Effects of Iron Gate Dam Discharge and Other Factors on the Survival and Migration of Juvenile Coho Salmon in the Lower Klamath River, Northern California, 2006–09

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U.S. Geological Survey

Cover: Photograph of the Klamath River looking downstream near its confluence with the Salmon River, northern California. (Photograph taken by Steven Juhnke, U.S. Geological Survey, Cook, Washington, March 20, 2008.)

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Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
cubic inch (in^3)	0.01639	liter (L)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)

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

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^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)
liter (L)	61.02	cubic inch (in^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Effects of Iron Gate Dam Discharge and Other Factors on the Survival and Migration of Juvenile Coho Salmon in the Lower Klamath River, Northern California, 2006–09

By John Beeman and Steven Juhnke[1], U.S. Geological Survey; and Greg Stutzer[2] and Katrina Wright, U.S. Fish and Wildlife Service

Abstract

Current management of the Klamath River includes prescribed minimum discharges intended partly to increase survival of juvenile coho salmon during their seaward migration in the spring. To determine if fish survival was related to river discharge, we estimated apparent survival and migration rates of yearling coho salmon in the Klamath River downstream of Iron Gate Dam. The primary goals were to determine if discharge at Iron Gate Dam affected coho salmon survival and if results from hatchery fish could be used as a surrogate for the limited supply of wild fish. Fish from hatchery and wild origins that had been surgically implanted with radio transmitters were released into the Klamath River at river kilometer 309 slightly downstream of Iron Gate Dam. Tagged fish were used to estimate apparent survival between, and passage rates at, a series of detection sites as far downstream as river kilometer 33. Conclusions were based primarily on data from hatchery fish, because wild fish were only available in 2 of the 4 years of study. Based on an information-theoretic approach, apparent survival of hatchery and wild fish was similar, despite differences in passage rates and timing, and was lowest in the 54 kilometer (km) reach between release and the Scott River. Models representing the hypothesis that a short-term tagging- or handling-related mortality occurred following release were moderately supported by data from wild fish and weakly supported by data from hatchery fish. Estimates of apparent survival of hatchery fish through the 276 km study area ranged from 0.412 (standard error [SE] 0.048) to 0.648 (SE 0.070), depending on the year, and represented an average of 0.790 per 100 km traveled. Estimates of apparent survival of wild fish through the study area were 0.645 (SE 0.058) in 2006 and 0.630 (SE 0.059) in 2009 and were nearly identical to the results from hatchery fish released on the same dates. The data and models examined supported positive effects of water temperature, river discharge, and fish weight as factors affecting apparent survival in the Klamath River upstream of the confluence with the Shasta River, but few of the variables examined were supported as factors affecting survival farther downstream. The effect of water temperature on apparent survival upstream of the Shasta River was greater than Iron Gate Dam discharge, which was greater than fish weight.

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The estimated effect on apparent survival between release and the Shasta River with each 1 degree Celsius increase in water temperature was 1.4 times the effect of a 100 cubic feet per second increase in Iron Gate Dam discharge and 2.5 times the effect of a 1 gram increase in fish weight, and the effects of discharge and weight diminished at higher water temperatures up to the 17.91 degrees Celsius maximum present in the data examined. The rate of passage at the detection site near the confluence with the Shasta River was primarily affected by date of release, and water temperature was the only factor supported at the site near the confluence with the Scott River. Passage rates at sites downstream of the Scott River were affected by several of the variables examined, but the estimated effects were small and often imprecise. Results from this study indicate that discharge at Iron Gate Dam has a positive effect on apparent survival of yearling coho salmon in the Klamath River upstream of the Shasta River, but the effects are smaller than those of water temperature and are mediated by it. The results also support the use of hatchery fish as surrogates for wild fish in studies of apparent survival, but the available evidence suggests that study fish should be released well upstream of the area of interest, due to short-term differences in survival and migration behavior of hatchery and wild fish after release.

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 (NMFS) to list coho salmon populations within the Southern Oregon Northern California Coast (SONCC) Evolutionary Significant Unit as threatened under the Endangered Species Act on May 6, 1997 (Federal Register, 1997). The State of California listed the group as threatened in 2002 (California Department of Fish and Game, 2002).

The Bureau of Reclamation operates the Klamath Project to provide water to approximately 240,000 acres of cropland spanning 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, provide irrigation water, and generate electricity, although 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 Mediterranean-like conditions and vegetation in the middle and upper watershed.

Maintenance and restoration of anadromous fish populations requires sufficient stream flows 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 spring stream flows. In the Klamath River system, flows are now impeded by man-made 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 (2002) issued a Biological Opinion (BIOP) relative to the effects of the Klamath Project on the viability of SONCC coho salmon in the Klamath River downstream of IGD. The BIOP determined the operation of the Klamath Project jeopardized the existence of threatened SONCC coho salmon in the Klamath River and set forth Reasonable and Prudent Alternatives (RPA) to avoid jeopardizing their existence. Among the elements of the RPA were a prescribed regime of minimum river discharges at IGD and a water bank of 100,000 acre-ft 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 noted that although this may theoretically be possible, there was no existing information to support this conjecture for Klamath River coho salmon (National Research Council, 2001). In response to the National Research Council (2001) report, the BIOP mandated the Bureau of Reclamation to implement several studies, including those to determine the extent that spring IGD flow regimes affect survival of juvenile coho salmon during their downstream migration. As a result of that mandate, the U.S. Fish and Wildlife Service (USFWS) initiated a pilot study to determine the efficacy of using radio telemetry to estimate survival and migration behavior of juvenile coho salmon in the Klamath River downstream of IGD in 2005 (Stutzer and others, 2006). The USFWS and USGS subsequently partnered to study survival of juvenile coho salmon in the Klamath River downstream of IGD during 2006–09, resulting in a series of reports describing annual estimates of reach-specific survival (Beeman, 2007, 2008; Beeman and Juhnke, 2009; Beeman and others, 2009b) and two more comprehensive reports (Beeman and others, 2007, 2008). This report is a synthesis of the data collected during the 4-year period of study.

Factors affecting juvenile coho salmon migration, survival, and habitat preference during varying flow regimes in the Klamath River are largely unknown. The limited abundance of juvenile coho salmon within the main stem Klamath River and its tributaries preclude the use of passive mark and recapture methods to study movement and survival (National Marine Fisheries Service, 2002). However, active tools, such as radio telemetry, provide researchers with a 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). Given these capabilities, radio telemetry commonly is used to study juvenile salmon migration patterns (McCleave, 1978; Lacroix and McCurdy, 1996; Giorgi and others, 1997; Hockersmith and others, 2003; Miller and Sadro, 2003) and estimate survival of several salmonid species in various locations (Skalski and others, 2001, 2002; Beeman and others, 2010).

Studies of 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 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 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 studies of fish survival.

Methods

Study Area

The study area encompassed most of the lower 310 rkm of the main stem Klamath River from IGD to the estuary at the Pacific Ocean (fig. 1). Automated radio telemetry stations were located near the confluences of major tributaries and upstream of the estuary.

Study Fish

Collection and Release

This study was conducted using juvenile coho salmon of hatchery and wild origins, although wild fish were only available during 2 of the 4 years. Hatchery fish in each of the 4 years were obtained from Iron Gate Hatchery near IGD, and wild fish were captured in rotary screw traps operated by the California Department of Fish and Game. The study periods were selected to coincide with the peak outmigration of fish from the Shasta River based on rotary screw trap catches of wild coho salmon (see Underwood and others, 2010). Wild fish were from the Shasta River in 2006 and the Scott River in 2009. The trap in the Shasta River was approximately 1 km upstream of the confluence with the Klamath River and the trap in the Scott River was approximately 8 km upstream of the confluence of the Klamath River. In 2008, 28 hatchery fish captured in a rotary screw trap in the Klamath River were tagged and released as a ‘migrant hatchery’ group for comparison with fish taken directly from the hatchery. Results from those fish are described in Beeman and others (2009b), but were not used in the analyses described in this report.

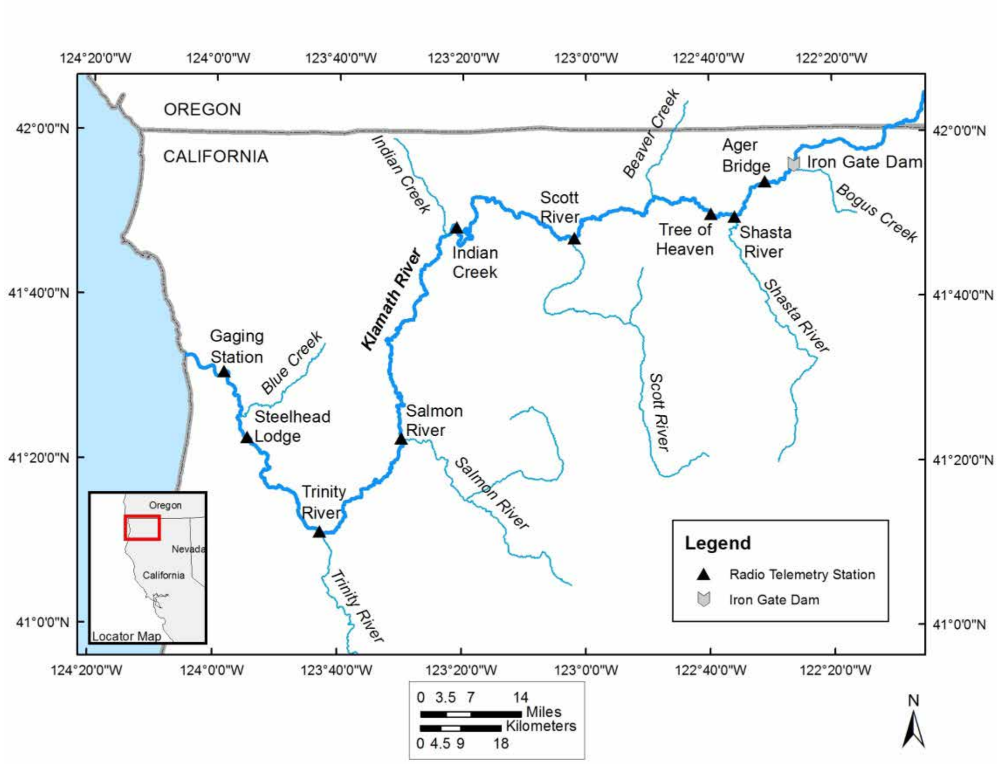

Figure 1. Map of the study area along the lower Klamath River, northern California.

The results in this report primarily are based on fish released near Iron Gate Hatchery (rkm 309), but other release sites were used during the course of the study. In 2006 and 2007, a paired-release survival model design based on fish released at two sites was used (Burnham and others, 1987). The upstream, or treatment group, was released near Iron Gate Hatchery in each year. The downstream, or control group, was released into the Klamath River at the mouth of the Shasta River (rkm 288) in 2006 and into the Klamath River near Tree of Heaven Campground (rkm 280) in 2007. In 2008 and 2009, the paired-release approach was discontinued due to violations of model assumptions (see Beeman and others, 2008). The fish released near Iron Gate Hatchery in 2008 and 2009 are analogous to the treatment groups in prior years.

Surgical Procedures

Procedures for surgical implantation of radio transmitters were similar among years and are described in Beeman and others (2007). The surgeon was the same during the first 3 years, and the surgeon in the fourth year was trained by the preceding surgeon. After tagging, no more than three radio-tagged coho salmon were held in each perforated bucket (19 L) in an in-river floating net pen for at least 24 h (range 24–36 h) before being released after nautical twilight. Only coho salmon weighing 8.6 g or greater were tagged to ensure the transmitter weight did not exceed 5 percent of the fish’s body weight (Adams and others, 1998).

Radio Telemetry System

Transmitter Specifications

Pulse-coded radio transmitters operating in the frequency range between 164 and 168 MHz were used throughout the study. Transmitters 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 (Lotek 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, but we determined the tag life of 25 tags empirically in each year.

Stationary Detection Systems

The number of automated radio telemetry detection sites installed along the mainstem Klamath River varied among years based on changes in the study design. Seven sites between Iron Gate Hatchery and rkm 20 were used consistently among years and two sites were used in only one or two years. The site at Tree of Heaven campground (rkm 280) was only used in 2008 and the site at Ager Road Bridge (rkm 300) was only used in 2008 and 2009 (fig. 1). Each station consisted of two to four Yagi aerial antennas (consisting of three- or six-elements each depending on coverage needed), mounted on a 3 m mast, and connected to two data-logging receivers. Two types of data-logging receivers were deployed at each array (SRX-400, Lotek Wireless, Newmarket, Ontario, Canada; Orion, Sigma8, Newcastle, Ontario, Canada) because each has unique characteristics that enhance the detection of radio tags. For example, the narrow-band SRX receivers are more sensitive, but have a longer scan cycle than the wide-band Orion receiver.

Each receiver was configured to maximize the potential for detecting radio-tagged fish. The SRX receivers monitored each frequency for 8.7 s before cycling to the next frequency, so the SRX receiver required approximately 26 s to cycle through three frequencies. The Orion receivers are a wide-band design and 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, 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 were generally set near -120 dB. When a signal was detected, transmitter frequency, code, signal strength, time, and date were recorded. Detections of beacon transmitters placed near the detection sites were used to verify system operation. The receivers were programmed to collect data continuously.

Data Analysis

Converting Radio Signals into Detection Histories

Measures to remove false positive records from the automated detection data were used prior to analysis. Valid detections were identified by filtering radio signal data using multiple data proofing criteria. These criteria included omitting records prior to the release time of a fish, those with transmitter codes not used as part on the study, those inconsistent with a downstream order of detections among sites, and those less frequent than two detections within 10 minutes. 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. A randomly chosen 10 percent of the records 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. Analyses were based on the dates and times of fish passing each detection site as well as the observed time for fish passing through river reaches bounded by detection sites.

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 each reach differed depending on the location of the mainstem and tributary flow gages (table 1). Water temperature data were collected at 30-min intervals using Onset Stowaway® Tidbit® temperature data loggers (range 4–38°C) placed within the mainstem Klamath River directly upstream of tributaries delineating the end of reach boundaries and in the net pens used to hold fish prior to release.

Table 1. USGS gage descriptions and equations used to quantify river discharge within study reaches, lower Klamath River, northern California.

[USGS gages: Iron Gate Dam (IGD) (11516530), Shasta River (11517500), Scott River (11519500), Seiad (11520500), Indian Creek (11521500), Salmon River (11522500), Orleans (11523000), Trinity River (11530000), Gaging Station (11530500)]

Reach	Gages used	Equation
Release to Shasta River	IGD	None
Shasta River to Scott River	IGD, Shasta River	IGD + Shasta River
Scott River to Indian Creek	Seiad	Seiad
Happy Camp to Salmon River	Seiad, Indian Creek, Salmon River, Orleans	((Orleans – Salmon River) + (Seiad + Indian Creek))/2
Salmon River to Trinity River	Orleans	Orleans
Trinity River to Steelhead Lodge	Orleans, Trinity River	(Trinity River + Orleans)
Steelhead Lodge to Gaging Station	Orleans, Trinity River, Gaging Station	((Trinity River + Orleans) + (Gaging Station))/2

Analyses of Migration and Survival

The approach used for analyses of migration and survival was similar. The premise behind the approach was to evaluate the support for effects of covariates by the data using multi-model inference as described by Burnham and Anderson (2002). A suite of *a priori* models representing hypotheses of the effects of covariates on the independent variable of interest (passage rate or survival) were constructed and their support from the data was evaluated using the Akaike Information Criterion (AIC) or one of its variants described below. This method assigns a weight of support for each model by the data and often identifies uncertainty as to which model is the best. We incorporated model-selection uncertainty into the parameter estimates and variances by constructing a 95-percent confidence set of models formed by adding the AIC weight of models ordered from largest to smallest weight until the sum was at least 95 percent. Model-averaged coefficients from the confidence set were used as estimates and variances of the slope, or effect, of each covariate (Burnham and Anderson, 2002). A slope of zero was used for the slope during model averaging if a model did not contain a covariate included in other models of the set. This procedure was completed by reach using data based on the following fish groups released in the Klamath River near the Iron Gate Hatchery: (1) all fish of hatchery origin obtained directly from Iron Gate Hatchery during 2006–09, (2) wild fish obtained from a rotary screw trap in the Shasta River in 2006 and fish of hatchery origin obtained directly from Iron Gate Hatchery on the same dates, and (3) wild fish obtained from a rotary screw trap in the Scott River in 2009 and fish of hatchery origin obtained directly from Iron Gate Hatchery on the same dates, except fish from these groups released on May 30, 2009, because this release date was 20 days later than the previous release date of wild fish and only included three wild fish. Analyses of migration and survival based on all fish of hatchery origin were the basis for inferences about the reach-specific travel time and survival and the effects the covariates had on migration rates and survival, as this group represented most of the data collected during the study. The other two groups were used to determine if there was evidence that the migration, survival, or effects of covariates differed between hatchery and wild fish, as well as to investigate the potential for expression of tagging or handling effects after release. Models with fewer covariates were used with the groups incorporating wild fish due to their small sample sizes relative to the first group.

Migration Analyses

Fish migration patterns were examined by plotting travel times between or among detection sites and by assessing the effects of several covariates on the passage rates at the detection sites. 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. They are commonly 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 within 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 covariates. 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 were incremented daily and include average daily river discharge, average daily water temperature, photoperiod (time between daily nautical twilight times at Yreka, California), and degree days accumulated for hatchery origin fish since March 15 in the year of study (accumulated thermal units; ATU).

The survivor function was used to display the distributions of travel times in each river reach in each year. 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 a 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 (Hosmer and Lemeshow, 1999). Survivor functions were plotted and statistically compared between years and fish origins. Comparisons of survivor functions 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 last detection at the downstream end of the reach, that is, the travel time.

The relation between selected covariates and fish passage rates at each site 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:

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

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 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. Correlations between variables were examined to determine autocorrelation. Linearity was assessed visually by plotting estimated hazards for several values of each covariate (Hosmer and Lemeshow, 1999). The proportional hazards assumption was not assessed because by definition data with time-varying covariates are related to time. Covariates included in the models were initially selected by applying logical subject-matter knowledge. Variables included as potential main effects include river discharge and water temperature in the reach of interest on the date the fish entered the reach, photoperiod, ATU (hatchery origin only, because we did not know the temperature histories of wild fish prior to release), ATPase and fish weight at the time of tagging, and serial date of release. Interactions between variables were added if their Pearson correlation coefficients were less than an absolute value of 0.8, based on general recommendations of Belsley and others (1980). The daily average values of the main effects of river discharge and water temperature were used as time-dependent covariates. Discharge was scaled to units of hundred cubic feet per second. Model selection was assessed using the Akaike Information Criterion or one of its variants as described in Burnham and Anderson (2002).

Survival Analyses

Apparent survival was estimated based on Cormack-Jolly-Seber capture-recapture methods (Cormack, 1964; Jolly, 1965; Seber, 1965). Apparent survival is the probability that an animal remains available for recapture, or more specifically "detection" in the context of this study. In 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 (for example, a tributary) and do not return during the study period are counted as mortalities. Fish remaining within the study area after their transmitters cease operating also are counted as mortalities. For this reason, the life of a subset of transmitters was empirically determined in each year. 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 separately estimated.

The analyses were carried out using Program MARK (White and Burnham, 1999). The process included assessing model fit, building a series of a priori models based on subject matter knowledge, ranking the models 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). Overdispersion was assessed using the median c-hat ($\hat{c}$) procedure (Cooch and White, 2006). Variants to AIC were used when sample sizes were small 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).

The ranking of support for hypotheses, given the data and models, was based on the principle of parsimony. Parsimony is the balance between bias and variance of prediction. The square of bias is reduced as parameters are added to a model, but this increases the variance (Burnham and Anderson, 2002). Thus, the principle of parsimony attempts to find a balance between the fit of the model and the number of parameters required. Models were compared based on the difference in the AIC values between them. Model selection techniques differ from the null hypothesis testing statistical framework because there is no strict cutoff representing "significance" between models. Rather support for differences between hypotheses is assessed based on the data and the models. As differences in AIC values between competing models increase, so does the support for differences in the hypotheses represented by the various models. Burnham and Anderson (2002) suggest that when AIC values differ by less than 2 the support for one hypothesis over another is not meaningfully different based on the data and models considered. They also suggest that differences of 4–7 indicate considerably less support for the model with the greater AIC and those greater than 10 indicate essentially no support for the model with the greater AIC. We will use the terms "no" or "weak" support, "moderate" support, and "strong" support for models differing by no more than 2 units, more than 2 and up to 7 units, or more than 7 units, respectively.

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: that tagged fish are uniquely identifiable, at least two downstream detection sites exist downstream of the release location, the re-release of all or some of the marked fish recaptured at each detection location, and the recording of the identity of the marked fish recaptured at each location (Peven and others, 2005). In studies of fish with active tags such as radio transmitters, there are no physical recaptures to record marks, so “recapture” in the preceding sentence can be considered a passive and instantaneous process. John Skalski (University of Washington) in Peven and others (2005) provides a discussion of the potential biases associated with this and other designs. There are two primary potential biases associated with this design. The first is that the expression of mortality due to tagging or handling cannot be separated from other sources of mortality. These can be separated using other designs, including the paired-release design of Burnham and others (1987). The second is that the live/dead status of tagged fish must be correctly assigned. Bias can arise if fish life within the study area exceeds transmitter life or if transmitter life exceeds fish life while in the study area. We empirically evaluated these possibilities by conducting transmitter life experiments using a subset (usually 25) of the transmitters and comparing those distributions to fish travel time distributions, and by releasing euthanized fish with live transmitters along with the other tagged study fish near Iron Gate Hatchery.

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. 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.

Single-release-recapture methods were used to estimate overall survival in each reach and among all reaches. In this analysis, the results were based on model-averaging and all models in the suite were considered after weighting by their AICc model weights. The overall survival from release to the second to last capture site was estimated as the product of each reach estimate ($\Phi_{Overall} = \Phi_1 * \Phi_2 * \Phi_3 * \Phi_4 * \Phi_{5,}$ etc.) with variance calculated using the delta method (Seber, 1982).

Results

Environmental Conditions

River discharges were much greater in 2006 than in the other years, but water temperatures were similar among years (fig. 2). In 2006, discharge at IGD ranged from 2,740 to 10,300 ft^3/s during the fish release period. Discharge at IGD in 2007–09 ranged from 1,020 to 3,060 ft^3/s during the fish release period. Discharge generally decreased over time during each year, but most of the variation in river discharge was in 2006. Water temperature near IGD increased steadily in each year, ranging from 8.03 to 10.57 °C during the first release date and 19.44–22.91 °C during the last release date, depending on the year.

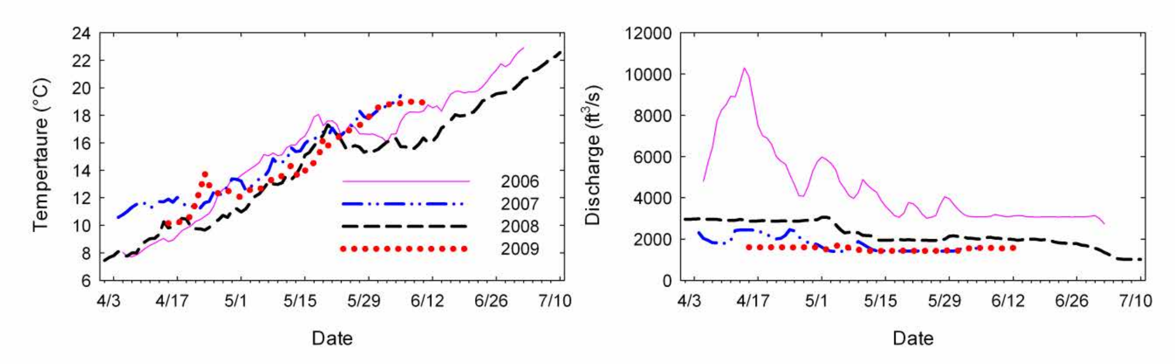

Figure 2. Graph of daily average Klamath River water temperatures and discharge downstream of Iron Gate Dam, lower Klamath River, northern California, 2006–09.

Hatchery Fish

Fish Releases

Hatchery fish were released into the Klamath River near Iron Gate Hatchery primarily during April and May in 2006–09. The dates of release ranged from April 4 to June 5 and varied slightly among years (appendix A). Releases in 2006 and 2007 began about 2 weeks earlier than in 2008 and 3 weeks earlier than in 2009. Releases in 2009 ended 12–20 days later than in the other years. The number of fish released near Iron Gate Hatchery in each year ranged from 114 to 221. Twenty-eight yearling coho salmon from Iron Gate Hatchery recaptured in a rotary screw trap and released in the Klamath River in 2008 were not included in analyses. The tagged fish were slightly larger in each year of the study (table 2). For example, the mean fork lengths of the fish released were 133.4, 140.3, 143.0, and 147.5 mm in 2006, 2007, 2008, and 2009, respectively. There was no evidence that euthanized fish with live transmitters were positively detected during the study, indicating the results were not biased from this source.

Table 2. Summary of the fork lengths (mm) and weights (g) of yearling coho salmon of hatchery origin used in analyses of migration and survival, lower Klamath River, northern California, 2006–09.

[Hatchery fish were from a tank at Iron Gate Fish Hatchery. *N*=sample size, Min=minimum, Max=maximum, Std=standard deviation, Se=standard error, mm=millimeter, g=gram]

Year	*N*	Mean	Median	Min	Max	Std	Se
---------- Fork Length ----------							
2006	114	133.4	133	108	170	11.47	1.07
2007	123	140.3	140	109	177	12.52	1.13
2008	221	143.0	139	113	195	15.89	1.07
2009	189	147.5	143	97	233	21.52	1.57
---------- Weight ----------							
2006	114	25.09	24.17	12.41	55.04	7.45	0.70
2007	123	29.91	28.83	14.96	50.45	7.98	0.72
2008	221	32.77	29.87	15.58	78.29	11.22	0.75
2009	189	36.31	31.20	11.50	130.60	18.30	1.33

Migration Timing

The rates and times of downstream migration varied among years. Fish released in 2009 traveled from release to the Shasta River site in a median of 2.00 d, whereas median times of fish from the others years ranged from 9.53 to 13.30 d (table 3, fig. 3). Travel times through reaches downstream of the Shasta River were short and generally similar among years, with medians of less than 2 days. The travel times from release to the Gaging Station site were similar in 2006, 2007, and 2008 (range of medians 24.01–25.93 d), but as in the first reach after release, were shorter in 2009 (median 15.11 d). Transmitter life measured empirically ranged from 10.6 to 91.8 days with a median of 62.6–83.0 days among the years of study, indicating transmitter life was suitable relative to fish travel times through the study area. The dates fish migrated through the study area varied slightly among years (fig. 4). The median date of passage at the Shasta River site was May 16 in 2006 and 2007, May 23 in 2008, and May 21 in 2009. The median dates of passage at the Gaging Station site were May 23, May 25, June 2, and May 27 during 2006, 2007, 2008, and 2009, respectively.

Table 3. Summary of travel times of yearling coho salmon of hatchery origin used in analyses of migration and survival, lower Klamath River, northern California, 2006–09.

