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Summary of Migration and Survival Data from Radio-Tagged Juvenile Coho Salmon in the Trinity River, Northern California, 2008

Open-File Report 2009-1092

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of the Trinity River looking upstream near the Burnt Ranch detection site.
(Photograph taken by Philip Haner, U.S. Geological Survey, Cook, Washington, March 11, 2008.)

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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2009

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Conversion Factors and Acronyms

Inch/Pound to SI

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
square kilometer (km^2)	247.1	acre
liter (L)	0.2642	gallon (gal)
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32.
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8.

Acronyms

PIT	passive integrated transponder
rkm	river kilometer
TRRP	Trinity River Restoration Program
USGS	U.S. Geological Survey

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Abstract

The survival of hatchery-origin juvenile coho salmon from the Trinity River Hatchery was estimated as they migrated seaward through the Trinity and Klamath Rivers. The purpose of the study was to collect data for comparison to a similar study in the Klamath River and provide data to the Trinity River Restoration Program. A total of 200 fish fitted with radio transmitters were released into the Trinity River near the hatchery (river kilometer 252 from the mouth of the Klamath River) biweekly from March 19 to May 28, 2008. Fish from the earliest release groups took longer to pass the first detection site 10 kilometers downstream of the hatchery than fish from the later release groups, but travel times between subsequent sites were often similar among the release groups. The travel times of individuals through the 239 kilometer study area ranged from 15.5 to 84.6 days with a median of 43.3 days. The data and models did not support differences in survival among release groups, but did support differences among river reaches. The probability of survival in the first 53 kilometers was lower than in the reaches farther downstream, which is similar to trends in juvenile coho salmon in the Klamath River. The lowest estimated survival in this study was in the first 10 kilometers from release in the Trinity River (0.676 SE 0.036) and the highest estimated survival was in the final 20 kilometer reach in the Klamath River (0.987 SE 0.013). Estimated survivals of radio-tagged juvenile coho salmon from release to Klamath River kilometer 33 were 0.639 per 100 kilometers for Trinity River fish and 0.721 per 100 kilometers for Klamath River fish.

Introduction

As part of a cooperative study among Federal, State, and Tribal groups, the survival of seaward migrating juvenile coho salmon (*Oncorhynchus kisutch*) in the Klamath River has been studied since 2006 (Stutzer and others, 2006; Beeman and others, 2008). These studies were among the first to estimate survival of juvenile salmonids in a northern California river, and the results were difficult to interpret due to a lack of survival estimates from similar areas. The purpose of the study in the Klamath River was to determine if there was a relation between discharge at Iron Gate Dam and survival of juvenile coho salmon downstream of the dam. The general design was to release fish several days per week from early April until mid-June to span the migration timing of wild fish in the area and cover a wide range of river discharges.

This study was conducted to provide estimates of survival to compare with data from the Klamath River study and to provide data on the migration timing and survival for the Trinity River Restoration Program (TRRP). The TRRP is a Federally mandated program to restore fish and wildlife populations in the Trinity River basin to levels comparable to those prior to construction of Trinity and Lewiston Dams (see *http://www.trrp.net*, accessed March 17, 2009). The general design of this study was similar to that of the Klamath River study in that fish were released periodically over several weeks during the spring. This study represents a pilot effort to estimate survival and migration metrics of juvenile salmon in the Trinity River, and was comprised of collaborative efforts from staff of Federal, State, and Tribal agencies. The study collaborators included the U.S. Geological Survey (USGS) and, in alphabetical order, the Bureau of Reclamation, State of California, U.S. Fish and Wildlife Service, and Yurok Tribal Fisheries Department.

The type of survival estimated in this study is called “apparent survival.” This is different from true survival, because mortality includes animals that actually died plus those that left the study population for various reasons. In the context of this study, apparent survival is the joint probability that the animal is both alive and migrates through the study area with a functioning transmitter. Fish are counted as mortalities if they stop migrating within the study area, travel permanently to areas outside the mainstem Trinity and Klamath Rivers, or remain within the study area after the radio tags deplete their battery and cease transmitting. All references to ‘survival’ in this document refer to apparent survival.

Study Site and Methods

This study was conducted in the Trinity and Klamath Rivers in northern California. The study area was between the California Department of Fish and Game Trinity River Hatchery at river kilometer (from the mouth of the Klamath River; rkm) 252 to rkm 13 on the Klamath River (fig. 1). The Trinity River drains a watershed of 7,389 km^2 in the Coast Range northwest of the Sacramento Valley and empties into the Klamath River at rkm 69. The river supports popular fisheries for resident and anadromous populations of salmonids and has been used since the 1950s as a water source for irrigation and hydroelectricity as part of the Central Valley Project. A Record of Decision by the U.S. Department of the Interior in 2000 reduced the amount of water diverted to the Central Valley Project and prescribed the timing and magnitude of discharges at Lewiston Dam on the Trinity River near Lewiston, California. The Record of Decision also mandated a pulse of discharge to simulate the spring freshet common to rivers in the Pacific Northwest.

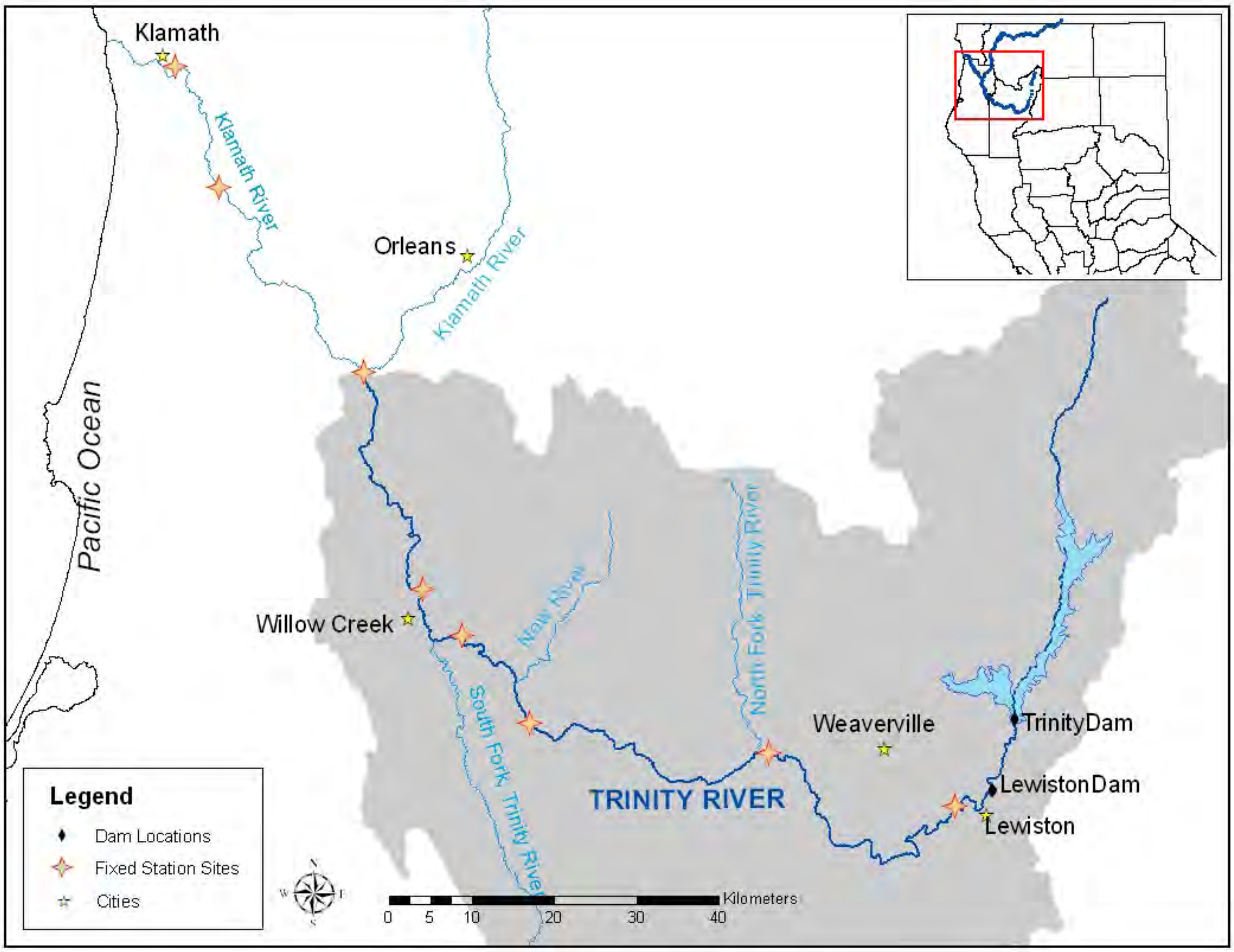

Figure 1. Map showing study area along the Trinity and Klamath Rivers, northern California, 2008. From the most upstream to downstream (right to left), the telemetry detection sites are: Bucktail, North Fork, Burnt Ranch, Sayler, Willow Creek, Weitchpec, Steelhead Lodge, and Blake's Riffle. Shaded area indicates portions of the map within the Trinity River basin.

