SURVIVAL AND MOVEMENT OF JUVENILE COHO SALMON (*Oncorhynchus kisutch*) IN THE SHASTA RIVER, CALIFORNIA

by

Christopher C. Adams

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Committee Membership

Dr. Margaret A. Wilzbach, Chair

Dr. Bret C. Harvey

Dr. Darren M. Ward

Dr. Allison O'Dowd, Graduate Program Coordinator

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ABSTRACT

Survival and Movement of Juvenile Coho Salmon (*Oncorhynchus kisutch*) in the Shasta River, California

Christopher C. Adams

Movement and survival of PIT tagged juvenile coho salmon (*Oncorhynchus kisutch*) were assessed using a network of detection stations located throughout the Shasta River, a tributary of the Klamath River in interior northern California. This highly productive river system promotes rapid growth rates of salmonids. Coho salmon are large enough to PIT tag during their first spring, allowing detailed information on movements and survival to be collected, from approximately three months after emergence to age-1 smolt outmigration. The general movement patterns observed were outmigration of age-0 coho salmon from the Shasta River at both fry and smolt life stages, extensive upstream movements to summer rearing locations, fall redistribution among segments of the watershed, and smolt outmigration at age-1 during the second spring. I developed a multi-state mark-recapture model to estimate apparent survival, movement, and detection probabilities among four segments of the Shasta River during the first spring, summer, winter, and age-1 smolt outmigration periods. Apparent survival estimates in different segments of the Shasta River ranged from 0.42 to 0.74 over the summer and from 0.52 to 1.00 over the winter. The estimated apparent survival probability for age-1 smolts migrating from the upper Shasta River to the Klamath River was 0.77. Findings in this

study may be used to guide restoration efforts for coho salmon in the Shasta River by focusing them on locations that are not meeting fish needs or during seasonal periods of low survival.

ACKNOWLEDGEMENTS

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INTRODUCTION

Restoration efforts for coho salmon (*Oncorynchus kisutch*) throughout most the Pacific Northwest are focused on freshwater habitat. In order to maximize success of these efforts, biologists are often tasked with identifying factors that may be limiting juvenile production from a particular system (Reeves et al. 1989; Beechie et al. 1994, Brakensiek and Hankin 2007). Obtaining accurate estimates of critical population parameters such as survival is essential for testing hypotheses about potential limiting factors. The first step is identifying general occupancy and movement patterns in the particular system being investigated, so that population parameters may be assessed at the appropriate temporal and spatial scale. This is necessary to accurately identify habitat segments that are not meeting fish needs, which may be indicated by low survival or movements away from a habitat segment during a specific time period. Evaluation of the relationship between population parameters and habitat features such as temperature or flow may then suggest how to direct restoration efforts to improve the specific factors impeding juvenile production.

Rapidly advancing technology and data analysis techniques involving passive integrated transponder (PIT) tags have provided biologists with a powerful tool for addressing the needs outlined above. Marking individual fish with PIT tags and later recapturing or detecting them with in-stream antennas has become a common and useful method for collecting qualitative data on occupancy and movement of coho salmon in natural habitats (e.g., Peterson et al 1994; Quinn and Peterson 1996; Ebersole et al. 2006; Bell and Duffy 2007). Incorporation of PIT tagging and detection data into mark-recapture study design potentially allows accurate estimation of a number of population parameters, including period-specific or reach-specific apparent survival probabilities (e.g., Brakensiek and Hankin 2007). This survival estimate is termed “apparent” because it is the joint probability of the individuals being alive *and* available for detection (i.e. remaining in the study area). Taking into account the relatively consistent timing of life history events of juvenile coho salmon and given the potentially efficient detection capabilities of instream PIT tag antennas, mark-recapture studies may be designed so that apparent survival is likely close to true survival. A host of assumptions associated with mark-recapture models, however, must be considered when designing the model and interpreting results.

The objective of this study was to assess movement and survival of juvenile coho salmon among segments of the Shasta River, a Klamath River tributary in Northern California. This was accomplished using PIT tags, remote detection stations, and a mark-recapture model. Many published studies that have estimated survival of juvenile coho salmon using PIT tags have focused on winter habitat, which is often considered the primary bottleneck to production of juvenile coho salmon in temperate coastal streams (Nickelson et al. 1992a; Quinn and Peterson 1996; Solazzi 2000; Bell et al. 2001). In these studies, age-0 fish were tagged in the fall and sampled downstream when they outmigrated as age-1smolts the following spring. The Shasta River is a highly productive spring-fed system in a high desert landscape, in which high summer temperatures and reduced flows from irrigation practices, coupled with relatively stable winter base flows, may limit production during summer. Effects of elevated summer temperatures on distribution of juvenile coho salmon have been investigated (e.g., Welsh et al. 2001; Madej et al. 2006) though no summer survival estimates have been made, usually because age-0 coho salmon are simply not large enough to PIT tag during spring or early summer. In the Shasta River however, rapid growth rates make PIT tagging possible during the first spring.

In order to document movements of individual juvenile coho salmon tagged in multiple river reaches and tributaries, detection stations were installed at multiple locations throughout the Shasta River watershed. This provided the adequate resolution to document the spatial extent of movements, but resulted in a complex mark-recapture dataset. Because of the relatively large number of detection stations employed and potential to observe complex movement patterns, a specialized mark-recapture analysis was needed. Multi-state mark-recapture models have great flexibility and potential for estimating demographic parameters from PIT tag and detection data on a variety of temporal and spatial scales, and have been used by some researchers to estimate survival and transition parameters for individually tagged juvenile salmonids (e.g., Horton et al. 2011).

In this study, I developed a multi-state mark-recapture model to estimate probabilities of detection, apparent survival, and transition (movement) among five reaches of the Shasta River watershed during four periods: age-0 spring distribution, summer, winter, and age-1 smolt outmigration. Estimating survival and movement parameters at this reach-specific, seasonal scale may allow fisheries managers to identify potential limits to juvenile coho salmon production, particularly when estimates are coupled with temperature, flow, and other habitat parameters. Using this information, the benefits of restoration efforts may be maximized by focusing them on the most critical habitat segments to ensure suitable conditions for particular life histories to be successful. Repeated data collection and analysis in subsequent years could serve as a tool to evaluate effectiveness of restoration activities.

STUDY SITE

The Shasta River is located in Siskiyou County in northern California, and flows roughly 100 kilometers from its headwaters to the Klamath River (Figure 1). The Shasta River is the fourth largest tributary to the lower Klamath River and historically was among the most productive for salmonids (Wales 1951). Its hydrology is diverse. Tributaries fed by precipitation flow from the northern slopes of Mount Shasta, western slopes of the Cascade Range, and eastern slopes of the Eddy Mountains. However, streamflow is primarily dominated by springs that supply the river at various locations throughout the valley floor. These springs are charged by glacial melt from Mount Shasta which becomes nutrient rich as it flows through porous volcanic and sedimentary rock. Water from the springs enters the river at a constant temperature of approximately 13ºC. These thermal and nutrient rich conditions promote high productivity in the Shasta River (Jeffres et al. 2010).

Gradient is relatively low throughout the Shasta Valley, but increases through the lowest ten kilometers, where the river flows through a canyon before converging with the Klamath River 350 river kilometers (RKM) from the Pacific Ocean. Dwinell Dam was constructed in 1928 at Shasta RKM 65 (65 kilometers upstream from the Klamath River), impounding Lake Shastina and blocking migration of anadromous fish. Numerous diversions exist throughout the Shasta River and its tributaries; diversion rates peakduring the summer irrigation season. The climate is semi-arid with annual

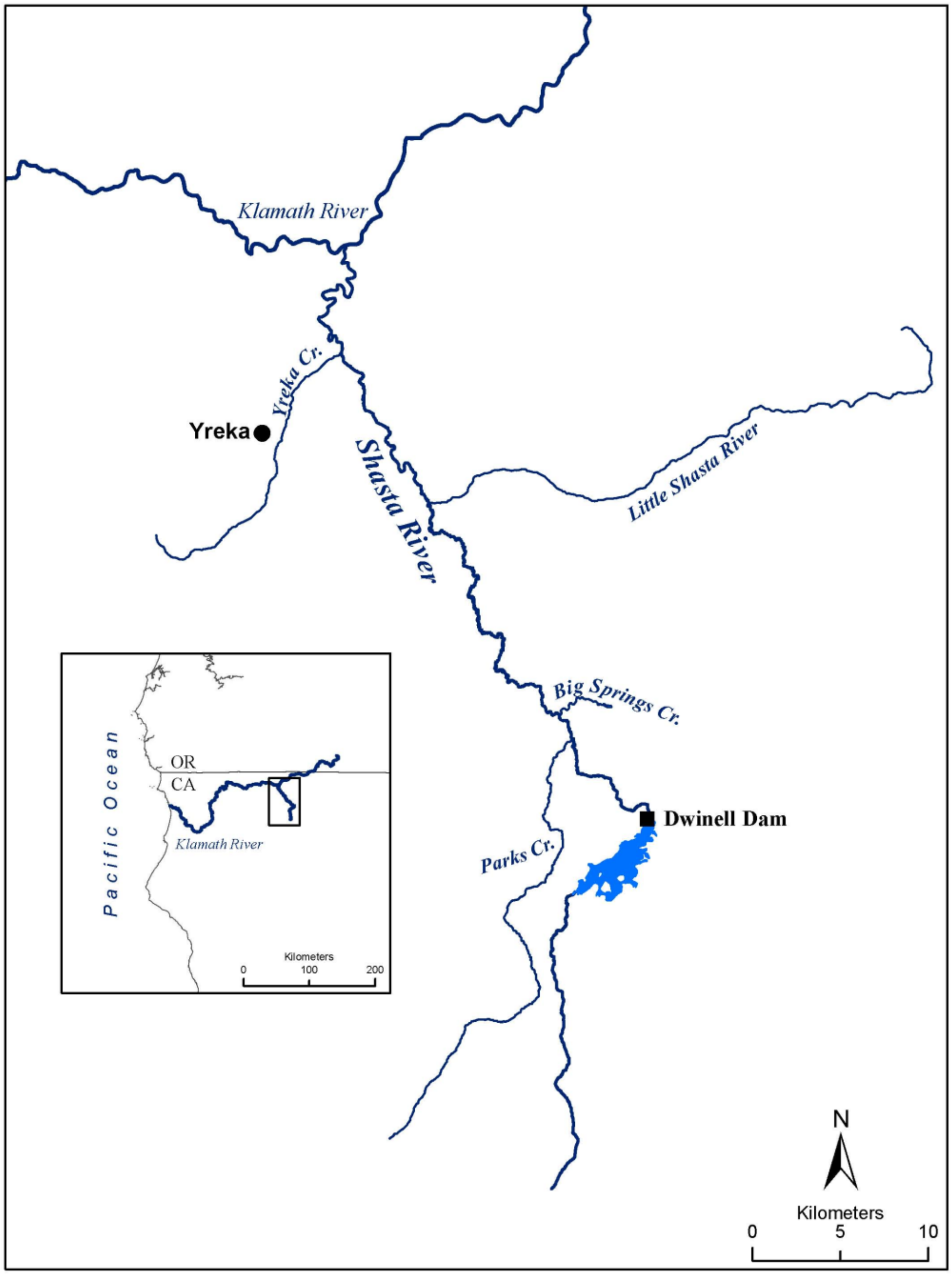


Figure 1. Map of the Shasta River in relation to the Klamath River.

precipitation ranging from about 25-45 cm, the majority of which falls as snow at the higher elevations in winter. The fish assemblage includes coho salmon (*Oncorhynchus kisutch)*, Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*Oncorhynchus mykiss*), Klamath smallscale sucker (*Catostomus rimiculus*), marbled sculpin (*Cottus klamathensis*), speckled dace (*Rhinichthys osculus*), tui chub (*Gila bicolor*), and Pacific lamprey (*Lampetra tridentata*).

METHODS

Sampling to estimate coho salmon survival focused on two general areas of the Shasta River. The first was the “upper basin”, which included the reach of the mainstem from RKM 46 to 60, Big Springs Creek, and the lowest nine kilometers of Parks Creek including Kettle Spring (Figure 2). The upper basin contains known spawning and rearing locations for coho salmon based on previous study by the California Department of Fish and Wildlife (CDFW) (Chesney and Knechtle 2011). The second sampling area was near the confluence of the Shasta and Klamath Rivers, where coho salmon could be sampled as they migrated out of the Shasta River. Although multiple year classes of coho salmon may be present in the Shasta River at any one time, this study was limited to brood year 2010 individuals (progeny of adults that spawned in the fall of 2010).

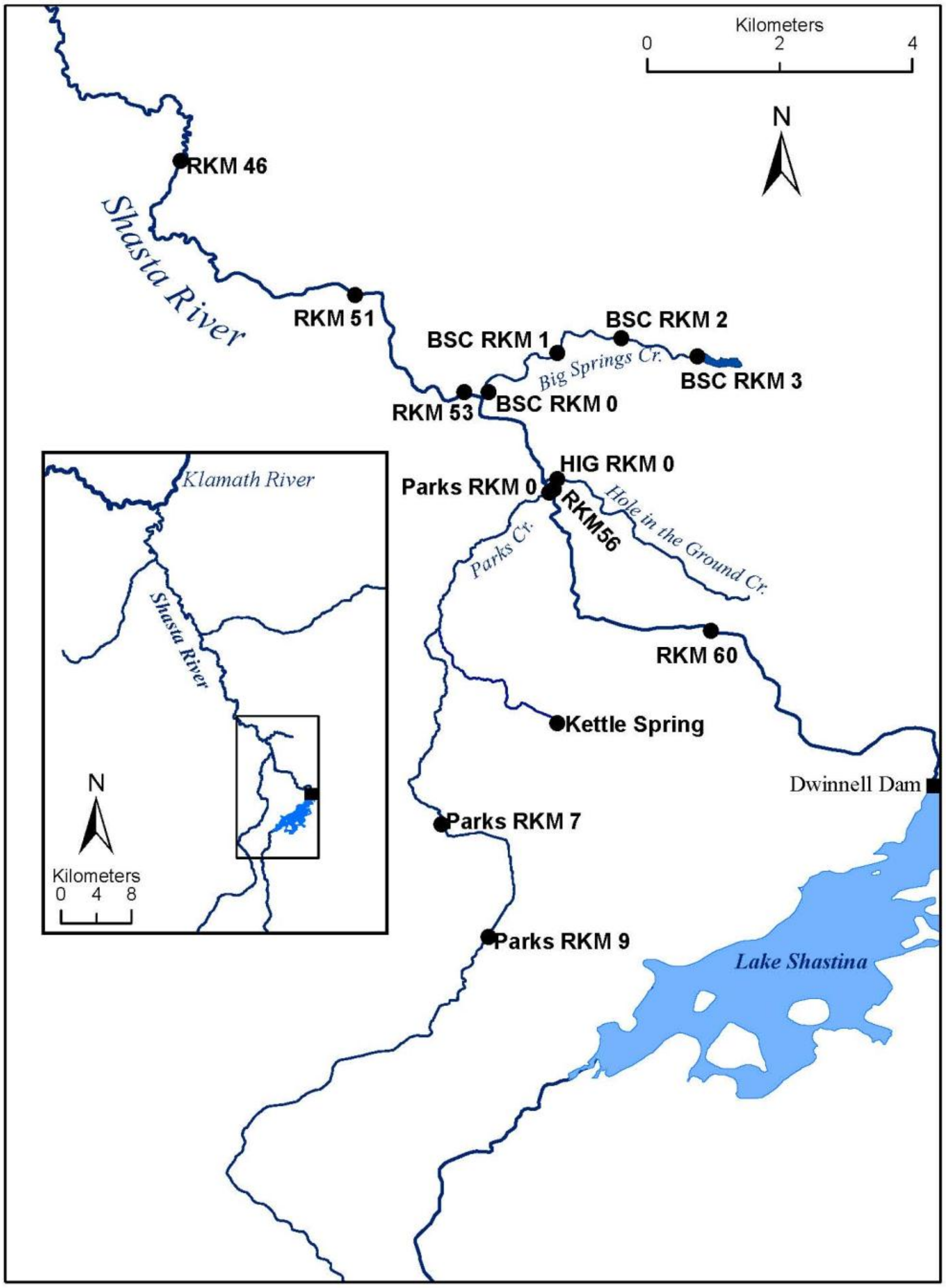


Figure 2. Map of sampling locations and PIT tag detection stations in the upper Shasta River basin, CA.