[*N*=sample size , Med=median, Min=minimum, Max=maximum]

	2006				2007			
	Travel time, in days				Travel time, in days			
Reach	*N*	Med	Min	Max	*N*	Med	Min	Max
Release to Shasta River	96	9.53	0.12	45.70	94	13.30	0.18	43.20
Shasta River to Scott River	79	1.76	0.34	26.20	69	1.06	0.46	33.39
Scott River to Indian Creek	72	1.62	0.29	20.95	66	0.87	0.42	4.21
Indian Creek to Salmon River	69	1.06	0.34	7.40	60	1.05	0.56	11.12
Salmon River to Trinity River	70	0.33	0.16	5.05	60	0.58	0.23	2.78
Trinity River to Steelhead Lodge	65	0.72	0.18	10.08	59	0.87	0.18	11.72
Steelhead Lodge to Gaging Station	60	0.33	0.10	42.39	54	0.26	0.13	1.33
Release to Gaging Station	64	24.86	5.96	54.44	55	24.01	8.10	48.32

	2008				2009			
	Travel time, in days				Travel time, in days			
	N	Med	Min	Max	*N*	Med	Min	Max
Release to Shasta River	158	11.27	0.16	42.79	163	2.00	0.18	37.78
Shasta River to Scott River	111	1.95	0.37	41.70	146	1.79	0.49	30.37
Scott River to Indian Creek	102	0.98	0.32	19.97	137	1.03	0.45	7.37
Indian Creek to Salmon River	94	1.95	0.49	24.43	118	1.19	0.56	22.68
Salmon River to Trinity River	90	0.86	0.18	20.33	108	0.56	0.22	8.64
Trinity River to Steelhead Lodge	83	0.99	0.16	20.07	100	0.53	0.21	12.64
Steelhead Lodge to Gaging Station	77	0.32	0.12	7.42	98	0.31	0.12	8.08
Release to Gaging Station	77	25.93	5.81	50.34	98	15.11	3.77	40.65

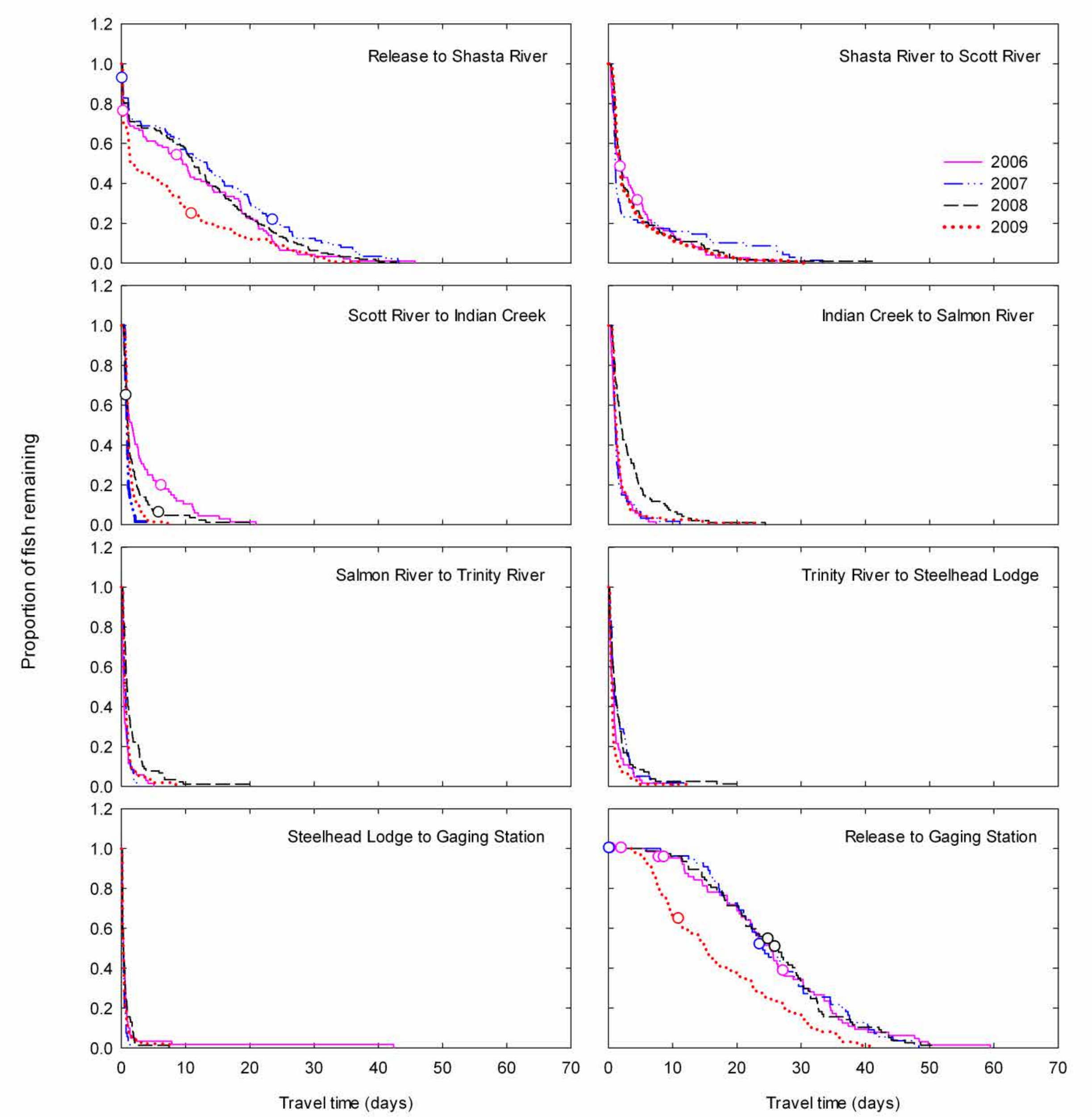

Figure 3. Graphs of travel time distributions of yearling coho salmon of hatchery origin, lower Klamath River, northern California, 2006–09. Circles indicate observations censored when tags were recovered.

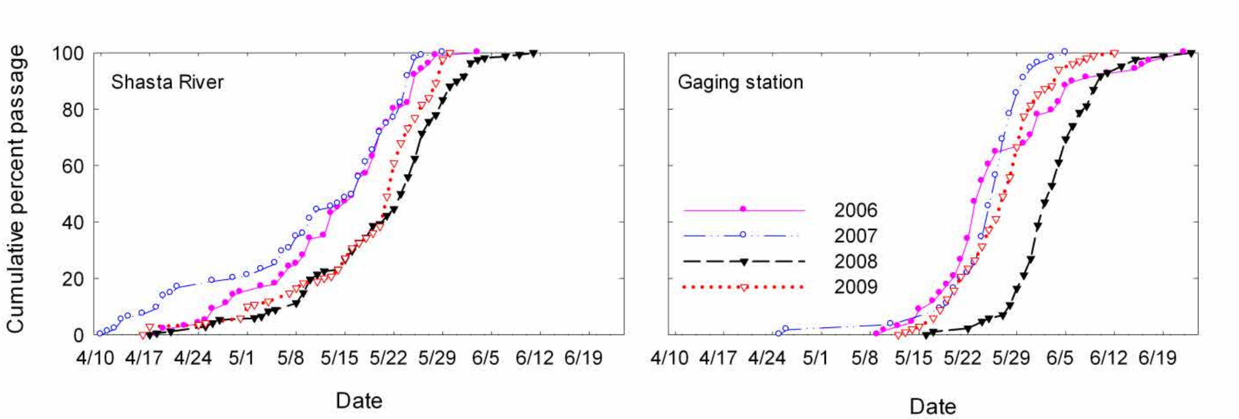

Figure 4. Graph of cumulative passage percentages of yearling coho salmon of hatchery origin, lower Klamath River, northern California, 2006–09.

Covariates of Passage Rates

A total of 24 models were evaluated to determine if the covariates examined affected passage rates. The set of 24 candidate models used in analyses of migration, and subsequently survival, are listed in table 4. The models used were based on seven covariates in various combinations to prevent using variables with high bivariate correlations in the same model (those greater than an absolute value of 0.80; Belsley and others, 1980). Photoperiod and ATU were highly correlated at every site (Pearson's correlation coefficient $r \geq 0.8072$, $P < 0.0001$; appendix B) requiring them to be used in separate models. Both variables increased with calendar time, as indicated by the site-specific correlation coefficients with day of the year ranging from 0.8725 to 0.9966 ($P < 0.0001$). Water temperature also was highly correlated with photoperiod and ATU at the Shasta River and Scott River sites, so these variables also were used in separate models in all analyses. A high degree of multicollinearity also was present when photoperiod, ATU, or water temperature was used in the same models, particularly at the Shasta River and Scott River sites.

Site-specific inferences about the effects of the covariates on passage rates were based on model-averaged coefficients from a small number of the candidate models. Models making up the top 95 percent of the AICc weights were comprised of four or fewer models at each site (appendix C).

Several covariates were supported by the model-averaged results as factors affecting passage rates at most of the sites studied. The data and models supported positive effects of date of release, photoperiod, fish weight at release, discharge, and ATU on passage rate at the Shasta site (table 5). The 95-percent confidence intervals of the coefficients for photoperiod and ATU overlapped zero considerably, indicating the predictions of the direction and magnitude of their effects were imprecise. The 95-percent confidence interval of the coefficient for discharge overlapped zero slightly. The hazards of the other variables (calculated by exponentiating the slope estimate) indicated passage rate increased by 6.23 percent as release date increased by 1 d (hazard = 1.0623), that rates increased by 0.99 percent for each additional gram of fish weight at tagging, and by 0.67 percent for each 100 ft^3/s increase in discharge at IGD (discharge at the upstream boundary of the reach). The standardized slopes indicated that the date was the most influential factor on passage rates and photoperiod was the least influential factor (table 6). The influence of the date was 5.2–32.0 times greater than the other variables. The influence of the date was 8.0 times greater than discharge.

Table 4. List of covariates in the 24 models used to assess effects of selected factors on passage rate and survival of yearling coho salmon of hatchery origin, lower Klamath River, northern California.

[Model covariates included river discharge in 100 ft^3/s increments (q100), fish weight in grams at tagging (wt), water temperature in degrees Celsius on the date of reach entry (temp), day length in hours (photo), date of reach entry (date), accumulated thermal units (sum of water temperatures beginning on March 15 of the release year; atu), and gill ATPase activity (atpase). q100*atpase is an interaction term]

Model No.	Covariates
1	q100
2	wt
3	temp
4	photo
5	date
6	atu
7	atpase
8	wt, temp
9	wt, photo
10	wt, date
11	wt, atu
12	wt, atpase
13	q100, wt
14	q100, date
15	q100, temp
16	q100, atu
17	q100, photo
18	q100, atpase
19	q100, wt, date
20	q100, wt, temp
21	q100, wt, atu
22	q100, wt, photo
23	q100, wt, atpase
24	q100, wt, atpase, q100*atpase

Table 5. Summary of model-averaged slope coefficients from analyses of passage rates of yearling coho salmon of hatchery origin based on unstandardized data, lower Klamath River, northern California, 2006–09.

[Results are based on model-averaging results from models within the top 95 percent of model weights among 24 models of passage rates. Models were run separately on each site. Models=number of averaged models the covariate was in; hazard=exponentiated slope coefficient. Covariates supported include date of release or passage at the upstream site (date), photoperiod (photo), fish weight at tagging (wt), river discharge at release or the upstream site in 100 ft^3/s increments (q100), ATPase (atpase), and water temperature in the reach (temp)]

		Slope				
				95-percent confidence interval		
Variable	Models	Coefficient	Standard error	Lower	Upper	Hazard
---------- Site = Shasta River ----------						
date	2	0.0605	0.0128	0.0354	0.0855	1.0623
photo	1	0.0445	0.2750	-0.4946	0.5836	1.0455
wt	4	0.0099	0.0032	0.0036	0.0161	1.0099
q100	3	0.0067	0.0064	-0.0058	0.0192	1.0067
atu	1	0.0010	0.0022	-0.0033	0.0053	1.0010
---------- Site = Scott River ----------						
temp	1	0.4961	0.0362	0.4251	0.5671	1.6423
---------- Site = Indian Creek ----------						
date	2	-0.0215	0.0040	-0.0293	-0.0137	0.9788
q100	2	-0.0139	0.0025	-0.0188	-0.0089	0.9862
wt	1	-0.0005	0.0021	-0.0045	0.0036	0.9995
---------- Site = Salmon River ----------						
temp	2	0.1218	0.0396	0.0441	0.1995	1.1295
wt	3	-0.0133	0.0042	-0.0215	-0.0052	0.9867
q100	1	0.0032	0.0026	-0.0018	0.0082	1.0032
atpase	1	0.0025	0.0122	-0.0215	0.0265	1.0025
---------- Site = Trinity River ----------						
wt	2	-0.0197	0.0050	-0.0294	-0.0100	0.9805
atu	2	-0.0031	0.0007	-0.0045	-0.0017	0.9969
q100	1	-0.0018	0.0014	-0.0046	0.0011	0.9982
---------- Site = Steelhead Lodge ----------						
temp	3	0.1467	0.0400	0.0684	0.2251	1.1581
q100	2	0.0024	0.0009	0.0006	0.0042	1.0024
wt	1	-0.0011	0.0029	-0.0068	0.0045	0.9989

Table 6. Summary of model-averaged slope coefficients from analyses of passage rates of yearling coho salmon of hatchery origin based on standardized data, lower Klamath River, northern California, 2006–09.

[Results are based on model-averaging results from models within the top 95 percent of model weights among 24 models of passage rates. Models were run separately on each site. Models=number of averaged models the covariate was in, Beta=slope coefficient. Covariates supported include date of reach entry (date), photoperiod (photo), fish weight at tagging (wt), river discharge in the reach in 100 ft^3/s increments (q100), ATPase (atpase), and water temperature in the reach (temp). Models for each site are listed in decreasing order of the absolute value of the slope coefficient]

		Slope			
				95-percent confidence interval	
Variable	Models	Coefficient	Standard error	Lower	Upper
		Site = Shasta River			
date	2	0.7369	0.1558	0.4316	1.0422
atu	1	0.1416	0.3061	-0.4584	0.7415
wt	4	0.1185	0.0383	0.0434	0.1936
q100	3	0.0915	0.0870	-0.0791	0.2621
photo	1	0.0230	0.1424	-0.2561	0.3022
		Site = Scott River			
temp	1	0.9252	0.0676	0.7928	1.0576
		Site = Indian Creek			
q100	2	-0.3217	0.0587	-0.4368	-0.2067
date	2	-0.2672	0.0495	-0.3643	-0.1702
wt	1	-0.0064	0.0282	-0.0618	0.0489
		Site = Salmon River			
temp	2	0.2466	0.0803	0.0892	0.4039
wt	3	-0.2344	0.0732	-0.3778	-0.0909
q100	1	0.0877	0.0708	-0.0510	0.2264
atpase	1	0.0063	0.0306	-0.0536	0.0662
		Site = Trinity River			
atu	2	-0.3919	0.0922	-0.5727	-0.2111
wt	2	-0.2763	0.0695	-0.4125	-0.1401
q100	1	-0.0790	0.0645	-0.2055	0.0474
		Site = Steelhead Lodge			
temp	3	0.2875	0.0783	0.1340	0.4411
q100	2	0.1898	0.0713	0.0501	0.3296
wt	1	-0.0150	0.0387	-0.0910	0.0609

Water temperature was the only covariate supported as affecting passage rate at the Scott River site. The model indicates passage rate increased 64 percent for each 1 °C increase in water temperature.

Discharge at the upstream boundary of the reach, date of reach entry, and fish weight were supported as factors affecting passage rate at the Indian Creek site. The slope of each covariate was small and its sign was negative, indicating passage rate decreased slightly as the covariate values increased. The model indicates that passage rates decreased 2.12 percent for each 1-day increase in the date fish passed the Scott River site, decreased 1.38 percent for each 100 ft^3/s increase in discharge, and decreased 0.05 percent for each 1-gram increase in fish weight. The 95-percent confidence interval for the weight coefficient overlapped zero considerably, indicating that the prediction of the direction and magnitude of its effects was imprecise. The standardized slopes indicate that the influence of discharge was 1.2 times greater than the influence of the date and 50.0 times greater than the influence of fish weight.

Water temperature, weight, discharge at the upstream boundary of the reach, and ATPase were supported as covariates affecting passage rate at the Salmon River site. Water temperature was the only covariate with a 95-percent confidence interval that did not overlap zero. The model indicates that the effect of water temperature was positive and passage rate increased 12.95 percent for each 1 °C increase. The predicted effects of weight, discharge and ATPase were small. The model predicts a 1-g increase in fish weight decreased passage rates by 1.32 percent, a 100 ft^3/s increase in discharge increased passage rate by 0.32 percent, and a 1- unit increase in ATPase increased passage rate by 0.25 percent. The direction and magnitude of the weight, discharge, and ATPase effects were imprecise; their 95-percent confidence intervals overlapped zero. The standardized slope coefficients indicate that the influence of water temperature was 1.05 times greater than weight, 2.81 times greater than discharge, and 39.2 times greater than ATPase.

Weight, ATU, and discharge at the upstream boundary of the reach were supported as covariates affecting passage rate at the Trinity River site. The model indicates that passage rate decreased 1.95 percent or less for each unit increase in these covariates. The 95-percent confidence interval of the discharge covariate overlapped zero. The standardized coefficients indicate that the influence of ATU was 1.42 times that of weight and 4.96 times that of discharge.

Water temperature, discharge at the upstream boundary of the reach, and weight were supported as factors affecting passage rate at the Steelhead Lodge site. The model indicates that passage rate increased 15.80 percent for each 1 °C increase in water temperature, increased 0.24 percent for each 100 ft^3/s increase in discharge, and decreased 0.11 percent for each 1-g increase in fish weight. The 95-percent confidence interval of the fish weight coefficient overlapped zero.

Estimates of Survival

The most common encounter histories in each year were of fish that were detected at every site, fish detected at the Shasta River site and never again, and fish that were never detected after release (appendix D). Tests of model fit indicated moderate overdispersion in the data, so a variance inflation factor "$\hat{c}$" of 2.02 was applied to the data (derived with Program MARK using the median $\hat{c}$ procedure). The most supported models of recapture probabilities were a multiplicative model of annual differences among sites and a simpler model with a common recapture probability for all sites differing by year (appendix E). These models received a total of 96 percent of the model weight and were both used in models of survival probabilities, resulting in 10 models of survival. Model-averaged estimates of recapture probabilities ranged from 0.893 (SE 0.026) to 0.994 (SE 0.004) among years and sites and were lowest in 2006 (range 0.893 [SE 0.026] to 0.899 [SE 0.024]).

Additive models of survival based on site and year were the only ones supported by the data, indicating the trend in survival among sites was similar among years (appendix E). The model-averaged results indicated that reach-survival generally increased with distance from the release site and in each year was lowest in the two reaches upstream of the Scott River (fig. 5). The point estimates of reach-specific survival in 2006 were similar to those in 2009 and those from 2007 and 2008 were similar to one another, however, the 95-percent confidence intervals of reach-specific estimates from the four years overlapped considerably. Annual estimates of reach-specific survival in the two reaches upstream of the Scott River (release to Shasta River and Shasta River to Scott River) ranged from 0.747 (SE 0.036) to 0.886 (SE 0.025) and the annual estimates from reaches farther downstream ranged from 0.864 (SE 0.031) to 0.999 (SE < 0.001; table 7).

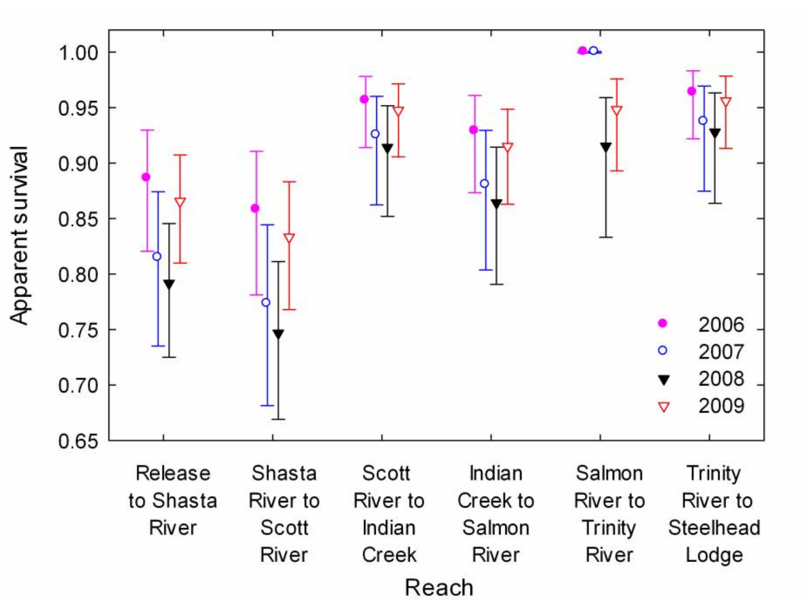

Figure 5. Graph of the model-averaged estimates of reach-specific survival of hatchery-origin yearling coho salmon in the lower Klamath River, northern California, 2006–09. Vertical bars represent 95-percent confidence intervals.

Table 7. Estimated apparent survivals and confidence intervals of yearling coho salmon of hatchery origin in study reaches of the lower Klamath River, northern California, 2006–09.

[Results are based on data from 114 to 221 hatchery fish from Iron Gate Hatchery released in each year. All fish were released in the Klamath River near the hatchery. Results are based on model-averaging the models in appendix E2. Data over multiple reaches were calculated as the product of the reach estimates with variances estimated using the Delta method (Seber, 1982)]

Reach number	Description	Reach length (km)	Apparent survival	Standard error	95-percent confidence interval	
					Lower	Upper
	---------- Year = 2006 ----------					
1	Release to Shasta River (rkm 288)	21	0.886	0.027	0.820	0.930
2	Shasta River to Scott River (rkm 234)	54	0.858	0.033	0.781	0.911
3	Scott River to Indian Creek (rkm 178)	56	0.956	0.015	0.914	0.978
4	Indian Creek to Salmon River (rkm 107)	71	0.929	0.021	0.873	0.961
5	Salmon River to Trinity River (rkm 69)	38	1.000	0.000	0.999	1.001
6	Trinity River to Steelhead Lodge (rkm 33)	36	0.963	0.014	0.922	0.983
	Release to Steelhead Lodge	276	0.648	0.070	0.510	0.785
	---------- Year = 2007 ----------					
1	Release to Shasta River (rkm 288)	21	0.814	0.035	0.735	0.874
2	Shasta River to Scott River (rkm 234)	54	0.773	0.042	0.681	0.844
3	Scott River to Indian Creek (rkm 178)	56	0.925	0.024	0.863	0.960
4	Indian Creek to Salmon River (rkm 107)	71	0.880	0.031	0.804	0.930
5	Salmon River to Trinity River (rkm 69)	38	1.000	0.000	0.999	1.001
6	Trinity River to Steelhead Lodge (rkm 33)	36	0.937	0.023	0.875	0.969
	Release to Steelhead Lodge	276	0.497	0.065	0.369	0.624
	---------- Year = 2008 ----------					
1	Release to Shasta River (rkm 288)	21	0.792	0.031	0.725	0.846
2	Shasta River to Scott River (rkm 234)	54	0.747	0.036	0.669	0.811
3	Scott River to Indian Creek (rkm 178)	56	0.914	0.025	0.852	0.952
4	Indian Creek to Salmon River (rkm 107)	71	0.864	0.031	0.791	0.915
5	Salmon River to Trinity River (rkm 69)	38	0.915	0.031	0.833	0.959
6	Trinity River to Steelhead Lodge (rkm 33)	36	0.928	0.024	0.864	0.963
	Release to Steelhead Lodge	276	0.412	0.048	0.319	0.506
	---------- Year = 2009 ----------					
1	Release to Shasta River (rkm 288)	21	0.866	0.025	0.810	0.907
2	Shasta River to Scott River (rkm 234)	54	0.833	0.029	0.768	0.883
3	Scott River to Indian Creek (rkm 178)	56	0.948	0.016	0.906	0.971
4	Indian Creek to Salmon River (rkm 107)	71	0.915	0.021	0.863	0.949
5	Salmon River to Trinity River (rkm 69)	38	0.948	0.020	0.893	0.976
6	Trinity River to Steelhead Lodge (rkm 33)	36	0.956	0.016	0.913	0.978
	Release to Steelhead Lodge	276	0.551	0.052	0.449	0.652

Covariates of Survival

Estimates of the potential effects of selected covariates on reach-specific survival were based on model-averaged results from the same suite of models used in analyses of passage rates. The number of models comprising the top 95 percent of the model weights for each reach ranged from 2 to 12 (appendix F). Summaries of the reach-specific values of the covariates are in appendix G.

The effects of several covariates of survival were supported in the release to Shasta River reach. The model-averaged results indicate that the effects of river discharge, water temperature, and fish weight affected survival in that reach. The sign of the slope coefficients of each variable indicate that they were positively related to survival, meaning survival increased as the value of the variable increased (table 8). The 95-percent confidence intervals of the discharge and water temperature slopes did not overlap zero, but the slope for fish weight did, indicating the direction and magnitude of the effect of fish weight is uncertain. As in analyses of passage rates, slope estimates for each variable standardized to a mean of zero and a standard deviation of one were calculated to enable comparisons of the influence of each covariate on a common scale. The standardized slope coefficients indicate that the influence of water temperature on survival in this reach is 0.6597/0.3929 = 1.8 times as great as discharge and 5.0 times as great as fish weight over the ranges in the data.

The effects of discharge in the release to Shasta River reach were mediated by water temperature and fish weight. The effect can be shown in plots of the predicted survivals based on the slopes from each variable over the range of discharge in the empirical data (14.1–98.8 hundred ft^3/s; fig. 6). The predicted survival in this reach = -3.3086 + (0.0268 * discharge in hundred ft^3/s) + (0.2987 * water temperature in °C) + (0.0105 * fish weight at tagging in grams), as indicated in Release to Shasta River section of table 8. The positive effect of discharge decreases as water temperature increases. The predicted range in survival over the range of discharge in the data is from 0.38 to 0.85 at the minimum temperature in the data (7.58 °C) and from 0.93 to 0.99 at the maximum temperature in the data (17.91 °C). The mediating effects of fish weight are smaller than those of water temperature, which is consistent with the size of the standardized slope coefficient.

Several variables were supported as having effects on survival in reaches downstream of the Shasta River, but the size and direction of their effects were uncertain in nearly every case. For example, in the Shasta to Scott River reach, the data and models supported both ATU and water temperature as factors affecting survival, but the 95-percent confidence intervals of the slopes for these variables overlapped zero, indicating an uncertain direction and magnitude of effect. For example, the slope estimate for the ATU variable is 0.0019 (SE 0.0013) and it has a 95-percent confidence interval of -0.0008–0.0046. The point estimate indicates a positive effect, but the confidence interval of the estimate overlaps zero, indicating that the true effect may be positive, zero, or negative. The results for water temperature in this reach are similar: a positive slope coefficient with a 95-percent confidence interval overlapping zero. This pattern is common in estimates of slopes in all reaches with two exceptions. Discharge was estimated to have a positive effect in the Salmon River to Trinity River reach with a slope of 0.0481 (SE 0.0216) and a 95-percent confidence interval of 0.0059–0.0904 and ATU was estimated to have a negative effect in the Trinity River to Steelhead Lodge reach with a slope of -0.0141 and a 95-percent confidence interval of -0.0203–-0.0079.

Table 8. Estimates of slope coefficients of variables supported as factors affecting survival of yearling coho salmon of hatchery origin, lower Klamath River, northern California, 2006–09.