River discharge and water temperature data were used to describe the study environment. Daily average river discharges at monitoring stations operated by the USGS were obtained from *http://waterdata.usgs.gov/nwis/dv*, accessed March 17, 2009. Water temperatures were collected from data loggers placed in the mainstem Trinity and Klamath Rivers by the U.S. Fish and Wildlife Service or from the California Department of Water Resources water-quality monitoring website at *http://cdec.water.ca.gov/wquality/*, accessed March 17, 2009.

Radio receivers and antennas were installed at eight sites along the Trinity and Klamath Rivers. The sites were selected after input from local biologists to represent sites that had been used in the past, encompass areas expected to have discharge changes such as near confluences with other rivers, or be relevant to restoration sites that were part of the TRRP. Locations of the sites are described in table 1. Each site included a Lotek SRX-400, a Sigma8 Orion telemetry receiver, and one or more Yagi antennas. Solar panels and batteries were used for power at all sites other than those at Bucktail and Weitchpec, which were connected to a 110-V power source, charger, and battery. Sites were visited weekly until June 10 and then biweekly thereafter to download data and check system operation. There also was a mobile tracking effort by the Yurok Tribal Fisheries Department, which is not included in this report.

The study was based on radio-tagged yearling coho salmon. The fish were reared by the California Department of Fish and Game at their Trinity River Hatchery near Lewiston, California. Fish were held in a concrete raceway at the hatchery and dip netted from the raceway into a 19 L bucket prior to anesthesizing them and implanting the radio transmitter. The fish were surgically implanted with radio transmitters using methods described in Beeman and others (2008). The transmitters were Lotek model NTC-3-2 KMF, with dimensions of 15.5 mm length, 6.3 mm width, 4.5 mm height, and 1.22 g weight in air, and a 24 cm trailing antenna. The transmitters emitted uniquely coded bursts at intervals of 7.8, 7.9, 8.0, 8.1, or 8.2 seconds, had an expected life of 109 days, and operated at frequencies of 164.320, 164.360, and 164.480 MHz. After tagging, fish were held in the raceway in perforated 19 L buckets (fig. 2) for 26–32 hours before being carried in the buckets about 400 m to the release site (fig. 3). The fish were released into the river by removing the lid and gently pouring the contents into the river from the shoreline near the time of civil twilight on each release date. Between 23 and 36 live fish were released on each of six biweekly dates between March 19 and May 28, 2008, for a total of 200 fish. All 200 tagged fish were released alive. An additional 25 tagged fish were euthanized and released with the live fish on March 31 (N = 8), April 14 (N = 8), and May 12 (N = 9) to test assumption A7 described below. The mean size of the fish released was 159.3 mm in length (range 132–232 mm) and 46.0 g in weight (range 23.8–151.2 g) and there were no significant differences in length or weight among release groups (ANOVA F_{length} = 0.852, df = 5,194, P = 0.5377, F_{weight} = 0.72, df = 5,194, P = 0.6062).

Table 1. Release site and automated radio telemetry station coordinates (WGS-84) on the Trinity and Klamath Rivers, northern California.

[The river kilometers (rkm) are from the mouth of the Klamath River]

Site location	rkm	Latitude	Longitude
Release site	252	40.726352	-122.7956
Bucktail	242	40.707254	-122.8475
North Fork	189	40.766805	-123.1148
Burnt Ranch	147	40.797695	-123.4592
Salyer	133	40.893477	-123.5567
Willow Creek	117	40.986551	-123.6354
Weitchpec	71	41.184585	-123.7059
Steelhead Lodge	33	41.379943	-123.9129
Blake's Riffle	13	41.511128	-123.9788

Figure 2. Photograph showing post-surgery holding method at the Trinity River Hatchery, California, 2008. Photograph by Steve Juhnke, U.S. Geological Survey, April 2008.

Figure 3. Photograph showing fish release site near the Trinity River Hatchery (rkm 252), California, 2008. Photograph by Steve Juhnke, U.S. Geological Survey, April 2008.

Transmitter life was tested to estimate the probability that the transmitters were operating when fish passed the detection arrays. The test entailed activating tags during the study period and monitoring failure over time in tanks at the Columbia River Research Laboratory in Cook, Washington. We randomly selected 24 transmitters comprising equal numbers from each of the frequencies. The tags were activated, submerged in water for the duration of the experiment, and monitored with a Lotek SRX-400 data logging receiver. The expiration times were determined by the last record of detection of each tag.

We also conducted a tag retention trial to determine if captive fish would shed tags or incur mortality over the estimated 109 day life of the transmitters. We surgically implanted dummy transmitters into 50 fish (tagged) and exposed an additional 50 fish (untagged) to only handling and anesthesia. The fish were obtained from an outside raceway at the Trinity River Hatchery that held the group of fish used in the field survival study. The transmitters were non-functioning transmitters identical to those used in the field study, and the treatment was applied at the beginning of the field study (March 19, 2008). Following treatment, both groups of fish were held indoors in rectangular raceways (0.9 m wide × 0.6 m deep × 5 m length) supplied with water from the same source as the outside raceway. Mortalities recorded during daily feeding were frozen for subsequent examination. All fish remaining alive after 126 days were euthanized and examined to determine growth and gross histological effects of the transmitters. A subset of mortalities that occurred during the trial were sent to the U.S. Fish and Wildlife Service California–Nevada Fish Health Center to determine their prevalence of disease.

Data from telemetry receivers were proofed to remove false positive records prior to analysis. The proofing criteria resulted in only keeping records from tags we released, records after the date and time of release, those records that made sense geographically (that is, no valid detections at downstream sites before valid detections at upstream sites), a minimum of two records within 10 min at a site, and modest minimum power thresholds. These criteria have been shown to remove false positives while creating little or no false negatives in similar studies (John W. Beeman, U.S. Geological Survey, unpub. data, February 25, 2009).

Travel times of fish were analyzed using event-time methods as described by Castro-Santos and Haro (2003) and Hosmer and Lemeshow (1999). In our analyses, the ‘event’ was the fish passing the downstream end of the river reach of interest and the ‘time to the event’ was the time from the last detection of the fish at the upstream end of the reach (or the release time in the case of the first reach) to the first detection at the downstream end of the reach, that is, the travel time. The Kaplan-Meier survivorship function was the primary measure used to examine migration timing. The survivorship function represents the probability of the fish not passing the end of a river reach by the end of a time interval. In the absence of censoring, it is the proportion of fish that have yet to pass. A censored observation is one that has an incomplete event time. In the context of this study, one may censor a fish if the fish was removed from the study for some reason. Right-censoring means the event time is longer than the censored time, but the event time is unknown. We right-censored one fish during this study because it was detected at a radio telemetry site on the Klamath River many kilometers upstream of the confluence with the Trinity River, and was likely eaten and transported by a bird. Differences in the timing of events (passage dates and times) among release groups statistically were compared using the Wilcoxon test, which weights comparisons equal to the number of subjects that have yet to experience the event and thus usually weights differences early in time more than differences later in time (Hosmer and Lemeshow, 1999). Differences in event times from the tag retention trial additionally were assessed using the Harrington-Fleming test, which was structured to preferentially weight differences later in time.

Survival was estimated using the Cormack-Jolly-Seber capture-recapture methods (Cormack, 1964; Jolly, 1965; Seber, 1965). Detection at a site is the product of the probability of survival to the site and the probability of recapture at the site, so these parameters must be separately estimated. A series of assumptions are associated with the single-release survival model used in this study. They are:

A1. Individuals marked for the study are a representative sample from the population of interest.

A2. Survival and recapture probabilities are not affected by tagging or sampling. That is, tagged animals have the same probabilities as untagged animals.

