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JUVENILE SURVIVAL AND ADULT RETURN AS A FUNCTION OF FRESHWATER REARING LIFE HISTORY FOR COHO SALMON IN THE KLAMATH RIVER BASIN

By

Molly P. Gorman

A Thesis Presented to
The Faculty of Humboldt State University
In Partial Fulfillment of the Requirements for the Degree
Master of Science in Natural Resources: Fisheries

Committee Membership
Dr. Darren Ward, Committee Chair
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ABSTRACT

JUVENILE SURVIVAL AND ADULT RETURN AS A FUNCTION OF FRESHWATER REARING LIFE HISTORY FOR COHO SALMON IN THE KLAMATH RIVER BASIN

Molly P. Gorman

The Scott and Shasta rivers, Klamath River tributaries, experience spatial disparity in habitat quality in spring and summer as a result of historical and current land-use. Juvenile Coho Salmon (*Oncorhynchus kisutch*) born in the upper tributary reaches often rear in natal streams before migrating to sea. However, those born in the lower reaches often encounter unsuitable habitat and emigrate during their first spring to seek non-natal rearing habitats. It is assumed that these early outmigrants are population losses. This study evaluated first-summer survival, and contribution to the adult population, of non-natal rearing juveniles in the Klamath River Basin. In the spring of 2014 and 2015 juveniles were tagged using Passive Integrated Transponder (PIT) tags as they were leaving the lower Scott and Shasta Rivers. Movement and survival was subsequently tracked using recapture and detection efforts in potential mainstem summer rearing locations. Strontium microchemistry from otolith samples of returning adult Coho Salmon throughout the basin was analyzed to estimate the contribution of non-natal rearing juveniles to adult returns. Few tagged individuals were detected in non-natal rearing habitats, but those detected in these habitats had survival rates comparable to natal-rearing individuals. Otolith analysis indicated that the proportion of juvenile Coho

Salmon rearing in non-natal habitats varied by spawning site. In total, 53% of the 116 adults sampled reared in a natal location as juveniles, while 47% reared in a non-natal location. These results suggest that non-natal rearing can contribute to adult returns and could be a significant population segment with increased restoration.

ACKNOWLEDGMENTS

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INTRODUCTION

Declining populations of Coho Salmon (*Oncorhynchus kisutch*) in the Klamath River Basin of northern California and Oregon have necessitated intensive conservation efforts. Their 1997 listing under the federal Endangered Species Act (NMFS 2012) has resulted in millions of dollars in funds directed toward conservation of this species. A large proportion of this investment has gone toward protecting and restoring freshwater habitat. In comparison with other anadromous salmonids, Coho Salmon may be more vulnerable to degraded habitat while residing in fresh water, particularly during the summer months (Bryant 2009). Their life history causes this susceptibility as Coho Salmon are exposed to stream conditions for longer periods of time than co-occurring salmonid species (i.e. ocean-type Chinook Salmon (*Oncorhynchus tshawytscha*)). Additionally, Coho Salmon have relatively narrow tolerance for extreme temperatures (Richter and Kolmes 2005) and water velocity (Taylor 1988). As a result of this vulnerability, historical Coho Salmon populations were likely composed of diverse juvenile life histories that used different juvenile habitats throughout the year (i.e. "the portfolio effect"; Schindler et al. 2010). This seasonal life history variation would have allowed the population to maintain itself in years with low survival in a particular habitat type. The so-called portfolio effect would have also buffered population growth against environmental variation by reducing correlation of vital rates between alternative life history strategies. In present-day, often degraded-stream environments, some life histories will consistently underperform and, therefore, may fail to contribute to the returning adult population. These induced differences in fitness may additionally affect selection allowing for life history variation to persist. This study compared growth, juvenile survival, and representation in the returning adult population for two life history variations of juvenile Coho Salmon: individuals that reared in their natal stream and those that emigrated from their natal stream to rear elsewhere.

In the Klamath River, juvenile Coho Salmon fry generally emerge from the gravel from late March to early April and emigrate to sea as smolts in April through June of the following year (Quinn 2005). If suitable habitat is available following emergence, fry will often remain to rear at the location in which they were born (called natal rearing). If fry encounter adverse habitat conditions upon emergence, or during subsequent seasons, (e.g. warm temperatures, low dissolved oxygen, competitive displacement), they will seek rearing locations elsewhere (called non-natal rearing). Some individuals express the non-natal rearing life history even when emigration is not obviously necessitated by habitat conditions or territorial competition (Kahler et al. 2001). Moving outside the natal environment is energetically expensive and introduces a host of risks, including increased exposure to predators or the possibility of ending up in even worse habitat. These risks have led to the assumption in many studies that individuals leaving the natal stream as juveniles are lost to the adult spawning population (Jeffres and Moyle 2012, Chapman 1962). However, there are increasing examples of cases in which both natal and non-natal life histories are viable (Koski 2009, Bennett et al. 2014, Jones et al. 2014).

Jeffres and Moyle (2012) argue that, in some cases, Coho Salmon rearing in non-natal locations is a component of an “ecological trap” in the Klamath River basin. An ecological trap is a scenario in which an organism selects a habitat based on cues that were historically associated with increased fitness, but as a result of habitat alteration these cues are no longer reliable (Schlaepfer et al. 2002). In the lower Shasta River, a Klamath River tributary, gravel enhancement projects have been undertaken in order to increase Chinook Salmon spawning habitat (Ricker 1997). This gravel provides cues that may prompt adult Coho Salmon to spawn, despite unsuitable summer rearing habitat for the juveniles produced due to upstream irrigation and land use (Robertson et al. 2013). Juvenile Coho Salmon are then forced to outmigrate early from their natal stream, potentially facing higher risk of juvenile mortality than natal rearing juveniles. Jeffres and Moyle (2012) assume that these non-natal outmigrants represent a loss to the spawning population. However, the relative performance and contribution to the adult population of natal and non-natal rearing Coho Salmon has not been evaluated in the Klamath River.

Management Background

The Klamath River Basin (Figure 1) is an area subject to controversy related to salmon, water management, and land use. Natural processes that require water (i.e. fish passage and habitat provision) compete with anthropogenic demands for water, particularly irrigation for agricultural practices. Agriculture and cattle ranching constitute much of the income and land use in this region. As such, basin-wide public opinion leans towards preservation of these practices, including the ability to appropriate river water for irrigation. Conservation efforts and environmental regulations, however, have prioritized the need to maintain river flow and in-stream habitat conditions to support fish production and to honor treaty obligations of indigenous peoples. As salmonids are highly prized by the general public nationwide and by local tribes as a dietary staple, these conservation efforts have firm supporters. Further, conservation is legally mandated due to the listing of Southern Oregon and Northern California Coast (SONCC) Coho Salmon under the Endangered Species Act (NMFS 2012). This controversy has come to a head with the potential removal of four PacifiCorp-operated hydroelectric dams on the Klamath River. These dams are nearing the end of their permitted operation and require extensive renovations to meet the fish passage standards necessary for reauthorization. Although the cost for removal of the four dams is estimated at $188,100,000 (USDOI et al. 2012), renovation for fish passage is likely to cost even more. Press coverage of the dam removals, and associated water use agreements, has dramatically raised the profile of salmon conservation in the Klamath River.

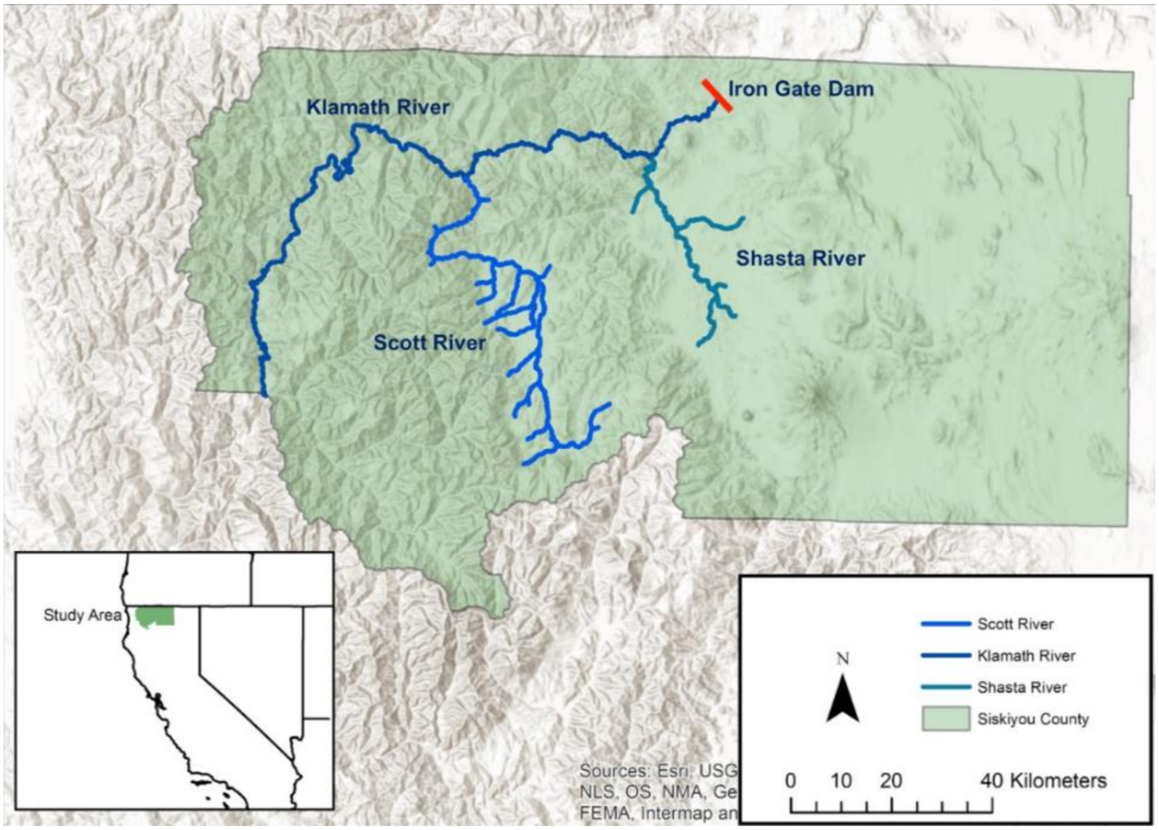

Figure 1. Map of Siskiyou County, California with the locations of the Shasta River, Scott River, Klamath River and Iron Gate Dam highlighted. Inset map indicates the location of Siskiyou County in relation to the states of California and Oregon as well as the Pacific Coast.

As restoration funds are generally limited, restoring salmon populations to their former abundance will require identifying the freshwater habitats that support successful salmon life histories under diverse environmental conditions, and focusing restoration efforts accordingly. This project set out to evaluate the relative contribution of the non-natal rearing life history strategy to Coho Salmon populations. While immediate outmigration from the natal stream has been considered an unsuccessful life history for Coho Salmon (Chapman 1962, Jeffres and Moyle 2012), the survival and potential return of non-natal rearing fish has never actually been evaluated in the Klamath River. If non-natal rearing positively impacts juvenile survival, protecting the existing habitats outside of salmon spawning areas for non-natal rearing fish would be an important priority. However, if non-natal rearing currently causes high mortality for a significant number of juveniles, there may be additional potential to increase non-natal contribution to adult populations by restoring or enhancing these external habitats. Determining the relative contribution of particular strategies to the overall population would give some indication of their success. In addition, investigating the type of habitat utilized by early outmigrants could focus restoration funds and further research on the habitats that support life history diversity.

The purpose of this study was to determine the relative survival and growth of natal and non-natal rearing juveniles during the freshwater rearing phase of their life cycle, as well as to determine the proportions of natal and non-natal rearing individuals in the upper Klamath River spawning population. This was accomplished through monitoring of natal and non-natal rearing juveniles, using Passive Integrated Transponder (PIT) tags, from two representative Upper Klamath streams, the Shasta and Scott Rivers. Strontium isotope otolith signatures from returning adult Coho Salmon, from throughout the Upper Klamath Basin, were then utilized to determine the relative contribution of early outmigrants to the spawning population.

Study Area

Shasta River

The Shasta River is the fourth largest tributary to the Klamath River with a drainage basin size of 2,100 km^2 and is located inland near the town of Yreka, CA (Figure 2). It flows approximately 97 kilometers from its headwaters to the confluence with the Klamath River at river kilometer (RKM) 285 (Jeffres et al. 2008) and has an approximate mean annual flow of 5.7 m^3/s (cubic meters per second). The Shasta River watershed is bounded by the Siskiyou Mountains, Shasta-Cascade Mountains, Klamath Mountains, and Mount Shasta (to the north, east, west, and south respectively). The Shasta Valley receives as little as 38 cm of precipitation per year and the majority of flow into the river comes from the surrounding mountains as runoff or glacial melt, supplying groundwater to a large spring complex in the upper basin (Stenhouse et al. 2012). The springs supply fairly consistent input to the Shasta Valley year-round. Near the river crossing with the I-5 corridor adjacent to Yreka, CA the river enters a steep, confined canyon region for 15 km before its confluence with the Klamath River (Jeffres et al. 2010). The 1928 installation of the Dwinnell Dam at river kilometer 65 impeded fish passage to the upper Shasta River watershed. The installation of this dam has greatly impacted the hydrology and habitat of the Shasta River (Jeffres et al. 2008). The Shasta River supports three native salmonids: Chinook Salmon, anadromous (steelhead) and resident Rainbow Trout (*Oncorhynchus mykiss*), and Coho Salmon. The river additionally supports several native and non-native species including: Klamath River Lamprey (*Entosphenus similis*), Pacific Lamprey (*Entosphenus tridentata*), Miller Lake Lamprey (*Entosphenus minimus*), Klamath River Small Scale Sucker (*Catostomus rimiculus*), Fathead Minnow (*Pimephales promelas*), Golden Shiner (*Notemigonus crysoleucas*), Speckled Dace (*Rhinichthys osculus*), Tui Chub (*Gila bicolor*), Japanese Pond Smelt (*Hypomesus nipponensis*), Brown Bullhead (*Ameiurus nebulosus)*, Yellow Bullhead (*Ameiurus natalis)*, Mosquitofish (*Gambusia affinis*), Marbled Sculpin (*Cottus klamathensis*), Largemouth Bass (*Micropterus salmoides*), Bluegill Sunfish (*Lepomis macrochirus*), Green Sunfish (*Lepomis cyanellus*), and Pumpkinseed Sunfish (*Lepomis gibbosus*).

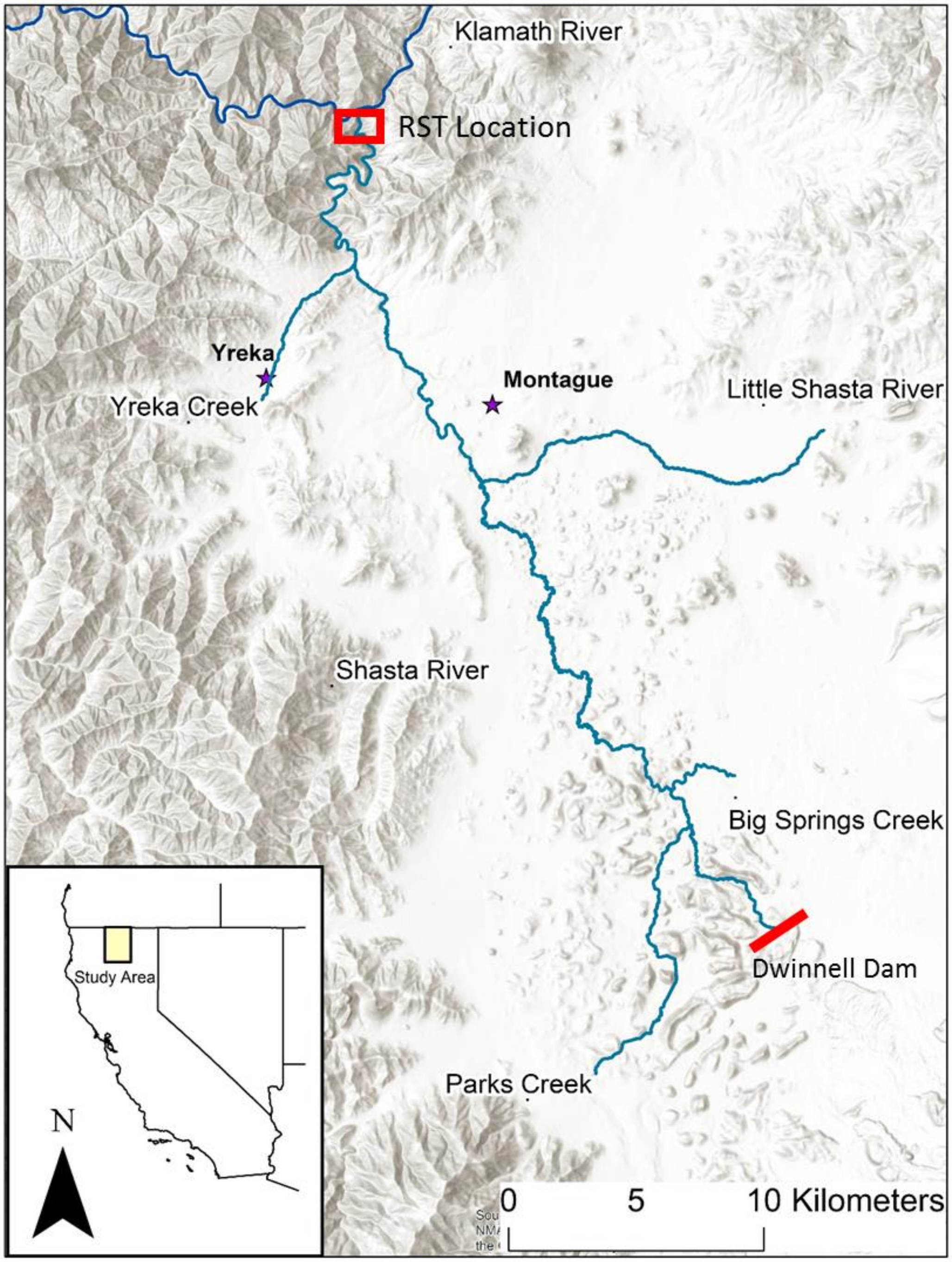

Figure 2. Map of the Shasta River with major tributaries, cities, and dams indicated. The location of the rotary screw trap operated by the California Department of Fish and Wildlife, which is mentioned throughout the text, is highlighted with a red box. Inset map shows relative location of the Shasta River within the state of California.

