This is particularly important in the upper Yakima River because it supports a robust resident population (Temple et al. 2013) exhibiting some hatchery introgression (Campton and Johnston 1985) and the resident and anadromous forms are known to interbreed (Pearsons et al. 2007; Blankenship et al. 2009). The interplay between the resident and anadromous forms of *O. mykiss* deserves attention because it is poorly understood and there is a strong potential for the resident form to either contribute to, or to limit, the recovery of the anadromous form (Allendorf et al. 2001; Thrower et al. 2004; Kendall et al. 2014). In addition, the interplay between the forms has the potential to confound evaluation of Viable Salmonid Population (VSP) parameters (McElhany et al. 2000) including population level abundance, productivity, spatial structure, and diversity of the anadromous form (Mobrand-Jones & Stokes 2005).

Remarkably, very little is known about the interactions between resident and anadromous forms of *O. mykiss* given the wide spatial distribution of the resident form and the generally depressed abundance of the anadromous form in the western United States. Furthermore, there are few locations in Washington State having abundance information generated for sympatric Rainbow Trout and steelhead trout (Scott and Gill 2008). In this study, we employ study methods to provide population level status and trend monitoring data for both life history forms in the upper Yakima River.

Methods

The general conceptual design associated with this project is to use large scale Passive Integrated Transponder (PIT) tagging efforts of rearing *O. mykiss* throughout the Yakima Basin (Figure 1), and subsequent tag detection histories from instream PIT tag detection arrays (Figure 2) coupled with a genetic parentage assessment (Appendix 1), to partition the life histories into their respective anadromous or resident components and to monitor status and trends associated with Yakima steelhead VSP parameters (Abundance, Productivity, Spatial Structure, and

Diversity; McElhaney et al. 2000; Crawford and Rumsey 2011). Protocols and methods employed during this contract period are described in detail at monitoringmethods.org and include: protocol 2165 method 118, method 120, method 1736, method 1360, and method 1090. Finally, it should be noted that our project extensively utilizes the facilities, staff, and data generated under separate collaborative projects (1995-063-25).

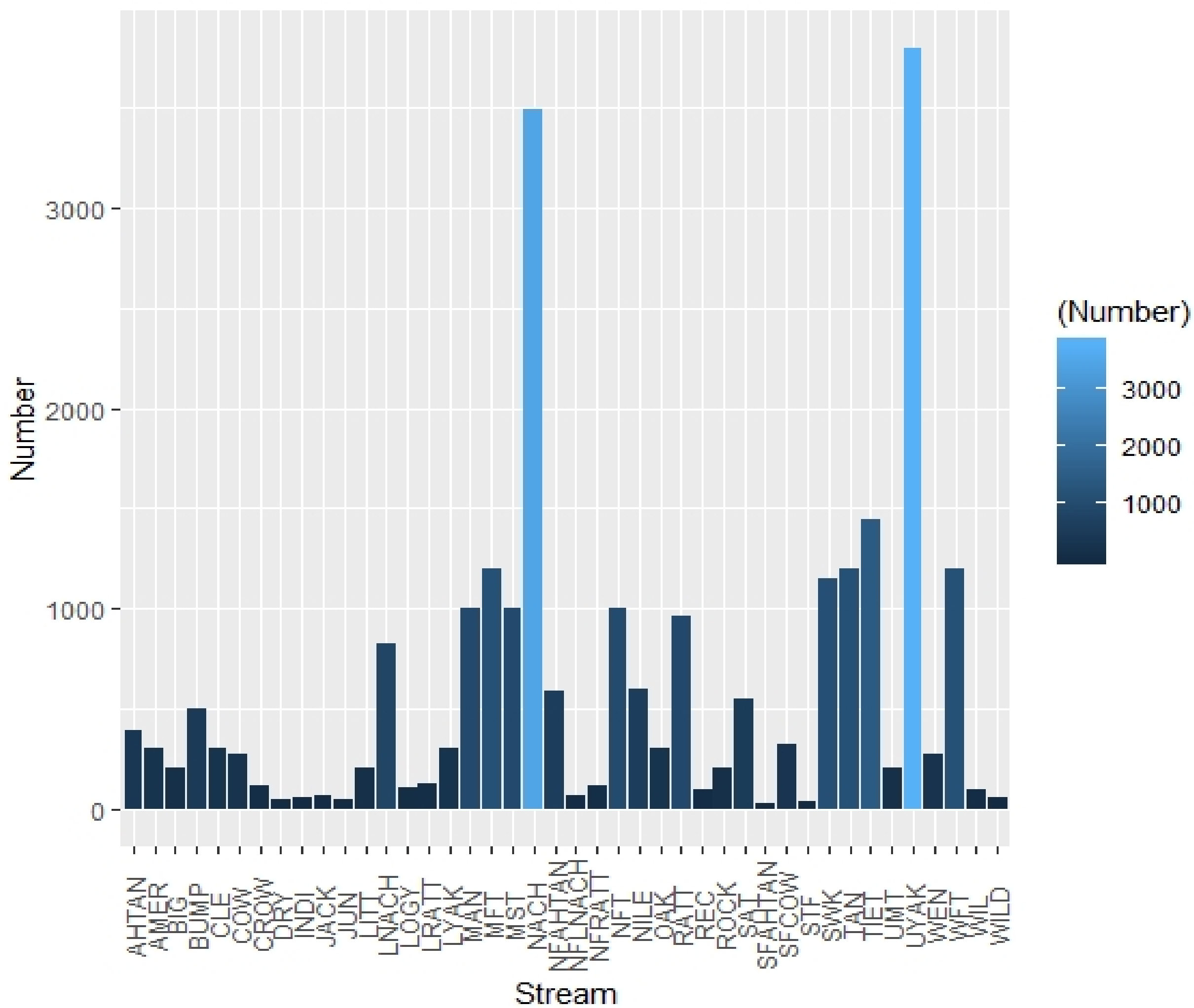

Figure 1. Number of *O. mykiss* PIT tagged throughout the Yakima Basin including the Naches, Satus, and Upper Yakima sub-basins, and Ahtanum and Wenas creeks in 2018. Stream abbreviations include: Ahtanum Creek (AHTAN), the American River (AMER), Big Creek (BIG), the Bumping River (BUMP), the Cle Elum River (CLE), Cowichee Creek (COW), Crow Creek (CROW), Dry Creek (DRY), Indian Creek (INDI), Jack Creek (JACK), Jungle Creek (JUN), Little Creek (LITT), the Little Naches River (LNACH), Logy Creek (LOGY), Little Rattlesnake Creek (LRATT), main stem Yakima River downstream from Roza Dam (LYAK),

Manastash Creek (MAN), Middle Fork Teanaway River (MFT), Mainstem Teanaway River (MST), the Naches River (NACH), North Fork Ahtanum Creek (NFAHTAN), North Fork Little Naches River (NFLNACH), North Fork Rattlesnake Creek (NFRATT), North Fork Teanaway River (NFT), Nile Creek (NILE), Oak Creek (OAK), Rattlesnake Creek (RATT), Reecer Creek (REC), Rock Creek (ROCK), Satus Creek (SAT), South Fork Ahtanum Creek (SFAHTAN), South Fork Cowichee Creek (SFCOW), Stafford Creek (STF), Taneum Creek (TAN), the Tieton River (TIET), Umtanum Creek (UMT), the main stem Yakima River (UYAK), Wenas Creek (WEN), West Fork Teanaway River (WFT), Wilson Creek (WIL), and Wildcat Creek (WILD). Colors represent a range of values from 0 (dark blue) to 4000 (light blue).

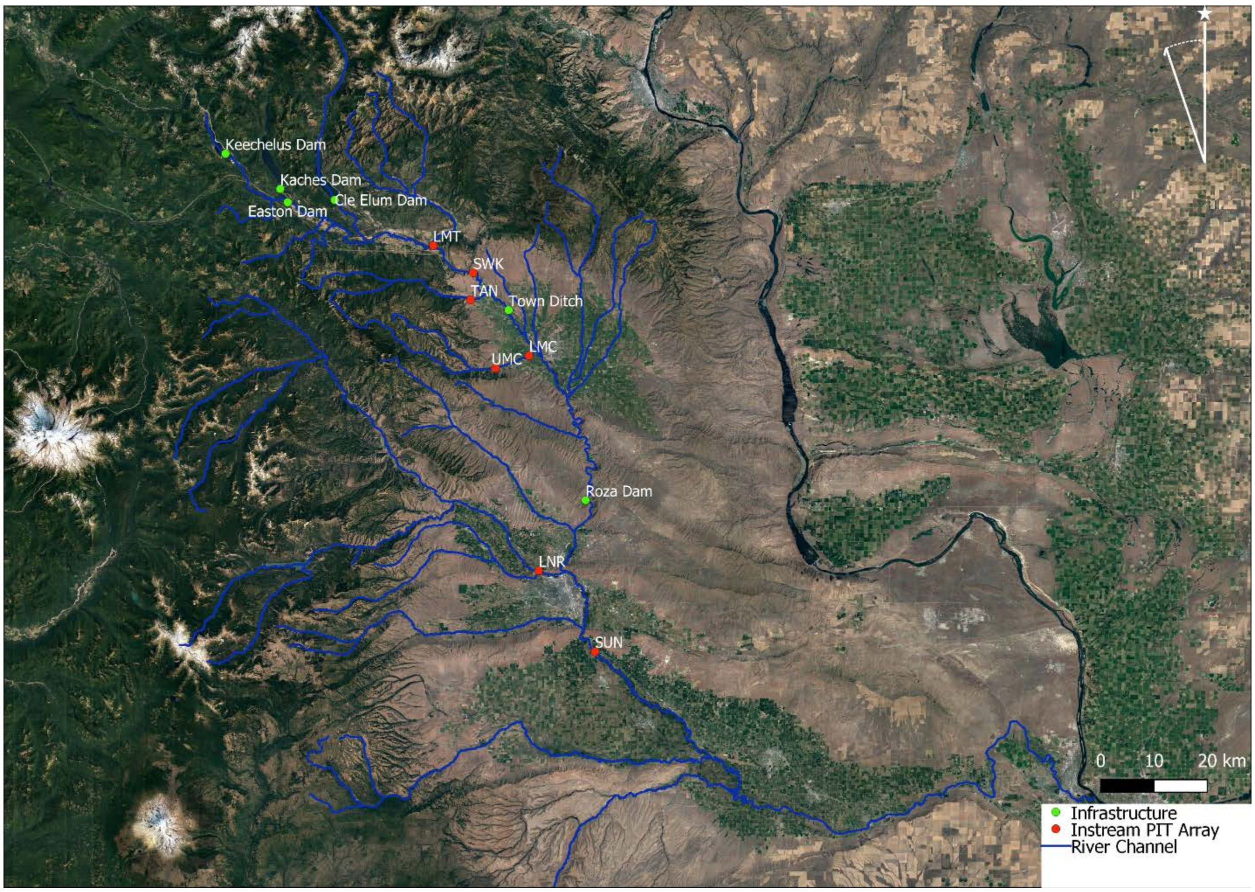

Figure 2. Map of Yakima River dam locations (infrastructure) and the instream PIT tag arrays at the lower Mainstem Teanaway River (LMT), Swauk Creek (SWK), Taneum Creek (TAN), lower Manastash and upper Manastash Creek (LMC and UMC, respectively), lower Naches River (LNR), and Sunnyside Dam instream array (SUN).

Results

General

The instream PIT tag interrogation sites were installed to detect fish movement timing and patterns. However, high water runoff events often occur during the winter and spring period in unregulated tributaries (e.g., November through April) and on several occasions have damaged instream equipment (Figure 3). On occasions that equipment has been damaged, the instream repair efforts are limited to the late summer and early winter periods when instream flow conditions are favorable for repair work. During periods that instream equipment is inoperable, we rely on the information gained from the 2012-2014 telemetry study to provide estimates of movement, timing, and abundance until instream arrays are repaired or re-installed.

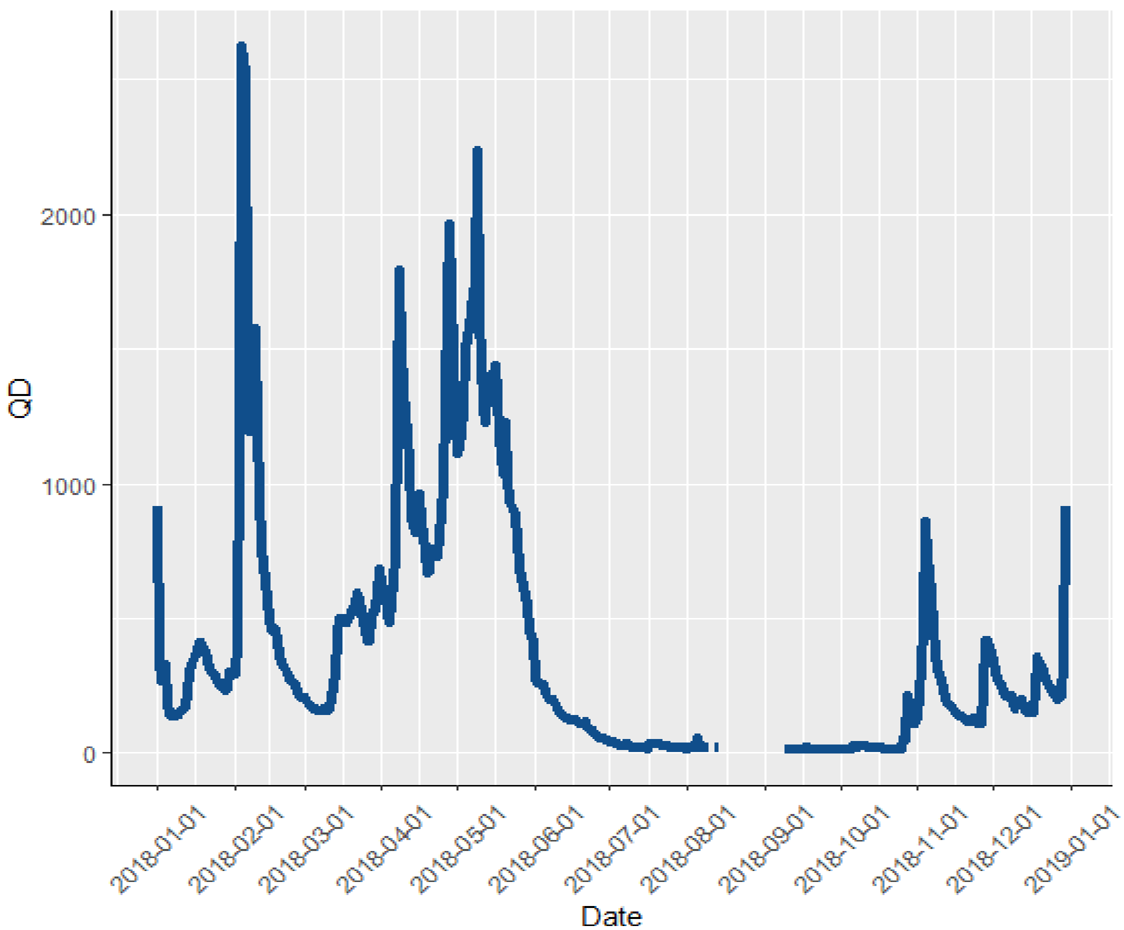

Figure 3. Mean daily stream discharge (QD; cfs) at the USBOR TNAW stream gauge in 2018.

Juvenile migrant monitoring within the upper Yakima Basin is somewhat limited by low detection efficiency of instream PIT tag arrays for small fish. For example, in March of 2015, 11,568 PIT tagged spring Chinook salmon were volitionally released from the Jack Creek Acclimation Facility in the North Fork Teanaway (NFT) River. Of those, 1568 were detected on our lower Mainstem Teanaway River instream PIT tag array (13.6%). Knowing that this group of fish passed our North Fork Teanaway River instream PIT tag array, we used the PTAGIS database (https://www.ptagis.org/) to determine that 289 of the fish detected at the Lower Mainstem Teanaway (LMT) site were also detected at the NFT site. The time stamps of the detections at both locations indicated the travel time between the two sites was relatively short on average (4.5hours), although one fish took as long as 64 days to migrate out of the system. The ratio of fish detected vs. those undetected at the NFT site indicated the juvenile detection efficiency following the acclimation release and subsequent downstream migration was approximately 18% illustrating that the juvenile detection efficiencies at this site were quite low. However, the LMT site has been reinstalled using an improved equipment design that we anticipate will significantly improve our detection efficiencies.

To estimate instream PIT tag array juvenile detection efficiencies for steelhead migrants, we used downstream detections to back calculate detection efficiency of the tributary arrays. Using incidental detections at the Roza Dam, we back calculated the juvenile detection efficiencies for our instream arrays (Table 1). We used the Roza Dam detections due to the proximity to the other instream arrays (Figure 1). Our estimates of detection efficiencies for steelhead migrants were much improved over those estimated for our Spring Chinook hatchery release. However, we caution that the sample sizes are low for *O. mykiss* (Table 1). Finally, we acknowledge there is still opportunity for improved operations and maintenance to increase the performance of our instream PIT tag arrays for juvenile abundance monitoring although they have proven useful for generating information on other juvenile monitoring metrics, and for adult monitoring (e.g., migration timing, migration duration, environmental conditions favoring outmigration, species detections, etc.).

Table 1. Interrogation site average juvenile *O. mykiss* detection efficiency for fish detected at Roza Dam that were also previously detected the North Fork Teanaway River (NFT), Swauk Creek (SWK), Taneum Creek (TAN), or Lower Mainstem Teanaway (LMT) instream arrays.

Stream	Roza Detections	Array Detections	Efficiency
NFT	8	4	0.50
SWK	8	8	1.0
TAN	7	7	1.0
LMT	20	11	0.55

One of our objectives in monitoring steelhead status and trends in population abundance is to use our PIT tag infrastructure to determine the spatial distribution and abundance of adult steelhead spawners in the Upper Yakima population. The radio telemetry study conducted between 2012 and 2014 was used to validate the use of our PIT tag infrastructure to estimate the steelhead spawning distribution and abundance by tributary. For adult spawner abundance in the upper Yakima, detections of radio tagged adults (that were also PIT tagged) at our PIT tag arrays were compared to the radio-telemetry mobile tracking detections that were conducted 2012-2014 to determine the detection rate of the PIT tagged individuals at our fixed monitoring sites. Fish that were known to have spawned in multiple streams were used to calculate array detection efficiencies for every interrogation site they were known to have passed. The tributary adult spawner abundance estimate was generated for each tributary by expanding the PIT tag detections upstream from each PIT tag array by the detection efficiency estimated at each array (from detections of radio tagged steelhead; Table 2). The general agreement between the PIT tag array detections and the radio-telemetry verification suggest the fixed site PIT tag arrays can be used to estimate spawner abundance and distribution with reasonable accuracy (Table 2).

Because the majority of our detection infrastructure in the Upper Yakima was not operational during the 2018 spawning migration, we used the average apportionment of the Roza Dam run escapement based upon the radio telemetry study conducted 2012-2014 to partition the run escapement estimate to major tributaries in the upper Yakima (Table 3). Run escapement to the main stem Yakima River (and unmonitored tributaries) was estimated as the difference between the total 2017/2018 Roza adult steelhead count and the sum of the estimated tributary escapement. The annual run of wild adult steelhead migrating upstream from Roza Dam was estimated to be 150 during the 2017/2018 spawning migration (www.YKFP.org).