Capture/PIT Tagging

Fish capture, handling and tagging procedures were approved through Humboldt State University Institutional Animal Care and Use Permit 10/11.F.22-A. In order to estimate summer survival, tagging effort was most intensive early in the study (May/June 2011). Several methods were employed to capture juvenile coho salmon for PIT tag implantation. A rotary screw trap (1.5 m diameter) and fyke nets were used regularly at RKM 51 to capture age-0 coho salmon in the spring and early summer of 2011. Reconnaissance snorkel surveys guided opportunistic capture efforts for juvenile coho salmon which were present in other areas of the upper Shasta River. Seine nets, hand nets, or fyke nets were used to capture these fish, depending on the type of habitat and fish behaviors observed. Capture efforts in the upper basin during the remainder of the study were limited and carried out primarily to recapture previously tagged individuals for growth data, although new individuals that were captured were also tagged. A rotary screw trap (1.5 m diameter) was operated annually by CDFW in the Shasta River about 200 meters upstream from its confluence with the Klamath River (RKM 0). The trap served as a capture location for age-0 coho salmon in 2011, and age-1 coho salmon in 2012. This trap was fished 6 days per week from February through June in both years.

Coho salmon captured in the upper watershed were anaesthetized with two 2.4g Alka-Seltzer tablets dissolved in approximately 2 L of river water, while those captured at the RKM 0 rotary screw trap were anesthetized with tanked CO_2. A Biomark FS-2001 (Boise, Idaho) PIT tag scanner was used to identify previously tagged individuals. Fish were then measured for fork length to the nearest millimeter. Coho salmon of 50-59 mm fork length were implanted with 9 mm 134khtz full duplex PIT tags, and those of 60 mm fork length and larger were implanted with 12.5 mm134khtz full duplex PIT tags. A 14 gauge syringe needle was used to make an incision posterior to the tip of the left pectoral fin and the PIT tag was inserted into the body cavity by hand. All PIT tags and syringe needles were disinfected with bleach and rinsed with distilled water prior to use.

PIT Tag Detection

In-stream PIT tag detection systems were operated at twelve locations in the Shasta River (Figure 2). These were constructed using Allflex® (Boulder, Colorado) Radio Frequency Identification readers and data storage units which were custom made in collaboration with Mauro Engineering (Mt. Shasta, California). In most locations, power was supplied by solar panels coupled with 12 volt batteries. Single loop antennas designed by Mauro Engineering were constructed with copper tubing housed in PVC pipe. Most antennas measured approximately 1 m tall and 3 m long, though other dimensions were used depending on the stream channel at a particular site. Antennas were set upright and perpendicular to the stream flow in a pass-through orientation, and secured to T-posts driven into the river bottom. Detections of individual PIT tags were recorded onto a compact flash card along with the antenna number, date, and time stamp. In two locations where the channel is narrow (RKM 56 and Parks Creek RKM 0), three antennas were placed in succession to determine upstream or downstream movement. At RKM 0, three separate detection stations were installed (RKM 0 A, B, and C, Figure 3).

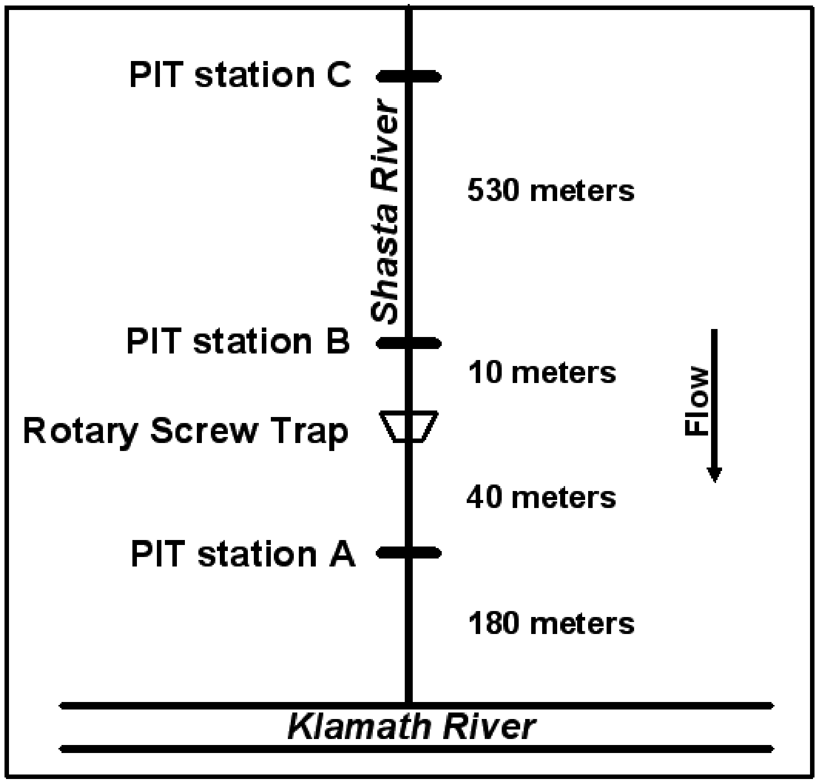


Figure 3. Schematic of PIT tag detection stations near the confluence of the Shasta River with the Klamath River (RKM 0).

With the exception of RKM 0 A and Big Springs Creek RKM 1, all detection stations were in place when the first coho salmon were tagged at the end of April 2011. Big Springs Creek RKM 1 was installed on 15 June 2011, and RKM 0 A was installed on 6 April 2012. Most systems operated throughout the majority of the study. Some instances of damage by wildlife or cattle and power outages caused short periods (days) of non-operation or compromised performance. Flood-transported debris damaged some systems in late winter and early spring 2012, particularly at RKM 0, 46, and 51. Daily performance was assigned to each station on a 0-3 scale based on the approximate percentage of the river transect that was covered by a PIT tag detection field (0=non-operational, 1=0-33%, 2=33-66%, 3=66-100%; Appendix A).

As part of ongoing juvenile coho salmon monitoring efforts throughout the Lower Klamath River, several remote PIT tag detection stations were in operation during this study in the mainstem Klamath River and other tributaries below the Shasta River. These were operated by various entities including the Karuk and Yurok tribes, U.S. Geological Survey, and Humboldt State University. Data from these capture and detection efforts were compiled on a Klamath Basin PIT tag database maintained by U.S. Geological Survey staff at the Klamath Falls field station. Encounters of Shasta River-tagged juvenile coho salmon outside of the Shasta River are included here.

Temperature Monitoring

Temperature loggers (Onset Corporation Hobo Temp Pro®) were deployed at all remote detection stations. These were housed in a section of steel pipe and attached to T-posts with steel cable. Temperature loggers were programmed to record temperature to 0.01 degree Celsius at one hour intervals and were downloaded about once every two weeks. Though temperature data were not analyzed in depth, they are used in discussion of movement patterns and will provide baseline data for future studies in the Shasta River.

Survival and Movement Model

A multi-state mark-recapture model was developed in Program MARK (White and Burnham 1999) to assess seasonal survival and movement of tagged juvenile coho salmon among reaches the Shasta River. Multi-state models are similar to Cormack-Jolly-Seber (Cormack 1964; Jolly 1965; Seber 1965) models, in which animals are individually marked and released, and then subsequently recaptured (or not recaptured) during a number of discrete sampling occasions. In the case of marking individuals with PIT tags, remote detections may constitute these recaptures. A capture history is compiled for each individual, indicating whether it was recaptured or not recaptured (1 or 0 in a Cormack-Jolly-Seber model) on each sampling occasion. All possible capture histories are represented with a probability expression, and maximum likelihood estimates are made for each parameter, based on the relative number of particular capture histories in the dataset. In a Cormack-Jolly-Seber model, two parameters are estimated: detection probability (p) during each sampling occasion and apparent survival probability (S) over each interval between sampling occasions. In a multi-state model, the particular "state" in which the individual is marked or recaptured is specified for each sampling occasion (e.g. A, B, C or 0 rather than 1 or 0). These states may be defined in a number of ways, such as by location or physiological status. Estimates of *p* are made for each sampling occasion (except occasion one), estimates of *S* are made over each interval, and a transition probability (ψ) is also estimated from each state to each other state between sampling occasions.

Four states were defined as segments of the Shasta River watershed (L, U, B, P) and included all detection and tagging locations located within them (Figure 4). A fifth state (M) was adaptively defined for each sampling occasion to represent outmigration from the study area. The lower mainstem state (L) encompassed the Shasta River within the upper basin study area below Big Springs Creek, including detection stations at RKM 46 and 51, and tagging locations at RKM 51 and RKM 53. The upper mainstem state (U) encompassed the Shasta River from Big Springs Creek upstream to Dwinell Dam, including detection stations at RKM 56 and 60, and tagging locations at RKM 55and 60. The Big Springs Creek state (B) included all detection and tagging locations within Big Springs Creek. The Parks Creek state (P) included detection stations at Parks Creek RKM 0 and 7, and Kettle Spring, and tagging locations at Parks RKM 9 and Kettle Spring.

Only individuals tagged in the upper Shasta River basin in May and June of 2011 were included in the multi-state model. Inclusion of the relatively few individuals tagged later in the study did not warrant added model complexity, and the majority of juvenile coho salmon tagged at RKM 0 in 2011 were assumed to have moved into the Klamath

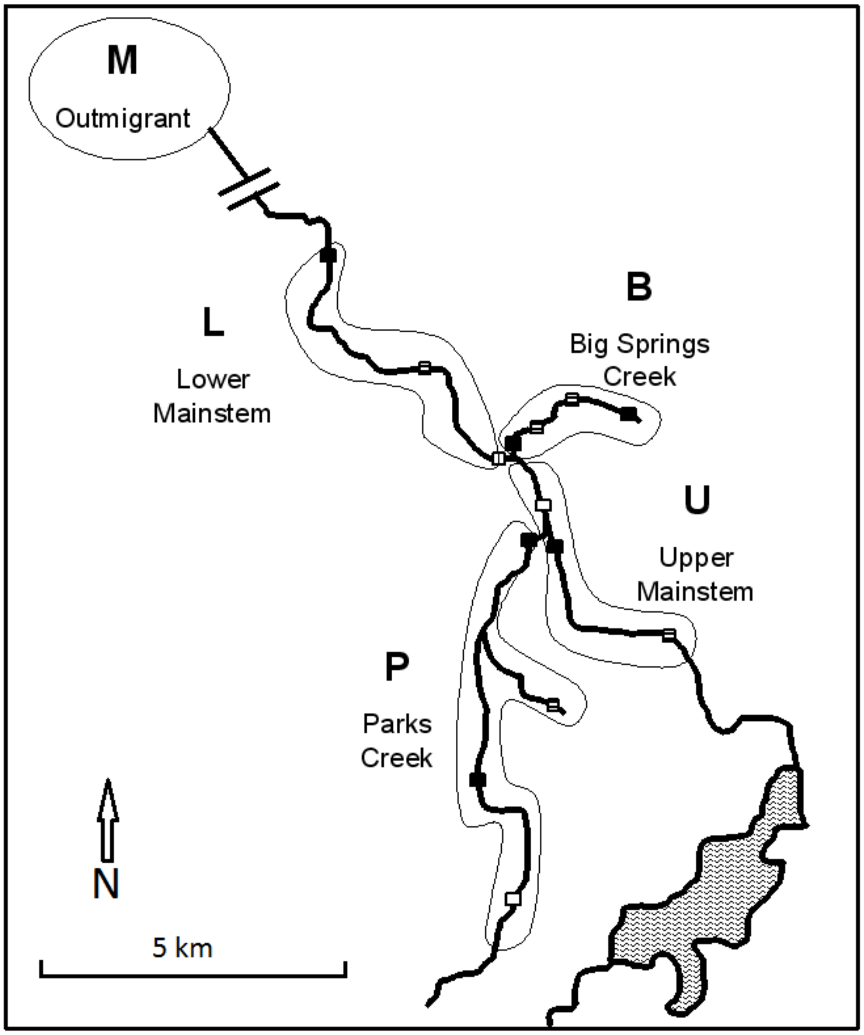


Figure 4. Location of the five states (L:Lower Mainstem, U:Upper Mainstem, B:Big Springs Creek, P:Parks Creek, M: Outmigrant) used in the multi-state mark-recapture study of PIT tagged juvenile coho salmon in the Shasta River, CA. Black squares represent detection locations, white squares represent tagging locations, and hatched squares represent locations where both detection and tagging took place.

River shortly after tagging. The encounter history was structured to estimate apparent survival during age-0 spring distribution, summer, winter, and age-1 smolt outmigration. Probability of transition was estimated from tagging location to summer rearing location and from summer rearing location to winter rearing location. The encounter history included six encounter occasions: a release of individuals tagged in the upper Shasta River in May or June of 2011 (t1); detection from May through September 2011, beginning ten or more days following tagging (t2); detection in a winter rearing location from October 2011 through February 2012 (t3); detection in the upper Shasta River basin during the smolt outmigration period from March through June 2012 (t4); detection at the upstream most antenna station at RKM 0 during the smolt outmigration period (t5); and detection or recapture at the downstream most detection stations and rotary screw trap at RKM 0 during the smolt outmigration period (t6).

For the summer (t2) and winter (t3) occasions, individuals were assigned to a state based on the location of last detection during that time period. Individuals detected at RKM 0 or RKM 46 during t2 and t3 were assigned the M state, as these fish outmigrated from the upper Shasta River at age-0. The fourth encounter occasion (t4) included detection of individuals anywhere in the upper Shasta River basin from March-July 2012. These individuals survived to the smolt outmigration period, and were assigned the M state for t4. All surviving tagged individuals were assumed to have outmigrated from the upper Shasta River during the March-July 2012 time period, as detections ceased after that point. All individuals detected at the upstream-most antenna station at RKM 0 in 2012 were assigned the M state for the fifth occasion (t5), and those detected at either downstream antenna station or rotary screw trap were assigned the M state for the sixth occasion. The following is a sample capture history:

LB0M0M

In this example, the individual was tagged in the L (lower mainstem state) in the spring of 2011, detected in B (Big Springs Creek) in the summer, not detected in the winter, detected leaving the upper basin in the spring of 2012, not detected at the upstream RKM 0 antenna, and then detected at a downstream RKM 0 antenna in 2012.

Using this approach, apparent survival estimates from one sampling period to the next are "instantaneous", and specific temporal changes in survival rates within an interval are not known. Likewise, an important assumption of this model is that survival depends on state at time i, not on the state at time i+1 or even the transition itself. In other words, an individual survives an interval in a particular state, and then instantaneously transitions to another state prior to the next sampling occasion. Obviously mortalities and transitions are not instantaneous, but rather distributed within the intervals, or in this case, sampling occasions. The temporal distribution of transitions is qualitatively known, occurring primarily in the beginning of each sampling occasion, and I believe that these seasonal estimates are valid.