[Estimates based on raw data (unstandardized estimates) and those based on slopes standardized to a mean of zero and standard deviation of 1 are listed. Models=number of models containing the variable used in model averaging to estimate slopes]

		Unstandardized estimates				Standardized estimates			
				95-percent confidence interval				95-percent confidence interval	
Variable	Models	Estimate	Standard error	Lower	Upper	Estimate	Standard error	Lower	Upper
Release to Shasta River									
Intercept	2	-3.3086	0.9459	-5.1626	-1.4545				
q100	2	0.0268	0.0099	0.0074	0.0461	0.3929	0.1450	0.1087	0.6771
temp	2	0.2987	0.0573	0.1864	0.4109	0.6957	0.1334	0.4342	0.9572
wt	1	0.0105	0.0095	-0.0081	0.0291	0.1398	0.1264	-0.1079	0.3876
Shasta River to Scott River									
Intercept	2	-1.7701	1.0870	-3.9006	0.3603				
atu	1	0.0019	0.0014	-0.0008	0.0046	0.2590	0.1874	-0.1082	0.6263
temp	1	0.1231	0.1006	-0.0741	0.3204	0.2300	0.1880	-0.1385	0.5986
Scott River to Indian Creek									
Intercept	12	10.9392	12.7910	-14.1311	36.0095				
atpase	1	0.0009	0.0176	-0.0335	0.0353	0.0025	0.0484	-0.0923	0.0973
atu	2	-0.0003	0.0012	-0.0027	0.0021	-0.0300	0.1097	-0.2450	0.1850
photo	3	-0.3665	0.7048	-1.7479	1.0148	-0.0945	0.1817	-0.4506	0.2616
q100	6	-0.0041	0.0070	-0.0179	0.0097	-0.0929	0.1593	-0.4051	0.2194
reldate	3	-0.0114	0.0155	-0.0417	0.0189	-0.1492	0.2021	-0.5453	0.2469
temp	1	-0.0009	0.0282	-0.0561	0.0543	-0.0015	0.0447	-0.0892	0.0862
wt	3	-0.0003	0.0052	-0.0104	0.0098	-0.0040	0.0747	-0.1504	0.1424
Indian Creek to Salmon River									
Intercept	6	23.2006	23.8139	-23.4747	69.8759				
atu	4	-0.0064	0.0029	-0.0120	-0.0008	-0.5901	0.2617	-1.1031	-0.0771
photo	2	-0.9121	1.3576	-3.5730	1.7487	-0.2342	0.3485	-0.9173	0.4490
q100	4	0.0094	0.0089	-0.0080	0.0268	0.2803	0.2641	-0.2373	0.7980
wt	3	-0.0112	0.0101	-0.0310	0.0087	-0.1625	0.1475	-0.4516	0.1265
Salmon River to Trinity River									
Intercept	6	38.3645	50.2536	-60.1326	136.8617				
atpase	1	0.0122	0.0780	-0.1406	0.1650	0.0316	0.2021	-0.3647	0.4278
atu	3	-0.0076	0.0041	-0.0156	0.0003	-0.8008	0.4267	-1.6371	0.0356
photo	2	-1.7932	2.7255	-7.1351	3.5488	-0.4474	0.6800	-1.7803	0.8855
q100	5	0.0481	0.0216	0.0059	0.0904	2.2319	1.0003	0.2714	4.1924
wt	4	-0.0152	0.0149	-0.0444	0.0140	-0.2200	0.2157	-0.6428	0.2028

Table 8. Estimates of slope coefficients of variables supported as factors affecting survival of yearling coho salmon of hatchery origin, lower Klamath River, northern California, 2006–09.–Continued

[Estimates based on raw data (unstandardized estimates) and those based on slopes standardized to a mean of zero and a standard deviation of 1 are listed. Models=number of models containing the variable used in model averaging to estimate slopes]

		Unstandardized estimates				Standardized estimates			
				95-percent confidence interval				95-percent confidence interval	
Variable	Models	Estimate	Standard error	Lower	Upper	Estimate	Standard error	Lower	Upper
------------------ Trinity River to Steelhead Lodge --------------------------									
Intercept	4	22.0979	31.5217	-39.6847	83.8805				
atu	3	-0.0141	0.0032	-0.0203	-0.0079	-1.4405	0.3232	-2.0738	-0.8071
photo	1	-0.4360	1.9338	-4.2262	3.3542	-0.1078	0.4783	-1.0453	0.8296
q100	3	0.0092	0.0115	-0.0133	0.0317	0.7271	0.9070	-1.0507	2.5049
wt	1	-0.0044	0.0113	-0.0266	0.0178	-0.0608	0.1566	-0.3677	0.2461

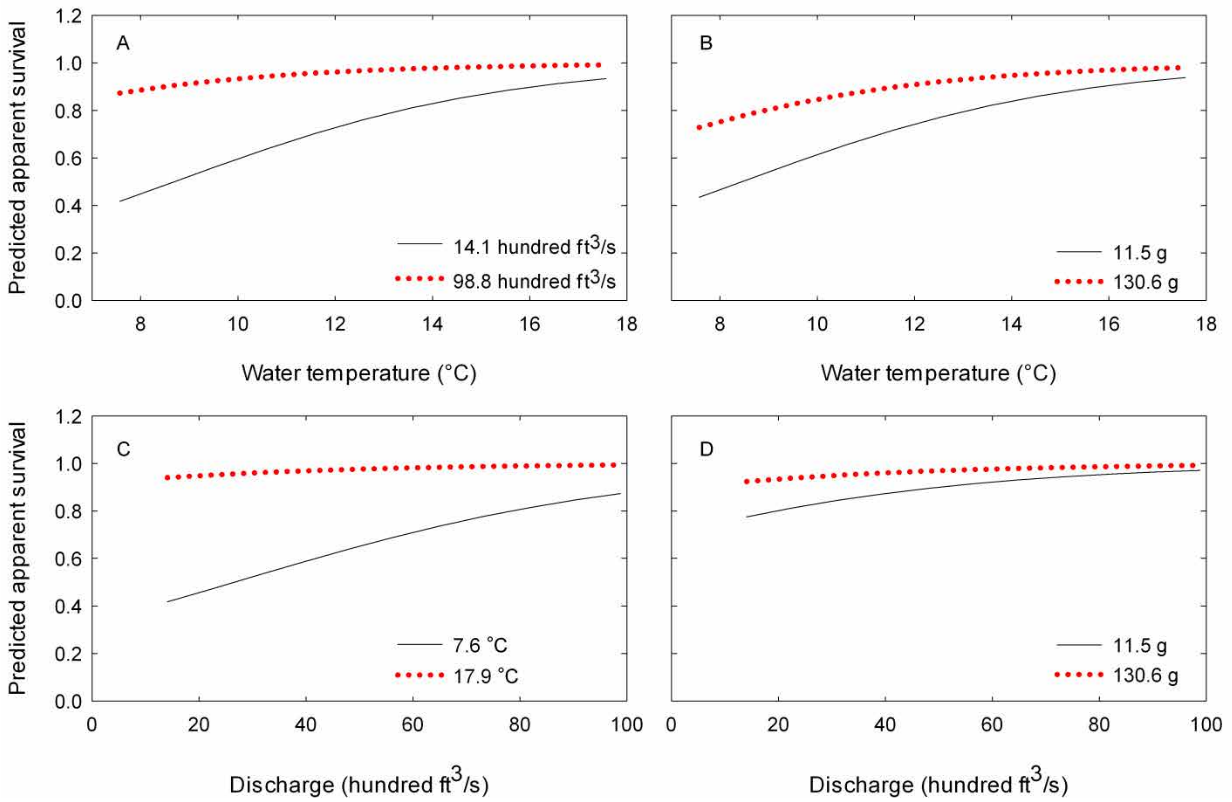

Figure 6. Graph of the predicted survival of hatchery-origin yearling coho salmon in the release to Shasta River reach at the minimum and maximum values of selected covariates, lower Klamath River, northern California. Graphs are changes in survival at (A) two values of discharge over the range of water temperature, (B) two values of fish weight over the range of water temperature, (C) two values of water temperature over the range of discharge, and (D) two values of fish weight over the range of discharge. Predictions are based on the results for the Release to Shasta River reach in table 8.

Comparisons of Hatchery and Wild Fish

Fish Releases

The availability of wild fish from streams near IGD in 2006 and 2009 enabled releases of tagged fish from wild and hatchery origins. The analyses of hatchery and wild fish were restricted to data from dates on which fish from each origin were released. In 2006, 80 hatchery fish and 94 wild fish were released over 10 dates from April 4 to May 16 and in 2009, 76 hatchery fish and 60 wild fish were released over 6 dates from April 16 to May 20 (appendix H). In 2009, a gap of 20 d occurred between the April 30 and May 20 releases due to trap damage from a high discharge event in the Scott River. We omitted the 19 hatchery and 3 wild fish released on May 20, 2009, from the analyses due to the long period since the previous release and the small number of wild fish released on that date, leaving 57 hatchery and 57 wild fish from 2009 for analysis.

Hatchery and wild fish were of different sizes in each year. In 2006 mean sizes of the hatchery fish were smaller than wild fish by 10.81 mm in fork length and 7.60 g in weight (table 9, fig. 7). The mean fork lengths of hatchery and wild fish in 2006 were 134.34 mm and 145.15 mm, respectively. In 2009 the average hatchery fish was larger than the average wild fish by a 37.46 mm and 22.88 g. In 2009 the mean weight of hatchery fish was over twice the mean weight of wild fish. This was primarily due to the wild fish being of smaller size than in 2006, rather than a large change in size of hatchery fish among years.

Table 9. Summary of the fork lengths (mm) and weights (g) of yearling coho salmon used in comparisons of migration and survival of fish from hatchery and wild origins, lower Klamath River, northern California, 2006 and 2009.

[Hatchery fish were from the Iron Gate Fish Hatchery. Wild fish were from a rotary screw trap on the Shasta River (2006) or Scott River (2009). Data from May 20, 2009, were omitted from analysis. *N*=sample size, Min=minimum, max=maximum, Std=standard deviation, Se=standard error]

Origin	Variable	*N*	Mean	Median	Min	Max	Std	Se
-----Year = 2006 -----								
Hatchery	Fork Length	80	134.34	134	108	170	11.88	1.33
Wild	Fork Length	94	145.15	144	122	174	11.86	1.22
Hatchery	Weight	80	25.55	24.36	12.41	55.04	7.73	0.86
Wild	Weight	94	32.62	31.95	18.40	54.20	8.10	0.84
-----Year = 2009 -----								
Hatchery	Fork Length	57	149.67	144	104	217	24.25	3.21
Wild	Fork Length	57	112.21	110	97	148	11.63	1.54
Hatchery	Weight	57	38.09	31.20	11.80	107.00	20.99	2.78
Wild	Weight	57	15.21	13.70	9.80	34.10	5.16	0.68

The analyses of hatchery and wild fish from 2006 and 2009 were completed separately, because the source of wild fish differed between years. The remainder of this report section will therefore be divided by migration year.

Data from the 2006 Migration Year

Migration Timing

Passage rates of hatchery and wild fish differed in 2006. Wild fish migrated downstream sooner after release than hatchery fish. Travel times between release and the Shasta River site ranged from 0.12 to 32.69 d for wild fish and 0.18 to 45.70 d for hatchery fish. The median travel time of wild fish was 9.94 d shorter than the hatchery fish in this reach (0.50 d versus 10.044 d), and the distributions of travel times were significantly different (Wilcoxon test $\chi^2 = 30.47$, df = 1, $P < 0.0001$; table 10, fig. 8). Travel times of hatchery and wild fish were similar through the reaches downstream of the Shasta River. Wild fish traveled from release to the most downstream site (Gaging Station) in a median of 10.39 d and hatchery fish took a median of 24.40 d.

The differences in travel times resulted in hatchery and wild fish passing the detection sites on different dates. Wild fish passed the Shasta site about 7 d prior to hatchery fish and passed the Gaging Station site about 13 d prior to hatchery fish (fig. 9).

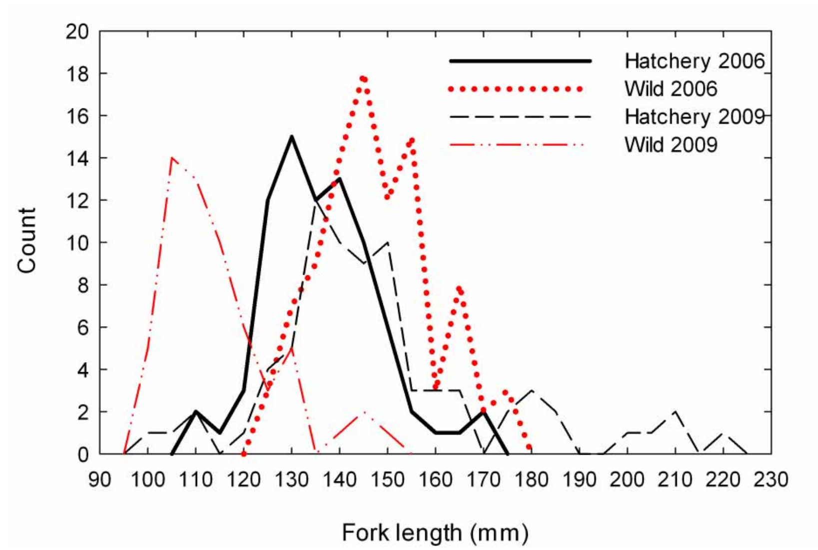

Figure 7. Graph of frequency distributions of fork lengths of yearling coho salmon of hatchery and wild origins, lower Klamath River, northern California, 2006 and 2009.

Table 10. Summary of travel times of yearling coho salmon used in comparisons of migration and survival of fish from hatchery and wild origins, lower Klamath River, northern California, 2006.

[The summary is based on 80 hatchery fish and 94 wild fish released on dates between April 4 and May 16, 2006. *N*=sample size, Min=minimum, Max=maximum, *P* =probability of a larger value Chi-square ($\chi2$) value from a Wilcoxon test with a one degree of freedom comparing the Kaplan-Meier survival distribution functions of the travel times]

	Hatchery origin Travel time, in days				Wild origin Travel time, in days				Wilcoxon test	
Reach	Median	*N*	Min	Max	Median	*N*	Min	Max	$\chi2$	*P*
Release to Shasta R.	10.44	67	0.18	45.70	0.50	74	0.12	32.69	30.47	< 0.0001
Shasta R. to Scott R.	1.51	54	0.34	26.20	3.10	36	0.31	13.85	0.72	0.3945
Scott R. to Indian Cr.	1.64	49	0.29	20.95	1.05	35	0.28	8.50	3.58	0.0585
Indian Cr. to Salmon R.	1.29	47	0.34	7.40	1.41	45	0.36	7.43	1.96	0.1612
Salmon R. to Trinity R.	0.38	48	0.16	5.05	0.40	38	0.18	5.25	0.07	0.7886
Trinity R. to Sthd L.	0.77	44	0.18	10.08	0.63	29	0.19	6.81	0.06	0.8143
Steelhead to Gaging S.	0.33	40	0.10	42.39	0.15	28	0.10	54.05	0.46	0.4985
Release to Gaging Station	24.40	43	11.78	59.43	10.39	48	2.42	63.82	32.2	< 0.0001

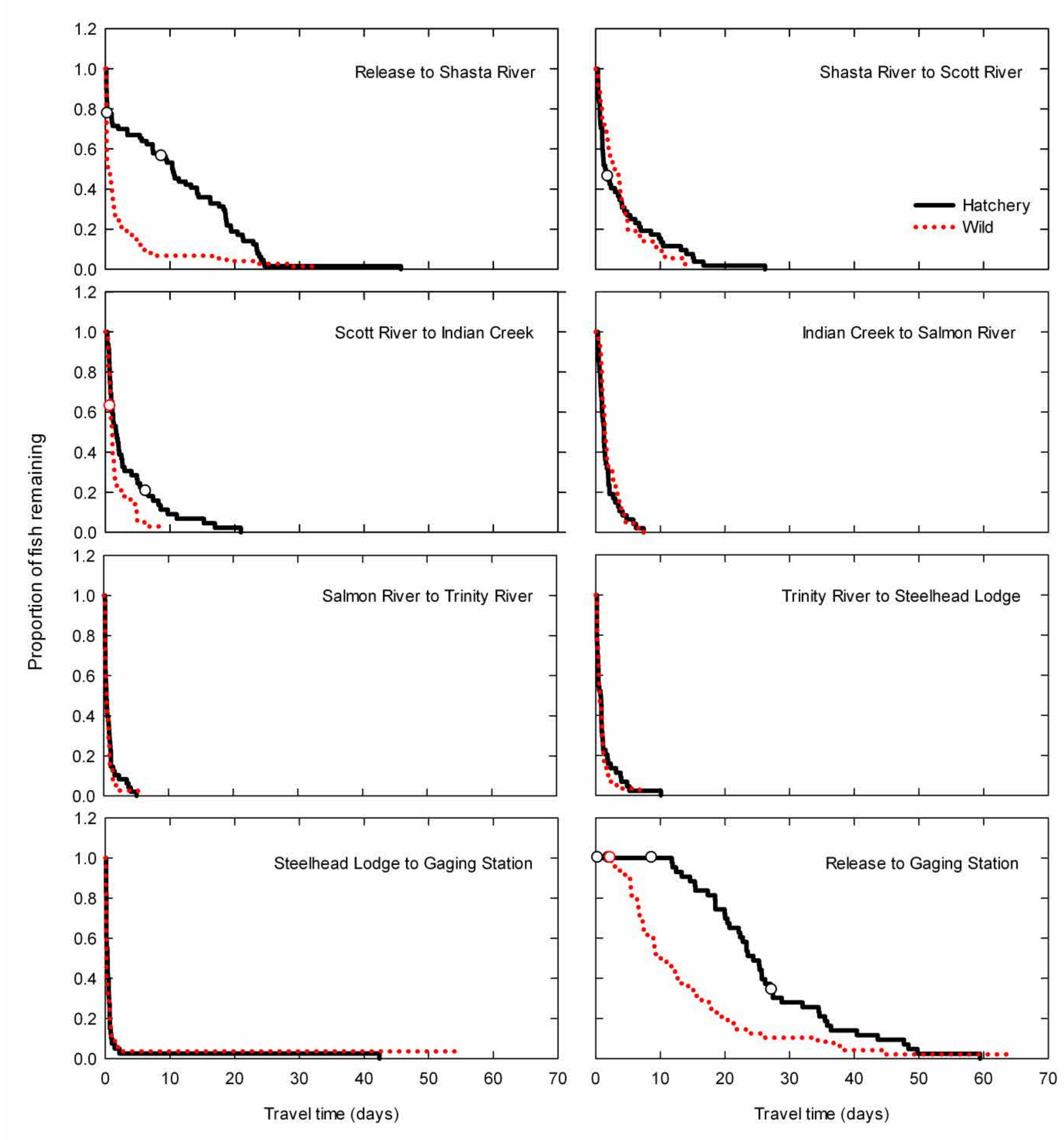

Figure 8. Graphs of travel time distributions of yearling coho salmon from hatchery and wild origins in each reach and over the entire study area (Release to Gaging Station), lower Klamath River, northern California, 2006. Circles indicate observations censored when tags were recovered.

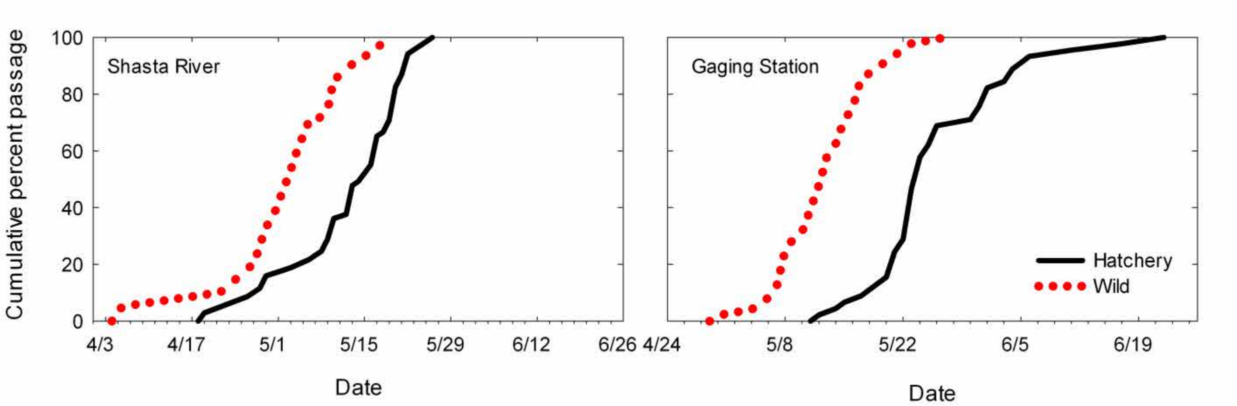

Figure 9. Graph of cumulative passage percentages of yearling coho salmon from hatchery and wild origins at the first detection site (Shasta River) and last detection site (Gaging Station), lower Klamath River, northern California, 2006.

Covariates of Passage Rates

The data and models support differences in the effects of several covariates on passage rates of hatchery and wild fish at the Shasta River site in 2006, but not at other sites. Results of Cox proportional-hazards regressions indicate moderate-to-strong support for origin-specific effects of river discharge, water temperature, and photoperiod on rate of passage at the Shasta site, as indicated by the small delta AIC values of the models with interaction terms (table 11). At this site, the results of analyses of the covariate fish weight indicate that it did not improve the fit of a model already including the fish origin factor. Analyses of the covariate ATPase were ambiguous, indicating similar support for models with and without origin-specific effects. Results of analyses of passage rates at all other sites indicated that the covariates did not improve the models, or that origin-specific effects of the covariates were unsupported.

The results indicate that the effects of river discharge, water temperature, and photoperiod on the passage rate at the Shasta site were greater for wild fish than for hatchery fish. The best-supported models of each of these covariates included an interaction term between fish origin and the covariate, meaning the effect differed for fish of each origin. For example, river discharge had a positive effect, indicating increases in river discharge increased the rate of passage at the Shasta River site. This effect was larger in wild fish than in hatchery fish and the difference in the effect of river discharge increased with discharge. The model predicts that the rate of passage of wild fish at the Shasta site is 3.2 times that of hatchery fish at 40.9 hundred ft^3/s (the 25^{th} percentile of the discharge data) and 7.9 times the rate of hatchery fish at 56.3 hundred ft^3/s (the 75^{th} percentile of the discharge data; table 12). These predictions are calculated by estimating the origin and covariate-specific hazards from the model estimates for each parameter, which for the Shasta site are listed in table 12. For example, the relative effect (that is, hazard ratio) of river discharge of wild vs. hatchery passage rates at the Shasta site is calculated as:

$$\frac{Exp[(-1.2002 * wildvalue) + (-0.093 * discharge) + (0.0581 * wildvalue * discharge)]}{Exp[(-1.2002 * hatcheryvalue) + (-0.093 * discharge) + (0.0581 * hatcheryvalue * discharge)]}$$

where the binary value for origin is 1 for wild fish and 0 for hatchery fish. At the median discharge of 40.9 hundred ft^3/s, the resulting hazard ratio based on this equation is 3.2, indicating wild fish passage at the Shasta site was over three times the rate of hatchery fish at that discharge.

Table 11. Model selection results from analyses of covariates of passage rates of yearling coho salmon from hatchery and wild origins at the Shasta River site, lower Klamath River, northern California, 2006.

[Model selection results from models based on origin (hatchery =0, wild=1), origin plus the covariate (cov), and origin plus the covariate plus an origin-covariate interaction are shown. Q100=river discharge at the upstream end of the reach divided by 100, temp=water temperature (°C) at the head of the reach, wt=fish weight (g) at the time of tagging, photo=day length in hours, atpase=value of gill ATPase activity at the time of tagging, K=number of parameters, AIC=Akaike Information Criterion, Delta AIC=difference between the AIC and the minimum AIC of the models in the same covariate grouping]

Covariate	Model	K	Deviance	AIC	Delta AIC
q100	origin	1	1111.202	1113.202	45.847
	origin, cov	2	1069.952	1073.952	6.596
	origin, cov, interaction	3	1061.356	1067.356	0.000
temp	origin	1	1111.202	1113.202	74.771
	origin, cov	2	1041.474	1045.474	7.043
	origin, cov, interaction	3	1032.431	1038.431	0.000
wt	origin	1	1111.202	1113.202	0.000
	origin, cov	2	1111.199	1115.199	([1])
	origin, cov, interaction	3	1110.048	1116.048	2.846
photo	origin	1	1111.202	1113.202	85.827
	origin, cov	2	1032.964	1036.964	9.589
	origin, cov, interaction	3	1021.375	1027.375	0.000
atpase	origin	1	1111.202	1113.202	3.647
	origin, cov	2	1105.841	1109.841	0.286
	origin, cov, interaction	3	1103.555	1109.555	0.000

[1]Model was removed from consideration due to similar deviance and delta AIC ≤2 units from a model with one fewer parameters.

Table 12. Parameter estimates from Cox proportional-hazards regressions of the passage rates of yearling coho salmon from hatchery and wild origins at the Shasta River site, lower Klamath River, northern California, 2006.

[Results from regressions models based on origin (hatchery=0, wild=1), water temperature (temp), or fish weight (wt), and the origin and covariate interaction are listed. DF=degrees of freedom, Se=standard error, χ2=chi square value, *P*=probability of a larger chi square value]

Covariate	Parameter	DF	Estimate	Se	χ2	*P*
q100	origin	1	-1.2002	0.8893	1.8213	0.1772
	q100	1	-0.0930	0.0169	30.2970	0.0000
	origin*q100	1	0.0581	0.0202	8.2528	0.0041
temp	origin	1	6.2712	1.6828	13.8871	0.0002
	temp	1	0.5518	0.0924	35.6689	0.0000
	origin*temp	1	-0.3137	0.1085	8.3621	0.0038
photo	origin	1	30.5945	8.9388	11.7147	0.0006
	photo	1	2.9517	0.4535	42.3570	0.0000
	origin*photo	1	-1.7431	0.5353	10.6055	0.0011

Passage rates also were positively affected by water temperature and photoperiod, with greater effects on passage of wild fish than hatchery fish. As in models of river discharge, different effects of these covariates were supported in hatchery and wild fish, however, unlike the results from the analysis of discharge, the difference between hatchery and wild fish diminished at larger values of these covariates. The most supported model with water temperature predicts that rate of passage of wild fish is 10.5 times the rate of hatchery fish at a water temperature of 12.5 °C and 3.8 times the rate of hatchery fish at a water temperature of 15.7 °C (the 25th and 75th percentiles of the water temperature data). Similarly, the most supported model with photoperiod predicts the rate of passage of wild fish was 12.6 times the rate of hatchery fish at a photoperiod of 16.1 h and 3.7 times the rate of hatchery fish at a photoperiod of 16.8 h. It is important to recall that over the course of the study season in 2006 discharge decreased and water temperature and photoperiod increased with calendar date and the fish travel time from release to passage at the Shasta site decreased with release date.

Estimates of Survival

The most common encounter history of hatchery and wild fish was from fish that were detected at every site (appendix I). Tests of model fit indicated slight overdispersion in the data, so a variance inflation factor $\hat{c}$ of 1.30 was applied to the data (derived with Program MARK using the median $\hat{c}$ procedure). The data and models evaluated supported additive and multiplicative models of detection probabilities based on fish origin and detection site, so these models were used in subsequent models of survival probabilities (appendix J). Results from a suite of 10 models of survival probabilities with various combinations of fish origin and site were model-averaged prior to estimating reach-specific survivals of hatchery and wild fish. The most supported models were those allowing survival to vary by site (QAICc weight 0.530) and origin and site (QAICc weight 0.333).

The model-averaged estimates of survival of hatchery and wild fish were similar in each reach. The reach-specific estimates of survival ranged from 0.878 to 0.992 and were lowest in the Shasta River to Scott River reach and highest in the Salmon River to Trinity River reach (table 13, fig. 10). The reach-specific estimates of survival of hatchery and wild fish followed a similar trend over the six reaches and were all within 0.030 of one another. The greatest difference in survival between fish origins was in the Salmon River to Trinity River reach, where the estimate for hatchery fish was 0.992 (SE 0.024) and the estimate for wild fish was 0.962 (SE 0.040).

Covariates of Survival

A suite of models was evaluated to determine if the effects on any one of several covariates on the survival of juvenile coho salmon differed between hatchery and wild fish. The analysis was restricted to the covariates river discharge, water temperature, and fish weight to avoid correlations between covariates and because sample sizes were relatively small. Support for the effect of each covariate was evaluated in terms of the four combinations of intercepts and slopes based on the two fish origins and each covariate.

Table 13. Estimated apparent survivals and confidence intervals of yearling coho salmon from hatchery and wild origins in study reaches of the lower Klamath River, northern California, spring 2006.