We used the Taneum Creek and the Manastash Creek instream PIT tag arrays to help validate our run apportionment for 2017/2018 derived from the efficiency expansions generated from the Radio Tag study conducted 2012-2014. Briefly, we estimated the instream PIT tag array detection efficiency for Manastash Creek and for Taneum Creek in 2018 following Connolly (2010). In Manastash Creek, we used the upstream detection array to estimate the downstream detection array efficiency, and the number of unique tags detected at the lower detection array were expanded into the spawning escapement estimate using the calculated detection efficiency. The PIT tag based estimate was compared to the telemetry based estimate as a gauge on the accuracy of using telemetry based apportionment of the Roza Count to index spawner escapement into Manastash Creek (Table 3). There was no difference between the estimates in 2018 as the the PIT based estimate and the telemetry based estimate were equal. Using a similar approach in Taneum Creek in 2018 (following Connolly 2010), we used upstream and downstream antenna detections of unique PIT tags and estimated a total system efficiency of 88.2%. Thus, expanding the total number of unique tags detected, the PIT tag based spawner escapement estimate was 25 fish. This represented a 7 fish difference between the PIT tag based spawner escapement estimate and the telemetry based apportioning of the Roza Dam count (Table 3). This suggests that using a fixed apportionment of the Roza Dam steelhead count to estimate tributary and main stem spawner escapement may produce biased estimates in some instances so we caution readers and acknowledge our telemetry based estimate should be regarded as an index and may not be accurate in years that instream PIT array detections are not available.

Table 2. Detections of adult steelhead that are double tagged (PIT tagged and Radio Tagged) and the adult detection efficiencies estimated during the spring spawning migration in 2014 in each tributary in the Upper Yakima that has an in stream PIT tag detection array.

Stream	Radio tag detections	Radio and Pit tag detections	Detection efficiency	Pit tag Detections (n)	Expanded Estimate	Percent of total run
Swauk Creek	5	5	1	47	47	12.5
Taneum Creek	6	6	1	62	62	16.5
Main stem Teanaway River	14	8	0.57	15	62	7
North Fork Teanaway	6	4	0.67	34	51	13.6

Upper Main stem Teanaway River (West and Middle Fork)	8	8	1	60	60	16
Manastash Creek	1	13	1	13	13	3.5
Umtanum Creek	1	1	1	1	1	0.3
Wilson Creek	3	NA	NA	NA	NA	NA

Table 3. Estimated upper Yakima tributary spawning escapement index for 2018 based upon the expansion factors and spawner escapement indices from apportioning the Roza dam count using the Radio Telemetry data collected 2012-2014. The PIT tag based spawner escapement estimate generated for Taneum Creek and Manastash Creek in 2018 is presented for comparison. The difference between the index and the estimates is also included for comparison (the relative percent difference is in parenthesis).

Stream	Expansion Factor	Spawner Escapement Index	PIT Based Estimate	Difference
Swauk Creek	0.125	19		
Taneum Creek	0.165	25	32	7 (22%)
Mainstem Teanaway River	0.07	11		
North Fork Teanaway	0.136	20		
Upper Mainstem Teanaway River (West and Middle Fork)	0.16	24		
Manastash Creek	0.035	5	5	0 (0%)
Umtanum Creek	0.003	1		
Mainstem Yakima and Unsampled Tributaries	Roza – Tributary Escapement	45		
Total Run Escapement		150		

We conducted small scale PIT tag retention studies to quantify the effect tag loss can have on survival and productivity estimates. Failing to account for tag loss in productivity estimates based on PIT tagged fish can have a profound effect on survival and productivity estimates. We used a dual tagging procedure (Bateman et al. 2009; Dieterman and Hoxmeir 2009; Meyer et al. 2011) conducted in unique tributaries each year 2013-2016 to estimate tag retention rates. We used coded wire tags (CWT; 2013) or Visual Implant Elastomer Tags (VIE; 2014-2016) for the secondary tag type because they are known to have high retention rates (Hale and Gray 1998). Briefly, *O. mykiss* were captured using electrofishing methods during routine tagging surveys during summer low flow conditions, measured (mm) and weighed (g), and marked following standard PIT tagging procedures (Prentice et al. 1990) and either a CWT injected in the dorsal musculature (2013) or a VIE tag injected in the adipose eye tissue (2014-2016). Dual tagged fish served as the tag subjects for the mark group. Recapture sampling was conducted at discreet time intervals following release of tagged fish and ranged from 24h to 365 days. Tag loss was computed as the ratio of the number of recaptured fish possessing only a CWT or a VIE tag without a corresponding PIT tag to the initial group of dual tagged fish released into each tag site.

Abundance

Hatchery steelhead have not been released in the upper Yakima Basin since 1993 and the releases in the early 1990's were relatively small and experimental in nature. Thus, status and trend monitoring under this contract is directed at the upper Yakima River wild population although we do observe a very small number of hatchery strays annually (Figure 4). With the exception of a short winter maintenance period, nearly a complete census of the adult brood year return is collected at Roza Dam during each return year. The geometric mean adult return for the Upper Yakima population as of the most recent status assessment was 246 adults. However, there generally appears to be a gradually increasing long-term trend in annual wild adult return numbers over the time period 1992-present although we have experienced significantly reduced returns during the last two spawning migrations corresponding with poor ocean conditions (Figure 4; https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/gforecast.cfm#TableSF-02). The 2018 spawning migration was the lowest observed during the last 10 year period.

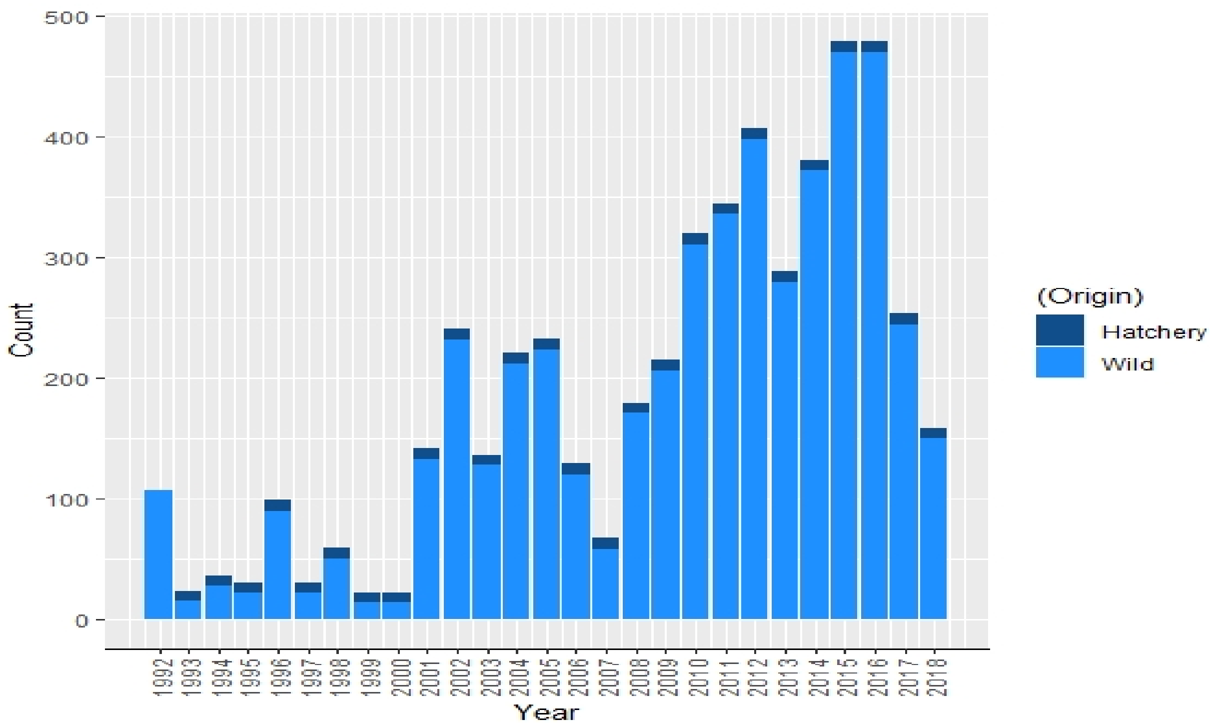

Figure 4. Number of hatchery (dark blue) and wild origin (light blue) steelhead adults passing Roza Dam during the annual adult spawning migrations.

It appears the adult steelhead returns to the Yakima major population group (MPG) are faring well relative to other regions throughout the Columbia Basin (Figure 5). The Prosser Dam count of wild adult steelhead (all 4 Yakima populations combined) presented as a proportion of the wild steelhead count at Bonneville Dam indicates a positive abundance trend since 1995. A similar pattern is observed for the upper Yakima steelhead population passing upstream from Roza Dam. However, the upper Columbia River region (Priest Rapids Dam count: not differentiated by hatchery or wild origin) and lower Columbia between Bonneville and McNary Dams do not appear to be following the same long-term trajectory. The Snake River region (Ice Harbor Dam count) does indicate an increasing trend but has remained fairly level for the last several years. While the reason for this increase is unknown, it has been the focus of recent discussion. Despite the increasing wild adult trends in the Yakima Basin, there is still significant progress to be made to meet the recovery goals that have been established (Conley et al. 2009; Figure 6).

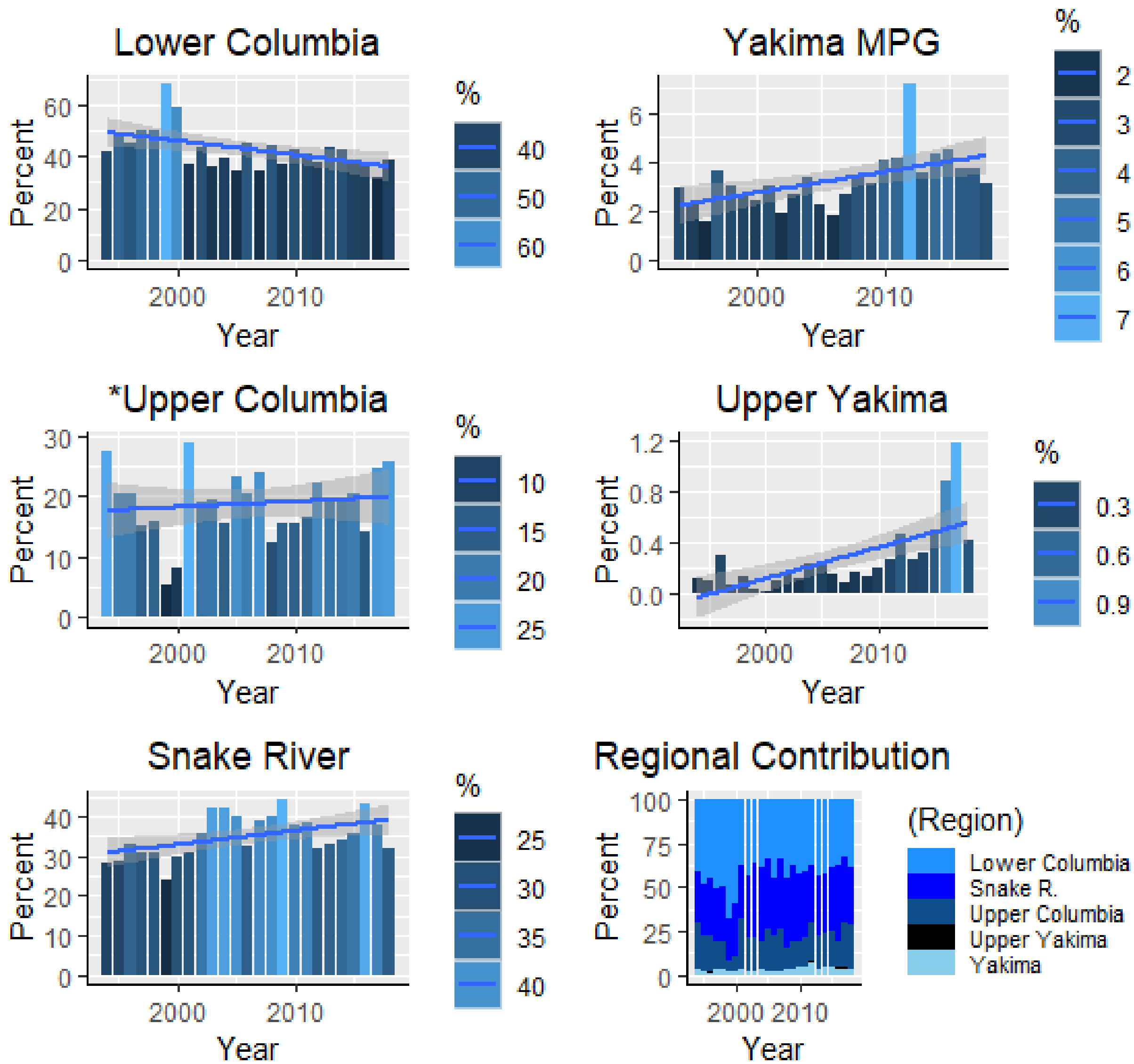

Figure 5. Annual trends in wild steelhead returns in the various Columbia River regions as a percentage of the Bonneville Dam Count. The Lower Columbia region depicts difference in the Bonneville and McNary dam counts and therefore does not include populations below Bonneville Dam and should be considered incomplete. The asterisk indicates a complete count, not differentiated by hatchery or wild origin. Trend lines represent the best fit line and bar colors indicate a range of values from small (dark blue) to large (light blue).

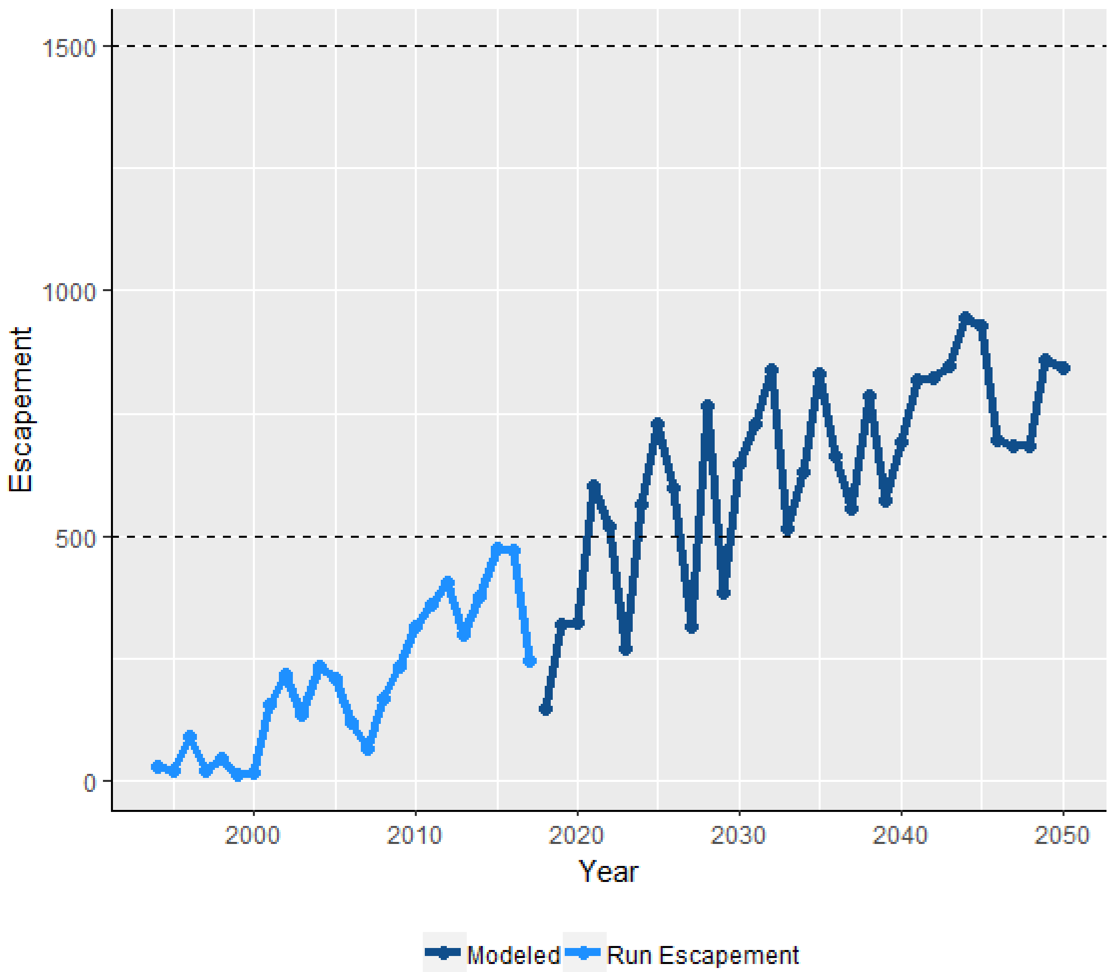

Figure 6. Observed (light blue) and modeled (dark blue) annual summer steelhead run escapement into the Upper Yakima. The short term (500) and long term (1500) recovery targets are presented as dashed lines for reference.

The population abundance of *O. mykiss* is highly variable from year to year in Yakima River tributary streams (Figure 7). We observed a slight reduction in abundance in all monitored tributaries in 2018 relative to the previous year. The slope of the best fit trend lines were used to determine if the *O. mykiss* population in each stream is increasing, decreasing, or remaining stable. All of the core long term monitoring tributary streams had abundance trajectories with positive slopes, three of which were significant (North Fork Teanaway $P = 0.19$; Swauk Creek $P<0.01$; Taneum Creek $P =0.28$; Middle Fork Teanaway River $P = 0.06$; West Fork Teanaway River $P = 0.02$; Mainstem Teanaway River $P = 0.01$). The Taneum Creek *O. mykiss* population abundance is also highly variable from year to year although the population appears stable.

Migrant production appears loosely correlated with total *O. mykiss* abundance in each stream in some cases (Figure 8).

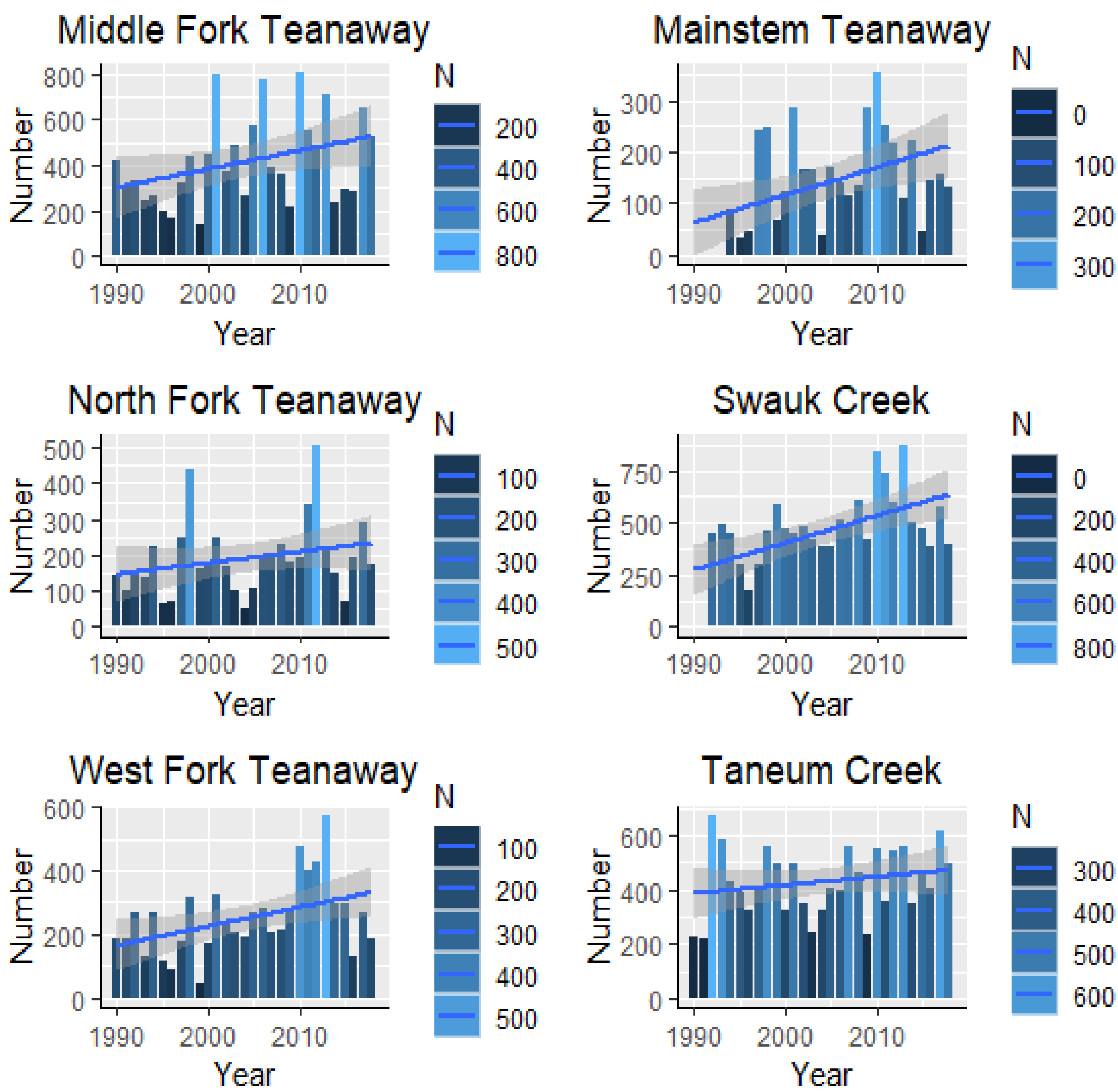

Figure 7. Annual population abundance (Number: N) of *O. mykiss* in core upper Yakima tributary streams. Trend lines in the individual stream panels represent the best fit trend line and bar colors indicate a range of values from few (dark blue) to many (light blue).

