Prepared in cooperation with the Bureau of Reclamation

Survival and Migration Behavior of Juvenile Coho Salmon in the Klamath River Relative to Discharge at Iron Gate Dam, Northern California, 2007

By John W. Beeman and Steve Juhnke, U.S. Geological Survey, Greg Stutzer and Nicholas Hetrick, U.S. Fish and Wildlife Service

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Conversion Factors

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
acre	4,047	square meter (m^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

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:

$$°C=(°F-32)/1.8.$$

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Survival and Migration Behavior of Juvenile Coho Salmon in the Klamath River Relative to Discharge at Iron Gate Dam, Northern California, 2007

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Abstract

This report describes a study of survival and migration behavior of radio-tagged juvenile coho salmon (*Oncorhynchus kisutch)* in the Klamath River, northern California, in 2007. This was the third year of a multi-year study with the goal of determining the effects of discharge at Iron Gate Dam (IGD) on survival of juvenile coho salmon downstream. Survival and factors affecting survival were estimated in 2006 and 2007 after work in 2005 showed radio telemetry could be used effectively. The study has included collaborative efforts among U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), the Karuk and Yurok Tribal Fisheries Departments, and the U.S. Bureau of Reclamation. The objectives of the study included: (1) estimating the survival of wild and hatchery juvenile coho salmon in the Klamath River downstream of Iron Gate Dam, determining the effects of discharge and other covariates on juvenile coho salmon survival (2) and migration (3), and (4) determining if fish from Iron Gate Hatchery (IGH) could be used as surrogates for the limited source of wild fish.

We have been able to meet the first objective by estimating the survivals of hatchery and wild fish (when available) downstream of IGD. We have not yet met the second or third objectives, because we have been unable to separate effects of discharge from other environmental variables as they pertain to the survival or migration of juvenile coho salmon. This was foreseen when the study began, as it was known there would likely be no experimental discharges. A multi-year analysis will be conducted after the data for the third planned year are available. The fourth objective was initiated in 2006, but wild fish were not available in 2007. The next year wild fish may be available is in 2009, based on their 3-year cycle of abundance.

River discharges during the 2007 study period (April 10 through July 28, 2007) were below average compared to the period of record beginning in 1962. Average daily discharge at IGD was 1,518 cubic feet per second (ft^3/s) and ranged from 1,020 to 2,460 ft^3/s. Average daily discharge near the estuary at river kilometer (rkm) 13 was 9,820 ft^3/s and ranged from 3,270 to 20,500 ft^3/s.

This study was based on hatchery fish taken directly from a holding tank at IGH. Wild fish were not available in numbers sufficient for use in 2007. Fish tagging began on April 9 and concluded on May 17, 2007. A total of 246 hatchery coho salmon were tagged and released, split evenly between releases in the Klamath River near IGH (rkm 309) and near the Tree of Heaven campground at rkm 280.

The two release sites were used to enable estimation of a relative survival between IGH and the campground using the paired-release design, because potential effects of tagging and handling can be cancelled out with this method. However, the assumption that the survival probabilities of fish from each release site are equal in the reaches they have in common was violated, preventing its use in 2007. All estimates of survival were therefore calculated using the single-release design.

The reach-specific estimates of survival were lower in 2007 than in 2006, but a similar survival pattern was evident among reaches in each year. The survival from IGH to rkm 33 was 0.653 [standard error (SE) 0.039] in 2006 and 0.497 (SE 0.044) in 2007. In each year, the reaches with the lowest survivals were upstream of the Scott River, which also is the area with the greatest differences in survivals between years. The reach with the highest survivals were in the Salmon River-to-Trinity River reach (at or near 1.0 in each year). The cause of the difference in survivals in each year were not identified, but could be related to differences in discharge or turbidity, as these are the primary differences between the years. These differences and other effects will be analyzed when the data from all study years (initially planned for 2006 through 2008) are available. Models of survival with and without a year effect were nearly equally supported by the data, indicating uncertainty in the importance of the difference between years. Estimates of survival were lower in fish released near Tree of Heaven campground than those released near IGH in the reaches they had in common. For example, estimated survival for fish released near the campground to rkm 33 were 0.301 (SE 0.041) and 0.700 (SE 0.058) for fish released near IGH. The largest difference in survival between the groups of fish released was in the reach from the campground to the Scott River, in which the survivals were 0.589 (SE 0.045) and 0.814 (SE 0.044); the point estimates of survival of fish released near IGH were higher than fish released near the campground in every reach. The cause of this difference is unknown, but possible explanations include differences in expression of tagging effects, slower migration of fish released near the campground, or the potential for a greater exposure to disease in these fish based on the prevalence of *Manayunkia speciosa*, a host in the life cycle of *Ceratomyxa shasta* and *Parvicapsula minibicornis*, near the campground.

The effects of discharge on migration in 2007 were affected by fish migration behavior. As in 2006, few hatchery fish released near IGH were detected passing the Shasta River site until May, despite releases that began in early April. The change in fish behavior from non-migrant to migrant affects the relation of discharge and migration, because of fish released near IGH those fish upstream of the Shasta River primarily are non-migrants and those downstream are migrants. The effects of discharge on passage rate were small at the Scott River site in 2007, and large in 2006—the slowest passage rates occurred during the highest discharges. The results are consistent with the data: fish migration rate increased with date of release, water temperature increased with date, and discharge generally decreased with date. The effects of discharge, water temperature, and date are often confounded.

Analyses prompted by the current results have led to increased knowledge of the factors affecting migration and survival. Data collected in 2006 and 2007 clearly indicate that hatchery fish released near IGH early in the study period reside upstream of the Shasta River for much longer than fish released later, because few fish migrate until about mid-May. Greater time in the river is often assumed to infer a greater risk of mortality, but the data do not support this inference. Models with a relation between release week and survival in 2006 and 2007 were not supported by the data, but the data do support a positive relation between fish weight and survival upstream of the Scott River. The comparison of release week and survival between years was based on a subset of the data available to eliminate the potential for seasonal differences between years, and some results contradict earlier analyses. We hypothesize that larger fish either out-compete smaller ones for the best cover habitat, spend less time feeding during periods of high mortality risk than smaller fish (for example, during the day), or both. These migration behaviors are well-supported in the literature.

We will alter the study design in 2008 based on data from 2006 and 2007. We will not implement the paired-release design, because (1) an important assumption was violated in 2007, (2) the design reduces sample sizes in the IGH-to-Shasta River reach by 50 percent, and (3) the tagging and handling mortality was negligible when the design was used in 2006. We will tag and release fish from a tank at IGH as well as hatchery fish captured in traps near the I-5 Bridge. The purpose of this added activity will be to see if the use of migrant hatchery fish will result in migration behavior more similar to the behavior of wild fish in 2006. An additional group of wild fish would improve this design, but wild fish probably will not be available in sufficient numbers for our use in 2008.

Introduction

Coho salmon (*Oncorhynchus kisutch)* is a species of Pacific salmon inhabiting most major river systems of the Pacific Rim from central California to northern Japan (Laufle and others, 1986). Several investigations have documented extinction of local populations of coho salmon in Washington, Oregon, Idaho, and California (Nehlsen and others, 1991; Frissell, 1993; Brown and others, 1994). A status review of coho salmon populations from Washington, Oregon, and California (Weitkamp and others, 1995) prompted the National Marine Fisheries Service (1997) to list coho salmon populations within the Southern Oregon/Northern California Coast (SONCC) Evolutionary Significant Unit (ESU) as threatened under the Endangered Species Act (ESA) on May 6, 1997.

The Bureau of Reclamation operates the Klamath Project to provide water to about 971 km^2 of cropland in three counties in southern Oregon and northern California. The Klamath Project relies primarily on water stored in Upper Klamath Lake near Klamath Falls, Oregon, but also includes water from Clear Lake Reservoir, Gerber Reservoir, and the Lost River. Several dams on the Klamath River between Upper Klamath Lake and the Pacific Ocean are used to regulate water releases to the Klamath River and generate electricity, though their reservoirs provide little or no storage capacity (National Research Council, 2001). PacifiCorp currently owns and operates Link River, Keno, J.C. Boyle, Copco #1, Copco #2, and Iron Gate Dams subject to Klamath Project rights. Iron Gate Dam (IGD) located at river kilometer (rkm) 310 is the lowermost dam on the Klamath River.

The Klamath River and its watershed encompass more than 40,403 km^2 in northern California and southern Oregon. Principal tributaries to the Klamath River include the Trinity, Salmon, Scott, and Shasta Rivers. Most of the middle and lower watershed is mountainous with intermittent small valleys. The upper watershed, which contains upper and lower Klamath, Tule, and Clear Lakes, consists of several large valleys and closed basins bordered by mountains. Dense coniferous forests along the coast, where annual precipitation values are some of the highest in the contiguous United States, give way to more Mediterranean conditions and vegetation in the middle and upper watershed.

Maintenance and restoration of anadromous fish populations requires sufficient streamflows to provide adequate habitat for spawning and rearing throughout the freshwater phase of their life cycle, as well as during the downstream migration of juvenile fish to the ocean (Cada and others, 1997). Coho salmon evolved in free-flowing rivers in which downstream migration of juveniles was often associated with high streamflows in the spring. In the Klamath River system, flows are now impeded by water storage reservoirs and reduced by water diversions, resulting in decreased water velocities. Lower water velocities in the spring may slow the downstream migration of juveniles and decrease juvenile salmon survival by increasing exposure to predation and disease (Cada and others, 1997; Clements and Schreck, 2003). Additionally, delayed migration may impair the osmoregulatory ability of juvenile salmon entering the marine environment (Berggren and Filardo, 1993).

In May 2001, the National Marine Fisheries Service [now National Oceanic and Atmospheric Administration (NOAA) Fisheries] issued a Biological Opinion (BIOP) relative to the effects of the Klamath Project on the viability of Southern Oregon/Northern California Coast (SONCC) coho salmon in the Klamath River downstream of IGD (National Marine Fisheries Service, 2002). This evolutionary significant unit of coho salmon was listed as threatened by NOAA Fisheries in 1997 and by the State of California in 2002 (National Marine Fisheries Service, 1997; California Department of Fish and Game, 2002). The BIOP determined that the operation of the Klamath Project jeopardized the existence of threatened SONCC coho salmon in the Klamath River and set forth a Reasonable and Prudent Alternative (RPA) to avoid jeopardizing their existence. Among the elements of the RPA were a prescribed regime of minimum flows at IGD and a water bank of 100,000 acre-feet with implementation to be phased in over a 10-year period. The premise of these elements was that increased river discharge would speed migration of juvenile coho salmon through the Klamath River and result in increased survival. The National Research Council (2001) noted that although this may theoretically be possible, information to support this conjecture does not exist for Klamath River coho salmon. In response to the NRC report, the BIOP mandated the Bureau of Reclamation to implement several studies, including those to determine the extent that spring IGD flow regimes affect survivorship of juvenile coho salmon during their downstream migration. This study is an outcome of that mandate.

Factors affecting juvenile coho salmon migration, survival, and habitat preference during varying flow regimes of the Klamath River are largely unknown. The limited abundance of juvenile coho salmon within the mainstem Klamath River and its tributaries preclude the use of traditional mark and recapture methods to study movement and survival (National Marine Fisheries Service, 2002). However, radio telemetry provides researchers with a powerful method of evaluating downstream migratory behavior and survival of fish populations where the ability to capture and mark large numbers of individuals is impaired (Hockersmith and others, 2003), and has been used to study juvenile salmon migration patterns (McCleave, 1978; Berggren and Filardo, 1993; Lacroix and McCurdy, 1996; Giorgi and others, 1997; Hockersmith and others, 2003; Miller and Sadro, 2003) and estimate survival (Skalski and others, 2001, 2002) of several salmonid species.

Studies on various salmonid species on the Columbia and Snake Rivers have provided evidence that the migration rate of juvenile salmon through impoundments is positively related to water velocity (Berggren and Filardo, 1993; Giorgi and others, 1997), but little evidence of a link to survival has been found (Smith and others, 2002). Berggren and Filardo (1993) also identified water temperature and release date as key factors influencing migration rate. Muir and others (1994) experimentally demonstrated that the level of smoltification and migration rate could be influenced by water temperature and photoperiod. Smith and others (2002) did not find a significant relation between river discharge and survival of yearling Chinook salmon and found only a weak relation in juvenile steelhead. However, the Klamath River is a much different system than the mainstem Columbia and Snake Rivers, and different processes may affect juvenile salmonids in the two river systems.

The objectives of this study were to: (1) provide estimates of the survival of hatchery and wild juvenile coho salmon downstream of IGD, (2) determine if there is a relation between flow and other environmental and physiological variables with survival of juvenile coho salmon, (3) determine if there is a relation between flow and other environmental and physiological variables with migration behavior of juvenile coho salmon, and (4) determine if juvenile hatchery coho salmon can serve as surrogates for wild fish for future survival studies.

Methods

Study Area

The study area encompassed most of the lower 310 rkm of the mainstem Klamath River from IGD to the estuary at the Pacific Ocean (fig. 1). Automated radio telemetry stations were installed near the confluences of major tributaries and upstream of the estuary. The reach from IGD (rkm 310) to the Scott River (rkm 234) is significantly influenced by IGD flow releases and was the primary focal area studied to address objectives 2-4.

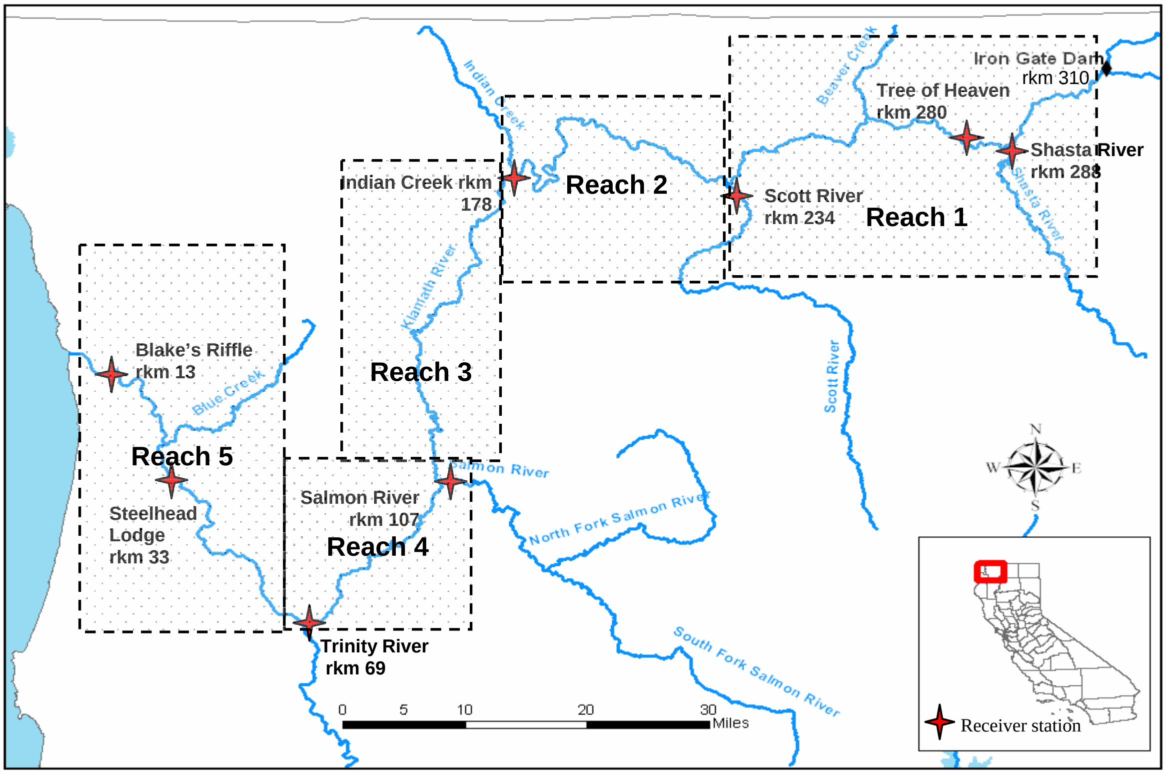


Figure 1. Map of the Klamath River study area showing tributaries of the five index reaches over which survival was estimated and locations of automated radio telemetry stations deployed in 2007.

Transmitter Specifications

Pulse-coded radio transmitters (or tags) operating at 164.320, 164.360, and 164.480 MHz were used. Transmitter dimensions were 5 mm wide by 3 mm high by 13 mm in length and weighed 0.43 g in air and 0.29 g in water (Lotek Wireless, Newmarket, Ontario, Canada; model NTC-M-2). The antenna (type S1) measured 0.3 mm wide by 16 cm in length and was covered in a Teflon® coating. Within each frequency, transmitters were differentiated into five subgroups based on the burst rate of the uniquely coded radio signal (7.8, 7.9, 8.0, 8.1, and 8.2 s). The expected life of transmitters using a coded burst rate of 8 s was 45 d.

Stationary Detection Systems

Eight automated radio telemetry stations were established along the mainstem Klamath River from IGD to rkm 13 (fig. 1). The location and dates of operations of each station are listed in table 1. Each station consisted of two to four Yagi aerial antennas (using three- or six-element antennas depending on coverage needed), mounted on a 3 m mast, connected to two data-logging receivers (fig. 2). Two types of data-logging receivers were deployed at each array (SRX-400, Lotek Wireless, Newmarket, Ontario, Canada; Orion, Grant Systems Engineering, Newcastle, Ontario, Canada) because each has unique characteristics that enhance the detection of radio tags. For example, SRX receivers are more sensitive and are better at detecting weak signals but have a longer scan cycle.

Each receiver was configured to maximize the potential for detecting tagged fish. The SRX receivers monitored each frequency for 8.7 s before cycling to the next frequency, so the SRX receiver requires approximately 26 s to cycle through the three frequencies. However, the Orion receivers are able to scan all frequencies simultaneously. Each array was supplied power by a 12 V system (180 amp hour battery) powered by a 170 W photovoltaic bank (solar panel). Receiver gain level was set to maximize signal reception while avoiding detection of erroneous signals caused by local interference (for example, power lines and private radio transmissions). The gain of most SRX receivers was set near 75 on a unitless scale of 0 to 99. The noise floors of the Orion receivers generally were set near -120 dB. When a signal was detected, transmitter channel (frequency), code, signal strength, time, and date were recorded. Stations collected data continuously. Radio telemetry data were downloaded from each site, at a maximum, weekly.

Table 1. Summary of automated radio telemetry stations deployed on the Klamath River, northern California, 2007.

[Reach designations: (Test) IGD – Tree of Heaven.; (1) IGD – Scott R.; (2) Scott R. – Indian Cr.; (3) Indian Cr. – Salmon R.; (4) Salmon R. – Trinity R.; (5) Trinity R. – Steelhead Lodge.; (5a) Trinity R. – Blake’s Riffle]

Site location / Flow reach	rkm	Receiver type	Dates of operation
Shasta River / Test	288	SRX-400 & Orion	4/4/07 – 8/08/07
Tree of Heaven / Test	280	SRX-400 & Orion	4/4/07 – 8/08/07
Scott River / 1	234	SRX-400 & Orion	4/4/07 – 8/08/07
Indian Creek / 2	178	SRX-400 & Orion	4/4/07 – 8/08/07
Salmon River / 3	107	SRX-400 & Orion	4/4/07 – 8/08/07
Trinity River / 4	69	SRX-400 & Orion	4/4/07 – 8/08/07
Steelhead Lodge / 5	33	SRX-400 & Orion	4/5/07 – 8/10/07
Blake’s Riffle / 5a	13	SRX-400 & Orion	4/5/07 – 7/17/07

Figure 2. Photograph showing typical automated radio telemetry detection station. This site is located approximately 1.5 km upstream of the confluence between the Klamath River and Indian Creek, northern California.

Mobile Detection Systems

Mobile tracking was conducted to collect data from tags between the stationary detection arrays to aid in determining tag fate. This task was important because data from mobile tracking were used as an aid in proofing data from automated receiving systems and recovered tags were censored during migration analyses (see section, "Migration Analyses" for a further description of censoring).

Mobile tracking surveys were made from automobiles and inflatable rafts using a Lotek SRX-400 receiver connected to a three-element Yagi antenna. Mobile tracking occurred 4 days a week throughout the season beginning on April 11, 2007 until no radio signals were detected between IGH and the Scott River (last detection was June 22, 2007). Information about the location, habitat, and migration behavior were recorded when radio-tagged fish were located. A Global Positioning System (GPS) receiver (Garmin model GPSMap 76S) was used to record spatial coordinates. Fish positions were then assigned the nearest river kilometer and Meso-Habitat Type unit (MHT) using aerial photographs of the river with this information superimposed over the image. Other information recorded each time a fish was located included: date, time, channel code (unique fish identifier), and scaled ratings of movement, and position relative to previous known position. Assignment of movement ratings were based on a minimum 5-min observation period at a maximum distance of approximately 5 m to the fish position.

Additional information was collected from radio-tagged fish when the expected remaining tag life was less than 10 d (that is, greater than 35 d since activation). Crews were provided instructions that included protocols for diving and use of underwater antennas (coaxial cable with terminal 10 cm of insulator removed) to determine exact location and recover transmitters that were no longer in fish. All surveys were conducted during daylight hours.

Fish Handling and Tagging

Collection

Hatchery fish used in this study were obtained from Iron Gate Hatchery (IGH). On April 2, 2007, 500 hatchery fish were transferred from an outdoor raceway into a large rectangular tank (2,256 L; 1.4 m width, 4.5 m length, 0.4 m depth). Fish held in this tank were either used in (1) the radio telemetry study, (2) a gill ATPase experiment to determine the relation between in-river exposure time and gill ATPase activity, or (3) sampling to determine the prevalence of bacterial kidney disease (BKD).

Transport

Transporting fish was required to accomplish a paired-release design, which required two release sites. Because transportation was required to move fish to the control site, we subjected the treatment fish to similar conditions by handling and transporting the fish an equal distance before returning them to the treatment site for tagging. All fish were transported by vehicle in a 115 L oval-shaped tank with a battery powered re-circulating pump. Stress Coat® (Aquarium Pharmaceuticals Inc., Chalfont, Pennsylvania) was added to the tank (1 mL/10 L) prior to transport to reduce electrolyte loss and damage to skin tissue. Water temperature and dissolved oxygen were recorded (YSI Model 55 YSI Incorporated, Yellow Springs, Ohio) at collection sites, and at pre-transport, post-transport, and at holding sites to ensure that proper water-quality conditions were maintained for holding and transporting fish. Prior to and during transport, dissolved oxygen in the transport tank was maintained at a minimum level of 80 percent saturation using oxygen supplied through an air stone at 10 lbs/in^2. Water temperature was maintained within 2°C of the collection source temperature during transport using dechlorinated ice when needed. If transport tank water (upon arrival at holding site) and holding site water (river water) temperatures differed by more than 2°C, the transport tank water was tempered to within 2°C at a rate of 0.5°C/15 min. Following transport, fish were held at tagging sites in floating net pens (dimensions were 1.2 ×0.6×0.6 m, lined with 5×5 mm bar mesh) before being tagged that day (fig. 3).