[Results are based on data from 80 hatchery fish from Iron Gate Hatchery and 94 wild fish taken from a rotary trap on the Scott River. All fish were released in the Klamath River near the hatchery between April 4 and May 16, 2006. Results are based on model-averaging the models in appendix table J2. Data over multiple reaches were calculated as the product of the reach estimates with variances estimated using the Delta method (Seber, 1982)]

Reach No.	Description	Reach length (km)	Apparent survival	Standard error	95-percent confidence interval	
					Lower	Upper
	-- Origin = Hatchery --					
1	Release to Shasta River (rkm 288)	21	0.927	0.026	0.856	0.964
2	Shasta River to Scott River (rkm 234)	54	0.878	0.041	0.772	0.938
3	Scott River to Indian Creek (rkm 178)	56	0.893	0.038	0.792	0.949
4	Indian Creek to Salmon River (rkm 107)	71	0.928	0.029	0.846	0.968
5	Salmon River to Trinity River (rkm 69)	38	0.992	0.024	0.944	1.039
6	Trinity River to Steelhead Lodge (rkm 33)	36	0.957	0.036	0.802	0.992
	Release to Steelhead Lodge	276	0.634	0.058	0.520	0.748
	-- Origin = Wild --					
1	Release to Shasta River (rkm 288)	21	0.935	0.024	0.871	0.968
2	Shasta River to Scott River (rkm 234)	54	0.891	0.036	0.798	0.944
3	Scott River to Indian Creek (rkm 178)	56	0.905	0.034	0.816	0.953
4	Indian Creek to Salmon River (rkm 107)	71	0.935	0.027	0.860	0.972
5	Salmon River to Trinity River (rkm 69)	38	0.962	0.040	0.747	0.995
6	Trinity River to Steelhead Lodge (rkm 33)	36	0.960	0.034	0.808	0.993
	Release to Steelhead Lodge	276	0.645	0.058	0.532	0.758

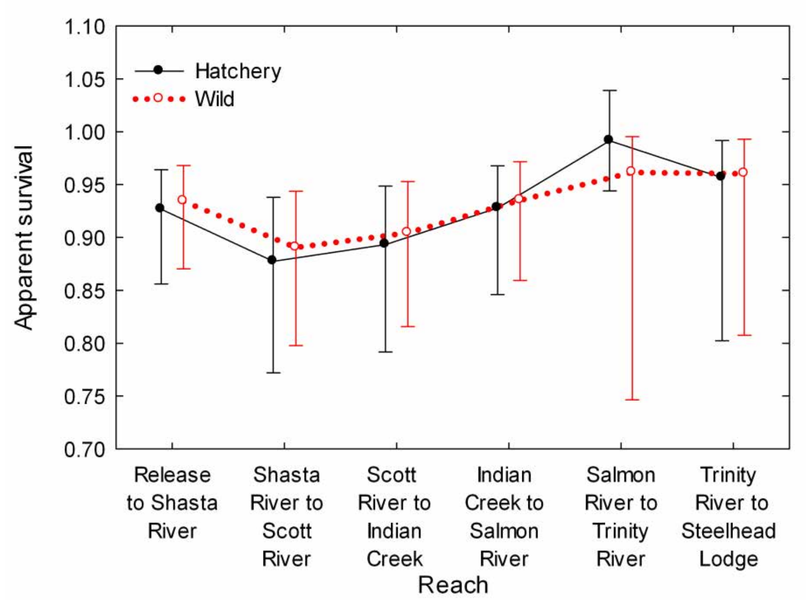

Figure 10. Graph of model-averaged reach-specific survival estimates of yearling coho salmon from hatchery and wild origins released on common dates, lower Klamath River, northern California, 2006. Vertical bars represent 95-percent confidence intervals.

Water temperature was the only covariate of survival supported in the analysis of data from hatchery and wild fish in the release to Shasta River reach in 2006 (table 14). Models including river discharge or fish weight received similar support as the model without the covariates, indicating that the covariates did not improve model fit. The models including water temperature were strongly supported over the model without the covariate (model 0), indicating temperature affected survival. All models with water temperature received similar support from the data, indicating they were equally plausible, yet no clear pattern was evident from these results. Thus, the data and models indicate that water temperature affected survival in 2006, but the results do not clearly support different effects on hatchery and wild fish.

Table 14. Model selection results from analyses of selected covariates on the survival of yearling coho salmon from hatchery and wild origins in the release to Shasta River reach, lower Klamath River, northern California, 2006.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. AICc=Akaike Information Criterion with a sample size adjustment, K =number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc Weight	Model Likelihood	K	Deviance
Covariate = River Discharge								
1	Same	Same	405.677	0.000	0.476	1.000	6	393.450
0	None	None	405.916	0.239	0.422	0.887	6	393.689
3	Different	Same	407.629	1.952	([1])	([1])	7	393.325
2	Same	Different	407.735	2.058	([1])	([1])	7	393.432
4	Different	Different	408.761	3.084	0.102	0.214	8	392.370
Covariate = Water Temperature								
1	Same	Same	393.138	0.000	0.647	1.000	6	380.911
4	Different	Different	394.353	1.215	0.352	0.545	8	377.962
2	Same	Different	394.871	1.733	([1])	([1])	7	380.567
3	Different	Same	395.178	2.040	([1])	([1])	7	380.875
0	None	None	405.916	12.778	0.001	0.002	6	393.689
Covariate = Fish Weight								
0	None	None	405.916	0.000	0.443	1.000	6	393.689
1	Same	Same	406.027	0.111	0.419	0.946	6	393.800
2	Same	Different	407.578	1.662	([1])	([1])	7	393.275
3	Different	Same	407.968	2.052	([1])	([1])	7	393.665
4	Different	Different	408.237	2.321	0.139	0.313	8	391.846

[1]Model was removed from consideration due to similar deviance and delta AICc ≤2 units from a model with one fewer parameters.

Fish weight and water temperature were the only covariates supported as having an effect on survival in any of the other reaches (appendix K). Models with fish weight were better supported than the no-covariate model in the Scott River to Indian Creek and Trinity River to Steelhead Lodge reaches, but in each case, all models with covariates received similar weight and did not support different effects on hatchery and wild fish. The different intercept/different slope model of water temperature was moderately supported relative to the no-covariate and other covariate models in the Trinity River to Steelhead Lodge reach; it had an AICc value at least 3.163 units smaller than the other models (appendix K). This model represents the hypothesis that the survivals of hatchery and wild fish differ at basal levels of water temperature (the intercept) and as water temperature increases (the slope). Analyses from the Salmon River to Trinity River reach were not conducted, because there was no mortality of hatchery fish in the sample.

Data from the 2009 Migration Year

Migration Timing

The hatchery fish migrated downstream sooner after release than the wild fish in 2009. Travel times from release to the Shasta River site was a median of 17.68 d (range 0.18–37.78 d) for hatchery fish and 23.96 d (range 0.18–37.41 d) for wild fish and the distributions of times were significantly different (Wilcoxon test $\chi^{2} =$ 4.36, df = 1, *P* = 0.0369; table 15). Recall that the hatchery fish were nearly twice the weight of the wild fish in 2009. The addition of the detection site at Ager Bridge 9 km downstream of IGD in 2008 enabled analyses of two reaches upstream of the Shasta River in 2009. The travel times of hatchery fish were shorter than the wild fish from release to the Ager Bridge site, with median travel times of 0.34 d for hatchery fish and 6.08 d for wild fish. In the Ager Bridge to Shasta River reach, the travel times were similar between origins (fig. 11). Conversely, the wild fish traveled faster through the Shasta River to Scott River reach than the hatchery fish, with a median travel time of 1.04 d compared to 3.14 d for the hatchery fish (Wilcoxon test $\chi^{2} =$ 8.47, df = 1, *P* = 0.0036). Travel times of hatchery and wild fish in reaches downstream of the Scott River were similar between origins and were a median of less than 1 d. The distributions of travel times of hatchery and wild fish were significantly different in the two most downstream reaches, but the differences in the median travel times in each reach were less than 4 hours.

Table 15. Summary of travel times of yearling coho salmon used in comparisons of migration and survival of fish from hatchery and wild origins, lower Klamath River, northern California, 2009.

[The summary is based on release of 57 hatchery fish and 57 wild fish released on dates between April 16 and April 30, 2009. *N*=sample size, Min=minimum, Max=maximum, *P* =probability of a larger value Chi-square (χ2) value from a Wilcoxon test with one degree of freedom comparing the Kaplan-Meier survival distribution functions of the travel times]

	Hatchery origin Travel time, in days				Wild origin Travel time, in days				Wilcoxon test	
Reach	Median	*N*	Min	Max	Median	*N*	Min	Max	χ2	*P*
Release to Ager Bridge	0.34	52	0.07	32.44	6.08	43	0.07	37.11	3.82	0.0505
Ager Bridge to Shasta River	3.96	48	0.10	35.72	0.40	34	0.10	32.86	0.24	0.6240
Release to Shasta River	17.68	48	0.19	37.78	23.96	38	0.18	37.41	4.36	0.0369
Shasta River to Scott River	3.14	43	0.55	30.37	1.04	37	0.52	26.92	8.47	0.0036
Scott River to Indian Creek	0.89	41	0.48	3.83	0.88	37	0.45	3.92	0.78	0.3755
Indian Creek to Salmon River	0.94	40	0.55	15.16	0.92	35	0.29	6.12	0.82	0.3657
Salmon River to Trinity River	0.45	38	0.22	4.50	0.39	34	0.24	0.77	0.65	0.4215
Trinity River to Steelhead Lodge	0.46	36	0.24	4.51	0.30	34	0.22	1.32	7.96	0.0048
Steelhead Lodge to Gaging Station	0.33	36	0.13	3.06	0.16	33	0.12	0.60	8.47	0.0036
Release to Gaging Station	28.22	36	14.30	40.65	28.69	33	11.86	41.49	0.10	0.7465

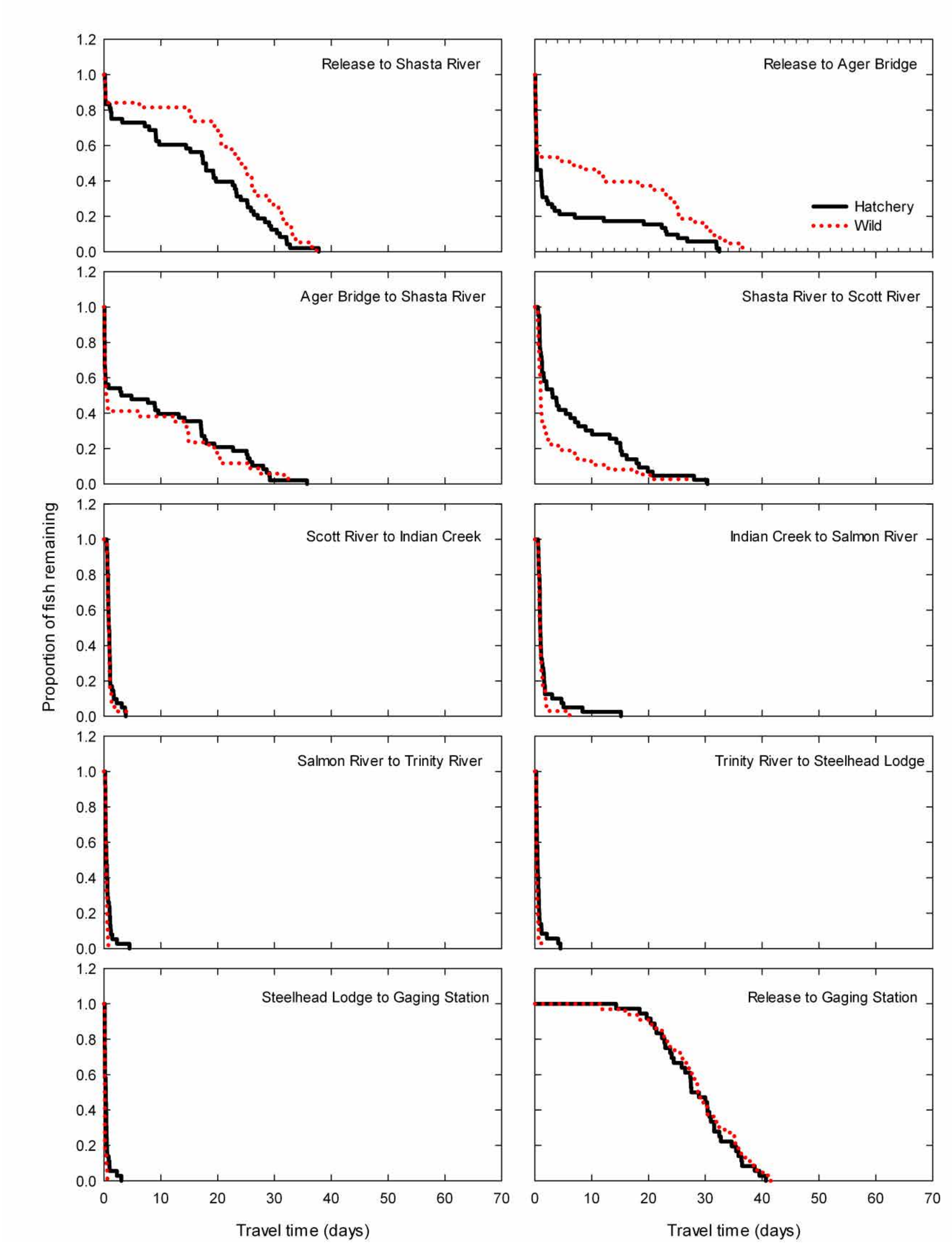

Figure 11. Graphs of the distributions of travel times of yearling coho salmon from hatchery and wild origins in each reach and over the entire study area (Release to Gaging Station), lower Klamath River, northern California, 2009.

The differences in travel times resulted in hatchery and wild fish passing the detection sites on different dates, but the difference was smaller in 2009 than in 2006. In 2009, the hatchery fish passed the Shasta site prior to the wild fish by approximately 7 d, although the shape of the passage distributions also differed (fig. 12). The cumulative passage distributions of hatchery and wild fish were similar by the time they reached the Gaging Station site.

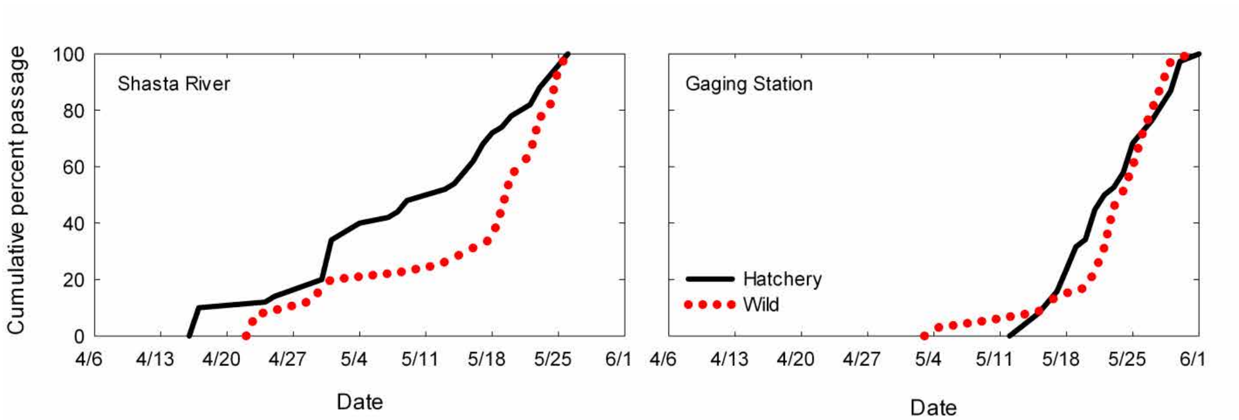

Figure 12. Graph of cumulative passage percentages of yearling coho salmon from hatchery and wild origins at the first detection site (Shasta River) and last detection site (Gaging Station), lower Klamath River, northern California, 2009.

Covariates of Passage Rates

The data and models supported origin-specific effects of several covariates on passage rates at the Shasta River and Scott River sites. Results of Cox proportional-hazards regressions indicated moderate-to-strong support for different effects on hatchery and wild fish for the covariates water temperature and fish weight at the Shasta River site (table 16). This site was used rather than the Ager Bridge site to be consistent with analyses from 2006 (prior to installation of the Ager Bridge site). A model with an interaction with fish origin was strongly supported for the water temperature and fish weight covariates. Models with photoperiod included were strongly supported relative to the model without the covariate, but support for models with identical or different effects on passage rates of hatchery and wild fish was similar, indicating little support for a different effect by fish origin.

Support for the models including interactions between fish origin and water temperature or fish weight indicated that the effect of each covariate differed between hatchery and wild fish at the Shasta River site. The effect of water temperature was greater in hatchery fish than in wild fish and the effect diminished as water temperature increased. Model parameter estimates are in table 17. The model including water temperature predicts that the passage rate of hatchery fish at the Shasta River site is 4.1 times the rate of wild fish at 12.5 °C (the 25th percentile of the data) and 2.2 times the rate of wild fish at 13.9 °C (the 75th percentile of the data). The model including fish weight predicts the passage rate of hatchery fish at the Shasta site is 1.3 times the rate of the wild fish at a weight of 13.1 g (the 25th percentile of the data) and 0.1 times the rate of the wild fish at a weight of 30.1 g (the 75th percentile of the data). Thus, for small fish, the hatchery passage rate is greater than the wild fish passage rate, but for large fish the reverse is true. This result may have been influenced by the differences in size of fish from the two groups.

Table 16. Model selection results from analyses of covariates of passage rates of yearling coho salmon from hatchery and wild origins at the Shasta River site, lower Klamath River, northern California, 2009.

[Model selection results from models based on origin (hatchery =0, wild=1), origin plus the covariate (cov), and origin plus the covariate plus an origin-covariate interaction are shown. Q100=river discharge at the upstream end of the reach divided by 100, temp=water temperature (°C) at the head of the reach, wt=fish weight (g) at the time of tagging, photo=day length in hours, atpase=value of gill ATPase activity at the time of tagging, K=number of parameters, AIC=Akaike Information Criterion, Delta AIC=difference between the AIC and the minimum AIC of the models in the same covariate grouping]

Covariate	Model	K	Deviance	AIC	Delta AIC
q100	origin	1	631.695	633.695	0.000
	origin, cov	2	630.173	634.173	0.479
	origin, cov, interaction	3	629.622	635.622	1.927
temp	origin	1	631.695	633.695	22.590
	origin, cov	2	616.060	620.060	8.956
	origin, cov, interaction	3	605.105	611.105	0.000
wt	origin	1	631.695	633.695	16.406
	origin, cov	2	619.874	623.874	6.585
	origin, cov, interaction	3	611.288	617.288	0.000
photo	origin	1	631.695	633.695	19.897
	origin, cov	2	611.486	615.486	1.689
	origin, cov, interaction	3	607.797	613.797	0.000
atpase	origin	1	631.695	633.695	1.634
	origin, cov	2	628.385	632.385	0.325
	origin, cov, interaction	3	626.060	632.060	0.000

Table 17. Parameter estimates from Cox proportional-hazards regressions of the passage rates of yearling coho salmon from hatchery and wild origins at the Shasta River site, lower Klamath River, northern California, 2009.

[Results from regressions models based on origin (hatchery=0, wild=1), water temperature (temp), or fish weight (wt), and the origin and covariate interaction are listed. DF=degrees of freedom, Se=standard error, $\chi 2$=chi square value, *P*=probability of a larger chi square value]

Covariate	Parameter	DF	Estimate	Se	$\chi 2$	*P*
temp	origin	1	-7.0152	2.0999	11.1606	0.0008
	temp	1	0.2495	0.1301	3.6794	0.0551
	origin*temp	1	0.4485	0.1411	10.1068	0.0015
wt	origin	1	-2.1618	0.7753	7.7744	0.0053
	wt	1	0.0233	0.0065	12.7653	0.0004
	origin*wt	1	0.1456	0.0470	9.5998	0.0019

The data and models supported a different effect of fish weight on passage rate of hatchery and wild fish at the Scott River site in 2009. The model of fish weight including the interaction term between origin and the covariate was moderately supported by the data, with an AIC value more than 5 units lower than the other two models (table 18). Model parameter estimates are in table 19. The model predicts that the passage rate of hatchery fish is 0.44 times the rate of wild fish at a fish weight of 13.1 g and 3.3 times the rate of wild fish at a weight of 30.1 g, with the weights representing the 25th and 75th percentiles from the data. It should be noted that hatchery fish were much larger than wild fish in 2009, which likely affects these results.

Table 18. Model selection results from analyses of covariates of passage rates of yearling coho salmon from hatchery and wild origins at the Scott River site, lower Klamath River, northern California, 2009.

[Model selection results from models based on origin (hatchery=0, wild=1), origin plus the covariate (cov), and origin plus the covariate plus an origin-covariate interaction are shown. Q100=river discharge at the upstream end of the reach divided by 100, temp=water temperature (°C) at the head of the reach, wt=fish weight (g) at the time of tagging, photo=photoperiod, atpase=value of gill ATPase activity at the time of tagging, K=number of parameters, AIC=Akaike Information Criterion, Delta AIC=difference between the AIC and the minimum AIC of the models in the same covariate grouping]

Covariate	Model	K	Deviance	AIC	Delta AIC
q100	origin	1	576.561	578.561	51.062
	origin, cov	2	524.962	528.962	1.462
	origin, cov, interaction	3	521.500	527.500	0.000
temp	origin	1	576.561	578.561	110.510
	origin, cov	2	464.052	468.052	0.000
	origin, cov, interaction	3	463.719	469.719	1.667
wt	origin	1	576.561	578.561	5.254
	origin, cov	2	574.888	578.888	5.581
	origin, cov, interaction	3	567.307	573.307	0.000
photo	origin	1	576.561	578.561	107.836
	origin, cov	2	466.725	470.725	0.000
	origin, cov, interaction	3	466.722	472.722	([1])
atpase	origin	1	576.561	578.561	0.000
	origin, cov	2	576.554	580.554	([1])
	origin, cov, interaction	3	572.762	578.762	0.201

[1]Model was removed from consideration due to similar deviance and delta AIC ≤2 units from a model with one fewer parameters.

Table 19. Parameter estimates from Cox proportional-hazards regressions of the passage rates of yearling coho salmon from hatchery and wild origins at the Scott River site, lower Klamath River, northern California, 2009.

[Results from regressions models are based on origin (hatchery=0, wild=1), fish weight (wt), and the origin and covariate interaction (origin*wt). DF=degrees of freedom, Se=standard error, χ2=chi square value, *P*=probability of a larger chi square value]

Covariate	Parameter	DF	Estimate	Se	χ2	*P*
wt	origin	1	2.3381	0.7955	8.6400	0.0033
	wt	1	-0.0057	0.0076	0.5648	0.4523
	origin*wt	1	-0.1174	0.0461	6.4766	0.0109

Estimates of Survival

The estimates of survival were based on model-averaged results from a suite of models. The most common encounter history was of fish detected at all sites (appendix L). Tests of model fit indicated no evidence of overdispersion in the data. The estimate of $\hat{c}$ was less than 1, so a variance inflation factor adjustment was not applied. The data and models evaluated supported an additive model of detection probabilities based on fish origin and detection site, so this model was used in subsequent models of survival probabilities. Results from a suite of five models of survival probabilities with various combinations of fish origin and site were model-averaged prior to estimating reach-specific survivals of hatchery and wild fish. The largest delta AICc value was 3.481, indicating similar support among the five models (appendix table M2).

The model-averaged estimates of survival of hatchery and wild fish were similar in each reach. The reach-specific estimates of survival ranged from 0.909 to 0.957 for hatchery fish and 0.887 to 0.971 for wild fish (table 20, fig. 13). The largest difference between survival estimates of hatchery and wild fish was in the Ager Bridge to Shasta reach, where the difference was 0.022. The estimates in the three reaches upstream of the Scott River were lower than the others, however all estimates generally were similar to one another, as indicated by the support for the model with a single value fitted to all reach and origin combinations (appendix table M2).

Covariates of Survival

In most cases, the covariates of river discharge, water temperature, and fish weight were not supported as factors affecting survival of hatchery and wild fish in 2009. These models generally received similar or less support than ones without the covariates (appendix N). However, in the Salmon River to Trinity River reach the different intercept/different slope model of river discharge was moderately supported relative to the no effect model (delta AICc = 4.746) and strongly supported relative to the other models (delta AICc at least 9.152), indicating moderate support for a difference between hatchery and wild fish in this reach. This model describes the hypothesis that the survival of hatchery and wild fish differ at basal levels of river discharge (the intercept) and as discharge increases (the slope). Analyses of data from the Trinity River to Steelhead Lodge reach were not conducted, because there was no mortality in the wild fish sample from that reach.

Table 20. Estimated apparent survivals and confidence intervals of yearling coho salmon from hatchery and wild origins in study reaches of the lower Klamath River, northern California, spring 2009.

[Results are based on data from 57 hatchery fish from Iron Gate Hatchery and 57 wild fish taken from a rotary trap on the Scott River. All fish were released in the Klamath River near the hatchery between April 16 and April 30, 2009. Results are based on model-averaging the models in appendix table M2. Data over multiple reaches were calculated as the product of the reach estimates with variances estimated using the delta method]

Reach number	Description	Reach length (km)	Apparent survival	Standard error	95-percent confidence interval	
					Lower	Upper
	---------- Origin = Hatchery ----------					
1	Release to Ager Bridge (rkm 300)	9	0.930	0.025	0.861	0.966
2	Ager Bridge to Shasta River (rkm 288)	12	0.909	0.038	0.802	0.961
3	Shasta River to Scott River (rkm 234)	54	0.936	0.026	0.862	0.971
4	Scott River to Indian Creek (rkm 178)	56	0.956	0.022	0.884	0.984
5	Indian Creek to Salmon River (rkm 107)	71	0.957	0.022	0.884	0.985
6	Salmon River to Trinity River (rkm 69)	38	0.955	0.023	0.883	0.983
7	Trinity River to Steelhead Lodge (rkm 33)	36	0.950	0.028	0.857	0.984
	Release to Shasta River	21	0.845	0.042	0.763	0.928
	Release to Steelhead Lodge	276	0.656	0.050	0.558	0.755
	---------- Origin = Wild ----------					
1	Release to Ager Bridge (rkm 300)	9	0.914	0.033	0.822	0.961
2	Ager Bridge to Shasta River (rkm 288)	12	0.887	0.052	0.741	0.956
3	Shasta River to Scott River (rkm 234)	54	0.932	0.028	0.850	0.970
4	Scott River to Indian Creek (rkm 178)	56	0.952	0.024	0.876	0.982
5	Indian Creek to Salmon River (rkm 107)	71	0.949	0.024	0.875	0.981
6	Salmon River to Trinity River (rkm 69)	38	0.950	0.024	0.874	0.981
7	Trinity River to Steelhead Lodge (rkm 33)	36	0.971	0.031	0.792	0.997
	Release to Shasta River	21	0.811	0.056	0.702	0.920
	Release to Steelhead Lodge	276	0.630	0.059	0.515	0.745

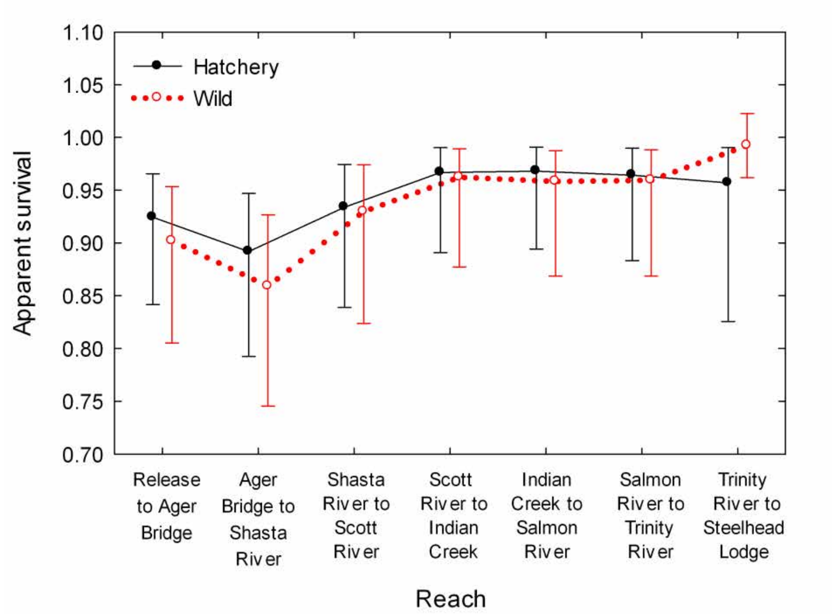

Figure 13. Graph of model-averaged reach-specific survival estimates of yearling coho salmon from hatchery and wild origins released on common dates, lower Klamath River, northern California, 2009. Vertical bars represent 95-percent confidence intervals.

Potential Effects of Tagging and Handling on Survival

The results from this study consistently show that apparent survival in reaches near the release site is lower than in reaches farther downstream. This result could be due to a variety of causes, including higher natural mortality pressures in those areas, a short-term handling effect, or some combination of the two. As previously mentioned, fish were released in 2006 and 2007 near Iron Gate Hatchery and at a site downstream to enable use of a paired-release survival model. Paired-release model assumptions were violated (mixing and survival of treatment and control groups), leading to the abandonment of that model in future years, but the releases of fish at the two sites may be used to examine the question of a handling effect on survival after release. The hypothesis is that tagging and handing effects on survival will be manifested in differential survival of fish released near Iron Gate Hatchery and fish released downstream in reaches of the river they both travel through.