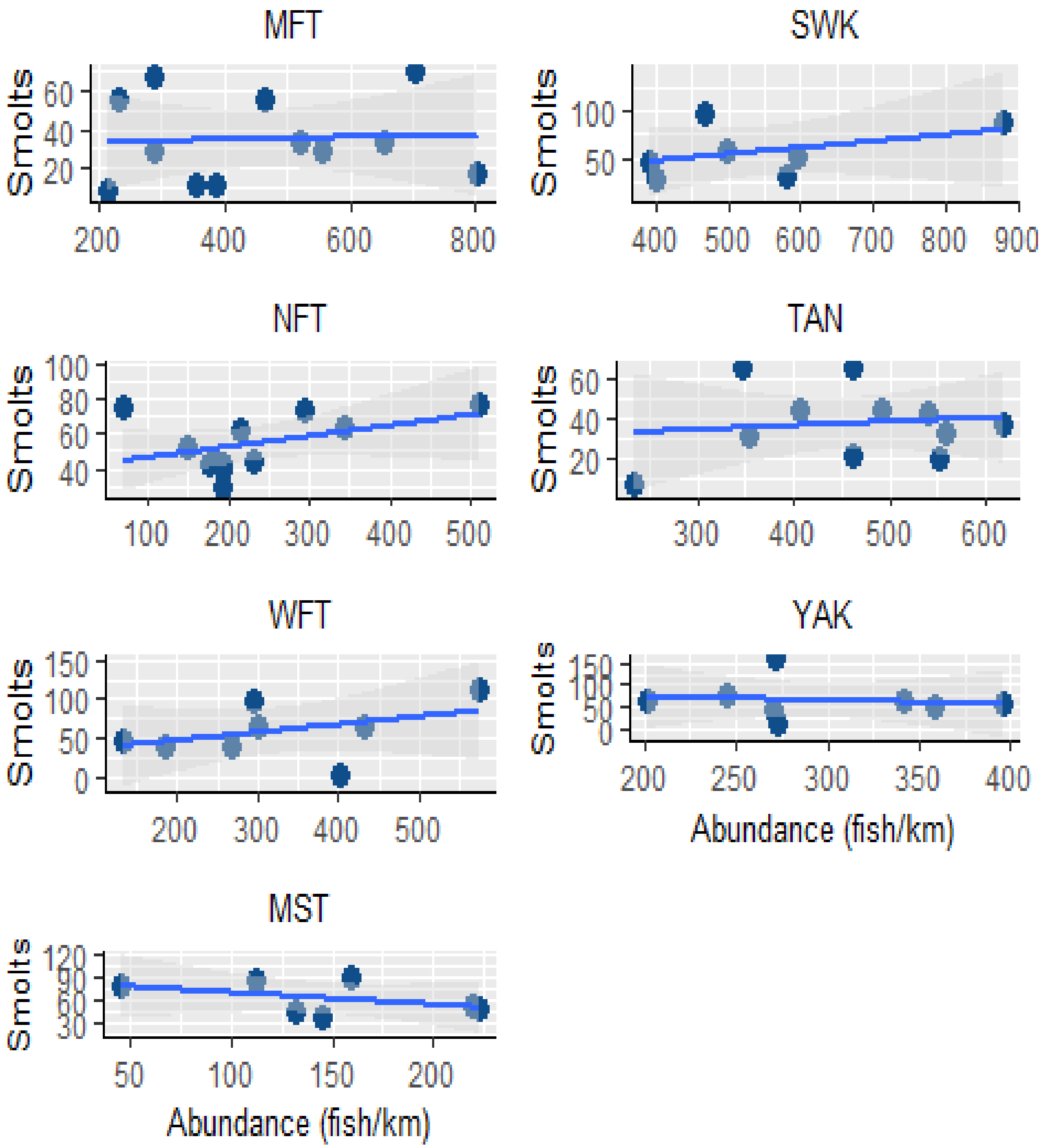

Figure 8. Relationship between total annual *O. mykiss* abundance for select upper Yakima Basin tributaries including the Middle Fork Teanaway River (MFT), the North Fork Teanaway River (NFT), the West Fork Teanaway River (WFT), the Mainstem Teanaway River (MST), Swauk Creek (SWK), Taneum Creek (TAN), and the main stem Yakima River (YAK; Age 1 in the main stem Yakima River) and the number of smolts detected annually in the upper Yakima Basin. Bird mortalities are not yet included as smolts.

Productivity

A recent description of Yakima Basin steelhead population productivity is presented in Frederiksen et al. (2015; 2016). Additionally, we have made some interesting observations based upon our juvenile tagging data. For instance, we have been able to make relative comparisons of smolt production from upper Yakima tributaries using PIT tag detections. The absolute number of migrants originating in various tributaries that were detected emigrating from the upper Yakima Basin in 2018 are presented in Figure 9, and as a percentage of the tags deployed in Figure 10. Consistently, we observe that the Teanaway Basin produces a larger number of steelhead trout migrants relative to other upper Yakima Tributaries although the basin consists of 3 major tributaries and a main stem, as well as numerous smaller streams. In contrast, Manastash Creek generally only produces a small number of migrants. Until the fall/winter of 2016, Manastash Creek had irrigation diversions in place that were thought to be complete migration barriers to adult steelhead Trout. Thus, smolt production in this stream has been attributed to resident trout spawning, which is currently supported by the genetic parentage analysis. The last significant irrigation diversion remaining in Manastash Creek, was removed during 2016 and the entire stream network is now open to anadromous passage. We now have the opportunity to monitor repopulation of an anadromous life history in this system. The absolute number of migrants originating in various tributaries that were detected emigrating from the Naches Basin in 2018 are presented in Figure 11, and as a percentage of the tags deployed in Figure 12.

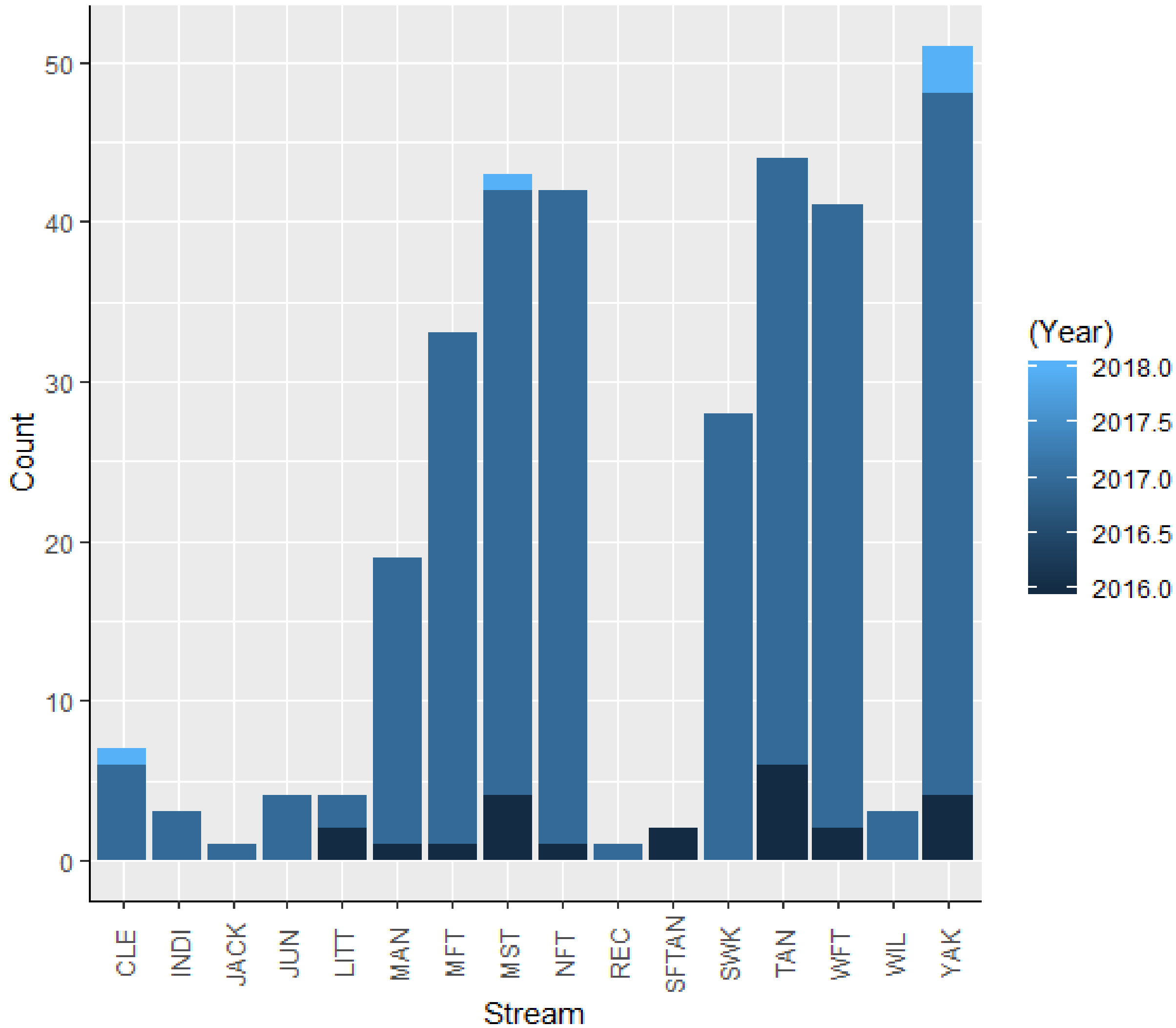

Figure 9. Number of smolts detected during the 2018 spring outmigration and the year they were tagged as juveniles (bar colors indicate a range of years between 2016 (dark blue) and 2018 (light blue) in upper Yakima streams including the Cle Elum River (CLE), Indian Creek (INDI), Jack Creek (JACK), Jungle Creek (JUN), Little Creek (LITT), Manastash Creek (MAN), Middle Fork Teanaway River (MFT), Mainstem Teanaway River (MST), North Fork Teanaway River (NFT), Reecer Creek (REC), South Fork Taneum Creek (SFTAN), Swauk Creek (SWK), Taneum Creek (TAN), West Fork Teanaway River (WFT), Wilson Creek (WIL), and the Yakima River main stem (YAK).

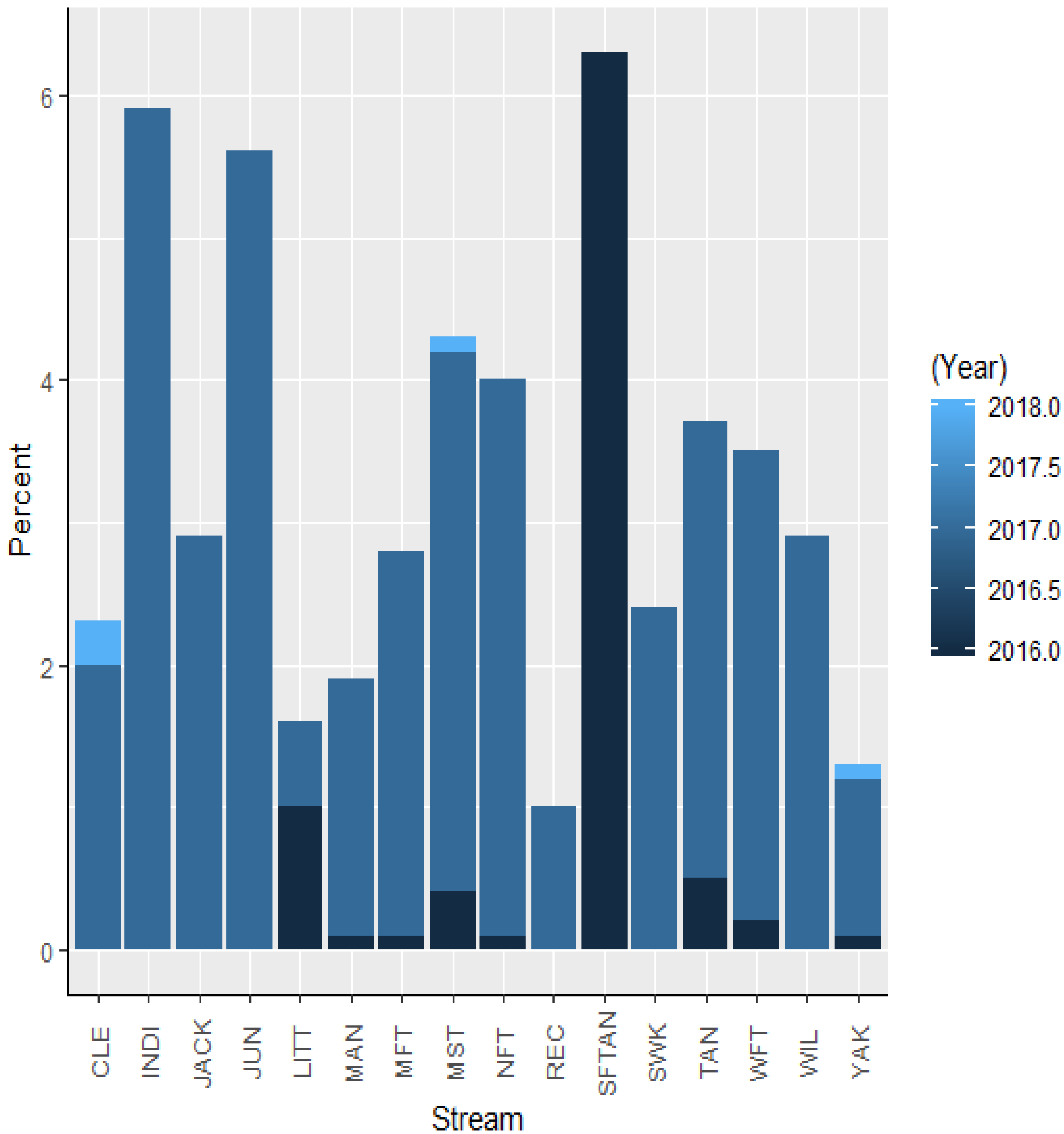

Figure 10. Percent of *O. mykiss* detected during the 2018 outmigration that were tagged in the Cle Elum River (CLE), Indian Creek (INDI), Jack Creek (JACK), Jungle Creek (JUN), Little Creek (LITT), Manastash Creek (MAN), Middle Fork Teanaway River (MFT), Mainstem Teanaway River (MST), North Fork Teanaway River (NFT), Reecer Creek (REC), South Fork Taneum Creek (SFTAN), Swauk Creek (SWK), Taneum Creek (TAN), West Fork Teanaway River (WFT), Wilson Creek (WIL), and the Yakima River main stem (YAK) between 2016 (dark blue) and 2018 (light blue).

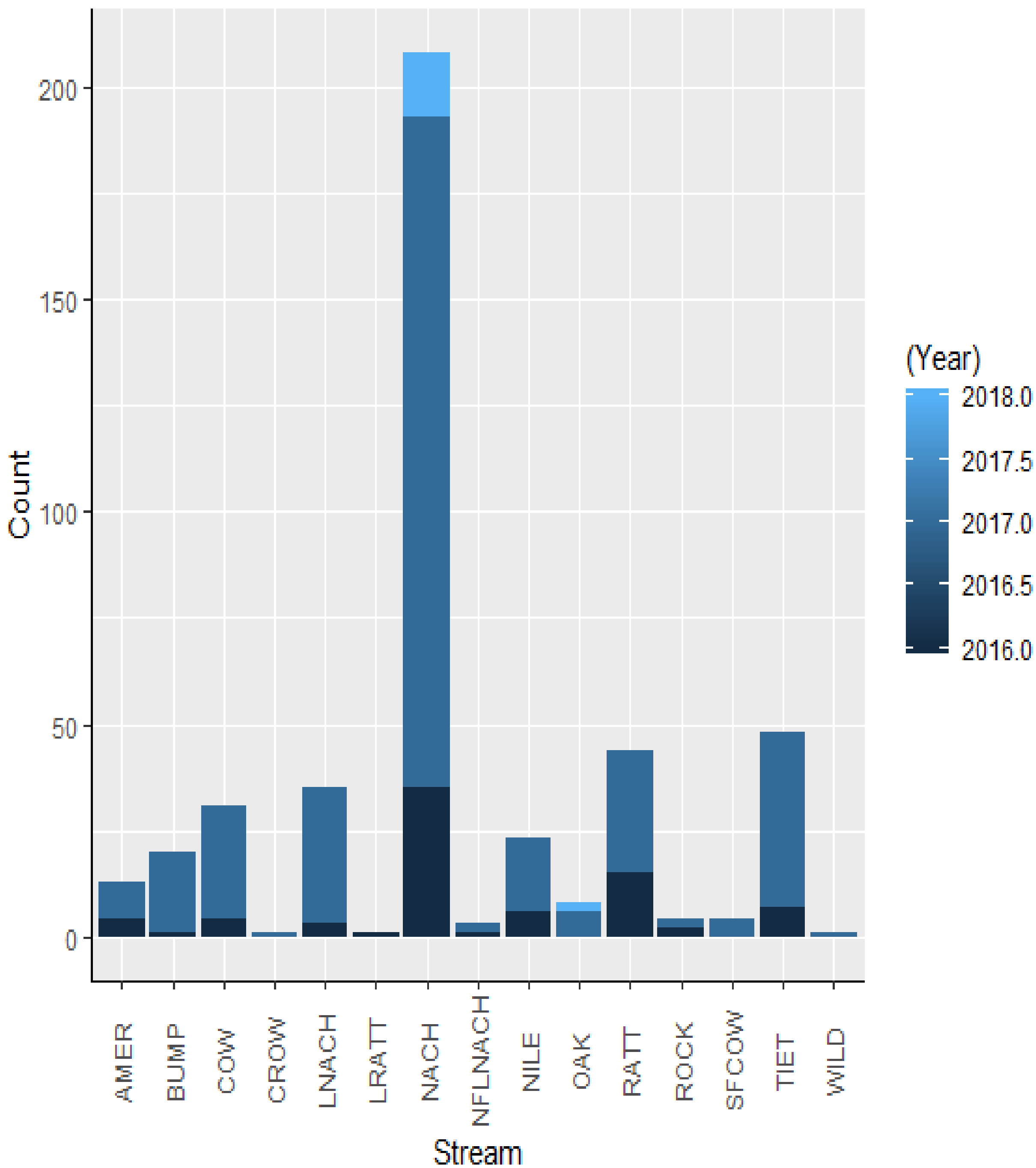

Figure 11. Number of smolts detected during the 2018 spring outmigration and the year they were tagged as juveniles in streams in the Naches Basin including the American River (AMER), Bumping River (BUMP), Cowichee Creek (COW), Crow Creek (CROW), Little Naches River (LNACH), Little Rattlesnake Creek (LRATT), Naches River (NACH), North Fork Little Naches River (NFLNACH), Nile Creek (NILE), Oak Creek (OAK), Rattle Snake Creek (RATT), Rock Creek (ROCK), South Fork Cowichee Creek (SFCOW), Tieton River (TIET), and Wildcat Creek (WILD) between 2016 (dark blue) and 2018 (light blue).

