Yakima Steelhead VSP Project

Resident/Anadromous Interactions Monitoring

BPA Project # 2010-030-00

Report covers work performed under BPA contract #(s) 70353

Report was completed under BPA contract #(s) 70353

1/1/2016 - 12/31/2016

[1]Gabriel M. Temple, [1]Ryan Fifield, [1]Ryan E. Steele,
[2]Chris Frederiksen, [2]Zack Mays, and [3]Todd Seamons

[1]Washington Department of Fish and Wildlife (WDFW), Olympia, WA, 98501
[2]Yakama Confederated Tribes, Toppenish, WA, 98948
[3]Washington Department of Fish and Wildlife Molecular Genetics Laboratory, Olympia, WA 98501

Report Created 09-2016

"This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA."

Abstract

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 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 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, and the fewest from high elevation tributaries and this trend does not necessarily correlate with anadromous spawner abundance. Finally, we endured several flood events that jeopardized much of our instream PIT tag detection infrastructure in 2016. Although much of the instream components of our interrogation system were destroyed during these flooding events, this did provide an opportunity to replace much of the instream equipment with improved designs that should improve the long-term performance of our monitoring network.

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 evolutionary significant unit) 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 the 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 (2 fish over 10 inches in 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 (Yakima Sub-basin Fish and Wildlife Planning Board 2004a) identified several key uncertainties and prioritized research needs consistent with steelhead recovery in the Yakima Basin. In 2009, a final draft of the Yakima Steelhead Recovery Plan was developed that addressed key uncertainties associated with steelhead recovery in the Yakima Major Population Group (MPG; Yakima Subbasin Fish and Wildlife Planning Board 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. 2009) 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; Kendal 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 et al. 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 2006). 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

General

The general conceptual design associated with this project is to use large scale PIT tagging efforts of rearing *O. mykiss* and subsequent detection histories to partition the life histories into their respective anadromous or resident components. Rearing juvenile *O. mykiss* are tagged in their natal tributaries. The proportion of the tags that are detected at downstream locations during the smolt outmigration are assigned to the anadromous life history. The remaining tagged fish that are not detected as migrants are assigned to the resident life history. One complication is that multiple age classes of juveniles are collected and tagged during the tagging period, so the anadromous component from any tagging event in any given year may not be detected for several years post tagging. We address this issue by collecting scale samples from each juvenile fish tagged so we can assign each fish to the appropriate cohort. In addition, genetic samples are collected from each fish at the time of tagging. Since nearly 100% of the adult steelhead returning to the Upper Yakima are genetically sampled at Roza Dam, we use genetic parentage assignments to assign anadromous smolts detected during each smolt migration to its respective parents. In cases that no parents are assigned, smolts are assigned to resident parents by default. The influence of the resident trout population on steelhead production is of particular interest given the uncertainty surrounding this phenomenon. We describe the information generated from our tagging program in this report in the context of the

VSP parameters abundance, productivity, spatial structure, and diversity for the upper Yakima *O. mykiss* population.

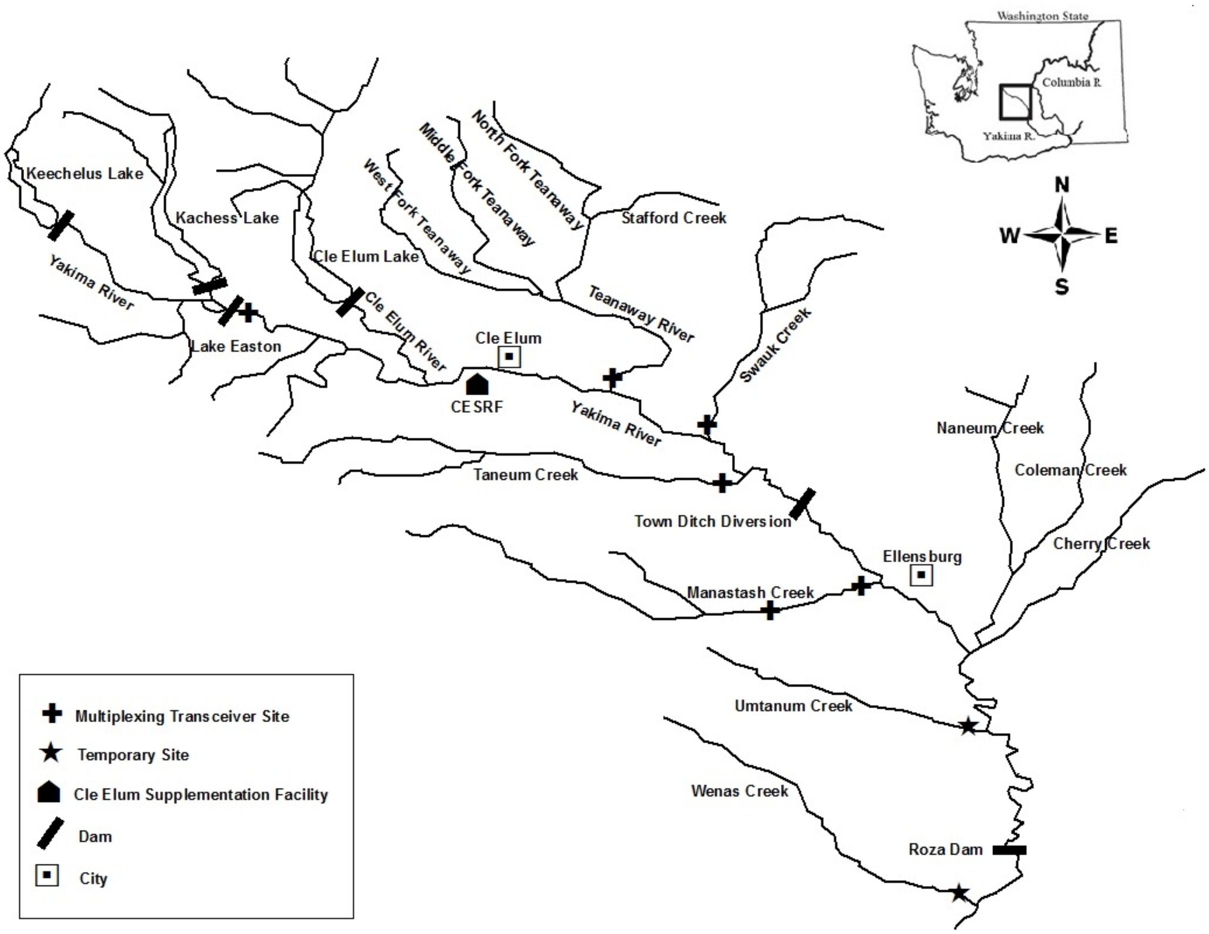

Figure 1. Map of the upper Yakima River basin and fish interrogation sites.

The upper Yakima River contains a unique monitoring infrastructure that complements our study (Figure 1). First, all migratory fish species entering the upper Yakima Basin must pass through the Roza Adult Monitoring Facility (RAMF) to gain access to the basin. All fish entering the facility enter a fish trap where they can be biologically sampled and returned to the river to continue their upstream migration. The majority of the upper Yakima Steelhead population spawn upstream from Roza Dam in the spring such that fish enumerated in the facility represent ~80%-90% of the run escapement estimate for this population (Figure 1; Frederiksen et al. 2015). The remaining proportion of the upper Yakima Steelhead population spawn in Wenas Creek and Mainstem areas below Roza Dam. Although some fish ascend the dam in the fall (e.g., October) and overwinter in the upper Yakima, the majority of the spawning migration occurs in the spring (e.g., March). The annual run escapement is corrected for pre-spawn mortality to estimate annual spawner escapement. Detailed methods used to generate the total annual spawning escapement for the upper Yakima steelhead population are presented in Frederiksen et al. (2015).

Juvenile abundance estimates in tributary streams were generated following backpack electrofishing methods as described in monitoringmethods.org (method 118). Juvenile abundance estimates in the main stem Yakima River were generated following drift boat electrofishing methods as detailed in monitoringmethods.org (method 120). Juvenile abundance estimates of rearing *O. mykiss* were partitioned into life history types following published protocols described in monitoringmethods.org (protocol 2165) utilizing recapture information of fish that have been previously PIT tagged (method 1736). Rearing *O. mykiss* juveniles were assigned to the appropriate age class using scale ageing techniques following methods published in monitoringmethods.org (method 1360; method 1090). Genetic samples collected at the time of tagging (juveniles) or at Roza Dam (adult steelhead) were combined in a Parentage Analysis to determine the maternal/paternal origins of the steelhead smolt juvenile migrants. Juvenile migrants that did not assign to at least one steelhead parent were assumed to be the progeny of resident/resident matings by default.

Abundance

Adult VSP parameters generated during 2016 were described in detail under contract 56662:REL87 (Frederiksen et al. 2016). Much of the adult information collected under that contract is incorporated in to this evaluation when appropriate (primarily the metrics associated with the upper Yakima population). However, the detailed descriptions of adult sampling and results are provided in Frederiksen et al. (2016).

Juvenile abundance estimates were collected under the Yakima Klickitat Fisheries Project’s Non-Target Taxa of Concern program (1995-063-25). Index monitoring sites were established upper Yakima Basin tributaries as early as 1990. Site selection criteria were described in detail in McMichael et al. (1992). Abundance estimates were generated using efficiency expansions to maintain consistency with historical data collection methods (Temple et al. 2011).

Gaining an understanding of the complex life history traits expressed in this population requires a substantial number of rearing juvenile *O. mykiss* be PIT tagged for subsequent monitoring. Our objective was to capture, sample, and release 10,000 juveniles in their natal streams throughout the upper Yakima Basin. Our annual target was to capture and tag a minimum of 1000 fish annually in tributaries, including Taneum Creek (TAN), Swauk Creek (SWK), the North (NFT), Middle (MFT), and West (WFT) forks of the Teanaway River as well as the main stem Teanaway River (MST), Manastash Creek (MAN), and 4000 fish in the main stem Yakima River (YAK). In addition, we continued our juvenile tagging effort in the Naches Basin during in 2016 (Figure 2). Additional fish were also tagged under other closely related monitoring projects (e.g., project 1995-063-25) but their bio-data and tagging histories prove beneficial to this project.

Fish are captured as rearing juveniles using back pack mounted electrofishing units using straight DC current. Captured fish are measured, weighed, PIT tagged, and a small genetic sample is collected and stored in ethanol. All sampled fish also have scale samples collected to facilitate age determination at a future date. Scale samples are collected and placed in the vials containing each individual fish’s genetic sample and stored at the Washington Department of Fish and Wildlife’s Ellensburg District 8 Field Office until processed. The number and location of juvenile *O. mykiss* PIT tags deployed are presented in Figure 2.

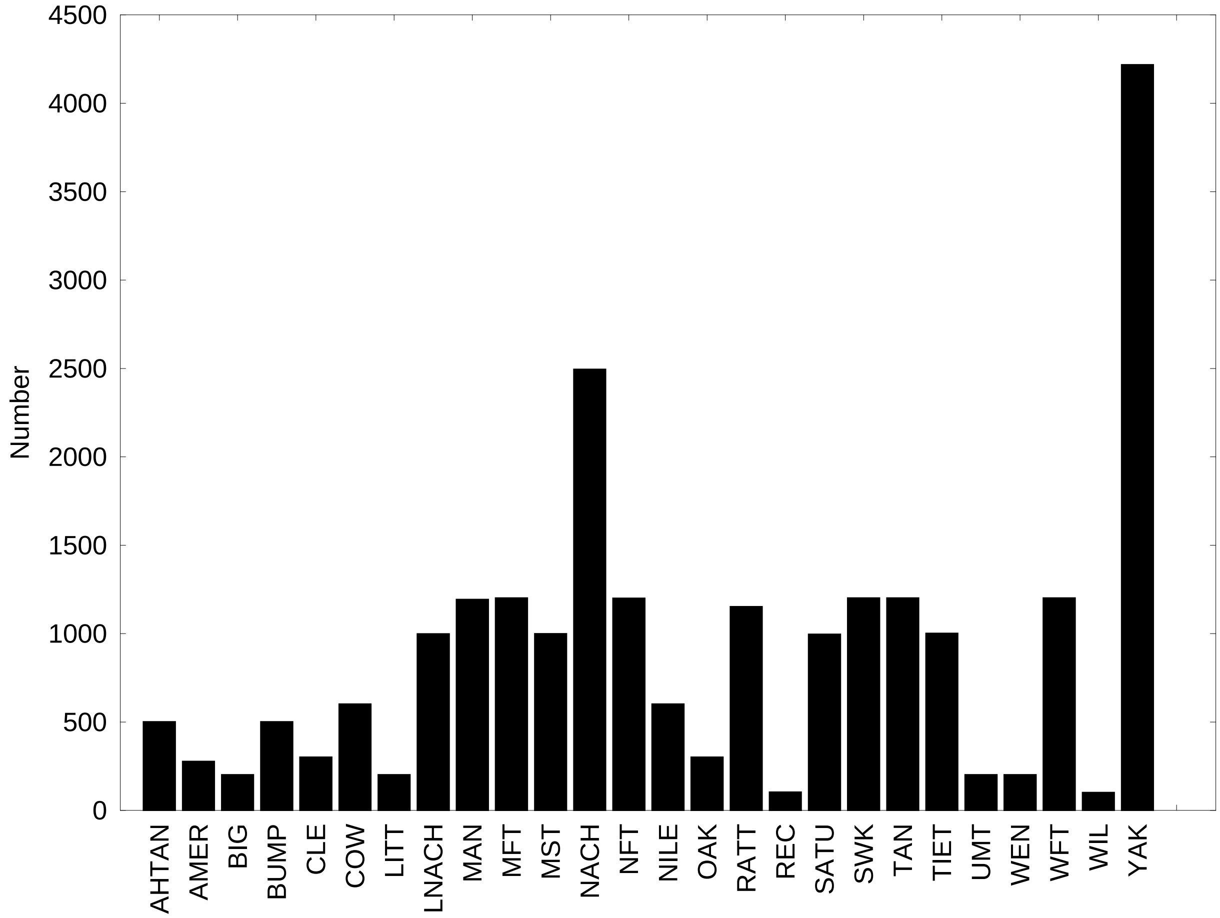

Figure 2. Number of *O. mykiss* PIT tagged in Ahtanum Creek (AHTAN), the American River (AMER), Big Creek (BIG), the Bumping River (BUMP), the Cle Elum River (CLE), Cowichee Creek (COW), Little Creek (LITT), the Little Naches River (LNACH), Manastash Creek (MAN), Middle Fork Teanaway River (MFT), Mainstem Teanaway River (MST), Naches River (NACH), North Fork Teanaway River (NFT), Nile Creek (NILE), Oak Creek (OAK), Rattlesnake Creek (RATT), Reecer Creek (REC), Satus Creek (SATU), Swauk Creek (SWK), Taneum Creek (TAN), the Tieton River (TIET), Umtanum Creek (UMT), Wenas Creek (WEN), West Fork Teanaway River (WFT), Wilson Creek (WIL), and the Yakima River (YAK), in 2016.