The downstream release sites differed between years. In 2006, the downstream release group, hereafter referred to as the control group, was released at the confluence of the Klamath and Shasta Rivers (Beeman, 2007). In 2007, the control group was released in the Klamath River near the Tree of Heaven campground between the Shasta and Scott Rivers (Beeman, 2008; Beeman and others, 2008). Fish also were released near Iron Gate Hatchery in each year (the treatment group), as described previously in this report. Hatchery-origin fish from Iron Gate

Hatchery and wild-origin fish from the rotary screw trap in the Shasta River (described previously in this report) were used in 2006, but only hatchery fish were used in 2007. Sample sizes in 2006 were 99 hatchery control fish, 114 hatchery treatment fish, 82 wild control fish, and 94 wild treatment fish (Beeman, 2007). Sample sizes in 2007 were 123 hatchery fish in each of the control and treatment groups (Beeman, 2008; Beeman and others, 2008).

Treatment and control groups were in the Shasta River to Scott River reach during the same general date range, but the travel times of the hatchery groups were quite different. The treatment group of hatchery fish entered the Shasta River to Scott River reach between April 19 and June 4 and passed the Scott River site between May 6 and June 2. The control group of hatchery fish was released near the mouth of the Shasta River between April 14 and May 24 and passed the Scott River site between May 7 and June 5. The travel times of hatchery fish through the Shasta River to Scott River reach were a median of 1.6 d (95-percent confidence interval 1.0–2.4 d) for treatment fish and 8.4 d (95-percent confidence interval 6.2–11.9 d) for control fish.

The treatment and control groups of wild fish entered the Shasta River to Scott River reach during similar dates and had similar travel times. The treatment group entered the Shasta River to Scott River reach between April 5 and May 19 and passed the Scott River site between April 25 and May 2. The control group was released near the mouth of the Shasta River between April 18 and May 16 and passed the Scott River site between April 24 and May 20. The travel times of wild fish through the Shasta River to Scott River reach were a median of 3.1 d (95-percent confidence interval 1.9–4.0 d) for treatment fish and 3.3 d (95-percent confidence interval 1.6–5.5 d) for control fish.

Models describing each of four hypotheses were used to evaluate the potential of a tagging and handling effect. Hypothesis 1 assumes the survival of control and treatment groups is different in every reach they had in common. This model allows survival and recapture probabilities of each group to be estimated without constraints (that is, the full model), and allows both short-term and long-term differences in survival between treatment and control groups. Hypothesis 2 assumes a common survival of the groups in the reach the control fish were released in, but survival may differ afterwards. This hypothesis assumes no short-term difference in survival between groups, but allows for long-term differences. Hypothesis 3 allows survival to differ only in the reach the control fish are released in, assuming a short-term effect but no long-term effect. Hypothesis 4 assumes the survival of treatment and control fish are the same in each reach they have in common and represents the hypothesis of no effect. The support for the hypotheses by the data was measured by the AICc values of each model.

The data from hatchery and wild fish in 2006 support different conclusions about the potential of tagging or handling effects. Data and models of hatchery fish in 2006 are equivocal about the presence of a short-term effect, as indicated by the similarity in AICc values of models 3 and 4 (table 21). Long-term effects included in models 1 and 2 were not supported by the data. Model-averaged estimates of reach survival based on the models in table 21 are shown in figure 14. The model-averaged reach-specific survivals in the Shasta River to Scott River reach are 0.833 (SE 0.035) for treatment fish and 0.812 (SE 0.033) for control fish. The conclusion from this analysis is that there is little evidence to support or refute a short-term handling effect over a 54-km distance and strong support against the hypothesis of a long-term handling effect in hatchery fish from 2006.

Table 21. Model selection summary from control and treatment group survivals of yearling coho salmon of hatchery origin released into the lower Klamath River, northern California, 2006.

[The models represent several hypotheses about potential short-term and long-term handling effects as indicated by comparisons of reach-specific survivals of fish released at Iron Gate Hatchery (treatment group) and the confluence of the Klamath and Shasta rivers (control group). AICc=Akaike Information Criterion with sample size adjustment, Delta AICc=difference between the AICc and the minimum AICc of the models in the set, K = number of parameters]

Model	Hypothesis	AICc	Delta AICc	AICc weights	Model likelihood	K	Deviance
4	No Effect	1097.250	0.000	0.634	1.000	18	120.212
3	Short Term Effect Only	1098.383	1.134	0.360	0.567	19	119.273
1	Short Term and Long Term Effect	1107.410	10.160	0.004	0.006	24	117.879
2	Long Term Effect Only	1108.351	11.101	0.002	0.004	24	118.820

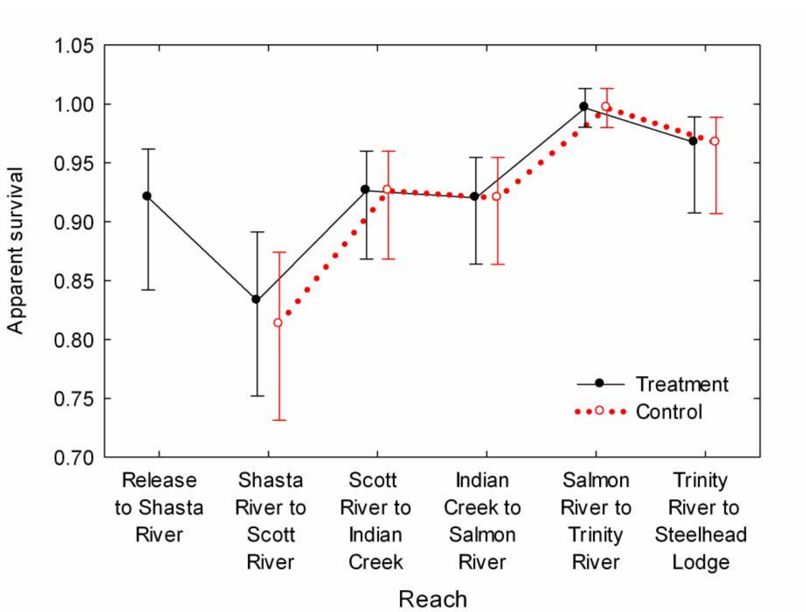

Figure 14. Graph of model-averaged reach-specific survival estimates of yearling coho salmon of hatchery origin released near Iron Gate Hatchery (Treatment) and the confluence of the Klamath and Shasta Rivers (Control), lower Klamath River, northern California, 2006. Vertical bars represent 95-percent confidence intervals.

Although the data and models are equivocal about a short-term tagging and handling effect in hatchery fish from 2006, the magnitude of an effect, should it exist, can be estimated from the data. However, due to the long travel time through the reach of release relative to those downstream described earlier in this report, treatment and control fish did not travel through the common reaches together, so there is the potential that they each experienced different mortality pressures (Beeman and others, 2008). Given this caveat, the effect expressed on a standardized reach length can be used to estimate the magnitude of the short-term handling effect on reach survival in the Release to Shasta River reach (the first reach for the treatment fish). The difference in survival per 100 km of treatment and control fish in the 54 km Shasta River to Scott River reach is 0.713–0.682 = 0.031. If this is added to the survival per 100 km of the treatment fish in the 21 km Release to Shasta River reach (0.674) the adjusted survival per 100 km in that reach is 0.706. That represents a reach survival of 0.929 in the Release to Shasta River reach, which is 0.009 larger than the original reach-survival estimate of 0.920. These survival estimates differ slightly from those described earlier in this report, because they are based on different data and models. The estimate of the short-term effect based on the results reported for hatchery fish in table 7 is an underestimate in Release to Shasta River survival of an average of 0.012 among years (range 0.010–0.015). The estimated short-term handling effect should be considered a maximum effect when applied to a reach shorter than the Shasta River to Scott River reach, because the measured effect in that reach was expressed over 54 km.

The data from wild fish in 2006 support a short-term tag or handling effect, but not a long-term effect. There is moderate support for the short-term effect, as indicated by the delta AICc of 4.595 between models 3 and 4 (table 22). A long-term effect was not supported by the data and models; the delta AICc of model 2 versus model 4 is 9.313. The smaller delta AICc between models 4 and 1 is likely due to model 1 including the short-term effect supported in model 3. The model-averaged estimates of reach survival are shown in figure 15. The model-averaged reach survivals in the Shasta River to Scott River reach are 0.934 (SE 0.044) for treatment fish and 0.784 (SE 0.056) for control fish.

Table 22. Model selection summary from control and treatment group survivals of yearling coho salmon of wild origin released into the lower Klamath River, northern California, 2006.

[The models represent several hypotheses about potential short-term and long-term handling effects as indicated by comparisons of reach-specific survivals of fish released at Iron Gate Hatchery (treatment group) and the confluence of the Klamath and Shasta Rivers (control group). AICc=Akaike Information Criterion with sample size adjustment, Delta AICc=difference between the AICc and the minimum AICc of the models in the set, K = number of parameters]

Model	Hypothesis	AICc	Delta AICc	AICc weights	Model likelihood	K	Deviance
3	Short Term Effect Only	1286.622	0.000	0.856	1.000	20	179.150
4	No Effect	1291.217	4.595	0.086	0.101	19	185.854
1	Short Term and Long Term Effect	1292.021	5.400	0.058	0.067	24	176.056
2	Long Term Effect Only	1300.529	13.908	0.001	0.001	24	184.564

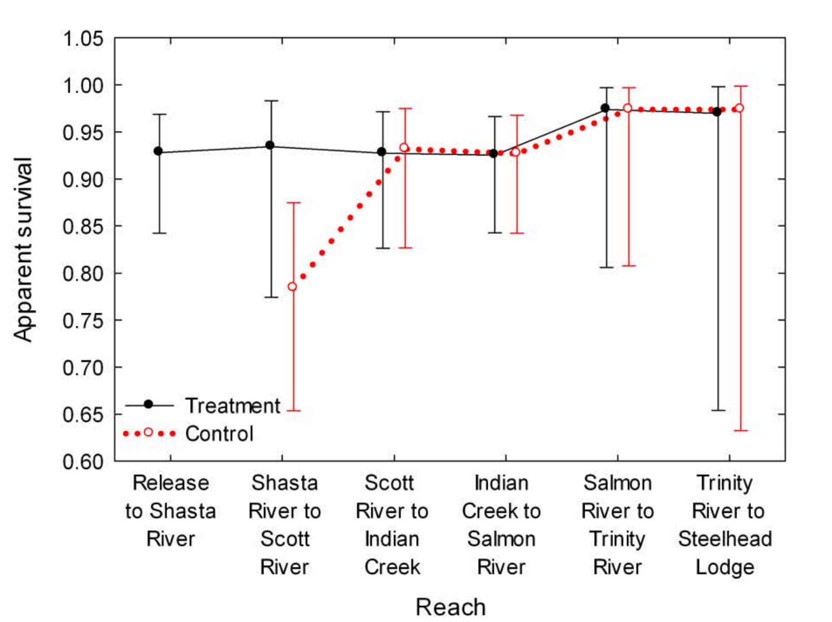

Figure 15. Graph of model-averaged reach-specific survival estimates of yearling coho salmon of wild origin released near Iron Gate Hatchery (Treatment) and the confluence of the Klamath and Shasta Rivers (Control), lower Klamath River, northern California, 2006. Vertical bars represent 95-percent confidence intervals.

The magnitude of the short-term effect in wild fish from 2006 can be estimated from the data as it was for hatchery fish. The difference in survival per 100 km of treatment and control fish in the Shasta River to Scott River reach is 0.882–0.637= 0.244. If this is added to the survival per 100 km of the treatment fish in the Release to Shasta River reach (0.700), the adjusted survival per 100 km in that reach is 0.945 (different from 0.944 due to rounding). That represents a reach survival of 0.988 in the 21-km Release to Shasta River reach, which is 0.060 larger than the original reach-survival estimate of 0.928. As noted previously, this should be considered an estimate of the maximum effect. These survival estimates differ slightly from those described earlier in this report, because they are based on different data and models. Estimates of the maximum short-term effect estimated here, if applied to the results reported for wild fish in tables 13 and 20 are underestimates in the Release to Shasta River survival of 0.059 in 2006 and 0.091 in 2009.

The data from hatchery fish in 2007 support short-term and long-term differences in survival of treatment and control fish. The data and models strongly support lower survival of treatment fish compared to control fish in the first common reach, which was the Tree of Heaven to Scott River reach in 2007. The AICc of model 1 was 12.395 smaller than the AICc of model 2 (table 23). Based on this result, model 3 (short-term effect only) was examined, but the delta AICc of 13.030 relative to model 1 indicated strong support against this hypothesis. Thus, the data and models strongly support differences in survival of treatment and control fish in every reach they had in common (fig. 16). The results from 2007 are not consistent with results from 2006. As noted in Beeman and others (2008), holding fish in the Tree of Heaven area prior to release may have exposed them to pathogens, reducing their survival. For this reason, we cannot separate the effects of handling from those of potential disease exposure unique to the control group in 2007.

Table 23. Model selection summary from control and treatment group survivals of yearling coho salmon of hatchery origin released into the lower Klamath River, northern California, 2007.

[The models represent several hypotheses about potential short-term and long-term handling effects as indicated by comparisons of reach-specific survivals of fish released at Iron Gate Hatchery (treatment group) and near the Tree of Heaven Campground (control group). AICc=Akaike Information Criterion with sample size adjustment, Delta AICc=difference between the AICc and the minimum AICc of the models in the set, K = number of parameters]

Model	Hypothesis	AICc	Delta AICc	AICc weights	Model likelihood	K	Deviance
1	Short Term and Long Term Effect	887.830	0.000	0.996	1.000	24	82.160
2	Long Term Effect Only	900.225	12.395	0.002	0.002	24	94.555
3	Short Term Effect Only	900.860	13.030	0.002	0.002	19	105.639
4	No Effect	913.511	25.682	0.000	0.000	19	118.290

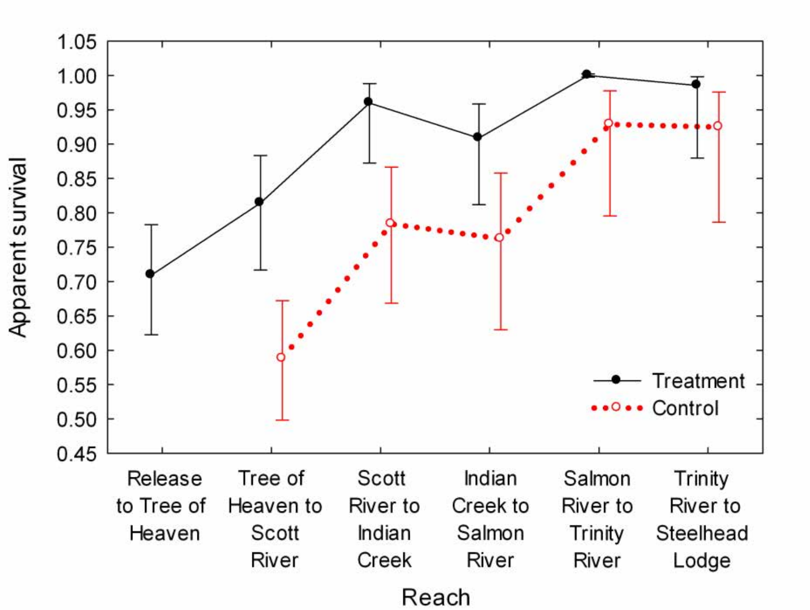

Figure 16. Graph of model-averaged reach-specific survival estimates of yearling coho salmon of hatchery origin released near Iron Gate Hatchery (Treatment) and near Tree of Heaven Campground (Control), lower Klamath River, northern California, 2007. Vertical bars represent 95-percent confidence intervals.

In summary, results from hatchery fish in 2006 are equivocal about a short-term handling effect and those from wild fish in 2006 moderately support a short-term effect. These results are based on comparisons of survival of treatment and control groups in common reaches. Treatment and control groups of fish were present in the Shasta River to Scott River reach over a similar range of dates, but the travel times of the hatchery groups differed and those of the wild fish were similar. In addition, the wild fish passed through the reach earlier than the hatchery fish. Neither data set supported a long-term handling effect (that is, longer than 54 km after release). Estimates of the short-term handling effect for hatchery fish, should one exist, indicate that reach survival in the 21-km Release to Shasta River reach was underestimated by a maximum of 0.010 in 2006. The estimated short-term handling effect for wild fish suggests that reach survival of wild fish in the Release to Shasta to River reach was underestimated by a maximum of 0.091 in 2006. The data from 2007 were not used to estimate a handling effect, because the survival of control fish was substantially lower than treatment fish in every reach and we suspect holding control fish in the Klamath River near the Tree of Heaven campground exposed them to pathogens in a manner unlike the treatment fish.

Discussion

The annual estimates of apparent survival of yearling coho salmon of hatchery origin through the 276 km area of inference in this study ranged from 0.412 to 0.648 and are similar to those of juvenile salmonids in other regulated river systems. The annual estimates of apparent survival represent a survival per 100 km ranging from 0.725 to 0.854 with an average of 0.790. Beeman and others (2009a) estimated that survival of radio-tagged yearling coho salmon released in the Trinity River near the base of Lewiston Dam to the Steelhead Lodge site in the Klamath River was 0.639 per 100 km in 2008. Survival through the Klamath River from release to the Steelhead Lodge site estimated from this study during the same year was 0.725 per 100 km. The estimated survival of juvenile coho salmon in the Klamath River is considerably higher than estimates for juvenile Chinook salmon in the Sacramento River. Perry and others (2010) estimated survival of juvenile Chinook salmon through the lower 101 km of the Sacramento River (rkm 92 to rkm -9) was 0.443 per 100 km and 0.564 per 100 km, depending on the release date. Survival of hatchery juvenile Chinook salmon from hatchery release through the undammed portion of the Snake River (to the tailrace of Lower Granite Dam), a much larger river than the Klamath River, ranged from 0.794 to 0.904 per 100 km and averaged 0.850 per 100 km from 1993 to 2003 (Williams and others, 2005).

The results of this study indicate that survival was lowest in reaches upstream of the Scott River. We could not definitively determine if this reflected natural processes, such as a higher rate of predation in these areas relative to those downstream, or if it reflected a bias in the data collected due to tagging or handling effects. It is not uncommon to find lower survival in areas near dams, fish hatcheries, and river confluences, which is presumably due to favorable foraging conditions for predatory birds and fish near these areas. These areas can provide concentrated sources of food and predators can react quickly to changes in prey density, such as those associated with releases of fish from hatcheries or changes in dam operations (Faler and others, 1988; Shively and others, 1996; Collis and others, 2005). There is a popular recreational fishery for rainbow trout (*O. mykiss*) between IGD and the Shasta River and pisciverous birds also are common in the area. We found several transmitters in river otter (*Lontra canadensis*) scat along the banks of the Klamath River. Hockersmith and others (1999) found that survival of radio-tagged juvenile Chinook salmon in an eastern Oregon river was lowest near the hatchery the fish were released from and at several river confluences along their seaward migration route. In that study, the fish were implanted with radio and PIT tags several weeks prior to release and were liberated with the production group of fish at the hatchery, presumably allowing sufficient time for tagging or handling effects to be expressed prior to release. Beeman and others (2009a) found the lowest survival of juvenile coho salmon in the Trinity River occurred in the 10-km reach nearest the release site at Lewiston Hatchery, but their methods were nearly identical to those used in this study, and also have the potential to include a short-term effect of tagging or handling. The potential for short-term mortality following release of tagged fish is not unique to this study. The issue resulted in use of a specialized statistical model designed to adjust estimates of survival for this potential bias in some studies on the Columbia River (Skalski, 2009), but Beeman and others (2011) found that the added complexity of the model may introduce other biases.

We used data from fish released near Iron Gate Hatchery and at sites downstream to determine if short-term mortality following release was supported, but the results were not conclusive. The data and models moderately support a differential survival consistent with a short-term tagging or handling effect in wild fish sufficient to represent a downward bias in estimated survival of wild fish in the release to Shasta River reach of 0.059 in 2006 and 0.091 in 2009. However, results of analyses using data from hatchery fish in 2006 were equivocal about a short-term effect, resulting in an estimated 0.010–0.015 negative bias in survival through the release to Shasta River reach, depending on the year. The data examined from 2006 did not support a long-term effect. The data from hatchery fish in 2007 supported short and long-term effects, which we consider to be anomalous due to the holding site used in that year. The Tree of Heaven campground area of the Klamath River is known to harbor large numbers of the polychaete worm *Manayunkia speciosa,* the primary host of both *Ceratomyxa shasta* and *Parvicapsula minibicornis* pathogens shown to cause high mortality in juvenile salmonids (Bartholomew and others, 2006).

The different conclusions about potential tagging or handling effects from wild and hatchery fish may be due to differences in smoltification and stress responses between the two groups. There can be a variety of differences between hatchery and wild juvenile salmonids, including differences in smoltification, migratory behavior, morphology, and stress response (Swain and others, 1991; Salonius and Iwama, 1993). Wild fish used in this study were caught in rotary screw traps and were therefore migrants when captured. However, as Rodgers and others (1987) found, juvenile salmonids also may emigrate from streams for reasons other than their normal seasonal seaward migrations, such as in response to changing environmental conditions. Migrating juvenile salmonids have generally been found to be farther along in the process of smoltification than non-migrants (Specker and Schreck, 1982; Barton and others, 1985; Rodgers and others, 1987), and ATPase activities in gill samples we collected from hatchery and wild fish we tagged were generally consistent with that premise (Beeman and others, 2007). Inasmuch as stress responses have been shown to be heightened in wild fish compared to hatchery fish (Salonius and Iwama, 1993), it is possible that the wild fish we used were more sensitive than the hatchery fish to the collection, tagging, and handling procedures, resulting in a short-term mortality following release. However, we saw no evidence of this while the fish were in our care (mortality, a crude measure of fish well being, was near zero in all groups prior to release). Olla and others (1992) found that stress responses of wild fish were greater than hatchery fish during controlled experiments, but that susceptibility to predation following a standardized stress returned to normal in less than 90 minutes. Their finding of only a short-term effect of stress on susceptibility to predation are similar to those of Mesa (1994), who found differences at 1 hour after exposure to multiple stressors but not afterward. Thus, there is evidence that wild fish may be more sensitive to stressors than hatchery fish, but increases in susceptibility to predation appear to be short-lived. However, our results are consistent with the theory that the heightened stress responses of wild fish compared to hatchery fish resulted in a greater rate of predation shortly after release.

Water temperature, river discharge, and fish weight were supported as factors affecting survival in the reach between IGD and the Shasta River. The most influential factor, as indicated by standardized slope estimates, was water temperature, followed by river discharge and fish weight. In this reach river, discharge primarily is influenced by discharge at IGD. The 95-percent confidence interval of the slope estimate for fish weight overlapped zero, indicating the estimation of the effect of this variable was imprecise. Survival was positively related to each of these covariates. High water temperature is often found to be detrimental to juvenile salmonids, but the highest water temperature in the data we collected in this reach was 17.91 °C, which is lower than levels known to cause reductions in growth or increases in mortality of juvenile salmonids (Marine and Cech, 2004). Connor and others (2003) and Smith and others (2003) found survival of juvenile Chinook salmon migrating in the Snake River was negatively related to water temperature, but water temperatures in their studies were higher than in this study. Predicted survival near the maximum water temperatures in our study, which occurred during mid-May in each year, were near 1.0, meaning the effects of other factors on survival were minimal at that time of year. The predicted effect of river discharge on survival was greatest for small fish in April when water temperatures were lowest. Connor and others (2003) and Smith and others (2003) also found a positive relation between survival and discharge in juvenile salmonids migrating in the Snake River. The results from this study must be interpreted within the ranges of the environmental factors present during the study. Water temperatures in the Klamath River downstream of IGD commonly exceed the values present in this study during summer months (see Perry and others, 2011) and may not be positively related to survival of juvenile coho salmon during those conditions. Water temperatures in the lower Klamath River can be above thermal preferences of juvenile coho salmon, as indicated by their use of cool-water thermal refugia (Sutton and Soto, 2010).

The factors initiating downstream migration of juvenile salmonids and controlling it once it begins generally are known. The prevailing ecological theory is that photoperiod is the causative factor indicating the season of migration with annual variation in the onset and rate of migration mediated by water temperature and river discharge (Jonsson and Ruud-Hansen, 1985; Jonsson, 1991). For coho salmon, seaward migration is primarily of yearling fish, indicating that fish size or age also is an important factor (Sandercock, 1998). The variables we included in analyses of passage rates were based on these ecological principles. We included both water temperature and ATU, based on the results of Sykes and others (2009), indicating that ATU was a better explanatory variable than mean daily temperature in a study of trap catches of juvenile Chinook salmon in a British Columbia river. Water temperature and ATU received similar support in models we examined.

Travel times through the reach upstream of the Shasta River were longer than in any of the reaches downstream, because this reach included the time prior to initiation of migration. Photoperiod was only supported as a factor affecting passage rate at the Shasta River site (the terminus of the reach fish were released in) which is consistent with the hypothesis that photoperiod is the causative factor indicating the season of migration. The travel times of fish through the reach of release in each year generally decreased as date and photoperiod (length of daylight) increased. This may be best exemplified with data from 2006, when the longest travel times in the reach of release were from fish released in early April when discharge at IGD was more than 10,000 ft^3/s and the shortest travel times were from fish released in late May when discharge at IGD was less than 4,000 ft^3/s (Beeman and others, 2007). Rodgers and others (1987) reported peaks in smoltification indices and migration of juvenile coho salmon in May during a decreasing hydrograph, in much the same pattern as the passage rates at the Shasta River site in this study.

Passage rates at sites downstream of the Shasta River site were minimally affected by the factors examined except for water temperature. Date of reach entry, river discharge, fish weight, ATU, and ATPase were supported as affecting passage rates at one or more of the reaches downstream of the Shasta River site, but in nearly every case, the 95-percent confidence intervals of the slope coefficients overlapped zero, indicating that the estimates of the magnitude and direction of the effects were imprecise. A positive effect of water temperature on passage rate was supported at three of the five sites and the estimated magnitude of the increase in passage rate ranged from 12.95 to 64.23 percent per 1 °C increase. The greatest estimated effect of water temperature was at the Scott River site, where it was the only factor supported. River discharge was supported as a factor affecting passage rate at five of the six sites, but the estimated effects were imprecise. The 95-percent confidence intervals of the slopes for river discharge overlapped zero in three of five cases and predicted effects were in opposite directions in the other two cases. Overall, the results of this study are consistent with the theory that season of migration is indicated by photoperiod and the rate of migration is driven primarily by changes in water temperature. There was no consistent effect of river discharge on passage rates supported by the data and models downstream from the Shasta River site.

Migration timing and passage rates differed between hatchery and wild fish, but survival was similar between origins. In 2006, the hatchery fish passed the Shasta River site at later dates than the wild fish released on the same dates and the effects of discharge, water temperature, and photoperiod were greatest in wild fish. This could be due to a fundamental difference between hatchery and wild fish, but we believe it is likely a result of the method and location of fish capture. Hatchery fish were taken directly from a tank at the hatchery and wild fish were captured in a rotary screw trap in a nearby tributary. The fish from the rotary screw trap were, by means of the capture method and location, taken from a group of migrants, whereas those from the hatchery tank were not. In addition, the travel times of hatchery fish were similar to those of wild fish in reaches downstream of the Shasta River site, indicating that once they began to migrate their rate was similar to wild fish. This is not a direct comparison, however, because the delay in migration of hatchery fish (most notably prior to mid-May in each year) resulted in their passage through the downstream reaches at a later date that the wild fish and therefore potentially under different environmental conditions. In 2009, the hatchery fish migrated sooner after release than the wild fish, but the wild fish were from a different source than in 2006 and the hatchery fish were nearly twice their size.

The survivals of hatchery and wild fish were similar in each year despite the differences in migration characteristics and fish sources. Results from 2009 indicated that the factors examined did not affect survival in most reaches, so the evaluation of the effects of covariates on survival of hatchery and wild fish was based on data from 2006. In 2006, water temperature was supported as a factor affecting survival in the release to Shasta River reach, but none of the factors were supported in reaches farther downstream. A difference in the relation between survival and river discharge based on fish origin was not clearly supported, because the models based on differences between origins were no more supported than a model based on no effect of discharge at all. The data and models from 2006 strongly supported an effect of water temperature on survival in the release to Shasta River reach, but were equivocal about differences between hatchery and wild fish. This supports the use of hatchery fish as surrogates for wild fish in studies of factors affecting survival in the lower Klamath River. However, the data and models moderately supported a short-term post-release mortality in wild fish, suggesting that use of hatchery fish as surrogates for wild fish in studies of survival may be biased in areas near the release site. As a general practice using the specific fish of interest, if available, is preferable to using surrogates.

