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Ecological Interactions Between Hatchery Summer Steelhead and Wild Oncorhynchus mykiss in the Willamette River Basin, 2014

December 2014

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Summary

The purpose of this study was to determine the extent to which juvenile hatchery summer steelhead *Oncorhynchus mykiss* and wild winter steelhead overlap in space and time, to evaluate the extent of residualism among hatchery summer steelhead in the South Santiam River, and to evaluate the potential for negative ecological interactions among hatchery summer steelhead and wild winter steelhead.

Wild winter steelhead populations have declined in the upper Willamette River Basin and are consequently listed as "threatened" under the Endangered Species Act. The U.S. Army Corps of Engineers funded the Pacific Northwest National Laboratory (PNNL) to determine whether releases of non-native hatchery summer steelhead juveniles into the South Santiam River (a tributary of the upper Willamette River) have the potential to negatively affect the river's wild winter steelhead population.

The 2014 study objectives were to 1) estimate the proportion of hatchery summer steelhead that residualized in the South Santiam River in 2014, 2) determine the extent to which hatchery and naturally produced *O. mykiss* overlapped in space and time in the South Santiam River, and 3) characterize the behavioral interactions between hatchery-origin juvenile summer steelhead and naturally produced *O. mykiss*.

We used a combination of radio telemetry and direct observations (i.e., snorkeling) to determine the potential for negative interactions between hatchery summer and wild winter steelhead juveniles in the South Santiam River. Both radio telemetry and direct observations were used to determine the spatial and temporal distribution of hatchery summer steelhead in areas containing naturally produced *O. mykiss*. In addition, radio telemetry was used to estimate the proportion of hatchery summer steelhead that residualized in the South Santiam River. Direct observations were used to assess ecological interaction rates and types among and between naturally produced and hatchery-origin *O. mykiss* and to evaluate the overlap in habitat use between the two groups.

A total of 199 hatchery summer steelhead juveniles from the South Santiam Hatchery were implanted with radio transmitters on March 20 and 21, 2014. The radio-tagged fish were held in a raceway at the hatchery for 11 to 12 days until the gate was pulled that allowed fish to volitionally leave the raceway to enter the South Santiam River in the Foster Dam tailrace. Thirty-five radio-tagged steelhead (17.6%) did not leave the hatchery during the volitional release period and were euthanized. Radio-tagged fish that did leave the hatchery were detected by fixed receivers located on Foster Dam, at the mouths of the South Santiam and Santiam rivers, in the Willamette River, and during mobile tracking surveys conducted in the South Santiam River.

Direct underwater observations were conducted at multiple locations in the South Santiam River between June 14 and July 31, 2014 to characterize the relative fish size, abundance, distribution, and behavioral interactions between residual hatchery summer steelhead and naturally produced *O. mykiss* juveniles.

Data collected from these two independent methods indicated that a significant portion of the hatchery summer steelhead released as smolts did not rapidly emigrate from the South Santiam River in 2014. Of the 164 radio-tagged steelhead that volitionally left the hatchery, 65 (39.6%) were detected outside of the South Santiam River: 12 of which were last detected near the mouth of the Santiam River

and the other 53 were last detected in the Willamette River. Forty-one (25.0% of 164) of the radio-tagged hatchery summer steelhead successfully emigrated to Willamette Falls. Thus, the last known location of the majority of the tagged fish (99 of 164 = 60.4%) was in the South Santiam River. Thirty-three of the tagged hatchery steelhead were detected in the South Santiam River during mobile tracking surveys. Of those, 21 were found to be alive in the South Santiam River over three months after their release. Because we did not survey the entire South Santiam River during mobile tracking surveys, the final fate (alive or dead) remained unknown for many of the tagged fish. Therefore, the proportion we detected alive (12.8%; 21 of 164) represents the absolute minimum residualization rate for the population of radio-tagged hatchery steelhead juveniles.

Snorkeling revealed considerable overlap of habitat use (in space and time) by residual hatchery steelhead and naturally produced *O. mykiss* in the South Santiam River. Results from our study (and others) also indicated that hatchery steelhead juveniles typically dominate interactions with naturally produced *O. mykiss* juveniles. The overlap in space and time, combined with the competitive advantage that residual hatchery steelhead appear to have over naturally produced *O. mykiss*, increases the potential for negative ecological interactions that could have population-level effects on the wild winter steelhead population of the South Santiam River.

We detected a potential mesohabitat-scale displacement of naturally produced *O. mykiss* by residual hatchery juvenile summer steelhead. We observed the highest densities of residual hatchery steelhead in sites located within 10 km of the South Santiam Hatchery, whereas the density of naturally produced *O. mykiss* generally increased with increasing distance from the hatchery. Much of the quality rearing habitat located downstream of Foster Dam appears to be situated in the 16 km between Foster Dam and McDowell Creek where the river has a higher gradient. Downstream of McDowell Creek, the South Santiam River has much lower gradient and consists of many long, slow glide habitats. Thus, it is possible that residual hatchery steelhead may be displacing naturally produced *O. mykiss* from the highest quality rearing habitat into suboptimal habitats, which could negatively affect the wild population.

Additional research is necessary to identify the population-level effects of hatchery summer steelhead releases on wild winter steelhead and hatchery management strategies that reduce these effects. Research needs, as identified by this study, include: 1) an evaluation of reduced feed levels during the last month of rearing on the residualization rate of hatchery summer steelhead, 2) an assessment of the carrying capacity of the South Santiam River downstream of the hatchery to help determine the appropriate level of hatchery steelhead production, and 3) a detailed investigation of the distribution, abundance, and movements of naturally produced *O. mykiss* throughout the spring and summer to help determine whether hatchery summer steelhead juveniles are displacing naturally produced *O. mykiss* from the highest quality rearing habitat into suboptimal habitats. This information could be used to adjust hatchery practices to help minimize the effects of hatchery summer steelhead on wild winter steelhead in the South Santiam River.

Acknowledgments

Performance of the work reported here was greatly enhanced by the excellent cooperative nature of many people within multiple organizations. First, the Oregon Department of Fish and Wildlife (ODFW) staff at the South Santiam Fish Hatchery, and in particular Brett Boyd, were very accommodating in support of the tagging work. University of Idaho staff Chris Caudill, Matt Knoff, Tami Clabough, Mark Morasch, Grant Brink, and Mike Jepson provided critical radio telemetry support throughout all phases of the project. ODFW research staff Cameron Sharpe, David Hewlett, and Justin Huff provided equipment for, and assistance with, mobile tracking surveys. Pacific Northwest National Laboratory (PNNL) staff that assisted with the work included Kate Deters, Ricardo Walker, Bryan Jones, Stephanie Liss, and Eric Oldenburg. David Leonhardt of the Portland District of the U.S. Army Corps of Engineers (USACE) was the technical lead for the project and Bob Wertheimer (USACE) also provided valuable technical oversight.

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1.0 Introduction

The ecological interactions study described herein was conducted by researchers from the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers, Portland District (USACE) during the spring and summer of 2014 as a follow-on to a study conducted in 2013. The purpose of this study was to determine the extent to which hatchery summer and wild winter steelhead juveniles overlapped in space and time and to investigate the potential for negative behavioral interactions. Because it is not possible to visually discern juvenile winter steelhead from resident rainbow trout *Oncorhynchus mykiss*, we treated all unclipped juvenile *O. mykiss* as one group that represented juvenile wild winter steelhead.

1.1 Background

Native winter steelhead in the Willamette Basin were listed as "threatened" under the Endangered Species Act in 1999 and their "threatened" status was reaffirmed in 2006. The 2006 review of the status of listed steelhead showed that the long-term trends for all populations in the Willamette Basin were negative (NOAA 2006). Further, the Federal Register pointed out that about one-third of the habitat that was historically accessible to these fish is now upstream of manmade barriers. The majority opinion of the Biological Review Team (BRT) was that the upper Willamette Distinct Population Segment (DPS) was "likely to become endangered within the foreseeable future." Finally, the BRT "remained concerned" that releases of non-native hatchery summer steelhead continue in the basin (NOAA 2006).

The Oregon Department of Fish and Wildlife (ODFW) manages the steelhead sport fishery in the Willamette Basin through extensive hatchery operations. ODFW began the hatchery steelhead program in the 1960s and currently releases more than 600,000 hatchery-reared summer steelhead (Skamania stock) to provide an enhanced sport fishery and to mitigate for reduced angling opportunities for native winter steelhead (Tinus and Freisen 2010). Summer steelhead are not native to the upper Willamette Basin. Additional reasoning for this hatchery summer steelhead program, as provided by Tinus and Friesen (2010), is that winter steelhead are generally present in the basin when angling conditions are less attractive (e.g., during rainy winter conditions).

As indicated by Tinus and Friesen (2010), data related to the upper Willamette Basin are needed to better understand the possible effects of the hatchery summer steelhead program on the native winter steelhead DPS. Therefore, it is necessary to determine the extent to which juveniles of these stocks compete for resources. Information about relative densities, behavioral interactions, movement, competitive effects, relative physiological condition, predation, and food habits is lacking for the upper Willamette Basin (Tinus and Friesen 2010). Further, the reproductive success of hatchery-origin summer steelhead and their genetic introgression with native naturally produced winter steelhead is of importance and is currently being assessed at some level by Van Doornik and Teel (2010) in their assessment of the genetics of unclipped (putatively naturally produced) juvenile steelhead collected at Willamette Falls. Van Doornik and Teel (2010) reported that 92% of the unclipped juvenile steelhead sampled at Willamette Falls in 2009 were of winter stocks, whereas about 8% were summer steelhead. In more recent work, Johnson et al. (2013) reported that 10% of the unclipped steelhead smolts at Willamette Falls were offspring of summer steelhead and an additional 10% were offspring of pairings between summer and winter steelhead (hybrids). Further, Johnson et al. (2013) found few "pure" summer steelhead juveniles in the North and South Santiam rivers, though summer steelhead hybrids represented 11.1% and 14.8% of samples, respectively.

In other areas of the Willamette Basin and in other areas in Washington and Oregon, researchers have found that interactions between hatchery and naturally produced salmonids can result in negative consequences for the naturally produced stocks/species. Stock-recruit analyses of steelhead productivity in the Clackamas River, a tributary to the lower Willamette River, showed that the wild winter steelhead population's productivity was negatively influenced by large releases of hatchery steelhead in that watershed (Kostow and Zhou 2006). The authors reported that the ODFW subsequently ceased releases of summer steelhead in the Clackamas Basin and prevented access to the upper watershed based on the findings of this productivity assessment.

The mechanisms for reduced productivity of a stock often relate to competition for limited resources or untimely migration. McMichael et al. (1999) described the behavioral interactions between hatchery-origin summer steelhead and naturally produced *O. mykiss* observed in a multi-year study. They reported that the typically larger hatchery-origin steelhead most often dominated the smaller wild fish, frequently resulting in the displacement of the wild fish. In situations where optimal foraging locations may be limited, these behavioral interactions and displacement events may reduce the fitness, and ultimately productivity, of the wild stocks. In paired growth experiments in enclosures within natural streams McMichael et al. (1997) found that wild *O. mykiss* paired with residual hatchery-origin steelhead had significantly lower growth than wild *O. mykiss* that were not paired with hatchery fish. The pairing of conspecifics (i.e., both stocks are within the same species, *O. mykiss*) significantly reduced the growth of wild fish, whereas pairing hatchery-reared steelhead with a different species (wild spring Chinook salmon *O. tshawytscha*) did not significantly reduce growth of the spring Chinook salmon. McMichael et al. (2000) suggested possible management actions that could be used to minimize the negative effects of hatchery-reared steelhead on naturally produced *O. mykiss*. Most of the strategies presented focused on attempts to separate the hatchery-origin fish from naturally produced fish in space, time, or both.

In 2013, we found no difference between release strategies (volitional release and off-station release) on the probability of hatchery summer steelhead juveniles migrating from the South Santiam River (McMichael et al. 2013). A large proportion of the radio-tagged fish were not detected migrating from the South Santiam River basin in 2013. However, we were unable to determine the ultimate fate (mortality or residualization) of these fish using only fixed station receivers. Although direct observations of behavioral interactions between hatchery-reared summer steelhead juveniles and naturally produced *O. mykiss* indicated behavioral dominance by hatchery steelhead, the potential population-level effect of these interactions remained unknown. The 2014 study addressed the uncertainties that remained following the 2013 study.