Instream PIT tag interrogation sites were strategically located near the mouth of the major upper Yakima tributary streams (Figure 1) accessible to steelhead in order to partition tributary and mainstem Yakima River spawners (protocol 2165). Previous work indicated that very few steelhead ascend Easton Dam so interrogation equipment was not installed on tributaries upstream from that point (Karp et al. 2009; Frederiksen et al. 2015). We did install a temporary pass through antenna in the adult ladder to verify our assumption. The Bureau of

Reclamation irrigation reservoirs establish the upper limit for anadromous fish distribution in the Upper Yakima Basin because they currently do not contain fish passage facilities. Finally, numerous irrigation diversions located throughout the low elevation agriculture lands north of the city of Ellensburg, WA are thought to block anadromous fish passage so we did not install or operate fish monitoring equipment in them (Figure 1). Thus, the major tributaries accessible to steelhead spawners are monitored utilizing instream PIT tag monitoring equipment, and spawners in the main stem Yakima River are estimated by subtraction. This allows us to identify important major and minor spawning areas throughout the basin.

The instream PIT tag interrogation sites were installed to detect fish movement timing and patterns. However, two unusually high water runoff events in November and December 2015 destroyed much of our instream detection equipment in the winter of 2015/2016 (Figure 3). The maximum daily stream discharge increased from 685 cfs to 9491cfs in less than 24h during a December flooding event in the Teanaway Basin (Figure 3). The short timeframe and lack of warning prevented us from taking preventative measures to remove our bankside equipment prior to the flood event. The rapid increase in stream discharge flooded our electronics at our lower Mainstem Teanaway Array site rendering it inoperable (LMT; Figure 4). We removed the sensitive electronics, transported them to the WDFW district office, disassembled the circuit boards, and scrubbed them with distilled water and a toothbrush in attempt to salvage the equipment. Preliminary tests indicate we were successful. Finally, we estimated movement and timing using the average observations from the previous three years given the equipment failure experienced during the winter 2015/2016.

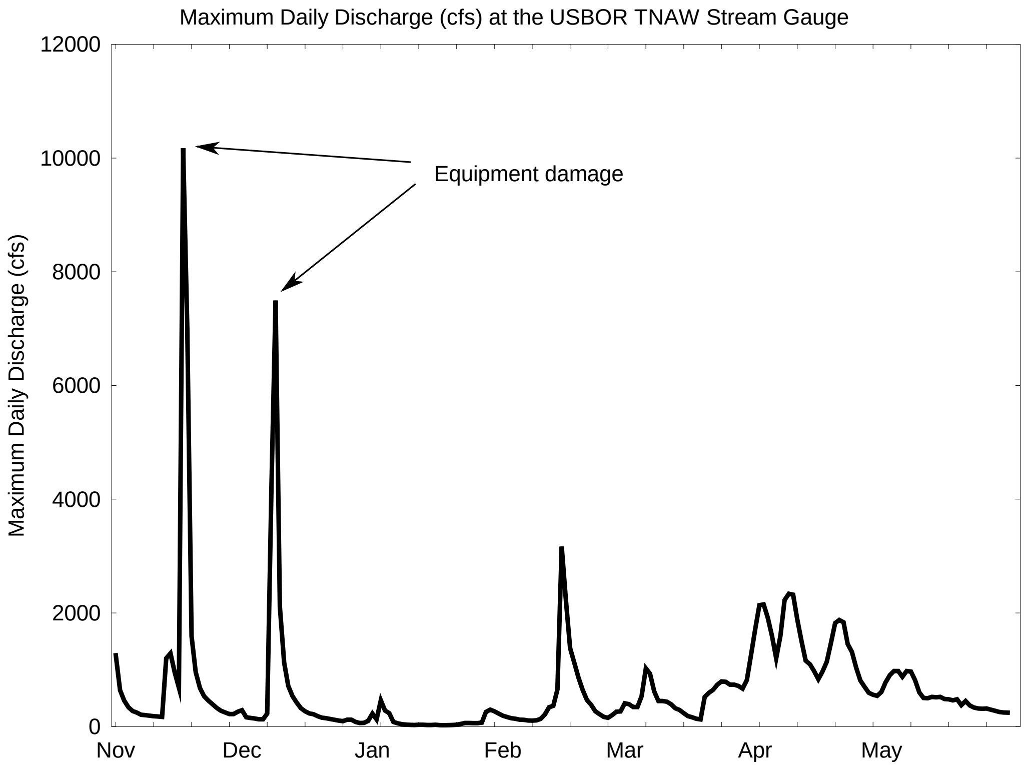

Figure 3. Maximum daily stream discharge (cfs) at the USBOR TNAW stream gauge.

Figure 4. Lower Mainstem Teanaway River instream PIT tag detection equipment following a December 2015 flooding event.

Juvenile *O. mykiss* tagged during their rearing phase in the upper Yakima comprise a combination of anadromous and resident life histories which cannot be distinguished during field sampling prior to the smolt stage. As previously mentioned, we used PIT tag detection histories of *O. mykiss* collected at downstream locations to distinguish migrants from resident juveniles. Juvenile migrants generally display a bimodal emigration from the upper Yakima tributaries with peak emigration in the spring and the fall (Temple et al. 2015). Fish that were detected at downstream locations during the spring smolt migration, either in the Yakima (e.g., Prosser Dam), or at one of the main stem Columbia River interrogation sites were considered to be anadromous smolts. When smolts were identified, their genetic samples were assembled from the collections stored at the WDFW district 8 field office in Ellensburg, WA, and forwarded to the WDFW Molecular Genetics Laboratory for processing.

Productivity

Productivity metrics are generally presented as some measure of recruits produced per adult parent. This can be a difficult metric to quantify due to the numerous factors that can influence survival during the freshwater rearing, smolt migration, marine phase, and adult return. In addition, steelhead are iteroparous so the spawners can have multiple spawning events over multiple years. The juvenile rearing phase can last from one to several years. Thus, a long time series of spawner and recruit data must be collected to ensure spawners and recruits are accounted for in productivity estimates. For example, several of the smolts that were detected in 2016 were tagged as juveniles during 2011: the first substantial year of juvenile tagging under this project.

We conducted small scale PIT tag retention studies each year 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.

Generating juvenile migrant abundance is a difficult task. Low juvenile detection probabilities at monitoring infrastructure coupled with low production stemming from depressed population sizes makes generating juvenile migrant estimates difficult. Others have attempted to circumvent these issues by considering recruitment to the returning adult stage. However, as previously discussed, several factors influence survival to the adult stage, so estimating productivity based upon adult returns is also a difficult task. We are attempting to work through these considerations to generate productivity estimates for the upper Yakima population (Frederiksen et al. 2015).

Spatial Structure

The spatial distribution of *O. mykiss* in the upper Yakima basin are reported under routine monitoring under the Yakima/Klickitat Fisheries Project (YKFP; 1995-063-25). Utilization (spatial distribution) in tributary streams is monitored via long term 200m long index monitoring sites following electrofishing protocols (Temple and Pearsons 2007). Under the monitoring prescriptions for *O. mykiss* established under the YKFP, tributaries are considered utilized when a minimum of 2 or more individuals occupy the site. When these minimum utilization criteria are met, the spatial distribution is extrapolated to the stream scale based upon the area the site represents. We began baseline data collection activities in 1990 and have a robust dataset for monitoring trends in spatial distribution. Our monitoring to date suggests *O. mykiss* spatial distribution remains stable in the Upper Yakima and substantial change in utilization trends has not been detected.

Spatial distribution in terms of NOAA's recommendations (e.g., spawner distribution; Crawford and Rumsey 2011) is not calculated for the Upper Yakima because we do not collect spawning information for the large resident population or for steelhead adults. This is due to low adult counts and the large geographical area encompassing potential spawning locations (i.e., proverbial needle in haystack). The steelhead spawning distribution for the upper Yakima population is inferred from PIT tag interrogations from our detection arrays at the mouth of each tributary, and in the main stem Yakima River by subtraction. As previously mentioned, equipment malfunctions prevented us from using PIT tag detections to estimate the spawning distribution in 2016, so we used the average proportion of the total run escapement (Roza dam count) apportioned to each tributary as derived from the observations from the previous years.

Diversity

We report only the status and trend in diversity metrics for naturally produced *O. mykiss* because as previously noted, the upper Yakima is composed predominantly of wild fish, and straying of hatchery origin fish into the Upper Yakima is generally very low. Because of the enormous variability of *O. mykiss* diversity metrics, observed change within these variables may reflect natural variation, rather than change in the diversity metrics. For instance, recent work suggests that *O. mykiss* can spawn during any month of the year in different locals, and that appears to be driven in large part by environmental factors (Bill McMillan, Personal Communication). Thus substantial change in spawn timing may actually reflect the species true plasticity and natural variation for this diversity metric. Detecting small significant changes to highly variable metrics is a difficult task, and generally result in statistical tests with low power (Ham and Pearsons 2000). Other diversity metrics currently monitored include adult spawn timing and distribution of anadromous fish that are radio tagged, age structure of returning anadromous adults, age structure of tributary rearing fish, length at age differences between life histories, and sex ratios of adults sampled at Roza Dam (collected via ultrasound). We also address the long term diversity monitoring strategy (Crawford and Rumsey 2011) by collecting genetic tissue samples on adult steelhead returning to Roza dam. In addition, genetic samples have been collected and processed intermittently (e.g., prior to this project) for *O. mykiss* in the upper Yakima Basin providing long term genotypic trend monitoring information for the rearing population (e.g., Campton and Johnston 1985).

PIT tagging a large number of juveniles in their natal streams as juveniles has many advantages. For instance, the diversity indices for several variables for the combined resident and anadromous *O. mykiss* population, as well as each independent life history can be evaluated.

Several interesting and important life history characteristics arising from the juvenile tagging studies are described in this report.

Results

General

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 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 to determine that 289 of the fish detected at the 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 sites were reinstalled during 2016 using improved equipment designs 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 are 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 are also PIT tagged) at our PIT tag arrays were compared to the radio-telemetry mobile tracking detections that were conducted routinely to determine the detection rate of the PIT tagged individuals at the 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). The annual run of wild adult steelhead migrating upstream from Roza Dam was estimated to be 376 during the 2014 spawning migration (www.YKFP.org). Radio Telemetry monitoring indicated that of the 68 radio-tagged steelhead tracked to their spawning locations, 69% were in tributaries, and 31% were located in the main stem Yakima River upstream from Roza Dam. A large number of main stem river spawners aggregated near the town of Ellensburg indicating this is an important spawning area.

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

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 5). 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 85 adults. However, recently, there appears to be an increasing trend in annual wild adult return numbers (Figure 5).