This study was conducted prior to the recent Klamath Basin Restoration Agreement and potential for removing the lowermost four dams on the Klamath River, including IGD. Preliminary results from this study were used by Courter and others (2010) to estimate a smolt emigration scalar in a life cycle model of coho salmon in the Klamath River Basin. They used coefficients of the effects of water temperature and discharge on survival that are consistent with those presented in this report. One concern with the current data is the relatively low survival in the reaches upstream of the Scott River, which could be viewed as a bottleneck to smolt survival even if dams are removed (Ian Courter, Cramer Fish Sciences, and Josh Strange, Yurok Tribal

Fisheries Department, oral commun., 2011). As previously discussed, we were unable to determine if the estimated survival in this area was negatively biased by a short-term tag or handling effect. We estimated a potential short-term negative bias of 0.267 per 100 km for wild fish and 0.031 per 100 km for hatchery fish. If IGD is removed, estimates of survival based on fish released farther upstream of Iron Gate Fish Hatchery could be used to determine if the current estimates of survival in the reaches upstream of the Scott River are biased.

In summary, the survival of juvenile coho salmon migrating seaward in the Klamath River downstream of IGD was similar or greater than survival of juvenile salmonids in several other regulated river systems. Survival was lowest in the reaches nearest the release site at Iron Gate Hatchery. We were unable to definitively determine if this was due to greater mortality pressures in that area, a short-term effect of tagging or handling, or both. Data from wild fish moderately support a short-term tag or handling effect, but data from hatchery fish do not. Travel times were longest in the reach fish were released in and passage at the terminus of that reach, the Shasta River site, was affected primarily by release date and water temperature. The factors examined had little effect on rates of passage at sites downstream of the Shasta River site. Fish survival in the reach upstream of the Shasta River site was positively related to water temperature, river discharge, and fish weight. The increase in survival in the release to Shasta River reach with each 1 °C increase in water temperature was 1.4 times the effect of a 100 ft^3/s increase in river discharge and 2.5 times the effect of a 1 g increase in fish weight, and the effects of discharge and weight diminished at higher water temperatures up to the 17.91°C maximum present in the data examined. The results of this study indicate that increasing discharge at IGD can increase survival upstream of the Shasta River, but the effect would be small relative to seasonal increases in water temperature. The greatest survival benefit of higher discharge would be when water temperatures are low, which in this study generally were prior to May, although the low passage rates during this time suggest that the benefit to survival is not from faster downstream migration, but through other mechanisms. Survival of hatchery and wild fish were similar, despite differences in migration timing and rates. This study provides estimates of survival of juvenile coho salmon in the lower Klamath River, estimates of the effects of selected covariates on their passage rates and survival, and supports using hatchery yearling coho salmon as surrogates for the limited supply of wild yearling coho salmon in studies of fish survival. However, origin-specific differences in migration behavior suggest that hatchery fish should not be used as surrogates for wild fish in studies of migration rates or timing shortly after release.

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References Cited

Adams, N.A., Rondorf, D.W., Evans, S.D., Kelly, J.E., and Perry, R.W., 1998, Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*): Canadian Journal of Fisheries and Aquatic Sciences, v. 55, p. 781-787.

Allison, P.D., 1995, Survival Analysis Using SAS®: A Practical Guide: SAS Institute Inc., Cary, North Carolina, 292 p.

Bartholomew, J.L., Atkinson, S.D., and Hallett, S.L., 2006, Involvement of *Manayunkia speciosa* (Annelida: Polychaeta: Sabellidae) in the life cycle of *Parvicapsula minibicornis*, a myxozoan parasite of pacific salmon: Journal of Parasitology, v. 92, p. 742-748.

Barton, B.A., Schreck, C.B., Ewing, R.D., Hemmingsen, A.R., and Patino, R., 1985, Changes in plasma cortisol during stress and smoltification in coho salmon, *Oncorhynchus kisutch*: General and Comparative Endocrinology v. 59, p. 468-471.

Beeman, J.W., 2007, Summary of survival data from juvenile coho salmon in the Klamath River, northern California, 2006: U.S. Geological Survey Open-File Report 2007-1023, 6 p. (Available at http://pubs.er.usgs.gov/publication/ofr20071023.)

Beeman, J.W., 2008, Summary of survival data from juvenile coho salmon in the Klamath River, northern California, 2007: U.S. Geological Survey Open-File Report 2008-1022, 5 p. (Available at http://pubs.er.usgs.gov/publication/ofr20081022.)

Beeman, J.W., Braatz, A.C., Hansel, H.C., Fielding, S.D., Haner, P.V., Hansen, G.S., Shurtleff, D.J., Sprando, J.M., and Rondorf, D.W., 2010, Approach, passage, and survival of juvenile salmonids at Little Goose Dam, Washington: Post-construction evaluation of a temporary spillway weir, 2009: U.S. Geological Survey Open-File Report 2010-1224, 100 p. (Available at http://pubs.er.usgs.gov/publication/ofr20101224.)

Beeman, J.W., Hansel, H., Juhnke, S., and Stutzer, G., 2009a, Summary of migration and survival data from radio-tagged juvenile coho salmon in the Trinity River, northern California, 2008: U.S. Geological Survey Open-File Report 2009-1092, 26 p. (Available at http://pubs.er.usgs.gov/publication/ofr20091092.)

Beeman, J.W., and Juhnke, S.D., 2009, Summary of survival data from juvenile coho salmon in the Klamath River, northern California, 2009: U.S. Geological Survey Open-File report 2009-1270, 8 p. (Available at http://pubs.er.usgs.gov/publication/ofr20091270.)

Beeman, J.W., Juhnke, S.D., and Hansel, H.C., 2009b, Summary of survival data from juvenile coho salmon in the Klamath River, northern California, 2008: U.S. Geological Survey Open-File Report 2009-1019, 6 p. (Available at http://pubs.er.usgs.gov/publication/ofr20091019.)

Beeman, J.W., Juhnke, S., Stutzer, G., and Hetrick, N., 2008, Survival and migration behavior of juvenile coho salmon in the Klamath River relative to discharge at Iron Gate Dam, 2007: U.S. Geological Survey Open-File Report 2008-1332, 72 p. (Available at http://pubs.er.usgs.gov/publication/ofr20081332.)

Beeman, J.W., Kock, T.J., Perry, R.W., and Smith, S.G., 2011, Analysis of dam-passage survival of yearling and subyearling Chinook salmon and juvenile steelhead at The Dalles Dam, Oregon, 2010: U.S. Geological Survey Open-File Report 2011-1162, 38 p. (Available at http://pubs.er.usgs.gov/publication/ofr20111162.)

Beeman, J.W., Stutzer, G.M., Juhnke, S.D., and Hetrick, N.J., 2007, Survival and migration behavior of juvenile coho salmon in the Klamath River relative to discharge at Iron Gate Dam, 2006: Final report prepared by U.S. Geological Survey, Cook, Washington and U.S. Fish and Wildlife Service, Arcata, California for the Bureau of Reclamation, Mid-Pacific Region, Klamath Basin Area Office, 06AA204092 and 07AA200181, Klamath Falls, Oregon.

Belsley, D.A., Kuh, E., and Welsch, R.E., 1980, Regression Diagnostics: New York, John Wiley and Sons, 292 p.

Berggren, T.J., and Filardo, M.J., 1993, An analysis of variables influencing the migration of juvenile salmonids in the Columbia River Basin: North American Journal of Fisheries Management, v. 13, p. 48-63.

Brown, L.R., Moyle, P.B., and Yoshiyama, R.M., 1994, Historical decline and current status of coho salmon in California: North American Journal of Fisheries Management, v. 14, p. 237-261.

Burnham, K.P., and Anderson D.R., 2002, Model selection and multimodel inference: A practical information-theoretic approach, second edition: New York, Springer Verlag, 488 p.

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C., and Pollock, K.H., 1987, Design and analysis methods for fish survival experiments based on release-recapture: American Fisheries Society, Monograph 5, Bethesda, Maryland, 437 p.

Cada, G.F., Deacon, M.D., Mitz, S.V., and Bevelhimer, M.S., 1997, Effects of water velocity on the survival of downstream-migrating juvenile salmon and steelhead: a review with emphasis on the Columbia River basin: Reviews in Fisheries Science, v. 5, p. 131-183.

California Department of Fish and Game, 2002, Status Review of California Coho Salmon North of San Francisco: Report to the California Fish and Game Commission, April 2002, 336 p.

Castro-Santos, T., and Haro, A., 2003, Quantifying migratory delay: a new application of survival analysis methods: Canadian Journal of Fisheries and Aquatic Sciences, v. 60, p. 986-996.

Clements, S., and Schreck, C.B., 2003, Juvenile salmonid survival in specific areas of the Nehalem watershed: Annual report OWEB, Salem, Oregon.

Collis, K., Beatty, R.E., and Crain, B.R., 2005, Changes in catch rate and diet of Northern Squawfish associated with the release of hatchery-reared juvenile salmonids in a Columbia River reservoir: North American Journal of Fisheries Management, v. 15, p. 346-357.

Cooch, E., and White, G., 2006, Program Mark: A gentle introduction, 5th Edition, accessed March 19, 2012, at http://www.phidot.org/software/mark/docs/book/.

Connor, W.P., Burge, H.L., Yearsley, J.R., and Bjornn, T.C., 2003, Influences of flow and temperature on survival of wild subyearling fall Chinook salmon in the Snake River: North American journal of Fisheries Management, v. 23, p. 362-375.

Cormack, R.M., 1964, Estimates of survival from the sighting of marked animals: Biometrika, v. 51, p. 429-438.

Courter, I., Teply, M., Jayasundara, N., Limanto, E., and Deas, M., 2010, Klamath coho integrated modeling framework version 1.4, Analysis summary prepared for the Secretarial Determination Expert Panel on Coho Salmon and Steelhead: Draft Report of Cramer Fish Sciences to Bureau of Reclamation, contract R09PX20070/0001, Klamath Falls, Oregon, 53 p.

Faler, M.P., Miller, L.M., and Welke, K.I., 1988, Effects on variation in flow on distributions of northern squawfish in the Columbia River below McNary Dam: North American Journal of Fisheries Management, v. 8, p. 30–35.

Federal Register, 1997, Final Rule. Endangered and threatened species: Threatened status for Southern Oregon/Northern California Coast evolutionarily significant unit (ESU) of coho salmon, May 5, 1997, v. 62, no. 87, p. 24588-24609.

Frissell, C.A., 1993, Topology of extinction and endangerment of native fishes in the Pacific Northwest and California (U.S.A.): Conservation Biology, v. 7, p. 342-345.

Giorgi, A.E., Hillman, T.W., Stevenson, J.R., Hays, S.G., and Peven, C.M., 1997, Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the mid-Columbia River Basin: North American Journal of Fisheries Management, v. 17, p. 268-282.

Hockersmith, E.E., Muir, W.D., Smith, S.G., Sandford, B.P., Perry, R.W., Noah, N.A., and Rondorf, D.W., 2003, Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling Chinook salmon in the Snake and Columbia Rivers: North American Journal of Fisheries Management, v. 23, p. 404-413.

Hockersmith, E.E., Smith, S. G., Muir, W.D., Sandford, B. P., and Williams, J.G., 1999, survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1997: Report to U.S. Department of Energy, Bonneville Power Administration, Contract DE-AI79-93BP10891, Project 93-029, 69 p.

Hosmer, D.W., and Lemeshow, S., 1999, Applied survival analysis: Regression modeling of time to event data: New York, John Wiley and Sons, Inc., 386 p.

Jolly, G.M., 1965, Explicit estimates from capture-recapture data with both death and immigration-stochastic model: Biometrika, v. 52, p. 225-247.

Jonsson, N., 1991, Influence of water flow, water temperature, and light in fish migration in rivers: Nordic Journal of Freshwater Research, v. 66, p. 20-35.

Jonsson, B., and Ruud-Hansen, J., 1985, Water temperature as the primary influence on timing of seaward migrations of Atlantic salmon (*Salmo salar*) smolts: Journal of the Fisheries Research Board of Canada, v. 42, p. 593-595.

Lacroix, G.L., and McCurdy, P., 1996, Migratory behavior of post-smolt Atlantic salmon during initial stages of seaward migration: Journal of Fish Biology, v. 49, p. 1086-1101.

Laufle, J.C., Pauley, G.B., and Shepard, M.F., 1986, Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) - coho salmon. 82(11.48): U.S. Army Corps of Engineers, TR EL-82-4, 18 p.

Marine, K.R., and Cech, J.J, Jr., 2004, Effects of high water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook salmon: North American Journal of Fisheries Management, v. 24, p. 198-210.

McCleave, J.D., 1978, Rhythmic aspects of estuarine migration of hatchery-reared Atlantic salmon (*Salmo salar*) smolts: Journal of Fish Biology, v. 12, p. 559-570.

Mesa, M.M., 1994, Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile Chinook salmon: Transactions of the American Fisheries Society, v. 123, p. 786-793.

Miller, B.A., and Sadro, S., 2003, Residence time and seasonal movements of juvenile coho salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon: Transactions of the American Fisheries Society, v. 132, p. 546-559.

Muenchow, G., 1986, Ecological use of failure time analysis: Ecology, v. 67, p. 246-250.

Muir, W.D., Zaugg, W.S., Giorgi, A.E., and McCutcheon, S., 1994, Accelerating smolt development and downstream movement in yearling Chinook salmon with advanced photoperiod and increased temperature: Aquaculture, v. 123, p. 387-399.

National Marine Fisheries Service, 2002, Biological Opinion, Klamath Project operations. Report prepared by the National Marine Fisheries Service on May 31, 2002, 107 p.

National Research Council, 2001, Endangered and threatened fishes in the Klamath River Basin: cause for decline and strategies for recovery: Washington, D.C., The National Academies Press, 358 p.

Nehlsen, W., Williams, J.E., and Lichatowich, J.A., 1991, Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington: Fisheries, v. 16, p. 4-21.

Olla, B.L., Davis, M.W., and Schreck, C.B., 1992, Comparison of predator avoidance capabilities with corticosteroid levels induced by stress in juvenile coho salmon: Transactions of the American Fisheries Society, v. 121, p. 544-547.

Perry, R.W., Risley, J.C., Brewer, S.J., Jones, E.C., and Rondorf, D.W., 2011, Simulating daily water temperatures of the Klamath River under dam removal and climate change scenarios: U.S. Geological Survey Open-File Report 2011-1243, 78 p. (Available at http://pubs.er.usgs.gov/publication/ofr20111243.)

Perry, R.W., Skalski, J.R., Brandes, P.L., Sandstrom, P.T., Klimley, A.P., Ammann, A., and MacFarlane, B., 2010, Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento-San Joaquin River delta: North American Journal of Fisheries Management, v. 30, p. 142-156.

Peven, C., Giorgi, A., Skalski, J., Langeslay, M., Grassell, A., Smith, S.G., Counihan, T., Perry, R., and Bickford, S., 2005, Guidelines and recommended protocols for conducting, analyzing, and reporting juvenile salmonid survival studies in the Columbia River Basin: Report to the U.S. Army Corps of Engineers, Portland, Oregon, 88 p.

Pyke, D.A., and Thompson, J.N., 1986, Statistical analysis of survival and removal rate experiments: Ecology, v. 67, p. 240-245.

Rodgers, J.D., Ewing, R.D., and Hall, J.D., 1987, Physiological changes during seaward migration of wild juvenile coho salmon (*Oncorhynchus kisutch*): Canadian Journal of Fisheries and Aquatic Sciences, v. 44, p. 452-457.

Salonius, K., and Iwama, G.K., 1993, Effects of early rearing environment on stress response, immune function, and disease resistance in juvenile coho (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*): Canadian Journal of Fisheries and Aquatic Sciences, v. 50, p. 759-766.

Sandercock, F.K., 1998, Life history of coho salmon (*Oncorhynchus kisutch*),*in*, Groot, C., and Margolis, L., editors, Pacific salmon life histories: Vancouver, UBC Press, 396-446 p.

Seber, G.A.F., 1965, A note on the multiple-recapture census: Biometrika, v. 52, p. 249-259.

Seber, G.A.F., 1982, The estimation of animal abundance and related parameters: New York, Macmillan, 672 p.

Shively, R.S., Poe, T.P., and Sauter, S.T., 1996, Feeding response by Northern Squawfish to a hatchery release of juvenile salmonids in the Clearwater River, Idaho: Transactions of the American Fisheries Society, v. 125, p. 230-236.

Skalski, J.R., 2009, Statistical design for the lower Columbia River acoustic-tag investigations of dam-passage survival and associated metrics: Report to the U.S. Army Corps of Engineers, Portland, Oregon, 94 p.

Skalski, J.R., Lady, J., Townsend, R., Giorgi, A.E., Stevenson, J.R., Peven, C.M., and McDonald, R.D., 2001, Estimating in-river survival of migrating salmonid smolts using radiotelemetry: Canadian Journal of Fish and Aquatic Sciences, v. 58, p. 1987-1997.

Skalski, J.R., Townsend, R., Lady, J., Giorgi, A.E., Stevenson, J.R., and McDonald, R.D., 2002, Estimating route-specific passage and survival probabilities at a hydroelectric project from smolt radio-telemetry studies: Canadian Journal of Fisheries and Aquatic Sciences, v. 59, p. 1385-1393.

Smith, S.G., Muir, W.D., Hockersmith, E.E., Zabel, R.W., Graves, R.J., Ross, C.V., Connor, W.P., and Arnsberg, B.D., 2003, Influence of river conditions on survival and travel time of Snake River subyearling fall Chinook salmon: North American Journal of Fisheries Management, v. 23, p. 939-961.

Smith, S.G., Muir, W.D., and Williams, J.G., 2002, Factors associated with travel time and survival of migrant yearling Chinook salmon and steelhead in the lower Snake River: North American Journal of Fisheries Management, v. 22, p. 385-405.

Specker, J.L., and Schreck, C.B., 1982, Changes in plasma corticosteroids during smoltification of coho salmon, *Oncorhynchus kisutch*: General and Comparative Endocrinology, v. 46, p. 53-58.

Stutzer, G.M., Ogawa, J., Hetrick, N.J., and Shaw, T., 2006, An initial assessment of radio telemetry for estimating juvenile coho salmon survival, migration behavior, and habitat use in response to Iron Gate Dam discharge on the Klamath River, California: U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR2006-05, Arcata, California, 57 p.

Sutton, R., and Soto, T., 2010, Juvenile coho salmon behavioral characteristics in Klamath River summer refugia: River research and Applications, Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/rra.1459.

Swain, D.P., Ridell, B.E., and Murray, C.B., 1991, Morphological differences between hatchery and wild populations of coho salmon (*Oncorhynchus kisutch*): Environmental versus genetic origin: Canadian Journal of Fisheries and Aquatic Sciences, v. 48, p. 1783-1791.

Sykes, J.E., Johnson, C.J., and Shrimpton, J.M., 2009, Temperature and flow effects on migration timing of Chinook salmon smolts: Transactions of the American Fisheries Society, v. 138, p. 1252-1265.

Underwood, K., Langendorf, H.D., Diviney, C., Debrick, A., Daniels, S., Crombie, W.B., and Chesney, W.R., 2010, Final report Shasta and Scott River juvenile salmonid outmigration monitoring project: Report prepared by California Department of Fish and Game for Pacific States Marine Fisheries Commission, Contract 09-62, 79 p.

Weitkamp, L.A., Wainwright, T.C., Bryant, G.J., Milner, G.B., Teel, D.J., Kope, R.G., and Waples, R.S., 1995, Status review of coho salmon from Washington, Oregon, and California: U.S. Department of Commerce, NOAA Technical Memo, NMFS-NWFSC-24, 258 p.

White, G.C., and Burnham, K.P., 1999, Program MARK: survival estimation from populations of marked animals: Bird Study v. 46 Supplement, p. 120-138.

Williams, J.G., Smith, S.G. , Zabel, R.W., Muir, W.D., Scheuerell, M.D., Sandford, B.P., Marsh, D.M. , McNatt, R.A., and Achord, S., 2005, Effects of the federal Columbia River power system on salmonid populations: U.S. Department of Commerce, NOAA Technical Memo NMFS-NWFSC-63, 150 p.

Appendix A. Summary of number of fish released on each date used in analyses of migration and survival of hatchery fish, lower Klamath River, northern California, 2006–09.

[Fish were from a tank at Iron Gate Hatchery]

Date	Year			
	2006	2007	2008	2009
4/4	8	0	0	0
4/10	0	6	0	0
4/11	0	6	0	0
4/12	0	5	0	0
4/13	0	5	0	0
4/14	9	0	0	0
4/17	0	6	7	0
4/18	9	6	7	0
4/19	0	5	7	0
4/20	0	5	0	0
4/21	9	0	0	0
4/24	0	6	15	0
4/25	9	6	6	11
4/26	0	5	7	0
4/27	0	5	0	0
4/28	8	0	0	0
5/1	0	6	13	12
5/2	9	6	6	11
5/3	0	5	7	0
5/4	0	5	0	0
5/5	8	0	0	0
5/7	0	0	16	0
5/8	0	6	17	12
5/9	9	6	16	11
5/10	0	5	17	0
5/11	0	5	0	0
5/12	10	0	0	0
5/14	0	0	16	0
5/15	0	6	17	8
5/16	10	7	16	8
5/17	0	0	5	0
5/22	0	0	12	22
5/23	0	0	14	23
5/24	16	0	0	0
5/29	0	0	0	19
5/30	0	0	0	24
6/5	0	0	0	14
Total	114	123	221	175

Appendix B. Correlation matrices of variables considered for use in analyses of passage rates of hatchery fish, lower Klamath River, northern California, 2006–09.

Table B1. Correlation matrix from data at the Shasta River site.

[The first row of data are Pearson correlation coefficients (r) and the second row are probabilities of a greater r under the hypothesis that r is zero. Date is date of reach entry, dayofyear is calendar date, and event time is the date and time of site passage. Sample size is 6,515 observations due to the counting-process style data format for migration analysis]

	discharge	temp	photo	date	atu	dayofyear	atpase	wt	event time
discharge	1.0000	-0.3243	-0.4177	-0.3224	-0.5299	-0.4084	-0.1208	-0.2313	0.1078
		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
temp		1.0000	0.8755	0.6057	0.8697	0.8672	-0.0739	-0.0057	-0.3002
			<.0001	<.0001	<.0001	<.0001	<.0001	0.6430	<.0001
photo			1.0000	0.7225	0.9426	0.9966	-0.2306	0.0391	-0.2995
				<.0001	<.0001	<.0001	<.0001	0.0016	<.0001
date				1.0000	0.5919	0.7265	-0.2429	0.1516	-0.7158
					<.0001	<.0001	<.0001	<.0001	<.0001
atu					1.0000	0.9465	-0.0627	0.0410	-0.1978
						<.0001	<.0001	0.0009	<.0001
dayofyear						1.0000	-0.2358	0.0399	-0.2926
							<.0001	0.0013	<.0001
atpase							1.0000	0.0005	0.0469
								0.9662	0.0002
wt								1.0000	-0.2588
									<.0001

Table B2. Correlation matrix from data at the Scott River site.

[The first row of data are Pearson correlation coefficients (r) and the second row are probabilities of a greater r under the hypothesis that r is zero. Date is date of reach entry, dayofyear is calendar date, and event time is the date and time of site passage. Sample size is 2,242 observations due to the counting-process style data format for migration analysis]

	discharge	temp	photo	date	atu	dayofyear	atpase	wt	event time
discharge	1.0000	-0.1027	-0.1688	-0.1674	-0.3239	-0.1648	-0.1475	-0.2280	0.0435
		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0393
temp		1.0000	0.8338	0.5957	0.8165	0.8100	-0.2186	-0.1090	-0.5983
			<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
photo			1.0000	0.7197	0.9425	0.9947	-0.2773	-0.0622	-0.6277
				<.0001	<.0001	<.0001	<.0001	0.0032	<.0001
date				1.0000	0.5846	0.7245	-0.2361	0.0249	-0.5637
					<.0001	<.0001	<.0001	0.2385	<.0001
atu					1.0000	0.9483	-0.1877	-0.0701	-0.5631
						<.0001	<.0001	0.0009	<.0001
dayofyear						1.0000	-0.2886	-0.0672	-0.6163
							<.0001	0.0015	<.0001
atpase							1.0000	0.0704	0.2455
								0.0009	<.0001
wt								1.0000	-0.0185
									0.3815

Table B3. Correlation matrix from data at the Indian Creek site.

[The first row of data are Pearson correlation coefficients (r) and the second row are probabilities of a greater r under the hypothesis that r is zero. Date is date of reach entry, dayofyear is calendar date, and event time is the date and time of site passage. Sample size is 1,131 observations due to the counting-process style data format for migration analysis]

	discharge	temp	photo	date	atu	dayofyear	atpase	wt	event time
discharge	1.0000	-0.4380	-0.2192	-0.2020	-0.4053	-0.2047	-0.1319	-0.1589	0.3445
		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
temp		1.0000	0.2124	0.3007	0.3445	0.1640	0.1168	0.0190	-0.1614
			<.0001	<.0001	<.0001	<.0001	<.0001	0.5231	<.0001
photo			1.0000	0.6540	0.8866	0.9861	-0.2756	-0.0193	0.2069
				<.0001	<.0001	<.0001	<.0001	0.5171	<.0001
date				1.0000	0.4076	0.6318	-0.2276	0.1459	0.1816
					<.0001	<.0001	<.0001	<.0001	<.0001
atu					1.0000	0.8971	-0.0903	-0.0468	0.0988
						<.0001	0.0024	0.1154	0.0009
dayofyear						1.0000	-0.2797	-0.0024	0.2377
							<.0001	0.9359	<.0001
atpase							1.0000	-0.0706	-0.2100
								0.0176	<.0001
wt								1.0000	0.0337
									0.2569

Table B4. Correlation matrix from data at the Salmon River site.

[The first row of data are Pearson correlation coefficients (r) and the second row are probabilities of a greater r under the hypothesis that r is zero. Date is date of reach entry, dayofyear is calendar date, and event time is the date and time of site passage. Sample size is 1,137 observations due to the counting-process style data format for migration analysis]

	discharge	temp	photo	date	atu	dayofyear	atpase	wt	event time
discharge	1.0000	-0.6619	-0.2887	-0.3143	-0.4680	-0.3009	-0.0631	-0.1830	-0.1422
		<.0001	<.0001	<.0001	<.0001	<.0001	0.0333	<.0001	<.0001
temp		1.0000	0.3866	0.4553	0.5933	0.4388	0.0423	0.0811	0.1087
			<.0001	<.0001	<.0001	<.0001	0.1538	0.0062	0.0002
photo			1.0000	0.6682	0.8072	0.9194	-0.3648	-0.0192	0.2295
				<.0001	<.0001	<.0001	<.0001	0.5182	<.0001
date				1.0000	0.4791	0.6279	-0.2786	0.1958	0.1434
					<.0001	<.0001	<.0001	<.0001	<.0001
atu					1.0000	0.9310	-0.1649	0.0922	0.4294
						<.0001	<.0001	0.0019	<.0001
dayofyear						1.0000	-0.3210	0.0858	0.4254
							<.0001	0.0038	<.0001
atpase							1.0000	-0.0775	-0.1732
								0.0090	<.0001
wt								1.0000	0.4475
									<.0001

Table B5. Correlation matrix from data at the Trinity River site.