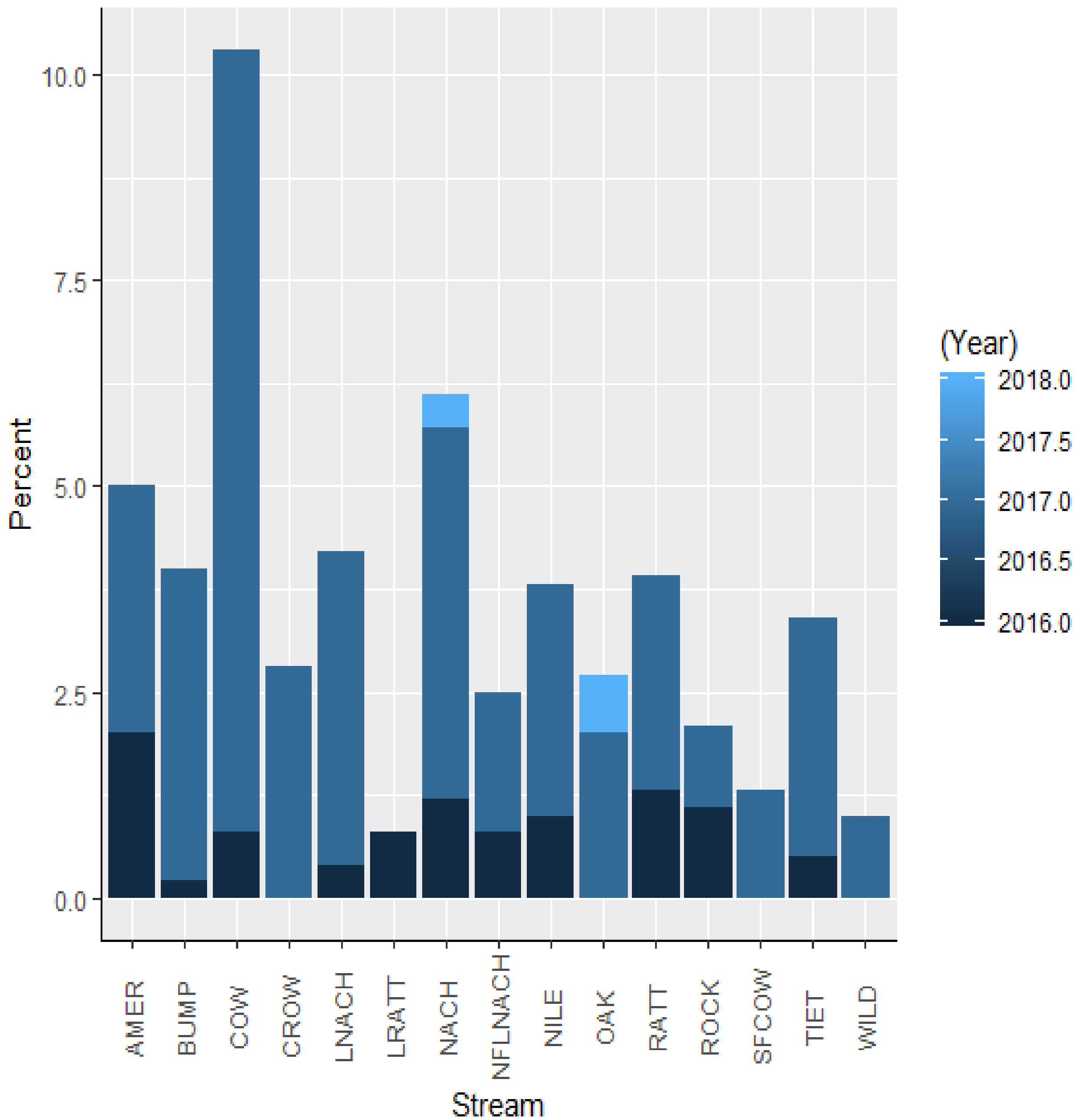

Figure 12. Percentage of *O. mykiss* detected during the 2018 outmigration that were tagged in streams in the Naches Basin including the American River (AMER), Bumping River (BUMP), Cowichee Creek (COW), Crow Creek (CROW), Little Naches River (LNACH), Little Rattlesnake Creek (LRATT), Naches River (NACH), North Fork Little Naches River (NFLNACH), Nile Creek (NILE), Oak Creek (OAK), Rattle Snake Creek (RATT), Rock Creek (ROCK), South Fork Cowichee Creek (SFCOW), Tieton River (TIET), and Wildcat Creek (WILD) between 2016 (dark blue) and 2018 (light blue).

Tag retention studies conducted in Manastash Creek (2013), Cowichee Creek (2014), Rattlesnake Creek (2015), and Wenas Creek (2016) indicate tag retention of stream dwelling *O. mykiss* was generally high. Pit tag retention was typically over 90% for time intervals between 48 h and 90 days. Tag retention dropped to 84% following a 1-year time period between marking and release (Table 3).

Table 3. Pit tag retention rates (%) for *O. mykiss* dual tagged (tag group) over various time intervals in several Yakima Basin tributaries.

Time interval	Tag group	Recaptured	PIT retained	Retention rate (%)
		Manastash Creek 2013		
48 hours	275	155	152	98.06
1 week				
2 weeks	275	242	233	96.28
1 month				
3 months	558	340	325	95.59
1 year	558	73	61	83.56
		Cowiche Creek 2014		
48 hours	98	34	32	94.12
1 week	98	28	27	96.43
2 weeks	98	31	29	93.55
1 month				
3 months	98	30	29	96.67
1 year				
		Rattlesnake Creek 2015		
48 hours	158	106	104	98.11
1 week				
2 weeks	158	75	75	100.00
1 month				
3 months	158	40	40	100.00
1 year				
		Wenas Creek 2016		
48 hours	115	21	20	95.24
1 week				
2 weeks	115	23	22	95.65
1 month				
3 months	115	11	10	90.91
1 year				

Accounting for tag retention rates in tagging studies is critical when making comparative estimates of population parameters based upon tagged fish. In general, high PIT tag retention rates for migrating anadromous juveniles have been reported in the literature. Our tag retention study based upon dual tagging procedures indicated that tag retention rates of tagged *O. mykiss* were generally high in our tributaries. Recent studies of resident fish in Idaho suggested spawning females can shed their tags during the act of spawning (Meyer et al. 2011). Thus tag retention of resident and anadromous *O. mykiss* may not be equivalent after the migration (smolts) and adult life stages (resident trout). The information generated from these studies will be necessary to incorporate when generating comparisons of resident and anadromous abundance, survival, and productivity estimates over long time intervals (e.g., 3 months or greater). We will also need to account for tag induced mortality rates in our tagging studies. However, long term tag induced mortality is very difficult to measure in the natural stream setting. We initiated a small scale tag mortality study in conjunction with a re-conditioned Kelt breeding study that was conducted in the semi-natural spawning channel at the Cle Elum Supplementation and Research Facility during the spring spawning period. In 2017, 10 resident Rainbow Trout were stocked into the artificial spawning channel in early March. Eight of them survived until the spawning period and were accounted for until mid-May representing a minimum survival estimate of 80% for 75days (Jeff Stephenson, Personal Communication).

We caution readers that developing true productivity estimates for steelhead trout takes a substantial amount of time. Crawford and Rumsey (2011) recommend a minimum of 12 brood years be collected to provide productivity estimates. This is due to the complex time requirements necessary to observe all possible combinations of freshwater residency and ocean migration over the lifespan of both juveniles and adults. Our project began in 2010 and we implemented juvenile tagging efforts in the upper Yakima Basin in earnest in 2011. We are now beginning to accumulate an adequate time series such that we can track entire cohorts back to their respective broodyear, and hence generate minimum productivity estimates (recruits per spawner). Although rare, some migrants that are six years old have been detected and thus, we have complete cohort tracking for three brood years (BY2010, 2011, and 2012), and near complete for one additional broodyear (BY2013). However, the majority of the migrants are of the one- and two-year-old age class and we do commonly observe three- and some four-year-old migrants. With this consideration, we have near complete accounting for an additional two broodyears (BY2014 and 2015; Table 4), and partial accounting for broodyears 2016 and 2017 (Table 4).

Table 4. Adult spawning brood year (BY) versus the respective age of recruits for each migration year. The light gray shaded area indicates the current juvenile recruitment time series data collected for each brood year over the duration of this project and the dark grey box represents complete or nearly complete brood years of migrant data collected through 2018.

	Migrants						
BY	Age0*	Age1	Age2	Age3	Age4	Age5	Age6
2008	2008	2009	2010	2011	2012	2013	2014
2009	2009	2010	2011	2012	2013	2014	2015
2010	2010	2011	2012	2013	2014	2015	2016
2011	2011	2012	2013	2014	2015	2016	2017
2012	2012	2013	2014	2015	2016	2017	2018
2013	2013	2014	2015	2016	2017	2018	2019
2014	2014	2015	2016	2017	2018	2019	2020
2015	2015	2016	2017	2018	2019	2020	2021
2016	2016	2017	2018	2019	2020	2021	2022
2017	2017	2018	2019	2020	2021	2022	2023
2018	2018	2019	2020	2021	2022	2023	2024

*We generally do not observe age0 migrants

The ratio of juvenile recruits produced per spawning adult must be greater than 1 for any population to persist (Ricker 1975). It appears that the anadromous recruitment per spawner ratio (R/S) for the upper Yakima population currently exceeds 1 because the trend in the Roza Dam count is positive over the time series we have available (refer to Figure 4). Comparisons of R/S between tributary and main stem Yakima River areas show a general trend of increased productivity with increasing distance (Rkm) from the Columbia River (Figure 13). Relative comparisons of R/S also indicate that the Teanaway Basin exhibits a greater number of R/S than lower elevation tributaries or the main stem Yakima River (Figure 13). However, there does not appear to be a strong correlation between the number of anadromous spawners and our index of productivity in the upper Yakima Basin (juvenile recruits per spawner index; Figure 14).

Because there are likely inherent differences in productivity of tributaries (unregulated) and the main stem Yakima River (regulated), we jackknifed the main stem Yakima River point from the correlation between steelhead spawners and our index of smolts per spawner to see the influence the main stem Yakima River point had on the trend line (Figure 14). Removing the point did not improve the model fit (R^2 = 0.12; P = 0.44; Figure 14).

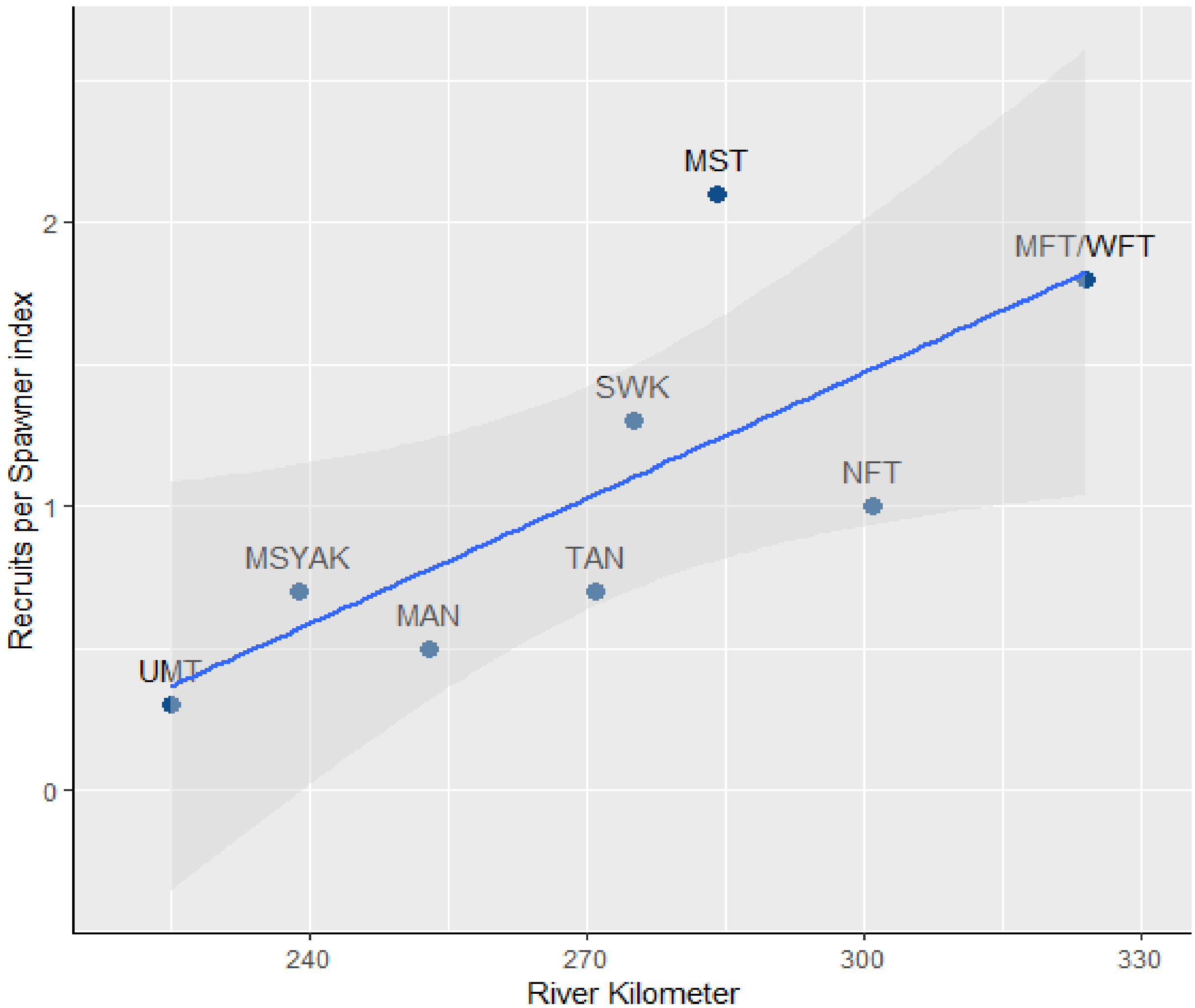

Figure 13. Average (2011-2014 broodyears) indices of steelhead smolt recruits per spawner (R/S) for Umtanum Creek (UMT), Manastash Creek (MAN), Taneum Creek (TAN), Swauk Creek (SWK), North Fork Teanaway River (NFT), Mainstem Teanaway River (MST), the combined West and Middle Fork Teanaway Rivers (MFT/WFT), and the main stem Yakima River (MSYAK), per river kilometer upstream from the Columbia River confluence. R/S should be considered a minimum index (unexpanded estimates) and as a relative measure.

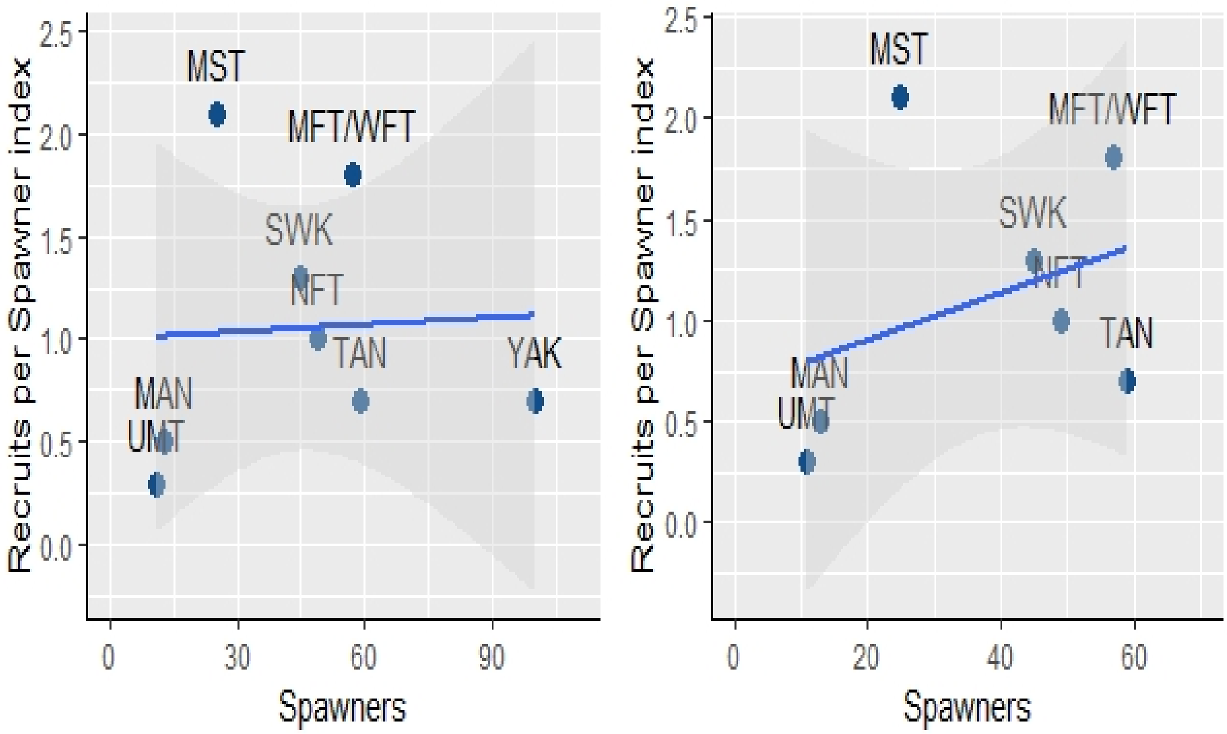

Figure 14. Relationship between steelhead spawners and productivity (smolt recruits per spawner index) for upper Yakima tributaries (right) and including the main stem Yakima River point (left) for brood years 2011-2014. Stream codes include Umtanum Creek (UMT), Manastash Creek (MAN), Taneum Creek (TAN), Swauk Creek (SWK), North Fork Teanaway River (NFT), Mainstem Teanaway River (MST), the combined West and Middle Fork Teanaway Rivers (MFT/WFT), and the main stem Yakima River (YAK).

We hypothesize that a combination of biotic and environmental factors influence *O. mykiss* productivity in the upper Yakima Basin. We used a combination of juvenile *O. mykiss* rearing density, average stream width, average base flow summer discharge, stream temperature recorded prior to sampling (mornings), an index of habitat complexity (water depths recorded at 1 meter intervals along the stream thalweg), and the proportion of pool habitat units in each tributary sampling site recorded annually in a stepwise multiple regression to determine the influence these factors had on our productivity index. The general form of the model was:

$$\frac{Recruits}{Spawner} = intercept + (B1 * v1) + (B2 * V2) + (Bx * Vx)$$

where *B* were model coefficients and *V* were the biotic or environmental parameters listed above. We used the backward stepwise approach to identify influential model parameters. This approach compared the fully parameterized model to models that systematically removed the parameters until the best fit was obtained. Best fit was determined using the Akaike Information Criterion formal model selection procedure (Burnham and Anderson, 2002). The relative importance (and 95% bootstrap confidence intervals) of the model parameters to overall model fit was estimated using the package relaimpo for the computer program R (R Development Core Team, 2009). Results from the multiple regression suggest rearing fish density, and water quantity (stream size) and quality (summer water temperature, pool habitat availability) were all influential upon our index of productivity ($P<0.001$; Adjusted $R^2=0.88$) with average stream width, summer baseflow discharge, and our index of habitat complexity being the most influential factors of those considered in the model.