Figure 3. Photograph of holding pens at Iron Gate Hatchery, located at the entrance to the adult fish ladder. Photograph on right shows the bucket layout within each net pen.

Surgical Procedures

Procedures for surgical implantation of radio transmitters were similar to those described by Adams and others (1998). A foam support with a center groove shaped to fit the dorsal surface of a small salmonid was lined with a chamois soaked in Poly Aqua® (Novalek, Inc., Hayward, California) to support the fish's body during surgery. Fish were placed into a primary anesthetic solution (approximately 70 mg/L) of tricaine methanesulfonate (Finquel® MS-222 (Argent Chemical Laboratories, Redmond, Washington) until loss of equilibrium occurred. After removal from the primary anesthetic solution, each fish was placed ventral side up in the surgical support and the gills were flushed with secondary anesthetic solution of tricaine methanesulfonate (20 mg/L) continuously administered at a rate of approximately 250 mL/min through a tube placed in the fish's mouth for the duration of the procedure.

Prior to insertion, transmitters were disinfected using a 0.5 percent disinfectant solution of chlorohexidine diacetate (Nolvasan® Fort Dodge Animal Health, Fort Dodge, Iowa). Transmitters were rinsed twice in sterile water and placed on the sterile portion of a surgical glove wrapper along with the surgical instruments immediately before surgery. Because complete sterilization of surgical equipment under field conditions is difficult, two sets of surgical instruments were alternately employed, enabling one set to be disinfected by soaking in 100 percent ethanol while the other set of instruments was being used in surgery. Sterile surgical gloves were worn during each surgical procedure.

To implant the transmitter, a 7-mm (approximate) incision was made about 5 mm anterior to the pelvic girdle and about 3 mm away from and parallel to the mid ventral line. The incision made was only deep enough to penetrate the peritoneum (Summerfelt and Smith, 1990). The shielded-needle technique described by Ross and Kleiner (1982) was used to provide an outlet through the body wall for the transmitter antenna. A 20-gauge × 50 mm catheter-covered needle (BD Angiocath I.V.) was inserted through the incision and guided 10 to 20 mm posterior and slightly dorsal to the pelvic girdle.

After depressing the needle through the body wall, it was removed through the incision, leaving the nylon catheter tube to guide the transmitter antenna through the body wall. The antenna of the transmitter was then fed through the incision end of the catheter and pulled out the exiting end as the transmitter was inserted into the body cavity. The transmitter was positioned to lie slightly posterior to the incision by gently pulling on the antenna. A single simple interrupted suture (Ethicon coated vicryl braided, 5-0 reverse cutting P-3 needle) closed the incision. After suturing, a small amount of antibacterial ophthalmic ointment (Neobacimyx®) was spread over the incision site to reduce the risk of infection (Summerfelt and Smith, 1990). After tagging, radio-tagged coho salmon were held in a perforated bucket (19 L) within the floating net pen (fig. 3) for at least 24 h (range 24-36 h) before being released after dark. Only coho salmon weighing 8.6 g or greater were tagged to ensure the transmitter weight did not exceed 5 percent of the individual's body weight (Adams and others, 1998).

Measures of Smoltification and Disease

Gill ATPase Activity

This common measure of smoltification was collected to aid in the evaluation of the potential for hatchery-reared fish to be used as surrogates for wild-origin fish. Smoltification of juvenile Pacific salmonids has been shown to occur largely after release from hatcheries, so we monitored Na^+-K^+ gill ATPase activity in all tagged fish as well as an addition group of hatchery fish during a time series after being removed from the hatchery.

A non-lethal sample of gill tissue was collected prior to surgical implantation of the radio transmitter to assess the relation between smoltification and migration rate or survival. The Na^+-K^+ gill ATPase activity level in the gill sample was quantified and used as a measure of smoltification. The small piece of gill filament (about 2×3 mm) was removed from the first gill arch on the left side and was suspended in a sample tube containing 0.5 mL of buffer solution, following the methods described in Schrock and others (1994). Sample tubes were placed directly into liquid nitrogen, and later stored at -80°C until processing. Each sample tube was uniquely labeled to identify the fish sampled.

An additional experiment was performed using unmarked hatchery fish to determine if ATPase activity changed after fish were transferred from the hatchery holding tank to either the mainstem Klamath River or the Shasta River. A group of 120 hatchery fish (split evenly between the two holding sites) were selected at random from the pool group of 500 fish held at IGH. These fish were transferred to in-river net pens, and gill samples (methods described in Schrock and others, 1994) were collected from 10 fish at each site at intervals of 1, 3, 6, 10, 14, and 21-d post transfer. The fish were held and sampled from April 11 to May 1, 2007. After the gill sample was collected, fish were allowed to recover from the effects of anesthesia and were then released into the river. The gill ATPase activities in samples collected throughout the study period (both from tagged and untagged fish) were later determined by Biotech Research and Consulting, Inc. (Corvallis, Oregon) using the methods described in Johnson and others (1977) for a whole homogenate assay.

Bacterial Kidney Disease

Although juvenile salmonids in the Klamath River are known to be infected with various diseases and parasites, for example, *Ceratomyxa shasta*, *Parvicapsula minibicornis*, and *Renibacterium salmoninarum*, most testing has been restricted to juvenile Chinook salmon. Little is known about the prevalence of infections in the other salmonids, including juvenile coho salmon. Because it could be important to know the prevalence and severity of diseases in coho salmon and the influence of the diseases on migration rate and survival, we sampled for *R. salmoninarum*, the causative agent of BKD, using a non-lethal sampling method. *Renibacterium salmoninarum* can be detected in small gill tissue samples; thus avoiding the mortality associated with collection of kidney tissue.

Disease sampling occurred on May 16, 2007, with fish netted from the same holding tank as fish held for the radio telemetry objective. Tissue collection was limited to non-tagged hatchery coho salmon at IGH. After each fish was anesthetized in MS-222 (approximately 70 mg/L of tricaine methanesulfonate), a small sample of gill tissue (approximately 2×3 mm) was removed from the first gill arch. The tissue sample was placed in a pre-weighed cryotube and immediately placed in liquid nitrogen for preservation. Dissecting scissors and gloves were replaced between each sampling event to prevent cross contamination. Samples were analyzed by U.S. Geological Survey, Western Fisheries Research Center, Seattle, Washington, following the methods described in Chase and others (2006).

Data Analyses

Converting Radio Signals into Detection Histories

Data from automated detection arrays were converted into detection histories to calculate detection probabilities specific to each array. The automated arrays recorded about 2.5 million radio signals that were processed to create reliable detection histories before analyzing fish detection data. These signals include multiple detections from live fish, potentially dead fish, as well as spurious signals. The purpose of signal processing was to segregate actual detections for radio-tagged fish from the spurious records.

Valid detections were identified by filtering radio-signal data using multiple data proofing criteria. Raw release and automated detection array data were merged and proofed against several criteria using a program written in SAS programming language (version 8.1; SAS Institute Inc., Cary North Carolina; fig. 4). Records that did not meet the automated criteria were examined independently by staff at the USGS and USFWS offices and reconciled to determine their validity. An additional 10 percent of the records passing the criteria were examined manually as a quality-control measure to ensure the automated process was performing satisfactorily. After reconciliation, a final dataset was created for use in analyses.

River Conditions

Daily average river discharge values were obtained from monitoring stations operated by the USGS at points along the mainstem Klamath River and its tributaries. Daily discharge data were obtained from http://waterdata.usgs.gov/nwis/dv. The method for quantifying the discharge experienced by a radio-tagged fish as it migrated through index flow reaches differed within each reach depending on the location of the mainstem and tributary flow gaging stations (table 2). Temperature data were collected at 30-min intervals using Onset Stowaway® Tidbit® temperature data loggers (range 4-38°C) placed in the mainstem Klamath River directly upstream of tributaries delineating the end of index reach boundaries and in the net pens we used to hold fish prior to release.

Migration Analyses

Migration was examined primarily using time-to-event analysis methods. These methods are designed for the analysis of the occurrence of the timing of events. These methods commonly are used in the health field to evaluate the effects of treatments on death rate, and hence they are often referred to as methods for "survival analysis." As such, much of the terminology used in these methods stems from their use in the medical field and can be confusing in other fields (for example, survivor functions). Their general use is well described in the literature (Muenchow, 1986; Pyke and Thompson, 1986; Hosmer and Lemeshow, 1999), but their use to describe fish movements was first described by Castro-Santos and Haro (2003). The methods are particularly suited to analysis of times until events occur because they allow for censoring (that is, removal of an observation of an individual from analysis after some point, but using its data beforehand) and analysis of time-dependent variables. An example of censoring would be to omit observations of an individual from analyses after it was known to have died, or its radio transmitter was found separated from the fish. Time-dependent variables include average daily river discharge and average daily water temperature, which change between detection sites over time.

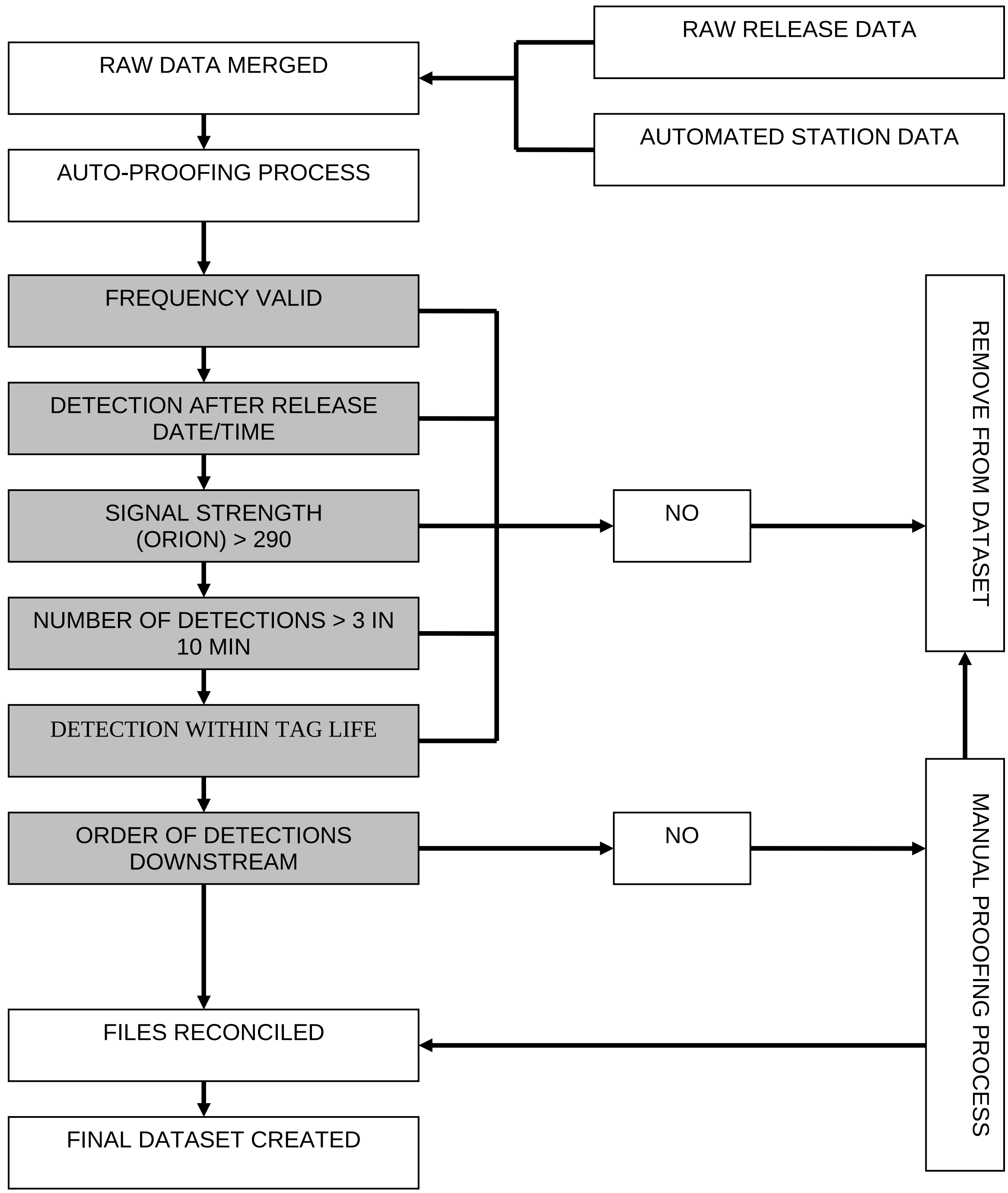


Figure 4. Diagram showing project data flow and criteria used to identify valid radio signals recorded at radio telemetry stations. Shaded boxes represent automated data filter criteria.

Table 2. USGS gage descriptions and calculations used to quantify river discharge within index flow reaches during the 2007 study period.

[Reach designations: (Test) IGD – Shasta R.; (1) IGD – Scott R.; (2) Scott R. – Indian Cr.; (3) Indian Cr. – Salmon R.; (4) Salmon R. – Trinity R.; (5) Trinity R. – Steelhead Lodge.; (5a) Trinity R. – Blake's Riffle. USGS gage sensor ID numbers: IGD (11516530); Shasta R. (11517500); Scott R. (11519500); Seiad (11520500); Indian Cr. (11521500); Salmon R. (11522500); Orleans (11523000); Trinity R. (11530000); Blake's Riffle (11530500)]

Reach	Gages used	Calculation
Test	IGD	None
1	IGD, Scott R., Seiad	(Seiad - Scott) + (IG)/2
2	Seiad	Seiad
3	Seiad, Indian Cr., Salmon R., Orleans	(Orleans - Salmon) + (Seiad + Indian Creek)/2
4	Orleans	Orleans
5	Orleans, Trinity R.	(Trinity + Orleans)
5a	Orleans, Trinity R., Blake's Riffle	(Trinity + Orleans) + (Blake's Riffle)/2

The survivor function was used to compare the distributions of event times between groups or origins within reaches. The survivor function of a variable T is defined as:

$$S(t) = \Pr\{T>t\},$$

where T is a random variable with a probability distribution, denoting an event time for an individual. If the event of interest is passing through a reach of the river, the survivor function gives the probability of not passing the terminus of river reach of interest after time *t*. As such, the median time occurs when the survivor function equals 0.5. Survivor functions were estimated using the Kaplan-Meier method, in which the time-interval boundaries are determined by the event times and censored observations are assumed to be at risk for the entire event period. The alternative is the Life Table method, in which the time-interval boundaries can be specified by the analyst and censored data are censored at the midpoint of the time interval (Hosmer and Lemeshow, 1999). Survivor functions were plotted and compared between fish groups (treatment or control). Comparisons of survivor functions between groups were made using Log-Rank and Generalized Wilcoxon Rank Sum tests (Allison, 1995; Hosmer and Lemeshow, 1999). In our analyses, the 'event' was passing the downstream end of the river reach of interest and the 'time to the event' was the time from the last detection 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, travel time.

The relation between selected covariates and fish travel time was assessed using Cox Proportional Hazards regression analysis. In these analyses, the effects are written in terms of the hazard function. The hazard function is defined as:

$$h(t) = \lim_{\Delta t \to 0} \Pr\{t \le T < t + 1 \mid T \ge t\} / \Delta t,$$

and is the instantaneous risk that an event will occur at time *t*. The equation describes a conditional rate: it is the ‘probability of the event time occurring in a limited time interval, conditional on the event having not occurred yet’, divided by the length of the interval (which makes it a rate, not a probability; Allison, 1995).

The Cox proportional hazards regression model was used to examine the effects of several time-independent and time-dependent variables and their interaction terms when appropriate. Data were examined to ensure model assumptions of linearity and proportional hazards were met and correlations between variables were examined to determine autocorrelation. Linearity was assessed visually by plotting the Martingale residuals. The proportional hazards assumption was assessed by plotting Schoenfeld residuals (Hosmer and Lemeshow, 1999). Covariates included in the models initially were selected by applying logical subject-matter knowledge. Variables included as main effects include group, river discharge in the reach of interest during the time the fish was present, river water temperature in the reach of interest during the time the fish was present, ATPase, fish weight, and serial date of release. Interactions of several of these variables also were added to the full models (that is, most parameterized). The daily average values of the main effects of river discharge and water temperature were used as time-dependent covariates. Model selection was assessed using Akaike Information Criterion (AIC) and AIC weights as described in Burnham and Anderson (2002). Robust sandwich variance estimates were used based on grouping fish into release cohorts by group and release date. This method adjusts the estimates of the variance of the model coefficients to account for correlation among related observations, such as those released on a common date (Hosmer and Lemeshow, 1999). An overall goodness of fit test was performed comparing the final models to those with an additional 10 dummy variables as described in Hosmer and Lemeshow (1999).

Migration analyses were restricted to reaches upstream of the Indian Creek site. This was done primarily because the ratio of IGD discharge to total river discharge, and hence the influence of operations at the dam, is reduced rapidly with distance from the dam.

Survival Analyses

The basis for estimating survival using mark-recapture methodology is described by Burnham and others (1987). Methods to accommodate specific issues related to the use of radio telemetry are described by Burnham and others (1987) and Skalski and others (2001) and their methods have been used successfully in various studies (Counihan and others, 2002; 2005; Skalski and others, 2002).

Apparent survivals were estimated based on Cormack-Jolly-Seber capture-recapture methods (Cormack, 1964; Jolly, 1965; Seber, 1982). Apparent survival is the probability that an animal remains available for recapture. In the context of this study, it is the joint probability that the animal is both alive and migrates through the study area. As such, fish that stop migrating, or travel to areas outside the mainstem Klamath River and do not return during the study period are counted as mortalities. Fish remaining in the study area after their transmitters cease operating also are counted as mortalities. All references to 'survival' estimated during this study refer to apparent survival. Inasmuch as detection at a site is the product of the probability of survival to the site and the probability of capture at the site, these parameters must be estimated separately. The assumptions associated with the method depend on the design of the experiment and are described below.

The analyses were carried out within the 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 on the basis of parsimony using the AIC or one of its variants, assessing model uncertainty and using model averaging where appropriate, and producing estimated apparent survivals (phi, Φ) and capture probabilities (*p*). Model fit was assessed using the median c-hat procedure (Cooch and White, 2006). When appropriate, adjustments to AIC were made for small sample sizes relative to the number of parameters in the models (AICc), to account for extra-binomial variation (QAIC), or both QAICc. Detailed descriptions of these methods can be found in White and Burnham (1999) and Burnham and Anderson (2002).

Single-Release Design

The single-release design was used to estimate survival of fish through the various study reaches and through the entire study area. The term "single-release" refers to the use of one or more releases of fish made at a single location. This design requires as a minimum the following elements: (1) tagged fish are uniquely identifiable, (2) at least two downstream detection sites exist downstream of release locations, (3) re-release of all or some of the marked fish recaptured at each detection location, and (4) recording of the identity of the marked fish recaptured at each location (Peven and others, 2005). John Skalski (University of Washington) in Peven and others (2005) provides a discussion of the potential biases associated with this and other designs. The primary potential bias associated with this design is that expression of mortality due to tagging or handling cannot be separated from other sources of mortality. These can be separated using the paired-release design, which is described later in this section.

Survival can be estimated from the release point to the next detection site and from then on, survival is estimated from the detection zone of one detection site to the next. Unique recapture probabilities can be estimated at both sites bounding each reach except the last reach (see single release schematic in fig. 5). In the last reach, only the joint probability of survival to, and being detected at, the last site can be estimated (that is, $\lambda = \Phi \bullet p$). Thus, the minimal study design must consist of at least two downstream detection locations. The assumptions of the single-release design are the following:

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 first assumption (A1) involves inferences from the sample taken to the target population. For example, if inferences are desired for juvenile SONCC coho salmon, then the sample of tagged fish should be drawn from that population. These assumptions could be violated if the fish selected for tagging were on average larger than the target population, or if they had a substantially different migration pattern.

Assumption (A2) again concerns making inferences to the target population (that is, untagged fish). If tagging has a detrimental effect on survival, then survival estimates from the single release-recapture design will tend to be negatively biased.

The third assumption (A3) stipulates that mortality is negligible immediately near the sampling arrays, so that the estimated mortality is associated with the river reaches and not the sampling event. For migrant salmonids, the time spent near detection equipment typically is brief relative to the time spent in the river reaches and the detection areas are small relative to the reaches between them.

The assumption of independence (A4) suggests that the survival or death of one fish has no effect on the fates of others. In a riverine situation, this is likely true. Violations of assumption (A4) may bias the variance estimate (true variability would be greater than estimated).

Assumption (A5) specifies that the prior detection history of the tagged fish does not affect subsequent survival. The lack of handling following initial release of radio-tagged fish minimizes the risk that subsequent detections influence survival.

Similarly, assumption (A6) could be violated if downstream detections were influenced by upstream passage routes taken by tagged fish. Violation of this assumption is minimized by designing telemetry detection fields that span the breadth of the river.