[The first row of data are Pearson correlation coefficients (r) and the second row are probabilities of a greater r under the hypothesis that r is zero. Date is date of reach entry, dayofyear is calendar date, and event time is the date and time of site passage. Sample size is 714 observations due to the counting-process style data format for migration analysis]

	discharge	temp	photo	date	atu	dayofyear	atpase	wt	event time
discharge	1.0000	-0.6592	-0.3660	-0.3225	-0.5374	-0.3461	-0.0023	-0.0446	-0.0977
		<.0001	<.0001	<.0001	<.0001	<.0001	0.9505	0.2344	0.0090
temp		1.0000	0.2153	0.3113	0.4396	0.2068	0.0689	-0.0742	0.1052
			<.0001	<.0001	<.0001	<.0001	0.0658	0.0475	0.0049
photo			1.0000	0.6342	0.8387	0.9460	-0.4401	-0.1294	0.3476
				<.0001	<.0001	<.0001	<.0001	0.0005	<.0001
date				1.0000	0.3921	0.5549	-0.2998	0.0977	0.0823
					<.0001	<.0001	<.0001	0.0090	0.0279
atu					1.0000	0.9158	-0.2797	-0.1942	0.5358
						<.0001	<.0001	<.0001	<.0001
dayofyear						1.0000	-0.4338	-0.1196	0.5352
							<.0001	0.0014	<.0001
atpase							1.0000	-0.0147	-0.2278
								0.6943	<.0001
wt								1.0000	0.0046
									0.9024

Table B6. Correlation matrix from data at the Steelhead Lodge.

[The first row of data are Pearson correlation coefficients (r) and the second row are probabilities of a greater r under the hypothesis that r is zero. Date is date of reach entry, dayofyear is calendar date, and event time is the date and time of site passage. Sample size is 777 observations due to the counting-process style data format for migration analysis]

	discharge	temp	photo	date	atu	dayofyear	atpase	wt	event time
discharge	1.0000	-0.6467	-0.3674	-0.3489	-0.5705	-0.3538	-0.1121	-0.1719	-0.1190
		<.0001	<.0001	<.0001	<.0001	<.0001	0.0018	<.0001	0.0009
temp		1.0000	0.2950	0.3815	0.5593	0.2793	0.0553	0.0022	0.0550
			<.0001	<.0001	<.0001	<.0001	0.1233	0.9513	0.1259
photo			1.0000	0.6074	0.8533	0.9726	-0.3969	-0.0774	0.2606
				<.0001	<.0001	<.0001	<.0001	0.0311	<.0001
date				1.0000	0.4314	0.5939	-0.2098	0.1090	0.0735
					<.0001	<.0001	<.0001	0.0024	0.0406
atu					1.0000	0.8725	-0.1990	-0.1315	0.2896
						<.0001	<.0001	0.0002	<.0001
dayofyear						1.0000	-0.3920	-0.0807	0.3297
							<.0001	0.0245	<.0001
atpase							1.0000	0.0654	-0.2163
								0.0686	<.0001
wt								1.0000	0.0998
									0.0054

Appendix C. Model selection results from 24 models of passage rates of hatchery fish, lower Klamath River, northern California, 2006–09.

Table C1. Model selection results from passage rate data at the Shasta River site.
[Models in the top 95 percent of AIC weight were used to estimate model-averaged slope coefficients for the covariates they contained. AIC=Akaike Information Criterion; K=number of model parameters]

Model No.	AIC	Delta AIC	AIC weight	Model likelihood	K	Deviance	Sum of AIC weight
19	5,325.189	0.000	0.433	1.000	3	5,319.189	0.433
10	5,325.564	0.375	0.359	0.829	2	5,321.564	0.791
21	5,327.327	2.138	0.149	0.343	3	5,321.327	0.940
22	5,330.926	5.737	0.025	0.057	3	5,324.926	0.964
5	5,331.349	6.160	0.020	0.046	1	5,329.349	0.984
9	5,332.308	7.119	0.012	0.028	2	5,328.308	0.997
14	5,332.380	7.191	0.000	([1])	2	5,328.380	0.997
16	5,335.853	10.664	0.002	0.005	2	5,331.853	0.999
4	5,338.410	13.221	0.001	0.001	1	5,336.410	0.999
17	5,338.817	13.628	0.000	0.001	2	5,334.817	1.000
11	5,340.169	14.980	0.000	0.001	2	5,336.169	1.000
6	5,345.019	19.829	0.000	0.000	1	5,343.019	1.000
8	5,346.817	21.628	0.000	0.000	2	5,342.817	1.000
20	5,347.619	22.430	0.000	0.000	3	5,341.619	1.000
15	5,357.227	32.038	0.000	0.000	2	5,353.227	1.000
3	5,359.079	33.890	0.000	0.000	1	5,357.079	1.000
13	5,575.372	250.183	0.000	0.000	2	5,571.372	1.000
23	5,576.604	251.415	0.000	([1])	3	5,570.604	1.000
24	5,577.856	252.667	0.000	([1])	4	5,569.856	1.000
1	5,584.870	259.681	0.000	0.000	1	5,582.870	1.000
18	5,585.995	260.806	0.000	0.000	2	5,581.995	1.000
2	5,590.599	265.410	0.000	0.000	1	5,588.599	1.000
12	5,592.522	267.333	0.000	([1])	2	5,588.522	1.000
7	5,610.480	285.290	0.000	0.000	1	5,608.480	1.000

[1]Model removed from consideration due to similar deviance and delta AIC ≤ 2 units from a similar model with one fewer parameters.

Table C2. Model selection results from passage rate data at the Scott River site.
[Models in the top 95 percent of AIC weight were used to estimate model-averaged slope coefficients for the covariates they contained. AIC=Akaike Information Criterion; K=number of model parameters]

Model No.	AIC	Delta AIC	AIC weight	Model likelihood	K	Deviance	Sum of AIC weight
3	5,325.189	0.000	0.994	1.000	1	5,319.189	0.994
8	5,325.564	1.211	0.000	([1])	2	5,321.564	0.994
15	5,327.327	1.828	0.000	([1])	2	5,321.327	0.994
20	5,330.926	3.160	0.000	([1])	3	5,324.926	0.994
21	5,331.349	11.730	0.003	0.003	3	5,329.349	0.997
16	5,332.308	13.027	0.001	0.001	2	5,328.308	0.998
6	5,332.380	13.953	0.001	0.001	1	5,328.380	0.999
11	5,335.853	14.113	0.001	0.001	2	5,331.853	1.000
4	5,338.410	21.172	0.000	0.000	1	5,336.410	1.000
9	5,338.817	21.769	0.000	0.000	2	5,334.817	1.000
17	5,340.169	23.022	0.000	([1])	2	5,336.169	1.000
22	5,345.019	23.753	0.000	([1])	3	5,343.019	1.000
14	5,346.817	214.709	0.000	0.000	2	5,342.817	1.000
19	5,347.619	216.487	0.000	0.000	3	5,341.619	1.000
5	5,357.227	216.954	0.000	0.000	1	5,353.227	1.000
10	5,359.079	218.954	0.000	([1])	2	5,357.079	1.000
18	5,575.372	226.190	0.000	0.000	2	5,571.372	1.000
1	5,576.604	227.189	0.000	0.000	1	5,570.604	1.000
23	5,577.856	227.911	0.000	0.000	3	5,569.856	1.000
13	5,584.870	228.829	0.000	([1])	2	5,582.870	1.000
24	5,585.995	229.890	0.000	([1])	4	5,581.995	1.000
7	5,590.599	233.635	0.000	0.000	1	5,588.599	1.000
2	5,592.522	235.416	0.000	0.000	1	5,588.522	1.000
12	5,610.480	235.602	0.000	([1])	2	5,608.480	1.000

[1]Model removed from consideration due to similar deviance and delta AIC ≤ 2 units from a similar model with one fewer parameters.

Table C3. Model selection results from passage rate data at the Indian Creek site.

[Models in the top 95 percent of AIC weight were used to estimate model-averaged slope coefficients for the covariates they contained. AIC=Akaike Information Criterion; K=number of model parameters]

Model No.	AIC	Delta AIC	AIC weight	Model likelihood	K	Deviance	Sum of AIC weight
14	3,895.021	0.000	0.711	1.000	2	3,891.021	0.711
19	3,896.819	1.798	0.289	0.407	3	3,890.819	1.000
18	3,919.982	24.962	0.000	0.000	2	3,915.982	1.000
17	3,920.997	25.977	0.000	0.000	2	3,916.997	1.000
1	3,921.280	26.260	0.000	0.000	1	3,919.280	1.000
23	3,921.653	26.633	0.000	0.000	3	3,915.653	1.000
22	3,922.183	27.162	0.000	0.000	3	3,916.183	1.000
15	3,922.396	27.375	0.000	0.000	2	3,918.396	1.000
13	3,922.714	27.693	0.000	([1])	2	3,918.714	1.000
16	3,922.900	27.880	0.000	0.000	2	3,918.900	1.000
24	3,923.440	28.420	0.000	([1])	4	3,915.440	1.000
20	3,923.923	28.903	0.000	([1])	3	3,917.923	1.000
21	3,924.157	29.136	0.000	([1])	3	3,918.157	1.000
5	3,926.177	31.156	0.000	0.000	1	3,924.177	1.000
10	3,928.116	33.095	0.000	([1])	2	3,924.116	1.000
3	3,933.805	38.784	0.000	0.000	1	3,931.805	1.000
8	3,935.778	40.758	0.000	([1])	2	3,931.778	1.000
7	3,938.901	43.880	0.000	0.000	1	3,936.901	1.000
6	3,940.478	45.457	0.000	0.000	1	3,938.478	1.000
12	3,940.896	45.876	0.000	([1])	2	3,936.896	1.000
11	3,942.478	47.457	0.000	([1])	2	3,938.478	1.000
4	3,943.115	48.095	0.000	0.000	1	3,941.115	1.000
2	3,943.120	48.100	0.000	0.000	1	3,941.120	1.000
9	3,945.097	50.076	0.000	([1])	2	3,941.097	1.000

[1]Model removed from consideration due to similar deviance and delta AIC ≤ 2 units from a similar model with one fewer parameters.

Table C4. Model selection results from passage rate data at the Salmon River site.

[Models in the top 95 percent of AIC weight were used to estimate model-averaged slope coefficients for the covariates they contained. AIC=Akaike Information Criterion; K=number of model parameters]

Model No.	AIC	Delta AIC	AIC weight	Model likelihood	K	Deviance	Sum of AIC weight
20	3,455.768	0.000	0.625	1.000	3	3,449.768	0.625
8	3,457.149	1.381	0.313	0.501	2	3,453.149	0.938
12	3,461.174	5.406	0.042	0.067	2	3,457.174	0.980
23	3,462.583	6.816	0.000	([1])	3	3,456.583	0.980
24	3,464.356	8.589	0.000	([1])	4	3,456.356	0.980
15	3,465.205	9.437	0.006	0.009	2	3,461.205	0.986
21	3,466.535	10.767	0.003	0.005	3	3,460.535	0.989
19	3,467.101	11.333	0.002	0.003	3	3,461.101	0.991
10	3,467.433	11.665	0.002	0.003	2	3,463.433	0.993
2	3,467.859	12.091	0.001	0.002	1	3,465.859	0.994
11	3,468.065	12.298	0.001	0.002	2	3,464.065	0.996
3	3,468.385	12.617	0.001	0.002	1	3,466.385	0.997
9	3,468.531	12.763	0.001	0.002	2	3,464.531	0.998
22	3,468.642	12.874	0.001	0.002	3	3,462.642	0.999
13	3,468.755	12.988	0.001	0.002	2	3,464.755	1.000
7	3,471.560	15.792	0.000	0.000	1	3,469.560	1.000
18	3,473.396	17.628	0.000	([1])	2	3,469.396	1.000
5	3,476.592	20.824	0.000	0.000	1	3,474.592	1.000
14	3,476.938	21.171	0.000	0.000	2	3,472.938	1.000
6	3,479.956	24.188	0.000	0.000	1	3,477.956	1.000
4	3,480.231	24.463	0.000	0.000	1	3,478.231	1.000
1	3,480.266	24.498	0.000	0.000	1	3,478.266	1.000
16	3,480.752	24.984	0.000	0.000	2	3,476.752	1.000
17	3,481.577	25.809	0.000	([1])	2	3,477.577	1.000

[1]Model removed from consideration due to similar deviance and delta AIC ≤ 2 units from a similar model with one fewer parameters.

Table C5. Model selection results from passage rate data at the Trinity River site.

[Models in the top 95 percent of AIC weight were used to estimate model-averaged slope coefficients for the covariates they contained. AIC=Akaike Information Criterion; K=number of model parameters]

Model No.	AIC	Delta AIC	AIC weight	Model likelihood	K	Deviance	Sum of AIC weight
21	3,272.094	0.000	0.621	1.000	3	3,266.094	0.621
11	3,273.352	1.257	0.331	0.533	2	3,269.352	0.953
9	3,278.028	5.933	0.032	0.051	2	3,274.028	0.985
24	3,279.677	7.583	0.014	0.023	4	3,271.677	0.999
22	3,280.026	7.932	0.000	([1])	3	3,274.026	0.999
23	3,286.580	14.486	0.000	0.001	3	3,280.580	0.999
12	3,287.475	15.381	0.000	0.000	2	3,283.475	1.000
6	3,288.370	16.275	0.000	0.000	1	3,286.370	1.000
16	3,289.571	17.477	0.000	([1])	2	3,285.571	1.000
4	3,289.726	17.632	0.000	0.000	1	3,287.726	1.000
10	3,290.757	18.662	0.000	0.000	2	3,286.757	1.000
17	3,291.653	19.558	0.000	([1])	2	3,287.653	1.000
19	3,291.853	19.759	0.000	([1])	3	3,285.853	1.000
20	3,292.770	20.675	0.000	0.000	3	3,286.770	1.000
18	3,293.231	21.137	0.000	0.000	2	3,289.231	1.000
7	3,294.052	21.958	0.000	0.000	1	3,292.052	1.000
13	3,295.229	23.135	0.000	0.000	2	3,291.229	1.000
2	3,296.441	24.346	0.000	0.000	1	3,294.441	1.000
5	3,296.533	24.438	0.000	0.000	1	3,294.533	1.000
15	3,297.480	25.386	0.000	0.000	2	3,293.480	1.000
14	3,297.814	25.720	0.000	([1])	2	3,293.814	1.000
8	3,298.215	26.121	0.000	([1])	2	3,294.215	1.000
1	3,301.931	29.837	0.000	0.000	1	3,299.931	1.000
3	3,304.322	32.227	0.000	0.000	1	3,302.322	1.000

[1]Model removed from consideration due to similar deviance and delta AIC ≤ 2 units from a similar model with one fewer parameters.

Table C6. Model selection results from passage rate data at the Steelhead Lodge site.

[Models in the top 95 percent of AIC weight were used to estimate model-averaged slope coefficients for the covariates they contained. AIC=Akaike Information Criterion; K=number of model parameters]

Model No.	AIC	Delta AIC	AIC weight	Model likelihood	K	Deviance	Sum of AIC weight
15	3,047.538	0.000	0.614	1.000	2	3,043.538	0.614
20	3,048.911	1.373	0.309	0.503	3	3,042.911	0.923
3	3,052.995	5.457	0.040	0.065	1	3,050.995	0.963
8	3,053.545	6.007	0.030	0.050	2	3,049.545	0.994
2	3,059.958	12.419	0.001	0.002	1	3,057.958	0.995
5	3,060.362	12.824	0.001	0.002	1	3,058.362	0.996
7	3,060.532	12.994	0.001	0.002	1	3,058.532	0.997
10	3,060.711	13.172	0.001	0.001	2	3,056.711	0.998
12	3,060.960	13.422	0.000	([1])	2	3,056.960	0.998
4	3,061.003	13.465	0.001	0.001	1	3,059.003	0.998
6	3,061.216	13.678	0.001	0.001	1	3,059.216	0.999
1	3,061.236	13.697	0.001	0.001	1	3,059.236	1.000
11	3,061.608	14.070	0.000	([1])	2	3,057.608	1.000
9	3,061.779	14.241	0.000	([1])	2	3,057.779	1.000
14	3,061.845	14.307	0.000	([1])	2	3,057.845	1.000
13	3,061.933	14.395	0.000	([1])	2	3,057.933	1.000
18	3,062.309	14.771	0.000	([1])	2	3,058.309	1.000
19	3,062.364	14.825	0.000	([1])	3	3,056.364	1.000
17	3,062.723	15.185	0.000	([1])	2	3,058.723	1.000
23	3,062.855	15.316	0.000	([1])	3	3,056.855	1.000
16	3,063.195	15.657	0.000	([1])	2	3,059.195	1.000
24	3,063.490	15.952	0.000	0.000	4	3,055.490	1.000
21	3,063.543	16.005	0.000	([1])	3	3,057.543	1.000
22	3,063.671	16.132	0.000	([1])	3	3,057.671	1.000

[1]Model removed from consideration due to similar deviance and delta AIC ≤ 2 units from a similar model with one fewer parameters.

Appendix D. Encounter histories of radio-tagged yearling juvenile coho salmon of hatchery origin released into the Klamath River at the hatchery based on 4 years of study, 2006–09.

[Results are based on data from 114 to 221 hatchery fish from Iron Gate Hatchery released in each year. All fish were released in the Klamath River near the hatchery. A '1' in the encounter history indicates detection at a site and a '0' indicates no detection at site. The encounter history includes columns representing tag operation at release (rkm 309) followed by columns for the sites of Shasta River (rkm 288), Scott River (rkm 234), Indian Creek (rkm 178), Salmon River (rkm 107), Trinity River (rkm 69), Steelhead Lodge (rkm 33), and Gaging Station (rkm 13)]

Encounter history	Year			
	2006	2007	2008	2009
11111111	44	53	80	99
11111110	1	6	5	2
11111101	2	0	0	0
11111100	2	1	7	9
11111011	2	0	0	0
11111010	1	0	1	0
11111000	0	0	3	11
11110111	5	0	5	0
11110011	1	0	0	0
11110000	3	5	9	19
11101111	0	1	0	0
11101110	1	0	0	0
11101000	0	0	1	0
11100001	1	0	0	0
11100000	6	3	9	9
11011111	4	0	0	0
11011011	1	0	0	0
11010000	2	0	0	0
11001110	1	0	0	0
11000001	0	1	0	0
11000000	17	24	48	17
10111111	3	0	0	3
10111110	1	0	0	0
10110111	1	0	0	0
10110000	0	1	0	0
10100000	1	0	0	0
10011111	1	0	0	0
10011101	1	0	0	0
10010101	1	0	0	0
10010000	1	0	0	0
10000001	1	0	0	0
10000000	9	28	53	20
Total	114	123	221	189

Appendix E. Model selection summaries from analyses of recapture probabilities and survival probabilities of hatchery fish, lower Klamath River, northern California, 2006–09

Table E1. Model summary from analyses of recapture probabilities (*p*) of hatchery fish from 2006–09.

[Results are based on data from 114 to 221 hatchery fish from Iron Gate Hatchery released in each year. All fish were released in the Klamath River near the hatchery. Models of *p* include those in which values can vary in various combinations of detection site (t) and year group (g). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all sites and years. QAICc is a quasi-likelihood adjustment to the Akaike Information Criterion adjusted for sample size. K indicates the number of estimable parameters]

Model	QAICc	Delta QAICc	AICc weights	Model likelihood	K	QDeviance
{phi(g*t), p(g*t)}	1,276.628	0.000	0.576	1.000	40	73.164
{phi(g*t), p(g)}	1,277.446	0.818	0.383	0.664	30	94.466
{phi(g*t), p(g+t)}	1,281.910	5.282	0.041	0.071	35	88.705
{phi(g*t), p(t)}	1,312.588	35.959	0.000	0.000	28	133.688
{phi(g*t), p(.)}	1,316.165	39.537	0.000	0.000	27	139.303

Table E2. Model summary from analyses of survival probabilities (phi) of hatchery fish from 2006–09.

[Results are based on data from 114 to 221 hatchery fish from Iron Gate Hatchery released in each year. All fish were released in the Klamath River near the hatchery. Models of phi include those in which values can vary in various combinations of detection site (t) and year group (g). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all sites and years. QAICc is a quasi-likelihood adjustment to the Akaike Information Criterion adjusted for sample size. K indicates the number of estimable parameters]

Model	QAICc	Delta QAICc	AICc weights	Model likelihood	K	QDeviance
{phi(g+t), p(g)}	1,258.066	0.000	0.935	1.000	11	113.625
{phi(g+t), p(g*t)}	1,263.401	5.335	0.065	0.069	26	88.575
{phi(g*t), p(g*t)}	1,276.628	18.563	0.000	0.000	40	73.164
{phi(t), p(g)}	1,277.421	19.356	0.000	0.000	12	130.965
{phi(g*t), p(g)}	1,277.446	19.380	0.000	0.000	30	94.466
{phi(t), p(g*t)}	1,280.789	22.724	0.000	0.000	26	105.964
{phi(g), p(g)}	1,308.433	50.367	0.000	0.000	9	168.021
{phi(g), p(g*t)}	1,310.894	52.828	0.000	0.000	24	140.138
{phi(g), p(g+t)}	1,313.508	55.442	0.000	0.000	6	179.128
{phi(.), p(g)}	1,318.446	60.380	0.000	0.000	21	153.783
{phi(.), p(g*t)}	1,318.430	46.705	0.000	0.000	11	173.990

Appendix F. Model selection results from 24 models of reach-specific survival of hatchery fish, lower Klamath River, northern California, 2006–09.

Table F1. Model selection results from survival data in the Release to Shasta River reach.
[Models in the top 95 percent of AICc weight were used to estimate model-averaged slope coefficients for the covariates they contained. AICc=Akaike Information Criterion with sample size adjustment, K=number of model parameters]

Model No.	AICc	Delta AICc	AICc weight	Model likelihood	K	Deviance	Sum of AICc weight
20	1,197.960	0.000	0.605	1.000	11	1,175.732	0.605
15	1,198.969	1.009	0.365	0.604	10	1,178.779	0.970
3	1,205.356	7.396	0.015	0.025	9	1,187.201	0.985
8	1,206.233	8.273	0.010	0.016	10	1,186.043	0.994
21	1,208.615	10.655	0.003	0.005	11	1,186.386	0.997
16	1,209.853	11.893	0.002	0.003	10	1,189.663	0.999
19	1,212.752	14.792	0.000	0.001	11	1,190.523	0.999
22	1,213.685	15.725	0.000	0.000	11	1,191.457	0.999
14	1,213.816	15.856	0.000	0.000	10	1,193.626	1.000
17	1,214.807	16.847	0.000	0.000	10	1,194.617	1.000
6	1,215.739	17.779	0.000	0.000	9	1,197.583	1.000
5	1,216.124	18.164	0.000	0.000	9	1,197.969	1.000
11	1,216.439	18.479	0.000	0.000	10	1,196.249	1.000
10	1,216.617	18.657	0.000	0.000	10	1,196.427	1.000
4	1,217.007	19.047	0.000	0.000	9	1,198.852	1.000
9	1,217.440	19.480	0.000	0.000	10	1,197.250	1.000
2	1,225.534	27.574	0.000	0.000	9	1,207.379	1.000
13	1,226.450	28.490	0.000	0.000	10	1,206.260	1.000
12	1,227.505	29.545	0.000	([1])	10	1,207.315	([1])
1	1,228.398	30.438	0.000	0.000	9	1,210.243	1.000
23	1,228.466	30.506	0.000	([1])	11	1,206.238	([1])
7	1,228.653	30.693	0.000	0.000	9	1,210.498	1.000
18	1,230.400	32.440	0.000	([1])	10	1,210.210	([1])
24	1,230.497	32.537	0.000	([1])	12	1,206.227	([1])

[1]Model removed from consideration due to similar deviance and delta AICc ≤ 2 units from a similar model with one fewer parameters.

Table F2. Model selection results from survival data in the Shasta River to Scott River reach.
[Models in the top 95 percent of AICc weight were used to estimate model-averaged slope coefficients for the covariates they contained. AICc=Akaike Information Criterion with sample size adjustment; K=number of model parameters]

Model No.	AICc	Delta AICc	AICc weight	Model likelihood	K	Deviance	Sum of AICc weight
6	787.456	0.000	0.498	1.000	5	777.392	0.498
3	787.638	0.183	0.455	0.913	5	777.575	0.953
11	788.908	1.452	0.000	([1])	6	776.819	([1])
8	789.034	1.578	0.000	([1])	6	776.944	([1])
16	789.156	1.701	0.000	([1])	6	777.067	([1])
15	789.421	1.965	0.000	([1])	6	777.331	([1])
21	790.284	2.828	0.000	([1])	7	776.165	([1])
20	790.970	3.514	0.000	([1])	7	776.851	([1])
4	792.166	4.711	0.047	0.095	5	782.103	1.000
9	793.702	6.246	0.000	([1])	6	781.613	([1])
17	794.117	6.661	0.000	([1])	6	782.028	([1])
22	795.722	8.266	0.000	([1])	7	781.603	([1])
1	807.961	20.505	0.000	0.000	5	797.897	1.000
5	808.977	21.521	0.000	0.000	5	798.913	1.000
2	809.019	21.563	0.000	0.000	5	798.955	1.000
7	809.160	21.704	0.000	0.000	5	799.096	1.000
14	809.809	22.353	0.000	0.000	6	797.720	1.000
13	809.859	22.404	0.000	([1])	6	797.770	([1])
18	809.862	22.407	0.000	0.000	6	797.773	1.000
10	810.712	23.256	0.000	([1])	6	798.622	([1])
12	810.794	23.338	0.000	([1])	6	798.704	([1])
19	811.740	24.284	0.000	([1])	7	797.621	([1])
23	811.759	24.304	0.000	([1])	7	797.640	([1])
24	812.762	25.307	0.000	0.000	8	796.609	1.000

[1]Model removed from consideration due to similar deviance and delta AICc ≤ 2 units from a similar model with one fewer parameters.

Table F3. Model selection results from survival data in the Scott River to Indian Creek reach.
[Models in the top 95 percent of AICc weight were used to estimate model-averaged slope coefficients for the covariates they contained. AICc=Akaike Information Criterion with sample size adjustment; K=number of model parameters]

Model No.	AICc	Delta AICc	AICc weight	Model likelihood	K	Deviance	Sum of AICc weight
5	507.823	0.000	0.197	1.000	6	495.719	0.197
4	508.556	0.734	0.136	0.693	6	496.453	0.333
14	508.650	0.827	0.130	0.661	7	494.511	0.463
17	509.459	1.636	0.087	0.441	7	495.320	0.550
10	509.837	2.014	0.000	([1])	7	495.698	([1])
6	509.880	2.058	0.070	0.357	6	497.777	0.620
1	510.267	2.444	0.058	0.295	6	498.163	0.678
16	510.501	2.678	0.052	0.262	7	496.362	0.730
9	510.550	2.727	0.000	([1])	7	496.411	([1])
7	510.601	2.779	0.049	0.249	6	498.498	0.779
3	510.635	2.812	0.048	0.245	6	498.531	0.827
2	510.643	2.821	0.048	0.244	6	498.540	0.875
19	510.688	2.865	0.047	0.239	8	494.509	0.922
22	511.298	3.475	0.035	0.176	8	495.119	0.957
11	511.859	4.036	0.000	([1])	7	497.720	([1])
15	512.076	4.253	0.000	([1])	7	497.937	([1])
21	512.178	4.356	0.022	0.113	8	496.000	0.979
13	512.240	4.417	0.000	([1])	7	498.101	([1])
18	512.275	4.452	0.000	([1])	7	498.136	([1])
12	512.622	4.799	0.000	([1])	7	498.483	([1])
8	512.656	4.833	0.000	([1])	7	498.517	([1])
20	512.937	5.114	0.015	0.078	8	496.758	0.994
23	514.031	6.208	0.000	([1])	8	497.853	([1])
24	514.254	6.431	0.000	([1])	8	498.075	([1])

[1]Model removed from consideration due to similar deviance and delta AICc ≤ 2 units from a similar model with one fewer parameters.