The complexity and number of parameters in a full multi-state model grows quickly with increasing numbers of states and encounter occasions. A fully interactive multi-state model with six sampling occasions and five states includes 150 parameters (S for each state over each interval, p for each sampling occasion after the release, and ψ from each state to each other state over each interval). However, many of the ψ parameters in this model were fixed and not estimated because they were impossible (fixed to 0) or given (fixed to 1) based on the structure of the study design (Figure 5). This approach made for a simpler, less parameterized global model, yet one that reflected the general movement patterns observed. Transition parameters from the M state to any other state were fixed to 0 over all intervals (no individuals moved from the outmigrant state back to an upper basin state). From t3 to t4, ψ from all four upper basin states to the M state were fixed to one, while all other movement parameters were fixed to 0 (any detection indicated that an individual survived to the outmigration period). All ψ's were fixed to 0 from t4 to t5, and from t5 to t6, essentially simplifying the last three encounter occasions to a Cormack-Jolly-Seber model (a multi-state model with one state). The survival parameters in the M state were fixed to 0 for t1 to t2, t2 to t3, and t3 to t4, in order to remove early outmigrants from further inclusion in parameter estimation. The M state survival parameter was estimated from t4 to t5, and represents survival of outmigrating smolts from the upper Shasta River to the Klamath River. From t5 to t6, the survival parameter in the M state was fixed to 1, given the close proximity and rapid downstream movement of smolts. Since the last *S* and *p* are confounded, fixing the *S* to 1 allows estimation of *p* for the last encounter occasion.

To compensate for overdispersion in the data and assess goodness of fit of the global model, a quasilikelihood correction factor (ĉ) value was estimated using the median ĉ estimation method in Program MARK (Cooch and White 2006). Using the global, fully interactive model as a starting point, reduced models were constructed with

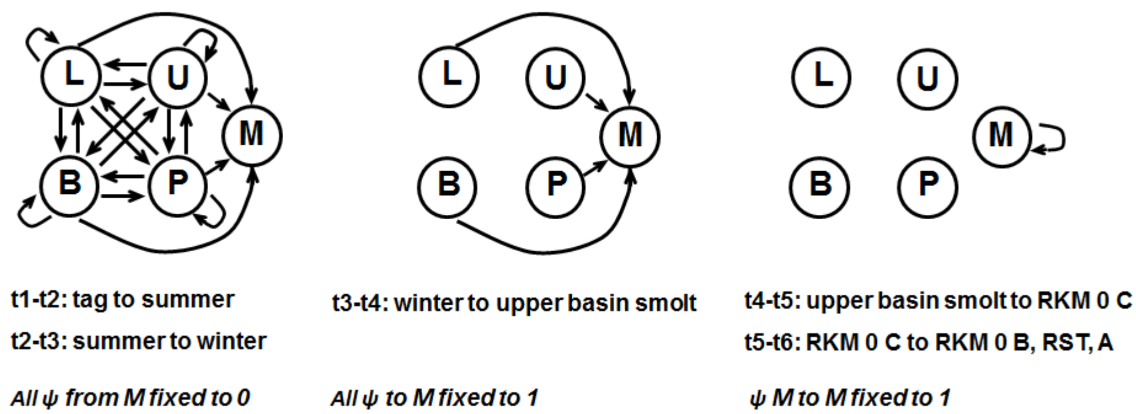


Figure 5. Schematic of transition parameters (ψ, represented as arrows) estimated in a multi-state mark-recapture model for juvenile coho salmon in five states (L:Lower Mainstem, U:Upper Mainstem, B:Big Springs Creek, P:Parks Creek/Kettle Spring, M: Outmigrant) in the Shasta River, California in 2011/2012.

S constrained by groups and/or time intervals (4 models in total). I compared these models using Akiake's Information Criterion (AIC$_c$) adjusted for overdispersion (QAIC$_c$, Burnham and Anderson 2002), using the estimated $\hat{c}$ factor to test for differences in survival among states. Akaike weights (w_i) are reported to provide a measure of each model's relative likelihood of being the best model in the set given the data (Burnham and Anderson 2002). Two different link functions were used for parameter estimation. A multinomial logit link function was used to estimate movement parameters so that all transitions summed to 1. A sin link function was used to estimate survival and detection probability parameters since some of these were boundary estimates (close to 0 or 1).

RESULTS

Capture/PIT Tagging

A total of 432 juvenile coho salmon were tagged in the upper Shasta River in May and June (Figure 6). A wet spring in 2011 caused poor visibility and trapping conditions in the mainstem Shasta River, resulting in limited reconnaissance dives and capture efforts during the emergence and initial fry colonization period. Only small numbers of age-0 coho salmon were encountered before May of 2011, when concentrations were observed at RKM 51, 53, 55, and 60. The first juvenile coho salmon was captured with the regular trapping effort at RKM 51 on 1 March 2011. A total of 178 were captured at the RKM 51 location from March through June 2011, 118 of which were PIT tagged. Opportunistic capture events using hand nets and seines resulted in capture and tagging of 95 total individuals at the RKM 53, 55, and RKM 60 sites in May 2011. Observations of substantial numbers of juvenile coho salmon ceased at these mainstem locations in June of 2011.

In Big Springs Creek, flow and turbidity are minimally affected by precipitation, and so reconnaissance dives were possible there throughout the study. However, few coho salmon were encountered in Big Springs Creek until 5 May 2011, when approximately 50 individuals were observed at BSC RKM 2. Once substantial numbers were observed at BSC RKM 2, seine, hand net, and fyke nets were used to capture and tag 179 individuals in that location in May and June 2011. Juvenile coho salmon were

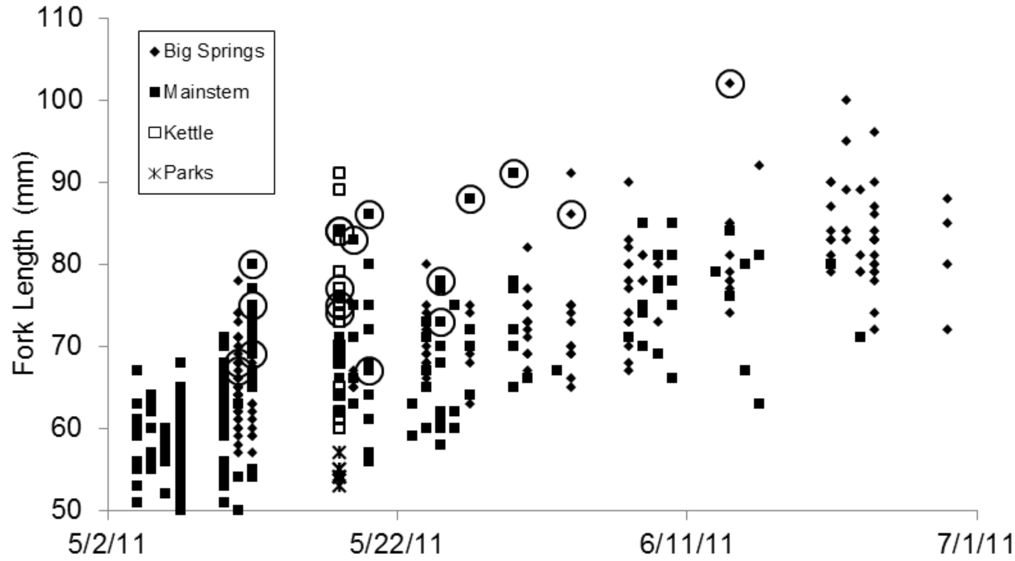


Figure 6. Fork length at date of capture for juvenile coho salmon PIT tagged in the upper Shasta River basin, CA in May and June, 2011. Circles around data points indicate individuals that were detected at RKM 0 in 2011 as age-0 outmigrants.

observed at this location throughout the remainder of the study. Spring and summer survey and capture effort in Parks Creek and Kettle Spring was limited to one occasion on 18 May 2011, when thirty-one juvenile coho salmon were captured with a seine at the outfall of Kettle Spring, and seven were captured with a hand net at Parks Creek RKM 9. PIT tags were implanted in all of these individuals.

Capture efforts in the upper Shasta River basin from July 2011 through the remainder of the study were limited to ten occasions. The primary purpose of these efforts was to capture previously tagged individuals, though new fish were implanted with PIT tags. At RKM 51, one individual was recaptured and three new individuals were tagged after July 2011. Fyke trapping at BSC RKM 1 and 2 resulted in the recapture of 13 and tagging of 41 new individuals.

A total of 330 untagged age-0 coho salmon were captured at the RKM 0 rotary screw trap in 2011 (Figure 7). The majority of these (247) were PIT tagged and released below the rotary screw trap. Three were captured that had been tagged in the upper basin (Table 1), and six that were tagged at RKM 0 were recaptured the next day. A total of 407 wild (unclipped) and untagged age-1 coho salmon were captured at the RKM 0 rotary screw trap in 2012 (Figure 8), while fourteen individuals were captured that had been tagged in 2011 (Table 1).

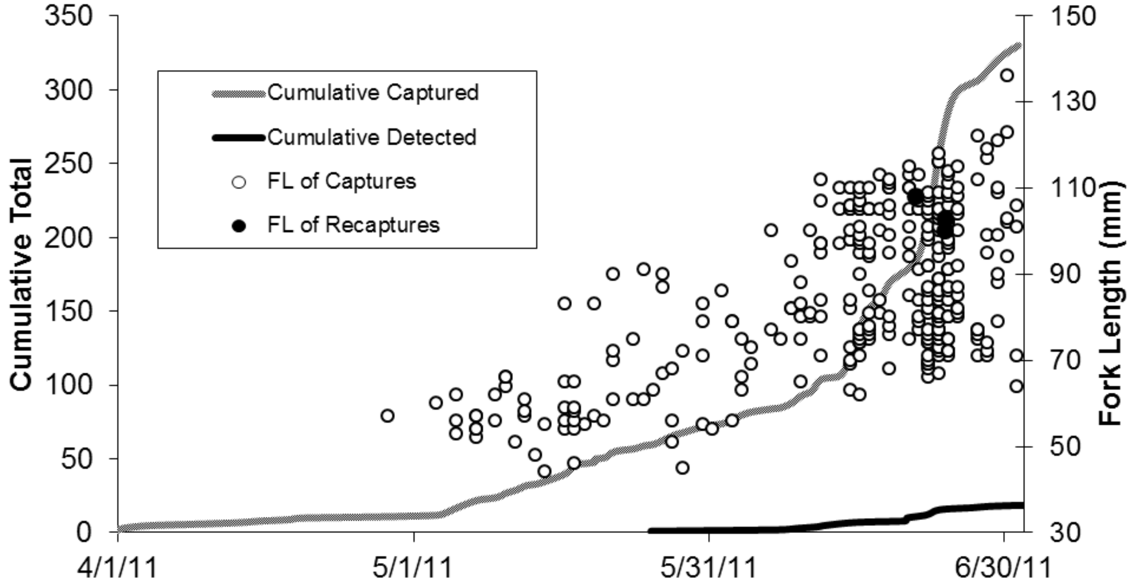


Figure 7. Age-0 juvenile coho salmon encountered at RKM 0 in the Shasta River, CA in 2011. Cumulative number captured in the rotary screw trap (gray line) and cumulative detections of upper basin-tagged individuals (black line) are shown on the left y-axis. Fork length of measured RKM 0 rotary screw trap captures (open circles) and recaptures of upper basin-tagged individuals (filled circles) are shown on the right y-axis.

Table 1. Initial capture location, date, and fork length (FL) of individual tagged coho salmon recaptured at the rotary screw trap at RKM 0 of the Shasta River, CA. Summer (May-September 2011) and winter October 2011-March 2012) rearing location are also included, based on remote detections. BSC=Big Springs Creek, Upper=Shasta above Parks Creek, Parks=Parks Creek, UNK=unknown.

Initial Capture/Tag			Summer Rearing	Winter Rearing	RKM 0 Recapture	
Location	**Date**	**FL**	**Location**	**Location**	**Date**	**FL**
Kettle Spring	5/18/11	75	x	x	6/24/2011	103
RKM 51	5/25/11	78	x	x	6/21/2011	108
BSC RKM 2	6/3/11	86	x	x	6/24/2011	100
BSC RKM 2	6/8/2011	74	BSC	BSC	4/18/2012	135
BSC RKM 2	6/8/2011	78	BSC	BSC	4/21/2012	120
BSC RKM 2	6/3/2011	70	BSC	UNK	4/22/2012	126
BSC RKM 2	5/19/2011	67	BSC	BSC	4/22/2012	130
BSC RKM 2	3/11/2012	107	UNK	UNK	5/3/2012	121
BSC RKM 2	5/12/2011	60	BSC	BSC	5/7/2012	131
Parks RKM 9	5/18/2011	54	UNK	UNK	4/23/2012	136
RKM 0	6/14/2011	98	UNK	UNK	4/25/2012	147
RKM 51	5/24/2011	60	UNK	UNK	4/17/2012	156
RKM 51	5/5/2011	63	BSC	Parks	4/24/2012	148
RKM 51	6/10/2011	81	BSC	BSC	4/26/2012	141
RKM 51	5/25/2011	61	BSC	Upper	4/28/2012	127
RKM 55	5/10/2011	55	Upper	Upper	4/23/2012	138
RKM 55	5/10/2011	67	Upper	Upper	4/26/2012	128

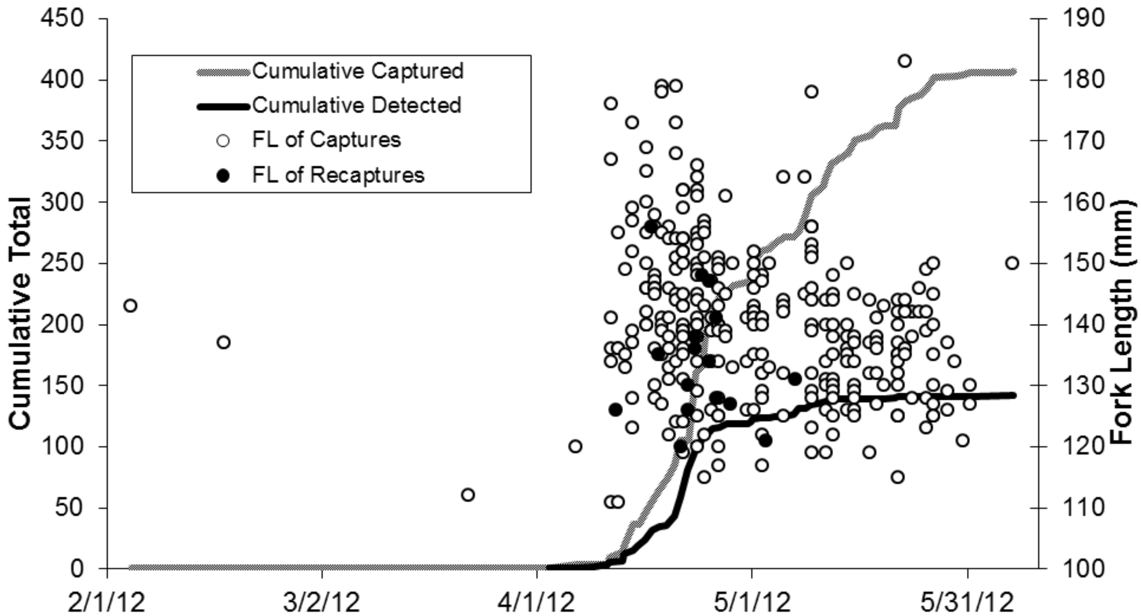


Figure 8. Age-1 juvenile coho salmon encountered at RKM 0 in the Shasta River, CA in 2012. Cumulative number captured in the rotary screw trap (gray line) and cumulative detections of upper basin-tagged individuals (black line) are shown on the left y-axis. Fork length of measured RKM 0 rotary screw trap captures (open circles) and recaptures of upper basin-tagged individuals (filled circles) are shown on the right y-axis.

Growth

Substantial differences in fork lengths of juvenile coho salmon captured in the spring of 2011 were observed. For example, the coho salmon sampled at Parks RKM 7 on 18 May 2011 were relatively small (n=9, mean=55 mm FL, range=53-57 mm FL), compared to those sampled at adjacent Kettle Spring (n=31, mean=73 mm FL, range = 60-91mm FL). Recaptures of individually marked juvenile coho salmon provided detailed information on their growth. At BSC RKM 2 individuals remained throughout much of the study, based on remote detections. Capture effort was consistent in this location, resulting in the most robust data set of recaptured individuals from a known rearing area. These fish illustrated rapid growth rates during the spring and early summer (Figure 9). Mean growth of individuals marked and recaptured during May or June 2011 in Big Springs Creeks was 0.46 mm/day (SD=0.15 min=0.22 max=0.81).