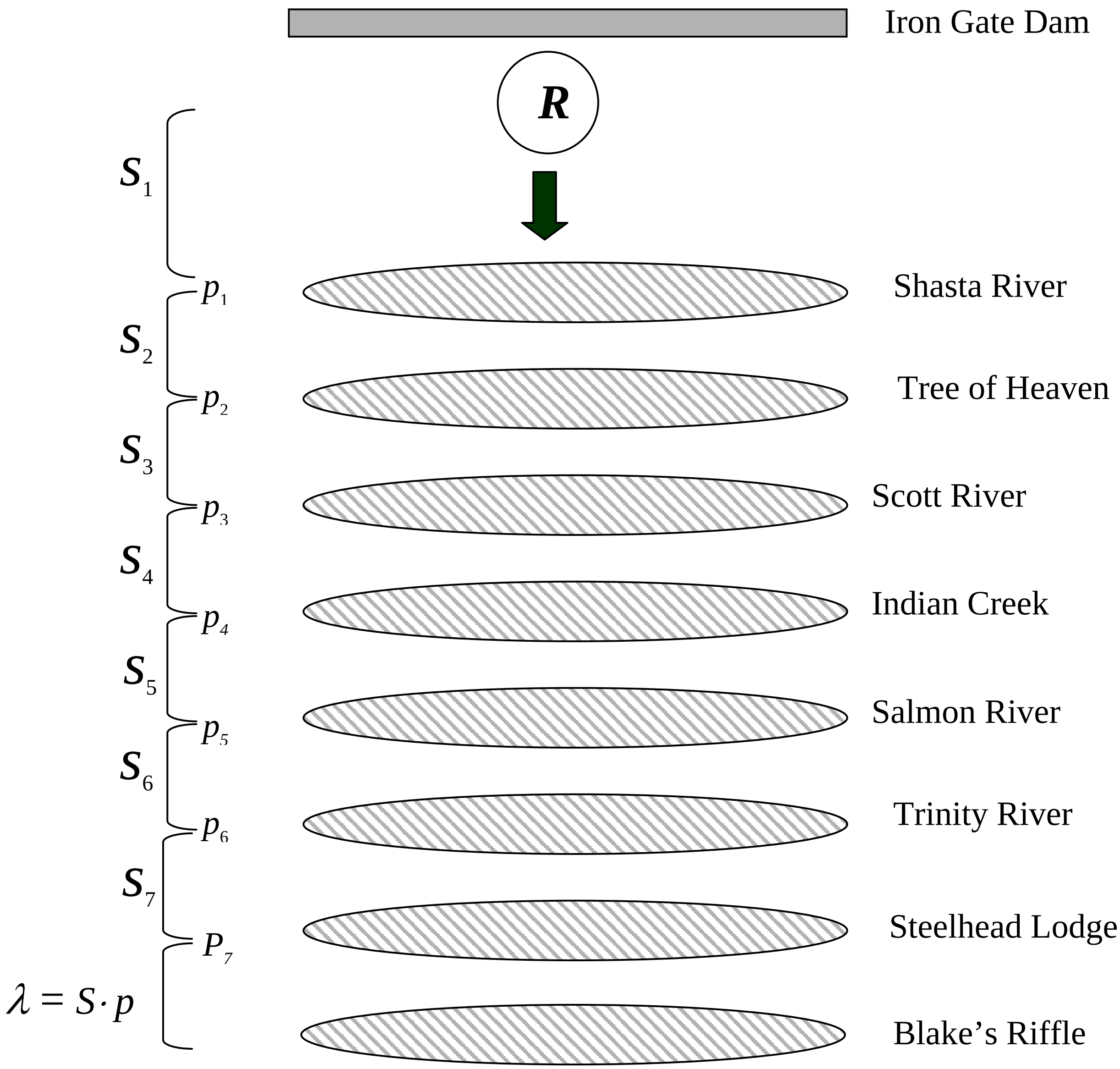


Figure 5. Schematic of release, possible detection sites, and estimated survival parameters (*S* = survival estimate, *p* = capture probability, and = *S* · *p*) generated in a single release-recapture design to estimate juvenile coho survival from release (R) downstream of Iron Gate Dam through several reaches of the Klamath River. Ovals represent potential detection sites. Survival from any two points is the product of the survivals between the two points (for example, survival from release to Indian Creek = *S*1 * *S*2 * *S*3 * *S*4). Only , the joint survival and capture probability can be estimated in the last reach.

Assumption (A7) implies that live fish do not lose their tags and are subsequently misidentified as non-detected, and dead fish with live tags are not falsely recorded as alive at detection locations. Tag loss and tag failure would result in a negative bias (that is, underestimation) of fish survival rates. The possibility of tag failure will depend on travel time relative to battery life. Dead fish drifting downstream could result in false-positive detections and upwardly bias survival estimates. Two actions were undertaken to determine if we met this assumption: data from a tag-life trial was compared with the time fish were in the study areas (appendix 1) and euthanized radio-tagged fish were released. A subsample of radio-tagged fish were euthanized and released at treatment and control sites. A total of 24 radio-tagged hatchery coho salmon (12 each at the treatment and control sites) were euthanized and released throughout the study period. Fish to be euthanized were haphazardly selected from the release group immediately prior to release.

Single-release-recapture methods were used to estimate an overall survival in each reach and among all reaches. In this analysis, the results of the most likely model were used to estimate survivals and confidence intervals for each reach. The overall survival from release to the second to last capture site was estimated as the product of each reach estimate [Φoverall = $\Phi_1 * \Phi_2 * \Phi_3 * \Phi_4 * \Phi_{5,}$ with variance calculated using the delta method (Seber, 1982)].

Model fit was assessed by plotting deviance residuals and overdispersion was assessed based on the most parameterized model. The program MARK provides several means to assess model fit; we chose to use the median c-hat procedure, because high capture probabilities resulted in many incalculable Chi-Square tests in the Test 2 and Test 3 goodness of fit methods of Burnham and others (1987), rendering the overall Test 2 and Test 3 goodness of fit method unsatisfactory. Models were developed based on logical divisions of the data, such as experimental group (control, treatment), year, or release date.

Paired-Release Design

The paired-release design was used to estimate survival from release near IGD to the Tree of Heaven campground (control site), without the potential effects of tagging and handling. The results are the apparent survival of treatment group fish released at IGD as a ratio, or relative, to those of control group fish released at Tree of Heaven. The paired-release design has the advantage of incorporating potential tagging and handling effects, thereby yielding an unbiased estimate of reach survival. As such, the result of this design represents the survival between the release site of the treatment group to the release site of the control group, without the potential effects of tagging and handling. The model requires a minimum of two release locations and at least one downstream detection site. In addition to the assumptions required for the single-release design, the paired-release design requires:

A8. Survival in the lower river segment of the first reach is conditionally independent of survival in the upper river segment (that is, $S_{t1} = S\text{t}_a * S\text{c}1$ and $S\text{t}_b = S_{c1}$; see fig. 6).

A9. Releases R_t and R_c have the same probability of survival in the lower segment of the reach they share in common (between the release location of R_c and the first detection location; i.e., $S_{tB} = S_{c1}$ in fig. 6).

Use of the paired-release design does not prevent estimating survival downstream of the reach of interest using the single-release design. Figure 6 depicts a schematic of the paired-release design and estimable parameters. Figure 7 illustrates the concept of canceling out tagging and handling effects using the paired-release design.

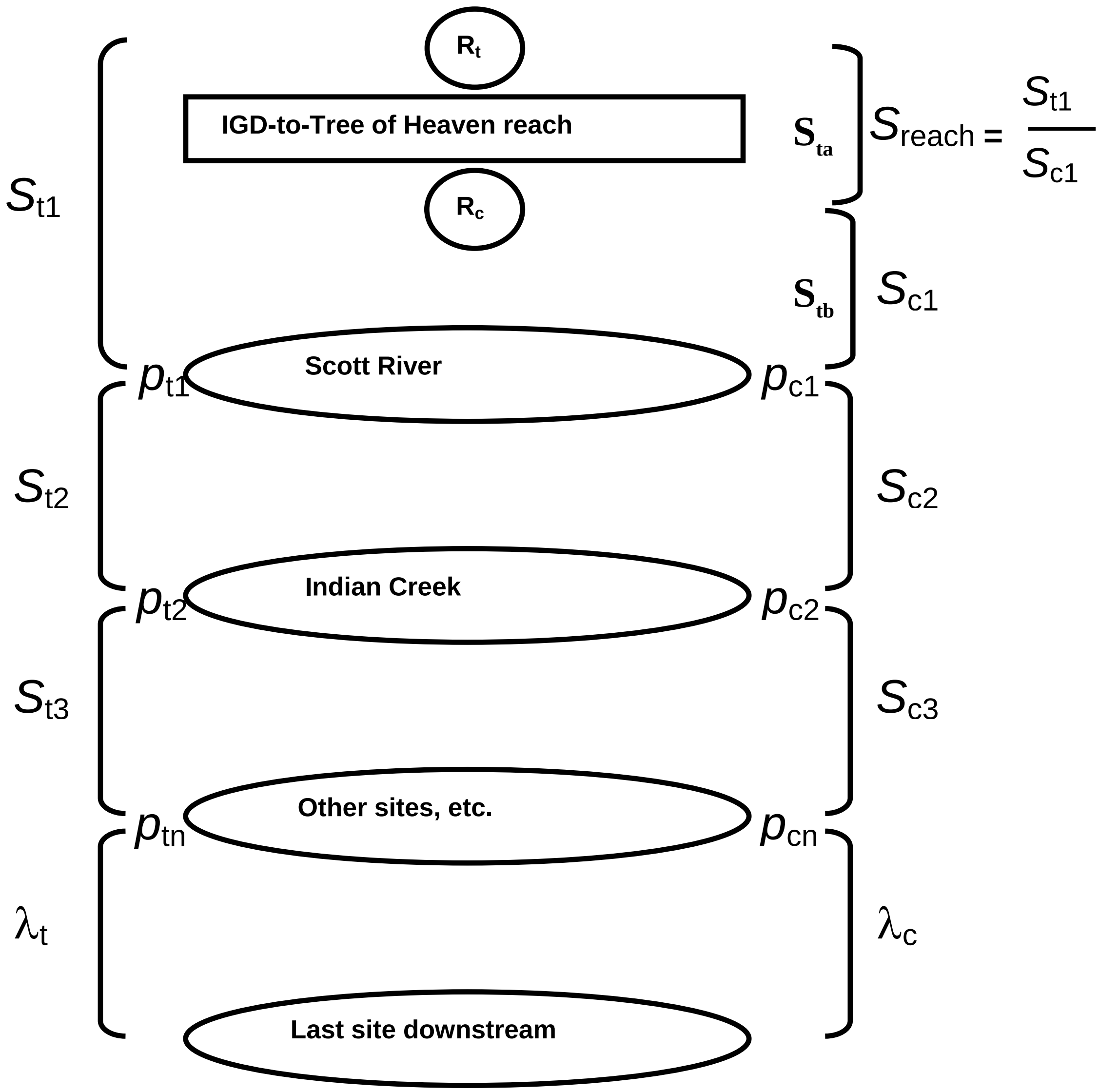


Figure 6. Schematic of a potential paired-release-survival model for the Klamath River juvenile coho salmon study. Treatment fish released near Iron Gate Dam (IGD) would be paired with control fish released near the detection site at the Tree of Heaven campground. Survival from release near the dam to the Tree of Heaven (*S*reach) would be measured relative to the control group, canceling out effects of survival due to tagging and handling (see fig. 7).

$$S_{reach} = \frac{S_{t1}}{S_{c1}} =$$

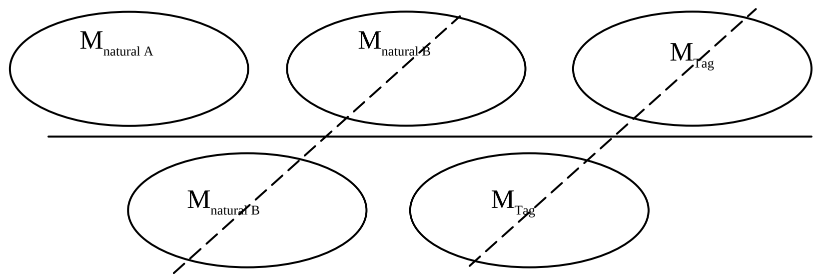


Figure 7. Conceptual representation of how tag effects can cancel out within the paired-release design. Survival of the treatment group in the reach between release and recapture (*S*t1) is affected by natural mortality in the reach between release of the treatment and control group (MNatural A), from there to the detection site (MNatural B) and tag and handling effects (MTag). Survival of the control group (*S*c1) is affected by natural mortality between release and detection (MNatural B) and tag and handling effects (MTag). All effects except MNatural A cancel out in the ratio of *S*t1 to *S*t2, resulting in an unbiased (*S*reach) when model assumptions are met. See fig. 6 for a schematic of the paired-release design.

Assessing Impacts of Covariates on Survival

The effects of several individual and group covariates on apparent survival were assessed using the program MARK. Covariates were added to the most supported model from the single-release analyses and their effects were determined by examining the rank of the new models in the suite and the sign, size, and standard errors of their beta coefficients describing the covariate effect (that is, slopes). The effects of the covariates: (1) average daily Klamath River water temperature near the Scott River the date after release, (2) average daily IGD discharge the date after release, and (3) release date, were separately assessed by comparing models describing four hypotheses. The hypotheses included covariate effects in: (1) only the first reach (release to Scott River; Acute effect), (2) all reaches except the first (Scott River to rkm 33, Chronic effect), (3) all reaches (release to rkm 33, Acute + Chronic effect), and (4) no covariate effect (Reach Only). These were selected based on results from the migration analyses, which indicated that fish spent much of their total time in the first reach, and the knowledge that the impact of IGD discharge diminishes as accretions from tributaries are added. The support for the hypotheses was assessed by comparing model weights among the four models of each covariate.

Comparisons Between 2006 and 2007 Data

Comparisons of migration and survival between 2006 and 2007 data were made using plots of migration timing and by comparing models of apparent survival. Release dates were grouped into weeks for the purposes of assessing the effects of release date on migration and survival, because we did not feel the data were robust enough to support models with parameters for each release date. Fish released on each date were grouped into release weeks defined as the serial date of release in each year divided by seven and rounded to the nearest integer. Data from release weeks common to both years were used so comparable time periods were used in each year. The purpose of restricting the analyses to common times from each year was to avoid differences between years that may be due to seasonal effects. Models of survival developed based on *a priori* hypotheses were compared using information—theoretic methods described earlier in this report. The hypotheses of the effects of release week on survival included: effects in all reaches downstream; in only the release-to-Shasta River reach; in only the release-to-Scott River reach; and no effect. All models included parameters describing additive effects of year and reach on survival and an effect of year on capture probability, as these effects were clearly supported by the data.

Quality-Assurance Measures

Prior to field season activities, a quality-assurance (QA) plan was implemented to ensure all field procedures and scientific data collection followed established protocols. The scope for this QA plan encompassed pre-season activities (planning), field activities (tagging, releasing, and downloading), and office activities after data collection, such as data processing, analysis, and report preparation.

Before the field season began, all personnel tasked with duties involving the creation or retrieval of data were required to review pertinent standard operating procedures (SOP) related to assigned tasks. When field activities began in April, a designated person monitored daily tasks to ensure all procedures conformed to written guidance. Periodic spot checks were done throughout the field season to ensure procedures continued to be followed.

Data collected (except automated detection data) were first handwritten, then at the earliest opportunity, entered into an electronic format, for example, Microsoft© Excel spreadsheet. The electronic spreadsheet was then visually proofed twice against the handwritten data to ensure accuracy before an electronic copy was sent to USGS and USFWS offices. At the USGS office, 10 percent of the data lines were randomly selected for another visual proofing before the electronic data were finalized and uploaded into the database. Discrepancies found during random line proofing were communicated back to the field staff for reproofing of entire datasheet. After the additional proofing, data were resubmitted for uploading. The automated detection data files also were subjected to proofing for completeness and file naming accuracy with 10 percent randomly selected prior to finalization. All quality assurance documents, copies of all handwritten data, and data files selected for proofing were stored with the 2007 Klamath River QA plan for later review.

Results

River Conditions

This study began after the discharge at IGD peaked during the third week of March (4,010 ft^3/s, fig. 8). During the 2007 study period, the average daily discharge downstream of IGD (rkm 309; USGS gage sensor ID 11516530) was 1,518 ft^3/s (range 1,020 to 2,460 ft^3/s). The average daily discharge recorded at Blake's Riffle (rkm 13; USGS gage sensor ID 11530500) was 9,820 ft^3/s (range 3,270 to 20,500 ft^3/s).

River discharge during the study period generally was below the average for the period of record (1962–2007). The probability of river discharge exceeding values recorded at IGD was 0.58 and 0.63 during April and May, but decreased to 0.21 and 0.10 in June and July due to minimum discharges at IGD mandated by a recent Biological Opinion (fig. 9).

The probability of river discharge exceeding values recorded at Seiad Valley, and Blake's Riffle during the 2007 study period was greater than 0.39 for the months of April–July. The contribution of IGD discharge to total river discharge volume was greatest within the uppermost three reaches during the 2007 study period. From the dam downstream to Seiad Valley, the proportion of IGD discharge relative to total river volume generally was greater than 0.34 throughout the April through July study period (fig. 10).

Mean daily water temperatures at the two release sites in the Klamath River were similar throughout the study period (average temperature difference = 0.65 °C) with the control site temperature generally warmer (fig. 11). Water temperatures in the Klamath River generally decreased downstream along the longitudinal gradient, due largely to accretions of colder water from tributaries. River discharge and water temperature were inversely related within all flow reaches during the 2007 study period.

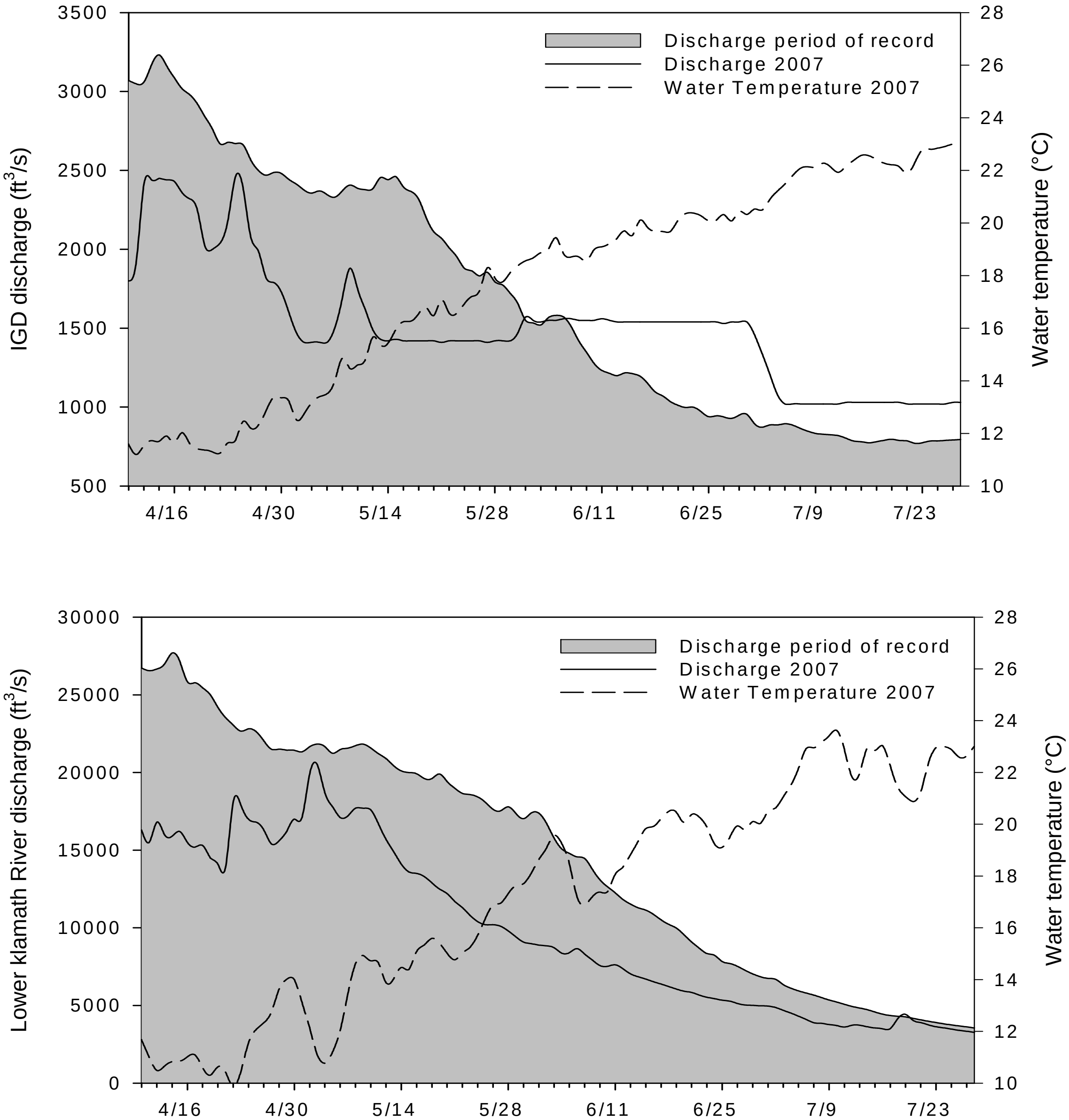
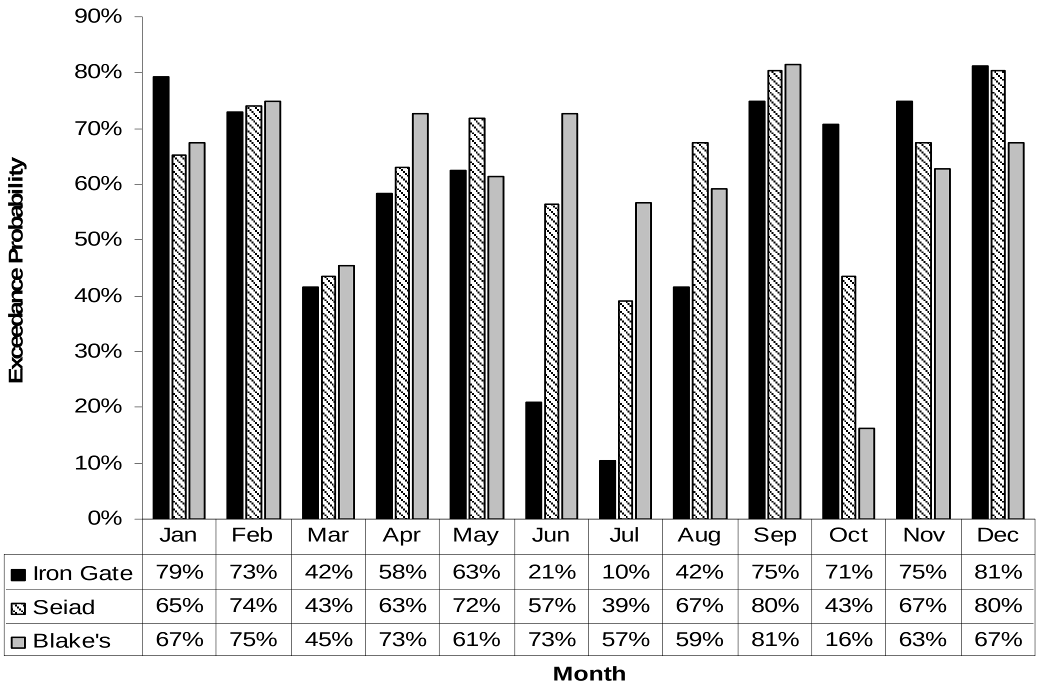
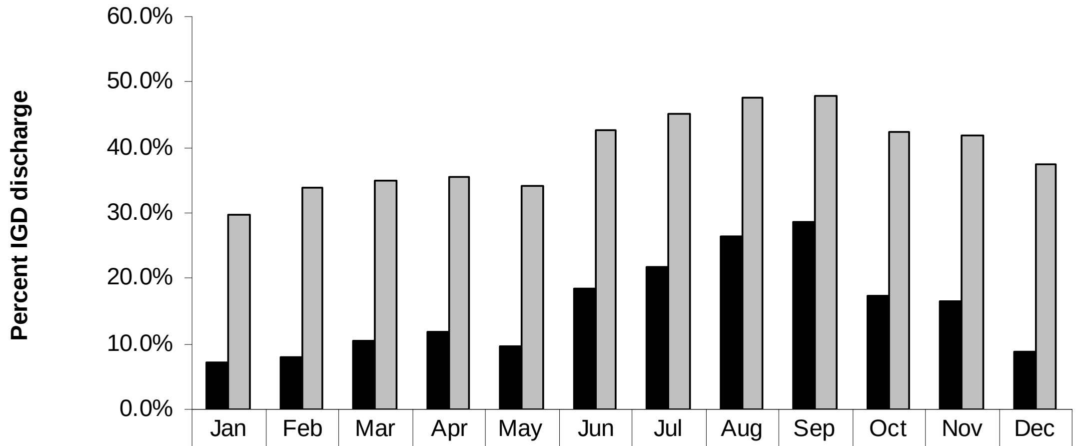


Figure 8. Mean daily discharge for period of record (1962–2007), and mean daily discharge (ft^3/s), and mean daily water temperature (°C) recorded at Iron Gate Dam (IGD; top figure; rkm 310) and Blake's Riffle (bottom figure; rkm 13) during the 2007 study period.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Iron Gate	79%	73%	42%	58%	63%	21%	10%	42%	75%	71%	75%	81%
Seiad	65%	74%	43%	63%	72%	57%	39%	67%	80%	43%	67%	80%
Blake's	67%	75%	45%	73%	61%	73%	57%	59%	81%	16%	63%	67%

Figure 9. Exceedance probabilities of river discharge values observed during 2007 at Iron Gate Dam (IGD; rkm 310), Klamath River near Seiad Valley (rkm 213), and Klamath River near the estuary (Blake's Riffle; rkm 13). Exceedance probabilities calculated using river discharge values for the period of record (1962–2007).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Blake's	7.2%	8.0%	10.5%	11.7%	9.5%	18.6%	21.7%	26.3%	28.7%	17.3%	16.6%	8.9%
□ Seiad	29.8%	33.8%	35.1%	35.5%	34.1%	42.6%	45.2%	47.7%	48.0%	42.4%	41.9%	37.3%

Month

Figure 10. Proportion of river discharge from Iron Gate Dam (IGD) relative to total river discharge at Seiad Valley (rkm 213), and at Blake's Riffle (rkm 13) during 2007.