This study was conducted to determine whether the hatchery summer steelhead program has the potential to adversely affect naturally produced *O. mykiss* in the upper Willamette Basin. We used radio telemetry and direct underwater observations to determine the spatial and temporal distribution of hatchery summer steelhead released as smolts and to examine the behavioral interactions of hatchery summer and naturally produced *O. mykiss* juveniles. The goal of this research effort was to address the critical uncertainties related to the spatial distribution and fate of residual hatchery-origin summer steelhead and the behavioral interactions between hatchery-origin and naturally produced *O. mykiss*.

1.2 Study Objectives

The objectives of this study were to 1) estimate the proportion of hatchery summer steelhead that residualized in the South Santiam River in 2014, 2) determine the extent to which hatchery and naturally produced *O. mykiss* overlapped in space and time in the South Santiam River in 2014, and 3) characterize the behavioral interactions between hatchery-origin juvenile summer steelhead and naturally produced *O. mykiss*. The relevant null hypotheses to be tested were as follows:

- $H_0$1: Hatchery-origin summer steelhead released as smolts did not remain in the South Santiam River for extended periods (>30 days).
- $H_0$2: Hatchery-origin summer steelhead released as smolts did not remain in areas where naturally produced *O. mykiss* rear for extended periods (>30 days).
- $H_0$3: Juvenile hatchery summer steelhead did not affect the rate and types of behavioral interactions of rearing *O. mykiss* juveniles.

1.3 Report Contents and Organization

This report is designed to provide a succinct and timely summary of the second year of ecological interactions research conducted in the South Santiam River in 2014. Results are reported separately for the radio telemetry and direct observation methods. The Discussion section (Section 4.0) provides an examination of the results to date with respect to the potential for negative ecological interactions and the published literature on the subject as well as recommendations for future research.

2.0 Methods

A combination of radio telemetry and direct observations (i.e., snorkeling) was used to determine the potential for negative interactions between hatchery summer and wild winter steelhead juveniles in the South Santiam River. Both radio telemetry and direct observations were used to determine the spatial and temporal distribution of hatchery summer steelhead in areas containing naturally produced *O. mykiss*. In addition, radio telemetry was used to determine the ultimate fate of residual hatchery-origin *O. mykiss* and direct observations were used to assess the types and rates of ecological interactions among and between naturally produced and hatchery-origin *O. mykiss*.

2.1 Radio Telemetry

Hatchery summer steelhead juveniles (N = 199) were collected from and tagged at the South Santiam Hatchery on March 20 and March 21, 2014. Water depth in the raceways was reduced and several hundred smolts were crowded with panels to aid collection. Ten smolts at a time were dip-netted from the raceway and placed in a 38-L holding bucket filled with about 20 L of oxygenated water that was obtained from the raceway (river water). Two to four fish were transferred at a time from the holding bucket to a 19-L anesthesia solution of river water and sodium-bicarbonate buffered MS-222 (tricaine methanesulfonate; 100 mg/L). In this anesthesia solution, fish reached stage 4 anesthesia (Summerfelt and Smith 1990) within 2 to 3 minutes. Holding and anesthesia containers were refreshed repeatedly to maintain the temperature near raceway temperatures. Sedated fish were weighed, measured, and randomly assigned to one of two surgeons before tagging.

Fish were implanted with Lotek NTC-4-2L transmitters that weighed 2.1 g (in air). Programmed with a 5-second pulse rate, these tags had an estimated battery life of 125 days. During surgery, each fish was placed ventral side up in a V-shaped groove in a foam pad. A “maintenance” dose of anesthesia (50 mg/L) was supplied throughout surgery from a gravity-fed line inserted into the fish’s mouth. A scalpel blade was used to make a 15-mm incision on the linea alba (ventral mid-line) starting about 10 mm anterior to the pelvic girdle. The incision was only deep enough to penetrate the peritoneum. A 16-guage catheter needle was inserted through the incision to a point 20 mm to 25 mm posterior to the origin of the pelvic fins and just off the ventral mid-line. Pressure was applied until the needle pierced the skin of the fish. The transmitter antenna was then threaded through the needle and the needle was gently pulled posteriorly until it was free from the fish. The transmitter was then inserted into the body cavity (Figure 2.1). The position of the transmitter was adjusted by gently pulling posteriorly on the antenna until the transmitter was horizontal and directly under the incision. The incision was closed using 4-0 Monocryl suture material with two simple, interrupted sutures tied with reinforced square knots (Deters et al. 2012). Knots were made with one wrap on each of four throws. Radio transmitters were disinfected in 70-80% ethanol for 15 minutes and rinsed in distilled water prior to insertion into the peritoneal cavity. Between surgeries, scalpels and suture materials were disinfected by exposure to ultraviolet light (wavelength of 254 nm) for 5 minutes and needle holders and forceps were disinfected by exposure to hot beads (240-270°C) for 20 seconds. A sterile catheter was used for each surgery. All surgical instruments were sterilized daily in an autoclave prior to the next tagging session. All animals used in this study were handled in accordance with federal guidelines, and study protocols were approved by the PNNL Institutional Animal Care and Use Committee (protocol number 2014-05).

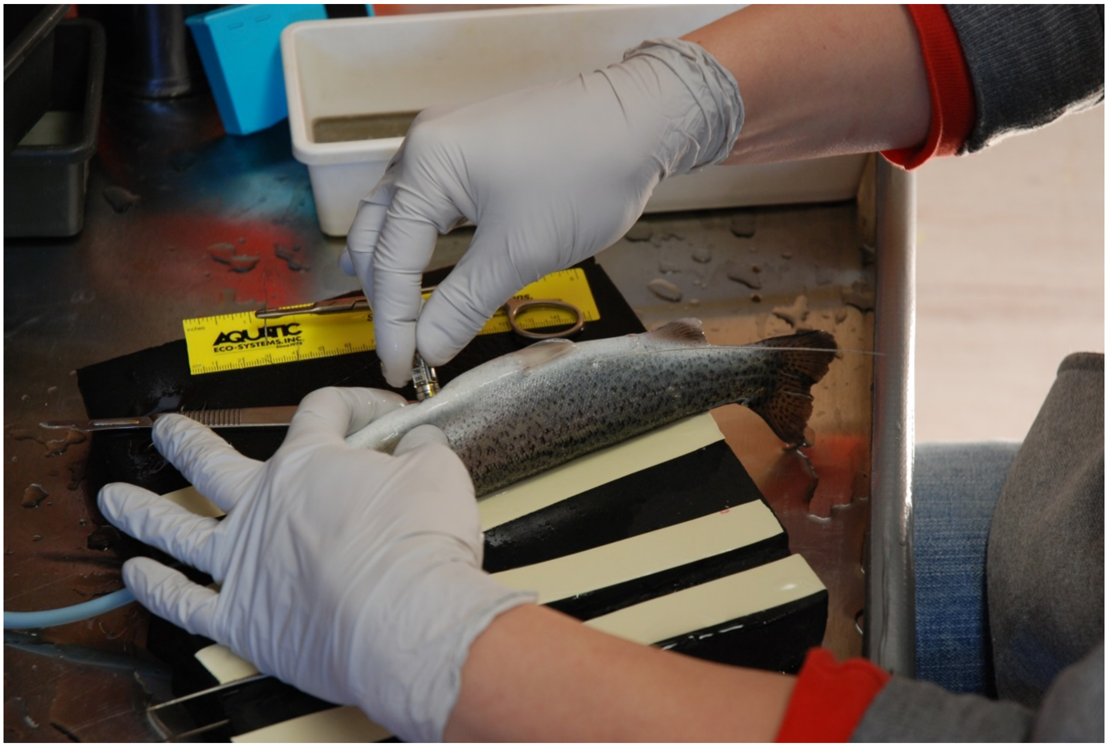

Figure 2.1. Radio Transmitter Being Inserted into the Body Cavity of a Juvenile Hatchery Steelhead at the South Santiam Hatchery on March 20, 2014. The transmitter antenna can be seen protruding from the fish posterior to the pelvic fins.

After the incision was closed, fish were placed in a partially perforated 38-L bucket filled with about 20 L of oxygenated raceway water. Once a group of 10 fish were tagged, the bucket was placed back into the raceway where it was suspended from a rope (Figure 2.2This process was then repeated until 199 fish were tagged (one of the original 200 tags malfunctioned and was not implanted). Tagged fish remained in the buckets for approximately 24 h after tagging, when they were released into the raceway. Beginning April 1, fish were allowed to leave the raceway and enter the South Santiam River in the tailrace of Foster Dam at their will until April 23, 2014, when the exit to the river was closed off and all remaining tagged fish were euthanized. Ten of the tags from fish that did not successfully emigrate from the South Santiam Hatchery were used to estimate tag life. The first tag being monitored ceased operating on August 24, 2014 (158 days after activation).

Figure 2.2. Buckets Containing Radio-tagged Juvenile Steelhead Suspended from a Rope in a Raceway at the South Santiam Hatchery in 2014

Radio-tagged fish were detected during mobile tracking surveys conducted by PNNL and by fixed station receivers maintained by the University of Idaho. Mobile tracking surveys were conducted from inflatable rafts on July 15-17 and July 29, 2014, using a Lotek SRX 600 receiver with a Yagi antenna. All mobile tracking surveys were conducted between Foster Dam and Waterloo County Park. During mobile tracking river floats, we attempted to determine the ultimate fate (i.e., alive or deceased) of non-emigrant fish. Fish were determined to be alive if they were detected in habitat consistent with the habitat preferences of juvenile *O. mykiss* and we were able to determine that a fish had moved, either by agitating the water over the source of the signal and observing a weakening of the signal (indicating movement) or by observing relocation between consecutive float trips. A fish was determined to be deceased if the tag was detected strongly out of the river (e.g., in an osprey nest). A fish's fate was classified as unknown if it did not fit the above-mentioned criteria for a living or deceased fish (e.g., in unexpected habitat and/or unable to determine movement). One fish's fate was determined by being captured by a recreational angler.

Fixed station receivers were located from the Foster Dam tailrace (SSF) to a site located downstream of Willamette Falls (WFD) (see Table 2.1and Figure 2.3). Because erroneous detections were common in the fixed station receiver data, filtering rules were developed to exclude false positives. The detection histories of fish with known locations (i.e., fish detected during mobile tracking surveys) were used to develop the filter rules to remove erroneous detections. The detection threshold (i.e. number of detections on a receiver within a specified time) for a valid detection block was derived by examining the number and pattern of false detections of mobile-tracked tags at fixed station receivers located downstream of their known location. Based on these rules, valid detection blocks consisted of four or more detections of the same fish on the same fixed receiver within 30 minutes of one another. The block remained open for a particular fish until the 30-minute detection buffer had been exceeded. Next, the blocks for a distinct fish were evaluated by analyzing the fish's movement throughout the river. If a fish passed three or more receivers without being detected, the subsequent detections were voided. The radio telemetry detection data from 2013 were re-analyzed using these newly developed filtering rules to validate the 2013 results and ensure false positives were not incorporated into the final results. Relevant selections of re-analyzed 2013 data are presented alongside data from 2014 in the results section of this report.

Fish detections were quantified by binning final detections for each fish into reaches that delineated sections of the river system. Reaches were based on the locations of the fixed station receivers and mobile tracking landmarks. The upstream station of a given reach was labeled the "from" receiver and the downstream station of a reach was labeled the "to" receiver. Fish were assumed to have passed a receiver travelling downstream, so fish were placed in the reach between the location of the last known detection ("from" site) and the next sequential "to" site. One extra station at the Pleasant Valley boat launch (PLV) was added to better incorporate mobile tracking detections. Determining a fish's last detection within a reach provided a method by which fixed station and mobile tracking data could be co-analyzed.

Detections from fixed station radio telemetry receivers were used to determine the movement rates, migration times, and probabilities of successful migration out of the Willamette River basin. Migration rates of radio-tagged hatchery summer steelhead juveniles that did not emigrate to Willamette Falls were compared to those that did using student's t-tests.