The Shasta River is utilized as an irrigation source for agriculture in the surrounding region. The withdrawal of water for irrigation and subsequent return flow of tail water, coupled with the naturally arid climate, leads to numerous unfavorable environmental factors for fish health. Local irrigation season in the Shasta River watershed runs from April 1st to September 30th and results in the diversion of approximately 90% of river flow (Figure 3; Jeffres et al.2008). Decreased flows lead to stagnant water, decreases in dissolved oxygen levels, and significant increases in stream temperature, particularly in the lower-basin canyon region (Stenhouse et al. 2012; Null et al. 2009).

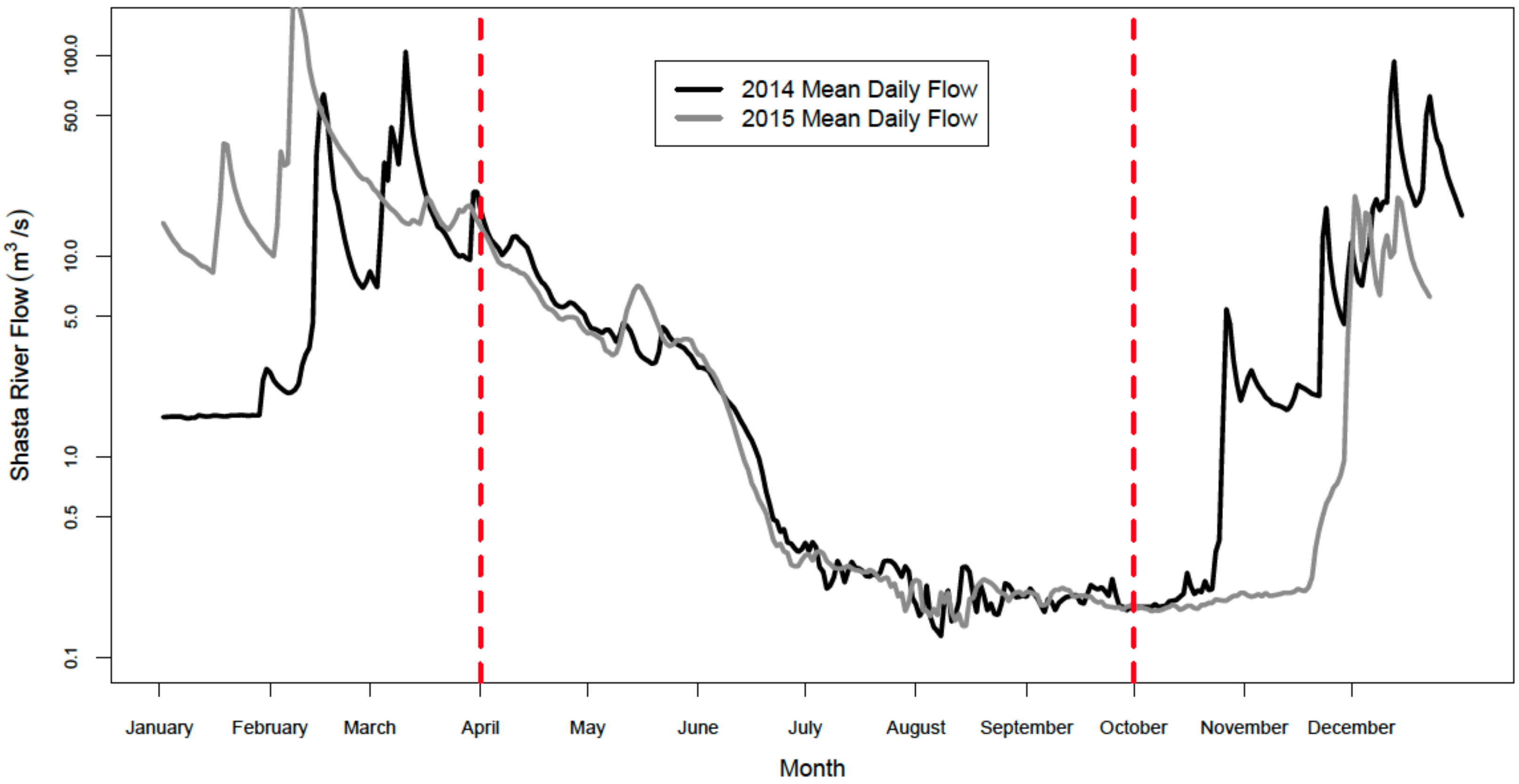

Figure 3. Mean daily flow in the Shasta River, measured at United States Geological Survey (USGS) stream gauge 11517500. The gauge is located just upstream of the rotary screw trap which is operated by the California Department of Fish and Wildlife in the Shasta River canyon region. Red dotted lines indicate the onset (April 1st) and cessation (September 30th) of irrigation season. The mean flow was calculated by averaging all flow values throughout a 24-hour period as measured at the stream gauge. The flow levels are shown for two years: 2014 (black line) and 2015 (grey line).

Coho Salmon in the Shasta River spawn in two discrete areas, the spring complex in the valley of the upper basin and the lower-basin canyon region. Suitable rearing habitat for juvenile Coho Salmon born in the upper Shasta River is available year-round in Big Springs Creek (Stenhouse et al. 2012), which enters into the Shasta River at RKM 54.2 (Jeffres et al. 2009) and is minimally affected by irrigation withdrawals. Big Springs Creek is a 3.7-kilometer spring system and part of the Big Springs Creek complex, which also includes Little Springs Creek, Parks Creek, Kettle Spring and Hole in the Ground Creek and is in part owned by The Nature Conservancy. The stable flows and temperature of the Big Springs Creek Complex provide suitable year-round rearing habitats for juvenile Coho Salmon (Adams 2013). However, Coho Salmon born in the canyon region of the lower Shasta River, near RKM 0, do not have access to Big Springs Creek due to distance, gradient, flows and anthropogenic barriers. Poor rearing habitat for juvenile Coho Salmon, including low water levels, high temperatures, and low dissolved oxygen content characterize the lower Shasta River's springtime conditions once irrigation begins in April (Stenhouse et al. 2012).

In summer (June-September), the lower river (canyon region's) water temperature is frequently higher than 21° C (Stenhouse et al. 2012) and may often exceed 27° C (Null et al. 2010), well above observed thresholds for juvenile Coho Salmon occurrence (Welsh et al. 2001). The maximum weekly maximum temperature (MWMT) was 28.17 ° C in 2015 (AFRAMP Annual Report 2015). Individuals that are born in the lower basin may therefore be more likely to outmigrate early from the Shasta River in order to find suitable rearing habitat (Jeffres and Moyle 2012). These fish move through the main stem

Klamath River, which also experiences very warm summer temperatures, and may seek suitable habitat in other tributaries.

Ongoing studies are being conducted in the Shasta River basin to characterize the use of Big Springs Creek as rearing habitat for Coho Salmon through PIT (passive integrated transponder) tag studies (Chesney et al. 2009; Adams 2013). This project was designed to supplement these studies by further investigating the Coho Salmon juveniles from the lower Shasta River that outmigrate during their first spring or summer, rather than rearing in the Shasta River.

Scott River

The Scott River (Figure 4) is the third largest Klamath River tributary and enters the mainstem downstream of the Shasta River. The Scott River begins with the junction of the East and South Fork Scott Rivers near the town of Callahan, CA. The river flows for approximately 93 kilometers before it joins the Klamath River at RKM 230 (Knecthle and Chesney 2009). This river system has been highly altered over time by activities such as logging, beaver removal, dredging and hydraulic mining, groundwater and surface water irrigation, riparian vegetation removal, and road construction (Knecthle and Chesney 2009). Irrigation is withdrawn from the river and groundwater for cattle ranching, alfalfa, and grain crops. The Scott River basin is mainly groundwater fed, but is highly dependent on runoff from snow pack in the warmer spring and summer months to maintain flow. A number of tributaries feed the mainstem Scott River and provide cool water and consistent, suitable rearing conditions in the summer. These tributaries include Sugar Creek, French Creek, Etna Creek, Patterson Creek, Kidder Creek, Tompkins Creek, Shackleford Creek, Mill Creek, Moffett Creek, Kelsey Creek, and Canyon Creek. These creeks may become seasonally detached from the Scott River main stem during low flows. Additionally, in particularly dry years some of these creeks may be constituted only of disconnected, remnant pools.

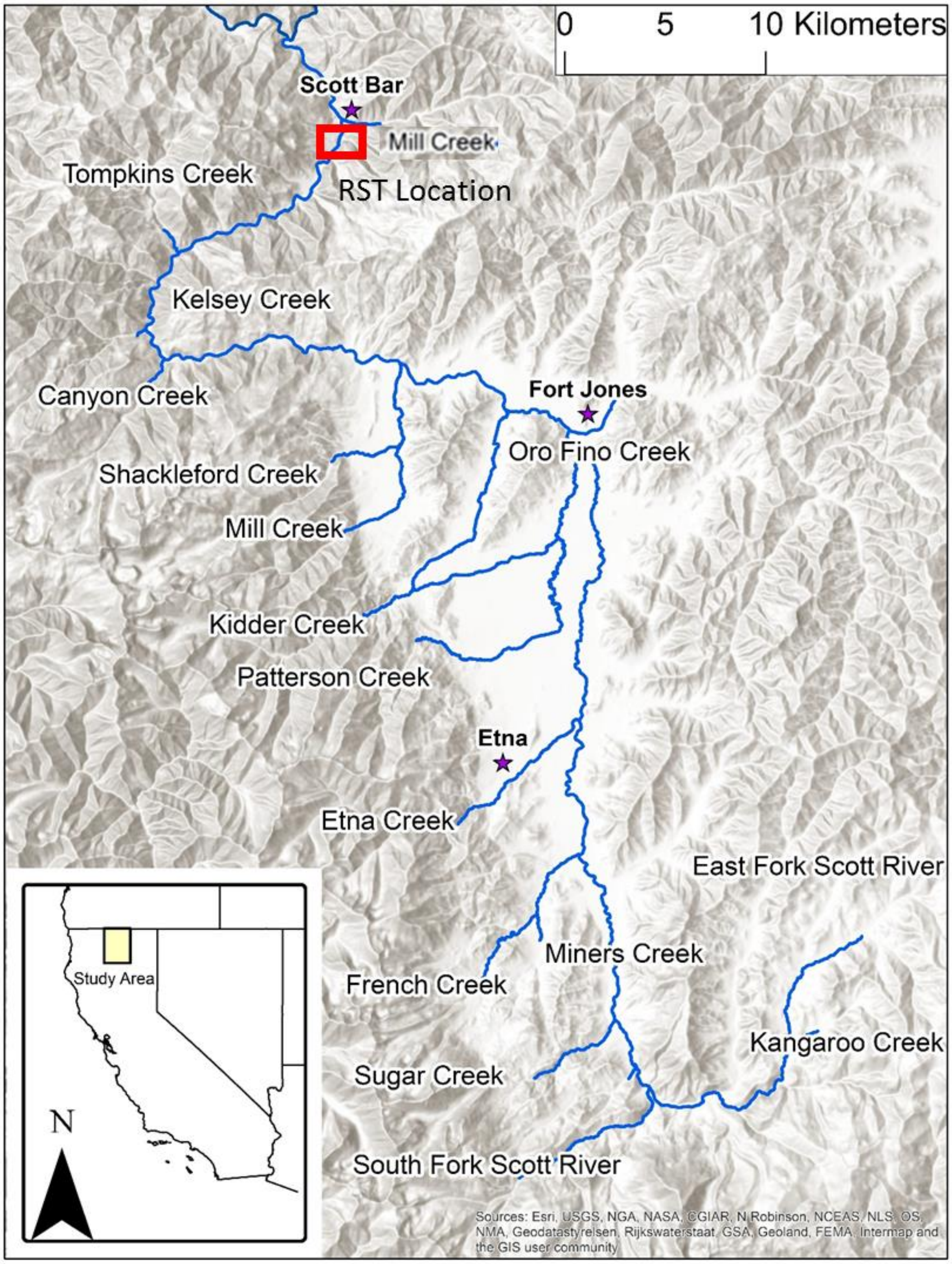

Figure 4. Map indicating the major tributaries to and cities surrounding the Scott River, California. The location of rotary screw trap operation by the California Department of Fish and Wildlife is highlighted in the red box. Inset map indicates relative location of the Scott River within the state of California.

Flow in the Scott River, as measured at USGS gauge 115195000 near the town of Fort Jones, CA, consistently falls well below the range identified as the minimum summer base flow necessary to maintain a viable fish population (0.85 to 4.25 m^3/s; California State Water Resources Control Board 1980; Figure 5). Like the Shasta River, the Scott River supports three native salmonids: Chinook Salmon, anadromous and resident Rainbow Trout, and Coho Salmon. The Scott River supports several native and non-native species including: Klamath River Lamprey, Pacific Lamprey, Miller Lake Lamprey, Klamath River Small Scale Sucker, Speckled Dace, Marbled Sculpin, Brook Stickleback (*Culaea inconstans*), Fathead Minnow, Brown Bullhead, and Japanese Pond Smelt.

Like the Shasta River, the lower section of the Scott River is characterized by a steep gradient canyon region, from river kilometer 34 to the confluence with the Klamath River (Knecthle and Chesney 2009;Quigley et al. 2001). The maximum weekly maximum temperature (MWMT) was 27.39 ° C in the Scott River canyon region in 2015 (AFRAMP Annual Report 2015). As in the Shasta River, juvenile Coho Salmon born in the lower Scott River are likely to outmigrate to seek rearing habitat due to low flow and high temperatures in the canyon region.

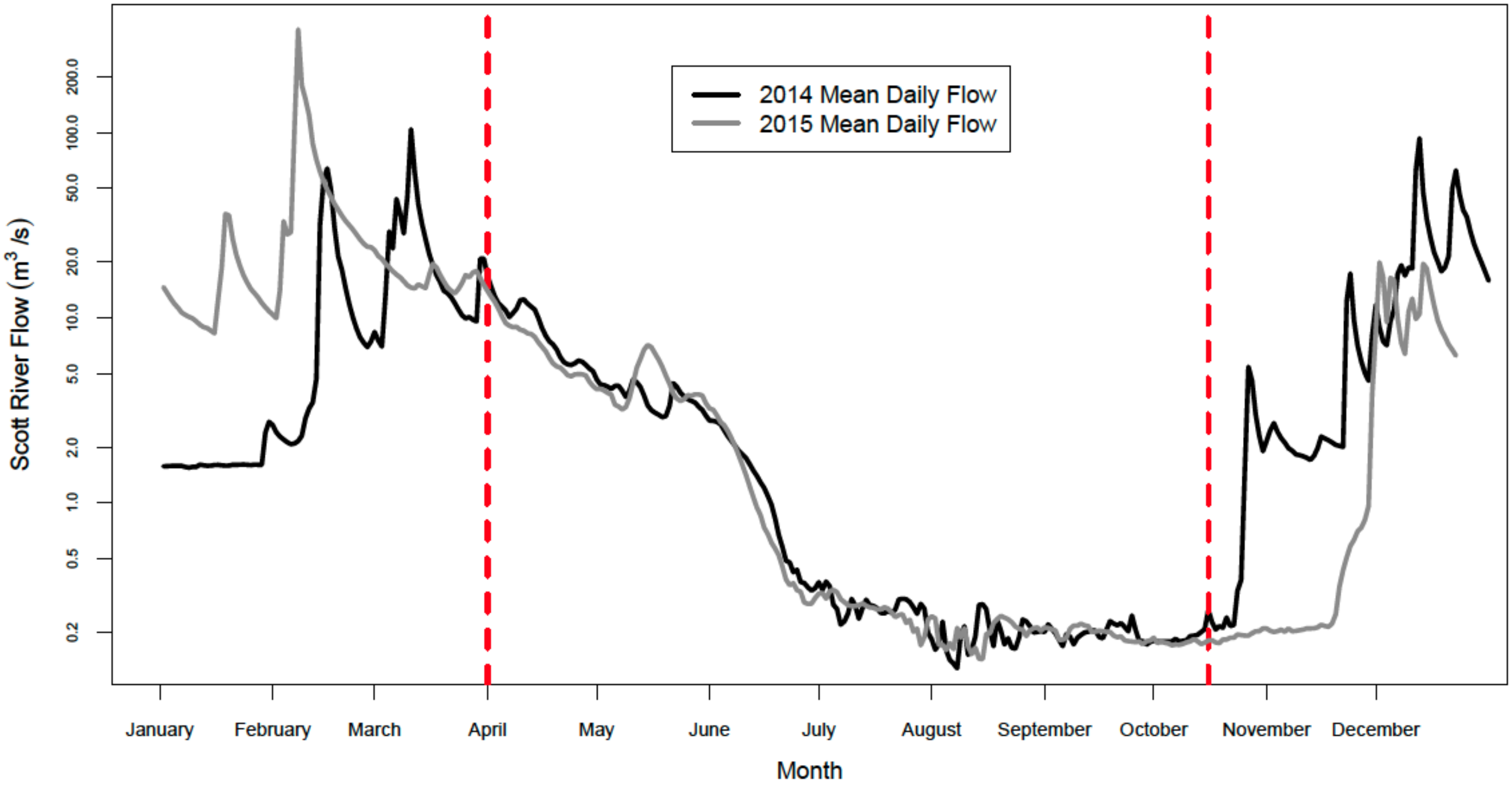

Figure 5. Mean daily flow in the Scott River as measured at United States Geological Survey (USGS) stream gauge 11519500. The gauge is located near the town of Fort Jones, CA, upstream of the rotary screw trap which is operated by the California Department of Fish and Wildlife in the Scott River canyon region. Red dotted lines indicate the onset (April 1st) and cessation (October 15th) of irrigation season. The mean flow was calculated by averaging all flow values throughout a 24-hour period as measured at the stream gauge. The flow levels are shown for two years: 2014 (black line) and 2015 (grey line).