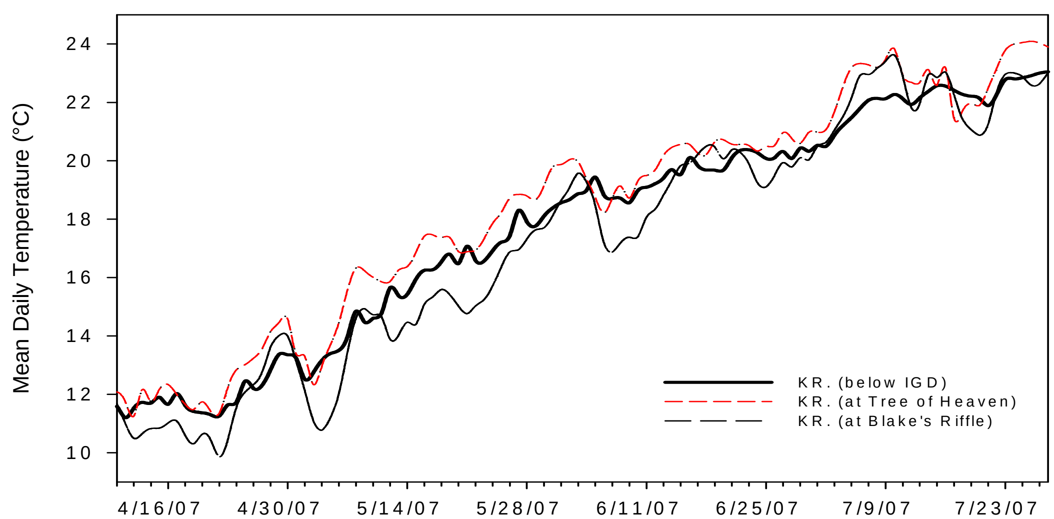


Figure 11. Mean daily water temperatures (°C) during the study period in 2007. Temperatures were measured in the mainstem Klamath River (KR) upstream of major tributaries and at holding sites in the Klamath River.

Fish Handling and Tagging

The mean fork length (FL) of hatchery coho salmon tagged in 2007 was 140.7 mm [standard deviation (SD) = 12.1]. The mean weight of hatchery fish tagged was 30.1 g (SD = 7.7). Because fish tagged and released at treatment and control sites were collected randomly from the same tank at the hatchery, mean fork lengths of the two groups were similar [140.8 mm (SD = 11.5) and 140.6 mm (SD = 12.7)] for treatment and control groups, respectively). The weight of radio transmitters (0.43 g in air) implanted in fish during 2007 represented an average of 1.4 percent of fish body weight (range = 0.8 to 2.9 percent).

Release Groups

We surgically implanted transmitters in a total of 246 juvenile hatchery coho salmon (split evenly between the treatment and control groups; 123 each) beginning April 10 and ending May 18, 2007. Because flow releases from IGD during the spring months are not predictable, we attempted to tag small release groups four times per week over the 6-week period. This approach was used to increase the likelihood of measuring juvenile coho salmon movement and survival in response to unpredictable changes in flows, and to allow comparison of migration behavior among hatchery fish exposed to different environmental conditions.

Measures of Smoltification and Disease

Gill ATPase of Tagged fish

The gill ATPase activity levels of the tagged fish varied over the 6-week tagging period, with a general trend of decreasing ATPase activity (fig. 12). The mean daily ATPase activity of fish from each tagging session ranged from 5 to 10 μmol P_i•mg protein^{-1}•h^{-1} throughout the season. Fish were transported to the control site prior to tissue collection, so we compared the mean daily ATPase activity levels using release site as well as collection date (when a tissue sample was taken). Initially, there was a significant interaction between release site and collection date (2-way ANOVA, F = 1.91, P = 0.0168), but further investigation revealed this was caused by a high ATPase activity level (18 μmol P_i•mg protein^{-1}•h^{-1}) measured from a sample date with only a single observation. After removing this observation from analysis, the interaction term was no longer significant (2-way ANOVA, F = 1.37, P = 0.1530). The ATPase activities of tagged fish were greater early in the tagging season, but the effect of collection date was not significant (2-way ANOVA, F = 0.98, P = 0.4977). No significant difference in ATPase activity was detected between IGH (mean ATPase = 5.6 μmol P_i•mg protein^{-1}•h^{-1}) and Tree of Heaven (mean ATPase = 6.4 μmol P_i•mg protein^{-1}•h^{-1}) release sites at the 0.05 level of significance, but there was at the 0.10 level (2-way ANOVA, F = 3.12, P = 0.0792).

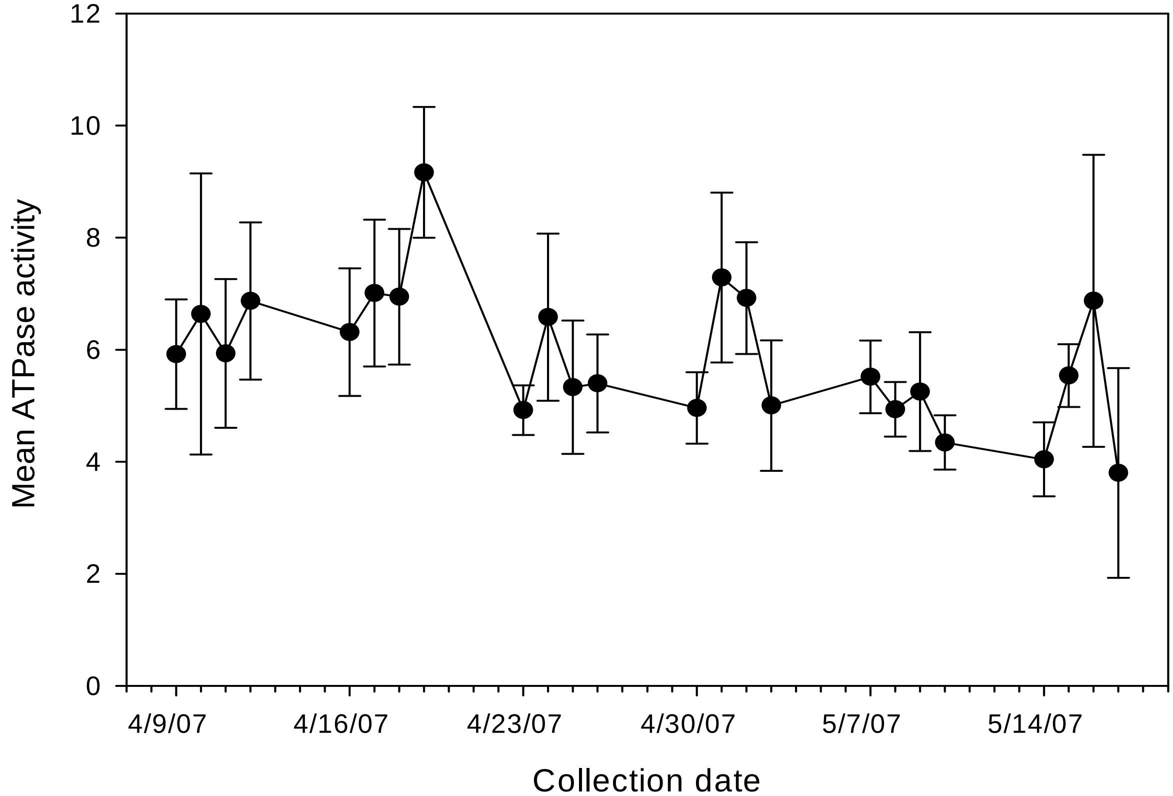


Figure 12. Mean gill ATPase activity levels (µmol P_i•mg protein^{-1}•h^{-1}) of radio-tagged juvenile coho salmon during spring 2007. Fish from the two release sites were pooled. Error bars represent the standard error (SE) for each daily mean.

Gill ATPase of Untagged fish

The gill ATPase activity levels of hatchery fish exposed to in-river conditions at two holding locations (different water sources) were similar throughout the 3-week experiment except for the last sample date (fig. 13). The general trend was a decrease in activity level over time from the start of the river exposures until the end of the exposures. The mean daily ATPase activity levels of fish from the river exposure experiment ranged from 3 to 7 µmol P_i•mg protein^{-1}•h^{-1} throughout the experiment. On the last sample date (day 21), the ATPase activity at the Shasta site (mean = 3.0, n = 3) was much lower than that of the fish at the Klamath River site (mean = 5.9, n = 7). Water temperatures at the two sites were similar until day 12 when temperatures increased in the Shasta River (fig. 14). The interaction term between sample site and collection date was not significant (ANOVA, F = 1.03, P = 0.4062), so it was removed from the final 2-way ANOVA model. The sample site mean ATPase activities were 5.3 µmol P_i•mg protein^{-1}•h^{-1} at the Klamath River site and 4.6 µmol P_i•mg protein^{-1}•h^{-1} at the Shasta River site. In the final model, there were no significant differences among sample dates (ANOVA, F = 0.86, P = 0.5095) or between sites (ANOVA, F = 0.46, P = 0.5005).

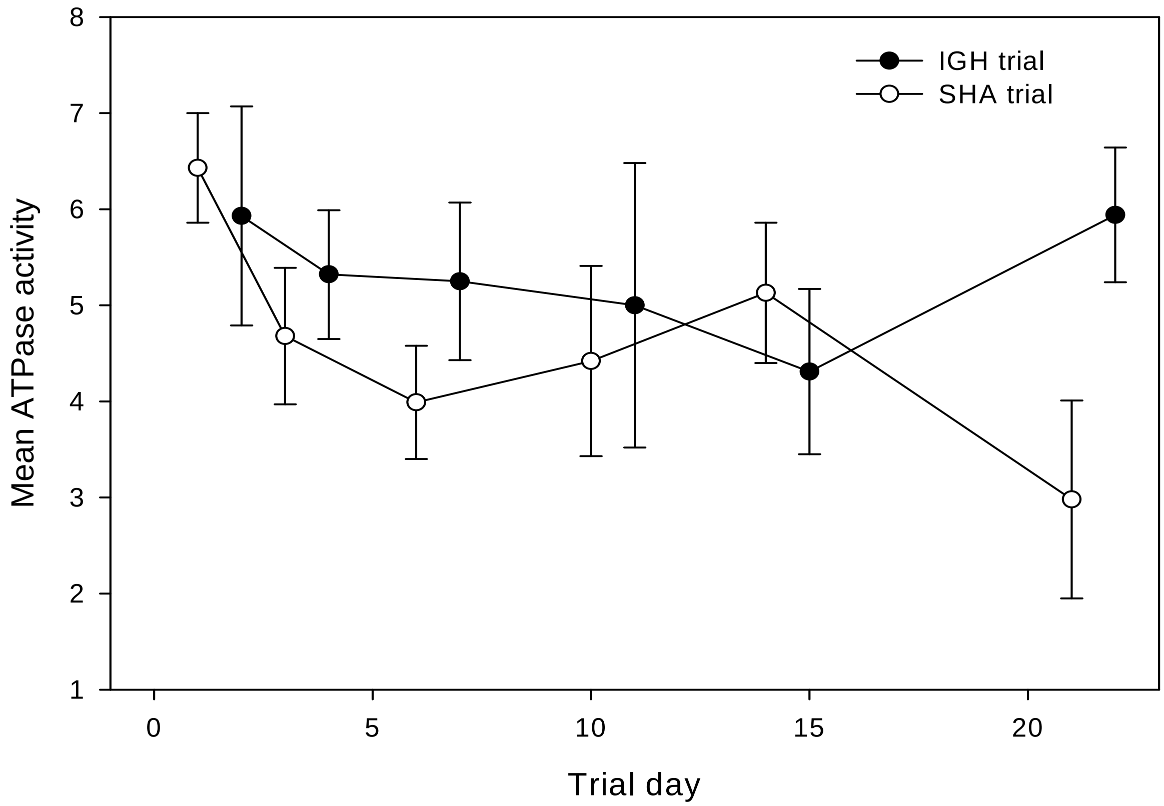


Figure 13. Mean gill ATPase activity levels (µmol Pi•mg protein-1•h-1) of untagged fish held for in-river exposure trials. Site trials were conducted simultaneously in the Klamath River near the Iron Gate Hatchery (IGH; filled symbols) and in the Shasta River (SHA; open symbols) from April 11 to May 1, 2007. Error bars represent the standard error (SE) for each daily mean. The IGH samples were offset by +1 d to prevent data from overlapping in the plot.

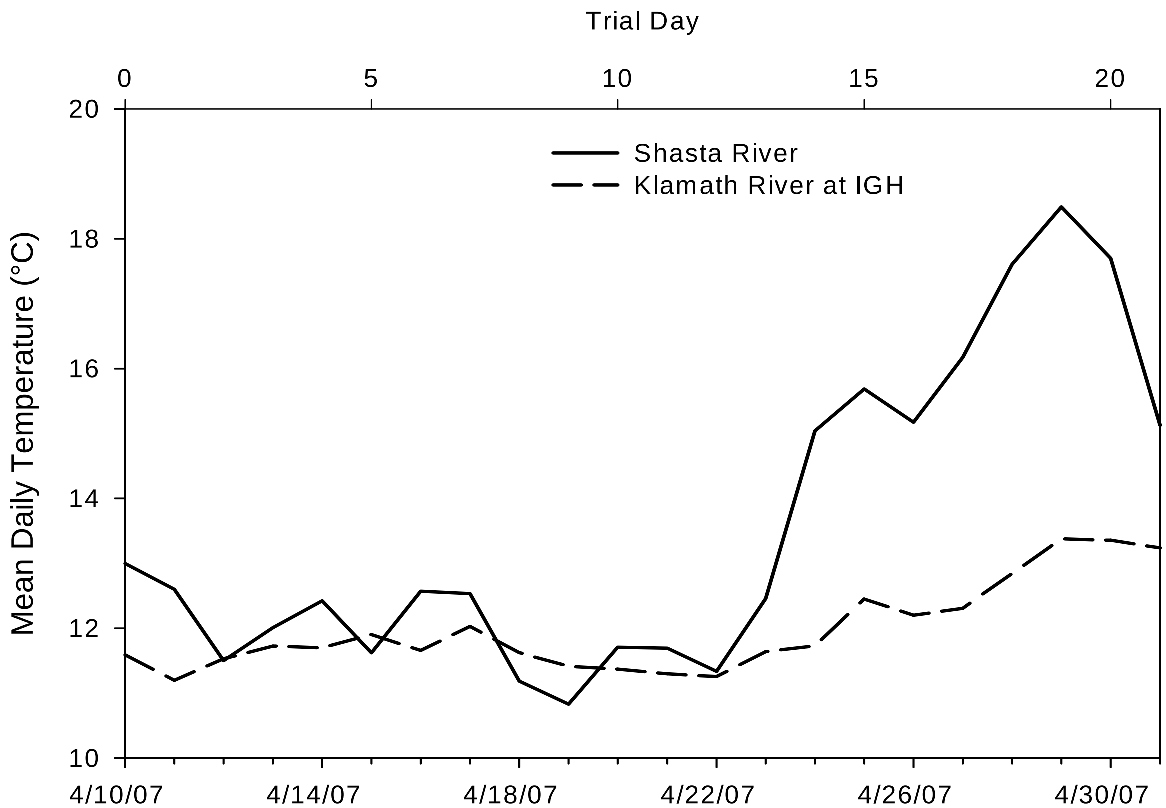


Figure 14. Mean daily water temperatures (°C) during the exposure trials in 2007. Temperatures were measured in the mainstem Klamath River at the holding site near Iron Gate Hatchery and in the Shasta River at the adult fish weir.

Bacterial Kidney Disease

The prevalence and severity of BKD in the fish tested was low, but varied by analytical method. The qualitative nested PCR method indicated that 2 of the 60 fish (3.3 percent) tested positive for *R. salmoninarum*, the causative agent of the disease. Results from the quantitative qPCR method indicated that 7 of the 60 fish tested positive (11.7 percent), but all positive fish had a low level of infection (<1,000 bacteria in total extraction; Diane Elliott, U.S. Geological Survey, written commun., January 17, 2008). Results are shown in appendix 2.

Migration Analyses

Analyses of migration behavior were based on data from fish released on all release dates. These comprised 123 treatment fish released near IGH (rkm 309) and 123 control fish released at the Tree of Heaven campground (rkm 280). Most fish released spent much of their time in the study area between the release site and the first detection site downstream. Fish released near IGH over the course of the study had a median travel time through the 21-km release-to-Shasta River reach of 11.6 d, but traversed the 54-km Shasta River-to-Scott River reach in a median of 0.9 d (table 3). Fish released near the Tree of Heaven campground had a median travel time through the 46-km reach from release to the Scott River of 7.2 d, but traveled through the 56-km Scott River-to-Indian Creek reach in a median of 1.8 d. Overall (release dates pooled), median travel times of both groups through the remaining reaches were less than 2.0 d, ranging from 0.2 to 11.7 d for individual fish.

The treatment group traveled faster than the control group in most reaches they had in common (fig. 15). The differences in travel times in reaches upstream of the Trinity River differed significantly (Wilcoxon Rank Sum Tests, $P < 0.0001$ for all comparisons). The difference in travel times between groups was less between the Trinity River and Steelhead Lodge (Wilcoxon Rank Sum Test $\chi^2 = 3.52$, df = 1, $P < 0.0604$) and the travel times were similar in the last reach, Steelhead Lodge to Blake's Riffle (Wilcoxon Rank Sum Test $\chi^2 = 2.56$ df = 1, $P < 0.1099$).

The travel time between release and the Scott River was longer for treatment fish than for control fish (Wilcoxon Rank Sum Test $\chi^2 = 27.85$, df = 1, $P < 0.0001$; fig. 16a), but the travel times from release to the last site, Blake's Riffle, were similar between groups (Wilcoxon Rank Sum Test $\chi^2 = 0.0066$, df = 1, $P < 0.9352$; fig. 16b). The treatment group traveled farther to reach the Scott River than the control fish (75 versus 46 km), but they were migrating faster than the control fish by the time they passed the release site of the control group. The similarity in travel times of the groups from release to the last site (Blake's Riffle) was due to the faster travel rates and longer distance traveled for the treatment group compared to the control group.

Table 3. Median days (range in parentheses) radio-tagged coho salmon spent in each reach, by release week in 2007.