A3. All sampling events are "instantaneous." That is, sampling occurs over a negligible distance relative to the length of the intervals between sampling locations.

A4. The fate of each tagged individual is independent of the fate of all others.

A5. All tagged individuals alive at a sampling location have the same probability of surviving to the next sampling location.

A6. All tagged individuals alive at a sampling location have the same probability of being detected at that location.

A7. All tags are correctly identified and the status of each fish (that is, alive or dead) is correctly assessed.

The analyses were carried out using program MARK (White and Burnham, 1999). The process included assessing model fit, building a series of *a-priori* models based on subject matter knowledge, ranking the models based on parsimony using the Akaike's Information Criterion with a correction for small sample sizes (AICc), assessing model uncertainty and using model averaging where appropriate, and estimating apparent survivals and recapture probabilities. These methods are described in detail in White and Burnham (1999) and Burnham and Anderson (2002).

Results and Discussion

Environmental Conditions

A prescribed pulse in discharge occurred during the study period. Discharge at Lewiston Dam was about 300 ft^3/s from the onset of the study until April 22 when changes began for the scheduled spring pulse discharge (fig. 4). Discharge was increased to about 1,200 ft^3/s until May 2, when discharge was increased to 6,200 ft^3/s. Discharge at Lewistown Dam was then decreased to 2,100 ft^3/s through a series of daily adjustments until the desired discharge was met on June 9. Discharge was held between 2,000 and 2,100 ft^3/s until July 9, when discharge was again decreased to about 400 ft^3/s. During the study period, the average daily discharge downstream of Lewiston Dam (rkm 251; USGS gaging station 11525500) was 1,368 ft^3/s (range 290–6,470 ft^3/s). The average daily discharge recorded at Blake's Riffle on the Klamath River (rkm 13; USGS gaging station 11530500) was 11,588 ft^3/s (range 2,490–35,300 ft^3/s).

Water temperatures were cooler and less variable in the Trinity River than in the Klamath River during the study period. The water temperature near the release site ranged from 7.7 to 11.5°C and the daily average was 9.8°C. The water temperature near Blake's Riffle on the Klamath River ranged from 8.1 to 22.6°C and averaged 16.6°C. Trinity River water temperatures increased as the water moved downstream and mixed with tributary inputs and the water temperatures at Hoopa were similar to water temperatures in the Klamath River at Blake's Riffle (fig. 5).

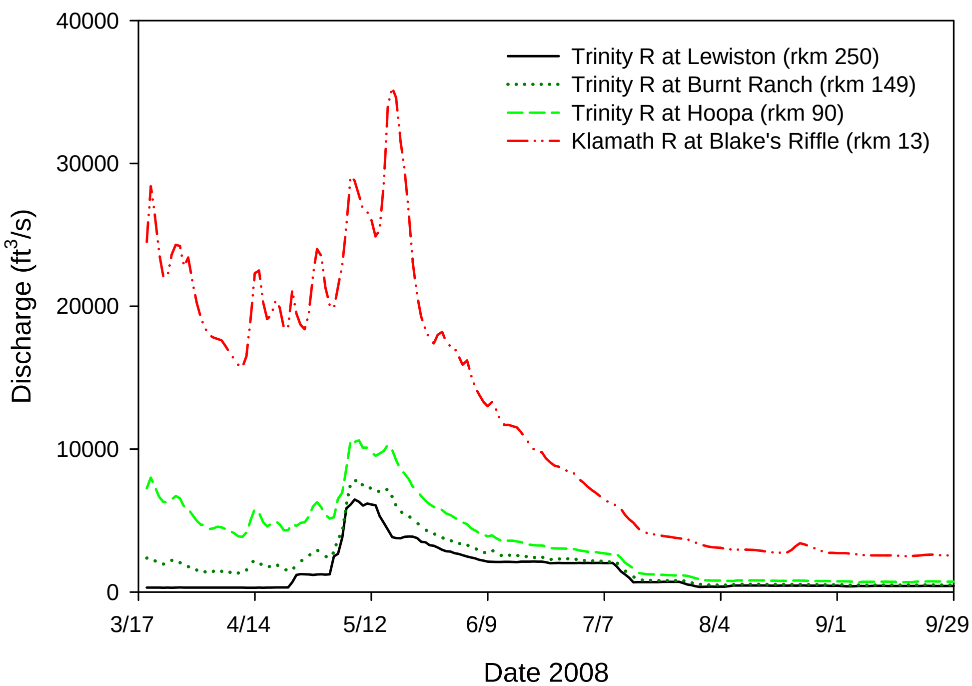

Figure 4. Graph showing discharge at several sites in the study area, 2008.

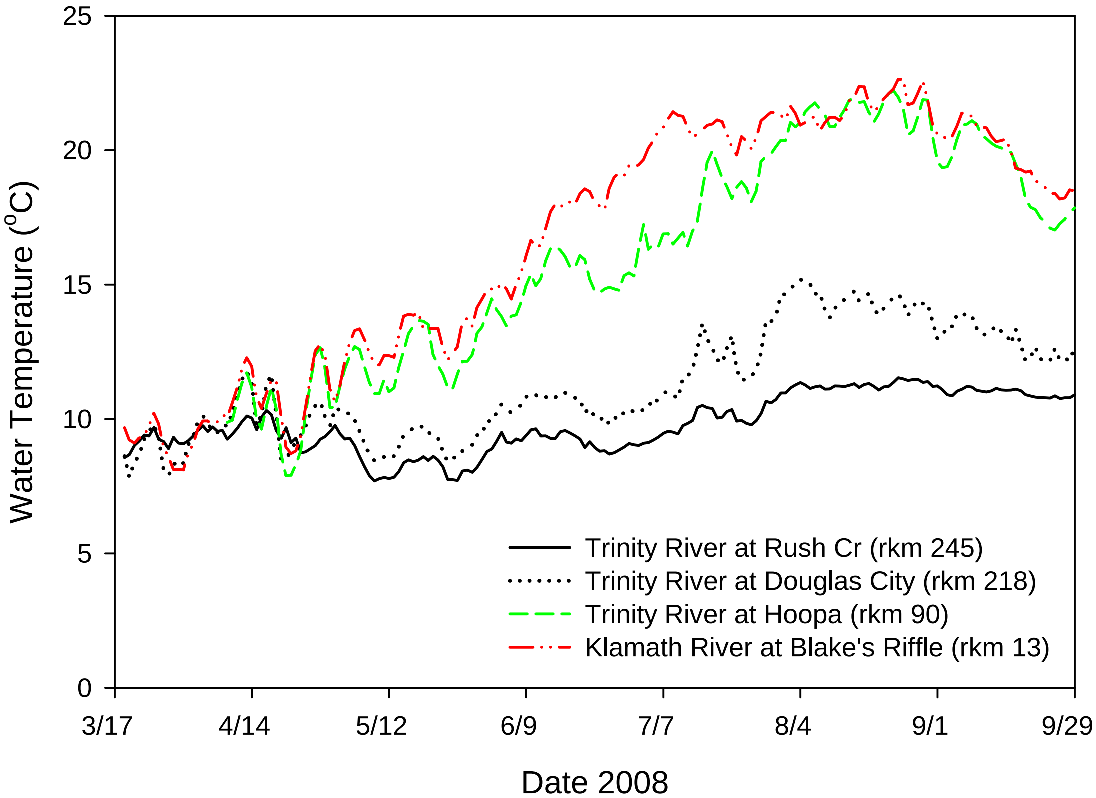

Figure 5. Graph showing water temperatures at several sites in the study area, 2008.

Evaluations of Assumptions

The tag life and tag retention trials and releases of euthanized tagged fish were formal evaluations to determine if the status of tagged fish (live or dead) was correctly assessed (assumption A7) and if tagging had a detrimental effect on survival (assumption A2). These assumptions are particularly important because the study fish are not actually seen after release and tag effects could alter the applicability of the results to the untagged population.

The results of the tag life test indicated that the minimum tag life was longer than the longest time the tagged fish were at large, so the assumption was not violated due to inadequate tag life. The mean tag life was 122.8 days (range 106.2–132.1 days). The longest travel time for a fish to migrate from release to the last detection site, Blake's Riffle at rkm 13, was 84.7 days, and the longest time from release to last detection was 112.1 days (this fish was thought to be a dead fish with a live transmitter near the Willow Creek detection site).