METHODS AND ANALYSIS

Capture and Tagging Methods

PIT Tagging in the Lower Scott and Shasta Rivers

All fish handling was conducted following a protocol approved on February 20, 2014 by the Humboldt State University Institutional Animal Care and Use Committee (IACUC 13/14.F.63-A).

A mark-recapture tagging study was conducted to estimate the proportion of juvenile Coho Salmon leaving the Scott and Shasta Rivers and successfully locating suitable summer rearing habitats. This tag study was conducted in the spring of 2014 and 2015 as juvenile Coho Salmon emerged from the gravel and migrated towards rearing habitat. Initial timing of tagging depended upon first appearance of juvenile Coho Salmon at the tagging sites as well as the size of fish captured. In both years the first tagging event was in mid to late April and tagging extended into early July. Tagging was accomplished in collaboration with the Yreka office of the Anadromous Fisheries Resource Assessment and Monitoring Program of the California Department of Fish and Wildlife. Juvenile Coho Salmon were captured using rotary screw traps located at RKM 0 of the Shasta River and RKM 7.6 of the Scott River. Screw traps catch fish moving downstream and are operated low in the watershed to catch individuals emigrating from their natal stream as smolts. In the Scott River, two traps (one 8’ and one 5’) were operated at river left and river right respectively (as viewed facing downstream), in the Scott River. However, due to low river flows in both sampling years, the 8’ trap was removed in May, shortly after tagging began, and replaced with the 5’ trap. Once captured, the fish were initially assessed to determine candidacy for tagging. Factors taken into account included normal swimming behavior and lack of physical injury, as well as size. Changes in federal regulation dictated different minimum sizes for tagging in the two years of sampling. In 2014 the minimum size for tagging was 55 mm while in 2015 this size increased to 60 mm. Biomark 9 mm length and 2 mm diameter 24.2 kHz ISO FDX-B PIT tags were utilized. All juvenile Coho Salmon that met the tagging criteria were given a PIT tag.

Prior to tagging, the juvenile salmon were anesthetized with carbon dioxide. A 12-gauge needle was used to make a small incision on the ventral left side of each fish between the pectoral and pelvic fins and a tag was inserted. The needle and tag were sterilized using 91% isopropyl alcohol and rinsed with distilled water prior to each tagging event. Each juvenile had its length and weight recorded along with the unique tag identification number. Tagged Coho Salmon were placed into a bucket of cool, aerated water in order to recover. Normal swimming ability and behavior were confirmed prior to release. Tagged individuals were then held until nightfall in time release boxes located just upstream of the rotary screw trap locations in either river. This allowed additional recovery time and recaptures of tagged fish aided in calculating efficiency estimates for the CDFW outmigrant monitoring program.

Upper Shasta River PIT Tagging

In order to compare survival and growth of early outmigrants with natal rearing individuals, data were also analyzed from the Upper Shasta River. For the past several years the California Department of Fish and Wildlife has been annually monitoring juvenile Coho Salmon utilizing the Upper Shasta River basin for rearing. A similar tagging effort to that outlined above was undertaken in 2014 and 2015 in the Upper Shasta River. Juvenile Coho Salmon were captured by a combination of fyke nets, hand nets, seining, minnow traps and rotary screw trap; individuals were subsequently tagged based on the same criteria stated earlier. Tagged fish were then detected using an extensive PIT tag antenna system in place throughout the Big Springs Complex, the upper Shasta River, and the lower Shasta River. Tagging was conducted throughout the spring and summer of both study years.

Fish that were physically recaptured during tagging efforts or by rotary screw trap in the lower Shasta River, were weighed and measured. Tagging efforts from only the Shasta River were included and analyzed as few antenna systems were in place throughout the Scott River basin. In the spring and summer of 2014, an extensive juvenile Coho Salmon fish rescue effort was undertaken by the California Department of Fish and Wildlife in the Scott River, which artificially altered abundance and movement of juvenile Coho Salmon throughout the upper Scott River basin.

Recaptures

Coho Salmon captured using any of the rotary screw traps were scanned for a PIT tag. If a previously tagged fish was caught, the PIT tag number, length and weight was recorded. Two antenna array systems were already in place directly upstream of the rotary screw trap location and directly upstream of the time release boxes. Both antenna arrays spanned the entire channel and were continuously operational. Any tagged fish that were detected by the antenna had their individual tag number logged along with the time and date. These systems were maintained and monitored by the Yreka CDFW field office. Additionally CDFW installed and maintained three antenna systems at Tom Martin Creek, a Klamath River tributary located just downstream of the Scott River. These antennas were installed in early summer of 2014 and were intermittently operational through late fall of 2015. One antenna was placed at the confluence of the creek and the Klamath River, another was placed at the entrance to a constructed off-channel pond, and the third was placed in the creek just upstream of the entrance to the pond.

Additional potential recapture sites outside of the Shasta and Scott Rivers were monitored through cooperation with agencies that independently conduct sampling efforts or maintain PIT antenna arrays on the main stem Klamath River or its tributaries. These other possible detection sites included operations by the Yurok Tribe, the Karuk Tribe, United States Geological Survey (USGS), Humboldt State University (HSU) and the Mid Klamath Watershed Council (MKWC) as well as CDFW. In addition to the PIT tag antenna system present at Tom Martin Creek, antenna systems were in place at both Seiad Creek and O’Neil Creek and their respective off-channel ponds. Fish were also periodically sampled by seining at all locations to enable detection of tagged individuals.

Growth Comparison and Analysis

Shasta River PIT Tag data were collected for fish tagged in the upper basin in order to compare growth rates between natal rearing individuals from the Shasta River and non-natal rearing individuals tagged in the lower Scott and Shasta Rivers. Only individuals recaptured and measured a second time after tagging were included in this analysis. For upper basin fish, data were specifically from tagging efforts in 2014, with recaptures extending through 2015. In-hand capture occasions for the fish tagged in the upper basin were typically rotary screw trap recaptures, at the mouth of the Shasta River, at the time of smolt outmigration the next spring. However, some recaptures did occur approximately one year after tagging in the upper Shasta River basin, presumably just prior to smolt outmigration. Typically, recapture occasions for non-natal fish tagged at emigration from the Scott and Shasta Rivers were physical recaptures in off-channel or Klamath River tributary locations. Growth for these records was calculated for each individual as millimeters grown per day (mm/day) and compared with individual growth rates calculated in the same manner for off-channel ponds on the Klamath River (likely non-natal rearing fish of unknown origin), using data from Krall 2016, as a very general relative indication of comparative habitat quality. If a fish was recaptured multiple times each growth rate (mm/day) was calculated individually using only the most recent prior recapture occasion.

The upper Shasta River produces a small number of juvenile Coho Salmon that grow sufficiently fast in their first spring to leave the system as smolts at age-0. These individuals were not included in growth calculations as they were likely not typical of growth rates experienced throughout the Klamath River basin in natal conditions. Age-0 smolt outmigrants were classified based on time of year tagging occurred, and size at the time of tagging. Generally, any fish exceeding 90 mm in a period after emergence, but before July (regardless of recapture location), was considered to be a candidate for age-0 smolt outmigration. Additionally, if a tagged fish was recaptured at the Shasta River rotary screw trap within the same year that it was tagged in the upper Shasta River, at a size indicating smoltification was occurring (greater than 90 mm), the fish was considered an age-0 smolt outmigrant.

PIT Tag Data Analysis

PIT Tag Data-Lower Scott and Shasta Rivers

PIT tag recaptures from antenna systems and other sampling efforts throughout the Klamath Basin were cataloged into encounter histories for each juvenile Coho Salmon tagged. Tagging and recapture data were collected for the Scott River in 2014 and 2015, as well as for the Shasta River in 2014 and 2015. However, no Coho Salmon from the lower Shasta River in 2014 were detected after tagging and both the Shasta River and Scott River in 2015 experienced very low numbers of suitable outmigrating age-0 juvenile Coho Salmon (Shasta: 87, Scott: 11). As such, these datasets were too sparse for mark-recapture analysis. Only the Scott River data set from 2014 was analyzed to estimate survival rates. In the Scott River in 2014, eight individuals were tagged in July or last detected in the tagging stream in July but never detected again outside the Scott River. In order to maintain temporal uniformity among the two-month encounter occasions, as well as a consistent first recapture event outside the stream of origin, these tagged fish were not included in analysis.

A Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965), implemented in program MARK (White and Burnham 1999), was used to estimate apparent survival (Φ or phi) and detection probability (p) of fish tagged in the lower Scott River in 2015. Apparent survival represents the probability that a tagged fish survives from one encounter occasion to the next and does not permanently leave the system. In this case, as Φ is determined by movement, apparent survival is biased low from true survival due to undetectable emigration as well as undetected residents that are not detectable during the study period (i.e. never pass an antenna system). Detection probability is simply the probability that a fish will be encountered during a particular occasion. Recapture occasions were defined as two-month long periods (Figure 6) and were not distinguished between recapture locations. Any recapture external to the river of tagging was considered to have taken place in a non-natal rearing location. In order to accommodate recapture events that occurred within two months of tagging an initial tagging event was created. Each fish tagged was given a “1” in the encounter history at this first event to indicate it was tagged, regardless of the actual month of tagging (May or June). Final encounter histories were defined by four occasions: (i) initial tagging in

May or June at the screw trap in the natal stream, (ii) detection in May or June outside of the natal stream, (iii) detection in July or August outside of the natal stream, and (iv) detection in September or October outside of the natal stream. Encounter histories continued through the month of October. Several example encounter histories are provided below for clarity:

i. 1111
ii. 1010
iii. 1100
iv. 1000

Each encounter history shown represents a juvenile Coho Salmon tagged in May or June. As stated above, each fish received an initial detection of "1" at the first occasion. In the first example (i), an individual was tagged and subsequently recaptured at every two-month period possible outside of its stream of origin. Therefore, this fish was detected outside of the tagging stream in May/June, July/August and September/October. In the second example (ii), an individual was only detected in the months of July/August, and is labeled with a "1" at the second recapture occasion. The first recapture occasion (May/June) is then labeled with a "0" in this case, as the fish was not detected outside of the tagging stream. Similarly the final occasion is also marked with a "0" due to lack of detection. In the third example (iii) a fish was encountered in May/June outside of its tagging stream and subsequently never encountered again. The final example (iv) indicates a juvenile that was tagged and never detected or recaptured again.

Any juvenile recaptures within the tagging river and in the same month as tagging were not included in the analysis. In addition, the last observed recapture within the river of origin, outside of the tagging month, was specified as the initial tagging event. Therefore, individuals last detected in the stream of origin in July were not included in analysis. This allowed the first time step for each individual to represent a potential transition period to a non-natal rearing location after outmigration. Juveniles exceeding 90 mm in length, or that exhibited smolt-like appearances, were not included in analysis or in total tag counts in order to exclude the possibility that these were outmigrating age-0 (from Big Springs Creek) or age-1 smolts.

A set of candidate models was evaluated to describe variation in apparent survival and probability of detection for Scott River fish tagged in 2014. These candidate models were fit using the sin link function and ranked using Akaike's Information Criterion adjusted for small sample size (AIC_C). Any model ranked within approximately 2 units of the top model was considered to be competitive. The models in the candidate set included alternatives that varied apparent survival temporally (Φ (t)), kept apparent survival fixed through time (Φ (.)), or varied apparent survival using a "transition" parameter (Φ (trans)). Models that included this transition parameter ("trans") made the assumption that the first time step for each tagging month represented a period of transition to a rearing location (Figure 6). Each subsequent time step was then classified as the rearing time period external of the natal location. Variation in detection probability was evaluated similarly to apparent survival in the candidate model set. Detection probability was varied temporally (p (t)), kept fixed through time (p (.)), or varied with the transition parameter (p (trans)). Approximate monthly apparent survival with corresponding confidence intervals was also estimated for the transition model, with the exception of the transition time step. Program MARK was utilized to specify encounter occasion length in order to more easily make direct comparisons between data sets (upper Shasta River and lower basin data).

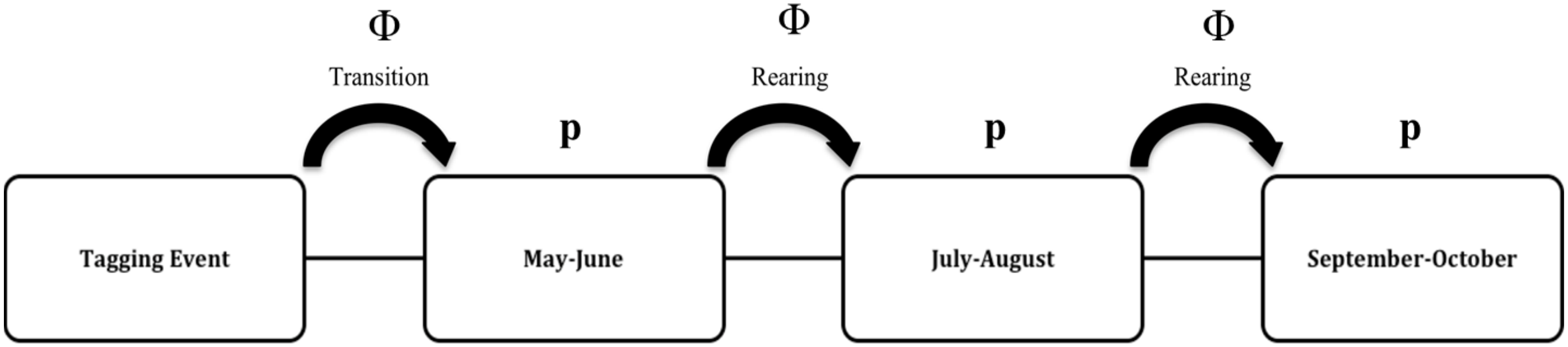

Figure 6. Visual representation of parameterization of Cormack-Jolly-Seber models in program MARK using a transition parameter. Each box represents a potential encounter occasion while the transition and rearing arrows indicate how Φ and p parameters were estimated between and during potential recapture occasions.

PIT Tag Data- Upper Shasta River

Tag recaptures and detections from antenna systems and sampling efforts throughout the Shasta River basin were synthesized into a month-based encounter history. No distinction was made between the different recapture locations within the Shasta River basin. These encounter histories were also analyzed using a CJS model in program MARK to estimate Φ and p. As tagging in the upper basin in 2014 continued throughout the spring and summer, the first occasion was not the tagging event for all individuals, as in the lower basin analysis. Instead each individual received a “0” up until the month in which it was tagged, beginning with April of 2014. The tagging event, and any recaptures or detections following tagging, are indicated by a “1” at that time step. Encounter histories extended until May of 2015 (the following year). Included below are two example encounter histories:

i) 11100000000000

ii) 00010000000100

The first encounter history (i) represents a fish tagged in April of 2014 and subsequently recaptured in May and June of 2014. After June this particular individual was not detected on an antenna system or recaptured again. The second example (ii) demonstrates an encounter history for a juvenile that was not tagged until July of 2014. This individual was then detected again in March of 2015 as its final encounter. In order to represent a full year of upper basin rearing, only data from juveniles tagged in the spring and summer of 2014 were analyzed. In total encounter histories were compiled for 574 juvenile Coho Salmon tagged in the spring and summer of 2014.

As in the analysis for the lower basin PIT tag data, a set of nested models were evaluated in Program MARK and ranked using AIC_C. In addition to simple time varying models (Φ (t), p (t)) and temporally fixed models (Φ (.), p (.)), this candidate model set also included a “season” parameter (Φ (season), p (season)). The “season” parameter classified certain months’ apparent survival or detection probability into spring (March, April, May), summer (June, July, August), fall (September, October, November), or winter (December, January, February) based on where they fall throughout the year. Models were fit with the sin link function, as in the lower basin Scott River analysis.

Otolith Processing

Strontium stable isotope ratios ($^{87}Sr/^{86}Sr$) in sagittal otoliths are useful in ascertaining the previous locations of an individual fish, if locations differ in chemical signatures (Hobbs et al. 2005). Strontium is deposited into the otolith as a fish ages as a ready substitute for calcium (Barnett-Johnson et al. 2008). Strontium isotope ratios in stream water show relatively considerable spatial variation but little temporal variation reflecting the composition of rocks within the watershed (Kennedy et al. 2000). Strontium isotope ratios in otolith increments formed at a particular age reflect that occurring within the stream environment inhabited at that age, due to uptake from both water and food

(Kennedy et al. 1997, Outridge et al. 2002). The pattern in $^{87}Sr/^{86}Sr$ measurements along a transect of the otolith reflects an individual fish's lifetime habitat use, including clear distinctions between the marine and freshwater environment.