[Numbers in parentheses below each reach designation are reach length. Sample sizes of treatment fish through individual reaches ranged from 9 to 19 fish, with a mean of 15.6. Sample sizes of control fish through individual reaches ranged from 8 to 15 fish, with a mean of 11.8]

Release Date	Release to Shasta River (21 km)	Shasta River to Tree of Heaven (8 km)	Tree of Heaven to Scott River (46 km)	Scott River to Indian Creek (56 km)	Indian Creek to Salmon River (71 km)	Salmon River to Trinity River (38 km)	Trinity River to Steelhead Lodge (36 km)	Steelhead Lodge to Blake's Riffle (20 km)
Treatment fish								
4/10/07 to 4/13/07	18.6 (0.2 – 43.2)	0.2 (0.1 – 29.9)	0.7 (0.5 – 3.4)	0.9 (0.6 – 2.0)	1.2 (0.9 – 4.3)	0.6 (0.3 – 1.6)	0.7 (0.2 – 2.8)	0.3 (0.1 – 1.1)
4/17/07 to 4/20/07	8.5 (0.2 – 32.9)	0.1 (0.1 – 20.7)	0.9 (0.4 – 28.1)	0.9 (0.5 – 2.1)	1.0 (0.8 – 11.1)	0.6 (0.2 – 2.3)	1.0 (0.2 – 11.7)	0.2 (0.1 – 0.4)
4/24/07 to 4/27/07	22.4 (0.3 – 31.1)	0.1 (0.1 – 12.7)	0.7 (0.4 – 13.0)	0.7 (0.5 – 1.8)	0.8 (0.6 – 5.0)	0.6 (0.3 – 2.0)	0.9 (0.3 – 2.3)	0.2 (0.1 – 0.4)
5/1/07 to 5/4/07	13.4 (0.3 – 22.0)	0.1 (0.1 – 11.1)	0.7 (0.4 – 26.2)	0.8 (0.4 – 1.2)	0.9 (0.6 – 3.8)	0.5 (0.3 – 1.4)	0.6 (0.2 – 3.6)	0.3 (0.2 – 0.9)
5/8/07 to 5/11/07	11.1 (0.2 – 15.7)	0.3 (0.1 – 6.0)	0.8 (0.4 – 15.8)	0.9 (0.5 – 1.8)	1.2 (0.7 – 2.6)	0.4 (0.3 – 1.2)	2.3 (0.3 – 6.8)	0.4 (0.1 – 1.0)
5/15/07 to 5/16/07	7.6 (1.1 – 12.8)	0.1 (0.1 – 0.8)	1.0 (0.4 – 8.0)	1.0 (0.7 – 4.2)	0.9 (0.7 – 1.0)	0.7 (0.4 – 0.9)	1.2 (0.2 – 1.4)	0.2 (0.2 – 0.5)
Overall	11.6 (0.2 – 43.2)	0.1 (0.1 – 29.9)	0.8 (0.4 – 28.1)	0.9 (0.4 – 4.2)	1.0 (0.6 – 11.1)	0.6 (0.2 – 2.3)	0.9 (0.2 – 11.7)	0.3 (0.1 – 1.1)
Control fish								
4/12/07 to 4/13/07	n/a	n/a	17.6 (0.3 – 33.2)	1.8 (0.9 – 23.7)	1.1 (0.8 – 11.2)	0.8 (0.2 – 6.2)	1.0 (0.2 – 7.0)	0.3 (0.2 – 2.4)
4/17/07 to 4/20/07	n/a	n/a	6.7 (1.0 – 37.0)	1.8 (0.9 – 4.9)	2.0 (0.8 – 3.8)	3.2 (3.0 – 8.4)	2.0 (0.3 – 3.4)	0.3 (0.1 – 0.5)
4/24/07 to 4/27/07	n/a	n/a	11.5 (0.8 – 19.9)	1.8 (0.4 – 9.3)	5.7 (1.2 – 7.7)	0.9 (0.7 – 1.3)	1.1 (0.8 – 2.4)	0.5 (0.1 – 5.8)
5/1/07 to 5/4/07	n/a	n/a	9.5 (3.3 – 22.8)	2.1 (0.8 – 7.7)	2.0 (0.5 – 11.6)	1.0 (0.5 – 8.4)	2.8 (0.3 – 8.9)	0.3 (0.2 – 1.0)
5/8/07 to 5/11/07	n/a	n/a	2.6 (1.1 – 18.7)	4.2 (0.7 – 6.8)	2.2 (1.2 – 8.1)	1.1 (0.4 – 3.0)	1.7 (0.5 – 2.8)	0.2 (0.2 – 0.6)
5/15/07 to 5/18/07	n/a	n/a	6.5 (1.0 – 11.5)	1.4 (1.0 – 4.1)	2.0 (1.0 – 4.8)	1.8 (1.2 – 3.8)	3.7 (1.0 – 8.2)	0.7 (0.5 – 9.7)
Overall	n/a	n/a	7.2 (0.3 –37.0)	1.8 (0.4 – 23.7)	2.0 (0.5 – 11.6)	1.2 (0.2 – 8.4)	2.0 (0.2 – 8.9)	0.4 (0.1 – 9.7)

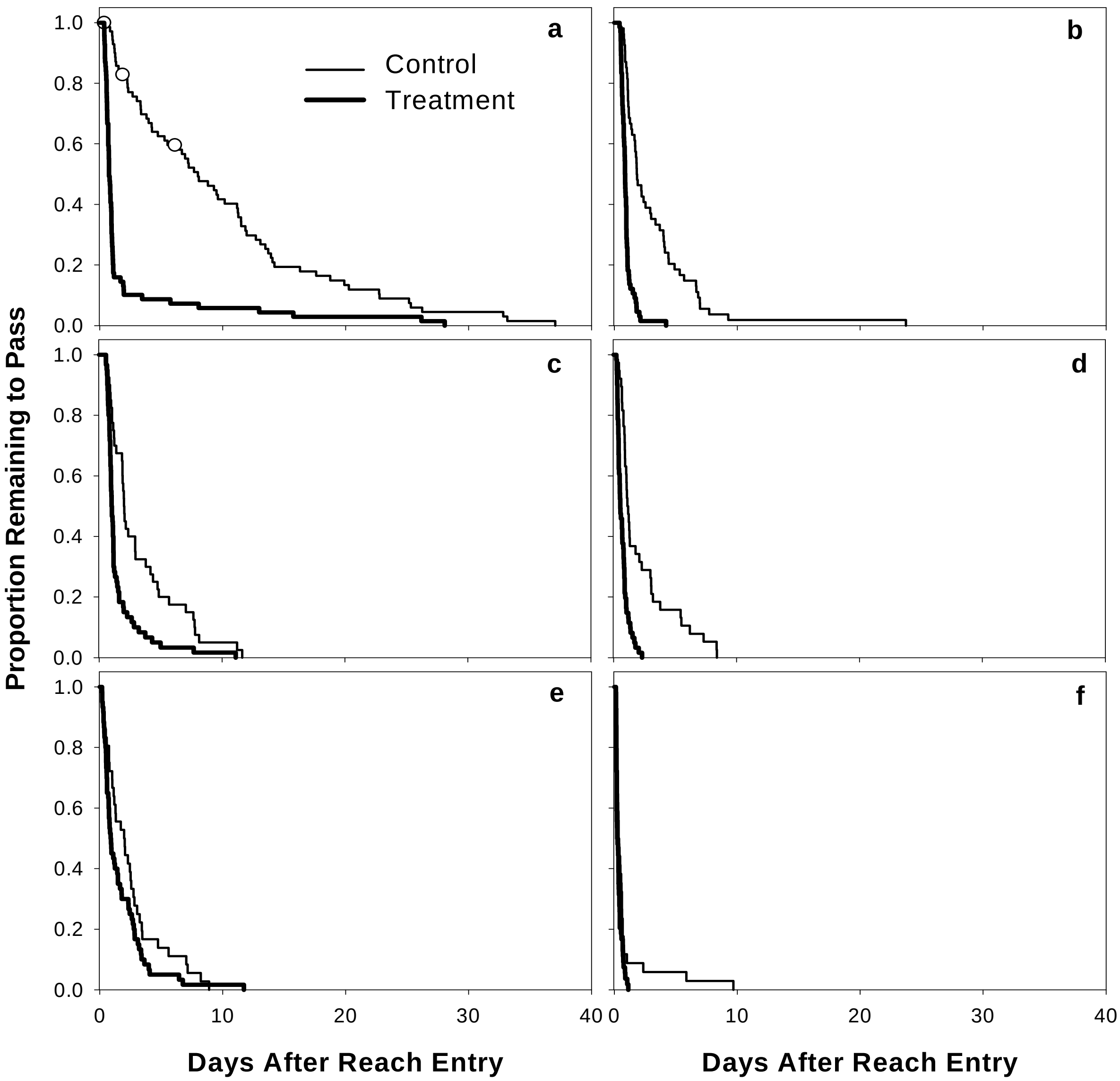


Figure 15. Kaplan-Meier curves describing the travel times of radio-tagged hatchery coho salmon from Tree of Heaven to Scott River (a), Scott River to Indian Creek (b), Indian Creek to Salmon River (c), Salmon River to Trinity River (d), Trinity River to Steelhead Lodge (e), and Steelhead Lodge to Blake's Riffle (f). Open circles represent censored individuals.

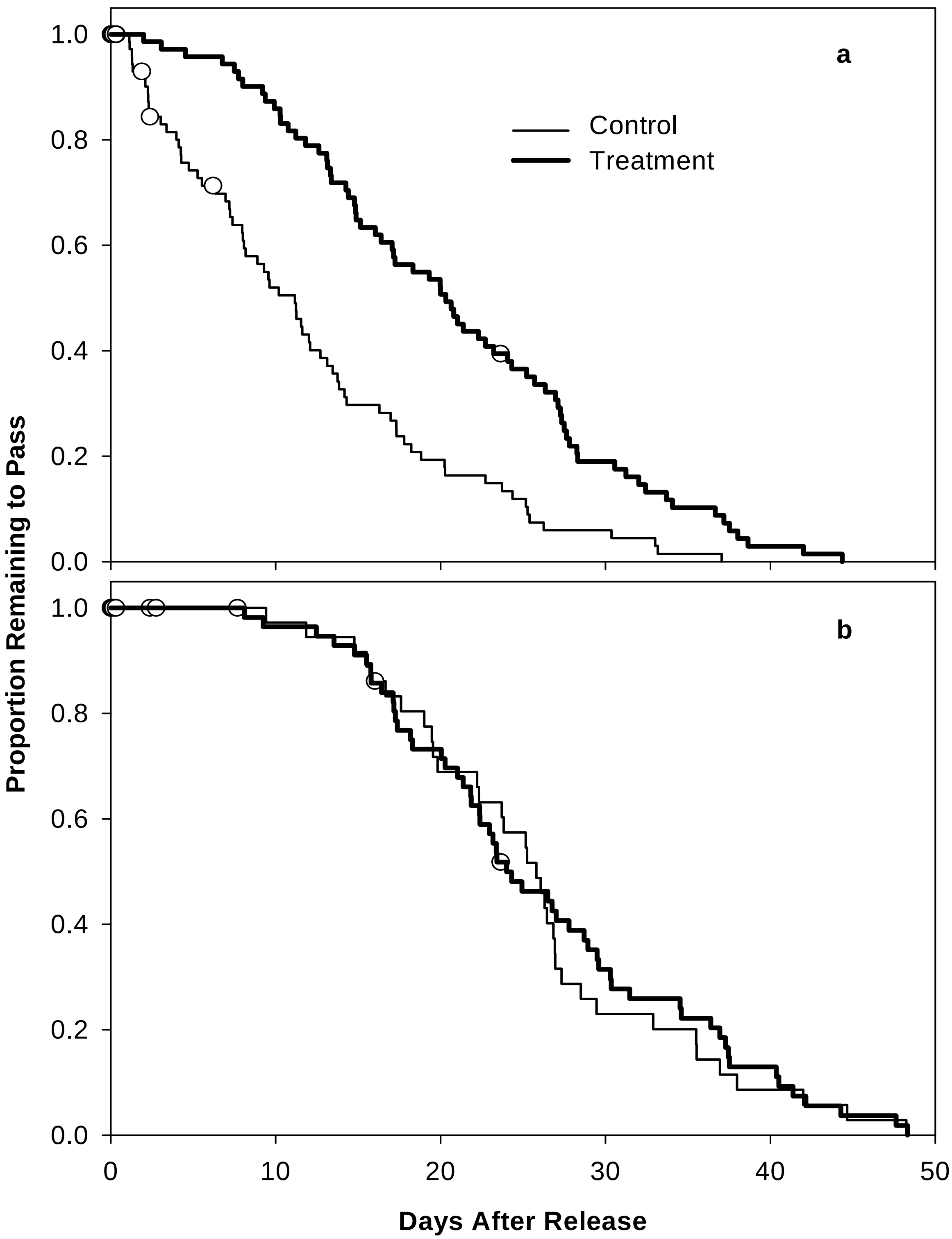


Figure 16. Kaplan-Meier curves describing travel times of radio-tagged hatchery coho salmon following release to Scott River (a) and Blake's Riffle (b) detection sites during the spring of 2007. Open circles represent censored individuals.

Travel times, river discharge, water temperature, and date of the year were all correlated with one another (see tables in reach-specific sections below). The travel time from release to the Scott River site decreased throughout the study as discharge decreased and water temperature and release date increased (fig. 17).

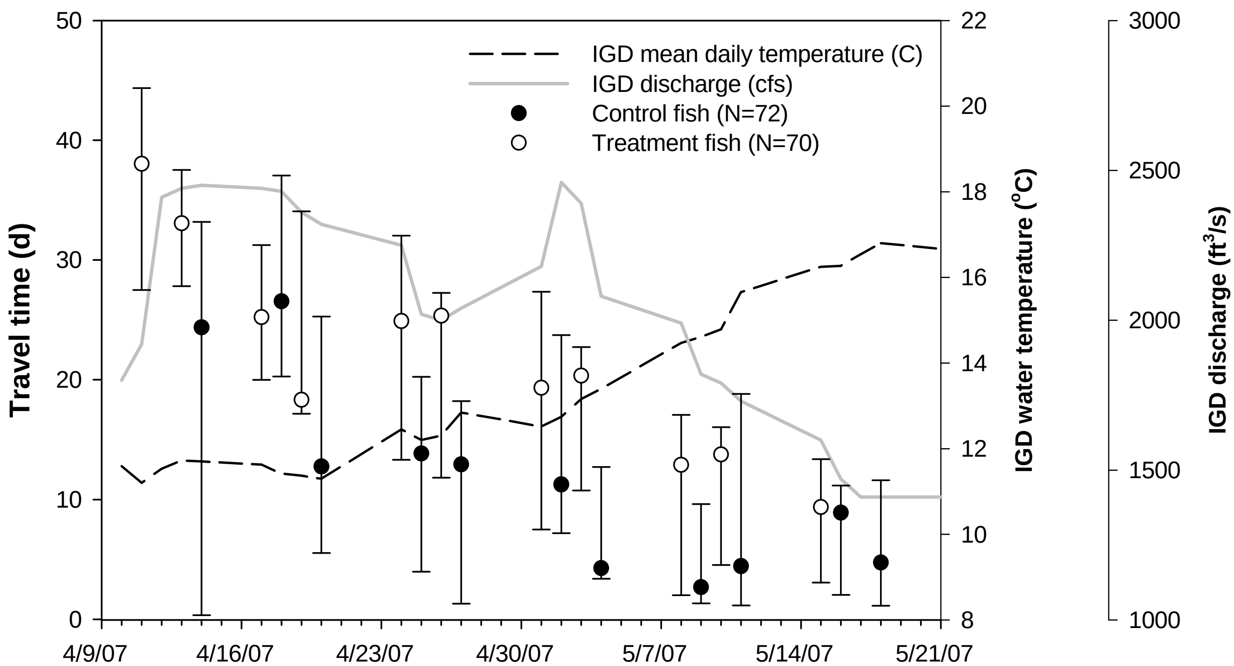


Figure 17. Median travel times (d) of radio-tagged hatchery coho salmon from release to Scott River (rkm 234) relative to mean daily discharge (ft^3/s) from Iron Gate Dam and mean daily water temperature (°C) within the reach. Circles represent median travel times of treatment and control release groups, error bars represent the range. Each point represents two releases and dates of control fish were offset by +1 d to prevent data from overlapping in the plot.

Models of Covariates in Reach 1 (release to Scott River)

Most variables met the assumptions of linearity and proportional hazards required for Cox Proportional Hazards regression. Date of release, average daily discharge, average daily water temperature, ATPase activity, and fish weight at release were evaluated. All variables met the assumption of linearity reasonably well based on plots of Martingale residuals. Taking the natural logarithm (LogQ) of discharge improved linearity and was used in all subsequent analyses. Plots of Schoenfeld residuals suggested most variables met the proportional hazards assumption. The $\log_e$ of discharge violated the assumption due to data from travel times less than about 8 days. There were few data points with these small values of travel time, so this variable was used in analyses with the caveat that the results may not be applicable to short travel times.

Each of the environmental covariates examined were important covariates of travel time in this reach. Separate models were made using $\log_e$ discharge (LogQ), water temperature, and date of release, due to correlations among them (table 4). In most cases, the correlation coefficients between these variables were |r|~ 0.7 or larger. Several models initially seemed to be supported by the data, but were omitted because their importance was driven by the presence of the well-supported environmental variable. For example, the second and third models in table 5 have delta AICc values within about 2 of the most supported model (delta AICc = 0), differ from it by only one parameter, and have similar log-likelihoods. This means the added parameter did not improve the fit to the data (little change in the log-likelihood) and the AICc value increased by about 2 simply due to the equation for AICc, which adds 2 for each additional parameter (Burnham and Anderson, 2002).

The most parsimonious models of the treatment group contained only the environmental covariates, whereas those of the control group also contained $\log_e$ weight. The parameter estimates in models of each group indicated that the rate of passage through this reach was negatively related to $\log_e$ of discharge and positively related to water temperature and release date (table 6). The effects of these variables reflect the increasing passage rate (shorter travel times) as the study season progressed and the associated decreases in river discharge and increases in water temperature. Models of control fish indicated that rates of migration were positively related to $\log_e$ weight.

Models of Covariates in Reach 2 (Scott River to Indian Creek)

All variables examined met assumptions of linearity and proportional hazards, though one outlier observation was omitted from analysis. A member of the control group with a travel time between the Scott River and Indian Creek sites of 23.72 d was omitted from analyses, because it was very influential in plots of Martingale residuals to evaluate the proportional hazards assumption. The next longest travel time of control fish in this reach was 9.25 d. The analyses in this reach were based on 66 treatment fish and 53 control fish after removal of the outlier.

Correlations between environmental variables were less in this reach than in the previous one, but separate analyses were conducted with each one. The correlation coefficients were generally less than |r| = 0.47 (table 7).

There was little model selection uncertainty in the treatment group, but considerable uncertainty in the control group. As in previous analyses, there were several models characterized as containing “pretender variables”, and they were omitted from model selection.

Table 4. Pearson product-moment correlation coefficients and P-values (in italics) from t-tests of their association in the release-to-Scott River reach.

[Serdate is the serial date of release, LogQ is the natural log of river discharge in the reach, and Logwt is the natural log of fish weight at the time of tagging. Event is the time to travel through the reach]

	Serdate	LogQ	Temp	Logwt	ATPase	Event
---------- Group = Control ----------						
Serdate	1	-0.9009	0.9094	0.0176	-0.3476	-0.5783
		<.0001	*<.0001*	*0.8784*	*0.0018*	*<.0001*
LogQ		1	-0.6822	0.0162	0.3117	0.5073
			<.0001	*0.8879*	*0.0055*	*<.0001*
Temp			1	0.0459	-0.3293	-0.5103
				0.6901	*0.0032*	*<.0001*
Logwt				1	-0.1362	-0.2754
					0.2345	*0.0147*
ATPase					1	0.1402
						0.2208
---------- Group = Treatment ----------						
Serdate	1	-0.7479	0.8666	0.1420	-0.0965	-0.7743
		<.0001	*<.0001*	*0.2341*	*0.4203*	*<.0001*
LogQ		1	-0.5221	-0.0531	-0.0673	0.5157
			<.0001	*0.6581*	*0.5746*	*<.0001*
Temp			1	0.1330	-0.2050	-0.6415
				0.2655	*0.0841*	*<.0001*
Logwt				1	-0.0375	-0.2117
					0.7544	*0.0743*
ATPase					1	0.0800
						0.5044

Table 5. Model selection summary from Cox Proportional Hazards regression analyses of travel time through the release to Scott River reach.

[Analyses are based on 72 radio-tagged juvenile coho salmon from the treatment group and 78 from the control group released in 2007. A * in Model Weight indicates that the model was not used in selection due to the similarity in log likelihood to the best model in the suite and a delta AICc of ≤ 2 times the difference in the number of parameters between the two models]

Group	Variables in Model	Log Likelihood	AICc	delta AICc	Model Likelihood	Model Weight	Num. Parms.
---------- Environmental Variable = LogQ ----------							
Treatment	logq	-219.71	441.41	0.00	1.00	1.00	1
	logwt, logq	-218.81	441.62	0.21	0.90	*	2
	logq, atpase	-219.73	443.47	2.06	0.36	*	2
	logwt, logq, atpase	-218.87	443.74	2.33	0.31	*	3
	logwt, atpase	-238.07	480.15	38.74	0.00	0.00	2
Control	logwt, logq	-256.08	516.16	0.00	1.00	0.92	2
	logwt, logq, atpase	-256.13	518.27	2.11	0.35	*	3
	logq	-259.97	521.93	5.77	0.06	0.05	1
	logq, atpase	-259.86	523.73	7.57	0.02	0.02	2
	logwt, atpase	-261.61	527.22	11.06	0.00	0.00	2
---------- Environmental Variable = Temperature ----------							
Treatment	temp	-200.09	402.19	0.00	1.00	1.00	1
	logwt, temp	-199.36	402.73	0.54	0.76	*	2
	temp, atpase	-199.85	403.70	1.51	0.47	*	2
	logwt, temp, atpase	-199.05	404.10	1.91	0.38	*	3
	logwt, atpase	-238.07	480.15	77.96	0.00	0.00	2
Control	logwt, temp, atpase	-225.62	457.24	1.09	0.58	*	3
	logwt, temp	-226.08	456.15	0.00	1.00	1.00	2
	temp, atpase	-233.48	470.96	14.81	0.00	0.00	2
	temp	-233.56	469.13	12.97	0.00	0.00	1
	logwt, atpase	-261.61	527.22	71.06	0.00	0.00	2
---------- Environmental Variable = Release Date ----------							
Treatment	logwt, reldate	-199.33	402.67	0.00	1.00	*	2
	reldate	-200.45	402.90	0.24	0.89	1.00	1
	logwt, reldate, atpase	-199.04	404.07	1.40	0.50	*	3
	reldate, atpase	-200.28	404.56	1.89	0.39	*	2
	logwt, atpase	-238.07	480.15	77.48	0.00	0.00	2
Control	logwt, reldate	-240.13	484.26	0.00	1.00	1.00	2
	logwt, reldate, atpase	-239.86	485.72	1.46	0.48	*	3
	reldate	-246.90	495.80	11.53	0.00	0.00	1
	reldate, atpase	-246.91	497.82	13.56	0.00	0.00	2
	logwt, atpase	-261.61	527.22	42.95	0.00	0.00	2

Table 6. Output from the most supported Cox regression models from the release to Scott River reach.