Spatial Structure

In 2014, we standardized our description of steelhead rearing distribution by stratifying each tributary into 200m sampling sections throughout its entire length and the main stem Yakima River into 500 m sections (Figure 15). The tagging location of each fish tagged is known to the nearest 200m in tributaries, and 500m in main stem river sections. We graphically plotted the ratio of migrants to the total number of fish tagged for each each index site that fish were released throughout the Upper Yakima Basin, the Naches Basin, and Satus creek (Figure 16). In addition, there has been much interest in Wenas Creek recently because some *O. mykiss* tagged upstream from Wenas Dam have been detected migrating out of the Yakima River as steelhead smolts. Wenas dam is currently a migration barrier to anadromous steelhead so anadromous smolt production upstream from the dam is the result of resident trout matings. The distribution of anadromous smolts originating from Wenas Creek in 2017 is presented in Figure

17. We detected only one smolt migrant from Wenas Creek in 2018 originating from site WEN86 (Figure 17).

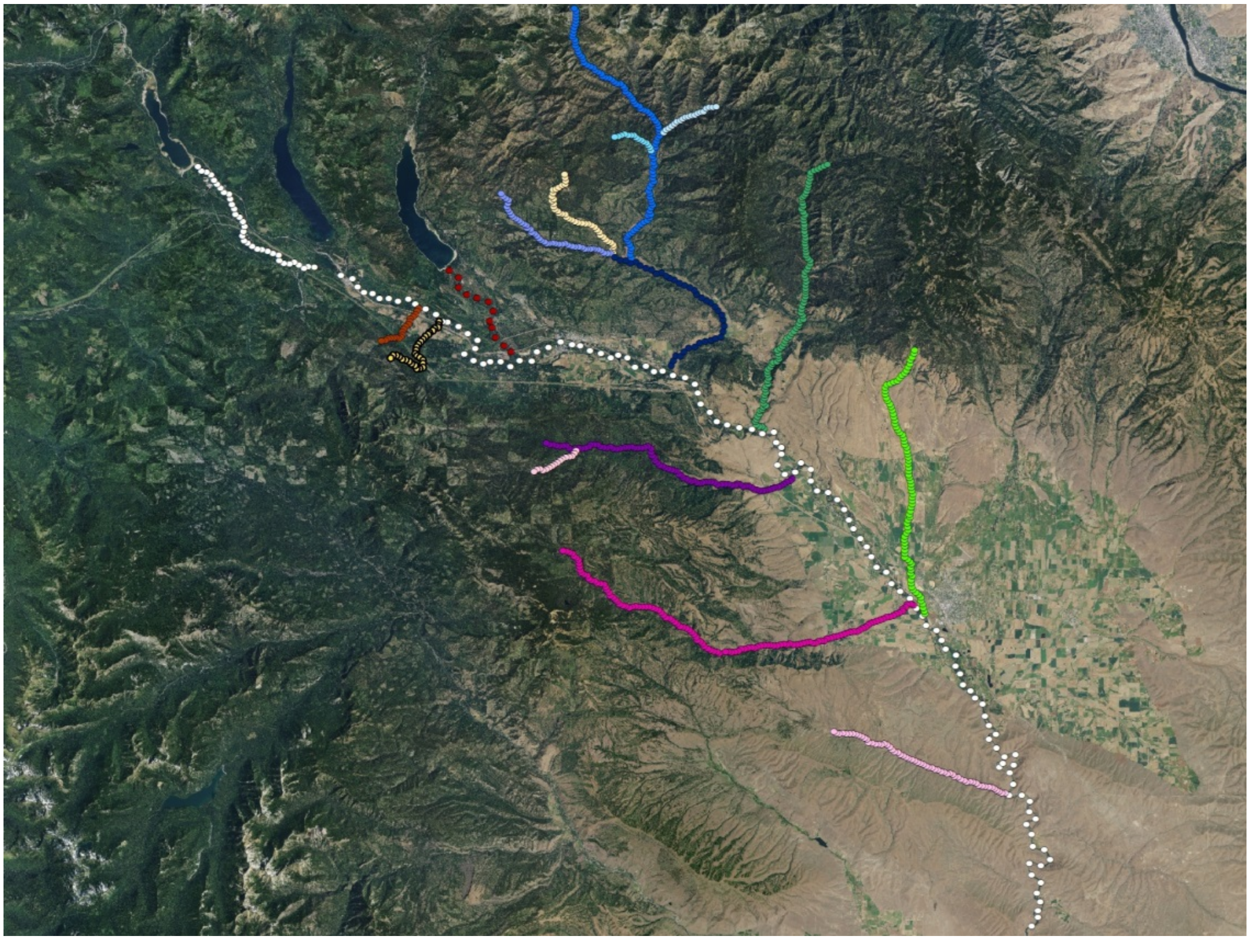

Figure 15. PIT tag collection sites in each tributary stream of the upper Yakima Basin. Collection site names are labeled sequentially moving up the stream channel. Each dot represents 200 m in tributary streams, and 300 m or 500 m in main stem stream sections.

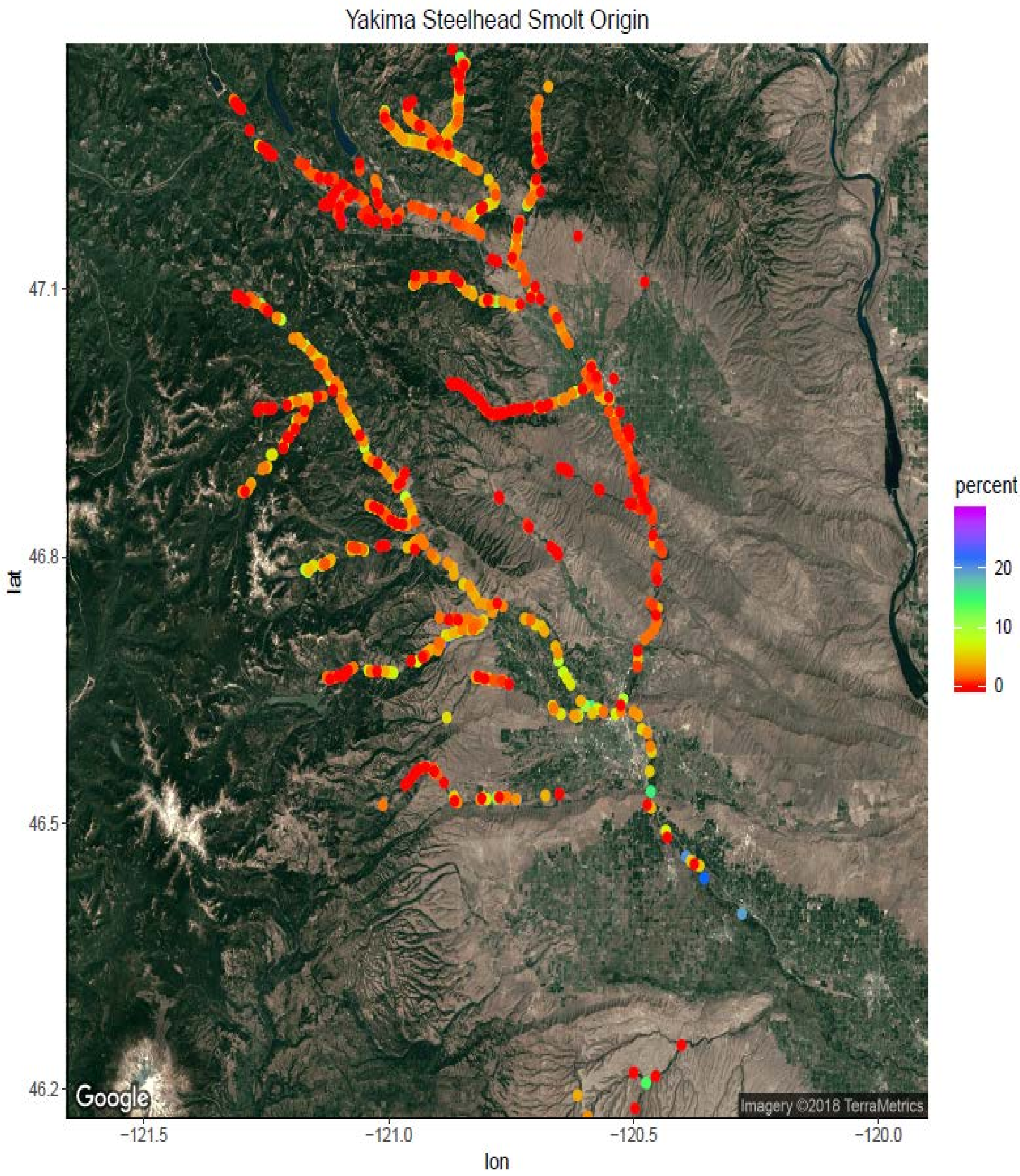

Figure 16. Percent of *O. mykiss* tagged throughout the upper Yakima Basin that were confirmed to be steelhead based on subsequent PIT tag detection histories. Colors represent a range of percentage values from zero (red) 30% (purple).

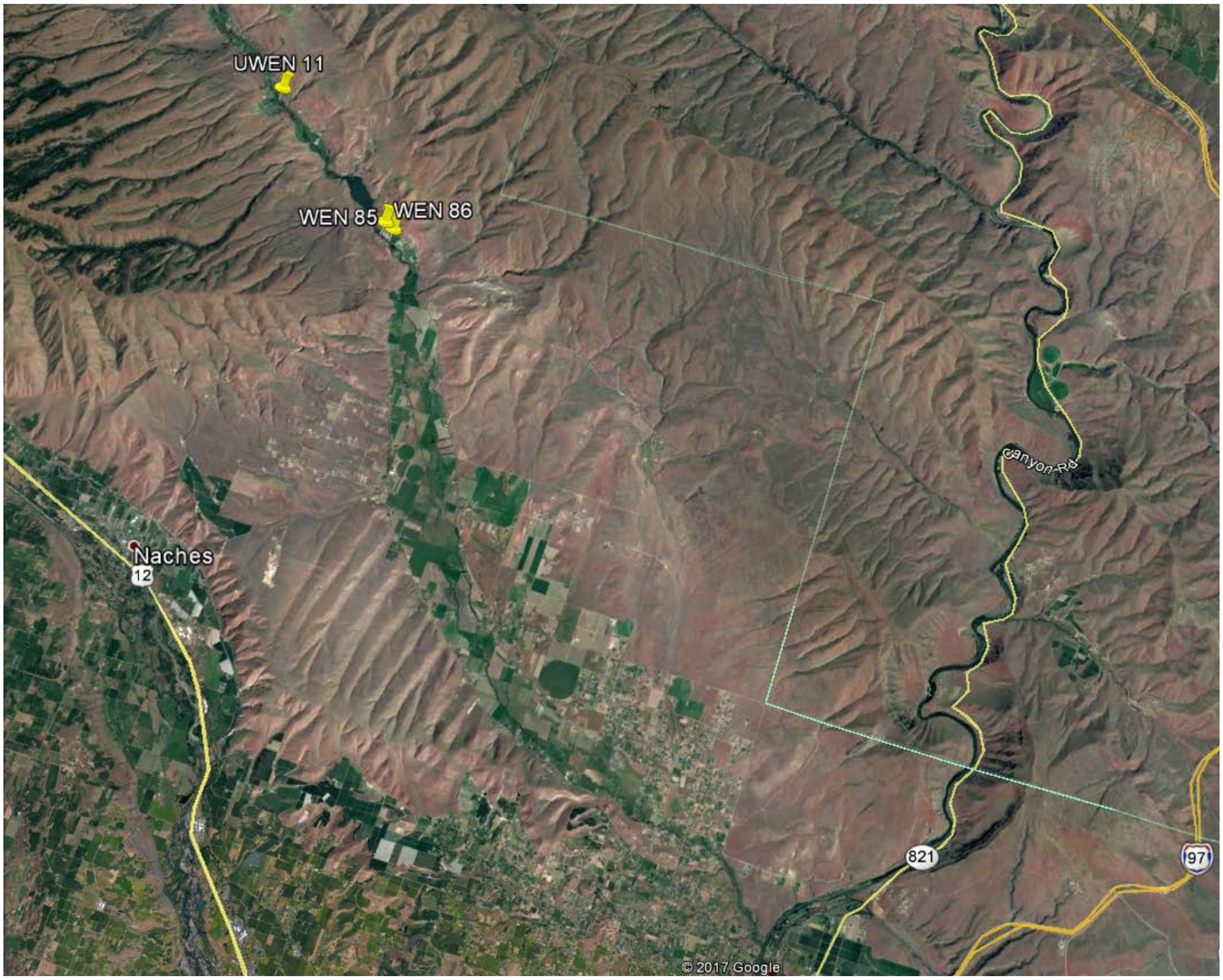

Figure 17. Origin of steelhead smolts detected during the 2017 smolt outmigration that were tagged in Wenas Creek collection sites including UWEN11 upstream from the reservoir, and WEN85 and WEN85 downstream from the reservoir.

Diversity

Pit tagging a large number of juvenile *O. mykiss* in their natal streams provided several interesting and important results related to life history diversity. First, it appears the bulk of the migration for juvenile steelhead smolts, and perhaps pre-smolts, generally emigrate from their natal streams during the spring (Figure 18). We also observed a fall migration of tagged juvenile *O. mykiss* out of the upper Yakima tributary streams (Figure 18). We speculated that the fall migration may be driven by dropping stream temperatures and increased fall discharge. While there was no clear relationship between these variables, there may be an inverse relationship between average monthly stream temperature and monthly emigration from Taneum Creek (Figure 19). While the juvenile emigration from the tributary streams did occur primarily in the spring and fall period, fish also moved past the Taneum Array during most months of the calendar year.

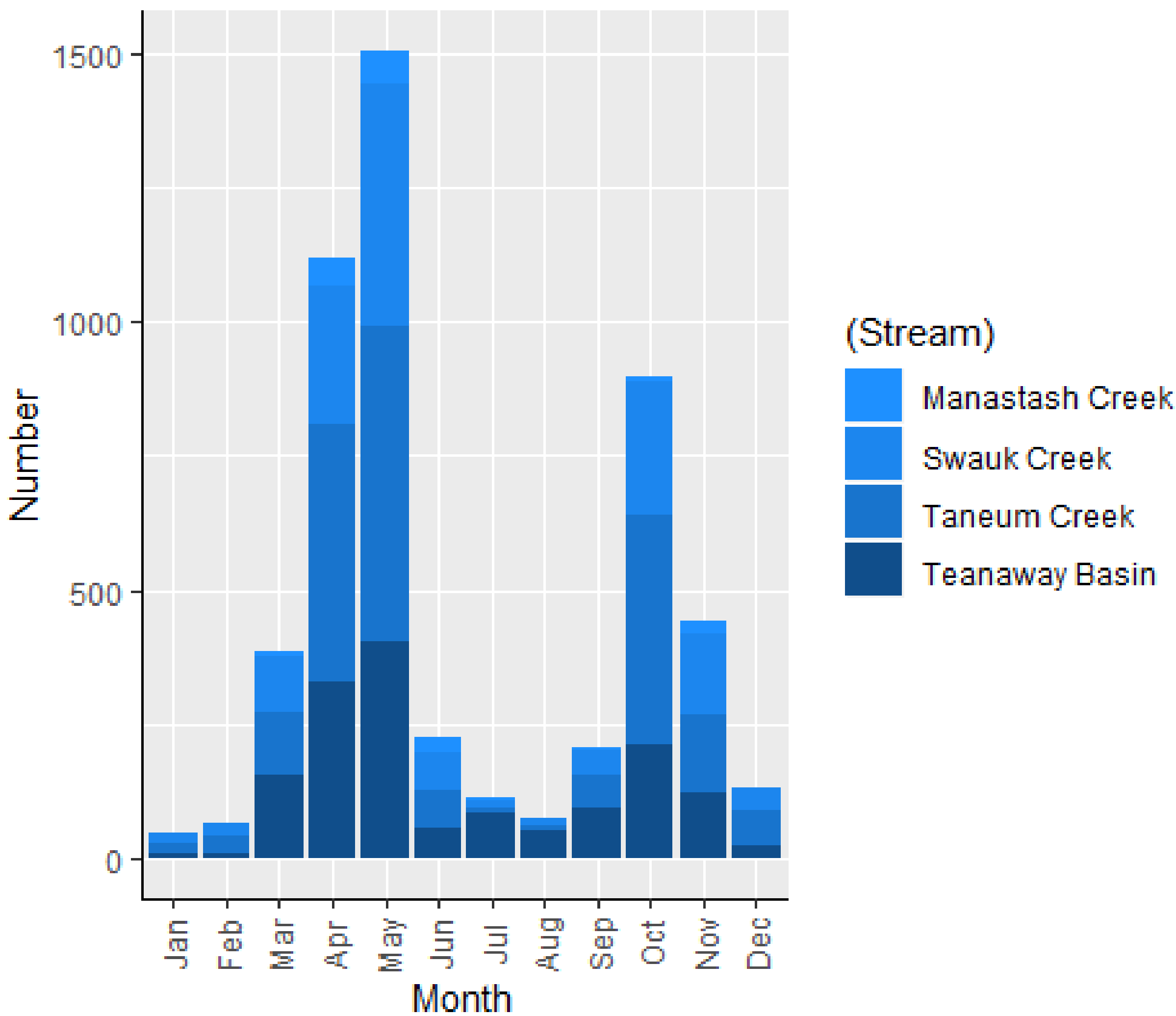

Figure 18. Total number of fish emigrating from select upper Yakima tributaries (Stream) during each month of the year. Monthly counts are totals observed over the lifespan of the project (2010 to present).

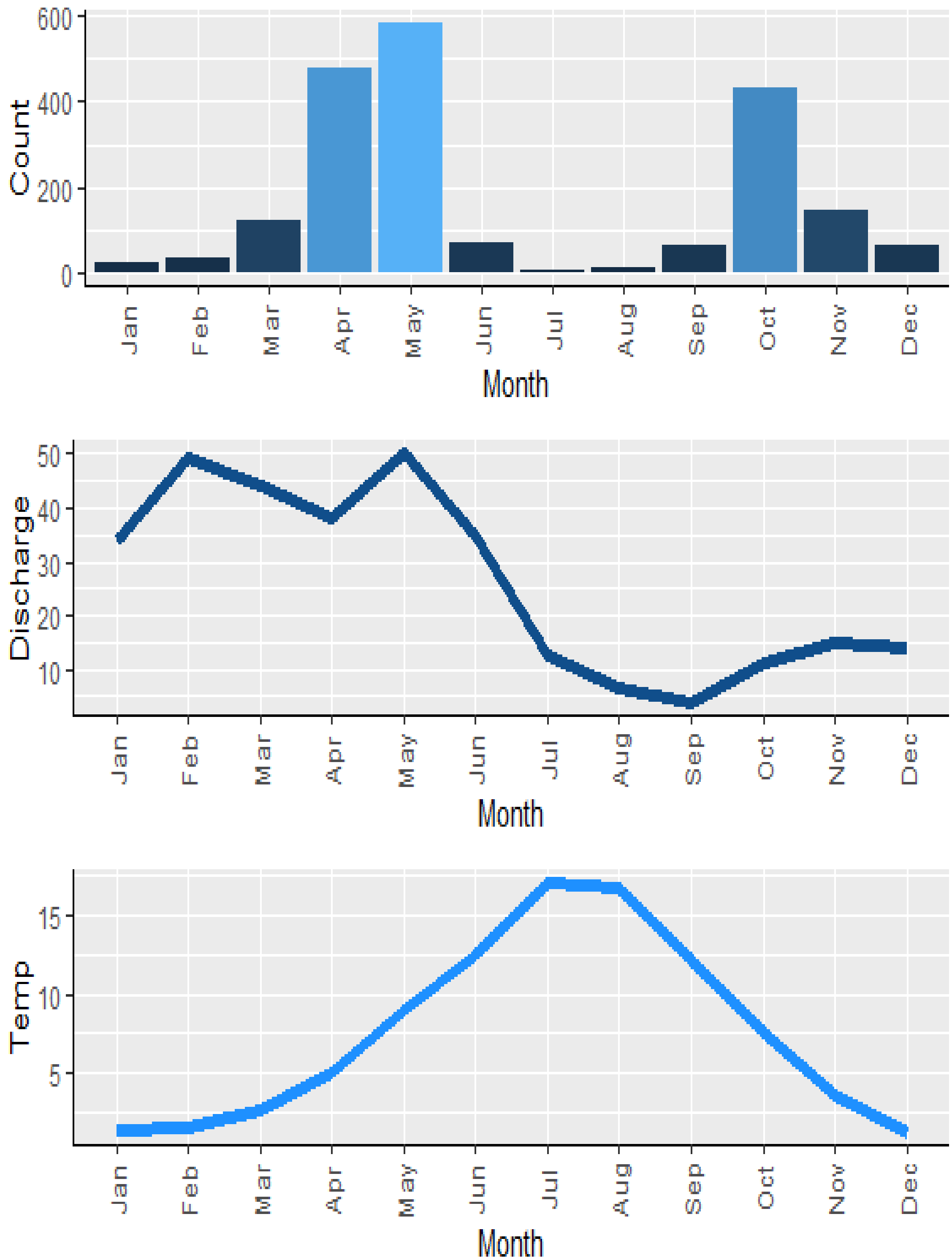

Figure 19. Total number of juvenile emigrants detected each month at the mouth of Taneum Creek (Count) during 2017 and 2018 compared to the average monthly stream discharge (2017 and 2018; cfs) and stream temperature (C) measured at the Brain Ranch stream gauging station.