The tag retention study indicated that assumption A7 was met, but assumption A2 was not met. No tags were expelled during the 126-day tag retention study, indicating that assumption A7 likely was not violated due to tag loss in the fish released. There was, however, a difference between mortality of tagged and untagged fish in the trial, indicating that assumption A2 likely was violated in the fish released (fig. 6). Mortality of the tagged fish began on day 16: 22 percent died by day 54, and 37 percent died during the trial. We right-censored (a) the record of one tagged fish at day 15 because it jumped out of the holding tank, and (b) records of all fish alive at the end of the trial. Fifteen percent of the tagged fish died after day 54. Mortality of the untagged fish began on day 56 and 14 percent died during the trial. The distribution of event times weighted heavier at early times was significantly different between groups (Wilcoxon test χ^2 [df = 1, N = 91] = 7.9, P = 0.0049), but there was no significant difference late in time (Harrington-Fleming test emphasizing late times, χ^2 [df = 1, N = 91] = 2.01, P = 0.1559). These results indicate that the difference in survival between the groups was due to the early mortalities in the tagged group and that the survival of both groups was statistically similar later in time. The difference in mortality between the tagged and untagged groups was unexpected based on other studies (Adams and others, 1998; Greg Stutzer, U.S. Fish and Wildlife Service, unpub. data, March 6, 2009), given the relatively low tag weight to body weight percentage in the trial (mean 3.1 percent, range 1.3–5.4 percent).

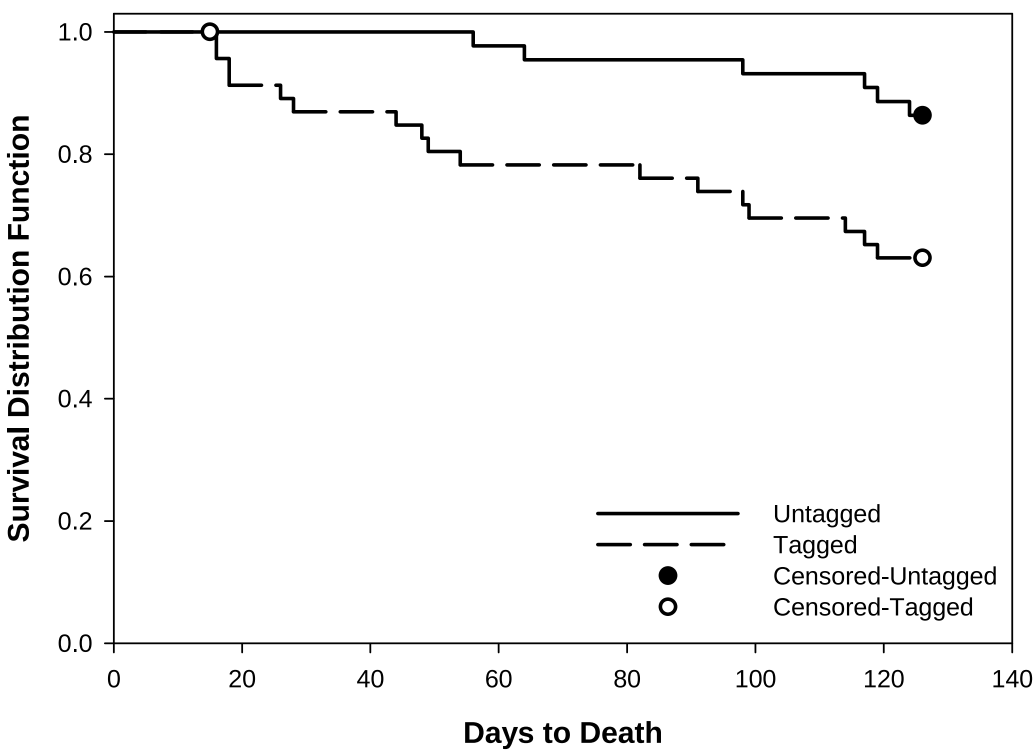

Figure 6. Graph showing Kaplan-Meier survival distribution function depicting the pattern of mortality among tagged and untagged juvenile coho salmon during a 126-day transmitter retention study, 2008. The y-axis represents the probability of a coho salmon surviving longer than the x-axis time. Fish remaining alive were censored at the end of the experiment and one tagged fish was censored on day 15 when it jumped out of the holding tank.

One of the 25 euthanized fish released was detected at the Bucktail site, indicating that assumption A7 was not met in the first reach due to the potential for dead fish to pass the site with live transmitters. The euthanized fish was released on April 16, 2008, at 21:30 hours and was detected at the Bucktail site on April 25, 2008, at 17:23 hours. The releases of euthanized fish were only made at the release site of the live fish, so these results are most applicable to the upstream portions of the study area. The effect of this result will be estimated in section, “Estimates of Survival.”

Migration Timing

Results pertinent to interpretation of the migration timing are presented in this section. Because the distance from the release site to the first detection site (Bucktail) is only 10 km, we used the travel time through this reach as an indicator of the time from release to initiation of migration. The dates release groups passed each detection station are important, as they may have bearing on the conditions each group were exposed to during their migration, which could affect their survival.

All but one of the telemetry detection sites operated continuously during the study. Power outages resulted in the Bucktail site being off from 12:26 hours on April 26 to 17:20 hours on May 1; 03:02 hours on May 4 to 13:45 hours on May 7; and 21:00 hours on May 9 to 09:45 hours on May 12. These outages caused low recapture probabilities at the Bucktail site for the first four releases (described in section, “Estimates of Survival”).

Travel times varied among release groups in several reaches. Travel times from release to the Bucktail site, an indicator of the time from release to the onset of migration, generally were shorter for each successive release date and differences in the distributions of event times (passage) were significantly different among release dates (Wilcoxon test, χ^2(df = 5, N = 112) = 58.73, P < 0.0001; fig. 7). The median travel times through the first reach decreased from nearly a month for the first release group to about 1 day for the last release group (appendix 1). In addition, the last three release groups traveled through this reach much faster than the first three (median 1–3 days versus 9–30 days). Differences in event time distributions among release groups also were present in the Bucktail to North Fork reach (Wilcoxon test, χ^2 (df = 5, N = 86) = 15.4, P = 0.0088), and in the Burnt Ranch to Salyer reach (Wilcoxon test χ^2 (df = 5, N = 90) = 13.3, P = 0.0208). No statistically significant differences were present among event time distributions among release groups in the other reaches (P > 0.1).

The dates of passage of fish from the six release groups overlapped considerably at most sites (fig. 8). The first three release groups passed most of the sites slightly earlier than the other groups. The overall (all release groups pooled) dates of arrival ranged from March 19 to June 26, 2008, at the Bucktail site and May 11 to July 10, 2008, at the Blake’s Riffle site.

A diel trend in passage times was evident at Trinity River sites, but not at Klamath River sites. Most fish were detected at the Trinity River sites during the night, indicating that the fish migrated predominantly at night. This conclusion could be confounded if there were diel differences in recapture probabilities, but the recapture probabilities at all sites other than Bucktail were 1.0, so the results are not biased from this source. The first detection times of fish at each of the six sites along the Trinity River were similar and were predominantly between 21:00 hours and 05:59 hours, comprising 81 percent of the total first detections. In contrast, 31 percent of the first detections were during this period at the two Klamath River sites.