Use of $^{87}Sr/^{86}Sr$ to map fish to specific locations depends on the existence of discrete $^{87}Sr/^{86}Sr$ signatures at different sites. Past research on the Shasta River indicates a clear differentiation of strontium isotope ratios in water between the upper and lower basin (Roddam 2014). Additionally, studies on the Klamath River basin's water chemistry have noted high levels of spatial variation, within and among different watersheds (Quiñones et al. 2012). Due to the complexity of the Klamath River isotope map there is also substantial overlap in $^{87}Sr/^{86}Sr$ at spatially discrete sites, which complicates identifying the specific location that a fish occupied. Due to financial and time constraints, a comparative approach was utilized to identify basic life history patterns (natal vs. non-natal rearing) rather than attempt to map individual fish to specific streams.

Otolith analysis was used to determine the relative contribution of natal and non-natal juvenile life histories to the adult spawning population. Natural-origin (i.e. not born in a hatchery and lacking a left maxillary clip) adult fish from several Klamath River basin locations were used (Table 1). The otoliths analyzed were collected by the California Department of Fish and Wildlife, the Karuk Tribe, the Mid Klamath Watershed Council (MKWC), and the Scott Valley Resource Conservation District (RCD) personnel during adult spawning ground surveys.

Otoliths were cleaned and rinsed with deionized water prior to mounting. After cleaning, I mounted the otoliths sulcal side up on a cover slip (cut to size) using Crystal

Bond™ 509. Subsequently, the cover slip piece with the otolith attached was affixed to a standard sized glass microscope slide for polishing. Two grits of sandpaper were used in order to expose the primordia and core of the otolith. The sandpaper used was cut to fit a Buehler™ Ecomet 3 Variable Speed Grinder-Polisher and otoliths were held face down on the sandpaper as it rotated at the lowest setting (50 rotations per minute). The slide orientation was shifted frequently to ensure even sanding throughout the sample. Initially, 320 grit sandpaper, wet with deionized water, was used until the primordia of the otolith first became visible. Progress was checked frequently using a standard compound microscope. The 600 grit sandpaper was utilized in a similar fashion until clear exposure of the core and a transect location. At this point sanding was discontinued. Once all samples were sufficiently sanded, the coverslip was cut from the microscope slide using a carbide tipped pen. Samples to be analyzed were then affixed to petrographic slides using double sided tape.

Table 1. Number of adult Coho Salmon sagittal otoliths analyzed via Laser Ablation Multi-Collector Inductively Coupled Plasma Mass Spectrometry at University of California Davis. River of collection is indicated. Iron Gate Hatchery (IGH) collected otoliths are marked as either Natural Origin Return (NR), indicating a non-hatchery raised individual or Hatchery Origin Return (HR), indicating a hatchery raised individual returning to its hatchery of origin.

River	Otoliths Analyzed
Scott River	59
Shasta River	5
IGH NR	30
IGH HR	4
Scott River Tributaries	
Shackleford Creek	6
Mill Creek	3
Sugar Creek	1
French Creek	6
Subtotal	16
Klamath River Tributaries	
Irving Creek	1
Horse Creek	2
Seiad Creek	7
Subtotal	10
TOTAL	124

Analysis of $^{87}Sr/^{86}Sr$ ratios was conducted using laser ablation throughout a dot transect, rather than a line transect. Dot transects decrease strontium reading contamination between data points by continuously reading at one point for a set time period, and then allowing time in between readings. Transects originated as close to the absolute core of the sagittal otolith as possible and proceeded until ocean entry. The core region of the otolith has a high degree of maternal influence, due to yolk sac feeding after emergence, leading to strontium levels near marine levels. Ocean entry was classified as the point at which strontium output discernibly increased toward the marine strontium baseline, for at least two dot data points, in an otolith region near the otolith check indicating the end of freshwater (slow) growth.

Each dot, along the otolith transect, had a diameter of 55 micrometers (µm) and a depth of 5 µm and was vaporized via laser for analysis. Dots were spaced along each transect at 55 µm apart and were analyzed for 25 seconds with a 12 second delay between dots (Figure 7). A marine standard reading was taken at two or three data points on at least one otolith per slide analyzed. Marine readings were taken in the outermost portion of the otolith where the fish would have been continuously exposed to marine conditions. I conducted all otolith analysis at the University of California Davis ICPMS MC Lab using Laser Ablation Multi-Collector Inductively Coupled Plasma Mass Spectrometry (New Wave Research UP 213 Laser System) (LA-MC-ICP-MS).

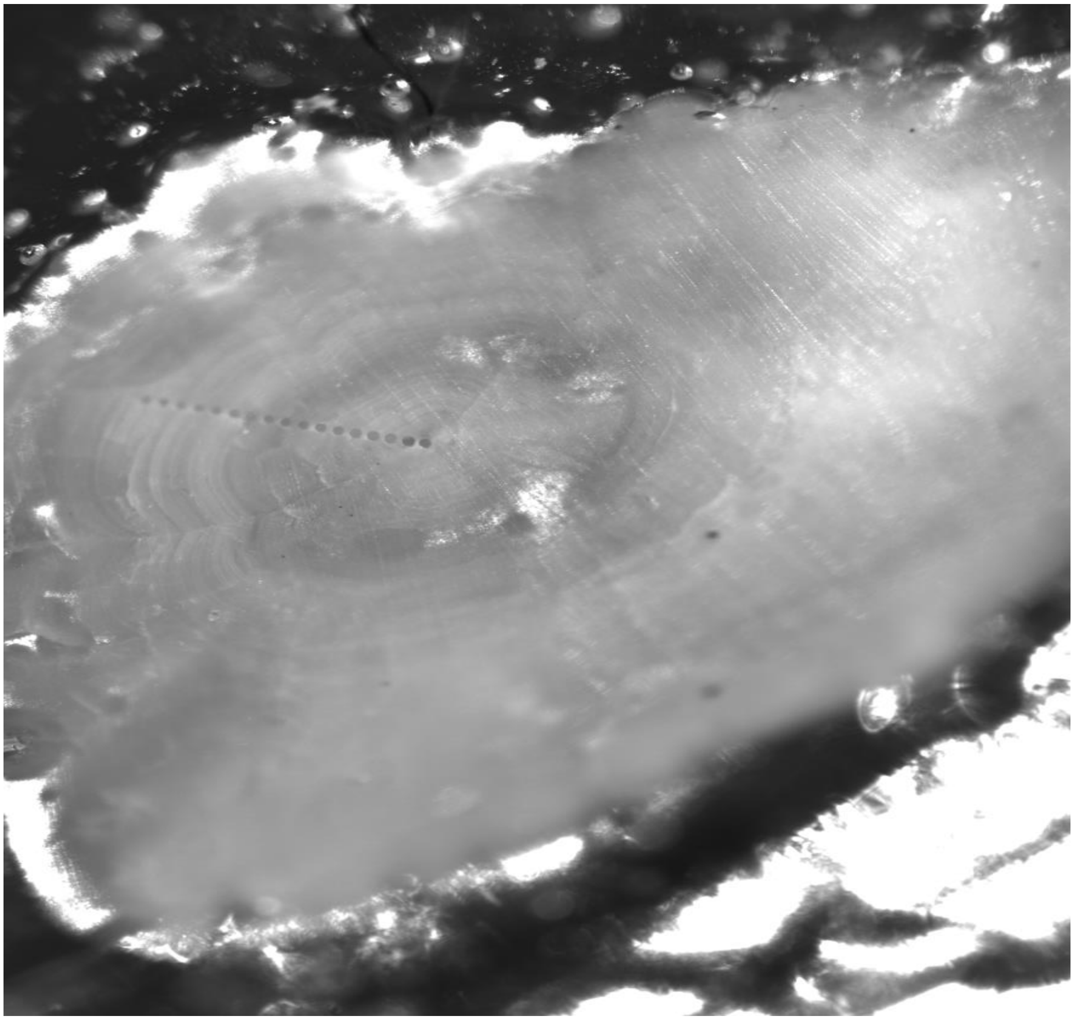

Figure 7. Adult Coho Salmon otolith after completion of laser ablation dot transect, shown at 25x magnification. Juvenile rearing transects started at the absolute core of the otolith (at center) and continued outward until reaching the marine environment. Each dot is 55 μm in diameter and dots are spaced 55 μm apart.

All readings were standardized to the averaged marine standard reading per slide using the known marine $^{87}Sr/^{86}Sr$ value of 0.709175. Transect readings were trimmed to only express variation in $^{87}Sr/^{86}Sr$ from the end of maternal influence (between 0.706 and 0.707) until the point of ocean entry. Four samples were not included in the final analysis due to possible errors in the strontium measurements or unlikely $^{87}Sr/^{86}Sr$ patterns.

Specifically these samples either had strontium level readings much higher than marine values, or indicated possible movement between the marine and freshwater environment (which could not be corroborated). Three of these samples were from the Scott River, where the largest number of samples were collected and analyzed, and one was collected at French Creek (a Scott River tributary).

Otolith Data Analysis

Output from the otolith analysis consisted of $^{87}Sr/^{86}Sr$ ratios across a dot transect conducted for each otolith. The standard deviation was calculated throughout each otolith transect. The average transect standard deviation for the 4 known HR fish was calculated, and a 95% Confidence Interval (CI) was constructed around the average. As these adult fish were known to have reared in one location (i.e. a “natal” life history, where the natal stream is the hatchery) the standard deviation of the hatchery origin adults was used as a baseline to evaluate the otoliths of fish with unknown life histories. Otoliths were classified as natal rearing individuals if the transect standard deviation fell below the upper 95% CI of the HR value. Any Coho Salmon otolith with a standard deviation value above the upper 95% CI range was considered to be a fish that reared in a non-natal location as a juvenile. Standard deviations were compared for natal and non-natal categories both between rivers and within river systems. Composition of natal and non-natal rearing adults returning to spawn was also compared across river systems and within river systems. Adults classified as NR Iron Gate Hatchery fish were comparatively analyzed for rearing behavior as a classification of possible patterns in straying adults. As all natural origin adult Coho Salmon returning to a hatchery setting are strays, the classification of their rearing behavior may provide some insight into how adult stray life history varies in the juvenile portion of the life cycle.

RESULTS

PIT Tagging- Lower Scott and Shasta Rivers

The number of fish tagged and recaptured varied widely between years and rivers (Table 2), despite few changes in tagging and screw trap protocol. In 2014, similar numbers of fish were tagged leaving the Shasta and Scott Rivers but numbers of individuals recaptured differed substantially between the rivers. In 2015, the number of fish tagged was much smaller at both rivers due to lower abundance of outmigrating juveniles. However, recaptures were proportionally much higher in 2015.

Though recaptures were limited (n=20), the majority of recaptures or detections of non-natal rearing fish occurred at Tom Martin Creek. Tom Martin Creek is located just under one kilometer (0.8 km) downstream from the Scott River (Figure 8) and features a groundwater connected, artificially constructed, off-channel pond. The percentage of overall recaptures from Seiad Creek (RKM 210) and May Pond (located approximately 0.5 km up Seiad Creek from the Klamath River), and O’Neil Creek (RKM 222) and Pond were much lower than those from Tom Martin Creek (Figure 9).

Table 2. Total number of juvenile Coho Salmon tagged at the Shasta (SH) and Scott (SC) River rotary screw trap locations in the spring of 2014 and 2015 and recaptured. Recaptures (Recaps) are classified by month; “Total Count” indicates the unique number of fish from each year and location that were recaptured. Proportion recaptured (Prop Recap) indicates the naïve estimate (or simply the proportion of the total recaptured) of recapture rate by calculating the proportion of total fish tagged that were recaptured from a particular year and river.

	Total Tagged	**Recaps**												**Total Count**	**Prop Recap**
		May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr		
SH 2014	307	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SH 2015	87	0	1	1	1	0	0	0	0	0	0	0	0	2	0.02
SC 2014	388	4	10	10	1	2	1	1	0	0	1	0	1	17	0.04
SC 2015	11	0	1	0	0	0	0	0	0	0	0	0	0	1	0.09

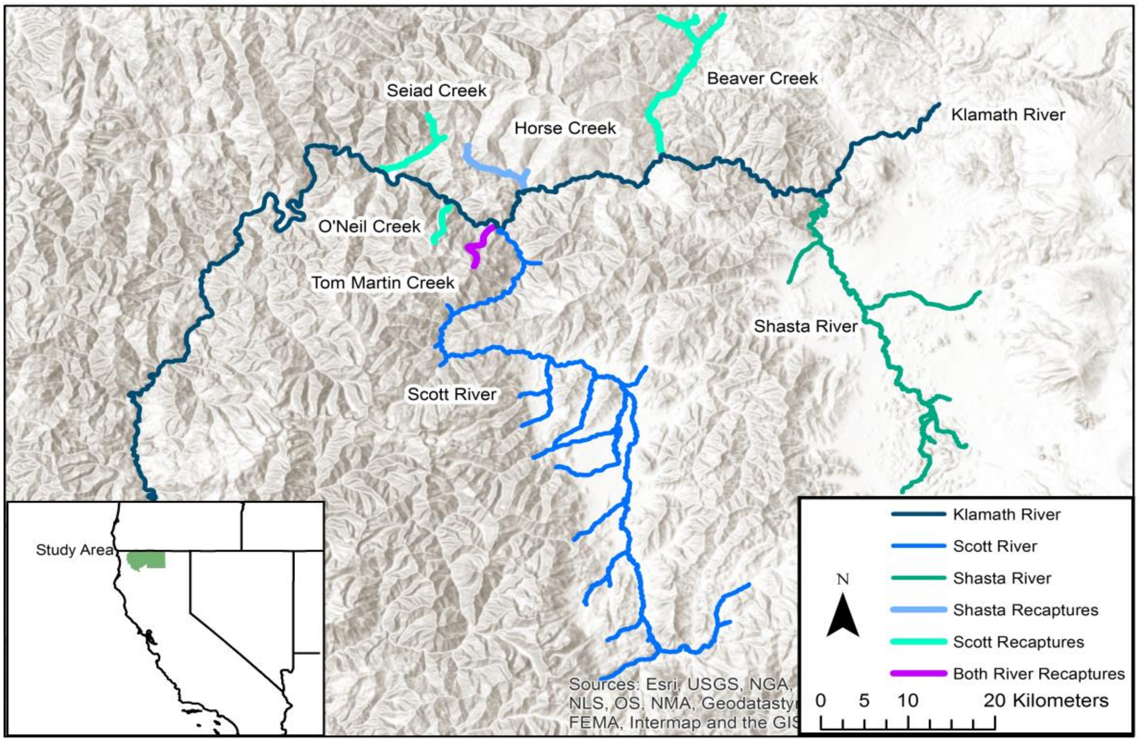

Figure 8. Map of both study streams (Shasta and Scott Rivers) as well as all Klamath River tributary locations in which a PIT tagged juvenile Coho Salmon was recaptured in 2014 or 2015. Recapture streams are color coordinated depending on the origin stream of the recaptured individual. Categories for recapture include: Shasta River recapture, Scott River recapture, or a stream location in which individuals from each tagging site were recaptured (see legend). Inset map indicates relative location of the middle Klamath River watershed within the state of California.

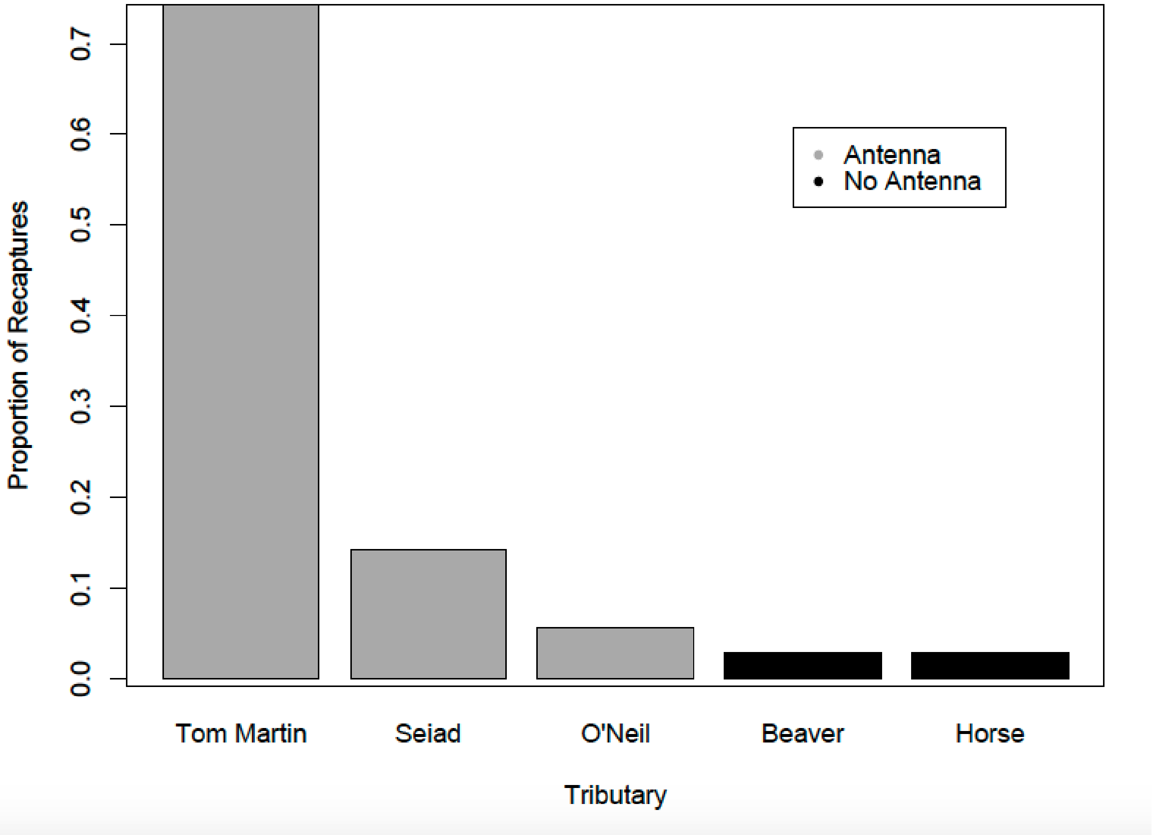

Figure 9. Proportion of total recaptures (n=20) for each recapture location of juvenile Coho Salmon tagged at the Shasta and Scott River rotary screw trap locations in 2014 and 2015. Recapture locations that had a PIT tag antenna array operating during the sampling periods are indicated in grey while locations without an operational PIT tag antenna array are indicated in black.