[The SE Ratio is a measure of the reduction in standard error associated with the use of the Robust sandwich estimates (< 1 = reduced error). df = 1 for all rows]

Group	Variable	Parameter Estimate	Standard Error	SE Ratio	Chi-Square	Pr > ChiSq	Hazard Ratio	95% Hazard Conf. Limits	
Environmental Variable = LogQ									
Treatment	LogQ	-8.009	1.530	0.975	27.390	<.0001	3.32E-04	0.000	0.007
Control	Logwt	1.431	0.298	0.569	23.016	<.0001	4.185	2.332	7.510
	LogQ	-2.799	1.167	1.350	5.753	0.017	0.061	0.006	0.599
Environmental Variable = Temperature									
Treatment	Temp	0.933	0.165	1.276	31.809	<.0001	2.541	1.838	3.514
Control	Logwt	1.981	0.480	0.910	17.048	<.0001	7.251	2.831	18.571
	Temp	0.643	0.111	1.211	33.601	<.0001	1.902	1.531	2.364
Environmental Variable = Release Date									
Treatment	Reldate	0.148	0.018	0.940	64.702	<.0001	1.160	1.118	1.202
Control	Logwt	1.894	0.435	0.822	18.913	<.0001	6.645	2.830	15.602
	Reldate	0.085	0.014	1.035	35.478	<.0001	1.089	1.059	1.120

Table 7. Pearson product-moment correlation coefficients and P-values (in italics) from t-tests of their association in the Scott River-to-Indian Creek reach.

[Serdate is the serial date of release, LogQ is the natural log of river discharge in the reach, and Logwt is the natural log of fish weight at the time of tagging. Event is the time to travel through the reach]

	Serdate	LogQ	Temp	Logwt	ATPase	Event
--- Group = Control ---						
Serdate	1	-0.4415	0.3119	0.0939	-0.2970	-0.1682
		0.0008	*0.0217*	*0.4994*	*0.0292*	*0.2240*
LogQ		1	-0.4500	0.2755	0.1217	0.3702
			0.0006	*0.0437*	*0.3807*	*0.0059*
Temp			1	-0.3492	-0.0527	-0.5574
				0.0097	*0.7052*	*<.0001*
Logwt				1	-0.2084	-0.1484
					0.1304	*0.2843*
ATPase					1	0.0402
						0.7731
--- Group = Treatment ---						
Serdate	1	-0.4654	0.3166	0.0956	-0.0947	0.0184
		<.0001	*0.0096*	*0.4451*	*0.4495*	*0.8834*
LogQ		1	-0.3681	0.1413	0.0666	0.2080
			0.0024	*0.2577*	*0.5950*	*0.0937*
Temp			1	-0.2654	-0.0359	-0.0778
				0.0313	*0.7746*	*0.5346*
Logwt				1	-0.0199	0.0059
					0.8742	*0.9625*
ATPase					1	-0.0259
						0.8367

The models most supported by the data were different for treatment and control fish. The most supported models of treatment fish passage rates included single-variable models of $\log_e$ discharge and water temperature (table 8). The most supported models of control fish passage rates often included $\log_e$ weight variable along with water temperature or $\log_e$ discharge. Single-variable models including release date also were among the best supported of those including this environmental variable, but these models generally were a poor fit to the data, as indicated by the insignificant Chi-Square statistics. As in the previous reach, passage rates were positively related to water temperature and release date and negatively related to $\log_e$ of discharge in the reach. The relation between $\log_e$ weight at release and passage rates was positive in control fish. These relations are evident in the sign of the parameter estimates in table 9, or they also can be interpreted using the hazard ratios. For example, the parameter estimate of the $\log_e$ discharge variable in the first model in table 9 is -1.5674, indicating the inverse relation between the passage rate and the $\log_e$ of discharge. The hazard ratio of 0.2090 indicates that the passage rate decreases (0.2090-1)*100 percent = 79.1 percent for each 1 unit increase in the dependent variable, $\log_e$ discharge in this case. This indicates that the passage rate at the Indian Creek site would decrease 79.1 percent as river discharge increased from 1,500 to 4,077 ft^3/s (note the large effect of a 1-unit increase in the $\log_e$ of discharge). Conversely, the effect of water temperature on treatment fish passage rate at the Indian Creek site was a (1.3920-1)*100 percent = 39.2 percent increase in passage rate for each 1 unit increase in water temperature.

Models of Covariates in Reach 3 (Indian Creek to Salmon River)

Violations of model assumptions prevented regressions using data from this reach. All variables in data from control and treatment fish met the linearity assumptions as indicated by plots of the Martingale residuals, but few variables met the assumption of proportions hazards assessed with plots of the Schoenfeld residuals. Smoothed lines plotted through the Schoenfeld residuals of the $\log_e$ discharge and temperature variables from the control group were curvilinear at small values of the event due to several observations with high residual values. Omitting these observations resulted in smoothed lines with considerable slope, indicating assumption violation.

Data from treatment fish generally met the proportional hazards assumption, but were influenced by several observations with long event times (for example, the 90^{th} percentile of the n = 60 treatment fish event times was 3.03 d and there were four observations between 3.73 and 11.11 d). When these observations were omitted, the Schoenfeld residual plots had a considerable slope, indicating violation of the assumption. Inasmuch as the outcome of the assumption evaluations were influenced by only a few observations, we chose not to proceed with the regressions.

Table 8. Model selection summary from Cox Proportional Hazards regression analyses of travel time through the Scott River to Happy Camp reach.

[Analyses are based on 66 radio-tagged juvenile coho salmon from the treatment group and 53 from the control group released in 2007. A * in Model Weight indicates that the model was not used in selection due to the similarity in log likelihood to the best model in the suite and a delta AICc of ≤ 2 times the difference in the number of parameters between the two models]

Group	Variables in Model	Log Likelihood	AICc	delta AICc	Model Likelihood	Model Weight	Num. Parms.
---------- Environmental Variable = LogQ ----------							
Treatment	logq	-211.96	425.97	0.00	1.00	0.93	1
	logwt, logq	-211.96	428.06	2.09	0.35	*	2
	logq, atpase	-211.96	428.06	2.09	0.35	*	2
	logwt, logq, atpase	-211.96	430.22	4.25	0.12	*	3
	logwt, atpase	-213.52	431.19	5.22	0.07	0.07	2
Control	logwt, logq	-157.39	318.97	0.00	1.00	0.55	2
	logq	-159.25	320.56	1.59	0.45	0.25	1
	logwt, logq, atpase	-157.39	321.17	2.21		*	3
	logwt, atpase	-159.02	322.23	3.26	0.20	0.11	2
	logq, atpase	-159.14	322.46	3.50	0.17	0.10	2
---------- Environmental Variable = Temperature ----------							
Treatment	temp	-211.05	424.15	0.00	1.00	0.97	1
	logwt, temp	-210.97	426.09	1.94	0.38	*	2
	temp, atpase	-211.03	426.20	2.05	0.36	*	2
	logwt, temp, atpase	-210.96	428.23	4.07	0.13	*	3
	logwt, atpase	-213.52	431.19	7.04	0.03	0.03	2
Control	logwt, temp	-153.45	311.08	0.00	1.00	0.70	2
	logwt, temp, atpase	-153.42	313.23	2.15	0.34	*	3
	temp	-155.65	313.37	2.29	0.32	0.22	1
	temp, atpase	-155.61	315.39	4.32	0.12	0.08	2
	logwt, atpase	-159.02	322.23	11.15	0.00	0.00	2
---------- Environmental Variable = Release Date ----------							
Treatment	reldate	-213.53	429.11	0.00	1.00	1.00	1
	logwt, atpase	-213.52	431.19	2.08	0.35	*	2
	reldate, atpase	-213.53	431.19	2.08	0.35	*	2
	logwt, reldate	-213.53	431.19	2.09	0.35	*	2
	logwt, reldate, atpase	-213.52	433.35	4.24	0.12	*	3
Control	logwt, atpase	-159.02	322.23	0.00	1.00	0.32	2
	logwt, reldate	-159.06	322.29	0.06	0.97	0.31	2
	reldate	-160.33	322.72	0.49	0.78	0.25	1
	logwt, reldate, atpase	-159.00	324.40	2.17	0.34	*	3
	reldate, atpase	-160.11	324.41	2.18	0.34	0.11	2

Table 9. Output from the most supported Cox regression models from the Scott River-to-Indian Creek reach.

[The SE Ratio is a measure of the reduction in standard error associated with the use of the Robust sandwich estimates (< 1 = reduced error). Models listed reflect model selection uncertainty in table 8. df = 1 for all rows]

Group	Variable	Parameter Estimate	Standard Error	SE Ratio	Chi-Square	Pr > ChiSq	Hazard Ratio	95% Hazard Ratio Confidence Limits	
Environmental Variable = LogQ									
Treatment	LogQ	-1.5674	0.8631	0.9410	3.2977	0.0694	0.2090	0.0380	1.1320
Control	LogQ	-1.5271	0.9106	0.8700	2.8126	0.0935	0.2170	0.0360	1.2940
	Logwt	1.2516	0.6533	1.0230	3.6708	0.0554	3.4960	0.9720	12.5790
	LogQ	-1.9838	0.9388	0.8540	4.4655	0.0346	0.1380	0.0220	0.8660
Environmental Variable = Temperature									
Treatment	Temp	0.3306	0.1424	0.9700	5.3906	0.0202	1.3920	1.0530	1.8400
Control	Temp	0.4608	0.1281	0.8080	12.9463	0.0003	1.5850	1.2330	2.0380
	Logwt	1.3900	0.6378	0.9750	4.7489	0.0293	4.0150	1.1500	14.0150
	Temp	0.5037	0.1132	0.7120	19.7964	<.0001	1.6550	1.3260	2.0660
Environmental Variable = Release Date									
Treatment	Reldate	0.0006	0.0112	1.0650	0.0032	0.9546	1.0010	0.9790	1.0230
	Logwt	0.0464	0.3931	0.7020	0.0139	0.9061	1.0470	0.4850	2.2630
	ATPase	-0.0036	0.0280	0.7140	0.0163	0.8986	0.9960	0.9430	1.0530
Control	Reldate	0.0011	0.0116	0.7910	0.0084	0.9269	1.0010	0.9790	1.0240
	Logwt	1.0433	0.6248	0.9620	2.7886	0.0949	2.8390	0.8340	9.6580
	Reldate	-0.0020	0.0127	0.8550	0.0241	0.8765	0.9980	0.9730	1.0230
	Logwt	0.9907	0.6424	0.9730	2.3785	0.1230	2.6930	0.7650	9.4850
	ATPase	-0.0118	0.0268	0.6360	0.1925	0.6608	0.9880	0.9380	1.0420

Survival Analyses

Survival analyses were conducted using fish from all release dates. Data were analyzed with treatment and control fish together, and then with treatment fish only. This enabled comparisons of fish from both groups over reaches they had in common as well as estimating survival in reaches between IGH and Tree of Heaven, through which only treatment fish migrated. There were 10 unique encounter histories in the analyses with both groups and 11 unique encounter histories in the analyses of treatment fish only; those of fish released and detected at all sites and those of fish released and never detected were the most prevalent in each case (appendixes 3 and 4).

Capture Probabilities

The most parsimonious model of capture probabilities indicated that a common value for all sites and experimental groups was applicable (table 10). This model received 95 percent of the model weight of the four models evaluated in analyses of treatment and control groups together and received 33 times more support from the data than the closest model, which allowed capture probabilities to vary among sites. The most supported model described a common capture probability of 0.975 (SE 0.007) for all sites and groups, and was used in all subsequent analyses of survival probabilities. This model also received greater than 300 times more support from the data than any other model in analyses of treatment fish, and used a common capture probability of 0.983 (SE 0.006) for all sites (model comparisons not shown).

Release of Euthanized Radio-Tagged Fish

Records from one euthanized fish were present in the raw data, but based on detection at three consecutive detection arrays and the number of individual records, there is question if the fish was actually dead. The fish (unique code 01081) was released at IGH (rkm 309) on May 1, 2007, then was detected passing Shasta River (rkm 288 on May 3), Tree of Heaven (rkm 280 on May 18), and Scott River (rkm 234 on May 31). The mobile tracking crew also detected the fish at rkm 283 (May 9 and 16), rkm 270 (May 23), and rkm 233 (June 12), but effort to visually identify the fish as live failed. Based on distances that euthanized fish drifted in 2006 (average = 5.1 km, range 0.1 to 19.9 km) and 2007 (described in following paragraph), it is unlikely that this fish was euthanized. Thus, the records from euthanized fish were logically excluded from the data and no evidence of violating assumption A7 was evident based on euthanized fish released.

During the mobile tracking effort, euthanized fish were detected regularly, and downstream drifting was monitored to determine distance from the release site. Most of the euthanized fish (11 of 12; 91.7 percent) released at IGH were later located via mobile-tracking. Euthanized fish released at this location drifted an average of 0.7 km (range 0.1 to 2.2 km). The fish mentioned in the previous paragraph was excluded from these calculations. Of the 12 euthanized fish released at the control site (rkm 280), 11 (91.7 percent) were later located during mobile tracking. Euthanized fish released at the control site drifted an average of 3.3 km (range 0.1 to 17.0 km).

Table 10. Models of capture probabilities (P) of 123 treatment and 123 control group juvenile coho salmon released in the Klamath River during 2007.

[Model descriptions include factors by which P may vary, including reach and group (treatment and control). Rankings are based on AICc, a modification of Akaike Information Criterion for small samples. A '+' between factors indicates an additive effect and '*' denotes a multiplicative effect. A '.' indicates a no effect (a single value fitted to all groups and sites). The models are based on a common model of survival (a multiplicative effect of group and site). Num. Parms. denotes the number of estimable parameters in the model]

Model	AICc	Delta AICc	Model Likelihood	Model Weight	Num. Parms.	Deviance
P(.)	790.953	0.000	1.000	0.954	12	79.702
P(Site)	797.947	6.995	0.030	0.029	16	78.400
P(Group+Site)	799.040	8.088	0.018	0.017	17	77.406
P(Group*Site)	807.092	16.139	0.000	0.000	21	77.055

Survival Through the Study Reaches

We were unable to use the paired-release survival design in 2007 due to violation of a model assumption. The purpose of this design is to estimate survival without the potential effects of tagging and handling. One of the assumptions (A9) in this design is that treatment and control fish experience the same mortality factors in the common reach, which was from Tree of Heaven-to-Scott River reach in 2007. This generally is met by altering release times of the two groups so their migrations through the common reach occur during a similar time period, or by having similar mortality factors during the different times the groups are in the reach. Neither of these conditions occurred in 2007. Differences in timing and survivals through the common reach were evident. Thus, the paired-release model could not be used with these data, though it was appropriate during the 2006 study.

The survivals of treatment and control groups through the various reaches in 2007 were estimated using the single-release design. The first detection site that the treatment and control fish had in common was the Scott River site. Reach survivals of data including treatment and control fish were made in each reach, but the two groups traveled different distances in the release-to-Scott River reach.

Models including parameters for differences in survival between treatment and control groups and among reaches were greatly supported by the data. The most supported model of survival, model #1 in table 11, was based on a multiplicative effect of group and reach. It received 99 percent of the Model Weight, indicating the other models were virtually unsupported by the data. This appeared to be due to the similarity of survivals of control (0.589 SE 0.045) and treatment (0.578 SE 0.044) groups from release-to-Scott River reach, and the disparity between these groups in subsequent reaches. This model received approximately 1,000 times more support from the data than a similar model without a group effect (Model Weight of model #1 divided by that of model #3), indicating little model selection uncertainty and strong support for a difference between survivals of treatment and control groups. This type of comparison, described as an “evidence ratio” by Burnham and Anderson (2002), is a measure of the strength of evidence of competing hypotheses given the data and the models. The multiplicative model of group and site also received greater than 100 times more weight than an additive model with the same factors (model #1 versus model #2). We chose to report survivals of treatment and control groups for each reach separately based on the weight of evidence for differences between them. Results from the control group were taken from the most supported model in table 11. A separate suite of models was used to estimate survivals and capture probabilities of treatment fish so that the IGH-to-Shasta River and Shasta River-to-Tree of Heaven reaches could be included, as the control fish did not travel through these reaches. In this suite, the most supported model received greater than 99 percent of the Model Weight (table 12). This model allowed survival to vary among reaches and included a common capture probability among sites (0.983 SE 0.006).

The estimates of survival of treatment fish were higher than those of control fish in the reaches they had in common and the differences were greatest upstream of the Salmon River (table 13). Treatment fish survival was 22.5 percent greater than the control fish survival in the Tree of Heaven-to-Scott River reach (0.814 SE 0.042 versus 0.589 SE 0.45), 18.1 percent greater in the Scott River-to-Indian Creek reach (0.959 SE 0.024 versus 0.778 SE 0.050), and 14.5 percent greater in the Indian Creek-to-Salmon River reach (0.910 SE 0.035 versus 0.765 SE 0.057). The differences between the groups were 7.0 and 6.1 percent in the two reaches downstream of the Salmon River. The treatment fish survival from IGH to rkm 33 was 0.497 (SE 0.044). The survivals from Tree of Heaven to rkm 33 were 0.700 (SE 0.058) for treatment fish and 0.301 (SE 0.041) for control fish.

Estimates of survival were lowest in the most upstream reach studied. The survival upstream of the Tree of Heaven site was lower in the 21 km IGH-to-Shasta River reach (0.773 SE 0.038) than in the 8 km Shasta River-to-Tree of Heaven reach (0.917 SE 0.029). However, the latter reach is very short and the estimate could be biased upward by dead fish drifting with live tags, which is more likely when reaches are short. The survival of treatment fish in the 46 km Tree of Heaven-to-Scott River reach was 0.814 (SE 0.042).

Covariates of Reach Survival

The effects of covariates on reach survival were assessed with treatment and control fish separately due to the differences in reach survivals between them. The Tree of Heaven site was omitted from analyses of treatment fish, because the Shasta River-to-Tree of Heaven reach was only 8 km long.

Weight at release was the only covariate supported by the data more than the Reach Only model in analyses of treatment fish (table14). The evidence ratio of the Acute Weight model was 6.7 compared to the Reach Only model. The sign of the slope of the Acute Weight model was positive, indicating survival upstream of the Scott River was greater for fish heavier at the time of tagging. Models of the other covariates of treatment fish all received similar or lower support from the data than the Reach Only model, indicating little support for an effect.

In analyses of control fish, only the Chronic model of water temperature was better supported than the Reach Only model (table 15). The evidence ratio of the Chronic temperature model was 4.18 relative to the Reach Only, indicating moderate support for the effect. The slope of the Chronic temperature model was negative, indicating survival of control fish downstream of the Scott River decreased as water temperatures increased. All other models had evidence ratios near 1.0 or less, indicating model selection uncertainty and little support from the data.

Table 11. Model summary from analyses of apparent survival and capture probabilities to estimate reach survivals of treatment and control hatchery coho salmon from all release dates.

[Models are based on data from 246 hatchery fish released from April 10 through May 18, 2007. Model descriptions include factors by which apparent survival (Phi) and capture probability (P) may vary, including reach and group (treatment or control). Rankings are based on AICc, a modification of Akaike Information Criterion for small samples. A '+' between factors indicates an additive effect. A '.' indicates a no effect (a single value fitted to all observations). The global model includes multiplicative effects of all factors. Num. Parms. denotes the number of estimable parameters in the model]

Model	AICc	Delta AICc	Model Likelihood	Model Weight	Num. Parms.	Deviance
Phi(Group*Reach),P(.)	790.953	0.000	1.000	0.991	12	79.702
Phi(Group+Reach),P(.)	800.494	9.542	0.009	0.008	8	97.457
Phi(Reach),P(.)	804.846	13.893	0.001	0.001	7	103.849
Global model	809.206	18.253	0.000	0.000	22	77.055
Phi(Group),P(.)	914.592	123.639	0.000	0.000	3	221.705

Table 12. Model summary from analyses of apparent survival and capture probabilities to estimate reach survivals of hatchery coho salmon from the treatment group from all release dates.

[Models are based on data from 123 hatchery fish released from April 10 through May 18, 2007. Model descriptions include those in which apparent survival (Phi) and capture probabilities (P) may vary among reaches (Reach) and those in which a single value is assumed for all observations ('.'). Rankings are based on AICc, a modification of Akaike Information Criterion for small samples. The global model includes multiplicative effects of all factors. Num. Parms. denotes the number of estimable parameters in the model]

Model	AICc	Delta AICc	Model Likelihood	Model Weight	Num. Parms.	Deviance
Phi(Reach), P(.)	481.967	0.000	1.000	0.996	8	55.569
Phi(Reach), P(Reach)	493.491	11.524	0.003	0.003	14	54.636
Global model	495.591	13.625	0.001	0.001	15	54.636
Phi(.),P(.)	515.605	33.639	0.000	0.000	2	101.424

Table 13. Estimated apparent survivals and profile likelihood confidence intervals of radio-tagged juvenile coho salmon in study reaches of the Klamath River.

[Results are based on data from 123 hatchery fish released near Iron Gate Hatchery (treatment group) and 123 hatchery fish released near Tree of Heaven campground (control group) from April 10 through May 18, 2007. Results from the Iron Gate Hatchery release site are based on the top model in table 12 and those for the Tree of Heaven release site are based on the top model in table 11. Data over multiple reaches were calculated as the product of the reach estimates with variance estimated using the delta method]

Reach Number	Description	Reach Length (km)	Apparent Survival	Standard Error	95% Confidence Interval	
					Lower	Upper
------------------------------------- Release Site = Iron Gate Hatchery (rkm 309) ---						
1	Hatchery to Shasta River (rkm 288)	21	0.773	0.038	0.694	0.842
2	Shasta River to Tree of Heaven (rkm 280)	8	0.917	0.029	0.849	0.963
3	Tree of Heaven to Scott River (rkm 234)	46	0.814	0.042	0.723	0.887
4	Scott River to Indian Creek (rkm 178)	56	0.959	0.024	0.894	0.991
5	Indian Creek to Salmon River (rkm 107)	71	0.910	0.035	0.827	0.963
6	Salmon River to Trinity River (rkm 69)	38	1.000	4.03E-06	0.969	1.000
7	Trinity River to Steelhead Lodge (rkm 33)	36	0.986	0.016	0.932	1.000
	Hatchery to Steelhead Lodge	276	0.497	0.044	0.410	0.584
	Tree of Heaven to Steelhead Lodge	247	0.700	0.058	0.586	0.814
------------------------------------- Release Site = Tree of Heaven (rkm 280) ---						
3	Tree of Heaven to Scott River (rkm 234)	46	0.589	0.045	0.500	0.674
4	Scott River to Indian Creek (rkm 178)	56	0.778	0.050	0.671	0.865
5	Indian Creek to Salmon River (rkm 107)	71	0.765	0.057	0.642	0.864
6	Salmon River to Trinity River (rkm 69)	38	0.930	0.040	0.827	0.984
7	Trinity River to Steelhead Lodge (rkm 33)	36	0.925	0.043	0.814	0.982
	Tree of Heaven to Steelhead Lodge	247	0.301	0.041	0.220	0.382

Table 14. Results of models [Phi(Reach), P(.)] assessing the effects of covariates of treatment fish survival along three hypotheses.