The upper basin tagged individuals detected at RKM 0 in 2011 (age-0 outmigrants) were among the largest tagged (Figure 6). All three juvenile coho salmon tagged in the upper basin that were recaptured at the RKM 0 rotary screw trap in 2011 exceeded 100 mm FL in their first June (Table 1). These along with other large age-0 juvenile coho salmon captured at the RKM 0 rotary screw trap in 2011 were smolt-like in appearance, with a lack of parr marks and a silvery coloration. Based on the movements and physical character of these individuals, it is likely that they were expressing an age-0 smolt life history. Sixteen upper basin tagged juvenile coho salmon were captured at the RKM 0 rotary screw trap in 2012 when they left as age-1 smolts (Table 1). Many of

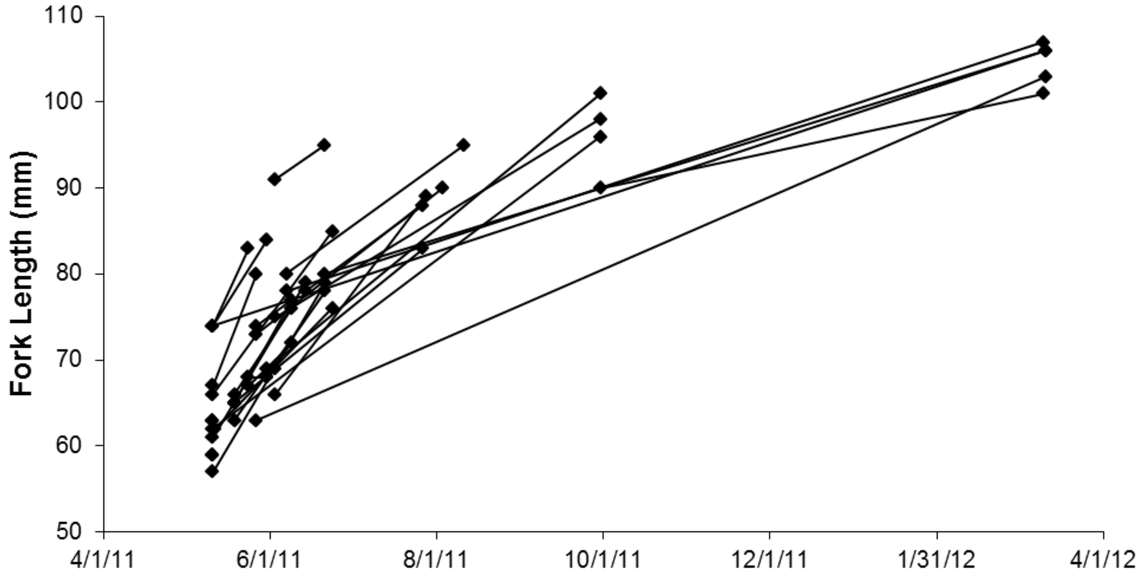


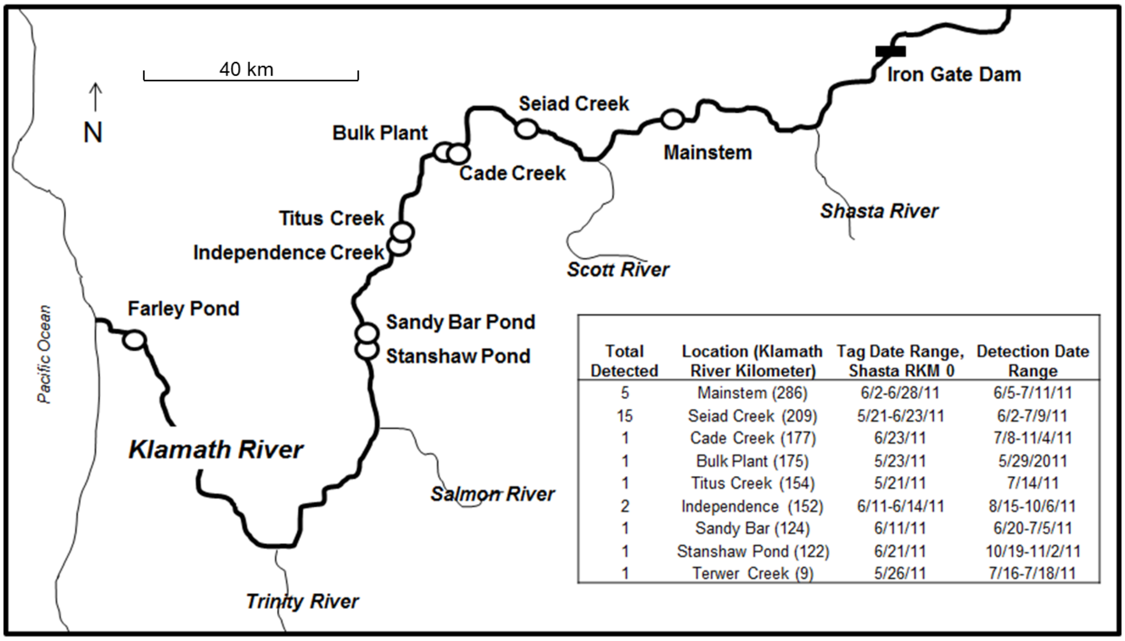
Figure 9. Fork length (FL) of coho salmon tagged and later recaptured in Big Springs Creek, CA. Lines represent linear growth rates (mm/day) of individuals.

these were only 10-20 mm larger than their age-0 outmigrant counterparts, despite having reared in the Shasta River for nearly a year longer. Some of the largest of these smolts reared in unknown locations.

PIT Tag Detection

Detection rates in the upper basin were high in late spring and early summer of 2011, as many tagged coho salmon dispersed from their location of tagging and passed antenna stations. The majority of the coho salmon tagged in upper mainstem locations (RKM 51, 53, 55) moved in an upstream direction shortly after tagging and were detected as they moved into Big Springs Creek, the Shasta River above Parks Creek, or Parks Creek. In contrast, few of the coho salmon tagged in Big Springs Creek were detected outside that location in the summer of 2011. Nineteen of the 432 coho salmon tagged in the upper basin from May-July 2011 were detected at RKM 0 during that same time period. These age-0 outmigrants from the upper basin included individuals from several different tagging locations (Appendix B).

Of the 247 individuals tagged at RKM 0 in 2011, 20 were detected within 10 days at the upstream-most antenna station at RKM 0 (C), 530 meters above the rotary screw trap tagging location. Four of these individuals were again detected at RKM 0 C in 2012, suggesting that they successfully reared at an unknown location in the lower Shasta River. A total of 26 juvenile coho salmon tagged in the Shasta River in 2011 were subsequently detected at downstream stations in the Klamath River (Figure 10, Appendix C). All of the individuals detected at downstream Klamath River locations were tagged



Total Detected	Location (Klamath River Kilometer)	Tag Date Range, Shasta RKM 0	Detection Date Range
5	Mainstem (286)	6/2-6/28/11	6/5-7/11/11
15	Seiad Creek (209)	5/21-6/23/11	6/2-7/9/11
1	Cade Creek (177)	6/23/11	7/8-11/4/11
1	Bulk Plant (175)	5/23/11	5/29/2011
1	Titus Creek (154)	5/21/11	7/14/11
2	Independence (152)	6/11-6/14/11	8/15-10/6/11
1	Sandy Bar (124)	6/11/11	6/20-7/5/11
1	Stanshaw Pond (122)	6/21/11	10/19-11/2/11
1	Terwer Creek (9)	5/26/11	7/16-7/18/11

Figure 10. Locations where juvenile coho salmon PIT tagged in the Shasta River were detected outside of the Shasta River, CA, 2011.

at Shasta RKM 0 in the spring of 2011. Twenty-two of the 23 individuals detected in off channel rearing habitats on the lower Klamath River were less than 100 mm at tagging in May or June 2011 (161 tagged <100 mm), whereas individuals greater than 100 mm were not detected at these locations (86 tagged >100 mm).

Detection rates were relatively low from mid-summer into fall, but increased in late fall and early winter. Movements tended to be out of Big Springs Creek and into the mainstem, primarily into the Shasta River above Parks Creek. Several individuals were detected during the fall/winter period that had not been encountered since their initial tagging. Detection rates were again low during the winter months. No individuals were detected at RKM 0 during fall 2011 or winter 2012.

In the spring of 2012, tagged coho salmon were detected at several stations as they outmigrated from the Shasta River as age-1 smolts. A total of 115 of the 432 age-0 coho salmon tagged in the upper basin in May and June of 2011 were detected at RKM 0 in the spring of 2012 as age-1 smolts. Individuals migrating from the mainstem Shasta River and Parks Creek departed primarily during the first two weeks of April; the departure schedule for individuals migrating from Big Springs Creek was more extended and began at the end of February (Figure 11). Mean migration time from last detection at Big Springs Creek, RKM 56 or Parks Creek RKM 0 to RKM 51 was 2 days (n=76 SD=4 min=1 max=36). Mean migration timing from last detection at any of the above sites to RKM 0 was 10 days (n=106 SD=11 min=1 max=46). Individuals that left the upper basin earlier tended to have longer migration times to RKM 0 (Figure 12). The total

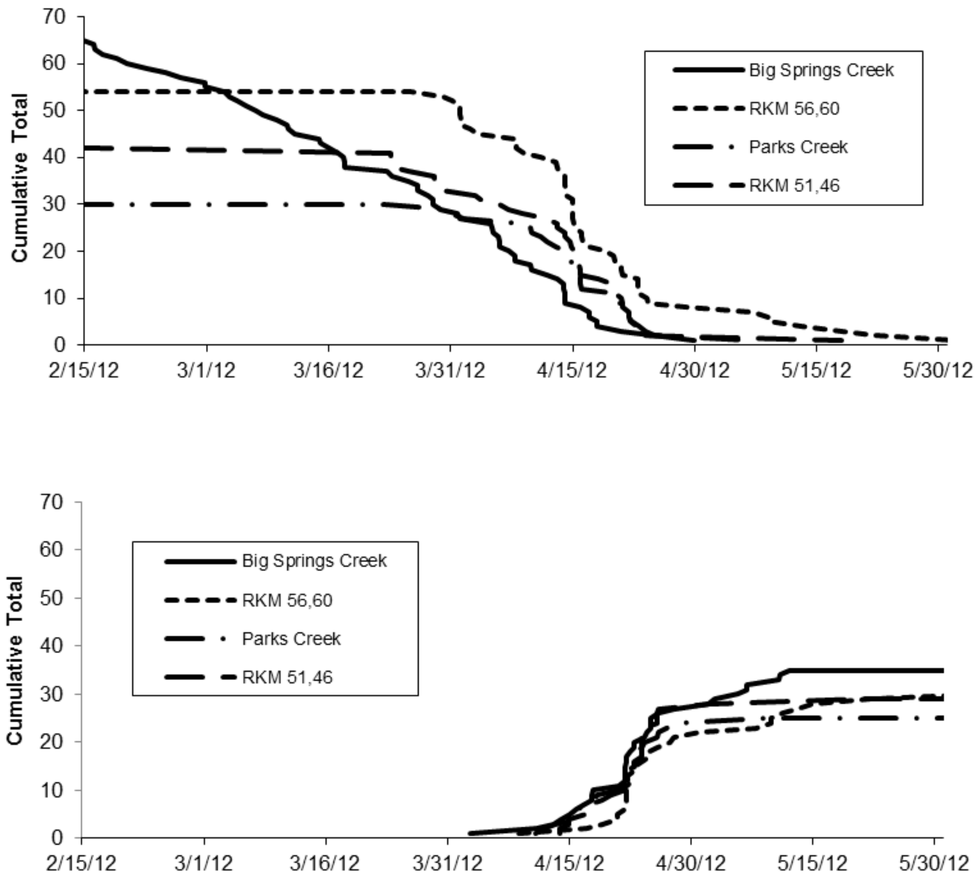


Figure 11. Cumulative number of individuals known to be rearing in areas of the upper Shasta River basin, CA, based on their date of last detection in that area (top). Cumulative total individuals detected at Shasta RKM 0 in spring 2012 from known rearing areas (bottom).

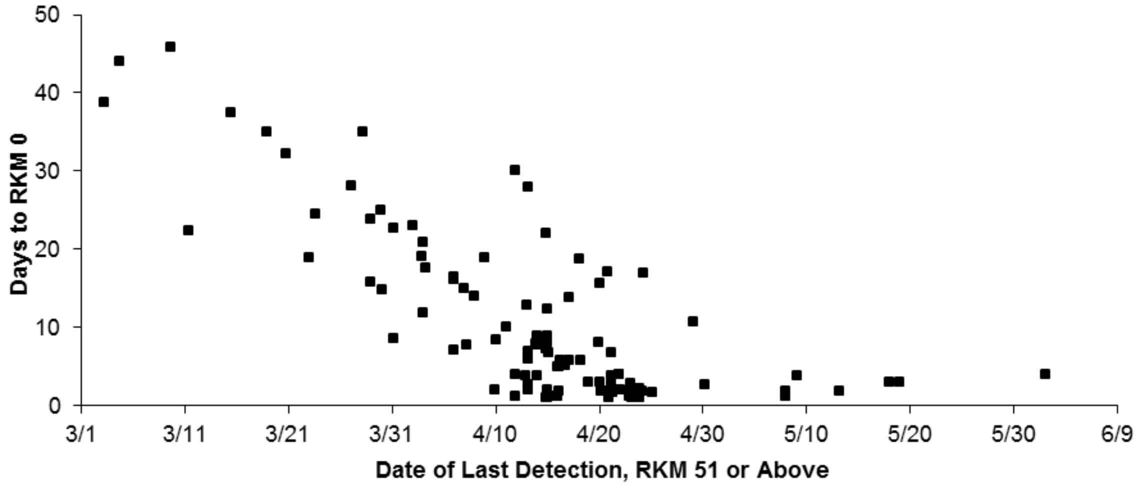


Figure 12. Travel time (in days) of PIT tagged Age-1 coho salmon smolts from the upper Shasta River, CA (RKM 51 or above) to RKM 0, 2012.

number of tagged coho salmon detected by month is shown for each location in Appendix D, and Appendix E summarizes detection locations of individuals from each tag location by season.

Temperature Monitoring

A wide range of temperature regimes were observed in the Shasta River watershed (Appendix F). Maximum daily summer temperatures exceeded 20ºC at most locations, a level thought to be detrimental for coho salmon (Stenhouse et al. 2012). Temperature at Big Springs Creek RKM 2 remained below this level throughout the study, and was the single location where juvenile coho salmon were known to have reared throughout the study in the immediate proximity of a temperature logger/PIT tag antenna station.

Survival and Movement Model

The 432 coho salmon tagged in the upper basin in May and June were used for the multi-state model. These included 171 tagged in the lower mainstem state, 42 in the upper mainstem state, 181 in the Big Springs Creek state, and 38 in the Parks Creek state (Table 2). Relative to other models considered, the fully interactive model was best supported by the data set, having nearly 100 percent of the AIC weight (Table 3). The other models had very little if any support, and so model averaging was not considered. The $\hat{c}$ estimated for the fully interactive model was 1.28, indicating reasonable fit of the model to the data and that overdispersion was not substantial. This value was used to

Table 2. Total number of individual juvenile coho salmon tagged and detected in each state (location) at each encounter occasion for multi-state model estimation of survival and movement of juvenile coho salmon in five states (L:Lower Mainstem, U:Upper Mainstem, B:Big Springs Creek, P:Parks Creek, M: Outmigrant) in the Shasta River, CA

State	Release	Summer Rearing	Winter Rearing	Spring 2012 Upper Basin	Spring 2012 RKM 0 C	Spring 2012 RKM 0 B, RST, A
L	171	21	14	x	x	x
U	42	45	33	x	x	x
B	181	191	110	x	x	x
P	38	31	9	x	x	x
M	x	19	0	155	74	94
Total	432	307	166	155	74	94

Table 3. $QAIC_c$ ranking results for multi-state models of juvenile coho salmon survival and movement in the Shasta River, CA ($\hat{c}$= 1.28). *S*=apparent survival probability, p=detection probability, Ψ=movment probability, t=time, g=state.