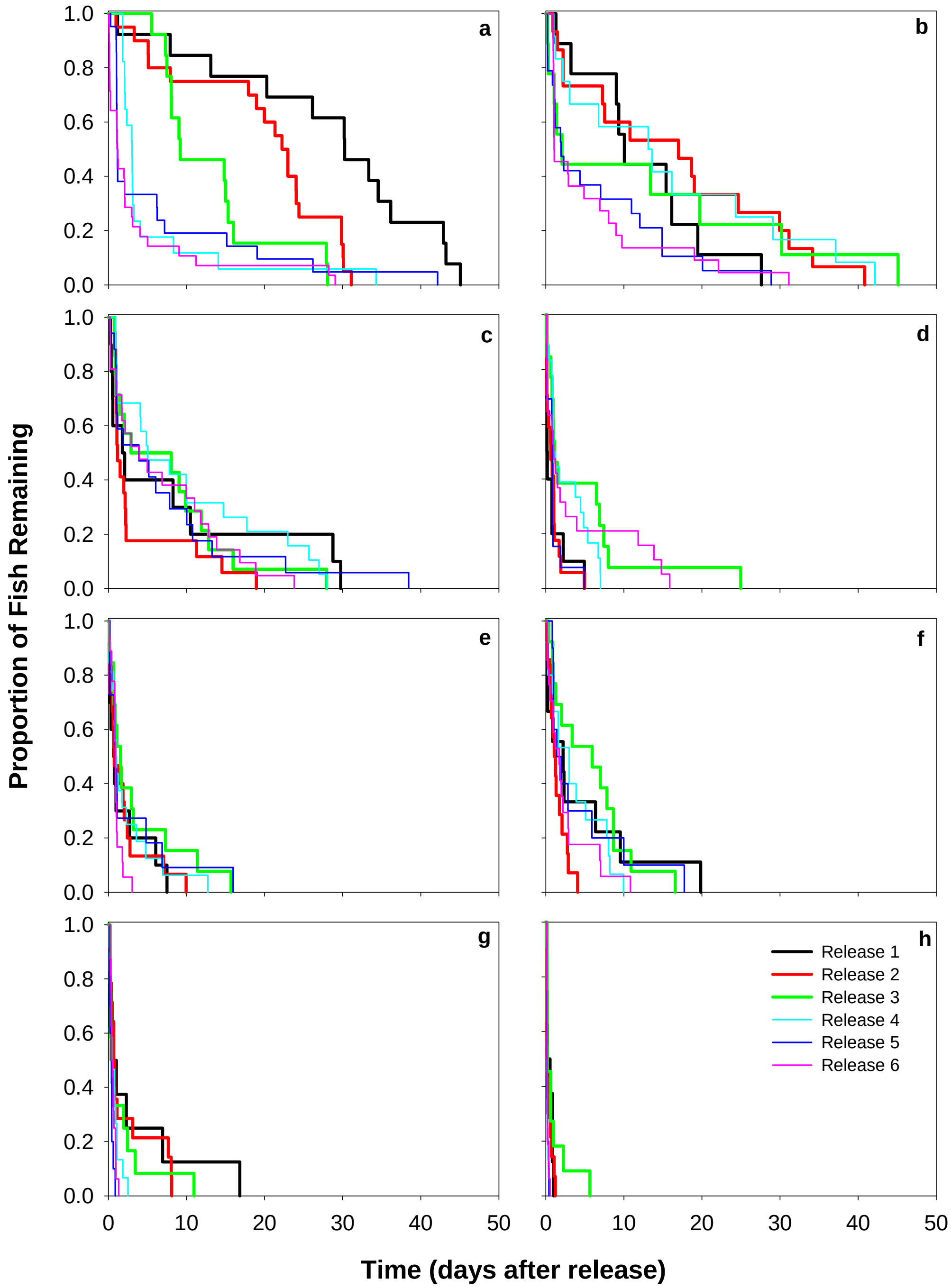

Figure 7. Graphs showing Kaplan-Meier curves describing travel times of radio-tagged hatchery juvenile coho salmon from release to (a) Bucktail, (b) Bucktail to North Fork, (c) North Fork to Burnt Ranch, (d) Burnt Ranch to Salyer, (e) Salyer to Willow Creek, (f) Willow Creek to Weitchpec, (g) Weitchpec to Steelhead Lodge, and (h) Steelhead Lodge to Blake's Riffle, 2008.

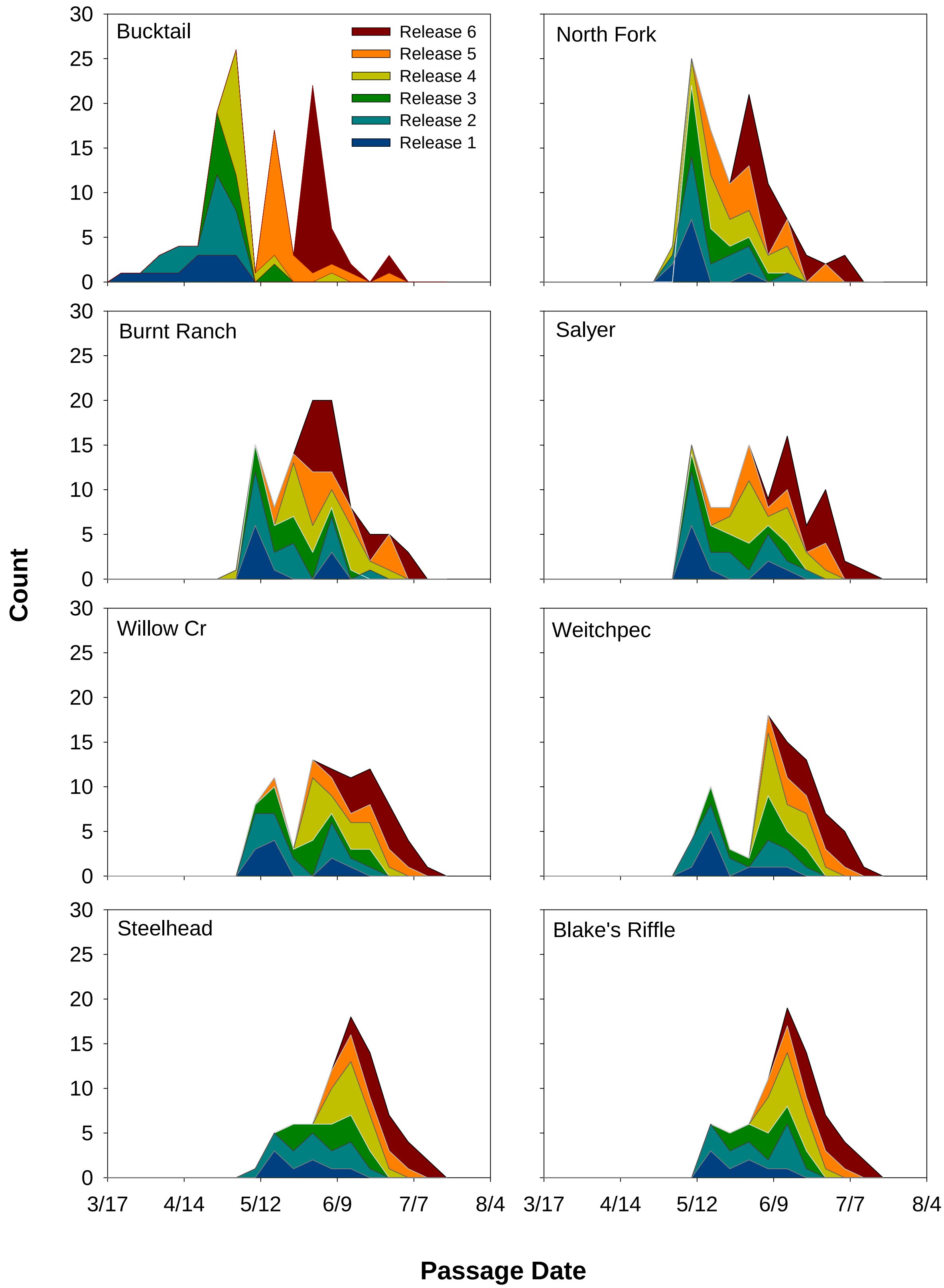

Figure 8. Graphs showing fish passage timing by release at each detection site in 2008.

Detections of tagged fish at the Bucktail site increased as calendar date and river discharge increased (fig. 9). The first four release dates were prior to the prescribed increases in discharge. Fish in these groups were detected passing the Bucktail site before and after the changes in discharge, indicating that the onset of their migration was not dependent on changes in discharge. However, the rate of travel of some groups, as indicated by the slopes of the lines in figures 7 and 8, did increase near the date of increased discharge. The power outages at the Bucktail site resulted in an apparent lag in passage of the first three release groups that coincided with the changes in discharge on April 24 and May 2, 2008. The last two release dates were after the prescribed discharge increases, so all fish were detected at the Bucktail site after the peak in discharge. The travel times of the fish in later release groups were shorter than earlier groups, indicating a possible effect of river discharge on travel times. However, the effects of release date, discharge, and other seasonal attributes such as water temperature are correlated and separating their effects may not possible from these data.

Estimates of Survival

Survival was estimated after choosing appropriate models of recapture probabilities and survival. The choice of a model for recapture probabilities is a necessary step when assessing models of survival, but the most supported model(s) of recapture probabilities are not of particular interest in this study. Estimates of survival and the hypotheses supported by the data are the primary interest.