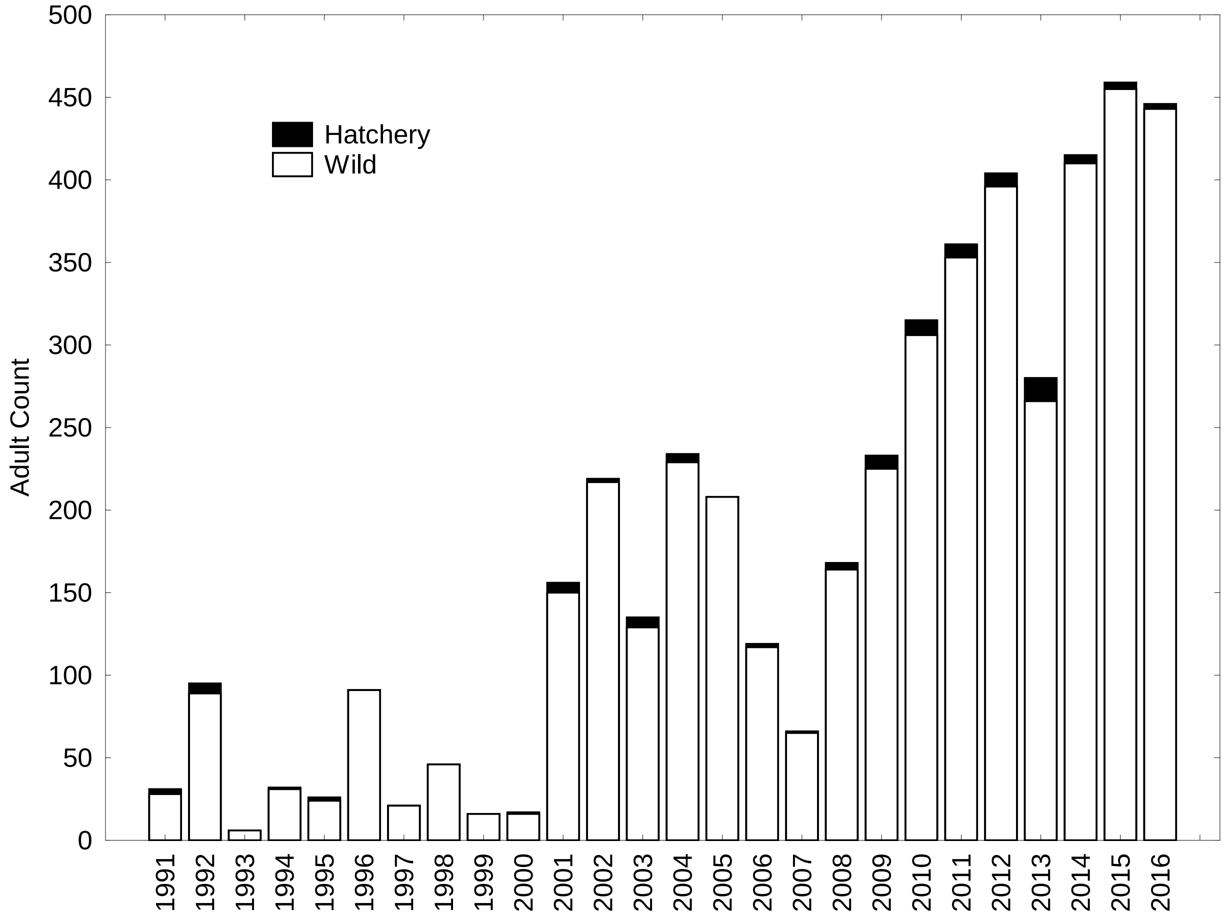

Figure 5. Number of hatchery and wild origin steelhead adults passing Roza Dam during the annual adult spawning migrations.

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 6). 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 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 is a 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 7).

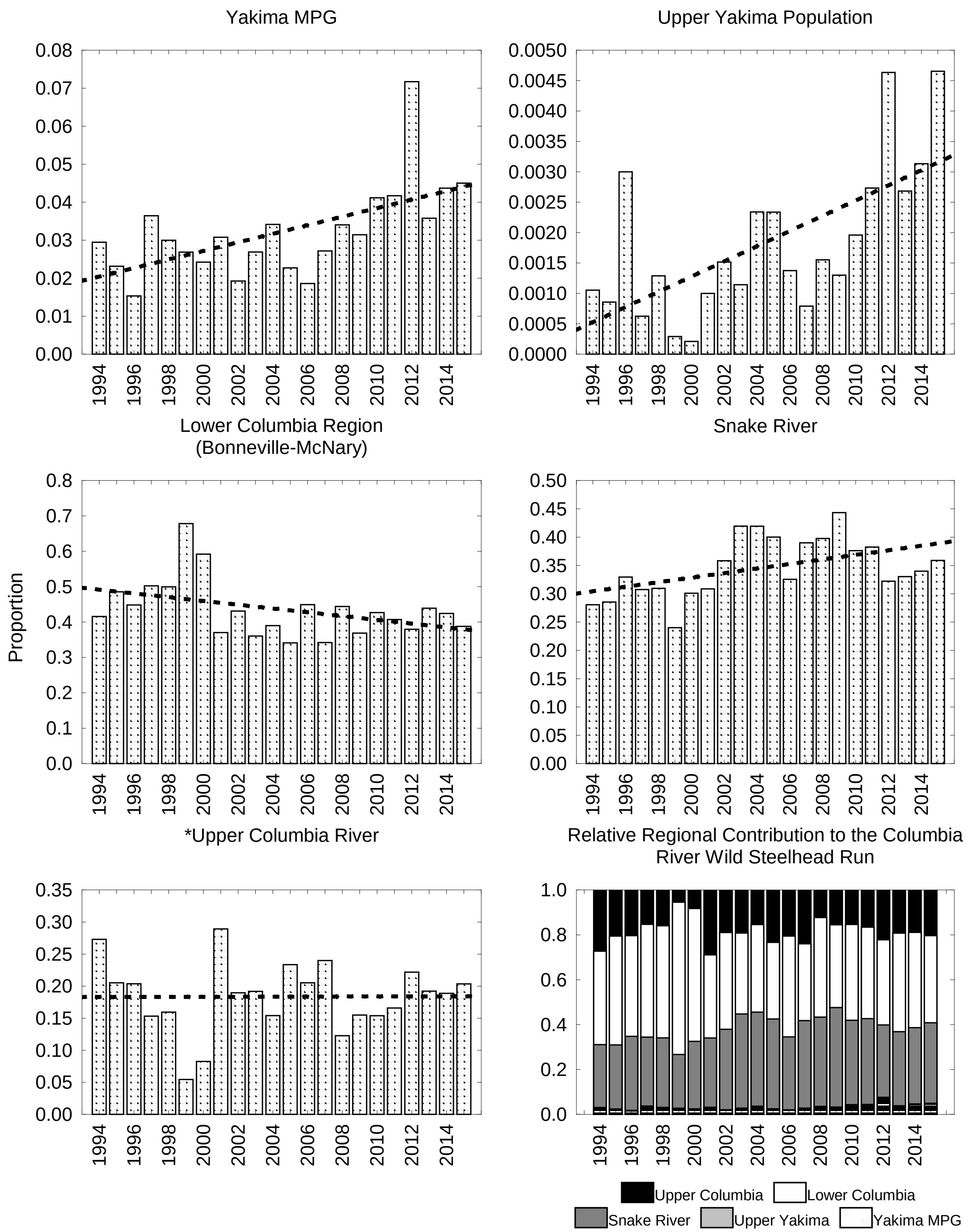

Figure 6. Annual trends in wild steelhead returns in the various Columbia River Regions as a proportion of the Bonneville Dam Count. The Lower Columbia region depicts difference in the Bonneville and McNary dam counts and therefore does not include populations below Bonneville Dam and should be considered incomplete. The asterisk indicates a complete count, not differentiated by hatchery or wild origin. The dashed lines represent the best fit line.

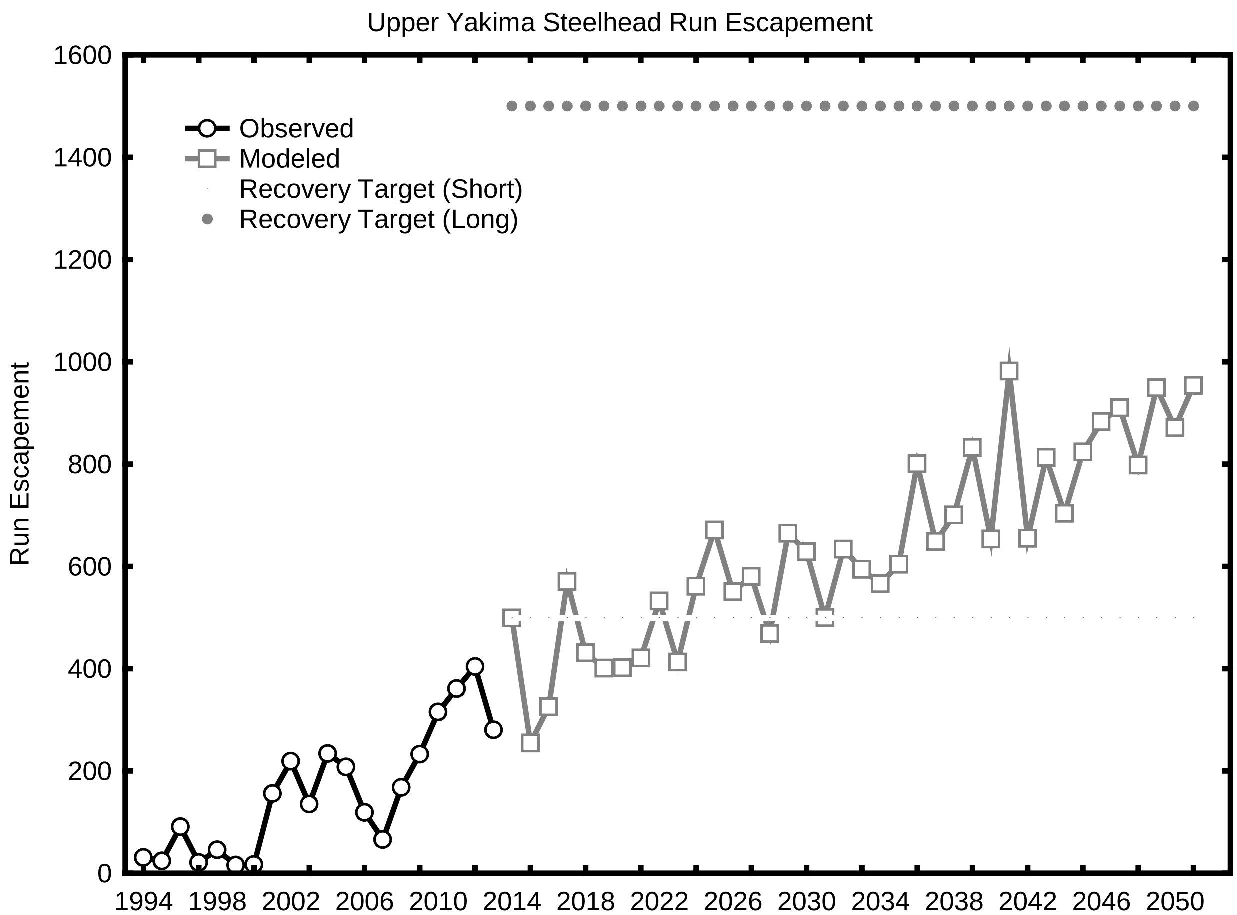

Figure 7. Observed and modeled annual summer steelhead run escapement into the Upper Yakima. The short term and long term recovery targets are presented as dashed lines.

The population abundance of *O. mykiss* is highly variable from year to year in Yakima River tributary streams (Figure 8). Despite decreased abundance in 4 of the 5 streams in 2016 relative to the previous year, we still detected significant positive trends in the population abundance through time. 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 5 of the core long term monitoring tributary streams have abundance trajectories with positive slopes, two of which were significant (Swauk Creek, P = 0.02; Middle Fork Teanaway River P = 0.15; West

Fork Teanaway River $P = 0.006$). The Taneum Creek *O. mykiss* population abundance is also highly variable from year to year although the population appears stable. The migrant production does not appear dependent with the overall *O. mykiss* abundance in each stream in the same year.