Model	QAICc	Delta QAICc	AICc Weights	Num. Par	QDeviance
{*S*(t*g)*p*(t*g)Ψ(t*g)}	2307.22	0.00	1.00	58.00	227.21
{*S*(t)*p*(t*g)Ψ(t*g)}	2323.10	15.88	0.00	49.00	262.93
{*S*(.)*p*(t*g)Ψ(t*g)}	2366.17	58.95	0.00	46.00	312.55
{*S*(g)*p*(t*g)Ψ(t*g)}	2368.61	61.39	0.00	51.00	304.06

adjust the fully interactive model for parameter estimate confidence intervals (Appendix G). Some estimates were extremely close to or at 1.00 or 0.00 (boundary estimates, e.g. all fish in a particular state survived a particular interval). Confidence intervals cannot be calculated for these parameter estimates.

During the tagging to summer rearing interval, apparent survival probability estimates were relatively high; L=1.00, B=0.96, U=0.87, P=1.00 (Figure 13). Movement probability estimates indicate that age-0 coho salmon tagged at RKM 51 and 53 (L state) have the highest probability of moving to another area for summer rearing, with an estimated probability of 0.34 moving into Big Springs Creek, and 0.15 moving into the Shasta River above Big Springs Creek (Figure 14). All other movement probability estimates among upper basin states were 0.1 or less from the tagging to summer rearing periods. Movement probability estimates from upper basin states to the outmigrant state (M) ranged from 0.02-0.06, indicating that some individuals from each upper basin state left the Shasta River at age-0. Detection probability estimates for the U, B, and P states were relatively high (0.75-0.94) for the summer period, compared to the L state (0.27, Figure 15). Since many individuals dispersed in an upstream direction from their tagging location, they were likely to pass by detection stations in the U, B, and P states, while detection stations in the L state were downstream of tagging locations. In addition, most individuals that were detected in the L state were later detected at RKM 0, and were assigned the M (outmigrant) state for the summer period.

Summer survival estimates were similar in the L and P states (L=0.43, P=0.42) and for the B and U states (B=0.70, U=0.74). This indicates that survival was favorable in the locations where the majority of mainstem tagged fish moved to in early summer, relative to the lower mainstem or Parks Creek states (Figure 13). Movement probability estimates from the L and B states from summer to winter rearing location were substantial (Figure 14). Estimates from the L state ranged from 0.14 to 0.27; however confidence interval were large due to the relatively small number of fish remaining in that state in summer. Movement probability estimates from the B state were highest to the L state (0.14) and to the U state (0.19). Movement probability estimates over the summer to winter interval were zero from the upper mainstem and Parks Creek states as well as to the M (outmigrant) state. Detection probability estimates were lowest overall during the winter in states where only mobile fish would likely be detected (L=0.44, U=0.37, P=0.40). The winter detection probability estimate for the B state was 1.00 however, where antennas were placed directly in rearing locations.

The winter survival estimate was highest in the U state (1.00, Figure 13). The estimate for the P state was also high (0.95), however the confidence interval was extremely large due to the low sample size in that state. The winter survival estimate was lowest for the B state (0.52) and only slightly higher for the L state (0.56). The detection probability estimate for the upper basin during the spring of 2012 was 0.84 (Figure15), and the survival probability estimate for smolts from the upper basin to the RKM 0 C antenna station was 0.77 (Figure 13). Detection probability estimates for RKM 0 C and RKM 0 B/RST/A were 0.52 and 0.66, respectively (Figure 15).

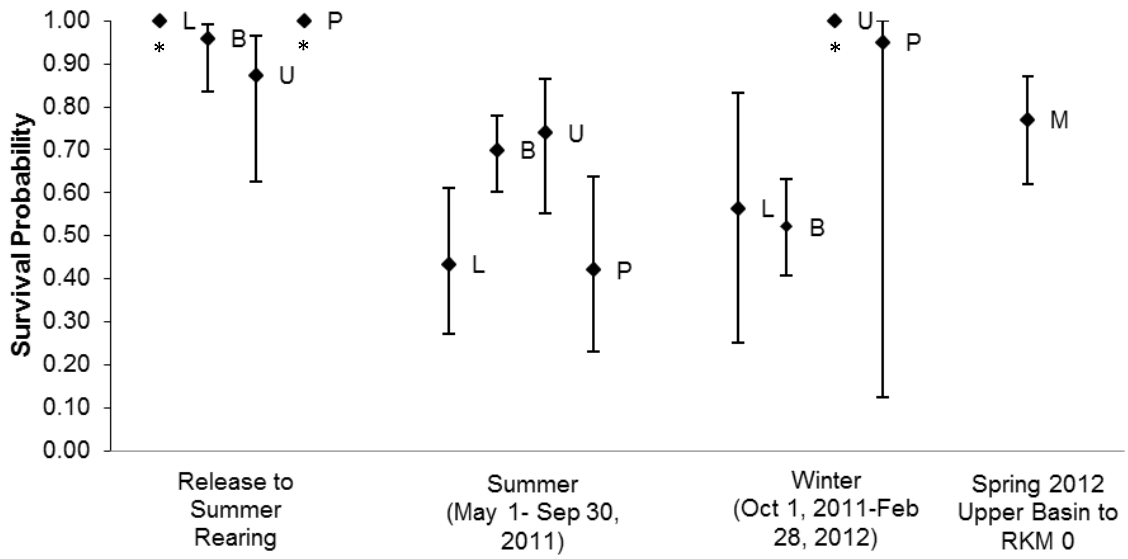


Figure 13. Estimates of apparent survival and confidence intervals in five states (L:Lower Mainstem, U:Upper Mainstem, B:Big Springs Creek, P:Parks Creek, M: Outmigrant) in the Shasta River basin, CA from t1 to t2 (release to summer rearing location), t2 to t3 (summer to winter rearing location), and t3 to t4 (winter to smolt outmigration) (*= confidence interval not estimable).

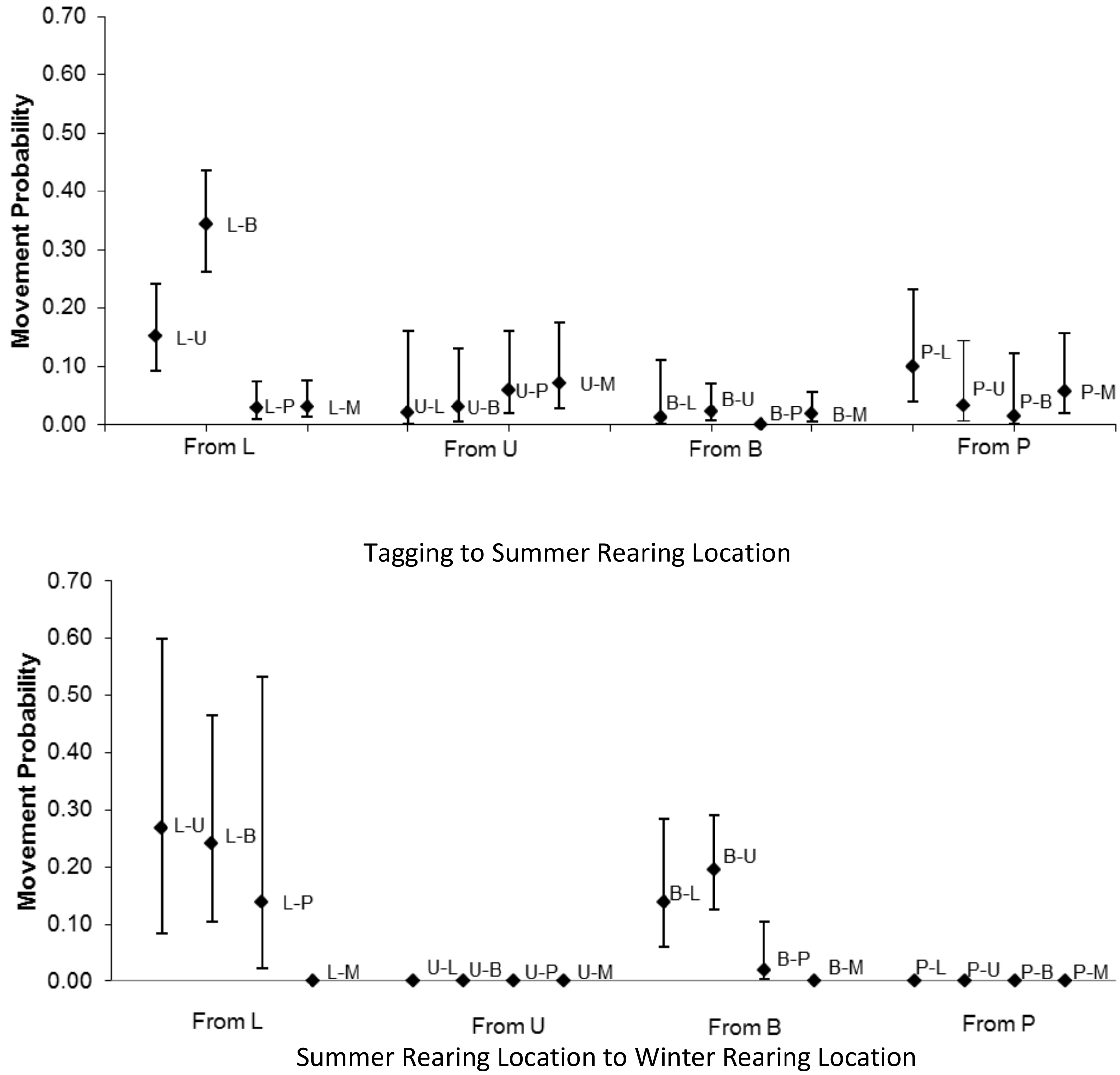


Figure 14. Movement probability estimates and confidence intervals for juvenile coho salmon in five states (L:Lower Mainstem, U:Upper Mainstem, B:Big Springs Creek, P:Parks Creek, M: Outmigrant) in the Shasta River, CA from the t1 to t2 interval (tagging to summer rearing location) (top), and t2 to t3 interval (summer rearing location to winter rearing location) (bottom).

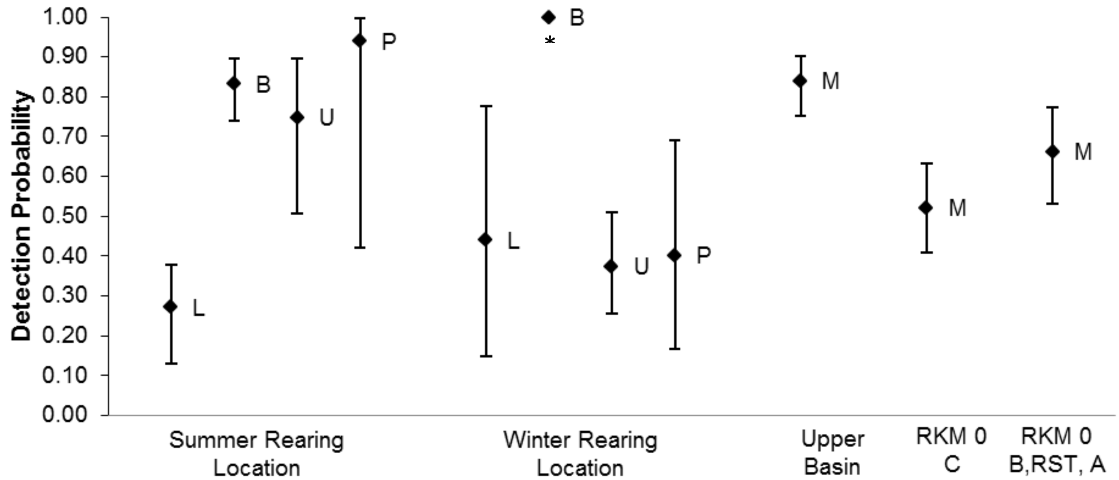


Figure 15. Estimates of detection probability in five states (L:Lower Mainstem, U:Upper Mainstem, B:Big Springs Creek, P:Parks Creek, M: Outmigrant) in the upper Shasta River basin, CA states at t2 (summer rearing location), t3 (winter rearing location), and t4 (upper basin detection, spring 2012) (*= confidence interval not estimable).

DISCUSSION

The movement patterns of juvenile coho salmon in the Shasta River were reflective of both the favorable conditions provided by the thermal and nutrient rich springs as well as unfavorable conditions resulting from water diversions. This was most apparent during the first spring when extensive movements were common and age-0 coho emigrated from the system at a variety of life history stages. Stream temperatures in many locations reached levels which may be detrimental or even lethal to coho salmon as early as May (Stenhouse et al. 2012). In order for coho salmon that initially rear in those areas to survive, they may be forced to move upstream or outmigrate from the Shasta River. Studies by Welsh et al. (2001) and Madej et al. (2006) have documented greater use of colder locations within coastal California watersheds. While elevated stream temperatures may be a primary cause for the movements observed in the Shasta River, other environmental factors that may be involved should be further investigated.

The majority of the age-0 coho salmon captured at the RKM 0 rotary screw trap probably emerged from redds in the lower canyon reach, and left the Shasta River as fry or parr. Detections of some of these individuals in summer rearing habitats lower in the Klamath River suggests that at least a portion of these age-0 fry or parr outmigrants are finding summer rearing areas outside of the Shasta River. The larger age-0 outmigrants from the upper basin were not detected in summer rearing habitats lower in the Klamath River, suggesting that they may be moving directly to the estuary. The occurrence of age-0 coho salmon smolts seems to be somewhat unique to the Shasta River, as little information exists in the literature regarding this life history in the wild. Age-0 coho smolts have been documented in the hatchery setting (Brannon et al. 1982). These fish were incubated and reared at elevated water temperatures and feeding was increased. Brannon et al. (1982) found that if age-0 coho reached 90 mm at the time of release at the end of May, they were likely to smolt. They also found that most of these fish spent 18 months at sea, returning a year earlier than their age-1 counterparts.

In years with poor summer rearing or outmigration conditions for age-1 coho salmon smolts, it may be advantageous for individuals to smolt in their first spring. Future monitoring of returning tagged adults should allow evaluation of the fitness consequences of smolting at age-0 or rearing at locations lower in the Klamath River. Temperature conditions in the lower Shasta River remained favorable throughout most of June 2011, when the majority of age-0 coho salmon smolts outmigrated. In some years, mean daily stream temperatures in the lower Shasta River exceed 20ºC by May or early June (CDFW, unpublished data). It is unknown if age-0 smolts experience mortality during outmigration in years of higher temperatures, or if they are able to continue rearing in the upper watershed until the following year. Further monitoring should provide information on the fate of age-0 coho salmon smolts in years when conditions become poor early.

While the occurrence of age-0 smolts form the upper basin is interesting and potentially important, the majority (approximately 90%) of individuals tagged in the upper basin remained to become age-1 smolts. These fish were subject to the conditions present in the watershed throughout an entire year. Upstream movements occurred early in the year, as many individuals were first encountered upstream of spawning locations. Movement probabilities estimated with the multi-state model suggest that individuals in the lower mainstem state were the most likely to move to another location, with movements into Big Springs Creek and the upper mainstem reach being the most common. Low movement probabilities from other locations during the tagging to summer rearing period were likely a result of those fish already having moved upstream from initial rearing locations before they were captured and tagged. Early movements may be a result of elevated stream temperatures in the mainstem Shasta River causing displacement from some rearing habitats. Substantial mortality may have occurred during this early displacement that was not observable given the methodology used. Apparent survival estimates from the tagging to summer rearing period were high in all locations. However these estimates may not be reflective of survival of an early displacement event, again because many fish were not tagged until they reached their summer rearing location. The timing and severity of the initial increase in stream temperatures above a tolerable level for juvenile coho salmon likely varies from year to year. The consequence of this displacement may therefore be more detrimental in some years than others, as earlier and more extreme high temperatures may force juvenile coho salmon to move before they are physically able to reach favorable conditions.