The number of steelhead smolts detected by any of the radio telemetry receiver stations located near Willamette Falls (WFF, WLL, 1WF, WFD) was divided by the number of radio-tagged smolts released from the South Santiam Hatchery to calculate the probability that steelhead successfully migrated to Willamette Falls. Therefore, we assumed that the probability of a radio-tagged smolt swimming by all four of these stations without being detected was 0.0. The residualization rate was calculated as the proportion of the total number of radio-tagged fish that volitionally left the hatchery that were determined to be alive during mobile tracking surveys. Because we were unable to determine the fate of all radio-tagged hatchery steelhead smolts, this calculation of the residualization rate represents the absolute minimum residualization rate for the tagged population.

Table 2.1. Site Names, Descriptions, and Coordinates of Fixed Station Radio Telemetry Receivers Used in the Study of Juvenile Hatchery Summer Steelhead in 2014. Telemetry receivers were installed and operated by the University of Idaho. River kilometer measurements start at Foster Dam (0.0 rkm) and increase in a downstream direction.

Site Name	Site Description	Latitude	Longitude	River Kilometer
WFD	Willamette Falls downstream	45.41907	-122.65422	220.9
1WF	Willamette Falls	45.35795	-122.6127	211.2
WLL	Willamette fishway below trap	45.35332	-122.61775	210.7
WFF	Willamette fishway above trap	45.3526	-122.61819	210.6
WFU	Willamette Falls upstream	45.30719	-122.66425	203.9
WL1	Willamette River Champoeg State Park	45.22548	-122.89995	179.7
WL2	Willamette River Eola/Salem	44.93014	-123.11371	111.9
WL3	Buena Vista, OR	44.77216	-123.14799	82.0
STM	Santiam River mouth	44.74734	-123.0955	72.9
SST	South Santiam River mouth	44.68566	-123.00823	58.9
SSF	Foster Dam tailrace	44.415394	-122.672633	0.2

We assessed the effect of several individual variables, including FL, weight, Fulton's condition factor (K), and tag burden, on the probability of successful migration to Willamette Falls for radio-tagged steelhead in 2014. Program SURPH (SURvival under Proportional Hazards; version 3.5.2) was used to evaluate the effect of each variable on the probability of emigration from the hatchery and on the probability of migration to Willamette Falls by modeling migration probabilities as a function of each individual-based covariate using the hazard link (Skalski et al. 1993; Smith et al. 1994). A nonparametric curve that did not depend on the parameters of any particular model was also plotted. The nonparametric curve can be thought of as a "moving average" survival as the selected individual covariate increases across the range of observed values. The size of the "window" for which the "moving average" survival probability was calculated ranged from a minimum of eight individuals up to 20% of the entire number at risk in the selected interval (Smith et al. 1994). The effect of each variable on migration probability was evaluated using likelihood ratio tests (LRTs) to compare each covariate model to a model of no covariate effect. Additionally, variables were evaluated using Kolmogorov-Smirnov (KS) tests (Conover 1980) to compare the probability distributions of successful and unsuccessful migrants over the range of observed values for a given variable.

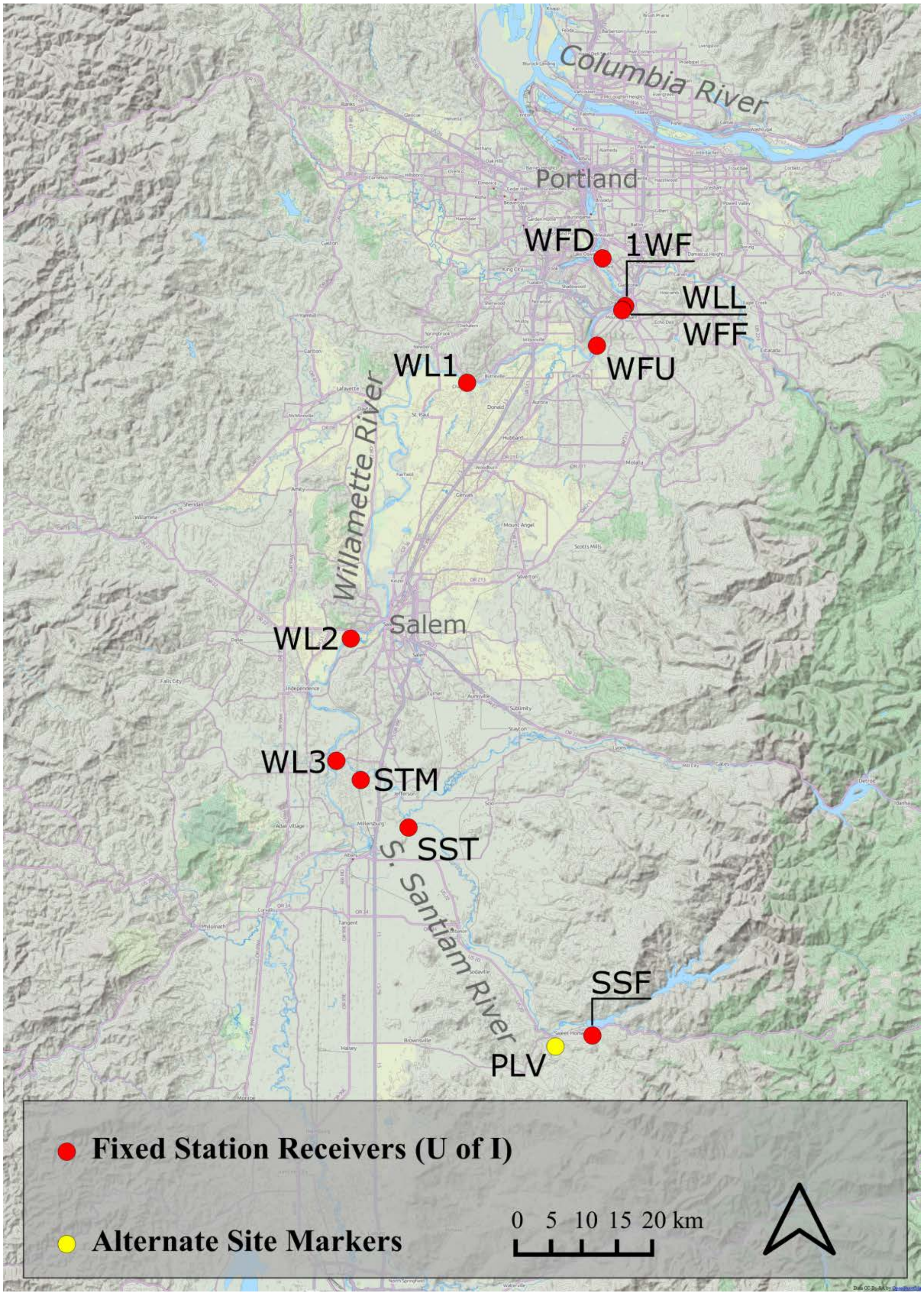

Figure 2.3. Map of the 2013-2014 Radio Telemetry Receiver Stations (Deployed and Operated by the University of Idaho) Used to Collect Data on Radio-tagged Juvenile Hatchery Summer Steelhead in the South Santiam River and the Willamette River. The Pleasant Valley boat launch (PLV) and the cities of Salem and Portland, Oregon, are also shown for reference.

2.2 Direct Observations

We conducted direct underwater observations using snorkeling equipment and underwater video cameras (GoPro Hero 3) to characterize the behavioral interactions and relative abundance of hatchery steelhead and naturally produced *O.* mykiss in the South Santiam River. Direct observations were conducted at multiple sites between the South Santiam Hatchery and Waterloo County Park on four separate one- to three-day trips between June 14 and July 31, 2014 (Table 2.2). All direct observations were completed during daylight hours. Reference sites were observed in the first year of this study; therefore, control observations were not repeated in 2014.

Figure 2.4 A Snorkeler Searching for a Group of Juvenile *O. mykiss* in the South Santiam River During a Float Survey Between Andrew Wiley Park and the Pleasant Valley Boat Launch on July 29, 2014

Observation sites were selected based on the presence of what appeared to be quality rearing habitat and measured approximately two channel widths in length. Each site was surveyed by one or two snorkelers who were trained in the identification of juvenile salmonids. Each snorkeler surveyed about half of each site and, beginning at the downstream end, carefully worked their way upstream so as not to disturb or alter the behavior of the fish at the site (Figure 2.4). Upon encountering a group of interacting fish, the snorkeler began recording the interactions with an underwater video camera. The observer recorded approximately 20 minutes of interactions with the camcorder before continuing their survey.

The species, origin (for *O. mykiss* only; naturally produced or hatchery-origin), and approximate length (50-mm bins) was recorded for each fish observed during the survey. The origin of *O. mykiss* observed was determined by the presence or absence of an adipose fin. Hatchery steelhead were identified by the absence of an adipose fin and all unclipped *O. mykiss* were considered to be naturally produced winter steelhead or rainbow trout. Observational data was recorded upon review of the collected video clips, using methods similar to those described by McMichael et al. (1999). Particular attention was directed towards the behavior of steelhead and the interactions between naturally produced *O. mykiss* and hatchery steelhead.

Table 2.2. Dates, Locations, Number of Observers, and Total Observer Hours for Direct Observation (i.e., Snorkel) Surveys Conducted in the South Santiam River to Assess the Effect of Hatchery Summer Steelhead Interactions on Wild Winter Steelhead

Date	Site	Number of Observers	Total Observer Hours
June 14-15	McDowell Creek Bridge	1	1.75
	Waterloo County Park	1	4.5
July 2-3	Waterloo County Park	2	11
	McDowell Creek Bridge	2	6
July 17	South Santiam Hatchery	1	0.3
July 29-31	South Santiam Hatchery to Waterloo County Park	2	12.0

Observational data included the number and type of interactions, origin (hatchery or naturally produced) and size of interacting fish, which fish initiated the interaction, which fish dominated the interaction, and whether the subordinate fish was ultimately displaced (i.e., when one fish caused the other to move at least two body lengths away). For each interaction, agonistic behavior was classified as a threat (aggressive fin flaring and body arching), crowd (causing the other fish to move laterally), chase (pursuing for more than two body lengths without physical contact), nip (actively biting the other fish), or butt (physical contact with a closed mouth). A fish was considered to be dominant in an interaction if it displaced its opponent in a contest or successfully defended its location from an opponent. A contest was defined as a single or multiple interactions that occurred less than 1 minute apart (a contest may have included many interactions). Proportions of interactions initiated by naturally produced and hatchery-reared *O. mykiss* toward *O. mykiss* of the same or different origin were compared using Fisher's exact test.

Observation rates were calculated separately for naturally produced *O. mykiss*, hatchery steelhead, and spring Chinook salmon by dividing the number of fish observed by the time spent observing. Interaction rates were calculated by dividing the total number of interactions observed by the number of fish observed, and then by the duration of the observation period (interaction rate = total interactions per fish per minute; McMichael et al. 1999). This rate was then multiplied by 1,000 to minimize the number of significant digits reported.

Direct observations were also used to assess the relative abundance of hatchery-reared and naturally produced *O. mykiss* in the South Santiam River. Trends in snorkel data led us to test for significant differences in the relative abundance of hatchery-reared and naturally produced *O. mykiss* (measured as CPUE; i.e., fish observed per observer minute) with increasing distance from the South Santiam Hatchery using generalized multiple linear regression models. Due to skewness in the data, the response variable (i.e., CPUE) was log-transformed to better fit the assumptions of the Gaussian family model.

3.0 Results

The results cover two primary topics: 1) radio telemetry to examine the post-release spatial and temporal distribution and migratory behavior of juvenile hatchery summer steelhead, and 2) direct observations to examine the relative abundance and behavioral interactions of juvenile hatchery summer steelhead and naturally produced *O. mykiss*.

3.1 Radio Telemetry

Thirty-five of the 199 (17.6%) radio-tagged hatchery steelhead did not emigrate from the raceway prior to the end of the volitional release period (3 weeks). We did not detect any significant relationship between the probability of emigrating from the hatchery volitional release pond and fish length (LRT: $\chi^2 = 1.11$, df = 1, $P = 0.293$), weight ($\chi^2 = 0.46$, df = 1, $P = 0.498$), condition factor ($\chi^2 = 0.61$, df = 1, $P = 0.433$), or tag burden ($\chi^2 = 0.67$, df = 1, $P = 0.414$; Figure 3.1).