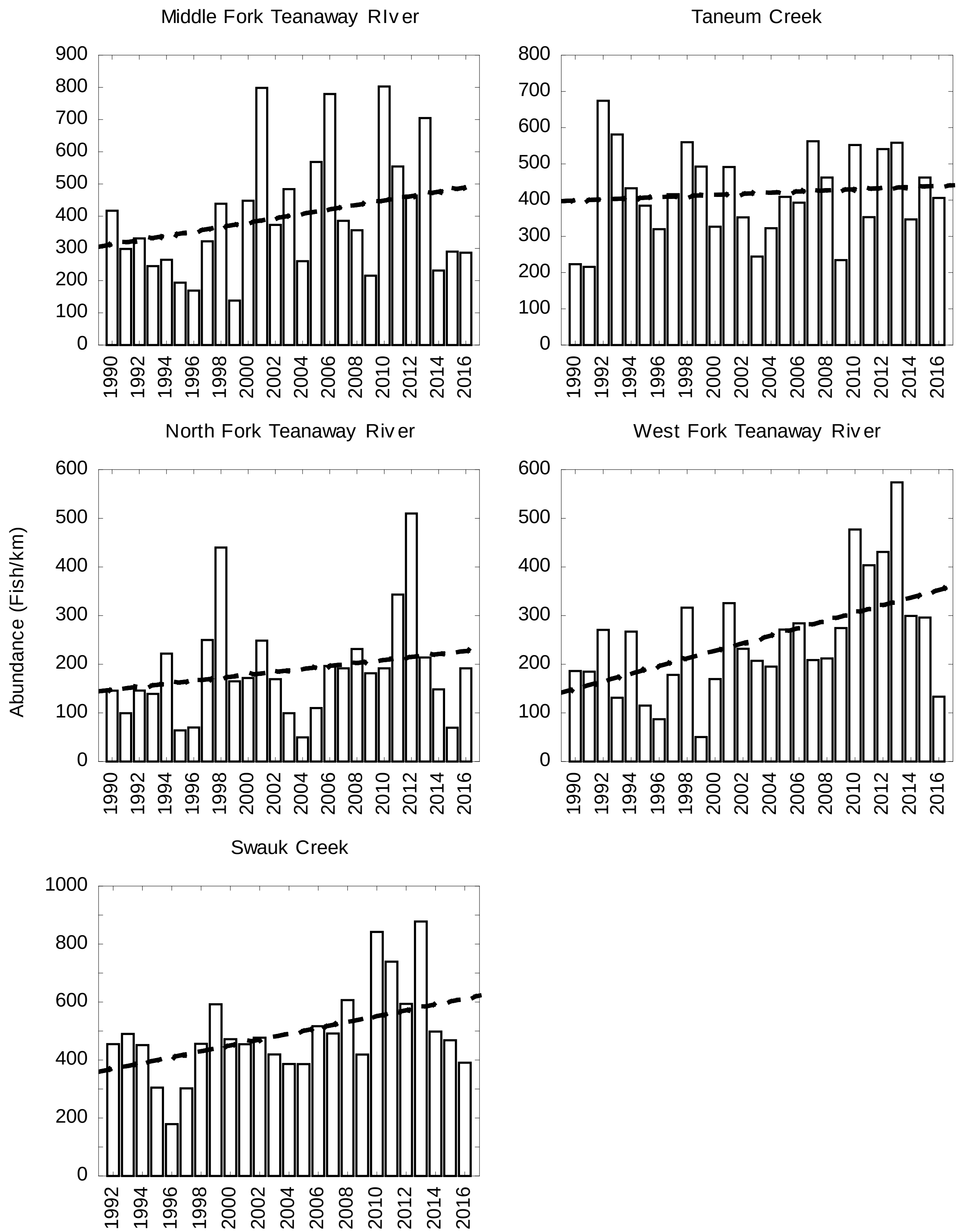

Figure 8. Annual population abundance of *O. mykiss* in core upper Yakima tributary streams. The dashed lines in the individual stream panels represent the best fit trend line.

Productivity

A recent description of Yakima Basin steelhead population productivity is presented in Frederiksen et al. (2015). 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 Yakima Basin in 2016 are presented in Figure 9. Consistently, we observe that the Teanaway Basin produces a larger number of steelhead 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. 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 will now have the opportunity so monitor recolonization of the stream by steelhead.

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 predominantly 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				

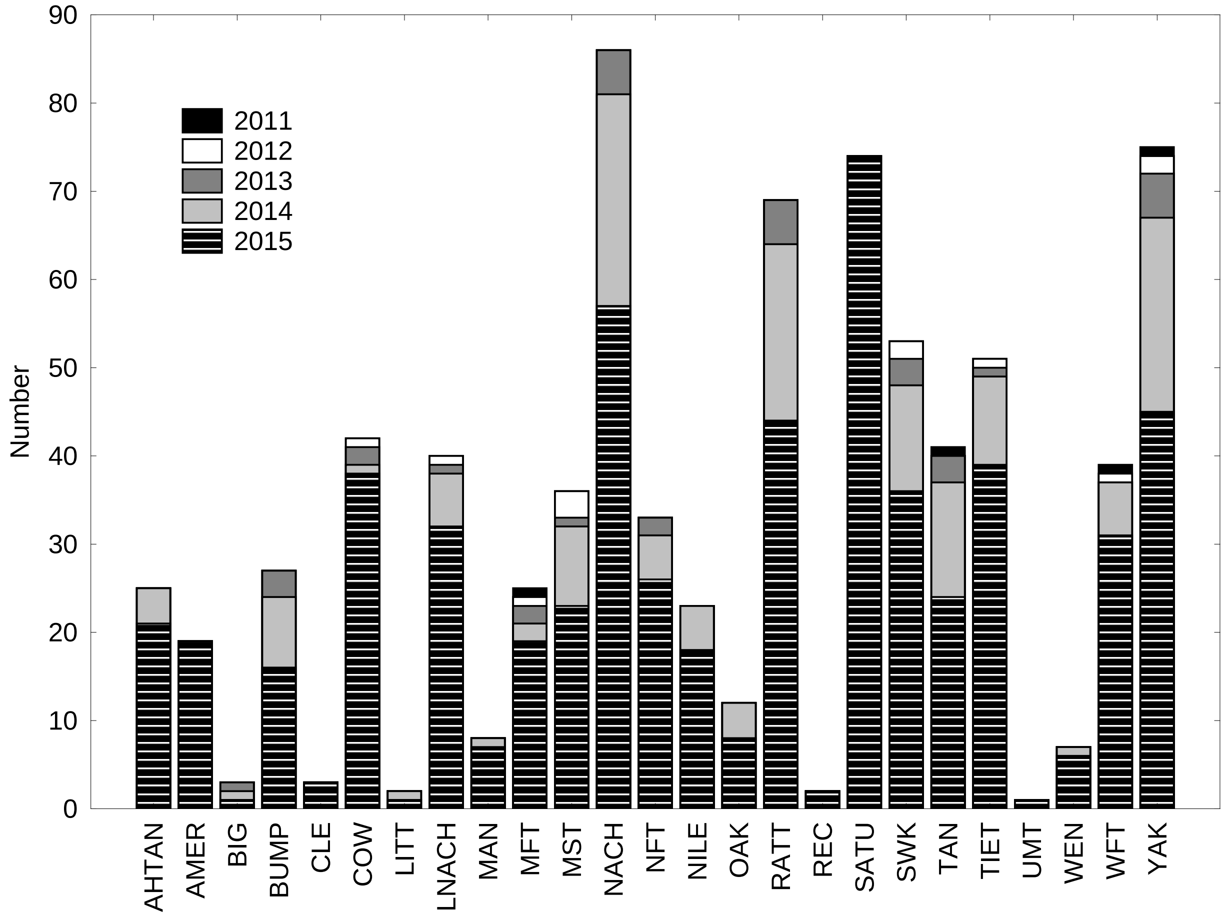

Figure 9. Number smolts detected during the 2016 spring out migration and the year they were tagged as juveniles in Ahtanum Creek AHTAN), the American River (AMER), Big Creek (BIG), the Bumping River (BUMP), the Cle Elum River (CLE), Cowichee Creek (COW), Little Creek (LITT), the Little Naches River, (LNACH), Manastash Creek (MAN), Middle Fork Teanaway River (MFT), Mainstem Teanaway River (MST), the Naches River (NACH), the North Fork Teanaway River (NFT), Nile Creek (NILE), Oak Creek (OAK), Rattlesnake Creek (RATT), Reecer Creek (REC), Satus Creek (SATU), Swauk Creek (SWK), Taneum Creek (TAN), the Tieton River (TIET), Umtanum Creek (UMT), Wenas Creek (WEN), West Fork Teanaway River (WFT), and the main stem Yakima River (YAK).

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 10). The tagging location of each fish tagged is known to the nearest 200m in tributaries, and 500m in mainstem river sections. We constructed simple frequency plots of steelhead smolt rearing origin in the main stem upper Yakima River (Figure 11), and from each tributary by river kilometer for the upper Yakima basin (Figure 12) and the Naches Basin (Figure 13). In addition, we overlayed the rearing distribution of known resident trout on these frequency plots to see if there were any differences in the stream sections occupied by resident trout and anadromous pre-smolts during the rearing period. It appeared that there was a high degree of overlap in the rearing distribution of anadromous and resident O. mykiss during the rearing period and the life histories were not spatially segregated.

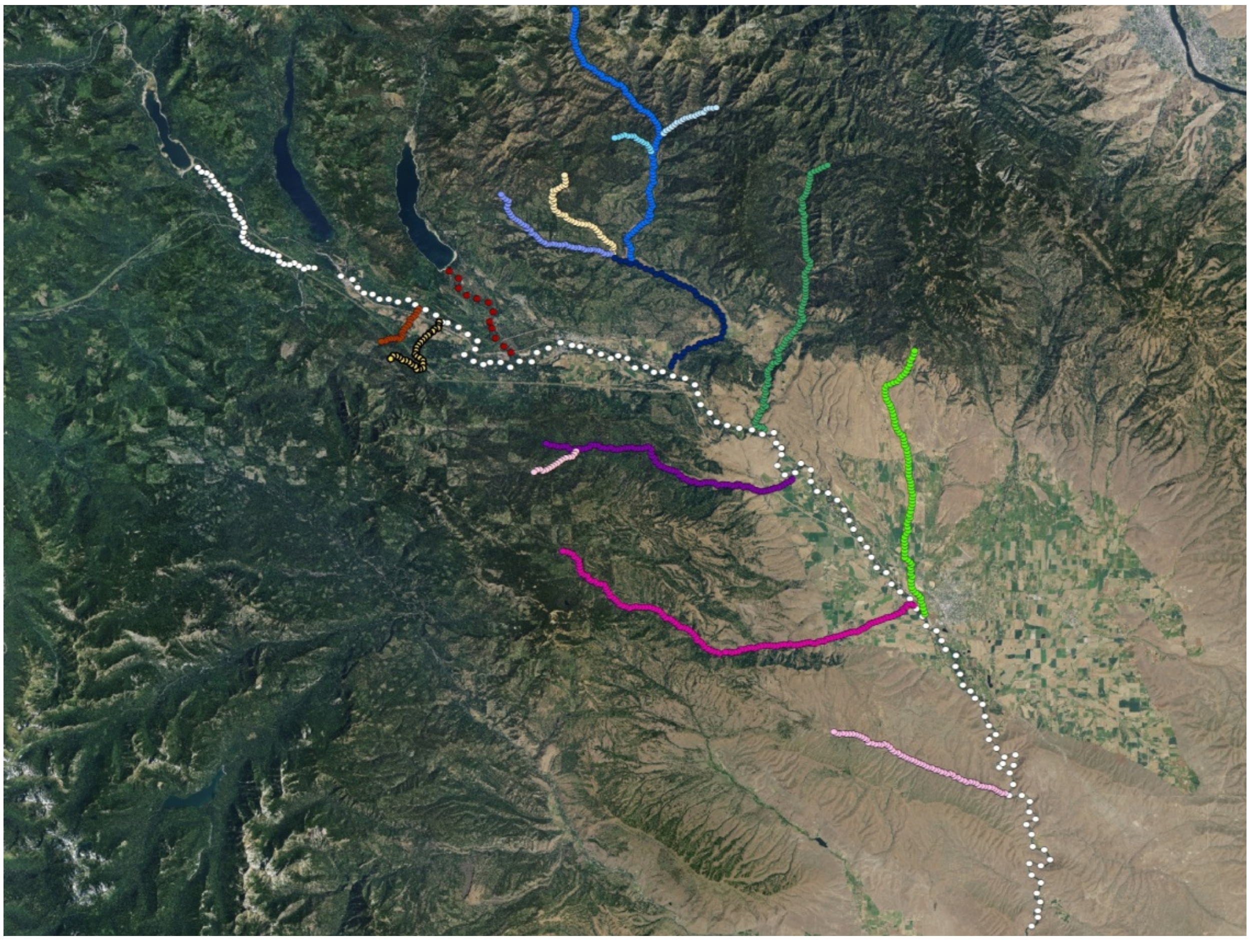

Figure 10. PIT tag collection sites in each tributary stream of the upper Yakima Basin. Collection site names are labeled sequentially moving up the stream channel. Each dot represents 200 m in tributary streams, and 300 m or 500 m in main stem stream sections.