We were interested to know if the length vs. weight relationship of anadromous juveniles at the time of tagging were any different than that of the resident or rearing *O. mykiss* population. An analysis of co-variance (ANCOVA) of the $\log_{10}$ transformed length vs. weight relationship indicated that there was no significant difference in the length/weight relationship between life history forms (P =0.13) for 2018 resident and anadromous juveniles. Anadromous juveniles generally weigh less at a given length than their resident counterparts (Figure 20) although the variation around these average relationships would make it difficult to distinguish between life histories for individual fish.

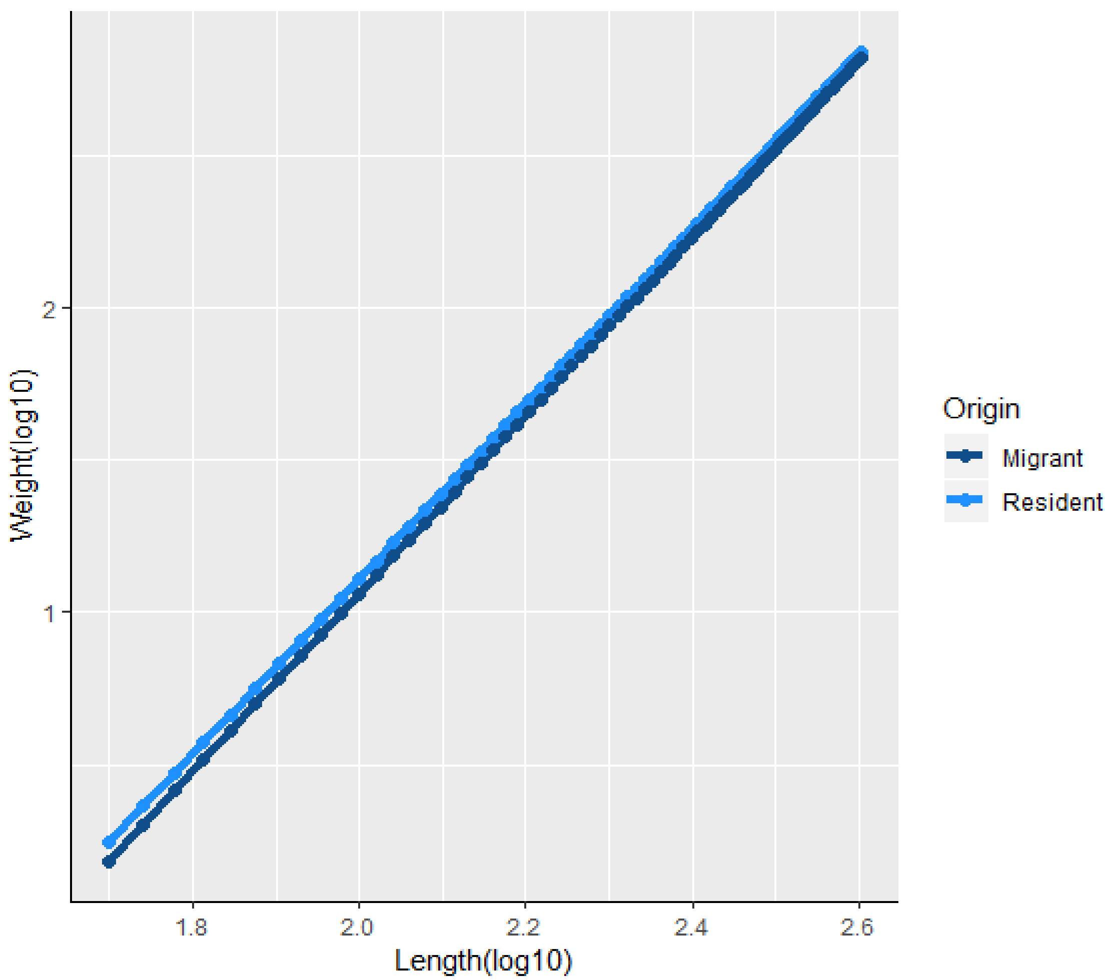

Figure 20. Log_{10} transformed length weight relationship for resident *O. mykiss* (Resident; light blue) and rearing steelhead juveniles (Migrant; dark blue). The steelhead were tagged as juveniles and detected as migrants during the 2018 smolt migration. The resident population was defined as tagged individuals exuding gametes upon capture in 2018.

We observed unusually high growth rates for *O. mykiss* in the Middle and West Fork Teanaway Rivers in 2018 as evidenced from scale growth patterns. We speculate that the Jolly Mountain Wildfire that burned much of the headwaters in these two tributaries in September 2017 contributed to large nutrient input into the headwater reaches and fish rearing in these streams following the fire exhibited unusually fast growth rates. We back calculated length at age using scale measurements from known resident trout (exuding gammetes at the time of capture) in streams affected by the Jolly Mountain Fire (Middle Fork and West Fork Teanaway Rivers, MFT and WFT respectively) and in two reference streams for comparison (Manastash Creek an Swauk Creek, MAN and SWK respectively). We restricted our evaluation to known resident trout to eliminate the influence that the migratory life history may have on estimates of fish growth and size. The length at age 1 that we computed in 2018 provided a pre-fire estimate of the size of fish in treatment and reference populations. We will extend the evaluation into 2019 to compare fish size at age in the Middle Fork and West Fork Teanaway River (treatment streams; post-fire), versus Manastash Creek and Swauk Creek (reference streams; post-fire). Pre-fire estimates of length at age 1 were not significantly different (ANOVA; $F_{3,134}$=0.69; P=0.55) and are presented in Figure 21. Finally, we intend to use our long time series of pre-fire fish size at age information in a Before-During-Control-Impact analysis (Stewart-Oaten et al. 1986; Stewart-Oaten and Bence 2001) in 2019 to determine if fish rearing in burn areas exhibited significantly increased growth relative to reference populations.

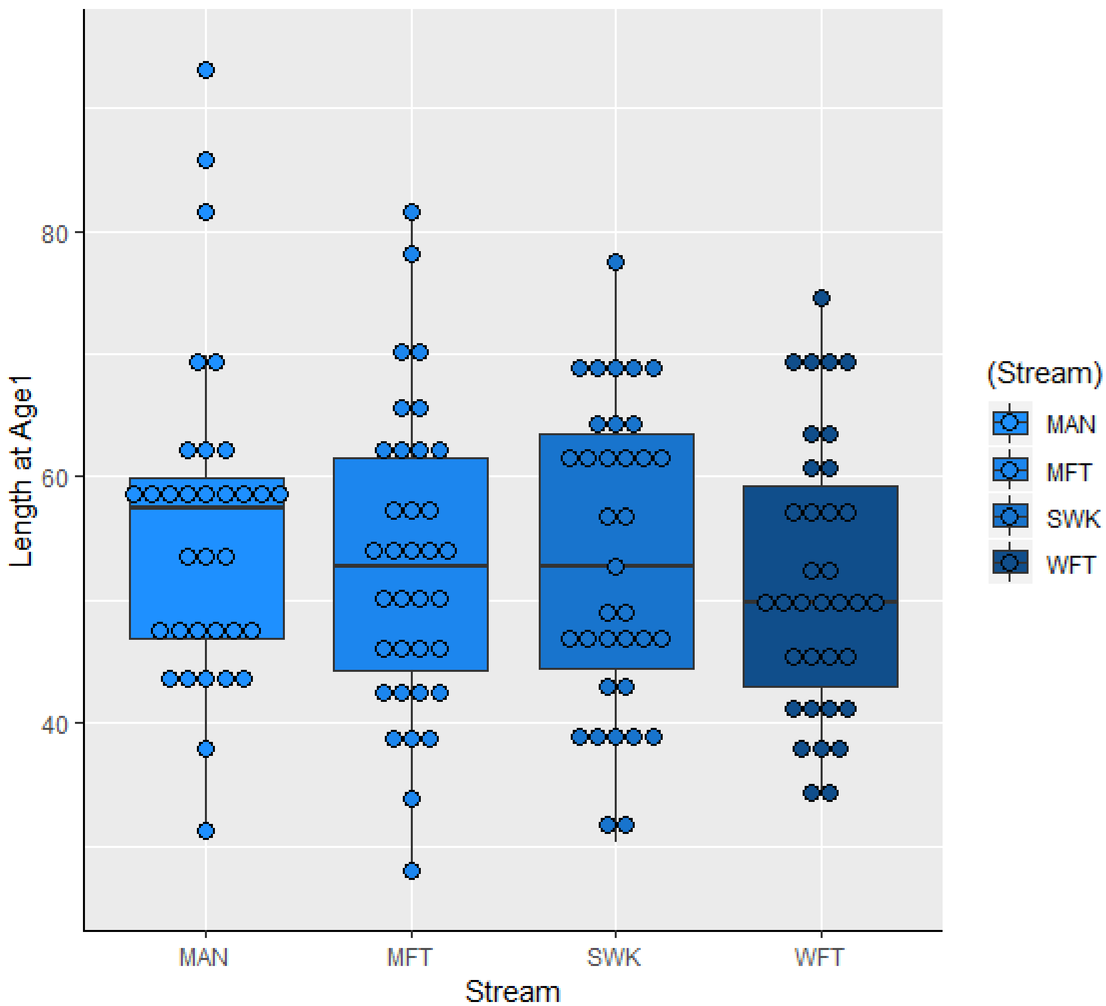

Figure 21. Back calculated length at age 1 (mm; fork length, FL) from scale samples collected from known resident Rainbow Trout in Manastash Creek (MAN), Middle Fork Teanaway River (MFT), Swauk Creek (SWK), and the West Fork Teanaway River (WFT).

As our project progresses, we are beginning to observe increased number of steelhead adults returning to the Yakima Basin that were tagged as juveniles in their natal streams several years prior. This information is used to track diversity metrics for the Naches population and the Upper Yakima population for resident and anadromous life histories. It appears that adult steelhead returning to the Naches and Upper Yakima populations have variable but similar run timing (entry into the Columbia River). Steelhead trout that were tagged as rearing juveniles in tributaries in both the Upper Yakima population and the Naches population were detected as returning adults at Bonneville Dam at approximately the same Julian Date (Figure 22) during the spawning migration. An Analysis of Variance indicated that there was no significant difference in the detection date at Bonneville dam for fish tagged in tributary streams in both basins (ANOVA; $F_{15,14}$=1.77; P = 0.15). The Teanaway Basin generally have the earliest returning steelhead adults while Cowichee Creek have had some of the latest returns.

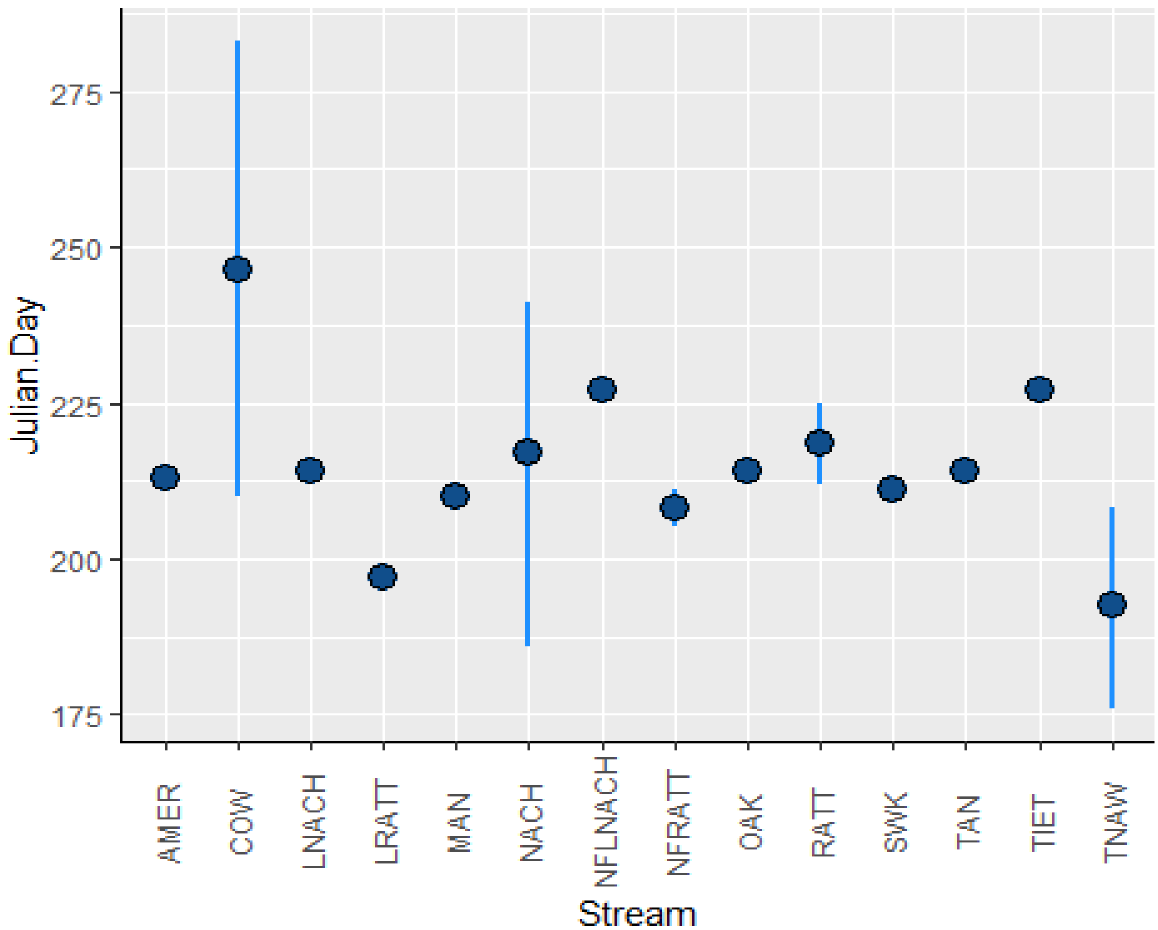

Figure 22. Average and the range (Min and Max) of dates (Julian Day) of the first detection of returning steelhead adults at Bonneville Dam in 2017 and 2018 for fish PIT tagged in their natal streams as juveniles. Stream abbreviations include the American River (AMER), Cowichee Creek (COW), Little Naches River (LNACH), Little Rattlesnake Creek (LRATT), Manastash Creek (MAN), Naches River (NACH), North Fork Little Naches River (NFLNACH), North Fork Rattlesnake Creek (NFRATT), Oak Creek (OAK), Rattlesnake Creek (RATT), Swauk Creek (SWK), Taneum Creek (TAN), Tieton River (TIET), and the Teanaway River Basin (including all forks).

The wide spread detections of PIT tagged upper Yakima steelhead throughout the Columbia Basin suggests that it is not uncommon for these fish to wander during their adult migration. Similar to previous years, we observed Yakima steelhead making extensive use of the entire Columbia River Basin during the 2018 adult spawning migration (Figure 23). Several Yakima steelhead were detected at the Deschutes River mouth, and in the Snake River Basin. Fish were also detected in the upper Columbia Basin passing upstream from Priest Rapids Dam. Several of these fish were detected in the juvenile fishways at mainstem Columbia River Dams as well, presumably in an attempt to move downstream through the hydro-system as they migrated throughout the basin or as post spawned kelts. In contrast, recapture information collected on rearing juveniles (combined life histories) indicated very little movement prior to the smolt stage.

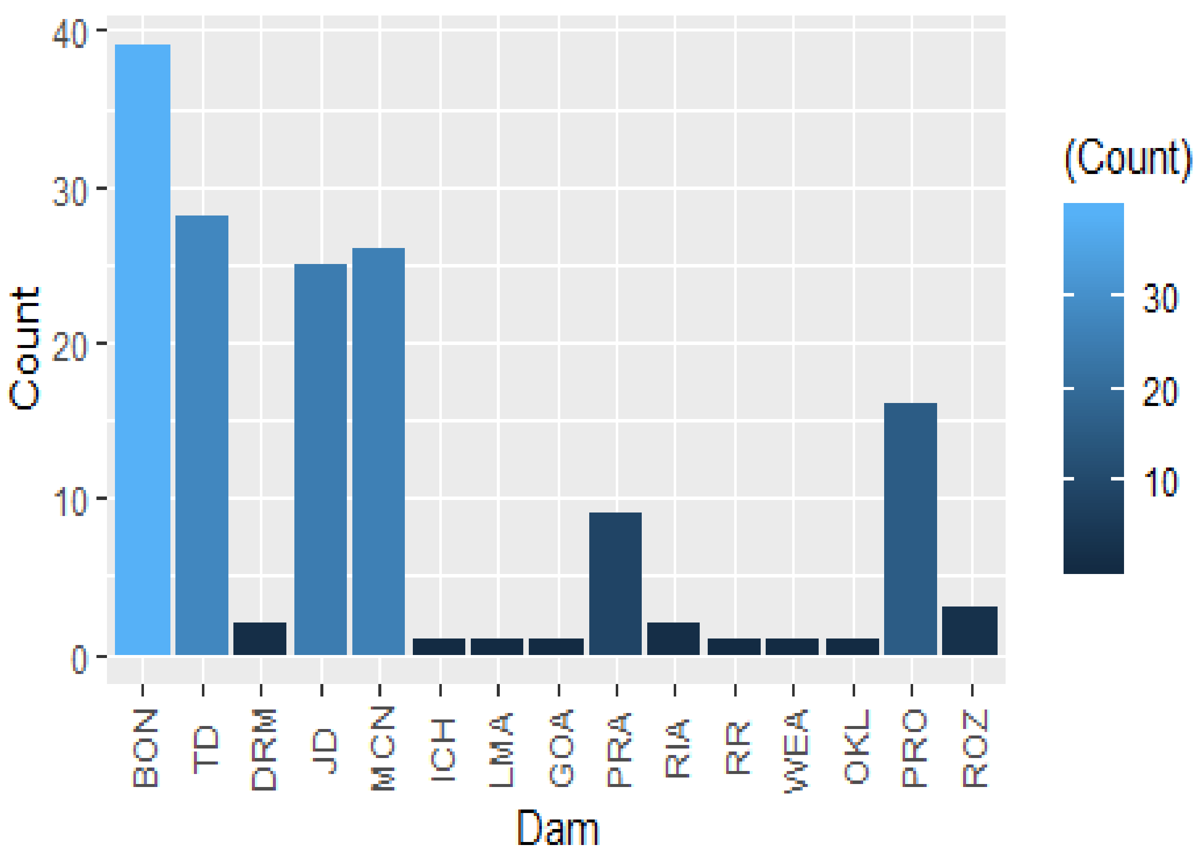

Figure 23. Number (count) of Yakima steelhead adults detected at instream PIT tag arrays at Bonneville Dam (BON), The Dalles Dam (TD), the Deschutes River mouth (DRM), John Day Dam (JDJ), McNary Dam (MCN), Ice Harbor Dam (ICH), Lower Monumental Dam (LMA), Little Goose Dam (GOA), Priest Rapids Dam (PRA), Rock Island Dam (RIA), Rocky Reach Dam (RR), Wells Dam (WEA), the Okanogan River Mouth (OKL), Prosser Dam (PRO), and Roza Dam (ROZ) in 2018. Colors represent a range of values from few (dark blue) to many (light blue).