For the Scott River in 2014, the top ranked model of survival was the model in which detection probability was fixed across time steps and Φ varied through time for each time step (Φ (t) p (.)) (Table 3). The $\hat{c}$ (c-hat) value was determined by calculating the average deviance for the global model, using Bootstrap Goodness of Fit testing, and dividing that value by the observed deviance for the global model. This ratio indicated a $\hat{c}$ of 1.9 for the Scott River in 2014, which is below 3.0, indicating an acceptable level of overdispersion (Cooch and White 2014). Any model that included Φ estimates that varied across time steps was surrounded by wide 95% confidence interval estimates, indicating probable variance estimation issues related to small sample size. Parameter estimates from both the top (Table 4) and second ranked (Table 5) model are presented below. The wide confidence intervals surrounding the top ranked model estimates overlapped heavily with the second ranked model parameter estimates and confidence intervals. Parameter estimates were therefore evaluated from the second-ranked model, which had an AIC_C value within 2.18 units of the top model and a lower number of parameters, as well as nearly equivalent and more easily interpretable results that helped account for fewer recaptures in the last sampling occasion.

The model ranked second was the “trans” model, in which parameter estimates varied between rearing and transition periods (Φ (trans) p (.)). Detection probability did not vary through time and remained fixed. Apparent survival was low for the first time step (the “transition” time step) in the transition-varying model (Table 5). The apparent survival estimate for the rearing time period greatly increased in comparison to the transition parameter.

Table 3. Model selection table for the mark recapture study conducted in the Scott River in 2014. Models vary both survival (Φ) and detection probabilities (p) by time, by a transition period, or remain constant. Models were ranked by AIC value corrected for small sample size (AICc).

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
Φ(t) p(.)	200.335	0.000	0.624	1.000	4	3.819
Φ(trans) p(.)	202.515	2.180	0.210	0.336	3	8.039
Φ(trans) p(trans)	204.284	3.949	0.086	0.139	4	7.768
Φ(t) p(t)	204.446	4.111	0.080	0.128	6	3.819
Φ(.) p(.)	229.847	29.512	0.000	0.000	2	37.401

Table 4. Top ranked model (Φ(t) p(.)) real parameter estimates for the Scott River in 2014. Each Φ parameter is varied through time and represents survival between two-month capture occasions (May/June, July/August, September/October). Detection probability (p) was held constant over time.

Parameter	Estimate	Std. Error	95% CI Lower	95% CI Upper
Φ 1	0.051	0.013	0.031	0.083
Φ 2	0.846	0.190	0.240	0.990
Φ 3	0.273	0.149	0.079	0.621
p 4	0.667	0.122	0.406	0.854

Table 5. Top selected, second ranked, model (Φ(trans) p(.)) real parameter estimates for the Scott River in 2014. The first Φ parameter estimate represents apparent survival during transition to a rearing location while the second Φ parameter represents survival during the rearing period. Detection probability (p) was held constant over time.

Parameter	Estimate	Std. Error	95% CI Lower	95% CI Upper
Φ 1	0.055	0.014	0.033	0.091
Φ 2	0.602	0.123	0.357	0.805
p 3	0.637	0.123	0.383	0.833

PIT Tagging- Upper Basin

The top ranked model for the CJS analysis conducted for the Upper Shasta River basin in 2014 was the time varying model (Φ (t) p (t))(Table 6). The apparent survival (Φ) and detection probability (p) parameter estimates both varied by month in this model. Any model ranked within two AIC_C units was again considered competing for this analysis. However, as the second ranked model (Φ (season) p (season)) was ranked nearly 158 units higher than the time varying model it was not considered for inference. Multiple time steps indicated Φ parameter estimates of 1.000 (Φ 3, Φ 11) with wide confidence intervals, likely due to low samples sizes and high recapture rates between those occasions. Apparent survival estimates varied monthly throughout the period analyzed (Table 7) but generally ranged from 74.4% (95% CI: 59.7, 85.0) to 89.0% (95% CI: 58.5, 97.9) in the spring and summer months. As the top ranked model was fully time varying it is important to note that both the last Φ and last p estimates are confounded with each other (Φ 13, p 26), and therefore the estimates actually reflect Φ*p for those time steps (Table 7). The $\hat{c}$ value of the global model was calculated as 1.4 using the same method detailed for the Scott River analysis, indicating an acceptable level of overdispersion. Apparent survival for the upper Shasta River top ranked model was compared to the monthly approximate estimates calculated for the top model in the lower Scott River. Early summer estimates of survival (May and June) could not be directly compared with the transition parameter from the Scott River 2014 analysis, but apparent survival was slightly higher in the upper basin for several months in the rearing portion of the summer (Table 8).

Table 6. Model selection table for Cormack Jolly Seber (CJS) analysis of 2014 Upper Shasta River PIT tag data. Models are ranked by AIC_C. Models either vary by time (t) or each time step, in this case monthly, or by season (time of year). Models with a (.) indicate no variation through time for that particular parameter estimate.

Model	**AICc**	**Delta AICc**	**AICc Weights**	**Model Likelihood**	**Num Par**	**Deviance**
Φ(t) p(t)	3986.089	0	1	1	26	1235.985
Φ(season) p(season)	4143.949	157.860	0	0	10	1426.762
Φ(t) p(.)	4157.459	171.370	0	0	14	1432.118
Φ(season) p(.)	4263.357	277.268	0	0	6	1554.274
Φ(.) p(.)	4328.111	342.0220	0	0	2	1627.083

Table 7. Parameter estimates for the top selected (Φ (t) p (t)) model in the 2014 Upper Shasta River CJS PIT tag analysis. Each Φ parameter estimate (apparent survival) represents the transition between monthly occasions starting with the transition from April 2014 to May of 2014 and continues through May of 2015 (Φ 13). Each probability of detection estimate (p) represents the probability of being detected for each particular time step and was also varied through time.

Parameter	**Estimate**	**Std. Error**	**95% CI Lower**	**95% CI Upper**
Φ 1	0.775	0.070	0.610	0.884
Φ 2	0.744	0.065	0.597	0.850
Φ 3	1.000	0.000	1.000	1.000
Φ 4	0.748	0.064	0.603	0.853
Φ 5	0.890	0.087	0.586	0.979
Φ 6	0.777	0.067	0.619	0.881
Φ 7	0.990	0.063	0.000	1.000
Φ 8	0.967	0.081	0.167	1.000
Φ 9	0.987	0.109	0.000	1.000
Φ 10	0.949	0.103	0.226	0.999
Φ 11	1.000	0.000	1.000	1.000
Φ 12	0.763	0.285	0.128	0.986
Φ 13	0.164	50.687	0.000	1.000
p 14	0.410	0.056	0.306	0.522
p 15	0.416	0.048	0.325	0.513
p 16	0.113	0.018	0.082	0.152
p 17	0.088	0.017	0.059	0.128
p 18	0.222	0.027	0.173	0.280
p 19	0.274	0.030	0.219	0.337
p 20	0.347	0.034	0.284	0.415
p 21	0.222	0.031	0.168	0.287
p 22	0.200	0.031	0.147	0.267
p 23	0.138	0.024	0.096	0.193
p 24	0.422	0.043	0.341	0.507
p 25	0.593	0.220	0.196	0.897
p 26	0.165	50.864	0.000	1.000

Table 8. Top selected model (Φ (trans) p (.)) real parameter estimates for the Scott River in 2014 shown with parameter estimates for the top selected (Φ (t) p (t)) model in the 2014 upper Shasta River CJS PIT tag analysis. Scott River parameters were adjusted to reflect monthly survival over the summer (July-October) rearing period for comparison to the upper Shasta River monthly apparent survival estimates. The transition parameter estimate was not converted to a monthly estimate as it does not represent a directly comparable variable. All parameters for both analyses include a standard error estimate as well as a 95% confidence interval.

Month	**Scott River Estimate**	**Std. Error**	**95% CI Lower**	**95% CI Upper**	**Upper Shasta River Estimate**	**Std. Error**	**95% CI Lower**	**95% CI Upper**
May	--	--	--	--	0.744	0.065	0.597	0.850
June	--	--	--	--	1.000	0.000	1.000	1.000
Transition	0.055	0.014	0.033	0.091	--	--	--	--
July	0.776	0.079	0.587	0.894	0.748	0.064	0.603	0.853
August	0.776	0.079	0.587	0.894	0.890	0.087	0.586	0.979
September	0.776	0.079	0.587	0.894	0.777	0.067	0.619	0.881
October	0.776	0.079	0.587	0.894	0.990	0.063	0.000	1.000

Growth Comparison Results

Fork length and weight at tagging showed little variation between years and rivers (Figure 10, Figure 11). The only discernible difference was due to the limited allowable fork length for tagging set in 2015. Growth was higher for individuals rearing in natal habitat in the Upper Shasta River than for early outmigrants from the Scott and Shasta Rivers (Table 9), or for individuals of unknown origin found rearing in artificially constructed ponds in the mid-Klamath River (Krall 2016) (Figure 12).

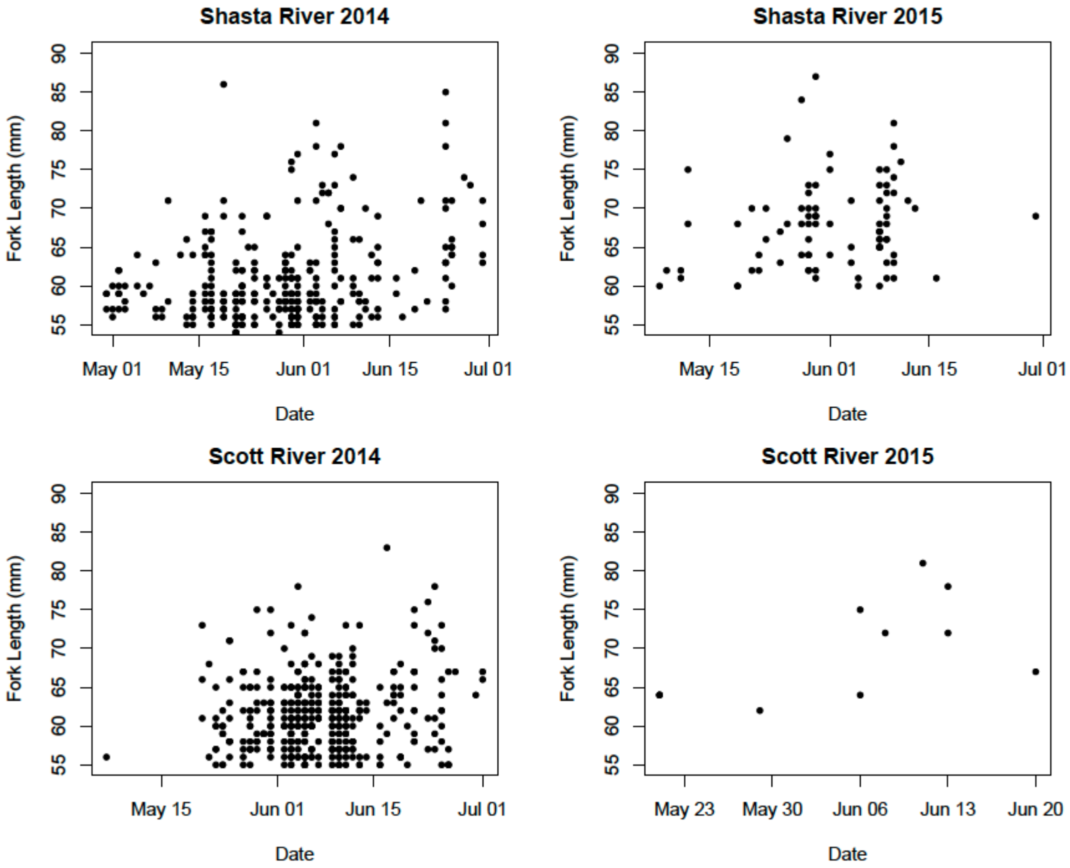

Figure 10. Fork lengths in millimeters (mm) measured at time of rotary screw trap tagging for both years (2014 and 2015) of study for the Shasta and Scott Rivers. Note that minimum tagging size was set at 55 mm for the 2014 tagging season but was increased to 60 mm in the 2015 tagging season.

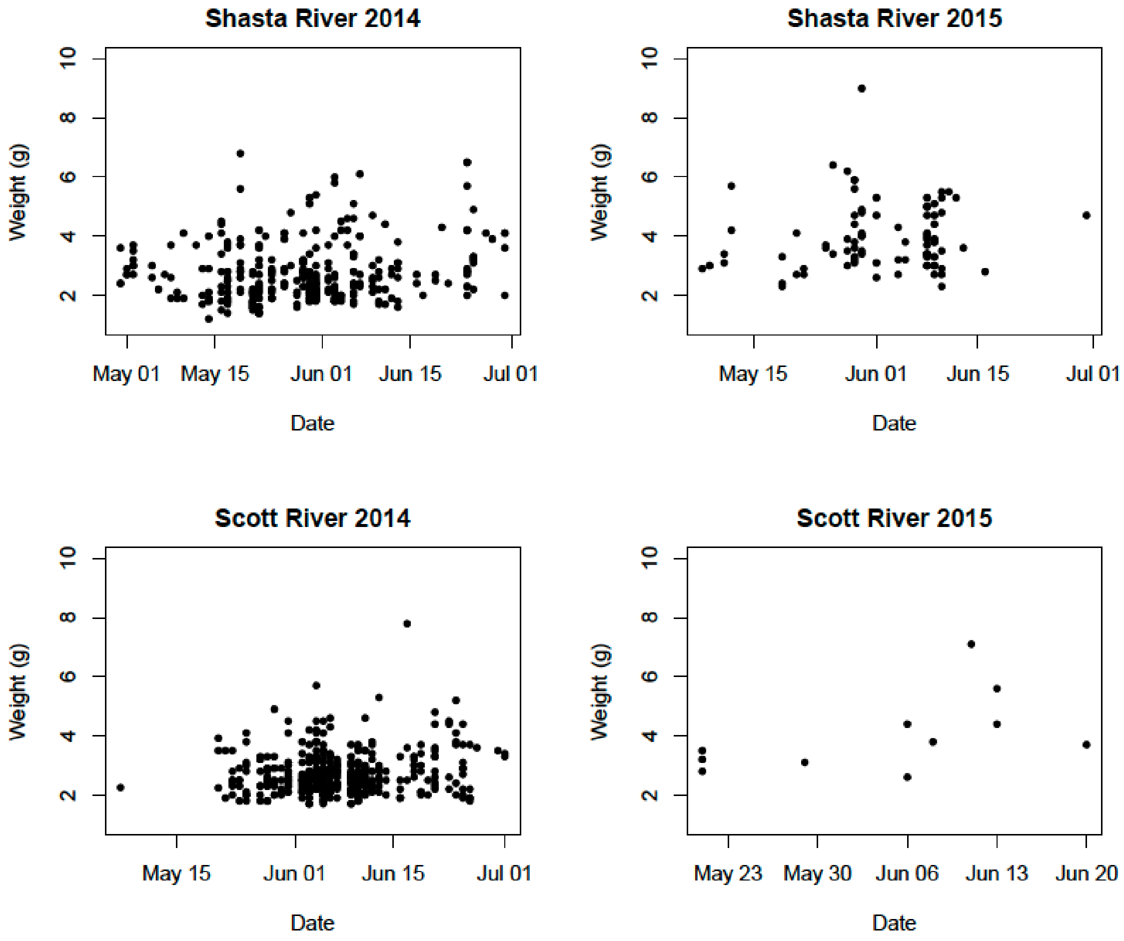

Figure 11. Weight, measured in grams (g), for all juvenile Coho Salmon tagged at the Shasta and Scott River rotary screw traps in 2014 and 2015.

Table 9. River and tagging location at initial capture, tag number (last 6 digits) and date, fork length in millimeters (mm) and weight in grams (g) for all juvenile Coho Salmon physically recaptured outside of their stream of origin. Location of recapture is also shown along with individual date of recapture, fork length and weight when available. Millimeters and grams grown per day (MM/Day, Grams/Day) were calculated between each recapture event.