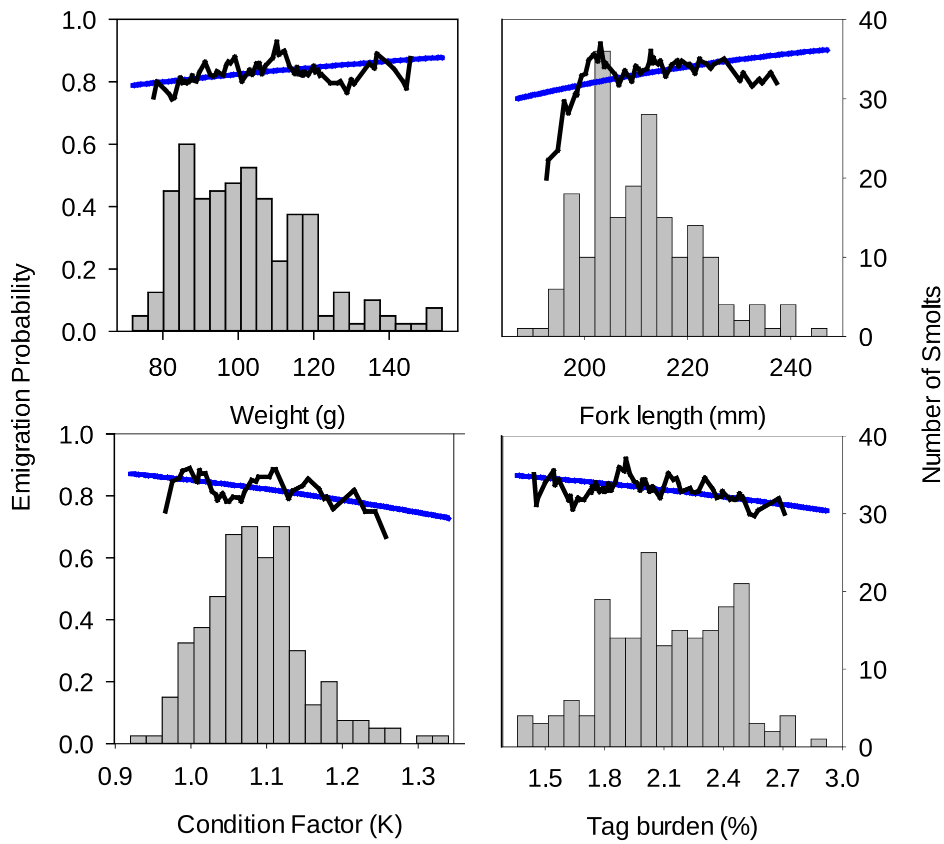

Figure 3.1. Covariate Analysis Results Displaying Nonparametric (Black Line) and Modeled (Blue Line) Probabilities of Volitional Emigration from the South Santiam Hatchery for Radio-tagged Hatchery Summer Steelhead Smolts in Relation to Weight, Fork Length, Fulton's Condition Factor (K), and Tag Burden. Frequency histograms (gray bars) display the number of smolts in each bin of the independent variables.

Of the 164 radio-tagged steelhead that volitionally left the hatchery, 65 (39.6%) were detected outside of the South Santiam River (Table 3.1). Twelve of the tagged hatchery steelhead were last detected near the mouth of the Santiam River (STM) and the other 53 tagged fish were last detected in the Willamette River with 41 (25% of 164) successfully emigrating to Willamette Falls (WFF, WLL, 1WF, and WFD; Figure 3.2). Thus, the last known location of the majority of the tagged fish (99 of 164 = 60.4%) was in the South Santiam River (Figure 3.3). Thirty-three of the 99 tagged hatchery steelhead remaining in the South Santiam River were detected between Foster Dam and Waterloo County Park during mobile tracking surveys. Fifty tagged fish (30.5% of 164) were last detected by the fixed receiver station in the Foster Dam tailrace (SSF) and 14 were never detected after they left the hatchery. Two fish were last detected in the South Santiam River near the mouth (SST). We assumed the 50 fish last detected by the SSF station and the 14 fish that were never detected residualized in the South Santiam River downstream of Waterloo County Park or perished within the South Santiam River and were carried away from the river (by birds, humans, etc.) because they were not detected by the fixed stations located at or downstream of the South Santiam River mouth, or during mobile tracking surveys.

Table 3.1. Distribution of Last Radio Telemetry Detections of Juvenile Hatchery Summer Steelhead Among Reaches of the Willamette River Basin for the 2014 Study Period (April 1 – August 31, 2014) and Updated 2013 Volitional and Off-Station Releases for Comparison. The 2014 Volitional release includes 14 fish that were never detected, the 2013 Off-Station release includes four fish that were never detected, and the 2013 Volitional release includes five fish that were never detected. These fish were considered last detected at their release location.

Reach	From	To	2014 Volitional	2013 Volitional	2013 Off-Station
1	SSF	SST	60%	65%	55%
2	SST	STM	1%	0%	0%
3	STM	WL3	7%	4%	5%
4	WL3	WL2	1%	0%	0%
5	WL2	WL1	0%	4%	2%
6	WL1	WFU	1%	6%	4%
7	WFU	WFF	4%	0%	3%
8	WFF	WLL	0%	0%	0%
9	WLL	1WF	1%	0%	0%
10	1WF	WFD	2%	0%	2%
11	WFD	Below WFD	23%	21%	29%

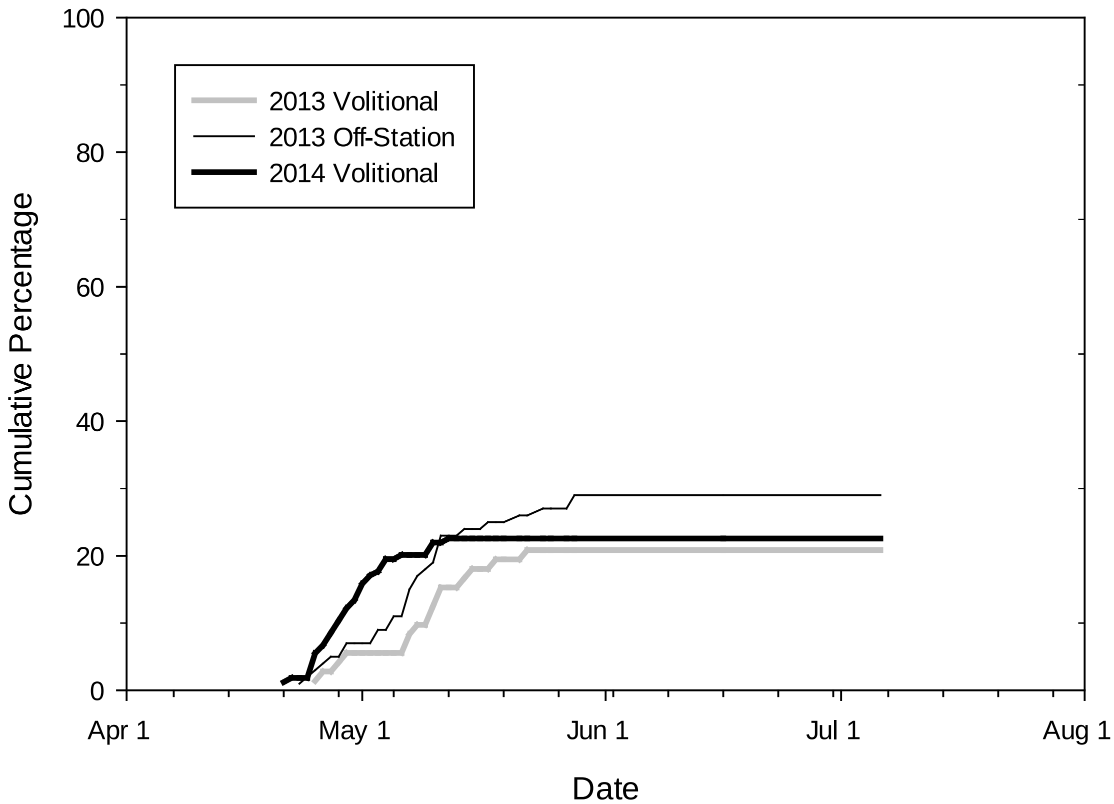

Figure 3.2. Cumulative Percent Emigration to Willamette Falls for Radio-tagged Juvenile Hatchery Summer Steelhead that Volitionally Left the Hatchery in 2014 and 2013 or were Released Off-station in 2013

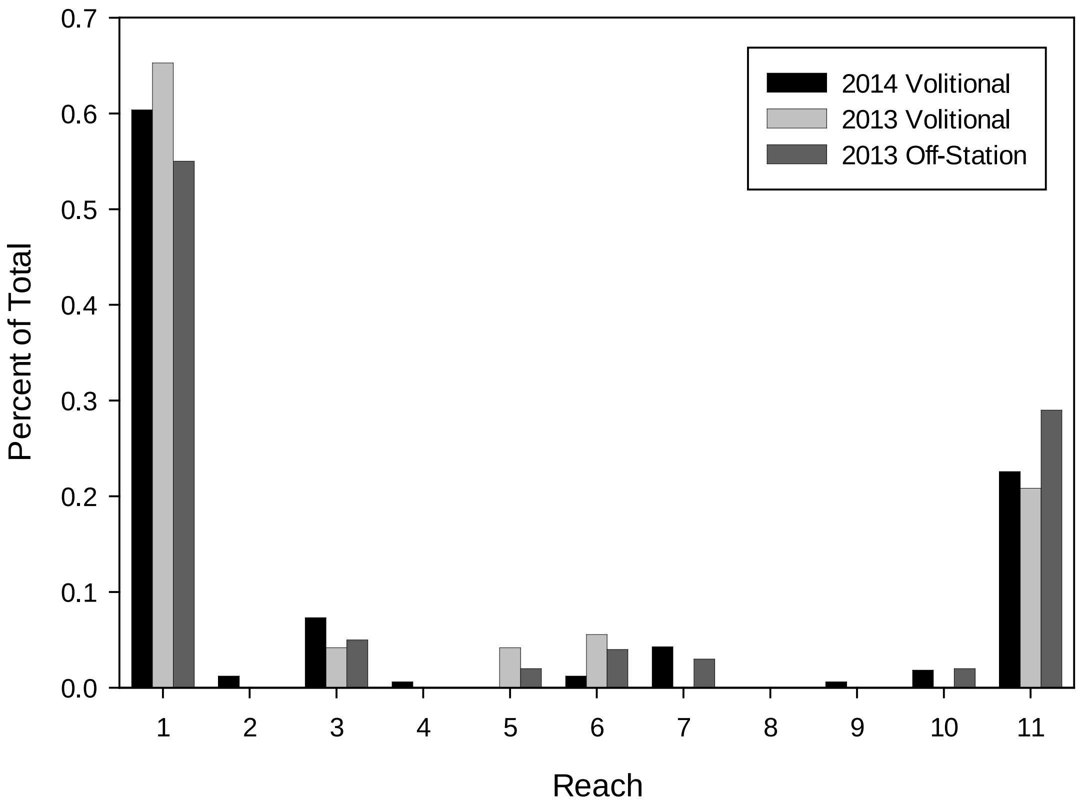

Figure 3.3. Percent of Radio-tagged Hatchery Summer Steelhead Juveniles Last Detected in Reaches of the South Santiam, Santiam, and Willamette Rivers in 2014 and 2013. The 2014 volitionally released fish (N=164) are in black, 2013 volitionally released fish (N=72) are in light gray, and 2013 off-station released fish (N=100) are in dark gray. Reaches correspond to those listed in Table 3.1.

Thirty-three radio-tagged hatchery steelhead juveniles were detected in the South Santiam River three months after their release during mobile tracking surveys. Of those, 21 were found to be alive, representing a minimum residualization rate of 12.8% (21 of 164) for the radio-tagged steelhead that volitionally left the hatchery. Applying this percentage to the number of hatchery steelhead released would result in an estimated 23,616 residual hatchery summer steelhead in the South Santiam River. The majority (71.4%; 15 of 21) of the residual radio-tagged hatchery steelhead that were determined to be alive were located upstream of PLV (Table 3.2; Figure 3.4). The other six fish determined to be alive were located between PLV and Waterloo County Park. Nine of the mobile-tracked fish were determined to be deceased and the fate of three others remained unknown.