[The hypotheses for each covariate are A) an effect only between release and Scott River (Acute), B) an effect only downstream from the Scott River (Chronic), and C) the combination of both effects (Acute + Chronic). The data were based on 123 treatment fish released from April 10 through May 18, 2007. A reach-dependent model without covariates (Reach Only) is presented to assess the relative improvement through the use of the covariates. Num. Parms. denotes the number of estimable parameters in the model. The Evidence Ratio is the Model Weight of the model divided by the Model Weight of the Reach Only model. The sign of the slope parameter is '?' if the 95% CI overlapped zero]

Covariate	Hypothesis	AICc	Delta AICc	Model Likelihood	Model Weight	Num. Parms.	Evidence Ratio	Slope Sign
Temperature	Acute	439.65	1.41	0.50	0.20	8	0.50	?
Temperature	Chronic	439.12	0.87	0.65	0.26	8	0.65	?
Temperature	Acute + Chronic	440.22	1.97	0.37	0.15	8	0.37	?
None	Reach Only	438.25	0.00	1.00	0.40	7	na	na
Discharge	Acute	440.22	1.97	0.37	0.18	8	0.37	?
Discharge	Chronic	440.29	2.04	0.36	0.17	8	0.36	?
Discharge	Acute + Chronic	440.30	2.05	0.36	0.17	8	0.36	?
None	Reach Only	438.25	0.00	1.00	0.48	7	na	na
Date	Acute	440.12	1.87	0.39	0.17	8	0.39	?
Date	Chronic	439.42	1.17	0.56	0.24	8	0.56	?
Date	Acute + Chronic	440.11	1.86	0.39	0.17	8	0.39	?
None	Reach Only	438.25	0.00	1.00	0.43	7	na	na
Weight	Acute	434.44	0.00	1.00	0.72	8	6.73	+
Weight	Chronic	437.73	3.30	0.19	0.14	8	1.29	?
Weight	Acute + Chronic	440.25	5.81	0.05	0.04	8	0.37	?
None	Reach Only	438.25	3.81	0.15	0.11	7	na	na

Table 15. Results of models [Phi(Reach), P(.)] assessing the effects of covariates of control fish survival along three hypotheses.

[The hypotheses for each covariate are A) an effect only between release and Scott River (Acute), B) an effect only downstream from the Scott River (Chronic), and C) the combination of both effects (Acute + Chronic). The data were based on 123 control fish released from April 10 through May 18, 2007. A reach-dependent model without covariates (Reach Only) is presented to assess the relative improvement through the use of the covariates. Num. Parms. denotes the number of estimable parameters in the model. The Evidence Ratio is the Model Weight of the model divided by the Model Weight of the Reach Only model. The sign of the slope parameter is '?' if the 95% CI overlapped zero]

Covariate	Hypothesis	AICc	Delta AICc	Model Likelihood	Model Weight	Num. Parms	Evidence Ratio	Slope Sign
Temperature	Acute	440.01	4.59	0.10	0.07	8	0.42	?
Temperature	Chronic	435.41	0.00	1.00	0.67	8	4.18	-
Temperature	Acute + Chronic	439.17	3.76	0.15	0.10	8	0.64	?
None	Reach Only	438.27	2.86	0.24	0.16	7	na	na
Discharge	Acute	440.18	1.90	0.39	0.18	8	0.39	?
Discharge	Chronic	440.36	2.09	0.35	0.17	8	0.35	?
Discharge	Acute + Chronic	440.24	1.97	0.37	0.18	8	0.37	?
None	Reach Only	438.27	0.00	1.00	0.47	7	na	na
Date	Acute	440.27	2.00	0.37	0.15	8	0.37	?
Date	Chronic	439.09	0.82	0.66	0.27	8	0.66	?
Date	Acute + Chronic	440.06	1.79	0.41	0.17	8	0.41	?
None	Reach Only	438.27	0.00	1.00	0.41	7	na	na
Weight	Acute	440.12	2.25	0.33	0.13	8	0.40	?
Weight	Chronic	437.87	0.00	1.00	0.41	8	1.22	?
Weight	Acute + Chronic	440.33	2.46	0.29	0.12	8	0.36	?
None	Reach Only	438.27	0.40	0.82	0.34	7	na	na

Comparisons Between 2006 and 2007 Data

The purpose of these analyses was to compare both the migration behaviors and survivals of fish released in 2006 and 2007. Data were examined for trends based on year, release week, and reach.

The analysis was restricted to fish released near IGH in weeks 15 through 19 in each year, as these site/week combinations were common to both years. This time period was from April 9 through May 13, 2006 and from April 8 through May 12, 2007. These data comprised 90 fish released in 2006 and 111 fish released in 2007. The number of fish released per week ranged from 17 to 22 in 2006 and 22 to 23 in 2007. The most common capture history was that in which fish were detected at all sites (appendix 5).

Migration behaviors of hatchery fish of the treatment groups released in weeks 15 through 19 were similar in each year. Few fish migrated downstream to the Shasta site prior to early May, regardless of when they were released (fig. 18). There were similar patterns in travel times from release to passage at the Shasta and Scott sites in each year (fig. 19). The travel times were slightly longer in 2007, but the difference was not statistically significant (stratified test of year controlling for release week, Wilcoxon Rank Sum Test χ^2 = 0.1644, df = 1, P = 0.6852). Fish released in the early weeks of the study spent much more time upstream of the Shasta River than those released later in the study. For example, the median travel times of fish pooled over years from release to the Shasta River ranged from 22.95 d for fish released in week 15 to 6.29 d for those released in week 19. As noted previously in this report and in Beeman and others (2007), fish traveled relatively quickly once they had been detected at the Shasta River site.

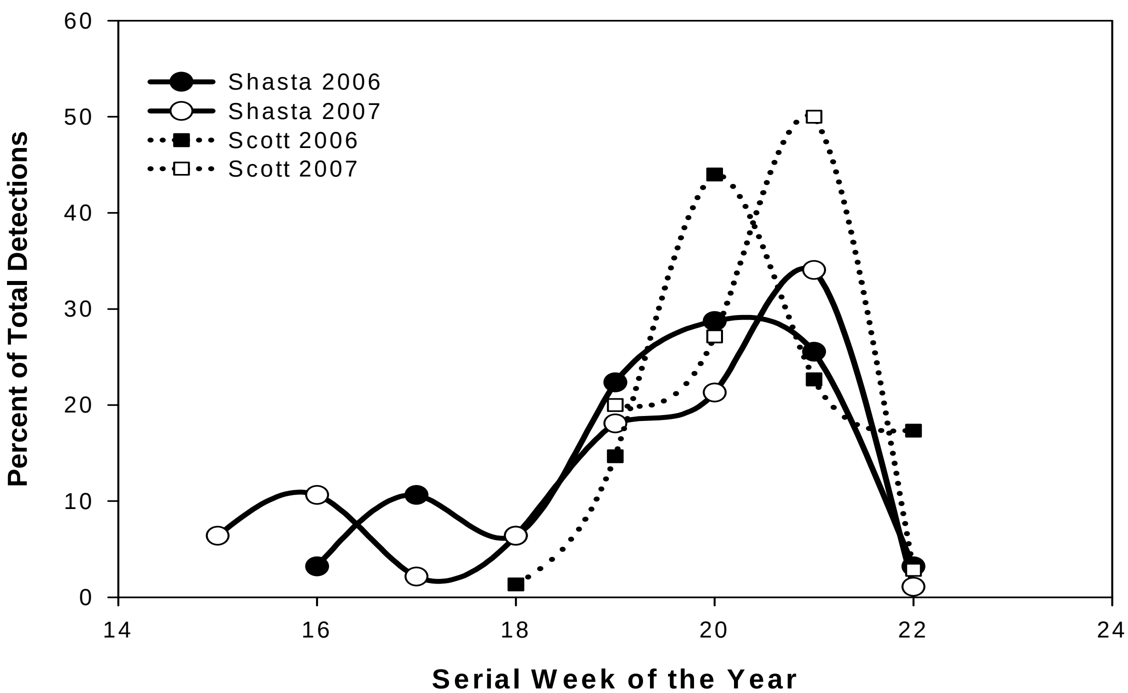


Figure 18. Passage timing of hatchery coho salmon released near IGH in 2006 and 2007 at the Shasta River and Scott River sites. Smoothed lines are drawn for clarity and may not represent the actual relation between week and detection.

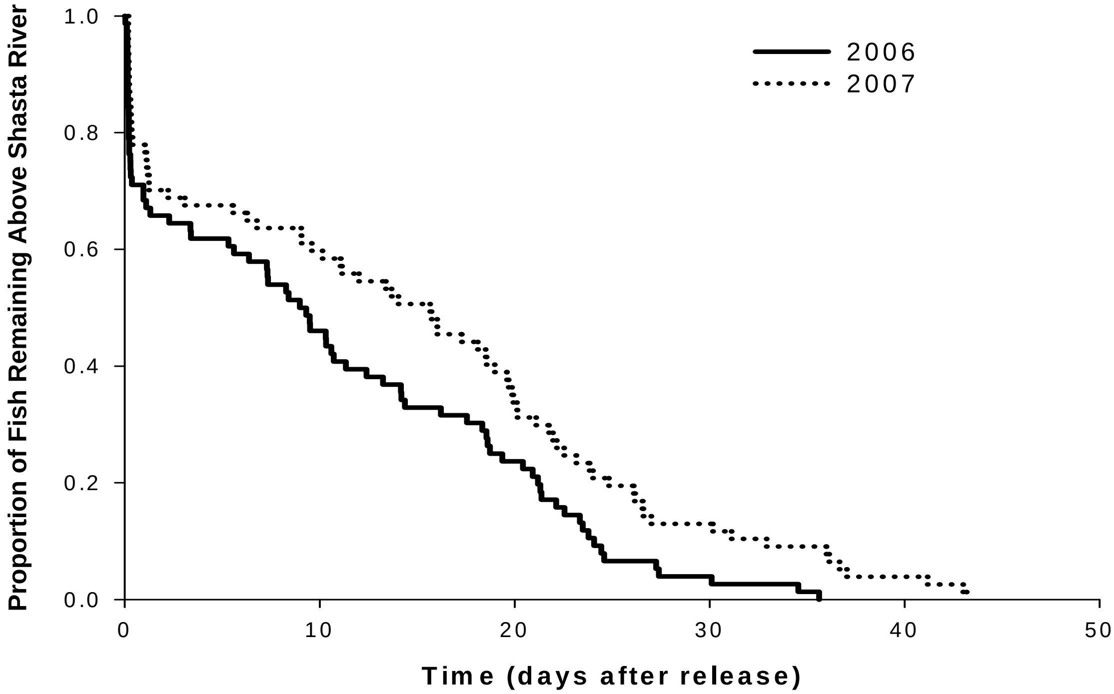


Figure 19. Kaplan-Meier curves describing travel times of radio-tagged hatchery coho salmon from release near IGH to the Shasta River in 2006 and 2007.

This supports the hypothesis that once fish released near IGH pass the Shasta River site they migrate quickly through the remainder of the study area downstream to rkm 13. Data from 2006 and 2007 indicate that most of these fish started passing the Shasta River site in about the 19^{th} week of the year, which is in the second week of May, and the peak passage was 1 to 2 weeks later.

Models of survival and capture probability were examined to determine if the release week, a surrogate for the time spent upstream of the Shasta River, affected survival. Tests of model fit based on the median c-hat procedure indicated moderate overdispersion, suggesting the variances would be underestimated. We corrected for this by applying a variance inflation factor median c-hat of 2.717 based on a 50-parameter model including additive effects of year, site, and release week on both survival and capture probability. A 134-parameter model with multiplicative effects of all variables was not used to assess model fit, because it would not converge during execution (likely due to the large number of parameters given the number of observations). All models of survival shared a common model of capture probability in which a different value was used for each year, as this was the most supported model of this parameter.

An effect of release week on survival was not supported by the data. Models with effects of release week on survival upstream of the Shasta River (model #4) and upstream of the Scott River (model #3) had evidence ratios less than 0.1 compared to the model without these effects (model #1), indicating virtually no support of these effects (table 16). The model with an effect of release week on survival anywhere downstream (model #6) was much less supported than models 1 and 4. Evidence ratios greater than about 4 to 7 begin to indicate meaningful differences between models (Burnham and Anderson, 2002).

Data indicate that there is considerable uncertainty in the importance of the effect of year on reach survivals. Most reach survivals in 2006 were slightly greater than those in 2007 (fig. 20). The data in this figure are model-averaged from models 1 and 2 in table 16, which together accounted for 92.7 percent of the model weights. The differences between years were greatest in the release-to-Shasta River and Shasta River-to-Scott River reaches and to a lesser extent in the Indian Creek-to-Salmon River reaches. The differences in the point estimates of survival in the other three reaches were ≤ 0.03 between years. The only two models of survival in the suite examined that were supported by the data were one with additive effects of year and reach (model #1) and another with only reach (model #2; table 16). The evidence ratio of 1.77 (model weight of model# 1 divided by that of model #2) indicates considerable model selection uncertainty and thus uncertainty in the importance of the effect of year on survival, which is the only difference between the two models. This uncertainty is affected by the relatively high c-hat value, which inflates variances and adds a selection penalty to models with more parameters, and the fact that the survivals were similar between years in several of the reaches.

Table 16. Model summary from analyses of apparent survival of hatchery coho salmon released near Iron Gate Hatchery during weeks 15 through 19 in 2006 and 2007.

[Models are based on data from 90 fish released in 2006 and 111 fish released in 2007. Model descriptions include factors by which apparent survival (Phi) may vary, including year, reach, and release week. Rankings are based on QAICc, a modification of Akaike Information Criterion for small samples and overdispersion. All models are based on a model of capture probability based on differences between years. The global model includes additive effects of year, reach, and week. Num. Parms. denotes the number of estimable parameters in the model]

Model Number	Model	QAICc	Delta QAICc	Model Likelihood	Model Weight	Num. Parms	QDeviance
1	Phi(Year+Reach)	338.471	0.000	1.000	0.592	9	95.33
2	Phi(Reach)	339.611	1.141	0.565	0.335	8	98.51
3	Phi(Year+Reach+Week effect upstream of Scott R)	343.434	4.963	0.084	0.050	12	94.15
4	Phi(Year+Reach+Week effect upstream of Shasta R)	345.007	6.536	0.038	0.023	13	93.66
5	Phi(Year)	352.709	14.238	0.001	0.000	4	119.71
6	Phi(Year+Reach+Week)	361.192	22.722	0.000	0.000	25	84.82
7	Global Model	405.921	67.451	0.000	0.000	50	75.25

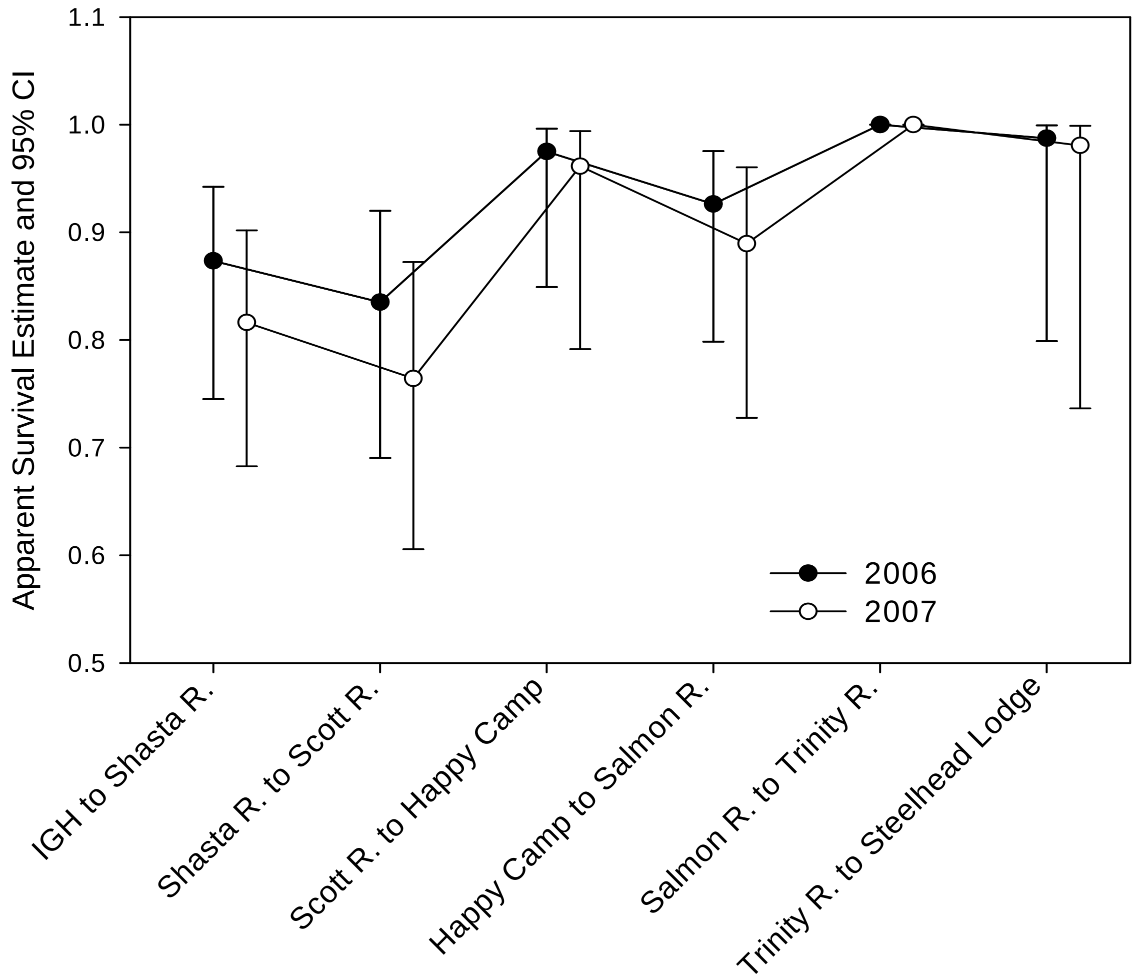


Figure 20. Estimated apparent reach survivals and 95 percent profile likelihood confidence intervals of hatchery coho salmon released near IGH during weeks 15 through 19 in 2006 and 2007 based on model-averaged results of models 1 and 2 in table 16.

Summary

This report describes the data collected from the first 2 years of a study planned for 3 years. As such, we have analyzed these data primarily to produce estimates of survival and to identify general trends in the data to determine if there are changes in the study design that are required to meet the original objectives, or if the available information suggests that the objectives should be altered prior to study completion. The final analyses will be completed after the data for the third year are collected. We briefly describe progress on topics related to the original four objectives below.The first objective is to estimate survivals of wild and hatchery juvenile coho salmon in the Klamath River downstream of IGD. We have met this objective in each year, but we were only able to use wild fish in 2006 due to their limited availability. We have produced estimates of survival from the fish released in 2006 and 2007. Data were summarized in USGS Open-File Reports (Beeman, 2007, 2008) and in more detail in this report and in a similar report of 2006 research (Beeman and others, 2007). The survival estimates of the fish in this study generally are similar to those from other river systems, though there are no estimates from drainages near the Klamath River. As described in Beeman and others (2007), estimates from the Klamath River are similar to those from the Yakima River and Columbia/Snake River systems when compared over similar migration distances.

Survival was lower in 2007 than in 2006. Survival from IGH to rkm 33 over the entire study period was 0.653 (SE 0.039) in 2006 and 0.497 (SE 0.044) in 2007. Reach survivals of fish released near IGH were lower in 2007 in three of six reaches, but the trends among reaches were similar to those in 2006. In each year, the lowest survivals were in the reaches upstream of the Scott River and the highest survivals were in the Salmon River-to-Trinity River reach (at or near 1.0 for fish released near IGD in each year). Too little is known about factors affecting survival in the Klamath River to attribute a cause to the differences between 2006 and 2007 survivals. Possible causes include the different discharges and turbidity (Gregory and Levings, 1998), or normal annual variation from these or other sources. Attributing the cause solely to the differences in discharge between years is not possible, because there were no experimental discharges. Analyses based on all hatchery release dates in 2006 indicated that survivals upstream of the Scott River were higher as date of the year progressed, but analyses of release weeks common to 2006 and 2007 show no effect of release date on survival (Beeman and others, 2007). This difference may be due to the truncated data set that the 2-year analyses were based on. The combined 2006–07 data did not support the hypothesis that release week (a surrogate for time spent upstream of the Shasta or Scott Rivers after release) affected survival in those reaches, which suggests that the mortality there must occur primarily after directed downstream migration has been initiated. Analyses of covariates of survival upstream of the Scott River indicate that large fish had greater survival than small ones. There are many potential mechanisms that could explain this difference. The size of juvenile salmonids is known to be an important factor in competition for cover habitat (Fausch and White, 1986; Armstrong and Griffiths, 2001), and cover is known to be important for fish survival (Metcalfe and others, 1998). The pattern evident in the data we collected could be explained if mortality is greater when fish migrate downstream than when they are non-migrants, presumably due to differences in concealment from predators.

The pattern also could be explained if large and small fish simply prefer different habitats and this resulted in differences in their survivals, or if larger fish are inherently less vulnerable to predation. Another alternative is that the data represent a tagging and handling effect, but this seems unlikely because there was no evidence of this in 2006 when the paired-release design was used successfully (Beeman and others, 2007).