During summer, long distance movements were limited. Individuals tended to remain in a summer rearing habitat once they arrived there. Overall, estimates of apparent summer survival were the lowest relative to the other periods evaluated.

Probability estimates of apparent summer survival were likely close to true survival, since movements were limited and detection probability was high during subsequent sampling occasions. The specific causes of mortality during this time are not known and further investigation into potential factors may be useful in improving survival during the summer months. Limited temperature monitoring may not capture the thermal heterogeneity that is known to exist in reaches of the upper Shasta River basin, which results from a number of factors including emerging springs, irrigation withdraws, tailwater releases, and ambient temperatures. There may be specific locations where survival is significantly lower than other locations within the reaches used for the multi-state model, perhaps as a result of this thermal heterogeneity. Specific locations where summer rearing took place could be identified in Big Springs Creek where multiple antennas were in place directly in rearing locations. With the exception of Kettle Spring, exact locations of summer rearing areas in the mainstem Shasta River and Parks Creek were not identified, as detections occurred only as individuals transitioned into those areas of the watershed. Based on temperature data at these detection stations, functioning summer habitat in these areas likely exists in patches associated with springs separated by reaches where temperatures become unsuitable.

Substantial fall redistribution within the upper Shasta River was observed. However, fall or winter movements out of the Shasta River were not observed. This suggests that while some areas of the watershed may become unfavorable in winter, other areas within the watershed are meeting the over winter rearing needs of coho salmon. The substantial movements out of Big Springs Creek in winter may be associated with the seasonal change in physical habitat. Currently, a large portion of the macrophyte growth, which provides most of the complex habitat in Big Springs Creek, dies off in winter. This loss of habitat complexity may motivate juvenile coho salmon to seek more suitable habitat elsewhere. The habitat in the Shasta River above Parks Creek, where many individuals moved to rear over the winter, is characterized by woody structure, deep pools, and low velocity.

The high apparent winter survival estimate (1.00) in the upper mainstem Shasta River is likely attributable to the favorable thermal conditions and stable base flows of the Shasta River during that time. In contrast, the probability estimate of apparent winter survival in Big Springs Creek was substantially lower (0.52), perhaps also attributable to the change in physical habitat discussed above, causing increased levels of predation. This estimate may be biased low given the more mobile behavior of fish in Big Springs Creek, coupled with compromised detection efficiency due to high flows in the early spring of 2012. While individuals in the mainstem Shasta River and Parks Creek outmigrated within a narrow time frame, those in Big Springs Creek seemed to “trickle out”, with a steadily decreasing number of detections of individuals throughout the late winter/early spring period. Since some detection stations were not fully operational during that period, some of these individuals may have left the Shasta River during early spring without being detected, causing a greater difference between true and apparent survival.

The estimate of apparent survival for smolts migrating from the upper Shasta River to the Klamath River (0.77) suggests that factors causing mortality during that time should be investigated. The timing of smolt outmigration coincides with the start of irrigation season. Monitoring and water management should be implemented to ensure suitable conditions for outmigrating smolts, particularly during late April and early May when the majority of the fish leave the Shasta River. Similar to 2011, flow and temperature conditions remained favorable throughout the majority of the age-1 smolt outmigration period in 2012. During warmer, drier years, conditions may become unsuitable for coho salmon earlier in the year, perhaps before the smolt outmigration period is complete, and survival rates of age-1 coho smolts may not be as high as they were in this study. Repeating a similar analysis in a variety of water years will be important for identifying variability in survival during smolt outmigration from the upper Shasta River. Departure and travel times varied among individuals emigrating from the upper Shasta River, and it is not known if these factors influenced survival rates.

Encounters of juvenile coho salmon tagged at RKM 0 in 2011 again in the spring of 2012 suggest that summer rearing habitat exists near that location. Considering the 20 detections of individuals tagged at the RKM 0 rotary screw trap at the station 530 meters upstream (RKM 0 C), it is likely that some are finding summer rearing habitat in the lower reaches of the Shasta River, though the extent of their upstream migration is unknown. It is also possible that these individuals reared successfully outside of the Shasta River (Klamath River or other tributaries) and moved back into the Shasta River prior to smolting. Operation of additional antenna stations in the lower reaches of the

Shasta River and in the Klamath River near the Shasta River may provide information on potential rearing locations in that area.

Comparable estimates of summer survival were not found in the literature. Estimates of juvenile coho salmon winter survival in the Shasta River are an interesting contrast to estimates in the literature. Nine studies of coho salmon winter survival were summarized by Brakensiek and Hankin (2007). The average winter survival estimate in these studies was 0.45, with a range of 0.11 to 0.78. The apparent survival estimate of 1.00 for the upper Shasta reach was substantially higher than any of the estimates in the literature, and the lowest winter survival estimate of 0.52 in Big Springs Creek was above average. Most of the published estimates of winter survival are a combination of winter survival and outmigrant smolt survival, since fish were sampled downstream of winter rearing locations. Winter survival and smolt survival was separated in this study, however survival of smolts from the Shasta River to the ocean (350 kilometers) was not evaluated and substantial mortality may have occurred during that time. Based on the findings from this study, the summer period may be most limiting to juvenile coho salmon production in the Shasta River. The effects of density on summer survival rates should be investigated, particularly if coho populations increase in the Shasta River.

The diversity of life histories observed was testament to the adaptability of these organisms. Continuing a monitoring system similar to that used in this study will be valuable in gaining understanding of juvenile coho salmon use of this unique habitat in years with different environmental conditions and water management scenarios.

Comparison of survival estimates during the key life history segments identified in this study will be a useful tool in assessing current restoration activities and guiding those of the future. Additional monitoring of habitat conditions such as temperature, flow, and food availability will provide more insight to the factors affecting survival rates, movement patterns, and growth of juvenile coho salmon in the Shasta River.

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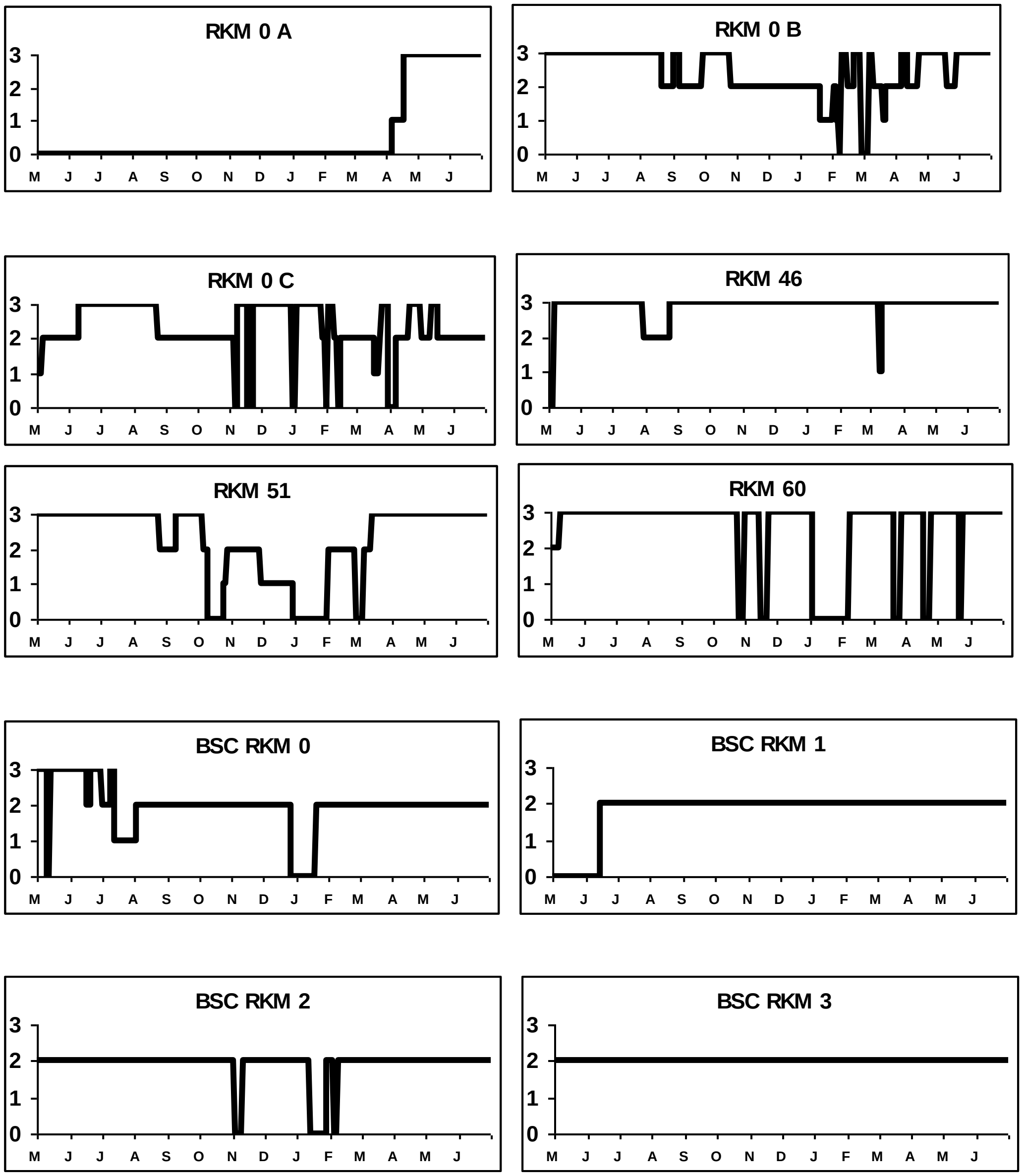
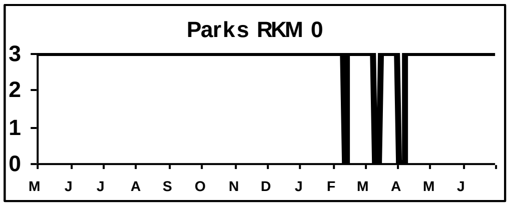
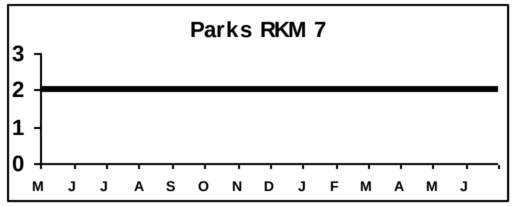
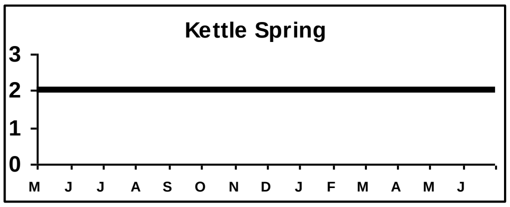


Appendix A. Graphs of daily antenna system performance based of percent of the rivers transect covered by a PIT tag detection field. 0=non-operational, 1=0-33%, 2=33-66%, 3=66-100%.







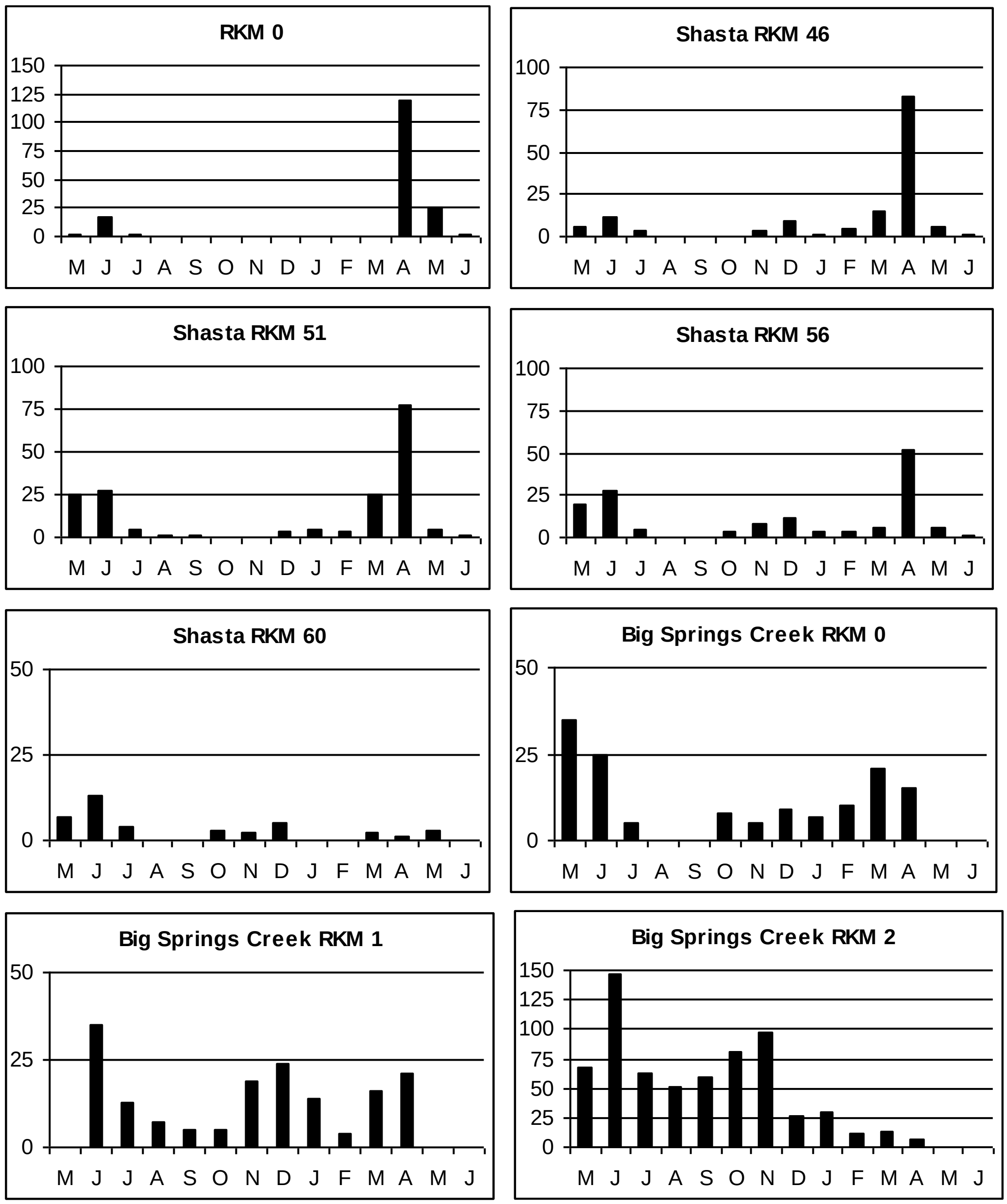
Appendix A. Continued

Appendix B. Tagging data for upper basin tagged coho salmon detected at RKM 0 (age-0 outmigrants) in the Shasta River, CA 2011.