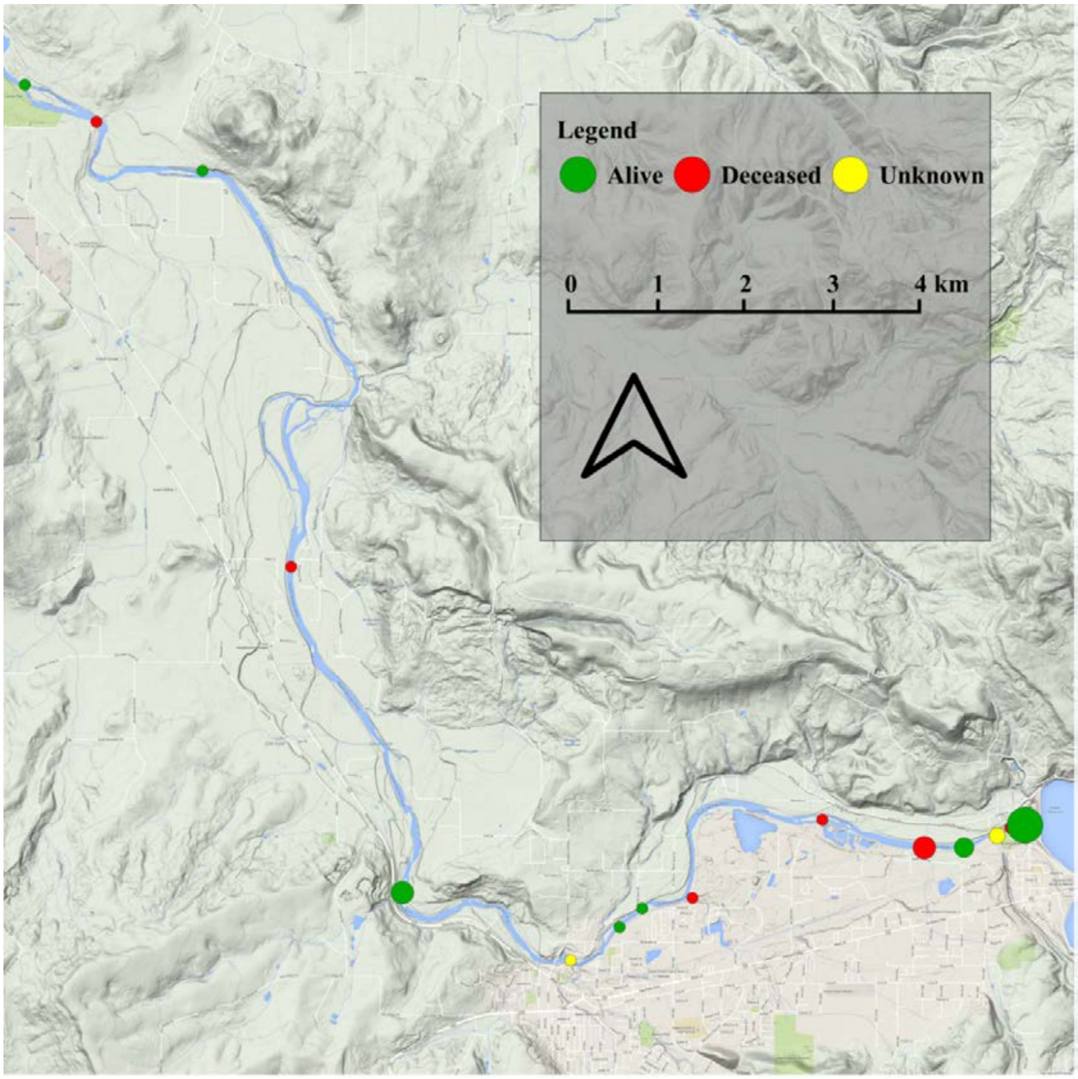

Figure 3.4 Map of the South Santiam River from Foster Dam to Waterloo County Park. Points on the map indicate the locations radio-tagged juvenile hatchery summer steelhead were detected during mobile tracking surveys color-coded by the ultimate fate of the detected fish and scaled to the number of fish detected at each location (larger circle = more fish detected).

Table 3.2. Number and Fates of Non-emigrant Radio-tagged Hatchery Summer Steelhead Juveniles Detected During Mobile Tracking Surveys on the South Santiam River in July 2014

Fate	Location		Total
	Below PLV	Above PLV	
Alive	6	15	21
Deceased	2	7	9
Unknown	1	2	3
	9	**24**	**33**

A portion of the radio-tagged fish that did not emigrate to Willamette Falls (non-emigrants) in 2014 moved throughout the river, as evidenced by detections on multiple receivers (Figure 3.5). Non-emigrant fish had significantly lower median movement rates (measured in river kilometers per decimal day) than fish that emigrated (Student's t-test: t = 16.72, df = 1, P < 0.001; Table 3.3).

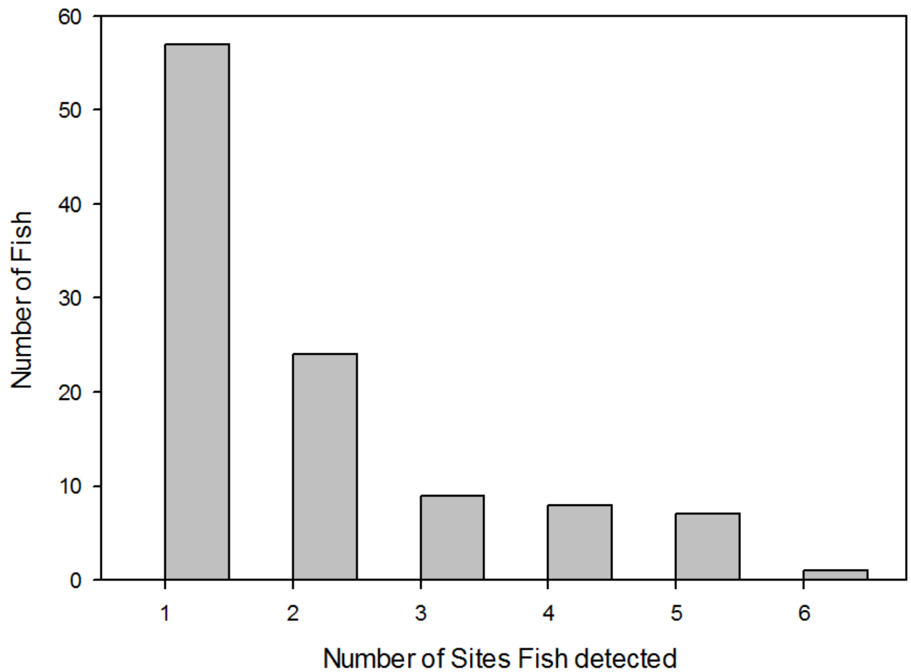

Figure 3.5. Detections of Non-emigrant Radio-tagged Juvenile Hatchery Summer Steelhead in the South Santiam River at Multiple Sites in 2014

Table 3.3. Movement Rates (rkm/day) Among Emigrant and Non-emigrant Radio-tagged Juvenile Hatchery Summer Steelhead Released in 2014 and Detected on Multiple Receivers in the South Santiam River

Emigration Status	Movement Rate (rkm/day)				
	Median	Mean	SD	Min	Max
Emigrants	7.48	7.36	1.67	4.1	11.11
Non Emigrants	0.09	1.68	3.00	0.001	18.2

Results from LRTs and individual covariate plots indicated there was a significant negative relationship between the probability of migrating to Willamette Falls and condition factor (χ^2 = 5.85, df = 1, P = 0.016; Figure 3.6), suggesting longer and slimmer fish were more likely to emigrate to Willamette Falls. We observed a weak, negative relationship between migration probability and fish weight but the relationship was not significant (χ^2 = 0.75, df = 1, P = 0.385). Similarly, positive relationships between fork length (χ^2 = 0.02, df = 1, P = 0.889) and tag burden (χ^2 = 0.98, df = 1, P = 0.322) were apparent, but not significant. Although K-S tests did not detect significant differences at an α level of 0.05, they revealed similar results to those obtained from the LRTs; that is, the greatest difference between the probability distributions of successful and unsuccessful migrants was observed over the range of condition factor values (D = 0.2205, P = 0.0749), followed by weight (D = 0.1667, P = 0.3048), tag burden (D = 0.1667, P = 0.3048), and fork length (D = 0.0788, P = 0.9847).

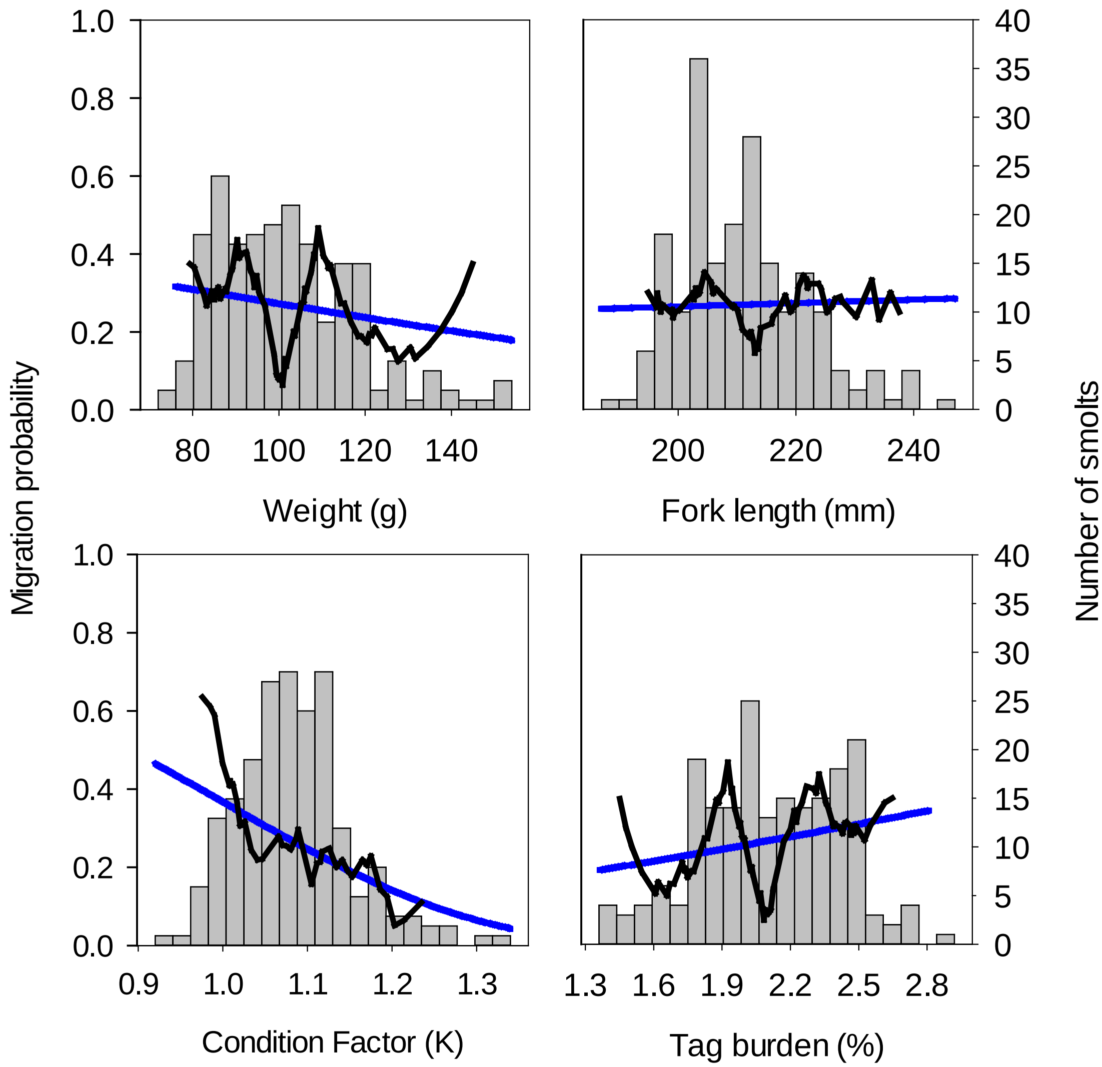

Figure 3.6. Covariate Analysis Results Displaying Nonparametric (Black Line) and Modeled (Blue Line) Probabilities of Migration to Willamette Falls for Radio-tagged Hatchery Summer Steelhead Smolts in Relation to Weight, Fork Length, Fulton's Condition Factor (K), and Tag Burden. Frequency histograms (gray bars) display the number of smolts in each bin of the independent variables.