The causes of the difference in the survivals of fish released near IGH and those released near the Tree of Heaven campground are unknown. The survival between Tree of Heaven campground and rkm 33 was 0.700 (SE 0.058) for fish released near IGH and 0.301 (SE 0.041) for those released near the campground. The largest survival difference between the groups was in the reach from the campground to the Scott River, in which the survivals were 0.814 (SE 0.044) and 0.589 (SE 0.045), though the point estimates of survival of fish released near IGH were higher in every reach. The fish released near the campground had longer travel times through most reaches than those released near IGH, but we could not determine if this was the cause of the survival differences. The differences also could reflect different rates of tagging and handling mortality or a tag effect on mortality in the two groups, however, this was not observed in 2006 and the standard operating procedures and surgeon were the same in each year. The Klamath River near the campground has been known to harbor *Manayunkia speciosa*, the polychaete host for *C. shasta* and *P. minibicornis* (Foott and others, 2004), suggesting that releasing fish in this area may have resulted in mortality from disease. However, the disease would not likely progress to a clinical stage prior to the time the fish were out of the study area, based on water temperatures and exposure times (Scott Foott, USFWS California-Nevada Fish Health Center, written commun., January 3, 2008). Exposure to disease possibly could affect survival in the wild prior to the onset of clinical effects of the disease. Results of an experiment with caged juvenile coho salmon from IGH in 2008 showed those held for 7-d near Tree of Heaven Campground died in laboratory tanks at a greater rate than those held near the hatchery, indicating our holding of control fish near the campground in 2007 may have exposed them to increased disease afterward (Foott and others, 2008).

The second and third objectives are to determine the effects of discharge and other environmental covariates on the survival (2) and migration behavior (3) of juvenile coho salmon. Thus far, we have not met these objectives, because we have been unable to isolate the effects of discharge on the migration or survival of the study fish from other environmental factors. The only way to directly isolate discharge from other factors is to experimentally vary discharge. This was known and openly discussed at the onset of the study, but experimental discharges, at least at that time, may have been premature given that little was known about the migration behavior of juvenile coho salmon downstream. Experimental discharges may be difficult to implement in the Klamath River due to the limited capacity for storage and other water issues. We now know that few hatchery juvenile coho migrate prior to early May even during the high discharges present in 2006. As such, using fish taken directly from IGH to assess the effects of experimental discharges prior to early May might not be useful if the intent is to mimic behaviors of wild fish, because most did not migrate until May during 2006 or 2007. Discharge could affect survival in several ways, but the general premise is that higher discharge will cause faster migration, which will result in less time exposed to predation risk and ultimately increase survival. Other means include changes in water temperatures, available habitat, turbidity, and quantity of cover habitat. Data collected thus far indicate that non-migrant and migrant fish respond differently to discharge and how it changes over time. We also know from analyses of data from periods common to both years that there appears to be no measurable effect of the time spent upstream of the Shasta or Scott Rivers on survival of hatchery fish downstream in 2006 or 2007, even though some fish spent a few days in the areas and others spent several weeks.

A key assumption of the paired-release survival design was violated, preventing its use in 2007. The survivals of the treatment and control groups were different through the first reach they had in common, violating Assumption A9. This assumption is often met by designing releases such that the two groups mix in the first common reach and therefore experience the same mortality factors. This becomes more difficult as the distance between the two release sites increases and when temporal changes in the emigration behavior of individuals occur. This assumption commonly is used in the Columbia River Basin in studying dam passage. In those studies, the release points of the two groups generally are less than 1 km apart, but in this study, release sites were 21 km in 2006 and 29 km in 2007. The assumption was met in 2006, perhaps due to the lag between release and migration of the control group released at the mouth of the Shasta River while the treatment group was migrating the 21 km between release sites. In 2007, the control fish did not show this delay and the treatment fish did not arrive in the common reach until after many of the control fish had passed. In addition, the treatment fish were migrating quickly by the time they entered the first common reach, traversing it in a median of 0.8 d, whereas fish in the control group were apparently not yet migrants and traversed in a median of 8.0 d. The goal of the paired-release design was to estimate survival in the reach nearest IGD without the effects of tagging and handling, should they be present. Data from 2006 do not indicate measurable tagging and handling mortality, so we will omit the paired-release design from 2008 work.

The fourth objective is to determine if hatchery-reared juvenile coho salmon can be used as surrogates for wild fish. Our success in meeting this objective is predicated on the availability of wild fish. There was not a clear difference in survival of hatchery fish compared to wild fish in 2006, though that was the only year we had access to wild fish. Beeman and others (2007) noted that that data supported models of differences in survivals of hatchery and wild fish nearly as well as a model without an origin effect, indicating uncertainty in the importance of fish origin on survival. This was true despite the large difference in their migration behaviors, though the differences in the migrations of hatchery and wild fish shortly after release may be a result of our sampling regime rather than overall differences between fish from the two origins. Data from 2006 and 2007 indicate that few hatchery fish released near IGH migrate downstream to the nearest detection site until early- to mid-May and this behavior was not evident in wild fish released at the same site in 2006. As we stated in Beeman and others (2007), this may reflect differences in smoltification of hatchery and wild fish, however, it also may be a result of the sampling regime. For example, we have been using hatchery fish taken directly from a tank at IGH, tagging them, and releasing them in the Klamath River nearby 24 h later. Few of the fish released near IGH in 2006 or 2007 were detected at Shasta River site (21 km downstream) until early May, despite releases beginning in early April. Most fish released in early April took weeks before passing the Shasta River site and most released in early May took days. The wild fish we used in 2006 were taken from the catch in the rotary screw trap in the Shasta River operated by CDFG. Wild fish from all release dates migrated quickly from the release site at IGH to the Shasta River. However, the peak catch at the rotary screw trap was in mid-May in 2006 and generally was in early May in the previous several years (see Beeman and others, 2007). We hypothesize that the wild fish we used were the early migrants of the wild fish population and the hatchery fish we used contained both migrants and non-migrants. Thus, the same processes that resulted in peak migration time in wild fish also did so in hatchery fish, but our sampling regime for wild fish selected only migrants from that population. This may be important in addressing Objective 4, the use of hatchery fish as surrogates for wild fish. The hatchery and wild fish may behave similarly under similar conditions, but we have been comparing the total population of hatchery fish to only the migrant population of wild fish. Given their 3-year cycle of abundance, the next likely opportunity to have wild fish available in sufficient numbers for a study like this one will be in 2009.

Data examined from 2006 and 2007 suggested slight changes in design would be useful prior to the third year of data collection in 2008. We will not implement the paired-release design based on its failure in 2007 and the fact that it effectively reduces sample sizes of fish in the IGH-to-Shasta River reach by 50 percent. We will instead divide the available transmitters between fish taken directly from IGH and hatchery fish captured in traps downstream near the I-5 Bridge. This will help us to determine if the change in behavior of hatchery fish from non-migrant to migrant in early May is due to fish origin, or the difference between naïve and migrant fish used in the study. We also will implement a companion study in the Trinity River to provide estimates of survival from another nearby river for comparison with data from the Klamath River. Analyses of the entire 3-year data set will be conducted when the data are available.

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Appendix 1. Tag life test.

Introduction

An assumption of release-recapture models used to estimate survival is that all live tagged individuals have the same probability of being detected at downstream detection arrays. Because radio transmitters (tags) have a limited and varied battery life, the tag failure rate may affect detection probabilities, depending on travel time of a tagged fish and the time a tag is on prior to release. Thus, survival estimates may be negatively biased if the tag expires prior to a fish passing all detection arrays. Information obtained by a tag-life study can be used to adjust survival estimates using the probability that a tag will expire prior to fish exiting the study area (Cowen and Schwarz, 2005; Townsend and others, 2006).

Methods

We used the methods of Townsend and others (2006) to conduct a tag-life study to estimate the probability that a tag was operating when passing our detection arrays. The tag-life study entailed activating tags during the study period, and monitoring tag failure over time. We randomly selected 24 model NTC-M-2 tags from the pool of tags to be deployed in the survival study, making sure to represent the three frequencies (channels) equally. Tags were activated, submerged in water, and monitored with a Lotek SRX-400 data logging receiver. The expiration time was determined by the last record of detection of each tag.

Tag-life data were used to model tag survivorship and for calculating the probability of a tag being operational at each detection array as per Townsend and others (2006). The tag-life data were fit to a Gompertz distribution (Elandt-Johnson and Johnson, 1980). A non-parametric form of the tag survival function was used because travel times of radio-tagged salmonids typically are highly skewed (that is, data are not normally distributed). Tag-life data were ranked to facilitate the estimation of model parameters. The Gompertz survival distribution function takes the form

$$S(t) = e^{(\beta/\alpha)(1-e^{\alpha t})},$$

where $S(t)$ is the probability the radio-tag is operational at time t and parameters α and β are to be estimated by fitting the model to the tag-life data.

Travel time to different detection arrays were then substituted into this function for estimating the probability a tag was operating when a fish arrived at a particular detection array. During our tagging procedures, tags were turned on prior to release (approximately18-36 hours), so the elapsed time a tag was operating before release was added to travel times.

The period that the tags were operational generally exceeded the minimum battery life (45 d for the model NTC-M-2) specified by the manufacturer. Two of the 24 tags tested expired prior to the specified 45 d. The first premature tag failure occurred at 35.8 d and the second at 43.3 d. The operational period of the remaining 22 tags ranged for 50.0 to 71.7 d. The mean operational period was 60.7 d.

The tag-life study was analyzed for generating model parameters of the Gompertz distribution and calculating probabilities radio-tags were alive at detection arrays. Our tag-life data fit well with the Gompertz survival distribution function (fig. A1) allowing us to use this model for calculating probabilities. Parameter estimates were $\alpha = 0.158$ (*SE* = 0.0427), $\beta = 0.574\times10^{-5}$ (*SE* = 0.140×10^{-4}), and $R^2 = 0.867$.

We determined that the probability of a tag being operational at downstream arrays was high, with all probabilities greater than 99 percent (table A1). The cumulative arrival distributions plotted with the Gompertz model over time shows that tagged coho salmon passed through downstream detection arrays before tag failure was substantial (fig. A2). Because the probability of a tag being operational at the downstream detection arrays for our survival studies was very close to one (table 1), we did not adjust our survival estimates.

Table A1. Estimated probabilities (mean, SD in parentheses) that a radio tag was operational at downstream detection arrays during 2007.

	Release Sites	
Detection Array Locations	**Iron Gate Hatchery (test)**	**Tree of Heaven (control)**
Shasta River	0.998 (0.007)	n/a
Tree of Heaven	0.997 (0.007)	n/a
Scott River	0.996 (0.008)	0.999 (0.002)
Indian Creek	0.996 (0.008)	0.998 (0.004)
Salmon River	0.995 (0.010)	0.997 (0.007)
Trinity River	0.994 (0.011)	0.995 (0.010)
Steelhead Lodge	0.992 (0.016)	0.993 (0.016)
Blake’s Riffle	0.991 (0.017)	0.992 (0.017)

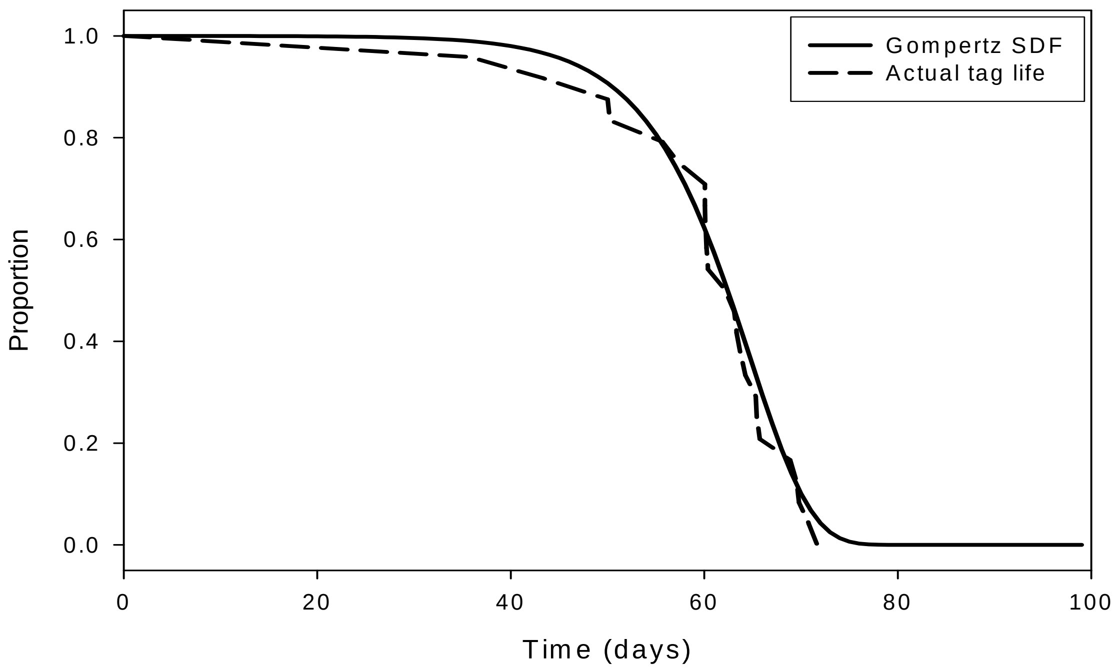

Figure A1. The Gompertz survival distribution function fit to the actual tag-life data.

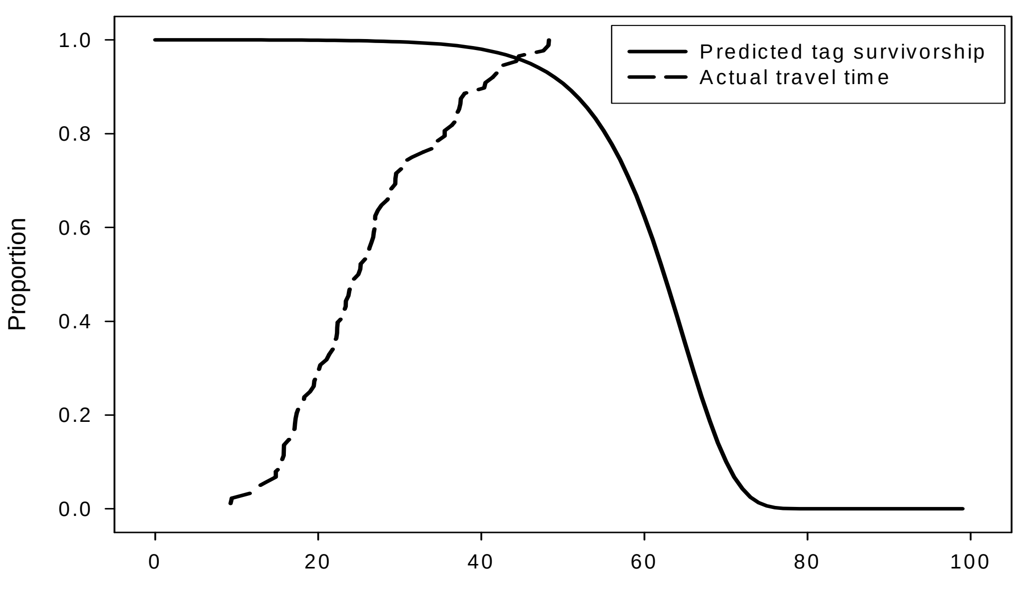

Figure A2. Cumulative travel time distribution of tags (dotted line) compared to survival distribution function for tag battery life (solid line) for 2006. Travel time distributions include the total elapsed time that the tag was operating prior to release of fish.

Appendix 2. Results of Analyses of Tissues for Bacterial Kidney Disease.

[Results of the qualitative nested polymerase chain reaction (PCR; Method 1) and the quantitative PCR (qPCR ; Method 2) tests to determine prevalence of bacterial kidney disease. Samples were taken from juvenile coho salmon at Iron Gate Hatchery, on May 16, 2007]

			Method 1	Method 2			
				qPCR			
Sample number	Sample Weight (mg)	DNA Concentration (µg/µL)	Nested PCR	*Renibacterium salmoninarum* presence	Quantity Mean*	Number of Bacteria in Total Extraction**	Total Bacteria per mg Tissue
1	2.3	0.025	neg	neg	0	0	0
2	2.5	0.0185	neg	pos	1	105	42
3	12.6	0.0185	neg	neg	0	0	0
4	3.7	0.018	neg	neg	0	0	0
5	6.0	0.0565	neg	neg	0	0	0
6	11.6	0.034	neg	neg	0	0	0
7	12.5	0.0365	neg	neg	0	0	0
8	1.0	0.0115	neg	neg	0	0	0
9	5.8	0.0095	neg	neg	0	0	0
10	5.4	0.0145	neg	neg	0	0	0
11	1.5	0.0245	pos	pos	3	237	157
12	8.7	0.0305	neg	pos	2	121	14
13	10.4	0.046	neg	pos	3	213	21
14	2.5	0.0325	neg	neg	0	0	0
15	5.8	0.0155	neg	neg	0	0	0
16	7.7	0.034	neg	neg	0	0	0
17	8.2	0.0295	neg	neg	0	0	0
18	4.8	0.0185	neg	neg	0	0	0
19	5.9	0.025	neg	pos	1	77	13
20	5.9	0.028	neg	neg	0	0	0
21	13.6	0.0265	neg	neg	0	0	0
22	4.1	0.0175	neg	neg	0	0	0
23	3.7	0.008	neg	neg	0	0	0
24	3.2	0.0145	neg	neg	0	0	0
25	7.8	0.0315	neg	pos	2	159	20
26	15.0	0.0225	pos	neg	0	0	0
27	0.0	0.013	neg	neg	0	0	0
28	5.1	0.0405	neg	neg	0	0	0
29	4.4	0.0115	neg	pos	2	171	39
30	6.4	0.0215	neg	neg	0	0	0
31	1.0	0.011	neg	neg	0	0	0
32	7.6	0.022	neg	neg	0	0	0
33	3.3	0.006	neg	neg	0	0	0
34	2.9	0.02	neg	neg	0	0	0

35	5.4	0.019	neg	neg	0	0	0
36	3.7	0.008	neg	neg	0	0	0
37	4.1	0.0175	neg	neg	0	0	0
38	3.0	0.0355	neg	neg	0	0	0
39	3.9	0.0215	neg	neg	0	0	0
40	3.5	0.0245	neg	neg	0	0	0
41	1.9	0.0225	neg	neg	0	0	0
42	4.9	0.037	neg	neg	0	0	0
43	4.3	0.011	neg	neg	0	0	0
44	7.8	0.019	neg	neg	0	0	0
45	5.7	0.0125	neg	neg	0	0	0
46	5.5	0.013	neg	neg	0	0	0
47	3.9	0.017	neg	neg	0	0	0
48	5.7	0.0485	neg	neg	0	0	0
49	5.6	0.145	neg	neg	0	0	0
50	3.0	0.0635	neg	neg	0	0	0
51	4.6	0.1125	neg	neg	0	0	0
52	3.5	0.053	neg	neg	0	0	0
53	2.7	0.0635	neg	neg	0	0	0
54	3.6	0.079	neg	neg	0	0	0
55	5.8	0.056	neg	neg	0	0	0
56	4.1	0.0755	neg	neg	0	0	0
57	6.5	0.015	neg	neg	0	0	0
58	5.8	0.0235	neg	neg	0	0	0
59	4.2	0.035	neg	neg	0	0	0
60	3.6	0.037	neg	neg	0	0	0
* In 5 µL							
** In 400 µL							

Appendix 3. Capture Histories of Hatchery Fish from Control and Treatment Groups Released from April 10 through May 18, 2007.

[Histories begin with ‘1’ for release and are ‘1’ if they were detected and ‘0’ if they were not at Scott River, Indian Creek, Salmon River, Trinity River, Steelhead Lodge, and Blake’s Riffle in the Klamath River, northern California]

Capture History	Control Observed	Treatment Observed
1111111	33	53
1111110	2	6
1111100	2	1
1111000	3	0
1110100	1	0
1110000	13	6
1101111	1	1
1100000	16	3
1000001	1	1
1000000	51	52
sum	123	123

Appendix 4. Capture Histories of Hatchery Fish from the Treatment Group Released from April 10 through May 18, 2007.

Histories begin with '1' for release and are '1' if they were detected and '0' if they were not at Shasta River, Tree of Heaven, Scott River, Indian Creek, Salmon River, Trinity River, Steelhead Lodge, and Blake's Riffle in the Klamath River, northern California.

Capture History	Observed
111111111	53
111111110	6
111111100	1
111110000	5
111101111	1
111100000	3
111000001	1
111000000	16
110000000	8
100110000	1
100000000	28
sum	123

Appendix 5. Capture Histories of Hatchery Fish from the Treatment Groups Released During Week (Wk) 15 through 19 in 2006 and 2007.

[Histories begin with ‘1’ for release and are ‘1’ if they were detected and ‘0’ if they were not at Shasta River, Scott River, Indian Creek, Salmon River, Trinity River, Steelhead Lodge, and Blake’s Riffle in the Klamath River, northern California]

Capture History	2006					2007				
	Wk 15	Wk 16	Wk 17	Wk 18	Wk 19	Wk 15	Wk 16	Wk 17	Wk 18	Wk 19
11111111	9	7	9	4	7	9	8	8	15	10
11111110	0	0	0	1	0	2	1	2	0	0
11111101	0	0	1	0	0	0	0	0	0	0
11111100	0	0	0	0	2	0	1	0	0	0
11111011	0	0	1	0	1	0	0	0	0	0
11110111	2	1	1	0	0	0	0	0	0	0
11110011	1	0	0	0	0	0	0	0	0	0
11110000	0	1	0	0	1	0	0	2	0	3
11101110	0	0	0	0	1	0	0	0	0	0
11100000	0	0	1	1	2	0	0	1	0	0
11011111	1	0	0	1	2	0	0	0	0	0
11011011	0	1	0	0	0	0	0	0	0	0
11010000	1	0	0	0	2	0	0	0	0	0
11001110	0	0	0	1	0	0	0	0	0	0
11000001	0	0	0	1	0	1	0	0	0	0
11000000	0	4	3	4	1	6	3	5	3	4
10111111	0	1	1	0	0	0	0	0	0	0
10111110	1	0	0	0	0	0	0	0	0	0
10110111	1	0	0	0	0	0	0	0	0	0
10110000	0	0	0	0	0	0	1	0	0	0
10100010	0	0	0	0	1	0	0	0	0	0
10011111	0	0	0	1	0	0	0	0	0	0
10010111	0	0	0	1	0	0	0	0	0	0
10000000	2	3	0	2	0	4	8	4	4	6
sum	18	18	17	17	20	22	22	22	22	23