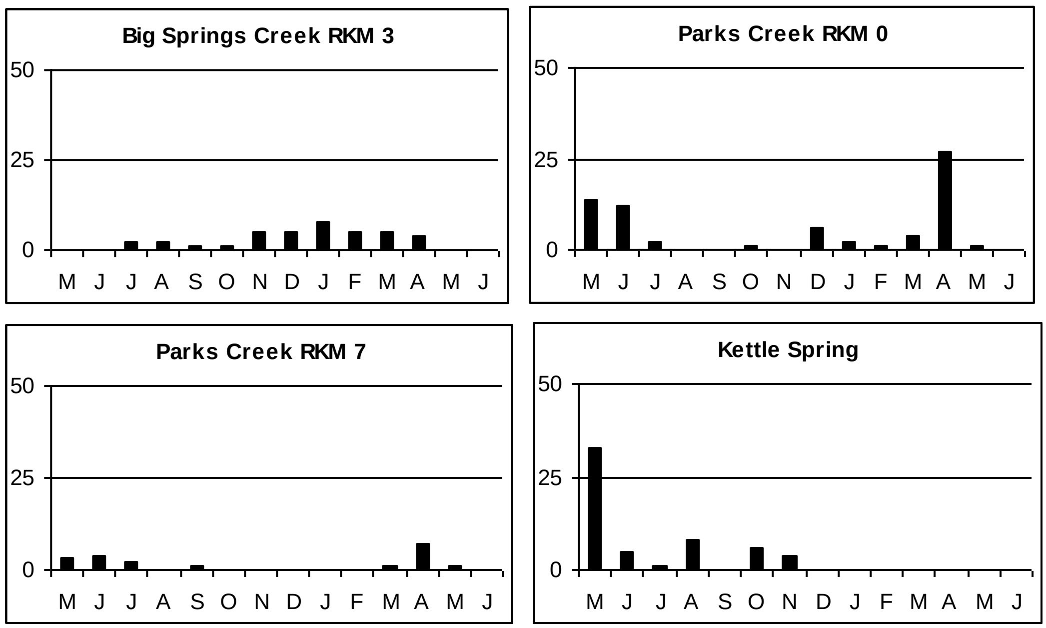
Capture/Tagging Location	Fork Length	Date	RKM 0 Detection Date
RKM 55	80	5/12/2011	6/7/2011
RKM 55	86	5/20/2011	6/8/2011
Kettle Spring	84	5/18/2011	6/10/2011
RKM 51	84	5/18/2011	6/11/2011
Kettle Spring	77	5/18/2011	6/14/2011
RKM 51	83	5/19/2011	6/14/2011
BSC RKM 2	102	6/14/2011	6/19/2011
RKM 55	75	5/12/2011	6/20/2011
RKM 51	78	5/25/2011	6/20/2011
BSC RKM 2	68	5/11/2011	6/22/2011
Kettle Spring	74	5/18/2011	6/22/2011
RKM 51	73	5/25/2011	6/23/2011
Kettle Spring	75	5/18/2011	6/23/2011
RKM 51	88	5/27/2011	6/23/2011
BSC RKM 2	86	6/3/2011	6/24/2011
RKM 60	91	5/30/2011	6/26/2011
BSC RKM 2	67	5/11/2011	6/28/2011
RKM 55	69	5/12/2011	7/4/2011
RKM 51	67	5/20/2011	7/15/2011

Appendix C. Tagging and detection data for brood year 2010 coho salmon tagged in the Shasta River that were detected outside of the Shasta River. One individual was detected at two locations, indicated by asterisk.

Tagging/Release			Detection	
Location	Fork Length	Date	Location	Date(range)
Shasta RKM 0	97	6/16/11	Mainstem	7/11/11
Shasta RKM 0	92	6/22/11	Mainstem	6/25/11
Shasta RKM 0	99	6/28/11	Mainstem	6/29/11
Shasta RKM 0	108	6/22/11	Mainstem	6/23/11
Shasta RKM 0	79	6/2/11	Mainstem	6/5/11
Shasta RKM 0	86	6/23/11	Seiad	7/3/11
Shasta RKM 0	85	6/23/11	Seiad	7/2/11
Shasta RKM 0	75	6/7/11	Seiad	6/17/11
Shasta RKM 0	85	6/20/11	Seiad	6/22/11
Shasta RKM 0*	72*	5/21/2011*	Seiad	6/13/11
Shasta RKM 0	66	6/3/11	Seiad	6/28/11
Shasta RKM 0	91	6/21/11	Seiad	7/2/11
Shasta RKM 0	79	6/21/11	Seiad	7/1/11
Shasta RKM 0	77	6/21/11	Seiad	6/26/11
Shasta RKM 0	77	6/23/11	Seiad	6/26/11
Shasta RKM 0	82	6/14/11	Seiad	6/23,7/9/11
Shasta RKM 0	79	5/30/11	Seiad	6/2/11
Shasta RKM 0	105	6/21/11	Seiad	6/23/11
Shasta RKM 0	69	6/4/11	Seiad	6/14/11
Shasta RKM 0	73	6/14/11	Seiad	6/23/11
Shasta RKM 0	77	6/23/11	Cade	7/8-11/4/11
Shasta RKM 0	61	5/23/11	BulkPlant	5/29/11
Shasta RKM 0*	72*	5/21/2011*	Titus	7/14/11
Shasta RKM 0	84	6/11/11	Independence	9/10/11
Shasta RKM 0	69	6/14/11	Independence	8/15-10/6/11
Shasta RKM 0	80	6/11/11	Sandy Bar	6/20-7/5/11
Shasta RKM 0	80	6/21/11	Stanshaw	10/19-11/2/11
Shasta RKM 0	67	5/26/11	Farley Pond	7/16-7/18/11



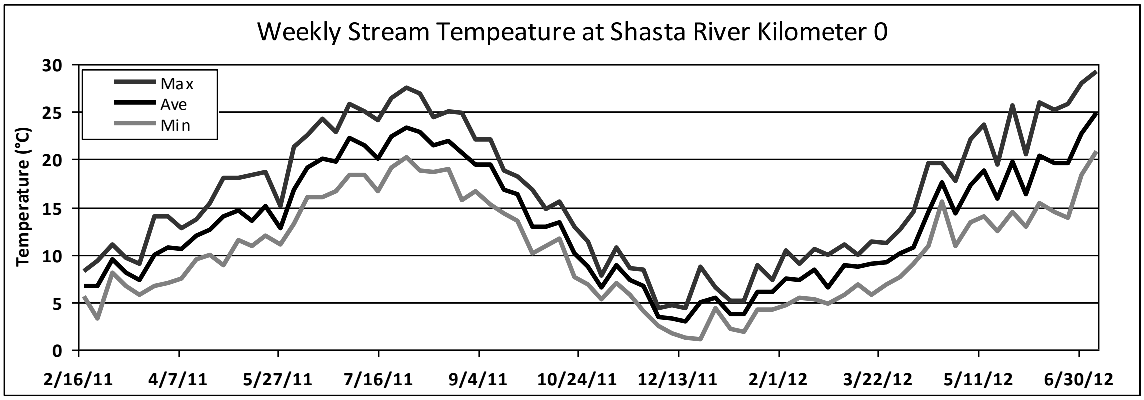
Appendix D. Total PIT tagged coho salmon detected by month at each location in the Shasta River, CA in 2011/2012.

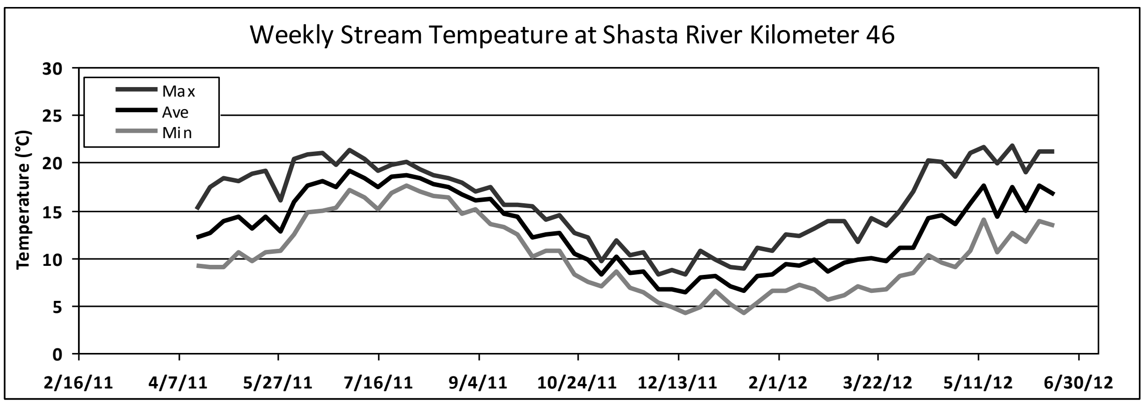


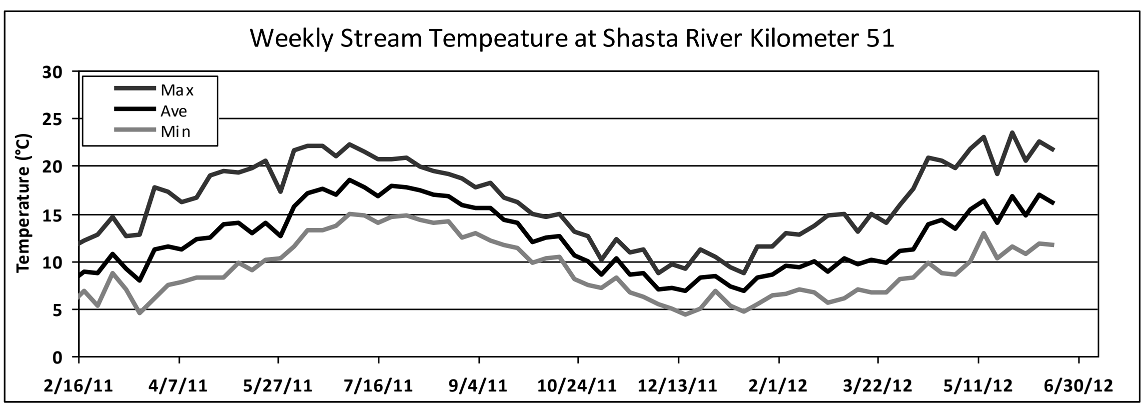
Appendix D. Continued

Appendix E. Summary of detections by season and location for PIT tagged coho salmon in the Shasta River

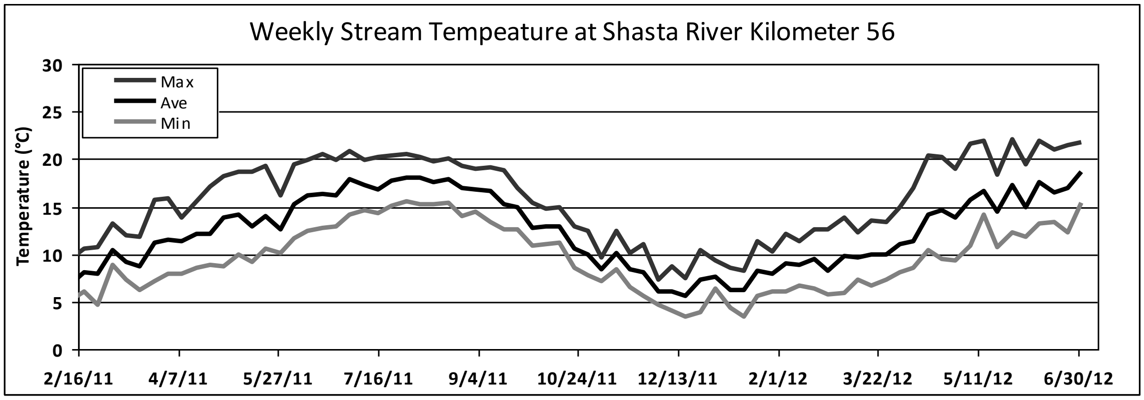
Tagging Data			Season	RKM	Lower			Big Springs Creek					Upper			Parks				Spring
Location	**Total**	**Date Range**	**Detected**	**0**	**Total**	**46**	**51**	**Total**	**0**	**1**	**2**	**3**	**Total**	**56**	**60**	**Total**	**0**	**7**	**Kettle**	**2012**
RKM 51	**118**	**5/4-6/23/11**	Summer	**6**	**30**	4	29	**37**	36	10	23	0	**14**	14	9	**4**	3	1	3	
			Winter	**0**	**4**	3	1	**29**	11	14	16	0	**11**	11	1	**4**	4	0	0	**53**
RKM 53	**53**	**5/6-5/10/11**	Summer	**0**	**0**	0	0	**20**	18	6	9	0	**9**	9	3	**5**	5	0	0	
			Winter	**0**	**2**	2	0	**15**	6	2	10	0	**8**	5	3	**2**	2	0	0	**18**
RKM 55	**13**	**5/10/2011**	Summer	**1**	**0**	0	0	**0**	0	0	0	0	**8**	7	3	**2**	2	0	0	
			Winter	**0**	**0**	0	0	**0**	0	0	0	0	**1**	0	1	**0**	0	0	0	**8**
HIG Creek	**22**	**5/12-5/20/11**	Summer	**4**	**2**	2	1	**2**	2	0	0	0	**11**	10	5	**4**	3	1	1	
			Winter	**0**	**0**	0	0	**0**	0	0	0	0	**3**	1	2	**1**	0	0	1	**8**
RKM 60	**8**	**5/30/2011**	Summer	**1**	**1**	1	1	**0**	0	0	0	0	**1**	1	1	**0**	0	0	0	
			Winter	**0**	**0**	0	0	**0**	0	0	0	0	**1**	0	1	**0**	0	0	0	**3**
BSC RKM 2	**192**	**5/11-7/28/11**	Summer	**4**	**4**	4	3	**144**	4	10	141	1	**3**	3	2	**1**	1	0	0	
			Winter	**0**	**10**	6	5	**106**	15	25	82	4	**10**	10	1	**3**	3	0	0	**72**
Kettle Spring	**31**	**5/18/2011**	Summer	**4**	**8**	7	8	**1**	1	1	0	0	**1**	1	1	**31**	11	5	31	
			Winter	**0**	**0**	0	0	**0**	0	0	0	0	**0**	0	0	**5**	1	0	5	**8**
Parks Creek	**7**	**5/18/2011**	Summer	**3**	**0**	0	0	**0**	0	0	0	0	**1**	1	0	**3**	1	3	0	
			Winter	**0**	**0**	0	0	**0**	0	0	0	0	**0**	0	0	**0**	0	0	0	**2**