River	Tag Number	Tag Date	Fork Length	Weight	Location	Date	Fork Length	Weight	MM/Day	Grams/Day
Scott	307256	5/24/14	59	2.50	May Pond (Seiad Creek)	6/17/14	68	--	0.38	--
Scott	309449	5/24/14	55	2.30	Lower Seiad Creek	2/2/15	80	5.13	0.10	0.01
Scott	364057	6/4/14	65	2.80	Beaver Creek	6/25/14	62	3.12	--	0.02
Scott	364407	6/9/14	63	2.80	O'Neil Creek Pond	9/25/14	80	5.44	0.16	0.02
Scott	368314	6/18/14	63	3.00	Tom Martin Pond	10/1/14	74	4.70	0.10	0.02
Scott	368314	6/18/14	63	3.00	Tom Martin Pond	2/16/15	82	6.22	0.08	0.01
Scott	368314	6/18/14	63	3.00	Tom Martin Pond	4/7/15	91	8.77	0.10	0.02
Shasta	714062	5/25/15	63	3.70	Horse Creek	8/13/15	75	4.82	0.15	0.01

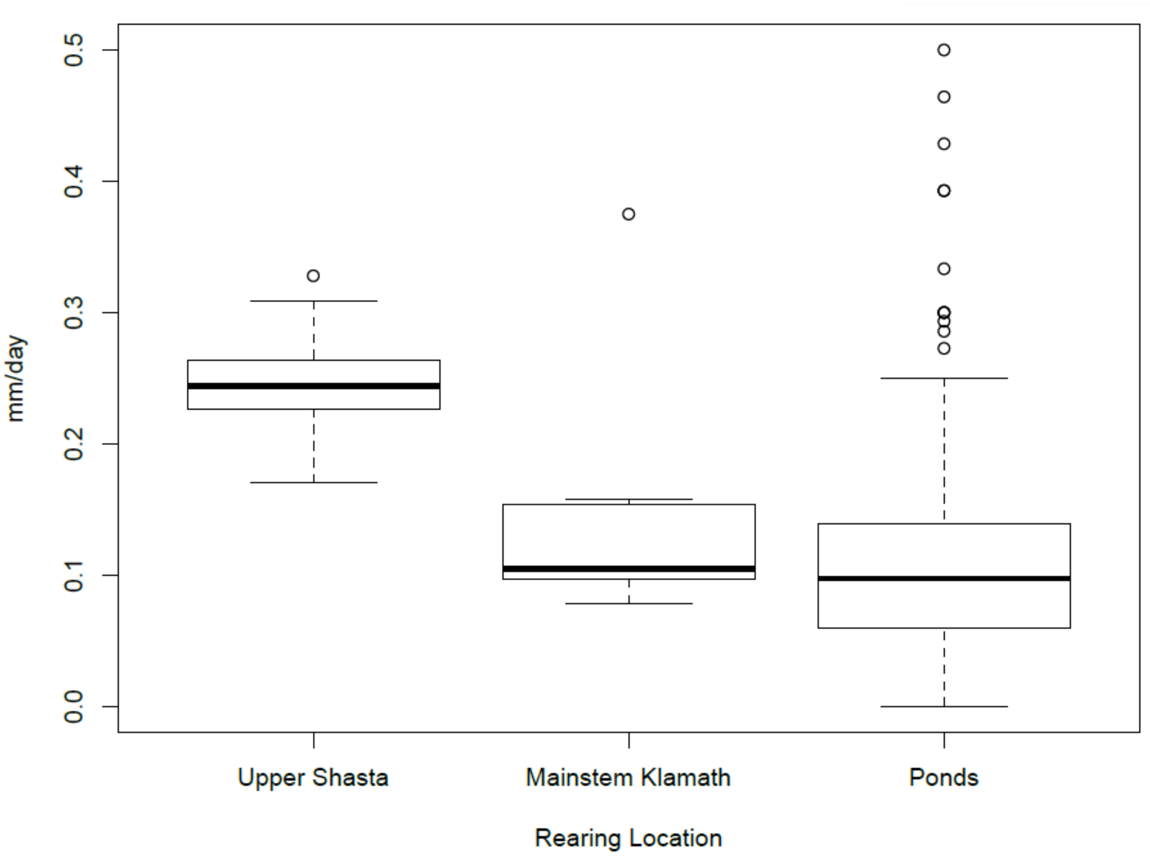

Figure 12. Box and whisker plot of growth rates (mm/day) estimated for juvenile Coho Salmon rearing for 1 year in the Upper Shasta River (n=46), various locations (tributaries or off-channel ponds) in the mainstem Klamath River (n=7), and in off-channel constructed ponds (n=479). The mainstem Klamath River category is solely composed of growth rates for juveniles which outmigrated from the Shasta and Scott Rivers during the course of this study. Pond growth rates were estimated in 2014 by Krall (2016). The Upper Shasta River growth rates were estimated using independent tagging data provided by the California Department of Fish and Wildlife in 2014-2015 and were estimated only for juveniles likely spending an entire year in the Upper Shasta River.

Otolith Analysis

The classification of natal and non-natal rearing individuals using the hatchery otolith baseline resulted in clear distinctions in groups among and within rivers (Figure 13). Movement, or lack of movement, in rearing transects was in some cases easily distinguishable between natal and non-natal rearing individuals (Figure 14, Figure 15). Overall a slight majority of adult otoliths analyzed were classified as juveniles that reared in their natal stream (Table 10). However, the proportions of natal and non-natal fish varied across stream locations (Figure 16). In the Shasta River most of the adults sampled reared in their natal stream as juveniles (Table 10, Figure 16). Unfortunately, due to small numbers of returning adults to the Shasta River and limited access to adult spawner otoliths, this statistic is based on a sample size of only five individuals. Conversely the Scott River exhibited a much higher proportion of non-natal rearing juveniles to natal rearing individuals (Table 10, Figure 16).

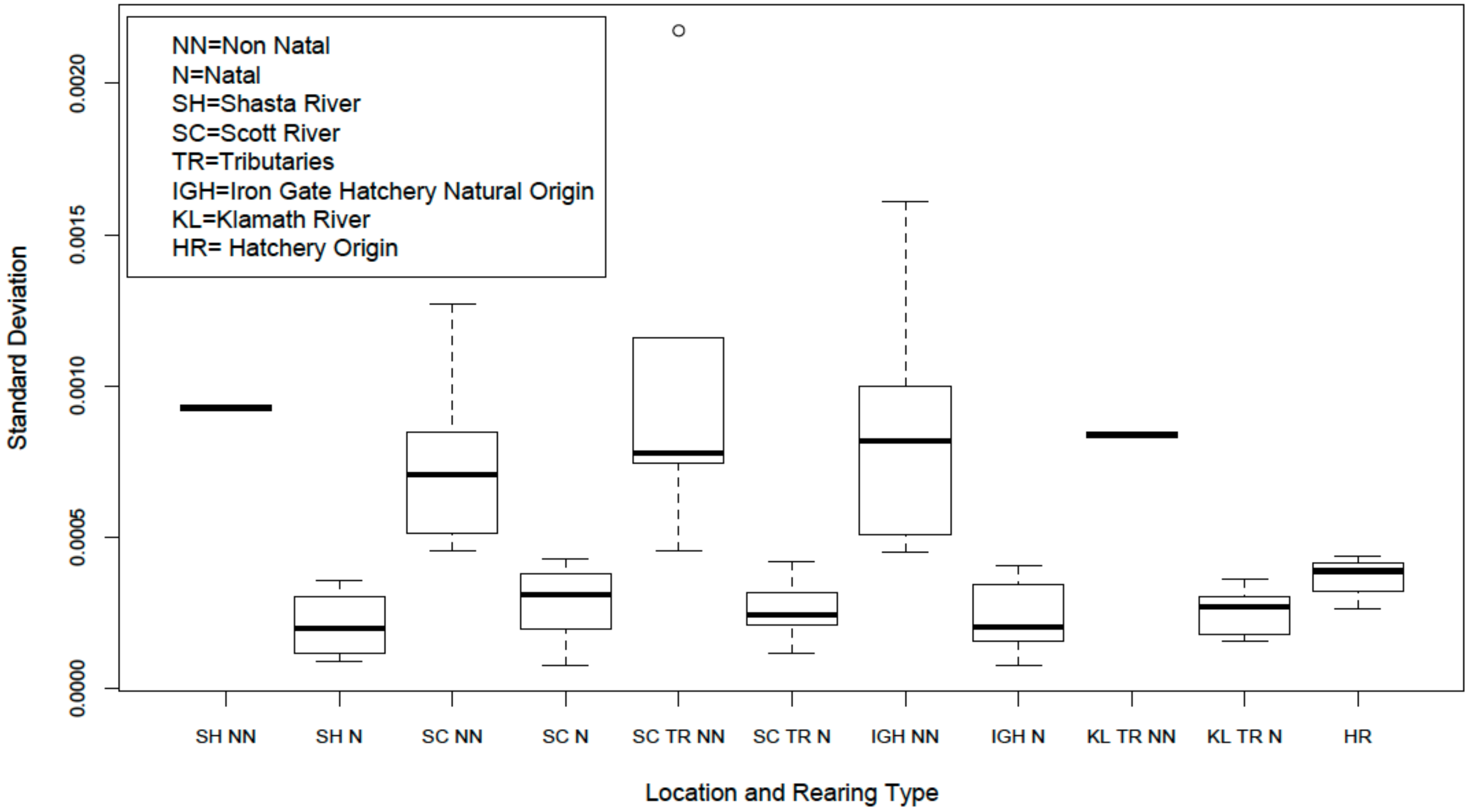

Figure 13. Box and whisker plot indicating rearing transect standard deviation variation between adult Coho Salmon otolith collection locations. Otoliths from each collection location are further classified as natal or non-natal rearing individuals. The HR category indicates the rearing transect standard deviation for 4 known Hatchery Origin Return individuals used as a natal rearing baseline. Locations sampled were the Shasta River (n=5), Scott River (n=56), Klamath (n=10) and Scott River Tributaries (n=15), and Iron Gate Hatchery (n=30) (Natural Origin Return individuals).

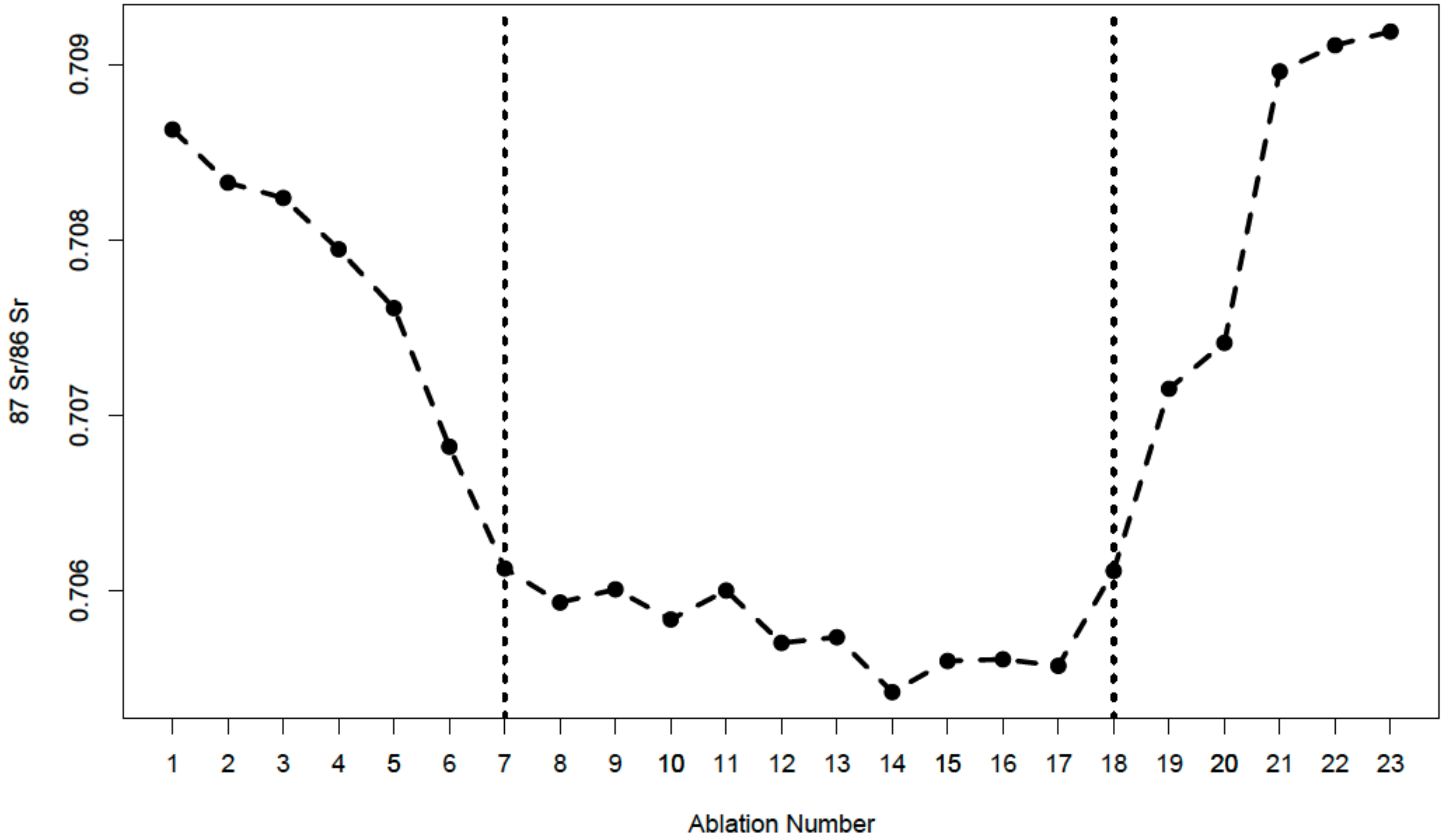

Figure 14. Example of 87 Sr/86 Sr transect measurements for an otolith classified as belonging to a natally rearing individual, collected from Shackleford Creek (a Scott River Tributary). Ablation number indicates each dot sampled using Laser Ablation Multi-Collector Inductively Coupled Mass Spectrometry starting from the core of the otolith and moving outward. Vertical dotted lines indicate the beginning and the ending of the rearing period (from cessation of maternal input to beginning of ocean outmigration). Entire transect covers the first year of life, from the beginning of maternal input until the point of ocean entry as a smolt.

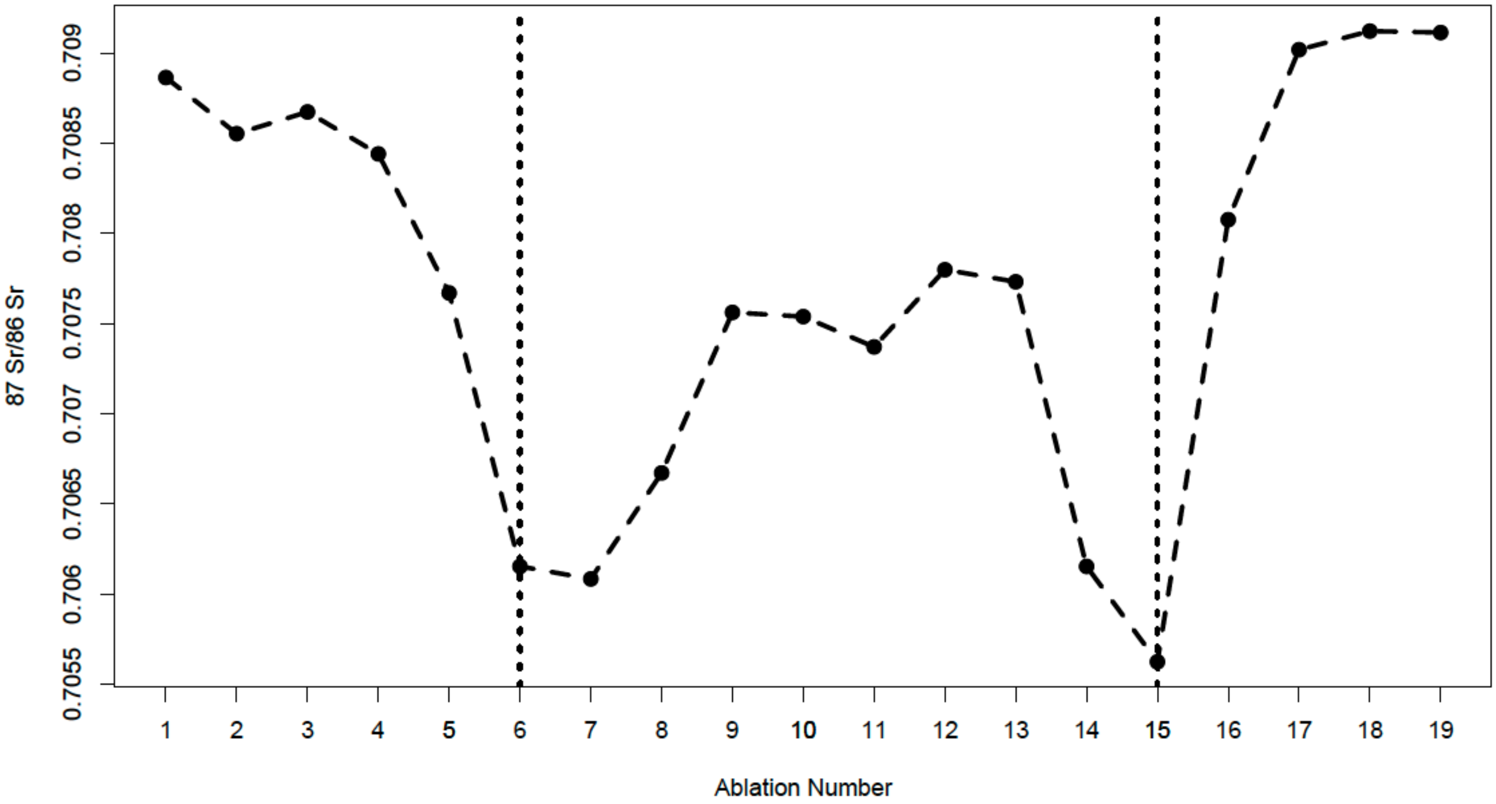

Figure 15. Example of 87 Sr/86 Sr transect measurements for an otolith classified as belonging to a non-natal rearing individual, collected from the Scott River. Ablation number indicates each dot sampled using Laser Ablation Multi-Collector Inductively Coupled Mass Spectrometry (LA-MC-ICP-MS) starting from the core of the otolith and moving outward. Vertical dotted lines indicate the beginning and the ending of the rearing period (from cessation of maternal input beginning of ocean outmigration). Entire transect covers the first year of life, from the beginning of maternal input until the point of ocean entry as a smolt.