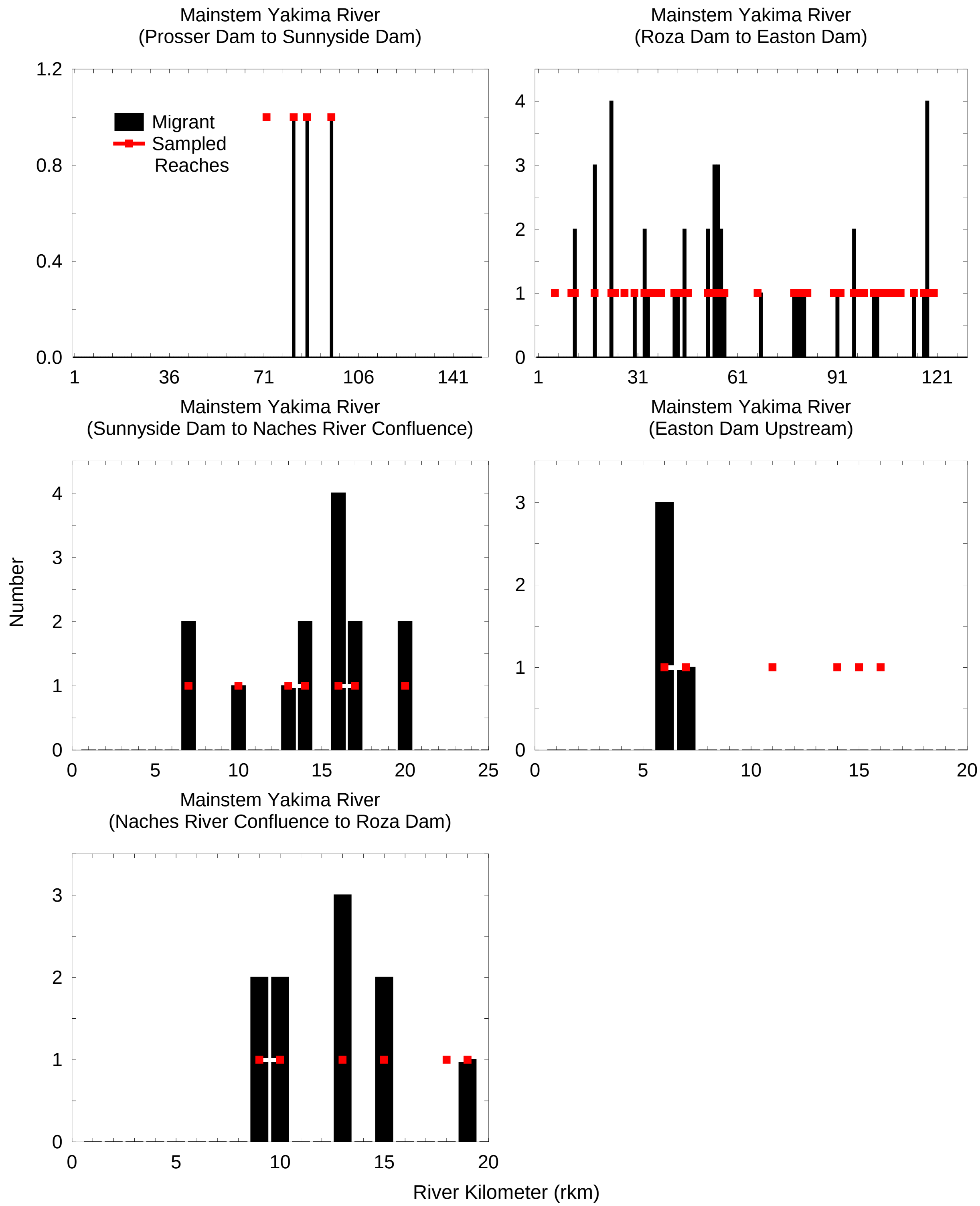

Figure 11. Origin (rkm) of known resident trout and anadromous steelhead juvenile migrants detected during the 2016 spring smolt migration that were tagged in the Yakima River. Red markers indicate sampled stream reaches.

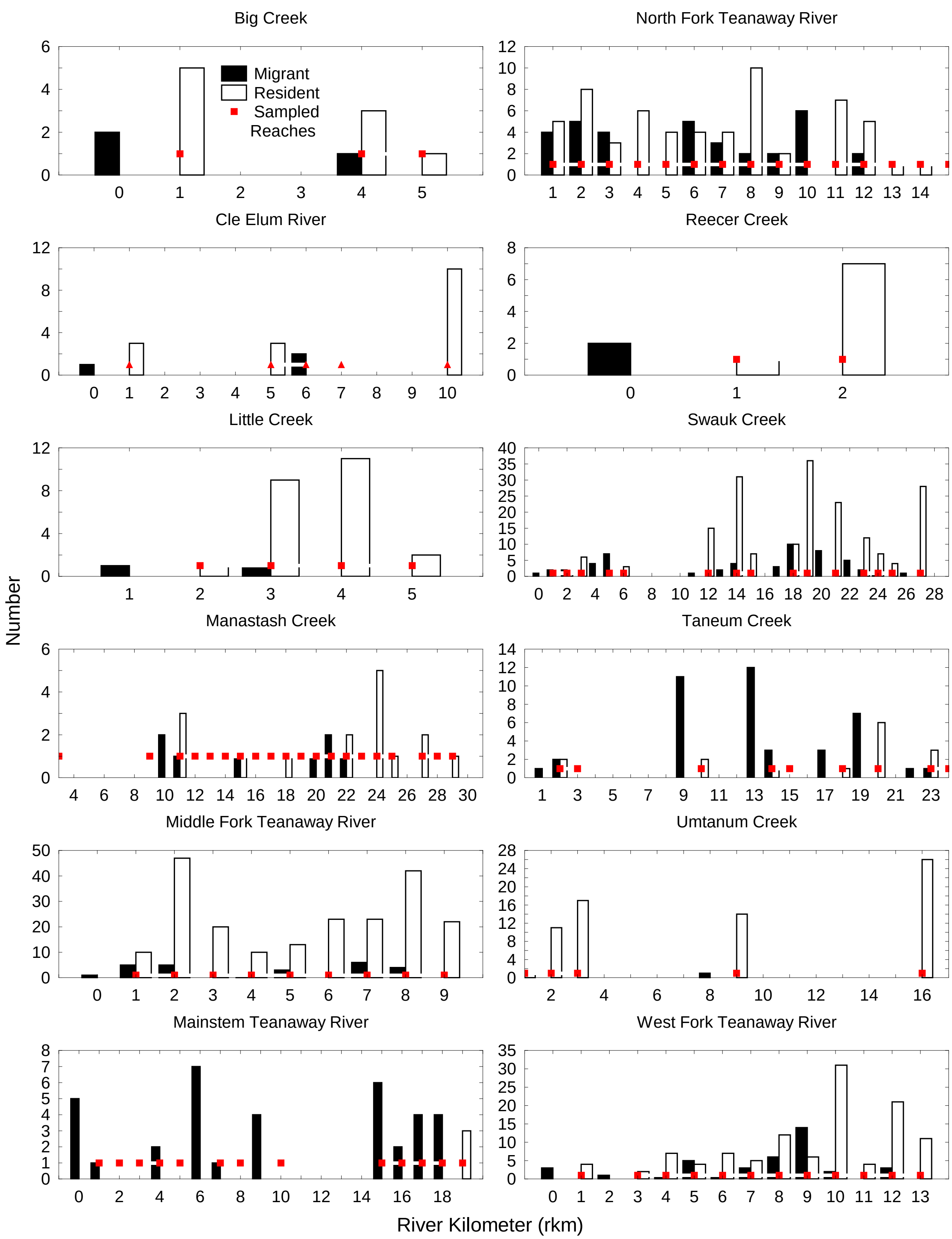

Figure 12. Origin (rkm) of known resident trout and anadromous steelhead juvenile migrants detected during the 2016 spring smolt migration that were tagged in the upper Yakima Tributary streams. Red markers indicate sampled stream reaches.

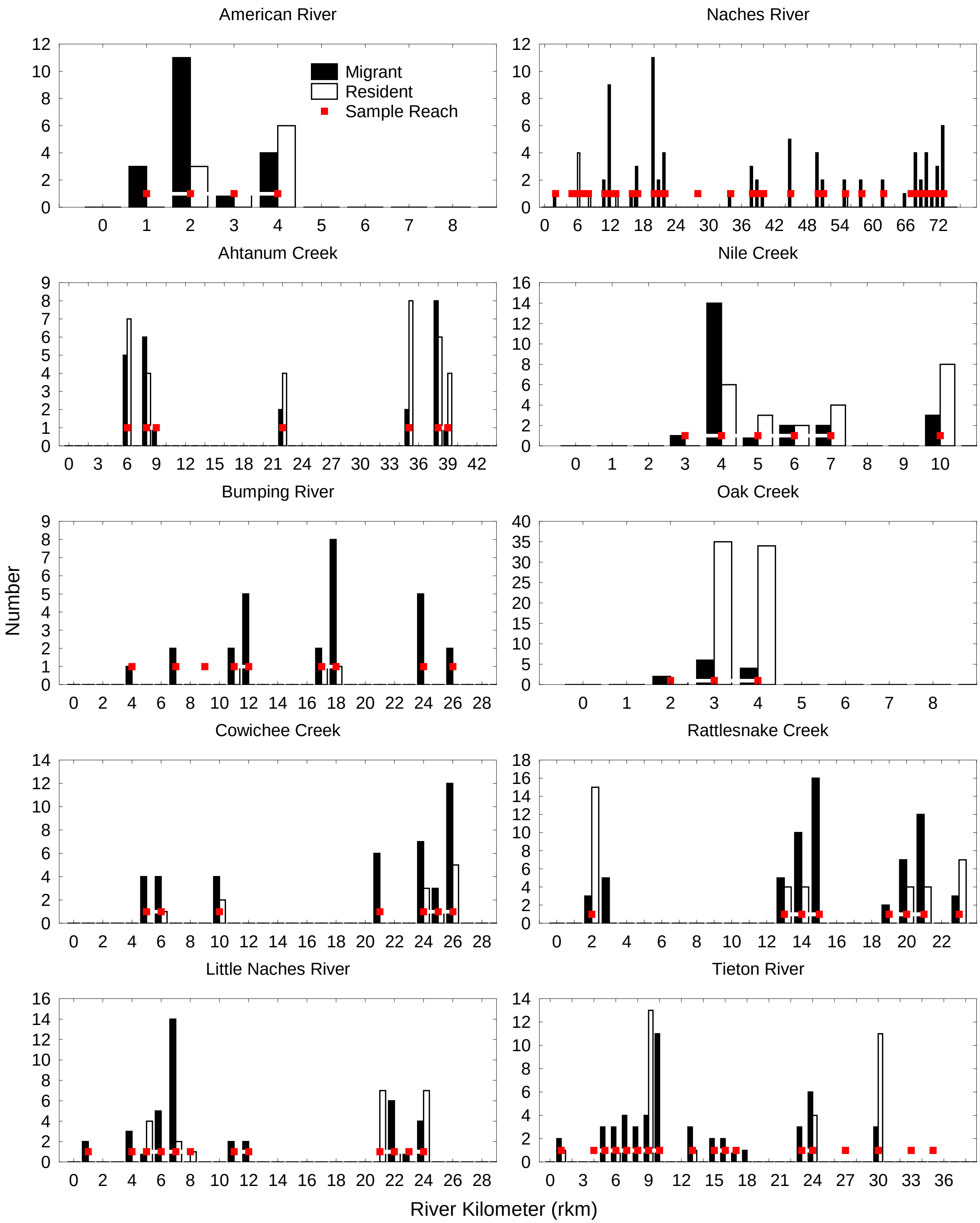

Figure 13. Origin (rkm) of known resident trout and anadromous steelhead juvenile migrants detected during the 2016 spring smolt migration that were tagged in the Naches Basin (including Ahtanum Creek; note axis scale differences). Red markers indicate sampled stream reaches.

Diversity

Pit tagging a large number of juvenile *O. mykiss* in their natal streams provide 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, emigrate from their natal streams during the spring (Figure 14). We also observed a fall migration of tagged juvenile *O. mykiss* out of the upper Yakima tributary streams (Figure 14). 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 the Teanaway basin (Figure 15). While the juvenile emigration from the tributary streams did occur primarily in the spring and fall period, fish did move past our interrogation site during most months of the calendar year. These observations are based upon the previous year's outmigration (2015) due to incomplete detections for our instream arrays in 2016 following the flood events that destroyed our equipment.

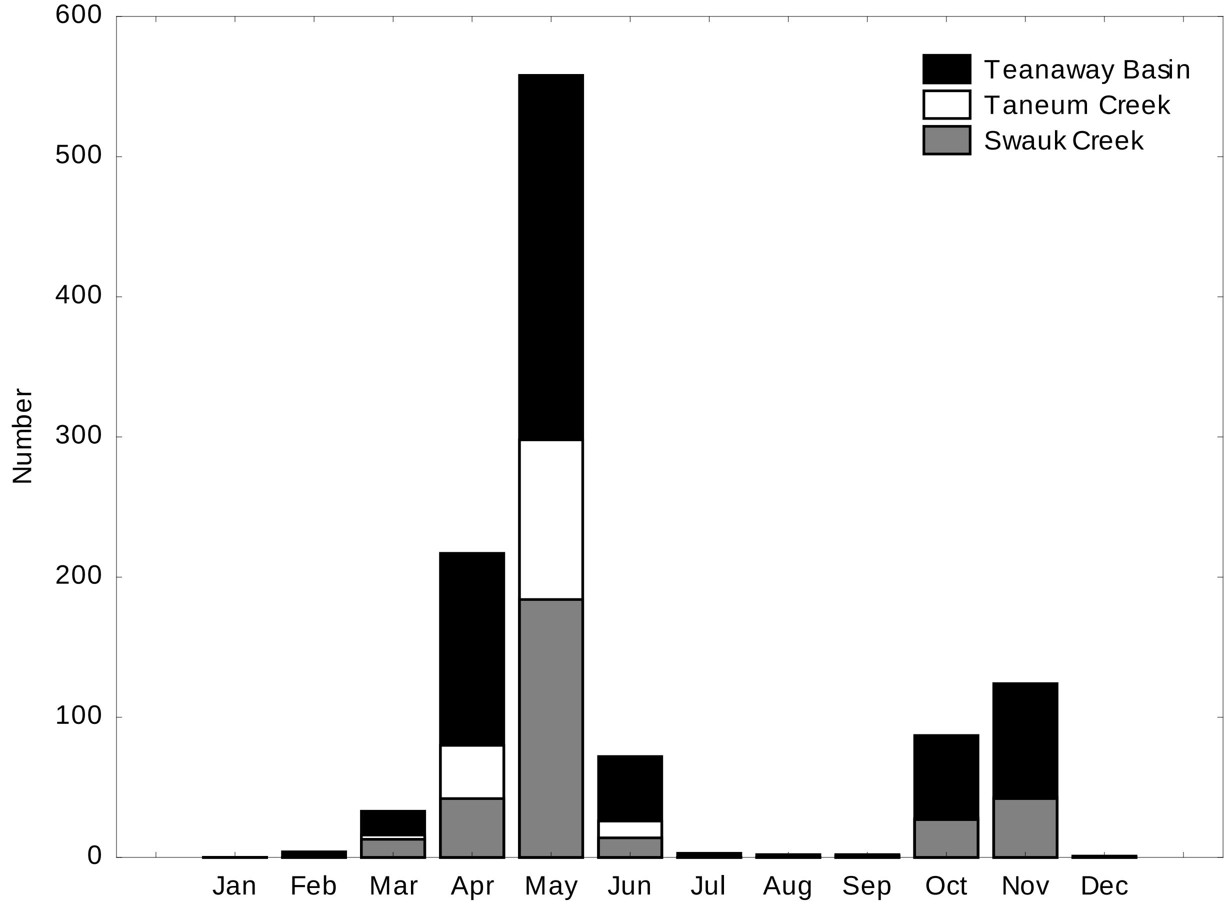

Figure 14. Number of fish migrating from select upper Yakima tributaries by month during 2015.