3.2 Direct Observations

Water-quality conditions during most direct observation surveys were conducive to observing behavioral interactions with turbidity largely remaining below 0.1 NTUs (Figure 3.7) and generally low discharge (<2000 cfs; Figure 3.8). The first set of snorkel surveys were conducted on June 14–15, 2014, at Waterloo County Park and near the mouth of McDowell Creek. The mean daily water temperature from June 14–15 was 10.7°C and discharge was the highest observed during all snorkel surveys at 1815 cfs (Figure 3.8). Turbidity was also the highest observed of any 2014 snorkel surveys on June 15 at 0.11 NTU. By July 2–3, the mean discharge had decreased to 1335 cfs, the mean daily water temperature had risen to 11.2°C, and mean turbidity was 0.065 NTU. The final snorkel surveys were conducted on July 29–31, 2014, during a series of raft floats between Foster Dam and Waterloo County Park. At the time of this trip, mean daily water temperature was 12.3°C and turbidity, as measured near Foster Dam, averaged 0.07 NTU.

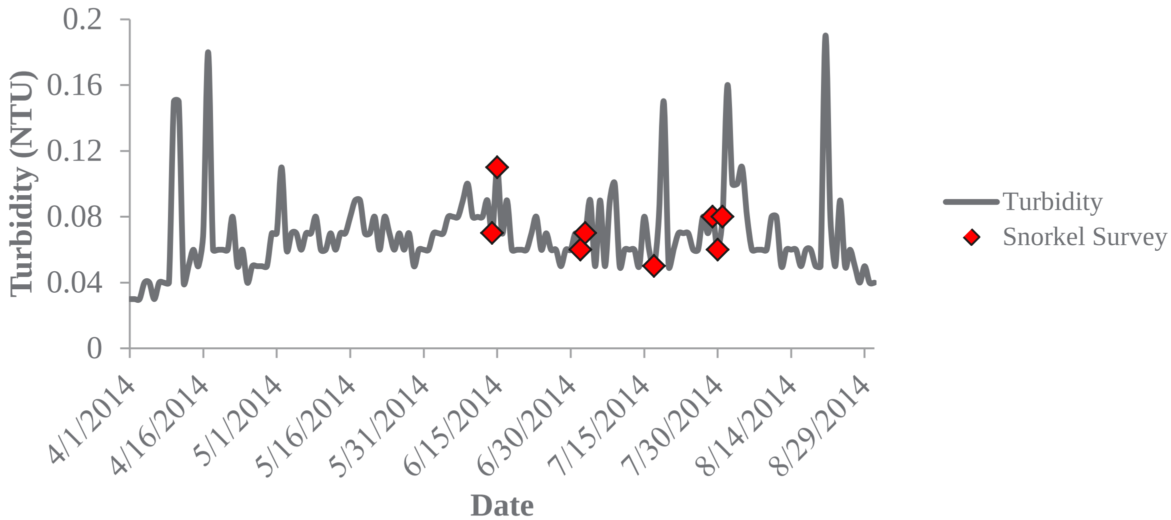

Figure 3.7. Turbidity Profile of the South Santiam River Near Foster Dam (Oregon Public Health Drinking Water Database) Between April 1 and August 30, 2014. Dates of Snorkel surveys are indicated by red diamonds on the turbidity line.

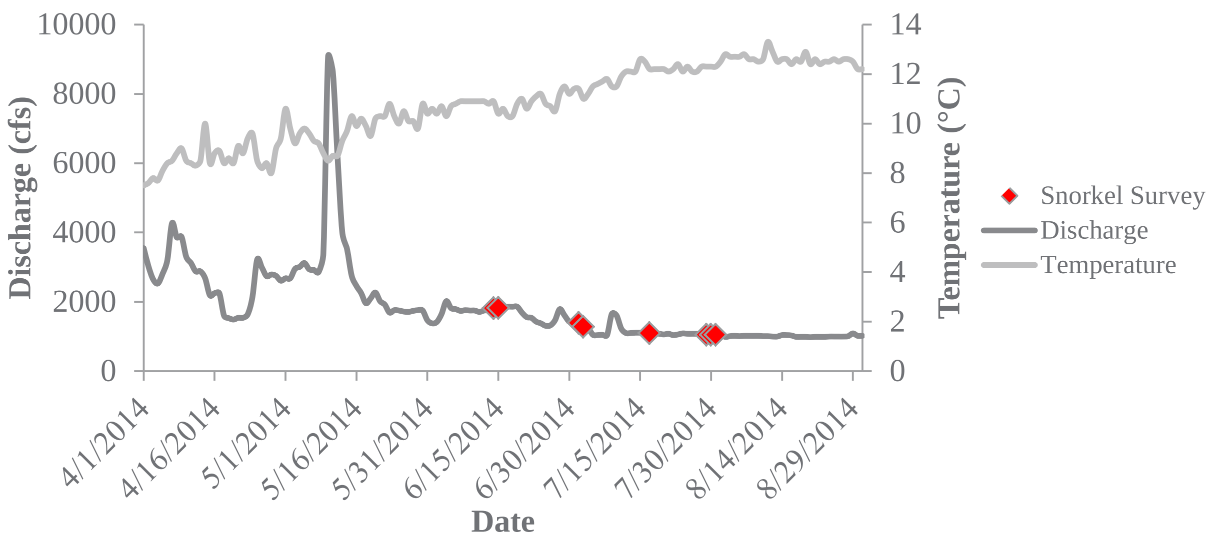

Figure 3.8. Discharge (Dark Gray Line) and Mean Daily Water Temperature (Light Gray Line) Profile of the South Santiam River Near Foster Dam (U.S. Geological Survey Gauge 14187200) Throughout the Study Period (April 1 – August 30, 2014). Dates of snorkel surveys are indicated by red diamonds on the discharge line.

On June 14–15 and July 2–3, 2014, snorkel surveys were restricted to Waterloo County Park and the mouth of McDowell Creek. The majority of fish observed during these surveys were naturally produced *O. mykiss* that measured 100–150 mm (Figure 3.9). However, hatchery-reared summer steelhead juveniles were also observed alongside naturally produced *O. mykiss*. The majority of naturally produced *O. mykiss* ranged in size from 100 mm to 200 mm and were more abundant than juvenile hatchery summer steelhead at both sites by a 27:1 margin. Hatchery summer steelhead observed during these surveys were generally larger than the naturally produced *O. mykiss* observed, ranging in size from 200-250 mm.

Higher densities of hatchery steelhead juveniles were observed during the final two snorkel surveys. The first of these efforts was a short snorkel survey conducted on July 17 at the South Santiam Hatchery following a session of radio tracking in which many fish were detected near the hatchery outflow pipe. Although difficult to quantify, it was estimated that approximately 30 hatchery steelhead juveniles lingered around the hatchery outflow pipe. No tagged fish were directly observed during the survey, indicating it is unlikely we observed all hatchery fish in the area.

During the final snorkel surveys, which were conducted July 29–31 during float trips between Foster Dam and Waterloo County Park, we observed a trend of decreasing CPUE for hatchery summer steelhead and increasing CPUE for naturally produced *O. mykiss* as we progressed downstream (Figure 3.10). A generalized linear model that compared the CPUE of hatchery-reared and naturally produced *O. mykiss* to the distance from the South Santiam Hatchery showed that the interaction between fish origin and distance from the South Santiam Hatchery had a significant effect on CPUE ($\chi^2 = 7.83$, df = 3, $P = 0.049$).

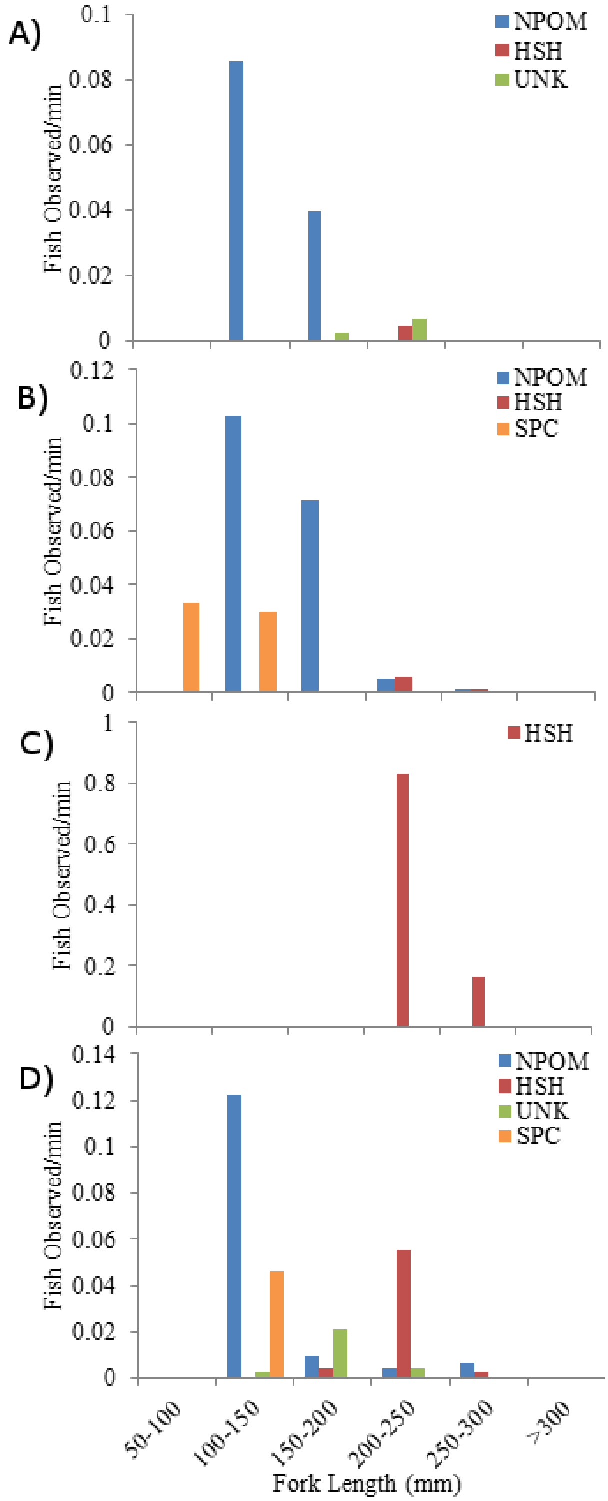

Figure 3.9. Fish Observed per Observer Minute by Size, Class, and Species During Four Snorkeling Trips in the South Santiam River; A) June 14–15, 2014, B) July 2–3, 2014, C) July 17, 2014, D) July 29–31, 2014. NPOM = naturally produced *O. mykiss*, HSH = hatchery steelhead, UNK = unknown origin *O. mykiss*, SPC = spring Chinook salmon.