Cursory examination of the data indicated that no fish passed sites downstream of the Bucktail site undetected and thus the recapture probabilities at sites other than Bucktail were 1.0 (appendix 2). Several fish were undetected at the Bucktail site during passage of the first two releases and the power outages during passage of release groups 3 and 4 resulted in many undetected fish. We therefore created a model of recapture probabilities describing this pattern and compared it to more general models. The results based on AICc model weights indicated that this model of recapture probability was essentially the only one supported by the data, receiving 99 percent of the AICc weight. Therefore, this model was used as a basis for all models of survival. The model produced estimates of recapture probabilities at the Bucktail site ranging from 0.611 (SE 0.093) to 0.889 (SE 0.063) during the first four releases and 1.0 (SE 0.00) for all other combinations of release dates and sites.

Models of survival describing differences among river reaches were supported by the data and those describing differences among release groups were not. An assessment of the presence of overdispersion was not applied to the data, because recapture probabilities were near 1.0; thus, overdispersion could not be estimated and was assumed to be minimal. The model selection results were unaffected by altering the variance inflation factor from one (no overdispersion) to three (extreme overdispersion), indicating that the presence of overdispersion would not affect the overall conclusions. The model describing differences in survival among reaches (model 1 in table 2) received 97 percent of the AICc model weight and the additive model of differences in reaches and releases (model 2) received 3 percent of the AICc model weight. No other *a-priori* models were plausible given the data. These results indicate that model 1 is 31 times more likely to be the best model than model 2 (AICc model weight of model 1 divided by that of model 2) and thus the hypothesis of survival varying among release dates was poorly supported by the data. This result may have been affected by the relatively low sample sizes among releases. All estimates of unstandardized apparent survival were based on model 1. A similar process with survival normalized to a 100 km reach resulted in the same conclusions.

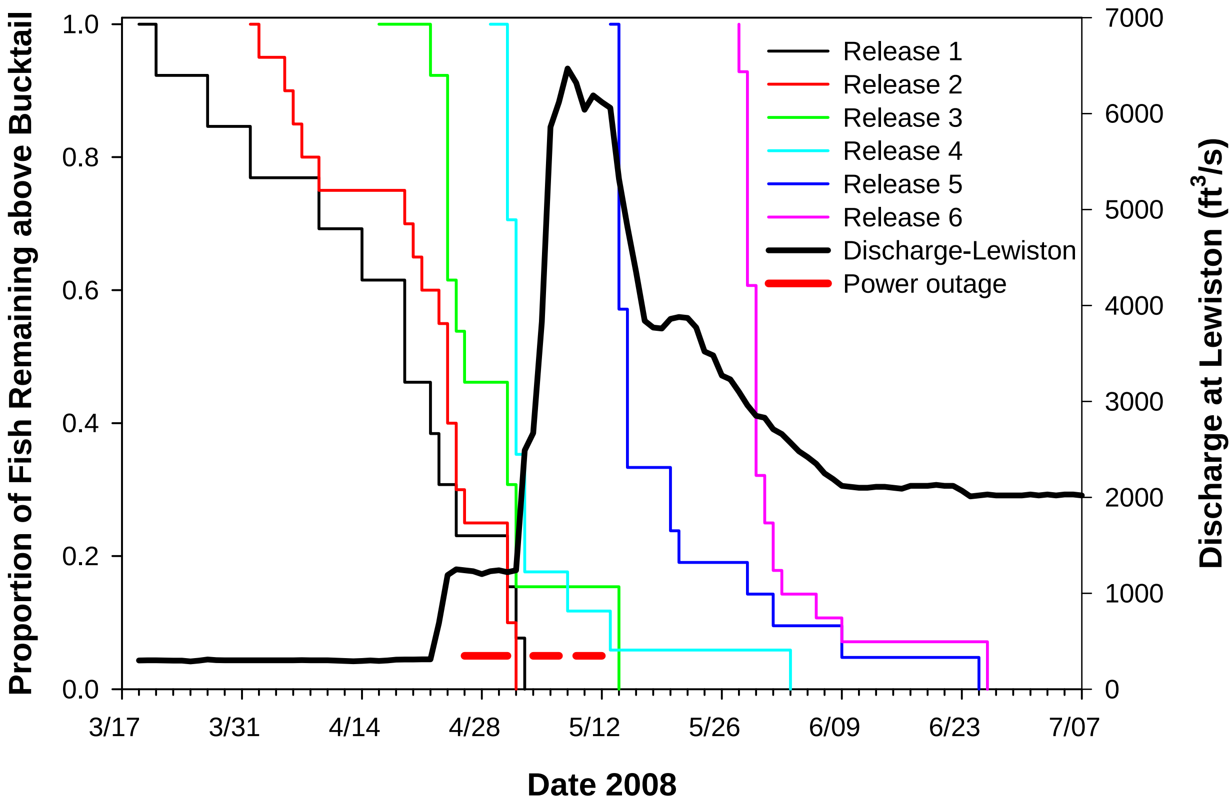

Figure 9. Graph showing Kaplan-Meier curves describing the travel times of radio-tagged hatchery coho salmon from release to Bucktail and mean daily discharge (ft^3/s) at Lewiston Dam, California. Note power outages during April and May.

Table 2. Model summary from analysis of unstandardized apparent survivals of radio-tagged hatchery-origin juvenile coho salmon from the Trinity River Hatchery, California.

[Results are based on data from a total of 200 live fish released in the Trinity River near the hatchery in biweekly groups from March 19 to May 28, 2008. A '+' between factors indicates an additive effect, a '*' indicates a multiplicative effect, and a '.' indicates a single estimate from all groups. All models shared a common model of recapture probability]

Model No.	Model description	AICc	Delta AICc	AICc weights	Model likelihood	Number of parameters	Deviance
1	Reach	706.738	0.000	0.969	1.000	12	52.033
2	Reach + Release	713.638	6.900	0.031	0.032	17	48.566
3	Reach * Release	755.096	48.358	0.000	0.000	52	13.765
4	.	785.531	78.793	0.000	0.000	5	145.131
5	Release	790.968	84.229	0.000	0.000	10	140.375

Estimates of survival were lowest in upstream reaches. The estimates in the two reaches upstream of North Fork were less than 0.77 and survival estimates of all other reaches were greater than 0.92 (table 3). It often is helpful to compare survivals normalized to a standard distance, so differences in reach lengths are removed from the comparisons. Survivals can be calculated as the unstandardized estimate raised to the power of (100 km ÷ reach length, in kilometers), but we estimated the values using program MARK to get estimates of variances and enable model selection, if needed. Estimates of survival per 100 km indicate that the survival rate was much lower in the reach from release to Bucktail (0.020 SE 0.11 per 100 km) than in the other reaches (0.54 SE 0.117 to 0.934 SE 0.063 per 100 km; fig. 10). The survivals per 100 km also were also relatively low in the reaches of Bucktail to North Fork, Burnt Ranch to Salyer, and Salyer to Willow Creek. Survival per 100 km of radio-tagged juvenile coho salmon released near Iron Gate Hatchery in the Klamath River in 2008 ranged from 0.172 (SE 0.052) in the 9 km reach from release to Ager Road Bridge (rkm 309 to 300) to 0.899 (SE 0.034) in the 71 km reach between Happy Camp and the Salmon River (rkm 178–107; Beeman and others, 2009).

Table 3. Estimated unstandardized apparent survivals and confidence intervals of radio-tagged juvenile coho salmon from the Trinity River Hatchery, California.