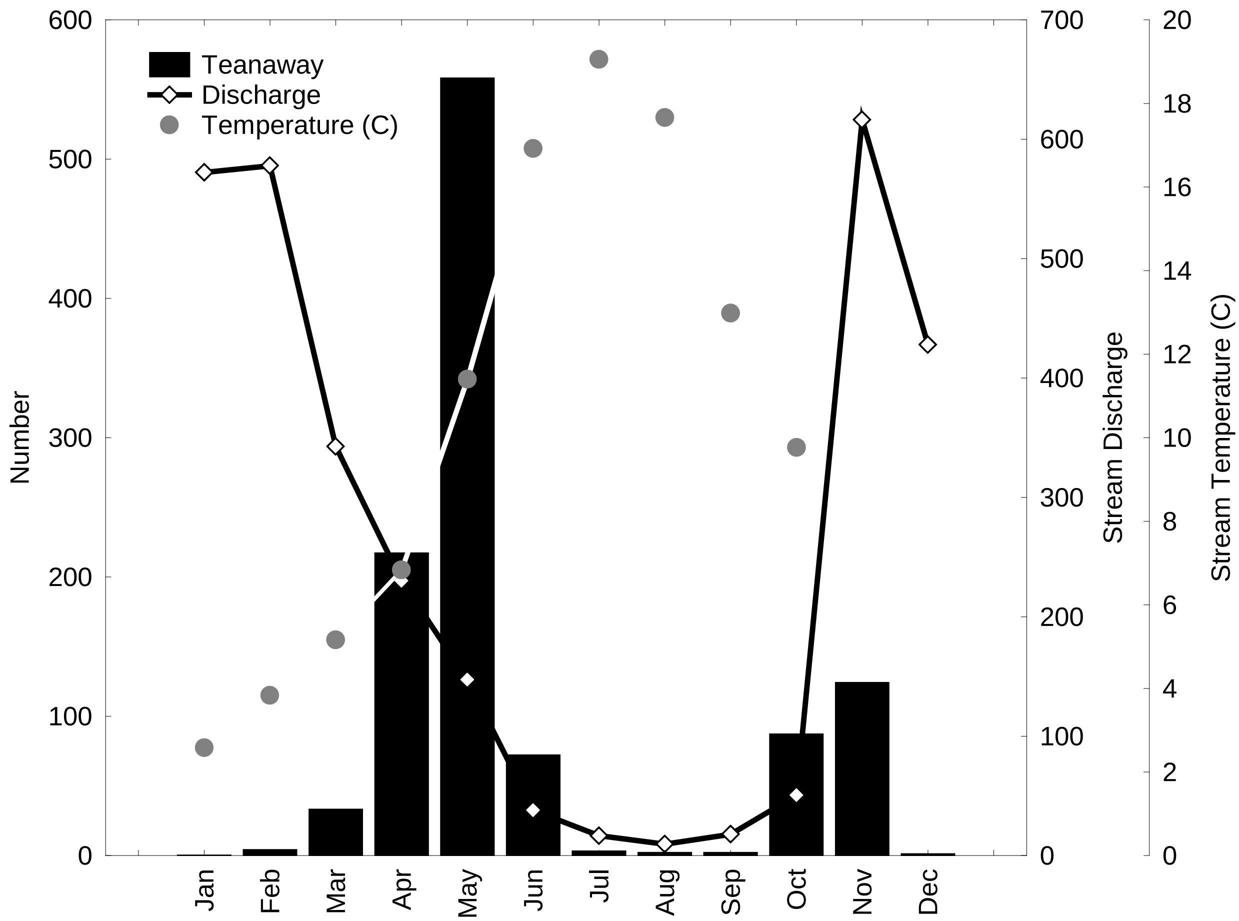

Figure 15. Number of juvenile emigrants detected each month at the mouth of the Teanaway River relative to average monthly stream discharge (cfs; right axis) and stream temperature (C; Second right axis). Water temperature was monitored until Oct. 15, 2015 when the monitoring equipment failed.

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 indicates that there is a slight, but significant, difference in the length/weight relationship between life history forms ($P < 0.001$). Anadromous juveniles generally weigh less at a given length than their resident counterparts (Figure 16) although the variation around these average relationships would make it difficult to distinguish between life histories for individual fish.

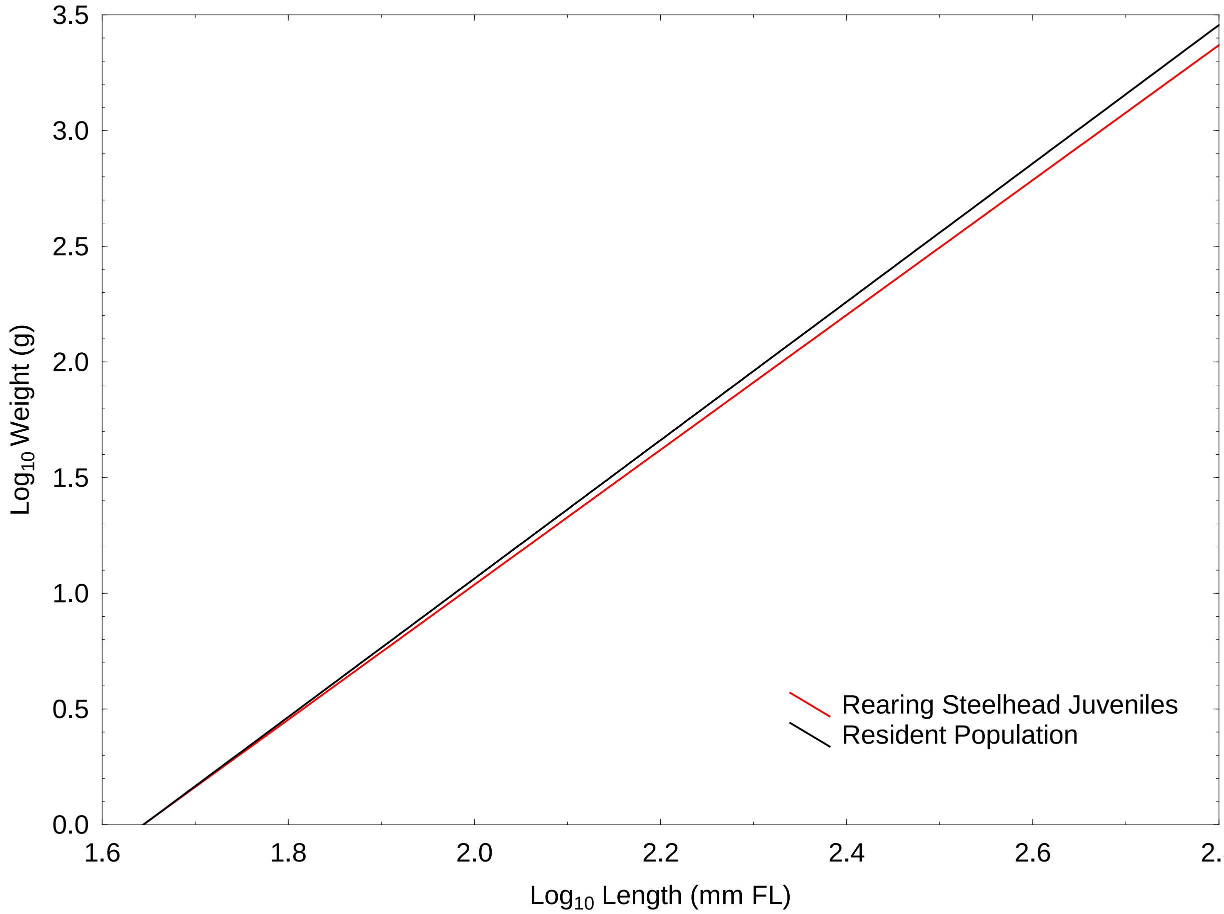

Figure 16. Log_{10} transformed length weight relationship for resident *O. mykiss* and rearing steelhead juveniles. The steelhead were tagged as juveniles and detected as returning adults in subsequent years. The resident population was defined as tagged individuals that were not detected as migrants in subsequent years.

Back calculations of the length at age for resident rainbow trout and anadromous steelhead smolts for the Middle Fork Teanaway River, North Fork Teanaway River, Swauk Creek, and the West Fork Teanaway River indicated there may be slight differences in the growth trajectories of the two life histories during the freshwater rearing phase (Figure 17). Low sample sized limited our comparisons to length at age 0 and age 1. There was no significant difference between resident and anadromous back calculated length at age 0 (P = 0.33) but there was for age 1 fish (P = 0.05) with smolts generally being larger at age 1 than their resident counterparts (Figure 17).

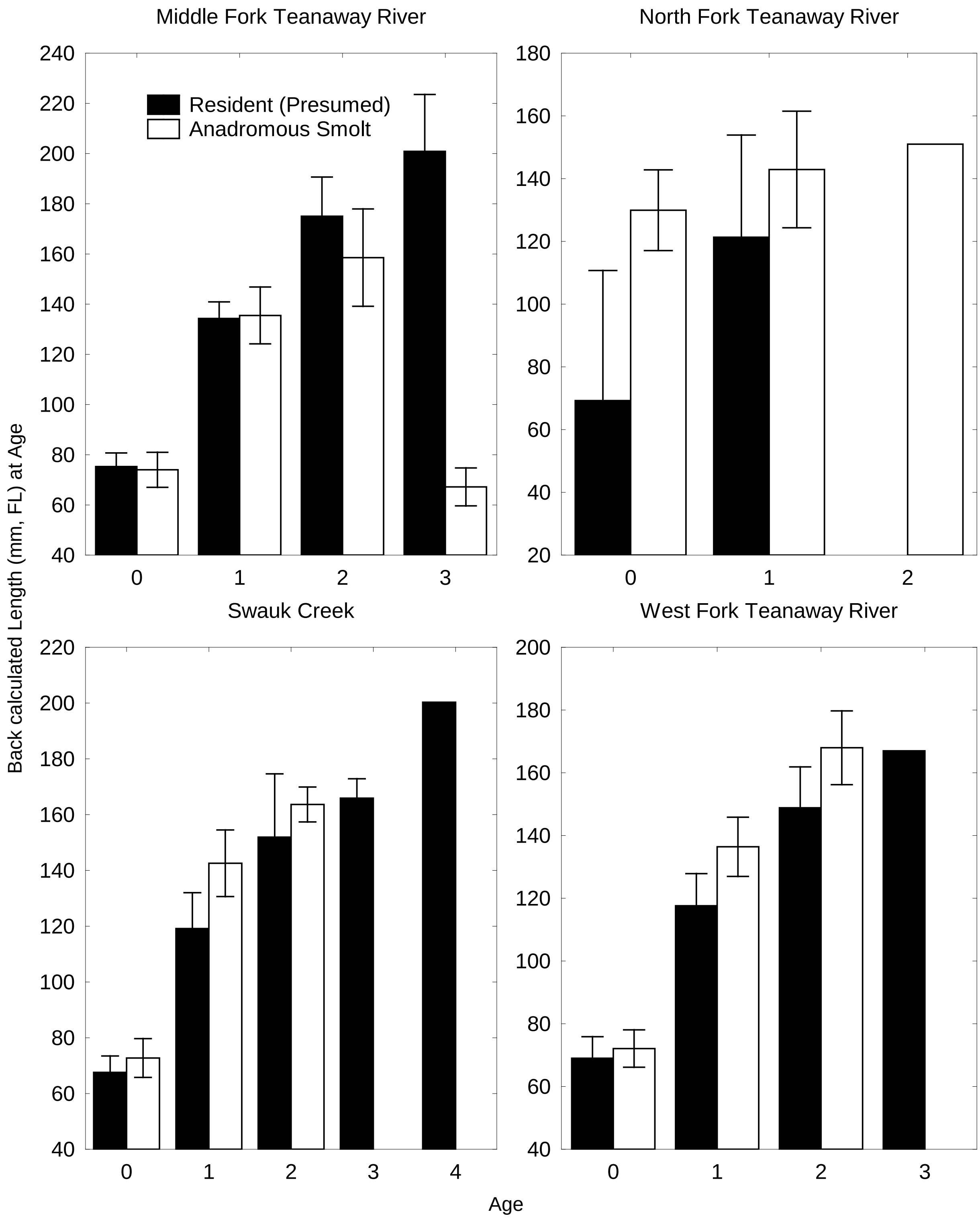

Figure 17. Back calculated length at age (mm; fork length, FL) from scale samples collected from resident rainbow trout based on PIT tag recapture histories, and known smolts from four upper Yakima Tributary streams.