Table 10. Total counts of otolith samples from adult Coho Salmon classified as natal or non-natal rearing individuals. Samples are categorized by otolith collection location and totaled by location and "natal" and "non-natal" classifications. Hatchery origin return Iron Gate Hatchery (IGH) Coho Salmon, used as natal baseline values, were not included in these totals. In addition 4 otolith samples analyzed were not included due to anomalies in the $^{87}Sr/^{86}Sr$ values output. IGH NR refers to natural origin return, Iron Gate Hatchery otoliths that were prepared and analyzed.

Location	**Natal**	**Non-Natal**	**Total**
Scott River	22	34	56
Shasta River	4	1	5
IGH NR	16	14	30
Scott River Tributaries			
Shackleford Creek	5	1	6
Mill Creek	2	1	3
Sugar Creek	0	1	1
French Creek	3	2	5
Subtotal	10	5	15
Klamath River Tributaries			
Irving Creek	1	0	1
Horse Creek	2	0	2
Seiad Creek	6	1	7
Subtotal	9	1	10
TOTAL	61	55	116

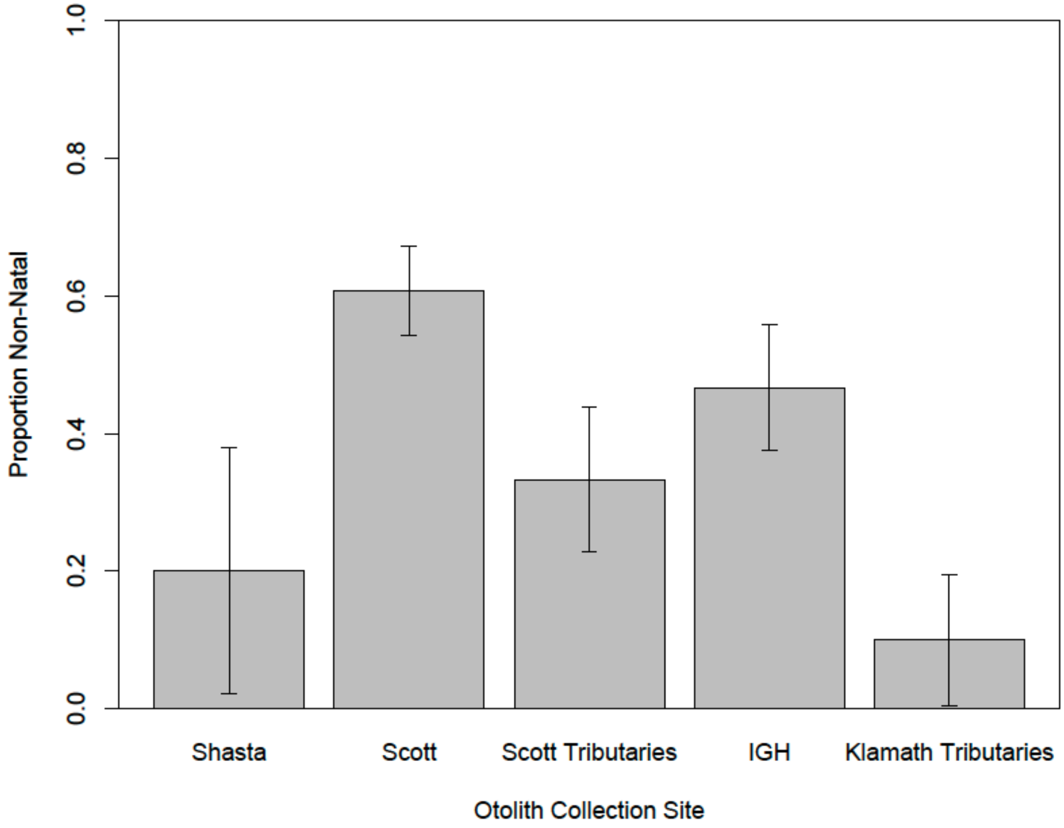

Figure 16. Proportion of total otoliths analyzed which were classified as belonging to non-natal rearing individuals. Standard error is indicated with vertical lines. Otoliths are categorized by location collected. Possible locations included samples collected at the Scott River (n=56), Shasta River (n=5), Klamath (n=10) and Scott River Tributaries (n=15), and Iron Gate Hatchery (IGH) NR (n=30) (Natural Origin Return) individuals.

Wild Coho Salmon captured at the hatchery were used as an indication of rearing behavior exhibited by strays. All wild (non-hatchery) adults returning to spawn at Iron Gate Hatchery are strays. Therefore, by analyzing the rearing patterns exhibited by these individuals, some indication of the effect of rearing behavior on straying could be determined. Similar numbers of NR Coho Salmon reared in natal and non-natal locations (Figure 16).

DISCUSSION

PIT Tag Analysis

Jeffres and Moyle (2012) hypothesized that early outmigrants, particularly from the Shasta River, were not contributing to the returning adult populations, and research in other systems has led to similar hypotheses (Chapman 1962). While very few early outmigrants tagged from the Scott and Shasta Rivers in this study were detected outside their natal stream, a small portion were detected in non-natal rearing habitat. Further, these results indicate survival may improve upon reaching these habitats. Juveniles rearing in the upper Shasta River were not exposed to unfavorable habitat conditions in the early spring and summer months, and were therefore not forced to transition to external rearing habitat. As a result these fish had relatively high survival through the spring period when lower basin fish were emigrating. However, survival for juveniles rearing in the upper Shasta River did not substantially differ from survival of early outmigrants that successfully located off-channel habitat in the Klamath River basin, likely as a result of non-natal habitat conditions.

This analysis provides a minimum estimate of apparent survival for juvenile Coho Salmon transitioning to a non-natal rearing location. Most streams and tributaries to the Klamath River are not consistently sampled, and do not have PIT tag antenna systems installed. Individuals using these habitats are not included in this estimate of transition survival. Further, individuals that were too small to tag early in the season could not be tracked, yet these individuals may have the potential to fare better due to cooler mainstem Klamath River conditions early in the season. Much more investigation into possible rearing locations and methods for tracking all early emigrants needs to be conducted. In the future it would be ideal to expand the PIT tag antenna network throughout the Klamath River Basin. This would allow for properly cataloging of locations used by fish, from all sub-basins, for non-natal seasonal rearing. Additionally, evaluation of genetic mark-recapture or other technologies for tracking fish that are too small to PIT tag would be beneficial.

Although these estimates of survival during the transition to non-natal streams are minimums, low survival would be expected for fish that outmigrate in late spring or early summer. Upon exiting the natal stream during this period, non-natal rearing juveniles may be exposed to adverse conditions for an extended time period while seeking locations in which to rear. In the Klamath River mainstem, potential stressors include environmental factors such as *Ceratonova shasta*, high water temperatures, low flow, and low dissolved oxygen (Sutton et al. 2007, Ray et al. 2012).

Individuals forced to outmigrate as young-of-the-year, as a result of poor natal conditions, experience a higher proportion of juvenile mortality than those rearing in natal streams, particularly during the transition period. High juvenile mortality while transitioning to a non-natal stream could, in turn, lead to decreased adult returns. This mortality could have particularly large effects on returns when, as in the study year (2014), the abundance of young-of-year outmigrants is much larger than the number of smolt outmigrants within a cohort (AFRAMP Annual Report 2014, AFRAMP Annual Report 2015). In 2014 the estimated number of young-of-the-year Coho Salmon outmigrating from the Shasta River was 10,752, while the population estimate for natal rearing smolts outmigrating in 2015 was only 6,279. Similarly in the Scott River 16,962 juvenile outmigrants were estimated in 2014, with only 7,253 smolts estimated to have left the system in 2015. Decreased smolt migration is likely to have a significant impact on the returns of spawning adults to each river.

While transition survival may be low, modeling results suggest that survival probability can increase when individuals reach non-natal habitat. Addressing the possibility of low transition survival presents an opportunity to bolster a potentially successful life history strategy. The goal of maintaining habitats that support variation in life history patterns is widely espoused for Pacific Salmon (Schindler et al. 2010). Increased recognition of the diversity in freshwater rearing and emigration life histories exhibited by juvenile Coho Salmon (Miller and Sadro 2003) has highlighted the need for greater understanding of what habitats are being used and how these contribute to adult returns. This is particularly true given the possibility that a substantial segment of juvenile Coho Salmon populations can consist of early emigrants (Rebenack et al. 2015, AFRAMP Annual Report 2014, AFRAMP Annual Report 2015). These study results indicate that off-channel non-natal rearing areas, such as Tom Martin Creek and Pond, were being used by Shasta and Scott River early outmigrants. Knowing that sites were being used, and that survival upon reaching these sites increased during the study period, helps to demonstrate their importance to non-natal rearing juveniles. Further, the lower growth rates exhibited by pond-rearing individuals, compared with natal stream rearing fish, may present the opportunity to improve these habitats by identifying likely causes of this disparity.

Although this analysis is not definitive, the transition from a natal location to a non-natal location may be the weak link in the early emigrant life history. The addition of more suitable off-channel and constructed habitat as a refuge could increase the probability of encountering suitable rearing locations, and therefore increase non-natal rearing representation in the adult population. Additionally, improving and preserving conditions within the mainstem Klamath River is vital to early emigrant survival during their migration to these habitats. This type of refuge habitat could be particularly effective if placed in locations lacking suitable habitat, downstream of highly productive Coho Salmon river systems, such as the Scott and Shasta Rivers. Offering nearby off-channel habitat could decrease the time spent by early outmigrant young-of-the-year in unfavorable mainstem conditions, leading to increased survival during the transition period.

Otolith Analysis

Due to the geological diversity within the Klamath River Basin, varying levels of deviation in $^{87}Sr/^{86}Sr$ exist across locations at different spatial scales. This complexity affects the interpretation of the otolith results presented here. While based on a limited sample size, these results suggest that non-natal rearing was more prevalent within the Scott River basin based on the $^{87}Sr/^{86}Sr$ transects. However, unlike the Shasta River basin, the Scott River has an extensive tributary system with high levels of geological and strontium diversity, as well as widely distributed Coho Salmon spawning habitat (Quiñones et al. 2012). For the Scott River otolith analysis, the term “non-natal” should be defined differently. Each tributary in the upper basin of the Scott River should be considered a “non-natal” tributary for fish which spawned in the mainstem or adjacent tributaries. A “non-natal” rearing juvenile within the Scott River basin does not imply that the individual emigrated to the mainstem Klamath River and entered an adjacent watershed to rear. In contrast, in the PIT tag analysis, individuals were tagged leaving the lower basin, so “non-natal” for those fish is defined as an individual passing through the mainstem Klamath River.

The otolith analysis indicated that a much higher proportion of the spawning population was composed of non-natal rearing fish in the Scott River than the Shasta River. This could be due to the inability to distinguish small-scale movement within the Scott River Basin from movement between basins, as described above. This scale issue is less problematic in the Shasta River, due to the known variation in $^{87}Sr/^{86}Sr$ values (Roddam et al. 2014). Further, the shorter distance from the Scott River to Tom Martin Creek, a known suitable rearing location, is much smaller for Scott River outmigrants than Shasta River outmigrants, which could lead to increased survival for traditionally defined non-natal juveniles.

The comparative analysis of $^{87}Sr/^{86}Sr$ levels in this study helped establish potential general rearing patterns. Expansion of this analysis to more definitively and conclusively link particular signatures with actual rearing locations holds great promise for new insights into rearing behavior. In the future it would also be beneficial to increase the number of samples used to determine the baseline signatures for natal and non-natal rearing individuals, as the current study (due to time and monetary constraints) was based on only four hatchery otolith signatures. Expansion of this baseline would allow for more definitive separation of natal and non-natal individual classifications, as well as more definitive conclusions.

Expanding the Klamath River database to include other chemical elements may also allow for a greater ability to distinguish the relative habitat use of discrete rearing locations (Shrimpton et al. 2014, Payne Wynne et al. 2015), and to assign natal and non-natal rearing individuals to a particular location of origin. Additionally, expansion of the water chemistry database could indicate which rivers have higher percentages of non-natal rearing fish, as well as more clearly identifying signatures as exhibiting natal or non-natal rearing patterns. Having an expansive outline of water chemistry signatures could also allow for some interesting opportunities to research adult salmon straying. In this study, a near even split of natal and non-natal rearing patterns appeared to be present within the population of known strays. However, if more identifiable signatures were available, it might be possible to identify the proportion of strays returning to particular locations, as well as the rearing location and strategy employed by these strays (Hamann and Kennedy 2012).

PIT Tag and Otolith Conclusions

This study demonstrated that some early outmigrants from the Scott and Shasta Rivers were able to find and rear in non-natal habitat, and the otolith analysis suggested that individuals rearing in non-natal locations can survive to return and spawn as adults. By acknowledging the potential for non-natal rearing individuals to return as spawning adults, restoration can be structured to benefit early outmigrants. This research has highlighted the potential importance of constructed off-channel habitats, such as the off-channel pond utilized on Tom Martin Creek. Increasing the number of accessible off-channel habitats has potential to increase the probability of non-natal Coho Salmon locating and utilizing the habitat. Maintaining ideal conditions year-round in these ponds has potential to support early outmigrants from multiple locations (Yurok Tribal Fisheries Program 2013).

While maintaining life history diversity within a population contributes to population persistence, this study offers insight into the most successful strategies within individual stream systems. The Shasta River otolith and PIT tag analysis, as well as the relative lack of early outmigrant recaptures in the two years of study, suggests that natal rearing contributes more to population persistence in the Shasta River than non-natal rearing. The higher apparent survival and adult return of natal-rearing Shasta River juveniles suggests relatively few successful life histories are present in the Shasta River basin, all of which rely on highly productive but relatively small and vulnerable habitat in the upper Shasta River. By comparison, the Scott River population is not offered quite as productive habitat, and appears to display a more diverse set of juvenile rearing life histories. As such, the Scott River would likely benefit from protection of natal habitats as well as restoration of non-natal habitats (both within and outside the Scott River basin). By contrast, the Shasta River may benefit from gearing restoration towards non-natal rearing individuals, while also maintaining the current natal rearing habitat and migration corridors. Adding Klamath River off-channel habitats, as well as locating off-channel habitats closer to the Shasta River (i.e. Tom Martin Creek for the Scott River), may bolster survival of non-natal rearing juveniles. As a whole these findings suggest the hypothesis that, currently, Scott River Coho Salmon would be much more likely to withstand extreme population impacts or habitat changes in the future.

Further examination of use of non-natal rearing locations may yield insights which would allow protection and restoration efforts to be more effectively focused. This study provides evidence that early outmigrant juveniles are not complete population losses, and that non-natal rearing may be a viable life history strategy. Acknowledging these variations in population structure, and implementing restoration accordingly, could lead to long-term positive impacts on the Klamath River Basin’s declining Coho Salmon populations.