Adult summer steelhead generally migrate into spawning tributaries between mid-February and late May. In spring of 2018, we detected 18 adult steelhead at the Taneum Creek instream PIT tag array (Figure 24). We did not observe any consistent trend between stream discharge in Taneum Creek (measured at the DOE Brain Ranch stream gauging station) and adult steelhead passage timing although 3 fish were detected on April 7 which corresponded to a sharp increase in stream discharge over a 3 day period prior to their detections (Figure 24). In contrast, 4 adults were detected on March 28 when stream discharge was at the lowest point during the adult migration.

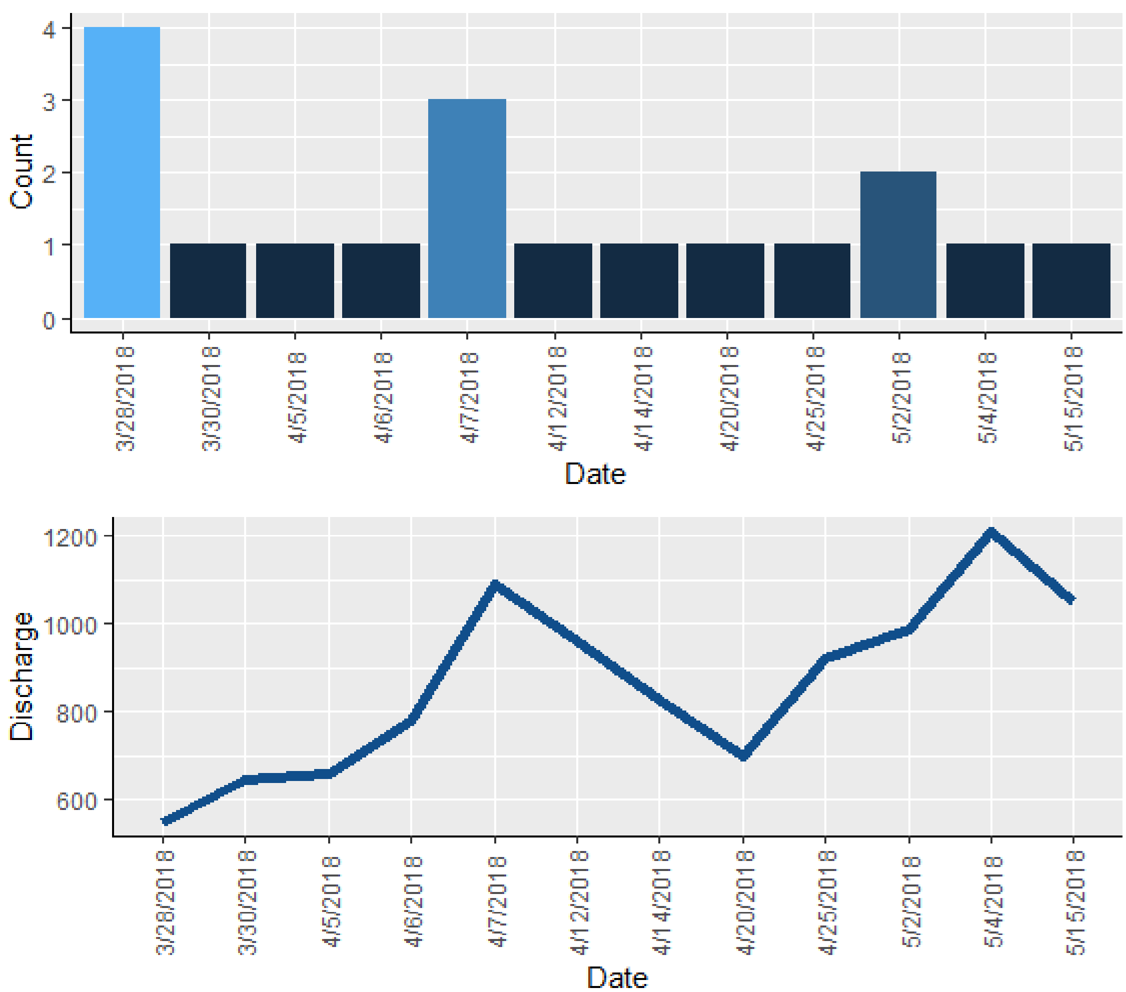

Figure 24. Mean daily stream discharge in Taneum Creek during the 2018 summer steelhead spring spawning migration and the number (count) of steelhead detected on the instream Taneum Creek PIT tag array. Bar colors represent a range of values from few (dark blue) to many (light blue).

Discussion/Conclusion

One of the primary objectives of this work is to collect population level status and trend data for the upper Yakima *O. mykiss* population (sympatric life histories). These data collection efforts are ongoing. One of the secondary benefits is that the data are collected in a manner to answer critical uncertainties associated with the interactions of life history types in this sympatric population. Little is known about how the interactions between resident and anadromous forms of *O. mykiss* affects the recovery objectives mandated for the anadromous form. Bettering our understanding of these interactions will fill these data gaps, and help facilitate our recovery efforts.

Our monitoring yielded several new and exciting results this contract period, particularly with respect to diversity and spatial structure metrics. This information will be useful for monitoring trends in the diversity and spatial structure metrics in future years that will support NOAA fisheries and the Columbia River BiOp and provide critical information improving the long term management of the sympatric life histories. Many of the variables monitored are currently being used to inform life cycle modeling efforts, and can be used in high level documents for the populations in the MPG (e.g., Steelhead at Risk Report; status assessments). Steelhead are notably the most complex species in the Pacific Salmonid group and recent research conducted under this project, and elsewhere, are beginning to improve our understanding of the complexities of this species which will in turn, support their best management.

Another useful product generated during this contract period includes the geo-referenced plot of smolt production presented at the basin scale. One strategy for recovering anadromous fish resources in the Yakima Basin is to repair fish habitat. Plots of *O. mykiss* smolt production per river kilometer in each tributary display stream reaches that are important for the natural production of anadromous steelhead trout juveniles. While we have identified the stream reaches that are producing steelhead smolts in the upper Yakima, we are working to improve the evaluation by attempting to identify causative factors. By identifying links between specific habitats and steelhead smolt production, we will be able to provide recommendations for habitat protection or specific habitat improvement actions that will benefit anadromous steelhead trout rearing. This is intended to help habitat managers prioritize actions aimed to benefit steelhead production in the freshwater rearing environment.

Adaptive Management & Lessons Learned

The instream PIT tag arrays provide a wealth of information pertaining to abundance, productivity, spatial structure, and diversity metrics: migration timing, run size, production, movement and movement/environmental relationships for example. However, the instream arrays have proven difficult to keep operational during high water discharge events. In the late fall of 2015 (November and December), two large unanticipated runoff events occurred rendering several of our instream arrays inoperable. Repair of these sites, and the installation of several large sites including the main stem Naches River, and Sunnyside Dam instream equipment coupled with a short work window arising from unusually hard winter in 2016/2017, complicated our ability to repair these sites. In instances where equipment is inoperable, we apply the 2012-2014 radio telemetry information to model the metrics for the adult abundance, and productivity until the instream equipment can be repaired. We are currently upgrading to HDPE antenna material in large high energy streams which should improve the resiliency of the instream equipment (Kazyak and Zydlewski 2012). In addition, we have redistributed much of the detection equipment in a strategy to increase the security, performance, and resiliency of our detection equipment for the future.

In 2017 we acquired three field tablet computers from the Washington Department of Fish and Wildlife and applied them to field data collection in 2018. The move to electronic data collection was an attempt to increase the efficiency and accuracy of our PIT tag data collection. The application of electronic data collection substantially reduced our data entry time and reduced PIT tag data transcription errors. We will continue to improve our electronic data collection protocols over the coming year.

The Teanaway Basin continues to produce a large proportion of the steelhead smolts originating from the upper Yakima Basin. The Teanaway also harbors a large number of steelhead spawners as evidenced from the radio telemetry data. The productivity information suggests that this basin is an important stronghold for steelhead production for the upper Yakima population despite its long history of habitat degradation. As such, we recommend continuing to pursue protective measures for fish and fish habitat in this basin, particularly when considering the potential adverse effects of climate change. Unfortunately, the headwater reaches of the Middle and West Forks of the Teanaway were severely impacted by the Jolly Mountain Wildfire during late summer in 2017. We did observe an apparent increase fish growth in the burn area in and will continue monitoring to determine if the effect persists in future years and if there is any effect on anadromous production. Finally, we have observed some of the largest number of migrants were tagged in the lowest elevations of the basin suggesting that the lower elevations of the Naches and Upper Yakima River and the main stem reach downstream from the confluence of the Naches and Yakima River are important areas for juvenile steelhead rearing. Coincidentally, these areas also contain high densities of avian and aquatic pisciverous predators known to consume large numbers of salmon and steelhead smolts (Sampson et al. 2016).

Understanding the factors influencing population productivity will be important to help focus future recovery actions intended to benefit the anadromous component of the *O. mykiss* population in the upper Yakima Basin. Preliminary modeling results indicate that steelhead productivity in the upper Yakima is influenced by a complex suite of environmental and biotic factors. Water quality, water quantity, and *O. mykiss* density appear important to population productivity. We will continue to refine the focus our productivity model and evaluation as additional information becomes available.

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Appendices

Appendix 1. Upper Yakima River genetic assessment update.

Methods

Sampling Location and Methods

Samples from adult wild steelhead (parents) were collected as they passed through Roza Dam in years 2009 through 2018 representing fish spawning in the spring each year of 2010 through 2018. Adult steelhead handled at the dam were sampled for sex, length, weight, origin, and a small fin clip was taken for genetic analysis. Fin clips were preserved in 100% ethanol and stored at room temperature.

Steelhead juveniles were collected and sampled from throughout the Yakima River and its tributaries upstream of Roza Dam via electrofishing. Captured fish scanned for presence of a PIT tag, measured for fork length and body weight. Untagged fish were given a PIT tag and a small sample of tissue was collected from each fish. Tissue samples were placed in individually labeled vials containing 100% ethanol. Scales were taken from a subset of individuals for age determination. After sampling, fish were released alive back into the river from where they were taken. Fish subsequently detected by PIT tag detectors downstream of Roza Dam were identified as migrants. Tissue from migrant juveniles was forwarded to the WDFW Molecular Genetics Laboratory for genetic processing and analysis.

Genetic Sample Processing

Samples were genotyped at the WDFW statewide steelhead panel of 379 SNPs (SW379 SNPs; Table 1) using a cost effective method based on custom amplicon sequencing called Genotyping in Thousands (GTseq, Campbell et al. 2015). Samples from previous years were genotyped using a TaqMan assay-based method implemented on a Fluidigm platform at 192 SNPs (panel E/F). The two panels overlap at 182 SNPs (Table 1). Included in both panels are three SNP loci developed to distinguish cutthroat trout (*O. clarkii*) from steelhead and rainbow trout (Table 1). Cutthroat were identified by having at least one cutthroat allele at all three species ID loci. Cutthroat x *O. mykiss* hybrids were identified by having both cutthroat and *O. mykiss* alleles at two or three loci. Any cutthroat or hybrid was removed from further analysis.

The SW379 SNP panel included 370 SNP loci developed to be used for population structure, parentage assignment, or other population genetic studies of *O. mykiss* (Table 1), three SNPs that distinguish cutthroat trout from steelhead and rainbow trout, six loci associated with run-timing in coastal steelhead (*O. mykiss irideus*), and one sex-linked locus that allowed genetic determination of sex.

To extract and isolate DNA from fin tissue from samples processed in 2018, Macherey-Nagel NucleoSpin kits ® (Macherey-Nagel, Bethlehem, PA) were used, following the recommended protocol for animal tissues. To start the library preparation, an ExoSAP cleanup was performed on10uL of extracted DNA. 1.3uL of Exonuclease I (New England BioLabs, M0293L), 0.3 uL of SAP (New England BioLabs, M0371L), 0.15uL of Exonuclease 1 Buffer (New England BioLabs, B0293S), and 1.25uL of nuclease free water were added to the extracted DNA for a combined volume of 13uL. Thermal cycling was conducted in 96-well PCR plates for all reactions and had the following conditions for the ExoSAP reaction: 37°C-60 min, 80°C-20 min, 4°C-hold. Following the ExoSAP reaction, amplification of the multiplexed pool of targeted loci was performed. The multiplex PCR cocktail reaction was 2uL of cleaned DNA extract, 3.5uL of Qiagen Multiplex PCR Plus mix (Qiagen, 10672201), and 1.5uL pooled primer mix (IDT, Tables 3 and 4, final volume = 7uL; final primer concentrations at each locus = 54nM). Thermal cycling conditions were as follows: 95°C-15 min; 5 cycles [95°C – 30 s, 5% ramp down to 57°C – 30 s, 72°C – 2 min]; 10 cycles [95°C – 30 s, 65°C – 30 s, 72°C – 30 s]; 4°C hold. Following the multiplex PCR, the amplified samples were diluted 20-fold. 3uL of diluted multiplex PCR product was then used in the barcoding PCR. The barcoding PCR is used to add indexes that identify each sample by well and by plate. For the barcoding PCR, 1uL of 10uM well-specific i5 tagging primer (IDT) and 1uL of 10uM plate-specific i7 tagging primer were added to the 3uL of amplified sample. 5uL of Qiagen Multiplex PCR Plus mix (Qiagen, 10672201) was then added for a final reaction volume of 10uL. Thermal cycling conditions were: 95°C – 15 min; 10 cycles [98°C – 10 s, 65°C – 30 s, 72°C – 30 s]; 72°C – 5 min; 4°C hold. Following the barcode PCR, each plate of samples (library) was normalized using the SequalPrepTM Normalization Plate Kit (Applied Biosystems, A1051001) according to the manufacturer's instructions. Upon completion of normalization, 10uL of each sample per 96-well plates was pooled into a 1.5mL tube constituting a library.

A purification step was then performed on each library with Agencourt AMPure® XP magnetic beads (Agencourt, A63881) according to the manufacturer's instructions for size selection with a 2:1 and 1.43:1 ratio of library to beads. The purified libraries were then eluted with 15uL of TE pH 8.0. In order to complete the final process of library preparation, each library was quantified and normalized. The libraries were quantified using a Qubit 3 Fluorometer (Invitrogen) and QubitTMdsDNA HS Assay Kit reagents (Invitrogen, Q32854) according to the manufacturer's instructions. Following the quantification, the concentration of each library was calculated using the molecular weight specific to the multiplex pool used. Then each library was normalized to 4nM and pooled with other libraries that were sequenced on the same sequencing run. Pooled libraries were then sequenced at a 2.5pM loading concentration on an Illumnia NextSeq 500 instrument of a single-end read flow cell using 111 cycles with dual-index reads of six cycles each.

To genotype the samples a bioinformatics pipeline was used (available online at https://github.com/GTseq/GTseq-Pipeline; Campbell et al. 2015). Essentially, there are a series of custom Perl scripts that ultimately create individual fastq files and genotype files for every individual that can be compiled for further analysis. Allele calling (nucleotide identification) is performed by counting amplicon-specific sequences for each allele, and allele ratios are used to determine the genotypes.

All samples were analyzed for matching genotypes. Biological data from any individuals with matching genotypes were interrogated to elucidate possible explanations for having matching genotypes. In some cases (see results), pairs or one member of a pair of samples with matching genotypes were removed from further analysis.

Evaluation of Loci

To evaluate genetic qualities of loci, we quantified several genetic parameters of the collections of adult samples collected at Roza Dam grouped by spawning year. To check for systematic scoring issues, we performed a two-tailed exact test of Hardy–Weinberg equilibrium

(HWE) for each locus in each collection using the Markov Chain method implemented in Genepop 4.2 (dememorization number 1000, batches 100, 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 4.2. Expected heterozygosity was calculated using GDA software (Lewis and Zaykin 2001).

Results and Discussion

Juvenile and Adult Sampling

Over 3,000 adult steelhead sampled at Roza Dam from 2007 through 2018 were SNP genotyped. Of those, 3,031 spawned in years 2010 through 2018 and had sufficient genetic data for parentage analysis. Of the many thousands of juvenile steelhead sampled and PIT tagged in the upper Yakima River basin, 2,392 were determined to be expressing a migrant life history, were spawned in years 2010 through 2016, and had sufficient genetic data for parentage analysis. An additional 91 non-migrant upper Yakima juveniles genotyped for baseline purposes were also included in parentage analysis, as were 26 migrant juveniles sampled in the mainstem Yakima River upstream of the mouth of the Naches, but downstream of Roza Dam.

Evaluation of Loci

Adult collections from each spawning year showed high levels of statistically significant deviations from Hardy-Weinberg Equilibrium and linkage disequilibrium suggesting natural processes that lead to deviations from HWE and LD. Adult collections were submitted to sibship analysis using COLONY to identify related individuals, which could cause HWE and LD problems if found in large proportions. Many related individuals were found in each brood year. On removal of a subset of related individuals from datasets and reanalysis slightly improved (i.e., reduced) levels of deviations from HWE or LD were observed. Four loci (A*Omy*067, A*Omy*105, A*Omy*192, and A*Omy*266) deviated from HWE in five of six brood years. Visual inspection of statistics for juvenile collections from the upper Yakima River at the same loci revealed that these loci also displayed comparably large deviations from HWE expectations that were not statistically significant at the $\alpha = 0.05$ level. Differences in statistical significance thus appear likely due to sample size differences (i.e., the Roza Dam adult collections are much larger than juvenile collections). These loci do not show other evidence of scoring issues and do not show high levels of HWE or LD issues in other Washington *O. mykiss* collections. Weak population structure is evident in the upper Yakima River (not shown). Thus, it may not be appropriate to analyze all adults sampled at Roza Dam as if they were one spawning population. Further investigation is needed; if population structure is strong enough for assignment tests, samples could be assigned and parsed into populations prior to analysis for deviations from HWE and LD. Nevertheless, the inclusion of them in parentage assignment analysis should not affect the accuracy or precision of parent assignments.

Matching genotypes and resampling adults

One hundred five pairs of adults from spawn years 2010 to 2017 had matching genotypes. Many pairs were the same fish sampled in two different spawn years, i.e., repeat spawners, verified by recaptured PIT tag numbers. Other pairs appeared to be repeat spawners based on the spawn years in which they were sampled, but were not verified by PIT tag information. Finally, many other pairs were fish sampled twice in the same spawn year, which could be fish that dropped back downstream over Roza Dam, re-ascended, and were sampled a second time.