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. In 2016, we detected 18 adult steelhead at Bonneville Dam that were tagged as juveniles in their natal streams in the upper Yakima Basin during the freshwater rearing phase. We also detected 7 adults that originated from the Naches Basin. This information provides an opportunity to describe diversity metrics from the population perspective comparing the Naches population to the Upper Yakima population, as well as resident and anadromous life histories. The information for the Naches is somewhat limited given that we only recently initiated our juvenile tagging studies in that basin. However, we expect that we will see increased information in the coming years as additional adult fish from the Naches population begin returning. Until that time, the comparisons of adult diversity metrics of fish tagged as juveniles are based upon small numbers of fish.

It appears that adult steelhead returning to the Naches and Upper Yakima populations have 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 18) 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; $F_{15,140}$=0.78; P = 0.69).

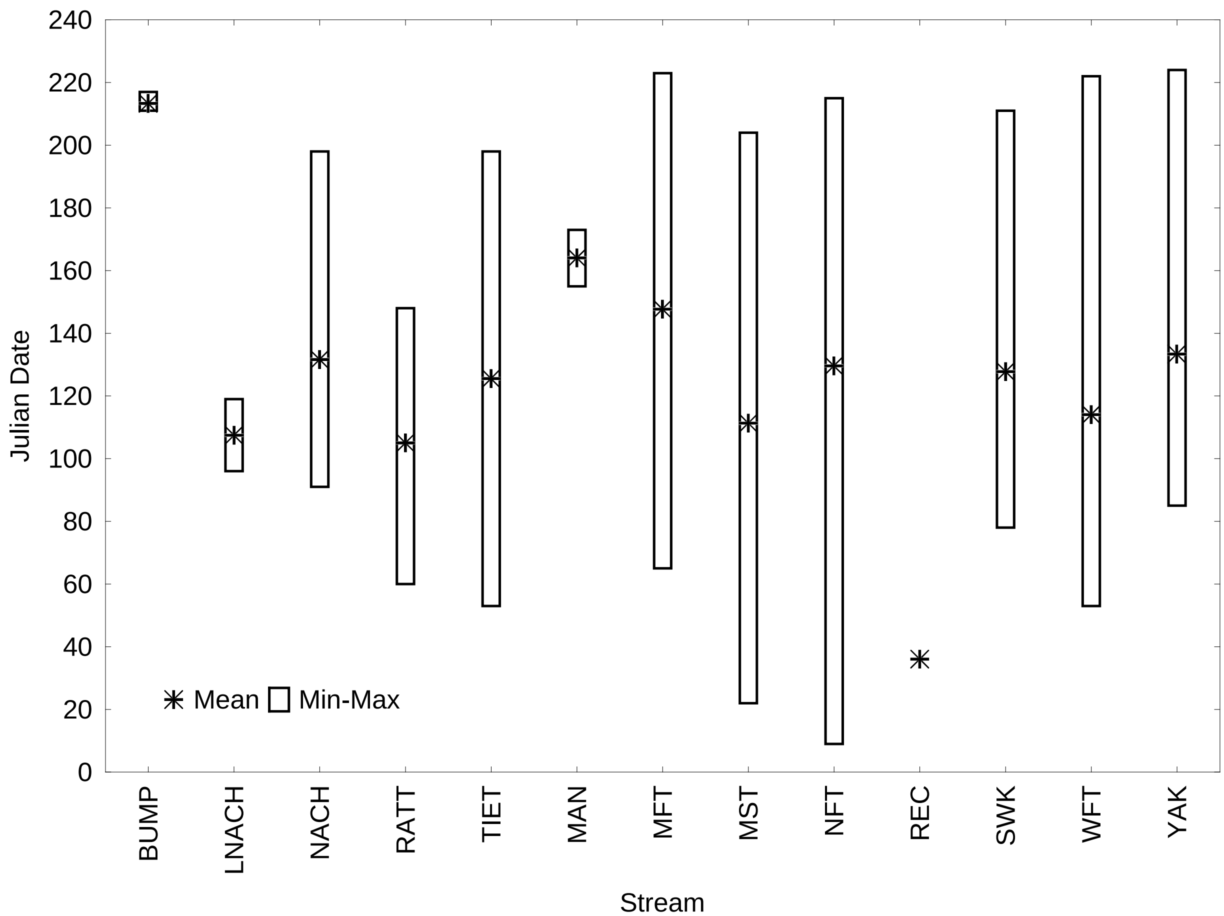

Figure 18. Average and the range of dates (Julian Day) of the first detection of returning steelhead adults at Bonneville Dam in 2016 for fish PIT tagged in their natal streams as juveniles. Stream abbreviations include Bumping River (BUMP), Naches River (NACH), Little Naches River (LNACH), Rattlesnake Creek (RATT), Tieton River (TIET), Manastash Creek (MAN), Middle Fork Teanaway River (MFT), Mainstem Teanaway River (MST), North Fork Teanaway River (NFT), Reecer Creek (REC), Swauk Creek (SWK), West Fork Teanaway River (WFT), and the main stem Yakima River (YAK).

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. We observed Yakima steelhead making extensive use of the Columbia River Basin during the 2016 adult spawning migration (Figure 19; Figure 20). 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. One fish was detected moving into the middle reaches of the Tucannon River in South East Washington. Several of these fish were detected in the juvenile fishways at mainstem Columbia River Dams as well, presumably in attempt to move downstream through the hydro-system as they migrated throughout the basin or as post spawned kelts. We observed similar widespread use of the Columbia River Hydrosystem for steelhead tagged as juveniles in the Naches sub-basin (Figure 20). These movement patterns are interesting because these fish were tagged as juveniles in their natal rearing areas.

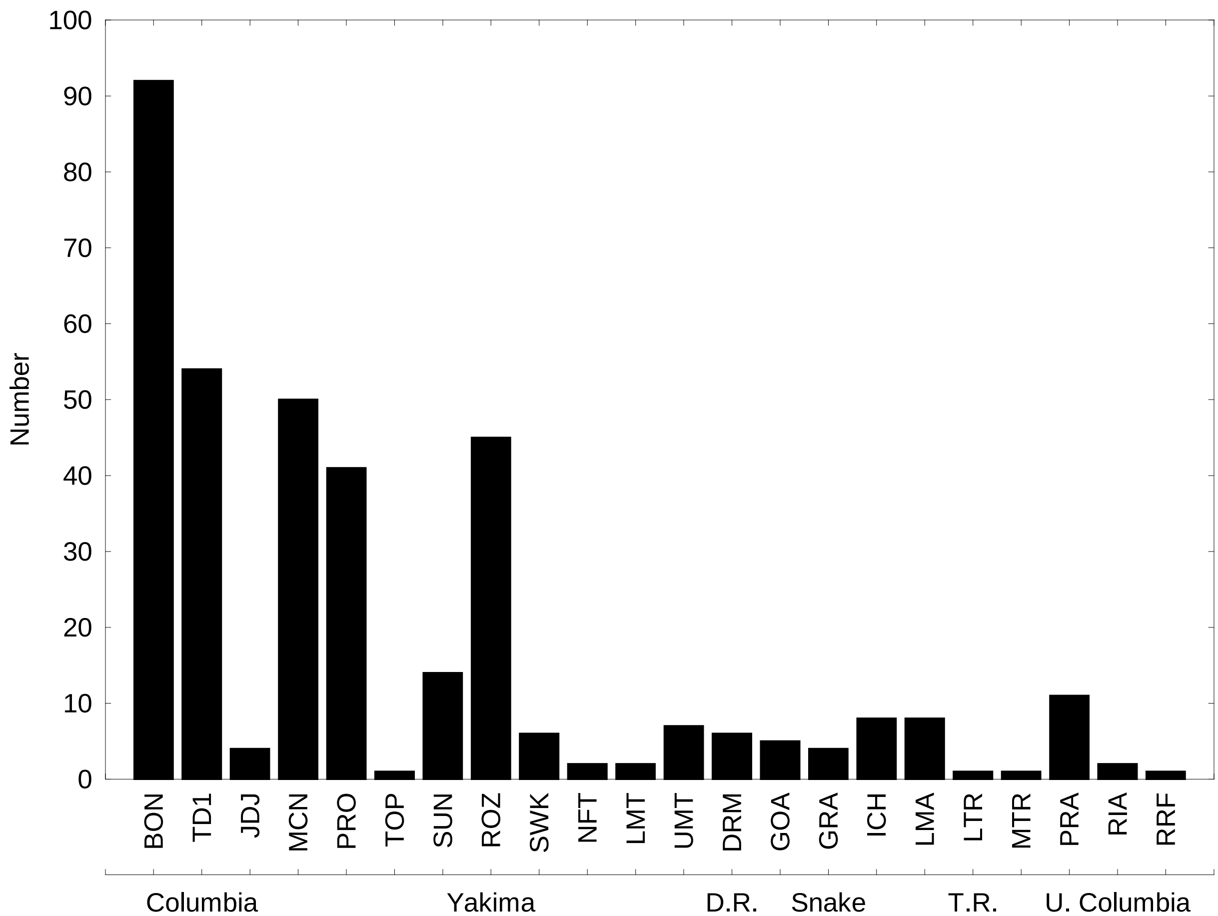

Figure 19. Number of Yakima steelhead adults detected at instream PIT tag arrays in the lower and mid-Columbia, Yakima, Deschutes River (D.R.), Snake, Tucannon River (T.R.), and Upper Columbia region. Detection sites include Bonneville Dam (BON), The Dalles Dam (TD1), John Day Dam (JDJ), McNary Dam (MCN), Prosser Dam (PRO), Toppenish Creek instream array (TOP), Sunnyside Dam (SUN), Roza Dam (ROZ), Swauk Creek (SWK), North Fork Teanaway River (NFT), the mouth of the Teanaway River (LMT), the upper Mainstem Teanaway River (UMT), the mouth of the Deschutes River (DRM), Little Goose Dam (GOA), Lower Granite Dam (GRA), Ice Harbor Dam (ICH), Lower Monumental Dam (LMA), lower and middle Tucannon River (LTR and MTR), Priest Rapids Dam (PRA), Rock Island Dam (RIA), and Rocky Reach Dam (RRF) in 2016.

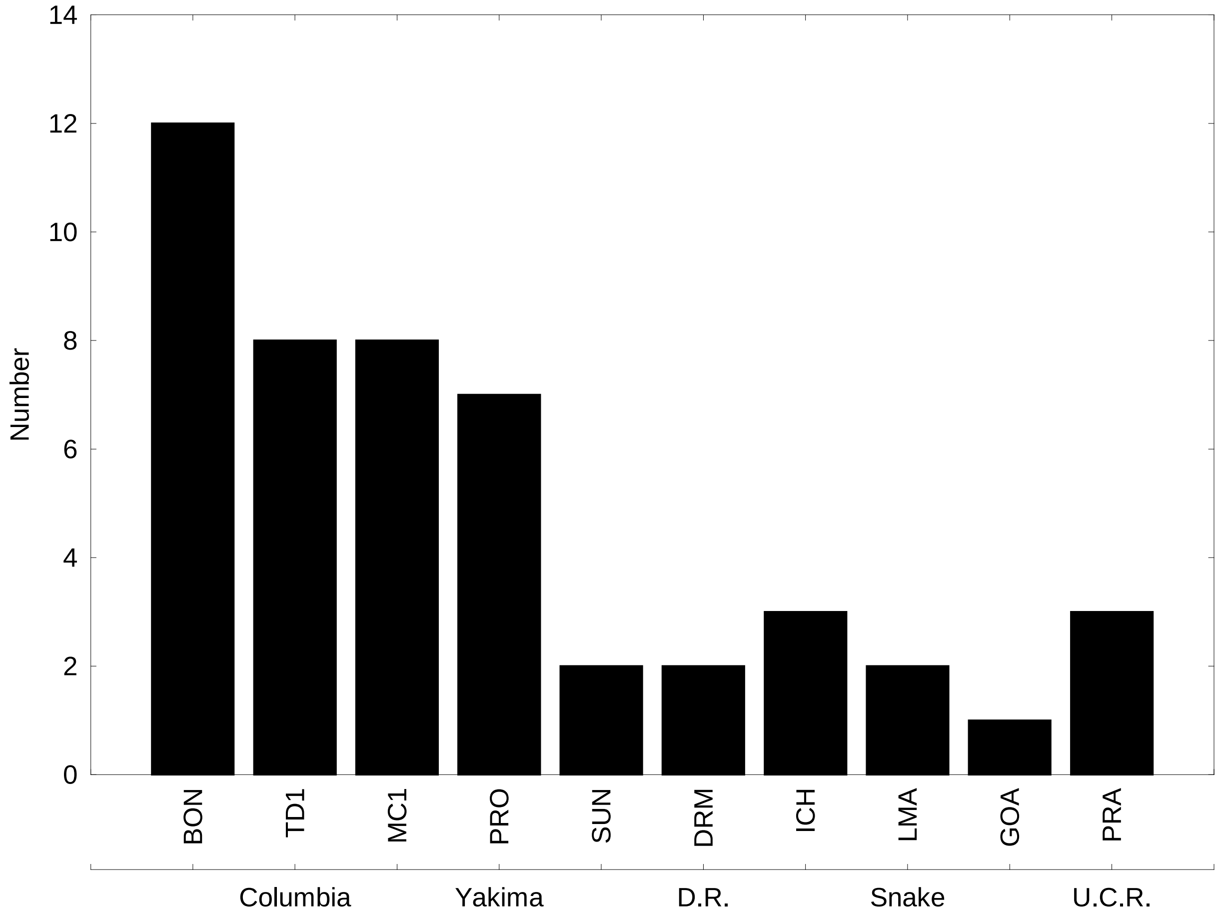

Figure 20. Detections of Naches River steelhead adults in the Columbia, Yakima, Deschutes, Snake, and upper Columbia regions in 2016. Detection sites include Bonneville Dam (BON), The Dalles Dam (TD1), McNary Dam (MC1), Prosser Dam (PRO), Sunnyside Dam (SUN), the Deschutes River Mouth (DRM), Ice Harbor Dam (ICE), Lower Monumental Dam (LMA), Little Goose Dam (GOA), and Priest Rapids Dam (PRA).