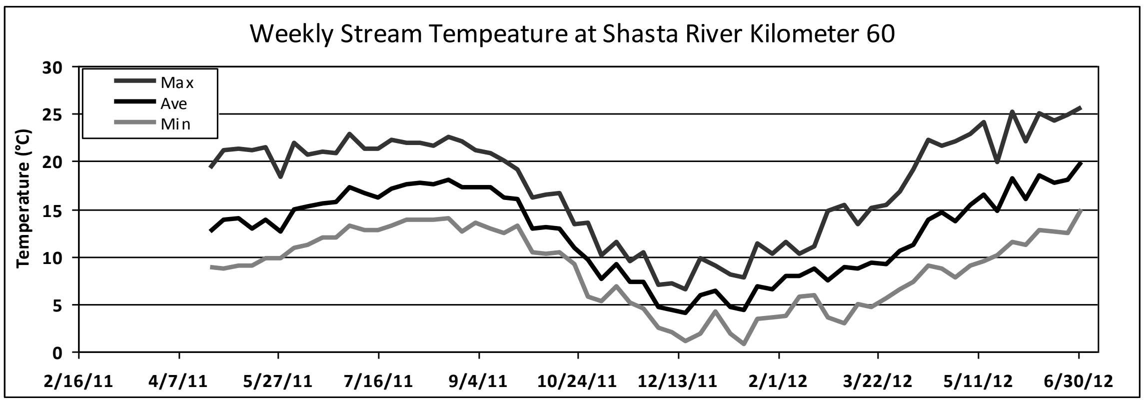


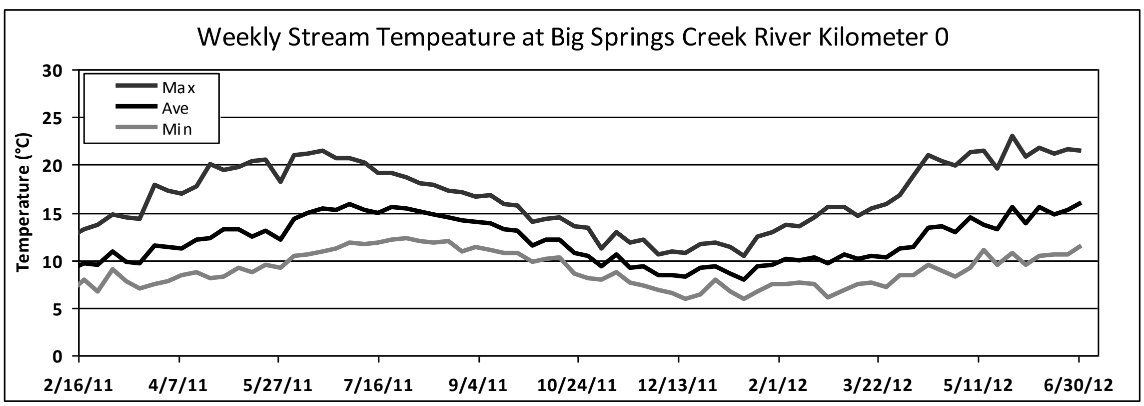




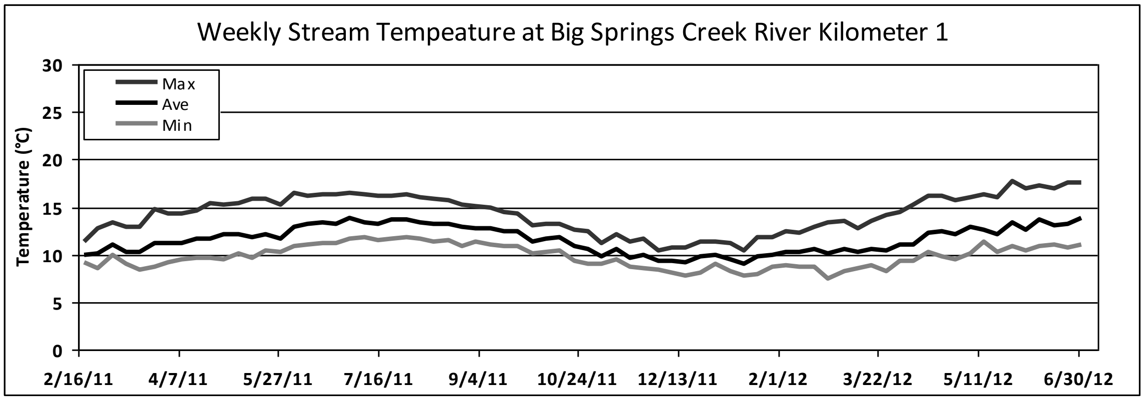
Appendix F. Weekly mean, maximum, and minimum temperatures at each PIT tag detection station location in the Shasta River.

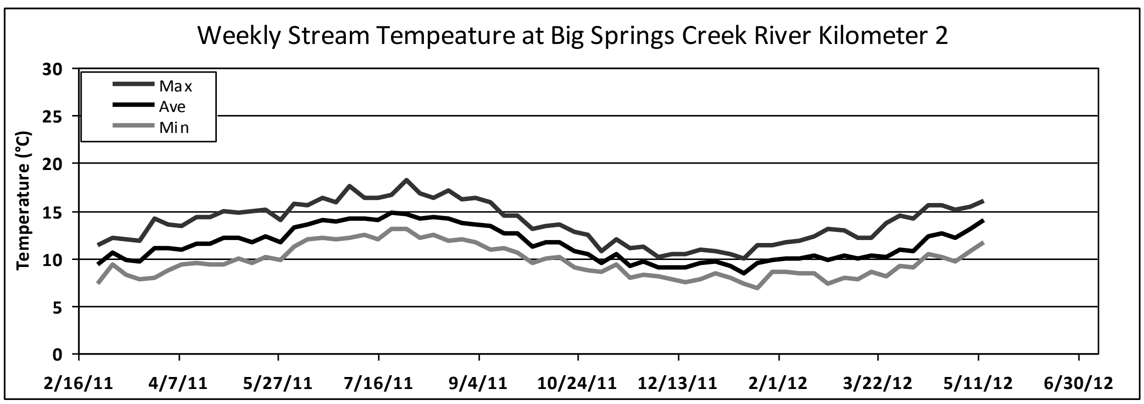


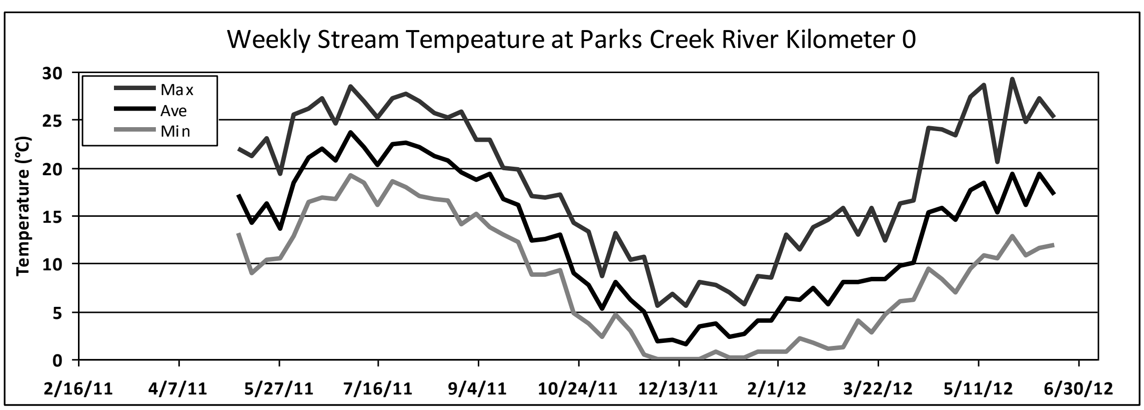




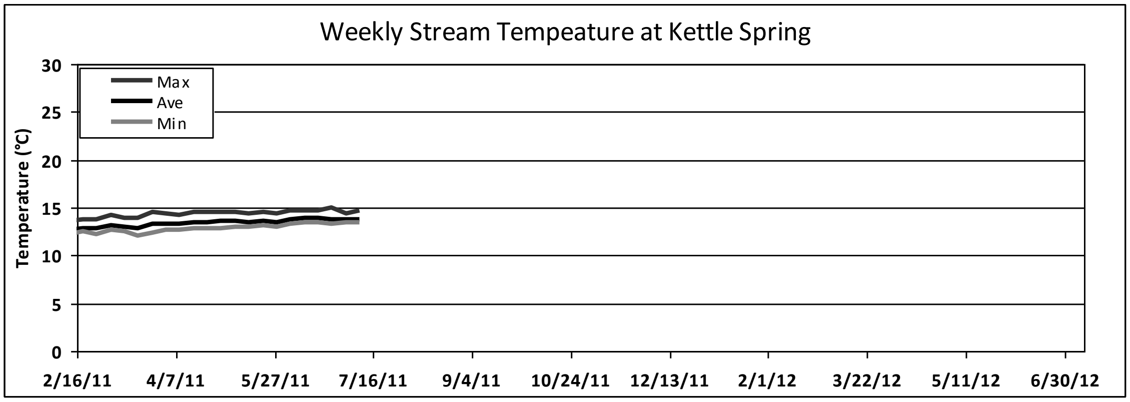
Appendix F. Continued.







Appendix F. Continued.



Appendix F. Continued.

Appendix G. Parameters in the multi-state model {*S*(t*g)*p*(t*g) Ψ (t*g)} of apparent survival (*S*), detection probability (*p*) and movement (Ψ) for juvenile coho salmon in the Shasta River, CA (adjusted for the estimated ĉ, 1.28). The five states are represented as L:Lower Mainstem, U:Upper Mainstem, B:Big Springs Creek, P:Parks Creek, M: Outmigrant. t1=tagging (May, June 2011), t2=summer (July-September 2011), t3=winter (October-February 2011-2012), t4= upper basin spring (March-June 2012), t5=RKM 0 C (March-June 2012), t6=RKM 0 B/A/rotary screw trap (March-June 2012). Asterisk indicates a boundary estimate.

Parameter	State	Interval	Link Function	Fixed To	Estimate	Lower 95%CI	Upper 95%CI
S	L	t1 to t2	Sin		*1.00	1.00	1.00
S	L	t2 to t3	Sin		0.43	0.27	0.61
S	L	t3 to t4	Sin		0.56	0.25	0.83
S	L	t4 to t5	Sin	0	0.00	0.00	0.00
S	L	t6 to t7	Sin	0	0.00	0.00	0.00
S	B	t1 to t2	Sin		0.96	0.83	0.99
S	B	t2 to t3	Sin		0.70	0.60	0.78
S	B	t3 to t4	Sin		0.52	0.41	0.63
S	B	t4 to t5	Sin	0	0.00	0.00	0.00
S	B	t6 to t7	Sin	0	0.00	0.00	0.00
S	U	t1 to t2	Sin		0.87	0.63	0.97
S	U	t2 to t3	Sin		0.74	0.55	0.87
S	U	t3 to t4	Sin		*1.00	0.00	1.00
S	U	t4 to t5	Sin	0	0.00	0.00	0.00
S	U	t6 to t7	Sin	0	0.00	0.00	0.00
S	P	t1 to t2	Sin		*1.00	1.00	1.00
S	P	t2 to t3	Sin		0.42	0.23	0.64
S	P	t3 to t4	Sin		0.95	0.13	1.00
S	P	t4 to t5	Sin	0	0.00	0.00	0.00
S	P	t6 to t7	Sin	0	0.00	0.00	0.00
S	M	t1 to t2	Sin	0	0.00	0.00	0.00
S	M	t2 to t3	Sin	0	0.00	0.00	0.00
S	M	t3 to t4	Sin	0	0.00	0.00	0.00
S	M	t4 to t5	Sin		0.77	0.62	0.87
S	M	t6 to t7	Sin	1	1.00	1.00	1.00
p	L	t2	Sin		0.27	0.17	0.41
p	L	t3	Sin		0.44	0.15	0.78
p	L	t4	Sin	0	0.00	0.00	0.00
p	L	t5	Sin	0	0.00	0.00	0.00
p	L	t6	Sin	0	0.00	0.00	0.00
p	B	t2	Sin		0.83	0.74	0.90
p	B	t3	Sin		*1.00	1.00	1.00
p	B	t4	Sin	0	0.00	0.00	0.00
p	B	t5	Sin	0	0.00	0.00	0.00
p	B	t6	Sin	0	0.00	0.00	0.00
p	U	t2	Sin		0.75	0.51	0.89
p	U	t3	Sin		0.37	0.26	0.51
p	U	t4	Sin	0	0.00	0.00	0.00

Appendix G. Continued.

Parameter	State	Interval	Link Function	Fixed To	Estimate	Lower 95%CI	Upper 95%CI
p	U	t5	Sin	0	0.00	0.00	0.00
p	U	t6	Sin	0	0.00	0.00	0.00
p	P	t2	Sin		0.94	0.42	1.00
p	P	t3	Sin		0.40	0.17	0.69
p	P	t4	Sin	0	0.00	0.00	0.00
p	P	t5	Sin	0	0.00	0.00	0.00
p	P	t6	Sin	0	0.00	0.00	0.00
p	M	t2	Sin	1	1.00	1.00	1.00
p	M	t3	Sin	1	1.00	1.00	1.00
p	M	t4	Sin		0.84	0.75	0.90
p	M	t5	Sin		0.52	0.41	0.63
p	M	t6	Sin		0.66	0.53	0.77
Ψ	L to B	t1 to t2	MLogit(1)		0.34	0.26	0.44
Ψ	L to B	t2 to t3	MLogit(2)		0.24	0.10	0.47
Ψ	L to B	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	L to B	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	L to B	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	L to U	t1 to t2	MLogit(1)		0.15	0.09	0.24
Ψ	L to U	t2 to t3	MLogit(2)		0.27	0.08	0.60
Ψ	L to U	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	L to U	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	L to U	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	L to P	t1 to t2	MLogit(1)		0.03	0.01	0.07
Ψ	L to P	t2 to t3	MLogit(2)		0.14	0.02	0.53
Ψ	L to P	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	L to P	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	L to P	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	L to M	t1 to t2	MLogit(1)		0.03	0.01	0.08
Ψ	L to M	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	L to M	t3 to t4	MLogit(3)	1	1.00	1.00	1.00
Ψ	L to M	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	L to M	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	B to L	t1 to t2	MLogit(1)		0.01	0.00	0.11
Ψ	B to L	t2 to t3	MLogit(2)		0.14	0.06	0.28
Ψ	B to L	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	B to L	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	B to L	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	B to U	t1 to t2	MLogit(1)		0.02	0.01	0.07
Ψ	B to U	t2 to t3	MLogit(2)		0.19	0.12	0.29
Ψ	B to U	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	B to U	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	B to U	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	B to P	t1 to t2	MLogit(1)		*0.00	0.00	0.00

Appendix G. Continued.

Parameter	State	Interval	Link Function	Fixed To	Estimate	Lower 95%CI	Upper 95%CI
Ψ	B to P	t2 to t3	MLogit(2)		0.02	0.00	0.10
Ψ	B to P	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	B to P	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	B to P	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	B to M	t1 to t2	MLogit(1)		0.02	0.01	0.06
Ψ	B to M	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	B to M	t3 to t4	MLogit(3)	1	1.00	1.00	1.00
Ψ	B to M	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	B to M	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	U to L	t1 to t2	MLogit(1)		0.02	0.00	0.16
Ψ	U to L	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	U to L	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	U to L	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	U to L	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	U to B	t1 to t2	MLogit(1)		0.03	0.01	0.13
Ψ	U to B	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	U to B	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	U to B	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	U to B	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	U to P	t1 to t2	MLogit(1)		0.06	0.02	0.16
Ψ	U to P	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	U to P	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	U to P	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	U to P	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	U to M	t1 to t2	MLogit(1)		0.07	0.03	0.17
Ψ	U to M	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	U to M	t3 to t4	MLogit(3)	1	1.00	1.00	1.00
Ψ	U to M	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	U to M	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	P to L	t1 to t2	MLogit(1)		0.10	0.04	0.23
Ψ	P to L	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	P to L	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	P to L	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	P to L	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	P to B	t1 to t2	MLogit(1)		0.01	0.00	0.12
Ψ	P to B	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	P to B	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	P to B	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	P to B	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	P to U	t1 to t2	MLogit(1)		0.03	0.01	0.14
Ψ	P to U	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	P to U	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	P to U	t4 to t5	MLogit(4)	0	0.00	0.00	0.00

Appendix G. Continued.

Parameter	State	Interval	Link Function	Fixed To	Estimate	Lower 95%CI	Upper 95%CI
Ψ	P to U	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	P to M	t1 to t2	MLogit(1)		0.06	0.02	0.16
Ψ	P to M	t2 to t3	MLogit(2)		*0.00	0.00	0.00
Ψ	P to M	t3 to t4	MLogit(3)	1	1.00	1.00	1.00
Ψ	P to M	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	P to M	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	M to L	t1 to t2	MLogit(1)	0	0.00	0.00	0.00
Ψ	M to L	t2 to t3	MLogit(2)	0	0.00	0.00	0.00
Ψ	M to L	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	M to L	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	M to L	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	M to B	t1 to t2	MLogit(1)	0	0.00	0.00	0.00
Ψ	M to B	t2 to t3	MLogit(2)	0	0.00	0.00	0.00
Ψ	M to B	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	M to B	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	M to B	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	M to U	t1 to t2	MLogit(1)	0	0.00	0.00	0.00
Ψ	M to U	t2 to t3	MLogit(2)	0	0.00	0.00	0.00
Ψ	M to U	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	M to U	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	M to U	t6 to t7	MLogit(5)	0	0.00	0.00	0.00
Ψ	M to P	t1 to t2	MLogit(1)	0	0.00	0.00	0.00
Ψ	M to P	t2 to t3	MLogit(2)	0	0.00	0.00	0.00
Ψ	M to P	t3 to t4	MLogit(3)	0	0.00	0.00	0.00
Ψ	M to P	t4 to t5	MLogit(4)	0	0.00	0.00	0.00
Ψ	M to P	t6 to t7	MLogit(5)	0	0.00	0.00	0.00