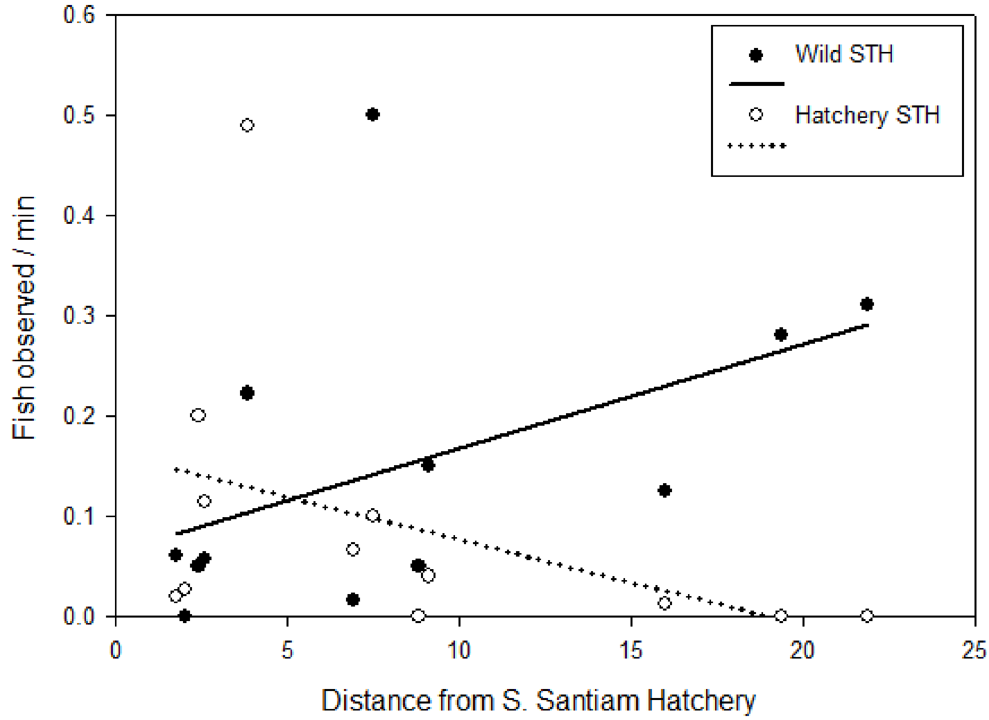

Figure 3.10. Regression Lines Describing the Relationship Between CPUE (Fish Observed per Observer Minute) and Distance from the South Santiam Hatchery for Hatchery-Reared and Naturally Produced (i.e., Wild) *O. mykiss*.

A total of 53 interactions were observed between juvenile *O. mykiss* during snorkel surveys in 2014. The majority of these interactions were classified as chase (43%), crowd (26%), or threat (21%) behaviors, whereas interactions that involved physical contact such as nipping or butting occurred less frequently (Table 3.4).

On June 14–15, 22 interactions were observed at a rate of 10.19 interactions·fish^{-1}·min^{-1}·1000 at McDowell Creek, most of which (77%) occurred between hatchery summer steelhead juveniles and naturally produced *O. mykiss* (Table 3.5). On June 15, the interaction rate observed at Waterloo County Park was much lower at 0.60 interactions·fish^{-1}·min^{-1}·1000. On July 2–3, five interactions were observed among naturally produced and hatchery-reared *O. mykiss* at Waterloo County Park at a rate of 0.06 interactions·fish^{-1}·min^{-1}·1000. On the same survey trip at McDowell Creek, two interactions were observed at a rate of 0.19 interactions·fish^{-1}·min^{-1}·1000. On July 17, five interactions were observed near the South Santiam Hatchery outflow pipe among hatchery-reared summer steelhead juveniles at a rate of 2.45 interactions·fish^{-1}·min^{-1}·1000. On July 29–31, nine interactions were observed among 168 fish, equaling an interaction rate of 0.075 interactions·fish^{-1}·min^{-1}·1000. The majority of these interactions (89%) occurred between naturally produced *O. mykiss*.

When a size difference existed (interacting fish were often the same size), the larger fish typically initiated and dominated the interaction. Overall, 90% of interactions were dominated by the initiating fish and 84% of interactions resulted in the displacement of the subordinate fish. In 16 of the 19 interactions (84%) between juvenile hatchery summer steelhead and naturally produced *O. mykiss*, the hatchery steelhead dominated and displaced the naturally produced *O. mykiss*.

Naturally produced *O. mykiss* were significantly more likely to initiate aggressive interactions toward other naturally produced *O. mykiss* than toward hatchery summer steelhead juveniles (Fisher's exact test: χ^2 = 5.6, df = 1, P = 0.039). Hatchery-reared juvenile summer steelhead were not significantly more likely to initiate aggressive interactions toward naturally produced *O. mykiss* than toward other hatchery summer steelhead (χ^2 = 4.2, df = 1, P = 0.071). Overall, 61.7% of all interactions observed were initiated by hatchery-reared juvenile summer steelhead, which comprised only 28.6% of the total number of *O. mykiss* observed during snorkel surveys.

Table 3.4. Number and Percent of Behavioral Interaction Types Observed at Treatment and Reference Sites on the South Santiam River During 2014 and 2013 Snorkel Surveys

	2014 Treatment		**2013 Treatment**		**2013 Reference**	
Interaction Type	N	Percent	N	Percent	N	Percent
Threat	11	21%	7	14%	0	0%
Chase	23	43%	16	31%	2	67%
Crowd	14	26%	24	47%	1	33%
Nip	4	8%	3	6%	0	0%
Butt	1	2%	1	2%	0	0%
Total	**53**		**51**		**3**	

Table 3.5. Direct Observation Data Displaying the Interaction Observation Time, the Total Number of Interactions, the Number of Observed Interactions Between Hatchery Steelhead (HSH) and Naturally Produced *O. mykiss* (NPOM), and Behavior Interaction Rates from Snorkel Surveys Conducted in 2013 and 2014 at Treatment and Reference Sites on the South Santiam River. Rate 1: total interaction rate (number of interactions·fish^{-1}·min^{-1}·1000); Rate 2: rate of interactions between HSH and NPOM only.

Date	Site	Interaction Obs. Time (min)	Total Interactions	HSH/ NPOM	NPOM/ NPOM	Rate 1	Rate 2
			Treatment 2014				
June 14–15, 2014	McDowell Creek Bridge	120	22	17	3	10.19	7.87
	Waterloo County Park	360	10	0	9	0.60	0.00
July 2–3, 2014	Waterloo County Park	660	5	2	3	0.06	0.02
	McDowell Creek Bridge	360	2	0	1	0.19	0.00
July 17, 2014	South Santiam Hatchery	30	5	0	0	2.45	0.00
July 29–31, 2014	South Santiam Hatchery to Waterloo County Park	720	9	0	8	0.07	0.00
Total		**2250**	**53**	**19**	**24**		
Mean						**2.26**	**1.32**
			Treatment 2013				
April 3, 2013	Waterloo County Park	-	-	-	-	-	-
April 26, 2013	Waterloo County Park	56	16	0	16	4.93	0.00
June 4–5, 2013	Wiley Creek	60	0	0	0	0.00	0.00
	Waterloo County Park	40	6	6	0	1.36	1.36
July 18–19, 2013	Waterloo County Park	40	7	5	2	2.87	2.05
	McDowell Creek Bridge	47	22	19	3	9.82	7.77
Total		**243**	**51**	**30**	**21**		
Mean						**3.80**	**2.24**
			Reference				
April 3, 2013	Riverbend Campground	-	-	-	-	-	-
June 4–5, 2013	Riverbend Campground	60	0	0	0	0.00	-
July 18, 2013	Riverbend Campground	40	3	0	3	1.63	-
Total		**100**	**3**	**0**	**3**		
Mean						**0.82**	-

4.0 Discussion

This section describes the reanalysis of the 2013 radio telemetry data, the 2014 ecological interactions study in the South Santiam River and the limitations of the data, provides a review of relevant literature on the subject, and recommends management actions and additional research that may further reduce uncertainties regarding the potential for negative ecological interactions between hatchery summer steelhead and wild winter steelhead in the South Santiam River.

We found little difference in the final detection sites of radio-tagged hatchery summer steelhead released in 2013 following reanalysis using the updated detection algorithms developed during the current study year. Five additional fish from the off-station release group were recorded as successfully migrating to Willamette Falls and four fish from the volitional release group were marked as not successfully emigrating. The distribution of detections across the fixed station receivers remained approximately the same. These small changes did not affect the conclusions reached in the 2013 report.

The results obtained in 2014 were generally similar to those from 2013. The data collected in both years of this study suggest that hatchery-reared juvenile summer steelhead residualize in the South Santiam River. Residual hatchery-reared steelhead have a high potential to interact negatively when sharing rearing habitat with naturally produced fish (McMichael et al. 1997; McMichael et al. 1999; Kostow 2008). Based on the radio telemetry data collected during two years of this study, the majority of tagged hatchery steelhead perished or residualized in the South Santiam River and only about one quarter of the tagged fish successfully emigrated to Willamette Falls. We were also able to confirm the residualization of juvenile hatchery summer steelhead through direct observation and radio telemetry more than three months after release. Further, snorkel surveys revealed that hatchery-reared juvenile summer steelhead were present in sympatry with naturally produced *O. mykiss* in most of the locations surveyed and hatchery fish generally dominated interactions with wild fish. Therefore, based on the results from the 2013 and 2014 studies, there appears to be potential for negative ecological interactions to take place between hatchery-reared and naturally produced *O. mykiss* in the South Santiam River.

Direct observations of hatchery-reared and naturally produced *O. mykiss* in both years of this study revealed that hatchery-reared juvenile summer steelhead tend to initiate more aggressive interactions than their naturally produced counterparts and fish of either origin disproportionately directed aggressive interactions toward naturally produced juvenile *O. mykiss*. The behaviors observed in both years of this investigation were very similar. Most of the interactions observed (90%) were less violent behaviors (e.g., chases, crowds, threats) and only 10% were the more violent butts and nips (i.e., behaviors involving physical contact). In comparison, McMichael et al. (1999) investigated hatchery and naturally produced *O. mykiss* interactions using similar methods and found that nearly half of the agonistic interactions observed were nips and butts. However, the apparent density of *O. mykiss* observed by McMichael et al. (1999) was higher than the density observed in this study, which may have resulted in more violent interactions in their study.

In general, hatchery-reared juvenile steelhead are larger than naturally produced *O. mykiss* in rearing areas where the two groups overlap (McMichael et al. 1999; Brignon et al. 2012; Snow et al. 2013). This was also the case in the South Santiam River in 2013 and 2014, where hatchery steelhead were generally estimated to be between 150–300 mm and most naturally produced *O. mykiss* were between 100–200 mm. Previous research on ecological interactions between hatchery steelhead and naturally produced *O.*

mykiss (e.g., McMichael et al. 1999, 2000) showed that size is highly correlated with behavioral dominance. Similarly, smaller, subordinate fish were typically displaced in the South Santiam River in 2014. Aggression among juvenile salmonids is thought to be directly related to competition because subordinate fish are often displaced into areas that are energetically less favorable and the growth of naturally produced *O. mykiss* can suffer as a result (McMichael et al. 1997; Weber and Fausch 2003). Subordinate fish may also be displaced into a habitat that exposes the displaced fish to an increased risk of predation (i.e., further from cover or into shallower water; Tatara et al. 2011).

In many laboratory studies, hatchery-reared salmonids have proven to be more aggressive than their wild counterparts, even when size-matched (Fenderson et al. 1968; Mesa 1991; Rhodes and Quinn 1998). Some researchers have noted that increased aggressiveness may be an unintended consequence of domestication due to selection for traits that are advantageous in the hatchery environment (Berejikian 1995; Berejikian et al. 1996; Berejikian et al. 1999; Einum and Fleming 2001). Berejikian et al. (1996) suggested that only 4–7 generations of domestication is enough to result in behavioral divergence of hatchery and wild populations. The stock of summer steelhead released annually in the Upper Willamette basin (Skamania 024) was established in the 1950s and the brood stock has since been maintained at the South Santiam Hatchery (ODFW 2014). It is possible that the Skamania stock may have behaviorally diverged from its wild parental stock, due to the duration of domestication, and become a more aggressive population. Releases of a larger, more aggressive conspecific competitor into the habitat occupied by wild winter steelhead juveniles have the potential to negatively affect the naturally produced fish by displacing them from preferred feeding territories or causing them to prematurely emigrate from the basin (Chapman 1962; Nielsen 1994; Peery and Bjornn 2004; Tartara et al. 2011). Steelhead, in particular, may be particularly vulnerable to releases of larger conspecific competitors into their habitat since juvenile steelhead may rear in freshwater for several years before smolting, thereby increasing the duration of cohabitation (Busby et al. 1996; Tatara and Berejikian 2011).