Adult summer steelhead generally migrate into the Teanaway basin between mid-February and late May. In spring of 2015, detections from the upstream North Fork, and upper Mainstem arrays were used to back calculate the passage timing of adults that were not detected on the lower array by using the average migration speed of fish that were detected at both an upstream and downstream interrogation site. The date that adults that were detected or estimated to have passed the Lower Teanaway array in 2015 were overlayed on a line plot of average daily discharge measured at the USBOR Teanaway Forks gauging station (Figure 21). Adults entered the Teanaway during the months of February, March, April, and May when they were presumed to have spawned. The adult detection efficiency was improved in 2015 relative to earlier years yet 3 adults passing the lower Mainstem Teanaway instream PIT tag array without being detected.

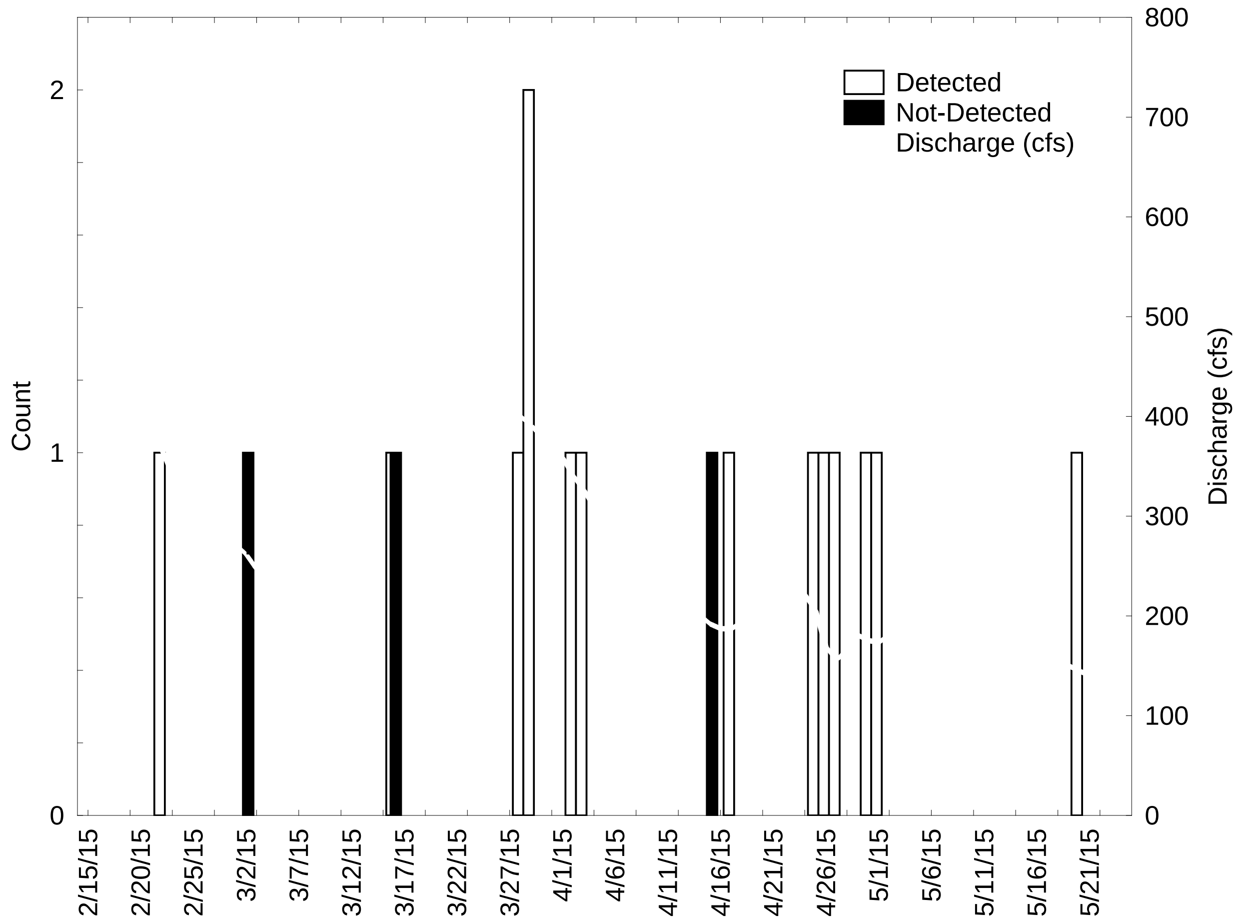

Figure 21. Mean daily stream discharge (cfs: dashed line) in the Teanaway River during the 2015 summer steelhead spring spawning migration and the number of steelhead detected (white) and not-detected (black) at the Lower Teanaway River instream PIT tag detection array (LMT).

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 will also be used to inform life cycle modeling efforts, and 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.

The proportion of the *O. mykiss* tagged in upper Yakima tributary streams that were detected as migrants at Main stem Columbia River Dams (including detections as PIT tag mortalities on the Bird Colonies), during this contract period were consistent with our observations in previous years. On average, 3% of population PIT tagged in the upper Yakima are detected as migrants annually. This is important because we are beginning to have the opportunity to present the proportion of the population that were migrants grouped by brood year: not just the number of tags observed migrating in a given year. This improves the accuracy of our estimates and facilitates spatial and temporal comparison of trends.

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. However, there is some indication that long term tag retention (e.g., 3 months or greater) may decrease over longer time intervals. 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. 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 is being conducted in the semi-natural spawning channel at the Cle Elum Supplementation and Research Facility during the spring spawning period. We conducted a pilot study in 2015 and 2016, but low recapture rates of the resident fish held in captivity have limited the utility of the data. At this time, it appears predators have limited the population of study fish in our artificial channel. Predator deterrents will be installed in 2017 which should improve the usefulness of this study in the coming year.

Another useful product generated during this contract period includes the geo-referenced plots of smolt production from each tributary stream. 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 juveniles. While we have identified the stream reaches that are producing steelhead smolts in the upper Yakima, we will work to improve the evaluation by attempting to identify causative factors. 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 rearing so habitat managers can 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 can be difficult to keep operational during large environmental events. In the late fall of 2015 (November and December), two large unanticipated runoff events occurred. The Teanaway Basin was particularly hard hit and stream flows increased several orders of magnitude from early November base-flow levels of approximately 150-200 cfs, to over 10,000 cfs, over a very short time period. The result was that all of the PIT tag infrastructure located in the Teanaway Basin was destroyed. The river channel migration at our North Fork Teanaway site (Site abbreviation NFT on Ptagis.org) nearly enveloped our shore side equipment (Solar Panels, Stand, Multiplexing Unit, Modem), and fortunately the equipment was removed prior to being destroyed. However the site is no longer suitable. The equipment at our Lower Teanaway PIT tag array (site LMT; Ptagis.org) was totally submerged in the flood event. We salvaged the equipment as soon as flood waters receded and disassembled and cleaned the electronic components but have not yet tested the equipment to see if it is still functional. Finally, the upper main stem Teanaway River site (site UMT on PTagis.org) had all the instream antennas destroyed but the shore side equipment was not harmed. As a result, we have re-evaluated our monitoring strategy and recommend relocating the equipment from UMT and NFT sites to the Easton Dam Fish ladder and to Wenas Creek. We will monitor the Teanaway Basin with a single downstream monitoring site by relocating our existing LMT site to a more protected location. In addition, the project will be testing different antenna material that may be more suitable and resilient to high stream discharge/flow events. The upgraded Easton site will provide better equipment protection, and directional movement information. The remaining salvaged equipment will be transferred to Wenas Creek to upgrade the equipment at that location. This approach should provide improved equipment security and longevity and improved monitoring capabilities.

References

Bateman, D. S., R. E. Gressweall, and A. M. Berger. 2009. Passive integrated transponder tag retention rates in headwater populations of coastal cutthroat trout. North American Journal of Fisheries Management 29:653-657.

Campton, D. E., and J. M. Johnston. 1985. Electrophoretic evidence for a genetic admixture of native and nonnative rainbow trout in the Yakima River, Washington. Transactions of the American Fisheries Society 114:782-793.

Conley, A, J. Freudenthal, D. Lind, P. Mees, and R. Visser. 2009. Yakima Steelhead Recovery Plan. Yakima Basin Fish and Wildlife Recovery Board. Available: *http://www.westcoast.fisheries.noaa.gov/publications/recovery_planning/salmon_steelhead/domains/interior_columbia/middle_columbia/mid-c-yakima.pdf* January 2015.

Crawford, B. A., and S. Rumsey. 2011. Guidane for monitoring recovery of Pacific Northwest salmon and steelhead listed under the federal Endangered Species Act. National Marine Fisheries Service Northwest Region.

Dieterman, D. J., and R. J. H. Hoxmeier. 2009. Instream evaluation of passive integrated transponder retention in brook trout and brouwn trout: effects of season, anatomical placement, and fish length. North American Journal of Fisheries Management 29:109-115.

Frederiksen, C. R., D. E. Fast, W. J. Bosch, and G. M. Temple. 2015. Yakima Steelhead VSP Project: Yakima River steelhead populations status and trends monitoring. Annual report to the Bonneville Power Administration, Project 2010-030-00, Portland, Oregon.

Ham, K. D., and T. N. Pearsons. 2000. Can reduced salmonid population abundance be detected in time to limit management impacts? Canadian Journal of Fisheries and Aquatic Sciences 57:17-24.

Karp, C., W. Larrick, M. Johnston, and T. Dick. 2009. Steelhead movements in the upper Yakima River Basin, fall 2002-spring 2006. United States Bureau of Reclamation, Denver, Colorado.

McMichael, G. A., J. P. Olson, E. L. Bartrand, M. Fischer, J. N. Hindeman, and S. A. Leider. 1992. Yakima River Species Interactions Studies Annual Report 1991. Annual report to the Bonneville Power Administration, Project 89-105, Portland, Oregon.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U. S. Department of Commerce, NOAA Tech. Memo. NMFS-NWFSC-42, 156p.

Meyer, K. A., B. High, N. Gastelecutto, E.R. J. Mamer, and F. S. Elle. 2011. Retention of passive integrated transponder tags in stream-dwelling rainbow trout. North American Journal of Fisheries Management 31:236-239.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990. Equipment, methods, and an automated data-entry station for PIT tagging. American Fisheries Society Symposium 7:335-340.

Satterthwaite, W. H., M. P. Beakes, E. M. Collins, D. R. Swank, J. E. Merz, R. G. Titus, S. M. Sogard, and M. Mangel. 2009. Steelhead life history on California's central coast: insights from a state-dependent model. Transactions of the American Fisheries Society 138:532-548.

Temple, G. M., and T. N. Pearsons. 2007. Electrofishing: backpack and driftboat. Pages 95-132 in D. H. Johnson, B. M. Schrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons. Salmonid Field Protocols Handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Temple, G. M., T. D. Webster, and Z. J. Mays. 2011. Validation of historical electrofishing data in a long term monitoring program. Pages 104-124 *in* G. M. Temple, T. D. Webster, Z. J. Mays, T.D. DeBoer, and N. D. Mankus. Ecological interactions between non-target taxa of concern and hatchery supplemented salmon. Annual report to the Bonneville Power Administration, Project 1665-063-25, Portland, Oregon.

Temple, G. M., Z. Mays, and C. Frederiksen. 2015. Yakima Steelhead VSP Project: resident/anadromous interactions monitoring. Annual report to the Bonneville Power Administration, Project 2010-030-00, Portland, Oregon.

Appendices

A.1: Data sets or products:

The juvenile tagging data is available via PTagis.org.