[Results are based on data from a total of 200 live fish released in the Trinity River near the hatchery in biweekly groups from March 19 to May 28, 2008. Results are based on model 1 in table 2. Data over multiple reaches were calculated as the product of the reach estimates with variances estimated using the delta method (Seber, 1982)]

Reach No.	Reach description	Reach length (km)	Apparent survival	Standard error	95% Confidence interval	
					Lower	Upper
1	Release to Bucktail (rkm 242)	10	0.676	0.036	0.603	0.742
2	Bucktail to North Fork (rkm 189)	53	0.769	0.039	0.683	0.837
3	North Fork to Burnt Ranch (rkm 147)	42	0.942	0.023	0.877	0.974
4	Burnt Ranch to Salyer (rkm 133)	14	0.918	0.028	0.845	0.959
5	Salyer to Willow Creek (rkm 117)	16	0.922	0.028	0.846	0.962
6	Willow Creek to Weitchpec (rkm 71)	46	0.940	0.026	0.863	0.975
7	Weitchpec to Steelhead Lodge (rkm 33)	38	0.962	0.022	0.887	0.988
8	Steelhead Lodge to Blake's Riffle (rkm 13)	20	0.987	0.013	0.911	0.998
	Release to Steelhead Lodge	219	0.375	0.058	0.260	0.490
	Release to Blake's Riffle	239	0.370	0.036	0.300	0.440

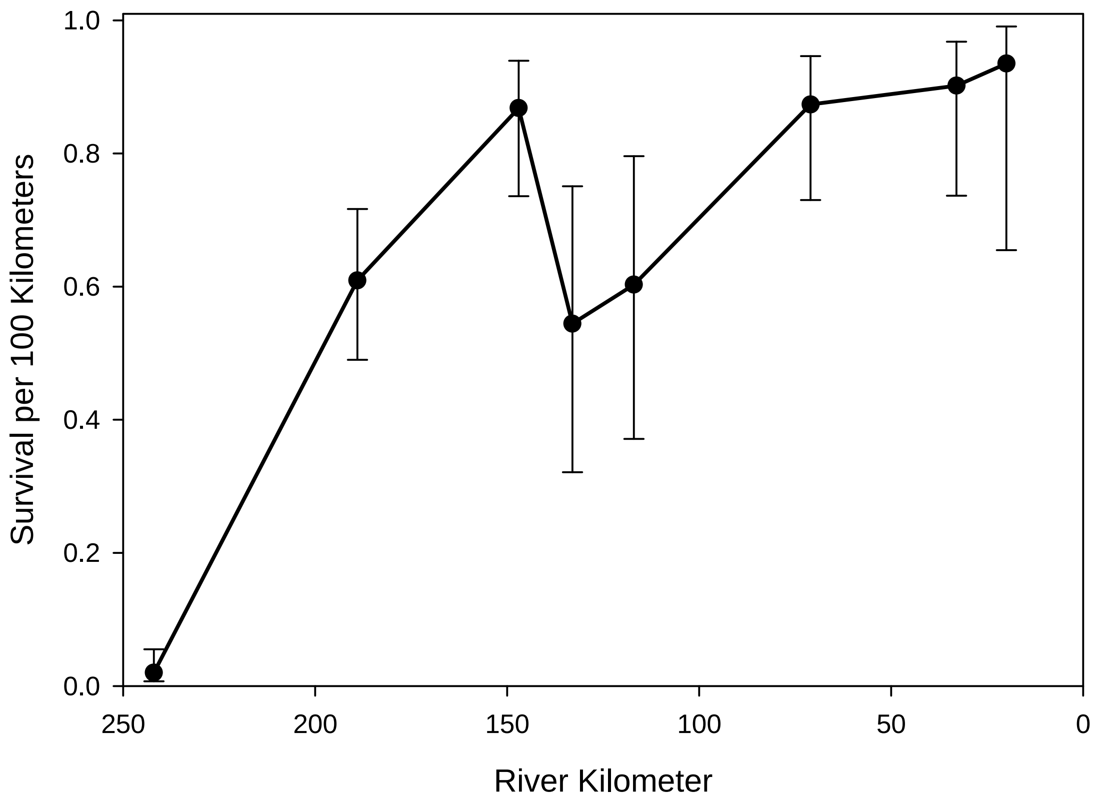

Figure 10. Graph showing estimated apparent survivals standardized to survival per 100 km and confidence intervals of radio-tagged hatchery coho salmon, 2008.

There are several potential causes of the low survival upstream of the North Fork site. These include the naïve nature of the fish shortly after release from the hatchery, expression of tag and handling effects, greater predator densities in the areas near the hatchery, a preference of predators for radio-tagged fish over untagged fish, fish leaving the study area, or any combination of these factors. The time fish spent in this area did not appear to affect their survival, because the effect of release date was poorly supported by the data; however, other seasonal changes among release dates may confound such comparisons. The time between release and the onset of migration of radio-tagged juvenile coho salmon in the Klamath River also decreases with release date, but is not accompanied by an increase in discharge, indicating that a change in discharge is not a required cue for the initiation of migration (Beeman and others, 2008). Data from radio-tagged coho salmon released in the Klamath River also indicate lower survival in reaches near the release site, and the causes may be similar to those from this study. The causes of the low survival per 100 km in the reaches between Burnt Ranch and Willow Creek are likely not related to naïve fish or expression of tag and handling effects, because it took most fish many days to reach these areas and these factors, if present, would likely have been expressed by then.

The cause of the low apparent survival upstream of the Bucktail site is particularly important because it represents a loss of more than 30 percent of the tagged fish in the first 10 km after release. If this is a result of tag and handling effects, the cause may have little applicability to untagged fish from the hatchery, but if not then the cause may reflect a meaningful issue. The magnitude of the mortality upstream of the Bucktail site is greater than would be expected from tag and handling effects based on results of tagging thousands of fish in the Columbia River basin where similar tagging methods are used routinely (Perry and others, 2007). However, radio-tagged juvenile salmon are known to be preferred over untagged fish as prey by smallmouth bass (*Micropterus dolomieu*) in laboratory trials (Adams and others, 1998), which indicates that they may be preferred prey of other fish as well. Thus, the mortality of the radio-tagged fish in this study may be expected to overestimate mortality of untagged fish in areas with significant predatory fish populations, which may be the case in some areas of the Trinity River. There is a popular fishery for brown trout (*Salmo trutta*) in the Trinity River and these fish may represent a significant source of mortality for the study fish. Some resident fish near hatcheries can quickly shift their diets from non-salmonids to salmonids after hatchery releases (Shively and others, 1996), indicating that resident fish in the area may key in on juvenile coho salmon when present. In addition, many avian predators were seen in the area near the hatchery; these predators also may contribute to losses in that area. It also is known that predation rates near hatcheries can be higher than in areas downstream. Hockersmith and others (1999) determined that fish with radio tags plus passive integrated transponder (PIT) tags had similar survivals to those with only PIT tags for the first 187 km downstream of a northeast Oregon hatchery, and used the fish with radio tags to describe survival in several reaches within the 187 km area. They determined that the survival from release at the hatchery to a site 3.1 km downstream was 0.858 (SE 0.050) and was 0.911 (SE 0.071) over the next 138 km. These survival rates equal 0.007 per 100 km shortly after release and 0.935 per 100 km in the next 138 km, which are similar to results in this study. In their case, it appeared that the low survival near the hatchery was not attributed to the radio tags and was a reflection of processes due to other factors near the hatchery. Lastly, results from the tag retention trial indicate that the study fish may have been infected with *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease, which may have accelerated losses due to predation. The tagged fish in the tag retention trial died in higher proportion than untagged fish (fig. 6) and a subset of fish (six tagged and four untagged) with mortality times ranging from 18 to 119 days post-tagging had high levels of *Renibacterium salmoninarum* present in kidney imprint samples (Scott Foott, U.S. Fish and Wildlife Service California–Nevada Fish Health Center, written commun., January 5, 2009). This indicates that a clinical level of infection existed among untagged and tagged fish in the tag retention study, and potentially in the tagged fish released into the Trinity River. Infection with *Renibacterium salmoninarum* has been shown to increase susceptibility to predation by other fishes (Mesa and others, 1998). Thus, the reach survivals of fish in this study may be negatively biased because the source of fish for the retention trial and survival study was the same. The results of the tag retention study indicate that the effects of bearing the transmitter increased the negative effects of the disease, and may partly explain the high mortality of tagged fish in the river.

Detection of the single euthanized fish at the Bucktail site indicates that estimates of survival were positively biased in the release to Bucktail reach. This bias likely is small relative to the estimated mortality in that reach, because only 1 of 25 euthanized fish were detected (4 percent). The effects of this bias were not thoroughly studied, as the releases of euthanized fish were made only periodically and did not span the entire range of river discharges. The unbiased survival of the tagged fish in this reach may be roughly estimated as the estimated survival minus 1/25, which is 0.676 – 0.04 = 0.636.