The number of hatchery-reared steelhead juveniles released into the South Santiam River also has the potential to exacerbate any negative effects hatchery-reared steelhead may have on naturally produced winter steelhead. As hatcheries release fish into a system, the population density of that system increases. A large portion of freshwater mortality among Pacific salmon and steelhead is dependent on the population density of the system (Grant and Kramer 1990; Achord et al. 2003; Keeley 2003). Tinus and Friesen (2010) recommended that the number of summer steelhead juveniles should not exceed 75% of the number of naturally produced winter steelhead in a system and that the composite population density (hatchery-reared + naturally produced *O. mykiss*) should not exceed the theoretical juvenile carrying capacity to avoid density-dependent effects. Kostow and Zhou (2006) concluded that large-scale hatchery summer steelhead release programs resulted in density-dependent mortality and contributed to the decline of the wild winter steelhead population in the Clackamas River, Oregon. Additional work is needed to better quantify the true carrying capacity of the South Santiam River to determine whether or not density-dependent effects are of concern.

Although we cannot confirm that residual hatchery steelhead are causing density-dependent mortality of wild winter steelhead in the South Santiam River, we did detect a potential mesohabitat-scale displacement of naturally produced *O. mykiss* by hatchery-reared juvenile summer steelhead. Displacement from preferred habitats, or forced migration, of wild steelhead smolts by introduced hatchery steelhead smolts through agonistic interactions has been shown to occur under certain circumstances (Berejikian et al. 1996). We observed the highest densities of residual hatchery steelhead in sites located within 10 km of the South Santiam Hatchery, whereas the density of naturally produced

O. mykiss generally increased with increasing distance from the hatchery. This type of density gradient has been observed in other systems that receive inputs of hatchery summer steelhead (Flesher et al. 2009). However, the potential of this displacement to negatively affect the wild population is dependent on relative densities and resource abundance (Tinus and Friesen 2010). In the South Santiam River, much of what appeared to be quality rearing habitat (i.e., riffles, pools with water velocities > 20 cm/s; Bisson et al. 1988) located downstream of Foster Dam is situated in the 16 km between Foster Dam and McDowell Creek where the river has a gradient of 0.285% (Figure 4.1). Downstream of McDowell Creek, the South Santiam River has much lower gradient (0.135%) and consists of many long, slow glide habitats. Displacement of naturally produced *O. mykiss* from the highest quality rearing habitat into suboptimal habitats would represent a negative effect of hatchery releases on the wild population.

The evaluation of longitudinal trends in relative abundance included in this report was an opportunistic observation made while conducting snorkel surveys to evaluate behavioral interactions. Therefore, a more detailed investigation is needed to determine whether residual hatchery summer steelhead juveniles are in fact displacing naturally produced *O. mykiss* from the highest quality rearing habitat into suboptimal habitats and whether this displacement confers any reduction in the survival of naturally produced *O. mykiss*. Similarly, Tinus and Friesen (2010) identified knowledge of reach scale habitat-specific densities, spatial distributions, and downstream movements of hatchery and wild smolts, juveniles, and residual hatchery steelhead as requirements to better understand the interaction effects of hatchery summer steelhead releases on native winter steelhead.

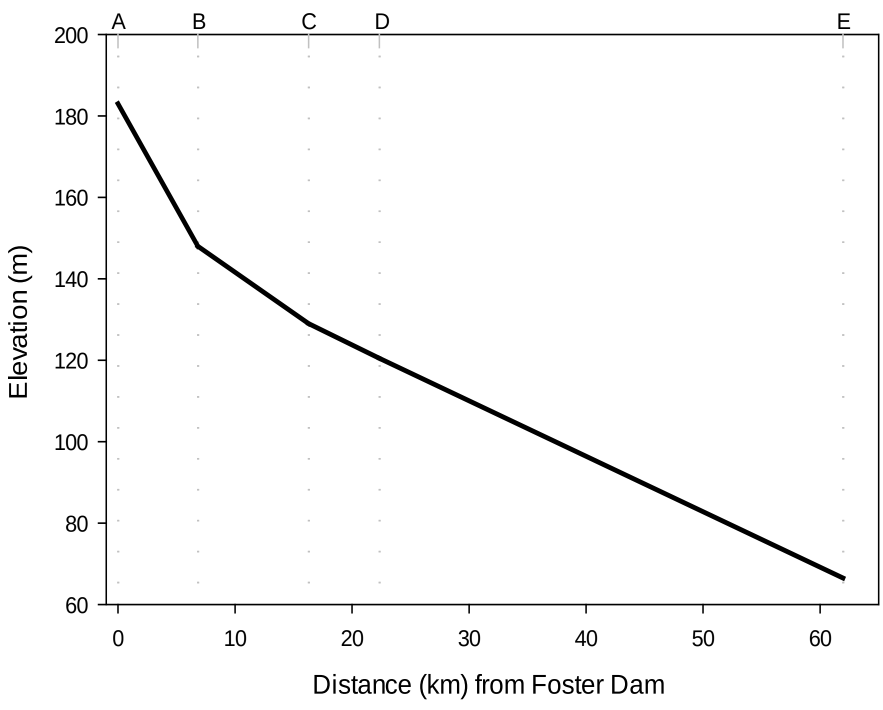

Figure 4.1. Elevation of the South Santiam River from Foster Dam (A) to the Mouth of the South Santiam River (E). B = Pleasant Valley Road bridge, C = McDowell Creek mouth, D = Waterloo County Park. Elevation data was obtained from the USGS National Elevation Dataset referenced to GPS coordinates of points of interest.

In addition to the competitive behavioral interactions we observed between residual hatchery steelhead and naturally produced *O. mykiss* juveniles, there may also be an increased risk of genetic introgression caused by the residualization of hatchery steelhead. Residual hatchery summer steelhead juveniles may display one of two life histories: smolt after several months or years of freshwater rearing, or revert to an entirely freshwater resident life history (Viola and Schuck 1995; McMichael et al. 1997). Residual male hatchery steelhead have a high probability of maturing precocially (Pepper et al. 1985; Mullan et al. 1992; Viola and Schuck 1995; Kostow 2008), which increases the chance that residual hatchery steelhead could spawn with returning naturally produced winter steelhead adults (Kostow et al. 2003; Kostow 2008). Johnson et al. (2013) estimated that 10% of all smolts originating from the South Santiam River were hatchery summer steelhead × wild winter steelhead hybrids. Hybridization of naturally produced winter steelhead and hatchery summer steelhead generally leads to lower survival of hybrid smolts and a decline of the naturally produced population (Kostow et al. 2003; Snow et al. 2013). Therefore, further sampling of residual hatchery-reared *O. mykiss* in the South Santiam River may be warranted to determine the extent to which residual hatchery steelhead are expressing resident and precocial life histories.

Some of the limitations of the 2014 study were related to the sampling effort used to identify longitudinal trends in the relative abundance of residual hatchery steelhead and naturally produced *O. mykiss*, the completeness of mobile radio tracking surveys to identify the fate and location of residual hatchery steelhead, and the representativeness of radio-tagged fish to the general hatchery population. As mentioned previously, assessing longitudinal trends in the relative abundance of hatchery and wild steelhead was an opportunistic observation rather than a rigorous hypothesis test accompanied by an appropriate experimental design. To better identify whether or not hatchery steelhead displace naturally produced *O. mykiss* from rearing habitats would require a larger sample size of sites that are distributed throughout the South Santiam River and are surveyed several times throughout the year (including before and after hatchery releases), accompanied by data on the movements of individual naturally produced *O. mykiss* (before and after hatchery releases) and hatchery steelhead using telemetry.

Mobile radio tracking surveys were spatially limited to the reach between Foster Dam and Waterloo County Park due to the lack of river access and quality rearing habitat downstream of Waterloo and due to the hazard posed by Waterloo Falls. The final fate (residualized or deceased) of radio-tagged hatchery steelhead that were last detected in the tailrace of Foster Dam (N =50) or were never detected (N =14) remained unknown. These fish were not detected during mobile tracking surveys; therefore, we can be confident they did not residualize between Foster Dam and Waterloo County Park. However, it is possible they residualized downstream of Waterloo; thus, our estimate of the percentage of radio-tagged fish that residualized and remained alive three months after release (12.8%) should be viewed as a minimum estimate (as it applies to the radio-tagged population). It is also possible that these fish perished in the South Santiam River and were carried far enough away from the river (by birds, humans, etc.) that they could not be detected during mobile tracking surveys. Mobile tracking surveys conducted along the full length of the South Santiam River from Foster Dam would provide a better estimate of the percentage of hatchery steelhead that residualized in the system.

Finally, we recognize there may have been issues with the representativeness of the radio-tagged fish to the general hatchery population. A much larger percentage (17.6%) of radio-tagged fish did not volitionally migrate from the South Santiam Hatchery compared to the general population of hatchery steelhead (~1%). Therefore, it is possible the radio-tagged fish also residualized in the river at a higher rate than the general hatchery population. Although we may have overestimated the residualization rate (as it applies to the entire hatchery population) because of this phenomenon, we still believe residualization of hatchery steelhead may be a problem in the South Santiam River due to the large numbers of untagged residual hatchery steelhead encountered during underwater observation surveys.

Results obtained over the past two years indicate there is potential for negative ecological effects of hatchery summer steelhead releases on naturally produced *O. mykiss* in the South Santiam River. We have demonstrated that only about one-quarter of the radio-tagged hatchery steelhead successfully emigrated to Willamette Falls with the majority remaining (either residualized or deceased) in the South Santiam River. We have also demonstrated that hatchery steelhead juveniles initiate and frequently dominate interactions with naturally produced *O. mykiss*. The result of these interactions is often the displacement of the naturally produced fish. An opportunistic evaluation of longitudinal trends in the relative abundance of hatchery steelhead and naturally produced *O. mykiss* indicated there may be a large-scale, population-level effect of these displacements, whereby large numbers of naturally produced *O. mykiss* are displaced downstream a considerable distance.

As proposed by the Action Agencies in the 2007 Supplemental Biological Assessment, changes to production levels or hatchery management strategies may be implemented to reduce the effects of the summer steelhead program on ESA-listed species (USACE 2007). Volitional releases and reductions in feed levels during the last month of rearing are two such strategies that have been shown to increase the rates and speed of hatchery steelhead emigration (Tipping and Byrne 1996; Snow et al. 2013). Whereas volitional releases are used at the South Santiam Hatchery, feed levels are not reduced during the last month of rearing to our knowledge (ODFW 2014). Similar to the results obtained in 2013 and from other studies (e.g., Tipping et al. 1995), we found condition factor to be significantly, negatively correlated with the probability of hatchery steelhead emigration, indicating a reduction in feed prior to release may reduce the rate of residualization. Therefore, we recommend an evaluation of the effect of pre-release feed reductions on the rate of hatchery steelhead residualization.

Reducing the number of hatchery summer steelhead released may also reduce the negative effect of the hatchery program on the wild winter steelhead population and the potential for any density dependent mortality. However, an evaluation should be conducted to estimate the carrying capacity of the South Santiam River before release numbers are reduced. Because we are primarily interested in the carrying capacity downstream of the South Santiam Hatchery, a habitat-based approach, such as the unit characteristic method (UCM; Cramer 2001; Cramer and Ackerman 2009), may be more appropriate than a watershed area-based approach. Habitat inventories of the South Santiam River downstream of Foster Dam would help to identify the amount of available rearing habitat, which could be used to estimate carrying capacity. This additional information would allow for a better estimation of the potential for hatchery steelhead releases to cause density-dependent effects that may be limiting the wild winter steelhead population. Similar assessments could be conducted in other tributaries of the upper Willamette River basin in which hatchery summer steelhead releases occur.

Additional research is necessary to identify the population-level effects of hatchery summer steelhead releases on wild winter steelhead and hatchery management strategies that reduce these effects. Research needs, as identified by this study, include: 1) an evaluation of reduced feed levels during the last month of rearing on the residualization rate of hatchery summer steelhead, 2) a thorough assessment of the carrying capacity of the South Santiam River downstream of the hatchery to help determine the appropriate level of hatchery steelhead production, and 3) a detailed investigation of the distribution, abundance, and movements of naturally produced *O. mykiss* before and after hatchery releases to determine whether hatchery summer steelhead juveniles are displacing naturally produced *O. mykiss* from the highest quality rearing habitat into suboptimal habitats. By addressing these research needs, uncertainties regarding the potential for negative effects of hatchery summer steelhead releases on wild winter steelhead juveniles will be greatly reduced.

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