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Table 1. List of general use, diploid single nucleotide polymorphic (SNP) loci genotyped in Yakima River steelhead

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_aspAT-123	AOmy005	Y	Y	T	C	General	(Campbell and Narum 2009; Campbell et al. 2009)
Omy_CRB2677.106	AOmy010	Y	N	G	T	General	(Sprowles et al. 2006)
Omy_e1-147	AOmy014	Y	Y	G	T	General	(Sprowles et al. 2006)
Omy_gdh-271	AOmy015	Y	Y	C	T	General	(Campbell et al. 2009)
Omy_GH1P1_2	AOmy016	Y	Y	C	T	General	(Aguilar and Garza 2008)
Omy_LDHB-2_e5	AOmy021	Y	Y	T	C	General	(Aguilar and Garza 2008)
Omy_MYC_2	AOmy023	Y	Y	T	C	General	(Aguilar and Garza 2008)
Omy_myoD-178	AOmy026	Y	Y	A	C	General	(Campbell et al. 2009)
Omy_nkef-241	AOmy027	Y	Y	C	A	General	(Campbell et al. 2009)
Omy_nramp-146	AOmy028	Y	N	G	A	General	(Campbell et al. 2009)
Omy_Ogo4-212	AOmy029	Y	Y	T	C	General	(Campbell et al. 2009)
Omy_BAC-F5.284	AOmy042	Y	Y	C	T	General	(Limborg et al. 2012)
Omy_u07-79-166	AOmy047	Y	Y	G	T	General	(Limborg et al. 2012)
Omy_113490-159	AOmy048	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_114315-438	AOmy049	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_121713-115	AOmy051	Y	N	T	A	General	(Abadía-Cardoso et al. 2011)
Omy_128693-455	AOmy056	Y	Y	T	C	General	(Abadía-Cardoso et al. 2011)
Omy_130524-160	AOmy058	Y	Y	C	G	General	(Abadía-Cardoso et al. 2011)
Omy_187760-385	AOmy059	Y	Y	A	T	General	(Abadía-Cardoso et al. 2011)
Omy_96222-125	AOmy061	Y	Y	T	C	General	(Abadía-Cardoso et al. 2011)
Omy_97077-73	AOmy062	Y	Y	T	A	General	(Abadía-Cardoso et al. 2011)
Omy_97954-618	AOmy065	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_aromat-280	AOmy067	Y	Y	T	C	General	WSU - J. DeKoning unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_arp-630	AOmy068	Y	Y	G	A	General	(Campbell et al. 2009)
Omy_cd59b-112	AOmy072	Y	Y	C	T	General	WSU - J. DeKoning unpubl.
Omy_colla1-525	AOmy073	Y	Y	C	T	General	WSU - J. DeKoning unpubl.
Omy_cox2-335	AOmy074	Y	Y	T	G	General	WSU - J. DeKoning unpubl.
Omy_g1-103	AOmy078	Y	Y	T	C	General	(Stephens et al. 2009)
Omy_g12-82	AOmy079	Y	Y	T	C	General	WSU - J. DeKoning unpubl.
Omy_gh-475	AOmy081	Y	Y	C	T	General	(Campbell et al. 2009)
Omy_gsdf-291	AOmy082	Y	Y	T	C	General	WSU - J. DeKoning unpubl.
Omy_hsc715-80	AOmy084	Y	Y	C	A	General	WDFW - S. Young unpubl.
Omy_hsp47-86	AOmy087	Y	Y	T	A	General	WDFW - S. Young unpubl.
Omy_hsp70aPro-329	AOmy088	Y	Y	A	G	General	(Campbell and Narum 2009)
Omy_hsp90BA-193	AOmy089	Y	Y	C	T	General	(Campbell and Narum 2009)
Omy_IL17-185	AOmy091	Y	Y	G	A	General	WSU - J. DeKoning unpubl.
Omy_IL1b-163	AOmy092	Y	Y	T	G	General	WSU - J. DeKoning unpubl.
Omy_inos-97	AOmy094	Y	Y	C	A	General	WSU - J. DeKoning unpubl.
Omy_mapK3-103	AOmy095	Y	Y	A	T	General	CRITFC - N. Campbell unpubl.
Omy_mcsf-268	AOmy096	Y	Y	T	C	General	WSU - J. DeKoning unpubl.
Omy_nach-200	AOmy100	Y	Y	A	T	General	WSU - J. DeKoning unpubl.
Omy_OmyP9-180	AOmy105	Y	Y	C	G	General	(Sprowles et al. 2006)
Omy_Ots249-227	AOmy107	Y	Y	C	T	General	(Campbell et al. 2009)
Omy_oxct-85	AOmy108	Y	Y	A	T	General	WSU - J. DeKoning unpubl.
Omy_star-206	AOmy110	Y	Y	A	G	General	WSU - J. DeKoning unpubl.
Omy_stat3-273	AOmy111	Y	Y	G	Deletion	General	WSU - J. DeKoning unpubl.
Omy_tlr3-377	AOmy113	Y	Y	C	T	General	WSU - J. DeKoning unpubl.
Omy_tlr5-205	AOmy114	Y	Y	T	A	General	WSU - J. DeKoning unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_u09-52.284	AOmy117	Y	Y	T	G	General	(Limborg et al. 2012)
Omy_u09-53.469	AOmy118	Y	Y	T	C	General	(Limborg et al. 2012)
Omy_u09-54-311	AOmy120	Y	Y	C	T	General	WDFW - S. Young unpubl.
Omy_u09-55-233	AOmy123	Y	N	A	G	General	(Limborg et al. 2012)
Omy_u09-56.119	AOmy125	Y	Y	T	C	General	(Limborg et al. 2012)
Omy_BAMBI4.238	AOmy129	Y	Y	T	C	General	WDFW - S. Young unpubl.
Omy_G3PD_2.246	AOmy132	Y	Y	C	T	General	WDFW - S. Young unpubl.
Omy_Il-1b_.028	AOmy134	Y	Y	T	C	General	WDFW - S. Young unpubl.
Omy_u09-61.043	AOmy137	Y	Y	A	T	General	WDFW - S. Young unpubl.
Omy_UT16_2-173	AOmy144	Y	Y	C	T	General	WDFW - S. Young unpubl.
Omy_U11_2b-154	AOmy147	Y	Y	T	C	General	WDFW - S. Young unpubl.
Omy_gluR-79	AOmy149	Y	Y	C	T	General	CRITFC - unpubl.
Omy_SECC22b-88	AOmy152	Y	Y	T	C	General	CRITFC - unpubl.
BH2VHSVip10	AOmy173	Y	N	C	T	General	Pascal & Hansen unpubl.
OMS00003	AOmy174	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00013	AOmy176	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00018	AOmy177	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00041	AOmy179	Y	Y	G	C	General	(Sánchez et al. 2009)
OMS00048	AOmy180	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00052	AOmy181	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00053	AOmy182	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00056	AOmy183	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00057	AOmy184	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00061	AOmy185	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00062	AOmy186	Y	Y	T	C	General	(Sánchez et al. 2009)

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
OMS00064	AOmy187	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00071	AOmy189	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00072	AOmy190	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00078	AOmy191	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00087	AOmy192	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00089	AOmy193	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00090	AOmy194	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00092	AOmy195	Y	Y	A	C	General	(Sánchez et al. 2009)
OMS00103	AOmy197	Y	Y	A	T	General	(Sánchez et al. 2009)
OMS00105	AOmy198	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00112	AOmy199	Y	Y	A	T	General	(Sánchez et al. 2009)
OMS00116	AOmy200	Y	Y	T	A	General	(Sánchez et al. 2009)
OMS00118	AOmy201	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00119	AOmy202	Y	Y	A	T	General	(Sánchez et al. 2009)
OMS00120	AOmy203	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00121	AOmy204	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00127	AOmy205	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00128	AOmy206	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00132	AOmy207	Y	Y	A	T	General	(Sánchez et al. 2009)
OMS00133	AOmy208	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00134	AOmy209	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00153	AOmy210	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00154	AOmy211	Y	Y	A	T	General	(Sánchez et al. 2009)
OMS00156	AOmy212	Y	Y	A	T	General	(Sánchez et al. 2009)
OMS00164	AOmy213	Y	Y	T	G	General	(Sánchez et al. 2009)

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
OMS00169	AOmy214	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00175	AOmy215	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00176	AOmy216	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00180	AOmy218	Y	Y	T	G	General	(Sánchez et al. 2009)
Omy_1004	AOmy220	Y	Y	A	T	General	(Hansen et al. 2011)
Omy_101554-306	AOmy221	Y	Y	T	C	General	(Abadía-Cardoso et al. 2011)
Omy_101832-195	AOmy222	Y	Y	A	C	General	(Abadía-Cardoso et al. 2011)
Omy_101993-189	AOmy223	Y	Y	A	T	General	(Abadía-Cardoso et al. 2011)
Omy_102505-102	AOmy225	Y	Y	A	G	General	(Abadía-Cardoso et al. 2011)
Omy_102867-443	AOmy226	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_103705-558	AOmy227	Y	Y	T	C	General	(Abadía-Cardoso et al. 2011)
Omy_104519-624	AOmy228	Y	Y	T	C	General	(Abadía-Cardoso et al. 2011)
Omy_104569-114	AOmy229	Y	Y	A	C	General	(Abadía-Cardoso et al. 2011)
Omy_105075-162	AOmy230	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_105385-406	AOmy231	Y	Y	T	C	General	(Abadía-Cardoso et al. 2011)
Omy_105714-265	AOmy232	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_107031-704	AOmy233	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_107285-69	AOmy234	Y	Y	C	G	General	(Abadía-Cardoso et al. 2011)
Omy_107336-170	AOmy235	Y	Y	C	G	General	(Abadía-Cardoso et al. 2011)
Omy_107806-34	AOmy237	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_108007-193	AOmy238	Y	Y	A	G	General	(Abadía-Cardoso et al. 2011)
Omy_109243-222	AOmy239	Y	Y	A	C	General	(Abadía-Cardoso et al. 2011)
Omy_109525-403	AOmy240	Y	Y	A	G	General	(Abadía-Cardoso et al. 2011)
Omy_110064-419	AOmy241	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_110078-294	AOmy242	Y	N	A	G	General	(Abadía-Cardoso et al. 2011)

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_110362-585	AOmy243	Y	Y	G	A	General	(Abadía-Cardoso et al. 2011)
Omy_110689-148	AOmy244	Y	Y	A	C	General	(Abadía-Cardoso et al. 2011)
Omy_111084-526	AOmy246	Y	Y	A	C	General	(Abadía-Cardoso et al. 2011)
Omy_111383-51	AOmy247	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_111666-301	AOmy248	Y	Y	T	A	General	(Abadía-Cardoso et al. 2011)
Omy_112301-202	AOmy249	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_112820-82	AOmy250	Y	Y	G	A	General	(Abadía-Cardoso et al. 2011)
Omy_114976-223	AOmy252	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_116733-349	AOmy253	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_116938-264	AOmy254	Y	Y	A	G	General	(Abadía-Cardoso et al. 2011)
Omy_117259-96	AOmy255	Y	N	T	C	General	(Abadía-Cardoso et al. 2011)
Omy_117286-374	AOmy256	Y	Y	A	T	General	(Abadía-Cardoso et al. 2011)
Omy_117370-400	AOmy257	Y	Y	A	G	General	(Abadía-Cardoso et al. 2011)
Omy_117540-259	AOmy258	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_117815-81	AOmy260	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_118175-396	AOmy261	Y	Y	T	A	General	(Abadía-Cardoso et al. 2011)
Omy_118205-116	AOmy262	Y	Y	A	G	General	(Abadía-Cardoso et al. 2011)
Omy_118654-91	AOmy263	Y	Y	A	G	General	(Abadía-Cardoso et al. 2011)
Omy_120255-332	AOmy265	Y	Y	A	T	General	(Abadía-Cardoso et al. 2011)
Omy_128996-481	AOmy266	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_129870-756	AOmy267	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_131460-646	AOmy268	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_98683-165	AOmy269	Y	Y	A	C	General	(Abadía-Cardoso et al. 2011)
Omy_cyp17-153	AOmy270	Y	Y	C	T	General	WSU - J. DeKoning unpubl.
Omy_ftzf1-217	AOmy271	Y	Y	A	T	General	WSU - J. DeKoning unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_GHSR-121	AOmy272	Y	Y	T	C	General	CRITFC - unpubl.
Omy_metA-161	AOmy273	Y	Y	T	G	General	CRITFC - unpubl.
Omy_UBA3b	AOmy274	Y	Y	A	T	General	(Hansen et al. 2011)
M09AAC.055	AOmy275	Y	Y	C	T	General	WDFW - S. Young unpubl.
M09AAE.082	AOmy276	Y	Y	T	G	General	WDFW - S. Young unpubl.
OMGH1PROM1-SNP1	AOmy277	Y	Y	A	T	General	(Abadía-Cardoso et al. 2011)
OMS00015	AOmy279	Y	Y	A	T	General	(Sánchez et al. 2009)
OMS00024	AOmy280	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00070	AOmy283	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00074	AOmy284	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00096	AOmy285	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00111	AOmy286	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00149	AOmy288	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00173	AOmy289	Y	Y	T	C	General	(Sánchez et al. 2009)
Omy_105105-448	AOmy290	Y	Y	C	T	General	(Abadía-Cardoso et al. 2011)
Omy_110201-359	AOmy291	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
Omy_128923-433	AOmy292	Y	Y	T	C	General	(Abadía-Cardoso et al. 2011)
Omy_anp-17	AOmy293	Y	Y	C	A	General	CRITFC - N. Campbell unpubl.
Omy_bcAKala-380rd	AOmy294	Y	Y	G	A	General	CRITFC - N. Campbell unpubl.
Omy_cin-172	AOmy295	Y	Y	C	T	General	CRITFC - N. Campbell unpubl.
Omy_ndk-152	AOmy296	Y	Y	A	G	General	CRITFC - N. Campbell unpubl.
Omy_nips-299	AOmy297	Y	Y	T	Deletion	General	CRITFC - N. Campbell unpubl.
Omy_ntl-27	AOmy298	Y	Y	G	A	General	CRITFC - N. Campbell unpubl.
Omy_rbm4b-203	AOmy299	Y	Y	Deletion	T	General	CRITFC - N. Campbell unpubl.
Omy_sys1-188	AOmy300	Y	Y	C	A	General	CRITFC - N. Campbell unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_txnip-343	AOmy301	Y	Y	T	C	General	CRITFC - N. Campbell unpubl.
Omy_vamp5-303	AOmy302	Y	Y	A	Deletion	General	CRITFC - N. Campbell unpubl.
Omy_vatf-406	AOmy303	Y	Y	T	C	General	CRITFC - N. Campbell unpubl.
OMS00077	AOmy305	Y	Y	C	G	General	(Sánchez et al. 2009)
OMS00101	AOmy306	Y	Y	A	G	General	(Sánchez et al. 2009)
Omy_G3PD_2-371	AOmy311	Y	Y	C	A	General	CRITFC - N. Campbell unpubl.
Omy_redd1-410	AOmy320	Y	Y	C	T	General	CRITFC - N. Campbell unpubl.
Omy_srp09-37	AOmy322	Y	Y	C	T	General	CRITFC - N. Campbell unpubl.
OMY1011SNP	AOmy324	Y	Y	C	A	General	(Hansen et al. 2011)
OMS00068	AOmy326	Y	Y	A	G	General	(Sánchez et al. 2009)
OMS00079	AOmy327	Y	Y	T	C	General	(Sánchez et al. 2009)
OMS00106	AOmy328	Y	Y	T	G	General	(Sánchez et al. 2009)
OMS00179	AOmy329	Y	Y	A	C	General	(Sánchez et al. 2009)
Omy_114587-480	AOmy331	Y	Y	T	G	General	(Abadía-Cardoso et al. 2011)
OMS00017	AOmy335	Y	Y	A	G	General	(Sánchez et al. 2009)
Omy_metB-138	AOmy341	Y	Y	T	A	General	CRITFC - unpubl.
Ocl_Okerca	ASpI001	Y	N	T	C	species ID	(McGlauflin et al. 2010)
Omy_F5_136	ASpI014	Y	N	C	G	species ID	(Finger et al. 2009)
Omy_Omyclmk438-96	ASpI018	Y	Y	A	C	species ID	CRITFC - unpubl.
Omy_myclarp404-111	ASpI016	N	Y	T	G	species ID	CRITFC - unpubl.
M09AAD.076	NA	N	Y	T	C	General	CRITFC - unpubl.
M09AAJ.163	NA	N	Y	T	C	General	CRITFC - unpubl.
Ocl_gshpx-357	NA	N	Y	G	T	species ID	CRITFC - unpubl.
OMS00002	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00006	NA	N	Y	T	C	General	CRITFC - unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
OMS00008	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00014	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00030	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00039	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00058	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00095	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00114	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00129	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00138	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00143	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00151	NA	N	Y	T	C	General	CRITFC - unpubl.
OMS00174	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_109894-185	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_97660-230	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_97865-196	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_99300-202	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_ada10-71	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_aldB-165	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_b1-266	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_b9-164	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_BAC-B4-324	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_BAMBI2.312	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_ca050-64	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_carban1-264	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_cd28-130	NA	N	Y	T	C	General	CRITFC - unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_cd59-206	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_cox1-221	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_crb-106	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_gadd45-332	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_hsf1b-241	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_hsf2-146	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_hus1-52	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_Il1b-198	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_IL6-320	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_impa1-55	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_LDHB-1_i2	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_LDHB-2_i6	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_lpl-220	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_NaKATPa3-50	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_nxt2-273	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_p53-262	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_pad-196	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_ppie-232	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD16104-20	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD17632-23	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD23577-43	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD26080-69	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD29700-18	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD35417-9	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD36848-7	NA	N	Y	T	C	General	CRITFC - unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_RAD38269-10	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD42793-59	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD43612-42	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD45104-18	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD47080-54	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD47444-53	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD47955-51	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD48799-69	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD52458-17	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD52812-28	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD58213-70	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD58835-15	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD62596-38	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD66218-58	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD66834-17	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD69583-33	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD7210-8	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD73204-63	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD74691-49	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD76882-63	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD77789-54	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD88028-7	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD88122-32	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_rapd-167	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_sast-264	NA	N	Y	T	C	General	CRITFC - unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_sSOD-1	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_zg57-91	NA	N	Y	T	C	General	CRITFC - unpubl.
OmyY1_2SEXY	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_CRBF1-1	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_GREB1_03	NA	N	Y	T	C	summer/winter associated	CRITFC - unpubl.
Omy_GREB1_05	NA	N	Y	T	C	summer/winter associated	CRITFC - unpubl.
Omy_GREB1_06	NA	N	Y	T	C	summer/winter associated	CRITFC - unpubl.
Omy_GREB1_07	NA	N	Y	T	C	summer/winter associated	CRITFC - unpubl.
Omy_GREB1_09	NA	N	Y	T	C	summer/winter associated	CRITFC - unpubl.
Omy_GREB1_10	NA	N	Y	T	C	summer/winter associated	CRITFC - unpubl.
Omy_RAD103359-45	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD10733-10	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD10945-51	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD116-59	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD1186-59	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD12439-64	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD12566-14	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD13034-67	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD13073-16	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD13499-13	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD14033-46	NA	N	Y	T	C	General	CRITFC - unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_RAD14269-30	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD14541-72	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD15709-53	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD1751-18	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD17849-16	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD18903-48	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD1919-22	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD19340-24	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD19578-59	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD20917-11	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD22123-69	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD2277-7	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD23354-66	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD23894-58	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD24287-74	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD24343-29	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD25042-68	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD25266-23	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD2567-8	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD25907-57	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD26691-36	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD27740-55	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD28236-38	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD29352-6	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD29559-69	NA	N	Y	T	C	General	CRITFC - unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_RAD2976-26	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD30230-25	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD30243-74	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD30392-17	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD30619-61	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD31079-58	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD31408-67	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD3209-10	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD32139-58	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD33122-47	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD33798-24	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD35005-13	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD35149-9	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD3651-48	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD366-7	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD36952-53	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD37492-53	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD37816-68	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD38406-19	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD39156-33	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD3926-22	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD40132-55	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD40520-48	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD40641-58	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD41594-34	NA	N	Y	T	C	General	CRITFC - unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_RAD42465-32	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD43117-55	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD43573-37	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD43694-41	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD45246-10	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD46314-35	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD46452-51	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD46672-27	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD4848-14	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD49111-35	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD49637-74	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD49827-67	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD50632-21	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD5374-56	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD54441-29	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD55404-54	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD55997-10	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD57916-29	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD59758-41	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD59950-44	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD60135-12	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD619-59	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD65808-68	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD65959-69	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD66402-36	NA	N	Y	T	C	General	CRITFC - unpubl.

Locus Name	WDFW nickname	Panel E/F	Omy379	Allele 1	Allele 2	Purpose	Reference
Omy_RAD68634-40	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD7016-31	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD72528-44	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD7384-50	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD739-59	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD73963-73	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD76060-20	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD76570-62	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD78147-27	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD78502-57	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD78776-10	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD79314-58	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD85131-35	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD86706-72	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD9004-13	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD92485-64	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD93580-37	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD9408-71	NA	N	Y	T	C	General	CRITFC - unpubl.
Omy_RAD98715-53	NA	N	Y	T	C	General	CRITFC - unpubl.

Primer and probe sequences for unpublished loci available by request.

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