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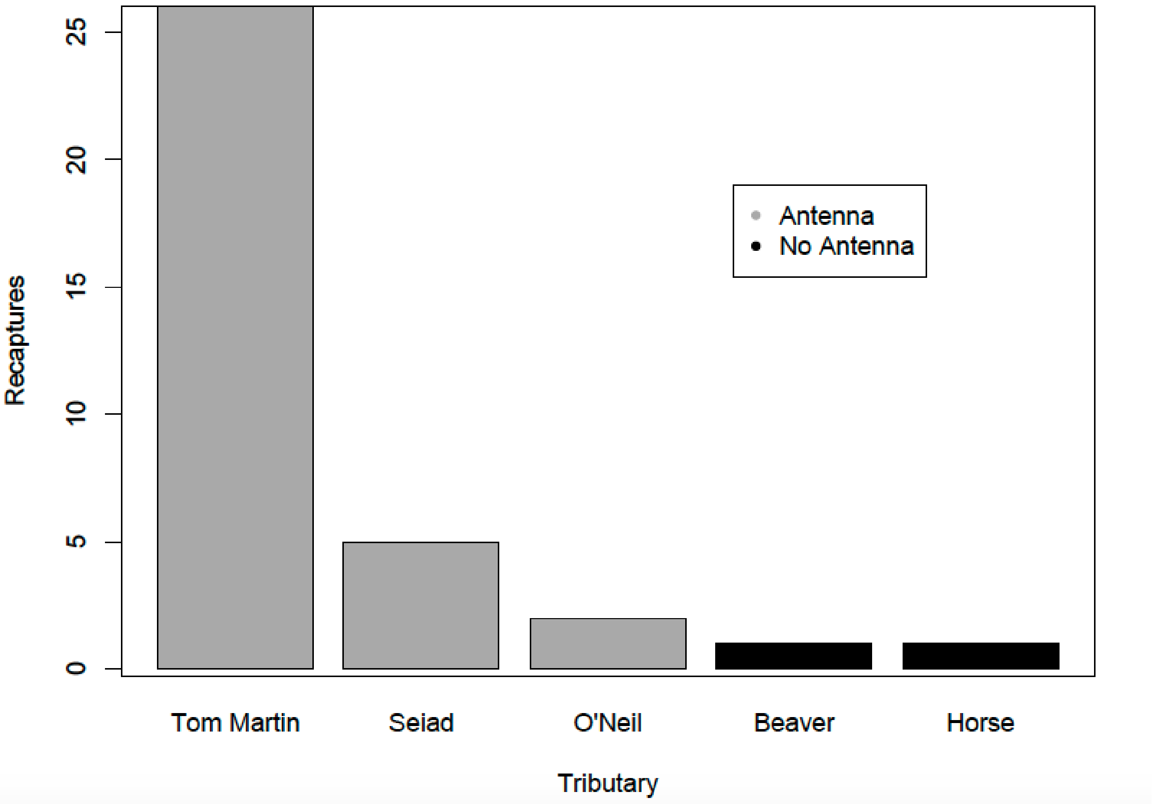
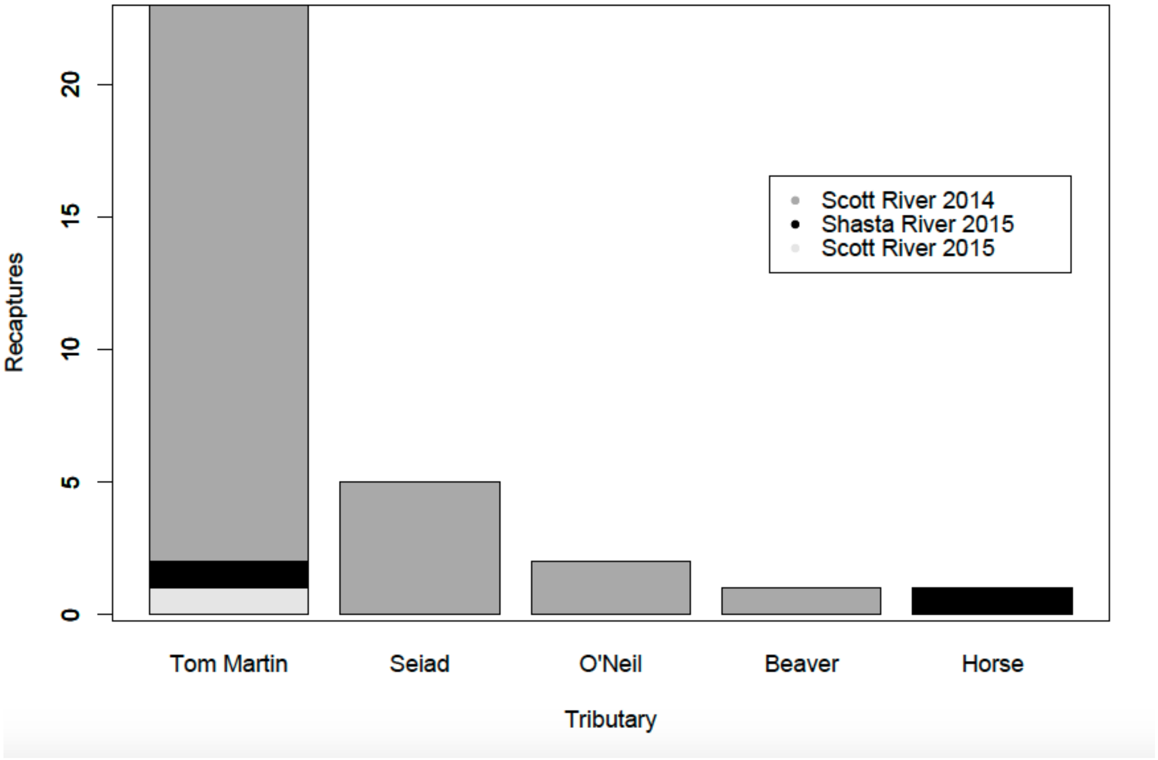
APPENDIX A



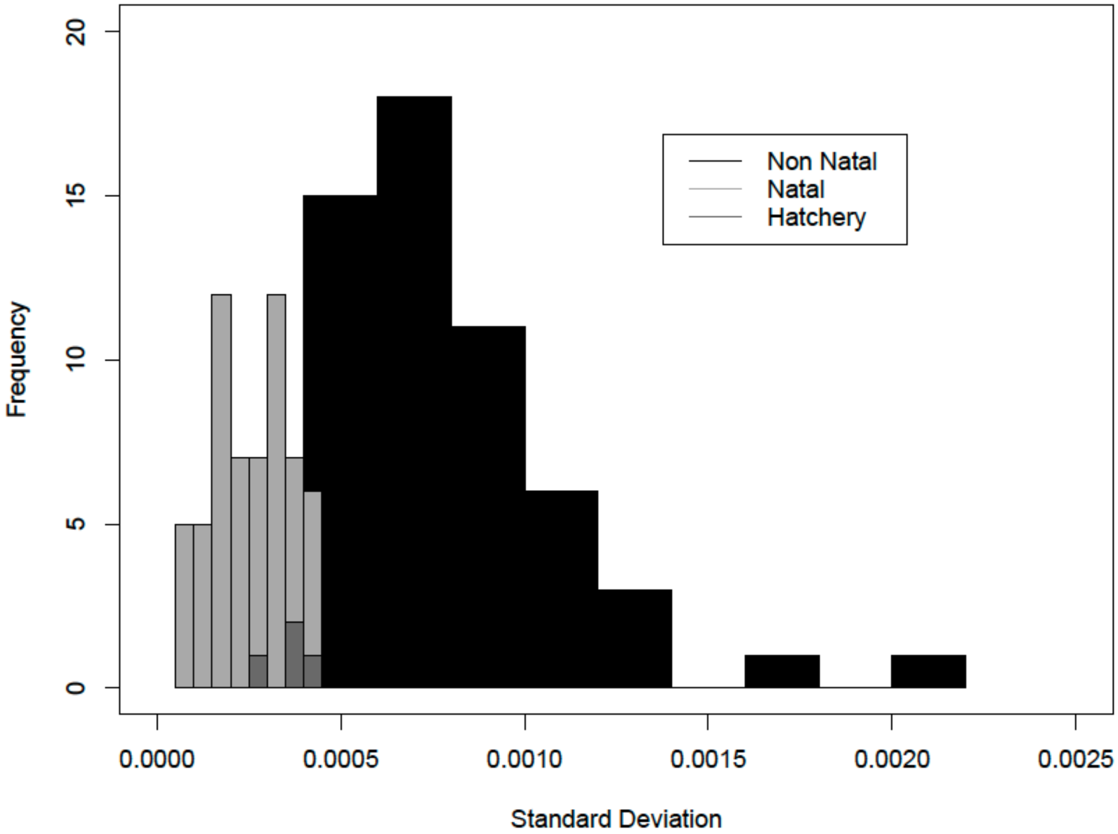
Appendix A. Recapture locations for juvenile Coho Salmon tagged in the Shasta and Scott Rivers in 2014 and 2015. All recapture locations shown were outside of the stream of origin. Recapture locations that had an operating PIT tag antenna throughout the study are shown in gray while locations with no functioning PIT tag antenna are shown in black. Recaptures are combined across all years (2014 and 2015) and rivers (Shasta and Scott River) and indicate absolute number of recaptures rather than proportions of the total recaptured.

APPENDIX B



Appendix B. Recapture locations for juvenile Coho Salmon tagged in the Shasta and Scott Rivers in 2014 and 2015. All recapture locations shown were outside of the stream of origin. Number of recaptures is separated by stream of origin and year of tagging. Dark gray indicates a fish tagged in 2014 at the Scott River, black indicates a fish tagged in 2015 at the Shasta River, and light gray indicates a fish tagged in 2015 at the Scott River. Note that the Shasta River in 2014 is not included due to the total lack of recaptures from that system in that year.

APPENDIX C



Appendix C. Histogram representing the variation in rearing transects standard deviation for Coho Salmon adult otoliths analyzed using Laser Ablation Multi-Collector Inductively Coupled Mass Spectrometry (LA-MC-ICP-MS). Transect standard deviations were classified as “natal” (light grey) or “non-natal” (black) based on the standard deviation present in the transects of 4 known Hatchery Origin Return (HR) Iron Gate Hatchery (IGH) individuals (shown in dark grey).

APPENDIX D

Appendix D. Complete list of all otoliths collected and analyzed (using LA-MC-ICP-MS) from spawning ground surveys in the Klamath River Basin. Collection river and specific location of collection are outlined. Additionally, the unique identifying label for each otolith is listed, along with the otolith collection date and collection year. Fork length (FL) in centimeters (cm) and sex (F= Female, M=Male) are given for each individual adult Coho Salmon that had an otolith analyzed.

Otolith	Date Collected	Year Collected	River	Location	FL (cm)	Sex
SH 1	11/3	2012	Shasta	Shasta Weir	61	F
SH 2	11/16	2012	Shasta	Shasta Weir	43	M
SH 3	11/28	2012	Shasta	Shasta Weir	68	M
SH 4	12/12	2012	Shasta	Reach 22	62	F
SH 5	12/23	2014	Shasta	Reach 20	67	F
SC 1	11/28	2011	Scott	Reach 14	73	M
SC 2	11/29	2012	Scott	Scott Weir- Reach 7	70	F
SC 3	12/2	2013	Scott	Reach 6	71	M
SC 4	12/16	2013	Scott	Reach 14	70	F
SC 5	12/16	2013	Scott	Reach 15	68	F
SC 6	12/23	2013	Scott	Reach 8	76	M
SC 7	12/23	2013	Scott	Reach 14	75	M
SC 8	12/26	2013	Scott	Reach 13	68	F
SC 9	12/31	2013	Scott	Reach 14	67	F
SC 10	1/2	2014	Scott	Reach 13	68	F
SC 12	1/2	2014	Scott	Reach 13	74	F
SC 14	1/2	2014	Scott	Unknown	74	F
SC 15	1/2	2014	Scott	Reach 12	73	F
SC 16	1/6	2014	Scott	Reach 15	65	M
SC 17	1/6	2014	Scott	Reach 15	67	F
SC 18	1/6	2014	Scott	Reach 15	68	F
SC 25	1/7	2014	Scott	Reach 14	71	F
SC 26	1/7	2014	Scott	Reach 14	74	M
SC 27	1/7	2014	Scott	Reach 14	75	M
SC 28	1/8	2014	Scott	Scott Weir- Reach 7	72	M
SC 29	1/9	2014	Scott	Reach 7	71	F
SC 30	1/9	2014	Scott	Reach 7	69	M
SC 55	1/9	2014	Scott	Reach 14	72	M
SC 56	1/9	2014	Scott	Reach 14	72	M
SC 57	1/13	2014	Scott	Scott Weir- Reach 7	62	F

Otolith	Date Collected	Year Collected	River	Location	FL (cm)	Sex
SC 58	1/13	2014	Scott	Scott Weir- Reach 7	69	M
SC 59	1/15	2014	Scott	Scott Weir- Reach 7	74	M
SC 60	1/16	2014	Scott	Scott Weir- Reach 7	72	M
SC 79	1/24	2014	Scott	Reach 8	74	F
SC 80	1/27	2014	Scott	Reach 13	69	M
SC 81	1/27	2014	Scott	Scott Weir- Reach 7	65	M
SC 82	1/27	2014	Scott	Reach 12	73	F
SC 83	1/27	2014	Scott	Reach 12	63	F
SC 84	1/27	2014	Scott	Reach 12	69	F
SC 85	1/27	2014	Scott	Reach 12	67	F
SC 86	1/27	2014	Scott	Reach 12	73	F
SC 87	1/27	2014	Scott	Reach 13	50	F
SC 88	1/27	2014	Scott	Reach 13	67	F
SC 89	1/27	2014	Scott	Reach 13	76	M
SC 90	1/27	2014	Scott	Reach 13	68	F
SC 91	1/27	2014	Scott	Reach 13	67	M
SC 92	1/27	2014	Scott	Reach 13	75	M
SC 93	1/27	2014	Scott	Reach 13	68	F
SC 94	1/27	2014	Scott	Reach 13	73	M
SC 95	1/27	2014	Scott	Reach 13	70	M
SC 96	1/27	2014	Scott	Reach 13	70	F
SC 97	1/27	2014	Scott	Reach 13	70	F
SC 98	1/27	2014	Scott	Reach 13	71	M
SC 99	1/27	2014	Scott	Reach 13	74	M
SC 100	1/27	2014	Scott	Reach 13	78	M
SC 101	1/27	2014	Scott	Reach 13	73	F
SC 102	1/27	2014	Scott	Reach 13	69	F
SC 103	2/3	2014	Scott	Reach 7	69	F
SC 105	2/3	2014	Scott	Reach 7	71	M
SC 106	2/3	2014	Scott	Reach 8	67	F
SC 107	2/5	2014	Scott	Scott Weir- Reach 7	72	M
SF 1	12/3	2014	Shackleford Creek	Mid	80	M
SF 2	12/10	2014	Shackleford Creek	Mid	64	F
SF 3	12/10	2014	Shackleford Creek	Mid	74	M
SF 4	12/10	2014	Shackleford Creek	Mid	77	M
SF 5	12/10	2014	Shackleford Creek	Mid	68	F

Otolith	Date Collected	Year Collected	River	Location	FL (cm)	Sex
SF 6	12/10	2014	Shackleford Creek	Mid	72	F
ML 1	12/3	2014	Mill Creek	Mid	42	M
ML 2	12/10	2014	Mill Creek	Mid	41	M
ML 3	12/10	2014	Mill Creek	Mid	68	F
FR 1	12/4	2014	French Creek	Mid	67	F
FR 2	12/17	2014	French Creek	Mid	40	M
FR 3	12/17	2014	French Creek	Mid	64	F
FR 4	12/17	2014	French Creek	Mid	65	F
FR 5	12/17	2014	French Creek	Mid	78	M
FR 6	12/17	2014	French Creek	Mid	76	M
SU 1	11/27	2014	Sugar Creek	Mid	62	M
LSD 1	12/4	2014	Lower Seiad Creek	Durazo to Mouth	63	F
LSD 2	12/9	2014	Lower Seiad	Lower Seiad	38	M
SD 1	12/9	2014	Seiad Creek	Panther to Buma	71	F
SD 2	12/9	2014	Seiad Creek	Durazo to Mouth	65	F
SD 3	12/18	2014	Seiad Creek	Durazo to Mouth	71	F
SD 4	12/18	2014	Seiad Creek	Durazo to Mouth	65	F
SD 5	12/18	2014	Seiad Creek	Durazo	67	F
HS 1	12/9	2014	Horse Creek	Horse Creek	61	F
HS 2	12/9	2014	Horse Creek	Horse Creek	67.5	F
IG 1	12/18	2014	Irving Creek	Irving Creek	42	M
IGH 6	11/15	2013	IGH	NR	67	F
IGH 7	11/15	2013	IGH	NR	69	M
IGH 8	11/20	2013	IGH	NR	69	M
IGH 9	11/22	2013	IGH	NR	77	M
IGH 10	11/25	2013	IGH	NR	70	F
IGH 11	12/2	2013	IGH	NR	66	F
IGH 12	12/2	2013	IGH	NR	63	F
IGH 13	12/9	2013	IGH	NR	69	F
IGH 14	12/9	2013	IGH	NR	65	M
IGH 15	12/9	2013	IGH	NR	69	M
IGH 16	12/9	2013	IGH	NR	72	M
IGH 17	11/17	2014	IGH	NR	72	F
IGH 18	11/21	2014	IGH	NR	69	M
IGH 19	11/21	2014	IGH	NR	64	F
IGH 20	11/25	2014	IGH	NR	79	M
IGH 21	11/25	2014	IGH	NR	68	M
IGH 22	11/25	2014	IGH	NR	67	M

Otolith	Date Collected	Year Collected	River	Location	FL (cm)	Sex
IGH 23	11/25	2014	IGH	NR	68	F
IGH 24	11/25	2014	IGH	NR	69	F
IGH 25	12/3	2014	IGH	NR	72	M
IGH 26	12/3	2014	IGH	NR	66	F
IGH 27	12/3	2014	IGH	NR	62	F
IGH 28	12/5	2014	IGH	NR	70	M
IGH 29	12/5	2014	IGH	NR	72	M
IGH 30	12/5	2014	IGH	NR	67	M
IGH 31	12/5	2014	IGH	NR	71	F
IGH 32	12/5	2014	IGH	NR	62	F
IGH 33	12/11	2014	IGH	NR	54	F
IGH 34	12/11	2014	IGH	NR	60	F
IGH 35	12/16	2014	IGH	NR	74	F
IGH 36	11/28	2012	IGH	HR	62	F
IGH 37	11/28	2012	IGH	HR	72	M
IGH 38	11/28	2012	IGH	HR	73	M
IGH 39	11/28	2012	IGH	HR	66	M

APPENDIX E

Appendix E. Number of adult Coho Salmon sagittal otoliths prepared and sanded, mounted for analysis, and analyzed via Laser Ablation Multi-Collector Inductively Coupled Plasma Mass Spectrometry at University of California Davis. River of collection is indicated. Iron Gate Hatchery (IGH) collected otoliths are marked as either Natural Origin Return (NR), indicating a non-hatchery raised individual or Hatchery Origin Return (HR), indicating a hatchery raised individual returning to its hatchery of origin.

River	**Otoliths Prepared**	**Otoliths Mounted**	**Otoliths Analyzed**
Scott River	134	107	59
Shasta River	5	5	5
IGH NR	35	35	30
IGH HR	4	4	4
Scott River Tributaries			
Shackleford Creek	6	6	6
Mill Creek	3	3	3
Sugar Creek	1	1	1
French Creek	6	6	6
Subtotal	16	16	16
Klamath River Tributaries			
Bogus Creek	31	27	0
Irving Creek	1	1	1
Horse Creek	2	2	2
Seiad Creek	7	7	7
Subtotal	41	37	10
TOTAL	235	204	124