We could not separate the mortality near the hatchery from the various potential factors as part of this study; however, a series of alternative methods could be used to separate some of these factors in future studies. Tag and handling effects can be mitigated through the use of paired-release survival models as in Burnham and others (1987), but their use requires about twice as many fish and the results can be biased when using naïve hatchery fish and long distances between treatment and control release sites (Beeman and others, 2008). Survivals of fish released at several sites also could be used to compare the post-release mortality of fish released near the hatchery with those released at downstream sites to determine if the acute post-release mortality of naïve fish is similar near the hatchery and farther downstream. This approach would not address the increased preference of tagged fish as prey by some fishes. The use of other tag types, such as PIT or small acoustic tags, also may reduce these potential impacts. The use of PIT tags seems attractive due to their low cost and low impact to the animal, but several in-stream detectors would have to be installed and evaluated prior to this endeavor. Acoustic telemetry also is attractive to some due to the lack of an external antenna, as there is some evidence it affects critical swimming speed (Murchie and others, 2004), but this technology is less suited to fast-moving systems than radio telemetry due to the ambient noise in some rivers. However, acoustic telemetry currently is being used successfully in the Columbia, Snake, and Sacramento Rivers.

Summary

This study provided information about migration timing and estimates of recapture and survival probabilities of radio-tagged juvenile coho salmon from the Trinity River Hatchery during their seaward migration in 2008. The purpose of the study was to describe migration and survival of juvenile coho salmon to compare to estimates of fish from the Klamath River and to provide information to the Trinity River Restoration Program.

The time between release and the onset of migration was inversely related to release date. This result, together with data from a similar study in the Klamath River, indicates that initiation of migration in juvenile coho salmon after release from a hatchery is dependent on seasonal factors other than river discharge. The data indicate that river discharge may be positively related to migration rates once migration is initiated. Migration in the Trinity River occurred primarily at night.

The estimated survivals were lowest in the 10 kilometer reach nearest the hatchery. Nearly one-third of the fish released were estimated to have died in this reach. There are many possible causes for this result, including bias in the estimates due to susceptibility of tagged fish to predation as affected by the tag itself and in combination with disease. The estimated survival in this reach likely underestimates the survival of the untagged fish population, but the magnitude of the underestimate is unknown. Survival on a per unit distance basis also was low between the sites at Burnt Ranch (river kilometer 147) and Willow Creek (river kilometer 117) relative to the other reaches for reasons unknown.

The survival estimates among reaches in this study followed a pattern similar to data from juvenile coho salmon in the Klamath River. The estimated survivals in both studies were clearly lowest in areas near the release sites at the hatcheries. The estimated survival of Trinity River coho salmon over the 219 kilometers between release and Steelhead Lodge at Klamath River kilometer 33 was 0.375 (SE 0.058). The estimate from Klamath River coho salmon over the 276 kilometer reach from release near Iron Gate Hatchery to Steelhead Lodge was 0.406 (SE 0.032). These equate to a survival of 0.639 per 100 kilometer for the juvenile coho salmon from the Trinity River and 0.721 per 100 kilometer for those from the Klamath River.

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Appendix 1. Travel Time Summaries of Radio-Tagged Juvenile Coho Salmon, 2008.

[Travel times (days) are based on data from a total of 200 fish released in the Trinity River near the Trinity River Hatchery, California, in six biweekly groups from March 19 to May 28, 2008. Data are listed by release date and pooled over all release dates (All)]

Release date	Number detected	Minimum	Percentiles 25th	50th	75th	Maximum
Release to Bucktail						
3/19	13	1.19	20.29	30.25	36.17	45.08
4/1	20	0.99	12.95	22.61	27.12	31.12
4/16	13	5.56	8.05	9.21	15.35	28.09
4/29	17	1.85	2.08	3.04	3.27	34.29
5/13	21	0.30	1.07	1.16	6.24	42.18
5/28	28	0.08	0.18	1.19	3.06	29.06
All	112	0.08	1.20	5.12	20.82	45.08
Bucktail to North Fork						
3/19	9	1.30	9.06	10.08	16.13	27.60
4/1	15	0.94	2.23	17.00	29.94	40.85
4/16	9	0.24	1.09	2.10	19.72	45.12
4/29	12	1.04	2.64	13.36	26.72	42.18
5/13	19	0.23	0.87	1.97	12.05	28.87
5/28	22	0.95	1.06	1.09	8.05	31.13
All	86	0.23	1.10	6.85	17.00	45.12
North Fork to Burnt Ranch						
3/19	10	0.30	0.55	1.96	10.50	29.74
4/1	17	0.79	0.97	1.20	2.23	18.94
4/16	14	0.81	0.96	5.47	11.93	27.95
4/29	19	0.94	1.04	5.05	17.75	28.03
5/13	17	0.26	1.05	3.93	10.03	38.45
5/28	21	0.23	0.98	3.97	11.85	23.82
All	98	0.23	0.99	2.58	11.05	38.45
Burnt Ranch to Salyer						
3/19	10	0.13	0.14	0.18	0.80	4.94
4/1	17	0.12	0.13	0.66	1.05	5.00
4/16	13	0.10	0.82	1.15	6.88	24.98
4/29	18	0.13	0.90	1.11	4.85	7.02
5/13	13	0.11	0.17	0.84	0.85	4.94
5/28	19	0.15	0.18	1.02	3.96	15.88
All	90	0.10	0.18	0.90	1.92	24.98

Appendix 1. — Continued.

Release date	Number detected	Minimum	Percentiles 25 th	50 th	75 th	Maximum
---------- Salyer to Willow Creek ----------						
3/19	10	0.13	0.20	0.73	2.71	7.51
4/01	15	0.11	0.18	0.76	2.44	9.96
4/16	13	0.11	0.71	1.57	3.20	15.70
4/29	16	0.14	0.73	1.02	2.95	12.75
5/13	11	0.16	0.20	0.91	4.84	15.99
5/28	18	0.14	0.81	0.93	1.07	3.08
All	83	0.11	0.54	0.93	2.31	15.99
---------- Willow Creek to Weitchpec ----------						
3/19	9	0.22	0.25	2.23	6.39	19.84
4/01	14	0.18	0.70	1.18	2.09	4.09
4/16	13	0.38	1.28	5.95	8.66	16.59
4/29	15	0.26	0.86	3.00	7.82	9.96
5/13	10	0.84	1.00	1.70	5.91	17.75
5/28	17	0.23	0.55	1.72	2.87	10.86
All	78	0.18	0.89	1.79	5.91	19.84
---------- Weitchpec to Steelhead Lodge ----------						
3/19	8	0.19	0.22	0.71	4.64	16.82
4/01	14	0.22	0.40	0.74	3.12	8.11
4/16	12	0.21	0.28	0.45	2.21	10.97
4/29	15	0.19	0.29	0.43	1.10	2.54
5/13	10	0.20	0.22	0.42	0.46	0.89
5/28	16	0.24	0.36	0.50	0.82	1.33
All	75	0.19	0.28	0.46	0.96	16.82
---------- Steelhead Lodge to Blake's Riffle ----------						
3/19	8	0.15	0.18	0.40	0.84	1.03
4/01	14	0.12	0.15	0.18	0.63	1.23
4/16	11	0.14	0.17	0.22	1.00	5.67
4/29	15	0.16	0.16	0.18	0.21	0.42
5/13	10	0.15	0.15	0.18	0.23	0.44
5/28	16	0.16	0.18	0.21	0.25	0.54
All	74	0.12	0.16	0.19	0.38	5.67

Appendix 2. Recapture Histories of Radio-Tagged Hatchery-Origin Juvenile Coho Salmon from Trinity River Hatchery Released on Each of Six Dates during 2008.

[Histories begin with ‘1’ for release and are ‘1’ if they were detected and ‘0’ if they were not at Bucktail (river kilometer from the mouth of the Klamath River [rkm] 242), North Fork (rkm 189), Burnt Ranch (rkm 147), Salyer (rkm 133), Willow Creek (rkm 117), Weitchpec (rkm 71), Steelhead Lodge (rkm 33), and Blake's Riffle (rkm 13). All but the last two sites are within the Trinity River and the last two are within the Klamath River]

Encounter History	Release Date					
	3/19	4/01	4/16	4/29	5/13	5/28
111111111	7	13	7	8	10	16
111111110	0	0	1	0	0	0
111111100	1	0	1	0	0	1
111111000	1	0	0	1	1	1
111110000	0	2	0	1	2	1
111100000	0	0	0	1	4	2
111000000	0	0	0	1	2	1
110000000	4	5	4	5	2	6
101111111	1	1	4	7	0	0
101111000	0	1	0	0	0	0
101110000	0	0	0	1	0	0
101100000	0	0	1	0	0	0
101000000	0	0	1	1	0	0
100000000	9	13	16	10	14	8
Sum	23	35	35	36	35	36

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