Table F4. Model selection results from survival data in the Indian Creek to Salmon River reach.
[Models in the top 95 percent of AICc weight were used to estimate model-averaged slope coefficients for the covariates they contained. AICc=Akaike Information Criterion with sample size adjustment; K=number of model parameters]

Model No.	AICc	Delta AICc	AICc weight	Model likelihood	K	Deviance	Sum of AICc weight
11	434.135	0.000	0.256	1.000	5	424.053	0.256
21	434.542	0.407	0.209	0.816	6	422.427	0.465
17	435.167	1.032	0.153	0.597	5	425.085	0.618
16	435.429	1.294	0.134	0.524	5	425.348	0.753
22	435.652	1.517	0.120	0.468	6	423.537	0.873
6	435.814	1.679	0.111	0.432	4	427.760	0.983
14	442.539	8.404	0.004	0.015	5	432.457	0.987
3	442.578	8.442	0.004	0.015	4	434.523	0.991
8	443.207	9.071	0.003	0.011	5	433.125	0.994
19	444.190	10.055	0.002	0.007	6	432.075	0.995
9	444.377	10.242	0.002	0.006	5	434.295	0.997
15	444.412	10.277	0.000	([1])	5	434.330	([1])
5	444.804	10.669	0.001	0.005	4	436.750	0.998
4	444.870	10.735	0.001	0.005	4	436.816	0.999
20	445.150	11.015	0.000	([1])	6	433.035	([1])
10	446.176	12.040	0.000	([1])	5	436.094	([1])
1	447.194	13.058	0.000	0.001	4	439.139	1.000
13	448.246	14.110	0.000	([1])	5	438.164	([1])
18	448.927	14.792	0.000	0.001	5	438.845	1.000
23	450.056	15.921	0.000	([1])	6	437.941	([1])
24	451.492	17.356	0.000	([1])	7	437.338	([1])
2	453.801	19.666	0.000	0.000	4	445.747	1.000
7	455.567	21.431	0.000	0.000	4	447.512	1.000
12	455.818	21.683	0.000	([1])	5	445.737	([1])

[1]Model removed from consideration due to similar deviance and delta AICc ≤ 2 units from a similar model with one fewer parameters.

Table F5. Model selection results from survival data in the Salmon River to Trinity River reach.
[Models in the top 95 percent of AICc weight were used to estimate model-averaged slope coefficients for the covariates they contained. AICc=Akaike Information Criterion with sample size adjustment; K=number of model parameters]

Model No.	AICc	Delta AICc	AICc weight	Model likelihood	K	Deviance	Sum of AICc weight
21	295.235	0.000	0.335	1.000	10	274.911	0.335
16	295.477	0.243	0.297	0.886	9	277.213	0.632
22	296.766	1.532	0.156	0.465	10	276.443	0.787
17	297.166	1.932	0.128	0.381	9	278.902	0.915
23	300.303	5.068	0.027	0.079	10	279.979	0.942
11	300.516	5.282	0.024	0.071	9	282.252	0.965
6	301.133	5.898	0.018	0.052	8	284.921	0.983
18	301.675	6.440	0.013	0.040	9	283.410	0.996
24	302.097	6.863	0.000	([1])	11	279.708	([1])
13	305.943	10.709	0.002	0.005	9	287.679	0.998
19	307.423	12.188	0.000	([1])	10	287.099	([1])
1	307.460	12.226	0.001	0.002	8	291.249	0.999
20	307.884	12.649	0.000	([1])	10	287.560	([1])
14	308.047	12.812	0.001	0.002	9	289.783	0.999
15	309.461	14.226	0.000	0.001	9	291.196	1.000
8	309.924	14.689	0.000	0.001	9	291.659	1.000
9	310.735	15.501	0.000	0.001	9	292.471	1.000
3	312.618	17.384	0.000	0.000	8	296.407	1.000
4	314.024	18.789	0.000	0.000	8	297.813	1.000
12	320.732	25.498	0.000	([1])	9	302.468	([1])
10	321.118	25.883	0.000	([1])	9	302.853	([1])
5	322.721	27.486	0.000	([1])	8	306.510	([1])
2	323.684	28.449	0.000	([1])	8	307.472	([1])
7	324.390	29.155	0.000	([1])	8	308.178	([1])

[1]Model removed from consideration due to similar deviance and delta AICc ≤ 2 units from a similar model with one fewer parameters.

Table F6. Model selection results from survival data in the Trinity River to Steelhead Lodge reach.

[Models in the top 95 percent of AICc weight were used to estimate model-averaged slope coefficients for the covariates they contained. AICc=Akaike Information Criterion with sample size adjustment; K=number of model parameters]

Model No.	AICc	Delta AICc	AICc weight	Model likelihood	K	Deviance	Sum of AICc weight
6	267.112	0.000	0.384	1.000	4	259.051	0.384
16	267.399	0.287	0.333	0.866	5	257.307	0.717
11	268.212	1.100	0.000	([1])	5	258.121	([1])
21	268.359	1.247	0.206	0.536	6	256.231	0.923
17	271.152	4.040	0.051	0.133	5	261.061	0.974
22	272.575	5.463	0.025	0.065	6	260.446	0.999
4	278.724	11.612	0.001	0.003	4	270.663	1.000
9	280.136	13.024	0.000	([1])	5	270.044	([1])
18	286.788	19.676	0.000	0.000	5	276.696	1.000
23	288.254	21.142	0.000	0.000	6	276.126	1.000
24	290.031	22.919	0.000	([1])	7	275.859	([1])
1	292.998	25.886	0.000	0.000	4	284.937	1.000
14	293.109	25.997	0.000	0.000	5	283.017	1.000
3	293.812	26.700	0.000	0.000	4	285.751	1.000
15	294.140	27.028	0.000	0.000	5	284.049	1.000
13	294.716	27.604	0.000	([1])	5	284.625	([1])
19	295.080	27.967	0.000	0.000	6	282.951	1.000
8	295.517	28.405	0.000	([1])	5	285.426	([1])
20	295.919	28.807	0.000	([1])	6	283.790	([1])
5	299.664	32.552	0.000	0.000	4	291.603	1.000
10	301.678	34.566	0.000	([1])	5	291.587	([1])
7	302.725	35.613	0.000	0.000	4	294.664	1.000
12	304.406	37.294	0.000	([1])	5	294.314	([1])
2	305.615	38.503	0.000	0.000	4	297.554	1.000

[1]Model removed from consideration due to similar deviance and delta AICc ≤ 2 units from a similar model with one fewer parameters.

Appendix G. Summary of reach-specific covariate values used for migration and survival analysis based on hatchery fish released near Iron Gate Hatchery, lower Klamath River, northern California, 2006–09.

[Covariates included discharge at the head of the reach in 100 ft^3/s increments (q100), water temperature in Celsius (temp), photoperiod (photo), acculturated thermal units since March 15 (atu), fish weight in grams at tagging (wt), date of entry into the reach (date), and gill ATPase activity at tagging (atpase). *N* = sample size, Std = standard deviation]

Variable	*N*	Mean	Std	Minimum	Maximum
--------------------Release to Shasta River -------------------					
q100	647	24.82	14.67	14.10	98.80
temp	647	13.56	2.33	7.58	17.91
photo	647	16.52	0.61	14.95	17.47
atu	647	501.76	139.18	172.35	779.44
WT	647	31.91	13.31	11.50	130.60
date	647	125.81	12.96	94.00	148.00
atpase	647	3.21	2.56	0.05	23.15
--------------------Shasta River to Scott River -------------------					
q100	532	27.97	12.43	16.86	77.30
temp	532	15.93	1.87	9.78	19.22
photo	532	17.01	0.47	15.30	17.73
atu	532	676.44	137.23	291.82	1,018.23
WT	532	32.39	13.74	11.50	130.60
date	532	126.75	12.90	94.00	148.00
atpase	532	3.20	2.63	0.05	23.15
--------------------Scott River to Indian Creek -------------------					
q100	424	45.13	22.69	22.80	104.00
temp	424	16.49	1.59	12.16	19.90
photo	424	17.24	0.26	16.17	17.73
atu	424	758.56	89.37	459.30	1,015.34
WT	424	32.58	14.46	11.80	130.60
date	424	126.99	13.07	94.00	148.00
atpase	424	3.23	2.75	0.05	23.15
-------------------- Indian Creek to Salmon River -------------------					
q100	395	58.61	29.78	28.13	127.09
temp	395	16.09	1.88	10.09	19.89
photo	395	17.29	0.26	16.25	17.82
atu	395	787.46	91.70	483.58	1,066.55
WT	395	32.58	14.55	11.80	130.60
date	395	126.67	13.12	94.00	148.00
atpase	395	3.24	2.63	0.05	20.66
--------------------Salmon River to Trinity River -------------------					
q100	356	93.27	46.37	25.40	225.00
temp	356	15.81	2.34	11.18	23.03
photo	356	17.34	0.25	16.62	17.82
atu	356	816.84	104.95	536.25	1,548.16
WT	356	32.23	14.46	11.80	130.60
date	356	125.98	13.21	94.00	148.00
atpase	356	3.24	2.59	0.05	20.66

Appendix G. Summary of reach-specific covariate values used for migration and survival analysis based on hatchery fish released near Iron Gate Hatchery, lower Klamath River, northern California, 2006–09.—Continued

[Covariates included discharge at the head of the reach in 100 ft^3/s increments (q100), water temperature in Celsius (temp), photoperiod (photo), acculturated thermal units since March 15 (atu), fish weight in grams at tagging (wt), date of entry into the reach (date), and gill ATPase activity at tagging (atpase). *N*=sample size, Std = standard deviation]

Variable	*N*	Mean	Std	Minimum	Maximum
--------------------Trinity River to Steelhead Lodge -------------------					
q100	341	154.87	78.98	64.70	346.00
temp	341	15.41	1.98	11.41	20.20
photo	341	17.36	0.25	16.65	17.82
atu	341	826.78	102.15	553.38	1,384.26
WT	341	31.78	13.82	11.80	130.60
date	341	125.62	13.08	94.00	148.00
atpase	341	3.29	2.62	0.05	20.66

Appendix H. Daily release numbers of hatchery and wild fish used in comparisons of hatchery and wild migration and survival, lower Klamath River, northern California, 2006 and 2009.

[Hatchery fish were from the Iron Gate Fish Hatchery. Wild fish were from a rotary screw trap on the Shasta River (2006) or Scott River (2009)]

Release Date	Hatchery	Wild
4/4/2006	8	8
4/18/2006	9	3
4/25/2006	9	10
4/28/2006	8	26
5/2/2006	9	15
5/5/2006	8	11
5/9/2006	9	11
5/12/2006	10	2
5/16/2006	10	8
2006 Total	80	94
4/16/2009	11	11
4/22/2009	12	12
4/23/2009	11	11
4/29/2009	12	12
4/30/2009	11	11
5/20/2009	19	3
2009 Total	76	60

Appendix I. Encounter histories of radio-tagged yearling juvenile coho salmon of hatchery and wild origin released into the Klamath River at the hatchery on dates wild fish were released, northern California, 2006.

[Results are based on data from 80 hatchery fish from Iron Gate Hatchery and 94 wild fish taken from a rotary trap on the Shasta River. All fish were released in the Klamath River near the hatchery between April 4 and May 16, 2006. A '1' in the encounter history indicates detection at a site and a '0' indicates no detection at site. The encounter history includes columns representing tag operation at release (rkm 309) followed by columns for the sites of Shasta River (rkm 288), Scott River (rkm 234), Indian Creek (rkm 178), Salmon River (rkm 107), Trinity River (rkm 69), Steelhead Lodge (rkm 33), and Gaging Station (rkm 13)]

Encounter history	Hatchery	Wild	Encounter history	Hatchery	Wild
11111111	30	9	11010011	0	1
11111110	1	4	11010001	0	2
11111101	1	4	11010000	2	3
11111100	2	3	11001111	0	1
11111011	2	1	11001110	1	0
11111001	0	1	11000100	0	1
11111000	0	1	11000010	0	2
11110111	4	1	11000000	13	8
11110110	0	1	10111111	1	1
11110101	0	2	10111110	1	0
11110100	0	1	10111100	0	1
11110011	0	1	10111001	0	1
11110000	2	2	10110101	0	1
11101110	1	0	10110100	0	1
11100001	0	1	10100011	0	1
11100000	4	5	10100000	1	1
11011111	3	9	10011111	1	0
11011110	0	1	10011101	1	1
11011101	0	4	10010111	0	1
11011011	0	1	10010101	1	0
11011001	0	2	10010001	0	1
11011000	0	1	10001000	0	1
11010111	0	1	10000001	1	0
11010100	0	1	10000000	7	8

Appendix J. Model selection summaries from analyses of recapture probabilities and survival probabilities of hatchery and wild fish, lower Klamath River, northern California, 2006.

Table J1. Model summary from analyses of recapture probabilities (*p*) of hatchery and wild fish from 2006.

[Results are based on data from 80 hatchery fish from Iron Gate Hatchery and 94 wild fish taken from a rotary trap on the Shasta River. All fish were released in the Klamath River near the hatchery between April 4 and May 16, 2006. Models of *p* include those in which values can vary in various combinations of detection site (t) and origin grouping (g). A '*' indicated a multiplicative effect and a '+' indicates an additive effect. QAICc is a quasi-likelihood adjustment to the Akaike Information Criterion adjusted for sample size. K indicates the number of estimable parameters]

Model	QAICc	Delta QAICc	AICc weights	Model likelihood	K	QDeviance
{phi(g*t), p(g+t)}	1,006.470	0.000	0.914	1.000	20	135.933
{phi(g*t), p(g*t)}	1,011.205	4.735	0.086	0.094	25	130.064
{phi(g*t), p(t)}	1,034.780	28.309	0.000	0.000	19	166.347

Table J2. Model summary from analyses of survival probabilities (phi) of hatchery and wild fish from 2006.

[Results are based on data from 80 hatchery fish from Iron Gate Hatchery and 94 wild fish taken from a rotary trap on the Shasta River. All fish were released in the Klamath River near the hatchery between April 4 and May 16, 2006. Models of phi include those in which values can vary in various combinations of detection site (t) and origin grouping (g). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all sites and years. QAICc is a quasi-likelihood adjustment to the Akaike Information Criterion adjusted for sample size. K indicates the number of estimable parameters]

Model	QAICc	Delta QAICc	QAICc weights	Model likelihood	K	QDeviance
{phi(t), p(g+t)}	997.478	0.000	0.530	1.000	14	139.487
{phi(g+t), p(g+t)}	998.409	0.931	0.333	0.628	15	138.341
{phi(.), p(g+t)}	1,001.351	3.873	0.076	0.144	10	151.618
{phi(g), p(g+t)}	1,003.264	5.786	0.029	0.055	11	151.474
{phi(t), p(g*t)}	1,004.512	7.034	0.016	0.030	20	133.975
{phi(g+t), p(g*t)}	1,005.417	7.939	0.010	0.019	21	132.770
{phi(.), p(g*t)}	1,008.424	10.946	0.002	0.004	16	146.273
{phi(g*t), p(g+t)}	1,008.580	11.102	0.002	0.004	21	135.933
{phi(g), p(g*t)}	1,010.127	12.649	0.001	0.002	17	145.887
{phi(g*t), p(g*t)}	1,013.342	15.864	0.000	0.000	26	130.064

Appendix K. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish, lower Klamath River, northern California, 2006.

Table K1. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Shasta River to Scott River reach in 2006.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc weights	Model likelihood	K	Deviance
			Covariate = River Discharge					
0	None	None	334.049	0.000	0.377	1.000	6	321.690
2	Same	Same	335.124	1.075	0.220	0.584	6	322.765
1	Same	Different	335.187	1.138	0.213	0.566	7	320.706
4	Different	Same	335.412	1.363	0.190	0.506	7	320.931
3	Different	Different	337.113	3.064	([1])	([1])	8	320.492
			Covariate = Water Temperature					
1	Same	Different	334.013	0.000	0.301	1.000	7	319.532
0	None	None	334.049	0.036	0.295	0.982	6	321.690
4	Different	Same	334.584	0.571	0.226	0.752	7	320.103
3	Different	Different	335.413	1.401	0.149	0.496	8	318.793
2	Same	Same	338.710	4.697	0.029	0.096	6	326.351
			Covariate = Fish Weight					
0	None	None	334.049	0.000	0.317	1.000	6	321.690
4	Different	Same	334.352	0.304	0.272	0.859	7	319.872
1	Same	Different	334.747	0.698	0.223	0.705	7	320.266
2	Same	Same	335.094	1.045	0.188	0.593	6	322.735
3	Different	Different	336.308	2.260	([1])	([1])	8	319.688

[1]Model removed from consideration due to similar deviance and delta AIC ≤ 2 units from a similar model with one fewer parameters.

Table K2. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Scott River to Indian Creek reach in 2006.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
Covariate = River Discharge								
2	Same	Same	173.800	0.000	0.566	1.000	6	161.413
0	None	None	174.332	0.532	0.434	0.766	6	161.945
1	Same	Different	175.844	2.044	([1])	([1])	7	161.326
4	Different	Same	175.853	2.053	([1])	([1])	7	161.334
3	Different	Different	177.980	4.180	([1])	([1])	8	161.310
Covariate = Water Temperature								
2	Same	Same	172.714	0.000	0.357	1.000	6	160.327
1	Same	Different	173.869	1.155	0.200	0.561	7	159.350
4	Different	Same	173.942	1.229	0.193	0.541	7	159.424
0	None	None	174.332	1.618	0.159	0.445	6	161.945
3	Different	Different	175.439	2.725	0.091	0.256	8	158.769
Covariate = Fish Weight								
2	Same	Same	167.220	0.000	0.396	1.000	6	154.833
4	Different	Same	168.028	0.808	0.265	0.668	7	153.509
1	Same	Different	168.359	1.139	0.224	0.566	7	153.840
3	Different	Different	169.910	2.691	0.103	0.260	8	153.241
0	None	None	174.332	7.112	0.011	0.029	6	161.945

[1]Model removed from consideration due to similar deviance and delta AICc ≤2 units from a model with one fewer parameters.

Table K3. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Indian Creek to Salmon River reach in 2006.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
				Covariate = River Discharge				
0	None	None	164.151	0.000	0.357	1.000	4	155.936
3	Different	Different	165.188	1.037	0.212	0.596	7	150.576
2	Same	Same	165.313	1.162	0.199	0.559	5	154.989
1	Same	Different	166.190	2.039	0.129	0.361	6	153.734
4	Different	Same	166.640	2.488	0.103	0.288	6	154.183
				Covariate = Water Temperature				
0	None	None	164.151	0.000	0.520	1.000	4	155.936
2	Same	Same	165.837	1.685	0.224	0.431	5	155.512
4	Different	Same	167.456	3.305	0.100	0.192	6	155.000
1	Same	Different	167.553	3.402	0.095	0.183	6	155.097
3	Different	Different	168.446	4.295	0.061	0.117	7	153.834
				Covariate = Fish Weight				
0	None	None	164.151	0.000	0.817	1.000	4	155.936
2	Same	Same	167.440	3.289	0.158	0.193	5	157.115
1	Same	Different	169.501	5.350	([1])	([1])	6	157.045
4	Different	Same	169.569	5.418	([1])	([1])	6	157.112
3	Different	Different	171.144	6.993	0.025	0.030	7	156.532

[1]Model removed from consideration due to similar deviance and delta AICc ≤2 units from a model with one fewer parameters.

Table K4. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Trinity River to Steelhead Lodge reach in 2006.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
Covariate = River Discharge								
2	Same	Same	176.990	0.000	0.540	1.000	6	164.472
3	Different	Different	178.270	1.279	0.285	0.527	8	161.370
1	Same	Different	178.991	2.000	([1])	([1])	7	164.295
4	Different	Same	179.162	2.172	([1])	([1])	7	164.466
0	None	None	179.236	2.246	0.176	0.325	6	166.717
Covariate = Water Temperature								
3	Different	Different	174.816	0.000	0.673	1.000	7	160.121
2	Same	Same	177.979	3.163	0.138	0.206	6	165.461
0	None	None	179.236	4.420	0.074	0.110	6	166.717
4	Different	Same	179.686	4.870	0.059	0.088	7	164.990
1	Same	Different	179.801	4.985	0.056	0.083	7	165.106
Covariate = Fish Weight								
2	Same	Same	176.718	0.000	0.697	1.000	6	164.200
4	Different	Same	178.782	2.063	([1])	([1])	7	164.086
1	Same	Different	178.880	2.162	([1])	([1])	7	164.185
0	None	None	179.236	2.518	0.198	0.284	6	166.717
3	Different	Different	180.515	3.797	0.104	0.150	8	163.615

[1]Model removed from consideration due to similar deviance and delta AICc ≤ 2 units from a similar model with one fewer parameters.

Appendix L. Encounter histories of radio-tagged yearling juvenile coho salmon of hatchery and wild origin released into the Klamath River at the hatchery on dates wild fish were released, northern California, 2009.

[Results are based on data from 57 hatchery fish from Iron Gate Hatchery and 57 wild fish taken from a rotary trap on the Scott River. All fish were released in the Klamath River near the hatchery between April 16 and April 30, 2009. A '1' in the encounter history indicates detection at a site and a '0' indicates no detection at site. The encounter history includes columns representing tag operation at release (rkm 309) followed by columns for the sites of Ager Road Bridge (rkm 300), Shasta River (rkm 288), Scott River (rkm 234), Indian Creek (rkm 178), Salmon River (rkm 107), Trinity River (rkm 69), Steelhead Lodge (rkm 33), and Gaging Station (rkm 13)]

Encounter History	Hatchery	Wild
111111111	36	30
111111110	0	1
111111100	2	0
111111000	2	0
111110000	1	2
111100000	2	1
111000000	5	1
110111111	2	1
110000000	4	8
101111111	0	4
101111000	0	1
100000000	3	8

Appendix M. Model selection summaries from analyses of recapture probabilities and survival probabilities of hatchery and wild fish, lower Klamath River, northern California, 2009.

Table M1. Model summary from analyses of recapture probabilities (*p*) of hatchery and wild fish during 2009.

[Results are based on data from 57 hatchery fish from Iron Gate Hatchery and 57 wild fish taken from a rotary trap on the Scott River. All fish were released in the Klamath River near the hatchery between April 16 and April 30, 2009. Models of *p* include those in which values can vary in various combinations of detection site (t) and year group (g). Model: '*',multiplicative effect; '+', an additive effect. AICc=the Akaike Information Criterion adjusted for sample size. K, number of estimable parameters]

Model	AICc	Delta AICc	AICc weights	Model kelihood	K	Deviance
{phi(g*t), p(g+t)}	363.583	0.000	0.996	1.000	11	6.739
{phi(g*t), p(t)}	375.680	12.096	0.002	0.002	12	16.764
{phi(g*t), p(g*t)}	376.100	12.517	0.002	0.002	17	6.739

Table M2. Model summary from analyses of survival probabilities (phi) of hatchery and wild fish during 2009.

[Results are based on data from 57 hatchery fish from Iron Gate Hatchery and 57 wild fish taken from a rotary trap on the Scott River. All fish were released in the Klamath River near the hatchery between April 16 and April 30, 2009. Models of phi include those in which values can vary in various combinations of detection site (t) and year group (g). Model: '*',multiplicative effect; '+', an additive effect. AICc=the Akaike Information Criterion adjusted for sample size. K, number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{phi(g+t), p(g+t)}	372.619	0.000	0.377	1.000	12	13.704
{phi(.), p(g+t)}	373.372	0.753	0.259	0.686	5	28.826
{phi(t), p(g+t)}	374.070	1.450	0.183	0.484	11	17.225
{phi(g), p(g+t)}	374.985	2.366	0.116	0.306	6	28.405
{phi(g*t), p(g+t)}	376.100	3.481	0.066	0.175	17	6.739

Appendix N. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish, lower Klamath River, northern California, 2009.

Table N1. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Release to Shasta River reach in 2009.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc weight	Model likelihood	K	Deviance
			Covariate = River Discharge					
0	None	None	216.668	0.000	0.416	1.000	6	204.315
4	Different	Same	217.419	0.751	0.286	0.687	7	202.946
1	Same	Different	217.516	0.849	0.272	0.654	7	203.044
3	Different	Different	219.278	2.610	([1])	([1])	8	202.668
2	Same	Same	222.284	5.617	0.025	0.060	6	209.931
			Covariate = Water Temperature					
0	None	None	216.668	0.000	0.436	1.000	6	204.315
1	Same	Different	217.469	0.802	0.292	0.670	7	202.997
4	Different	Same	217.755	1.087	0.253	0.581	7	203.283
3	Different	Different	219.548	2.880	([1])	([1])	8	202.938
2	Same	Same	222.997	6.329	0.018	0.042	6	210.644
			Covariate = Fish Weight					
0	None	None	216.668	0.000	0.743	1.000	6	204.315
4	Different	Same	218.787	2.119	([1])	([1])	7	204.314
3	Different	Different	220.181	3.513	0.128	0.173	8	203.571
1	Same	Different	221.433	4.765	0.069	0.092	7	206.960
2	Same	Same	221.716	5.048	0.060	0.080	6	209.363

[1]Model removed from consideration due to similar deviance and delta AICc ≤2 units from a model with one fewer parameters.

Table N2. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Shasta River to Scott River reach in 2009.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc Weight	Model Likelihood	K	Deviance
------- Covariate = River Discharge -------								
0	None	None	104.102	0.000	0.898	1.000	3	97.988
4	Different	Same	110.280	6.179	0.041	0.046	6	97.876
1	Same	Different	110.286	6.184	0.041	0.045	6	97.882
2	Same	Same	111.717	7.615	0.020	0.022	5	101.430
3	Different	Different	112.417	8.316	([1])	([1])	7	97.876
------- Covariate = Water Temperature -------								
0	None	None	104.102	0.000	0.558	1.000	3	97.988
1	Same	Different	106.566	2.465	0.163	0.292	5	96.279
4	Different	Same	106.615	2.513	0.159	0.285	5	96.327
2	Same	Same	107.168	3.067	0.120	0.216	4	98.978
3	Different	Different	110.819	6.717	([1])	([1])	7	96.278
------- Covariate = Fish Weight -------								
0	None	None	104.102	0.000	0.807	1.000	3	97.988
4	Different	Same	108.215	4.113	0.103	0.128	5	97.928
2	Same	Same	109.380	5.278	0.058	0.071	4	101.190
1	Same	Different	110.577	6.476	0.032	0.039	6	98.173
3	Different	Different	112.469	8.367	([1])	([1])	7	97.928

[1]Model removed from consideration due to similar deviance and delta AICc ≤2 units from a model with one fewer parameters.

Table N3. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Scott River to Indian Creek reach in 2009.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc Weight	Model Likelihood	K	Deviance
Covariate = River Discharge								
0	None	None	86.672	0.000	0.267	1.000	4	78.468
2	Same	Same	86.678	0.005	0.267	0.997	4	78.474
1	Same	Different	87.375	0.703	0.188	0.704	5	77.067
4	Different	Same	87.529	0.857	0.174	0.652	5	77.221
3	Different	Different	88.561	1.888	0.104	0.389	6	76.128
Covariate = Water Temperature								
0	None	None	86.672	0.000	0.348	1.000	4	78.468
2	Same	Same	86.911	0.239	0.309	0.888	4	78.707
4	Different	Same	88.061	1.388	0.174	0.499	5	77.753
1	Same	Different	88.116	1.444	0.169	0.486	5	77.809
3	Different	Different	89.893	3.220	([1])	([1])	6	77.460
Covariate = Fish Weight								
0	None	None	86.672	0.000	0.410	1.000	4	78.468
2	Same	Same	87.644	0.972	0.252	0.615	4	79.440
4	Different	Same	88.688	2.015	0.150	0.365	5	78.380
1	Same	Different	89.435	2.763	0.103	0.251	5	79.127
3	Different	Different	89.819	3.147	0.085	0.207	6	77.386

[1]Model removed from consideration due to similar deviance and delta AICc ≤2 units from a model with one fewer parameters.

Table N4. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Indian Creek to Salmon River reach in 2009.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc Weight	Model Likelihood	K	Deviance
------------------------------------- Covariate = River Discharge ---								
2	Same	Same	77.107	0.000	0.562	1.000	4	68.892
3	Different	Different	78.253	1.146	0.317	0.564	6	65.797
1	Same	Different	78.853	1.746	([1])	([1])	5	68.528
4	Different	Same	79.193	2.086	([1])	([1])	5	68.868
0	None	None	80.177	3.070	0.121	0.215	4	71.962
---------------------------------- Covariate = Water Temperature ---								
3	Different	Different	79.076	0.000	0.311	1.000	6	66.620
2	Same	Same	79.198	0.121	0.293	0.941	4	70.983
0	None	None	80.177	1.101	0.180	0.577	4	71.962
1	Same	Different	81.107	2.030	0.113	0.362	5	70.782
4	Different	Same	81.283	2.206	0.103	0.332	5	70.959
-------------------------------------- Covariate = Fish Weight ---								
2	Same	Same	77.637	0.000	0.373	1.000	4	69.422
1	Same	Different	78.466	0.829	0.247	0.661	5	68.142
4	Different	Same	79.012	1.376	0.188	0.503	5	68.688
0	None	None	80.177	2.540	0.105	0.281	4	71.962
3	Different	Different	80.547	2.910	0.087	0.233	6	68.090

[1]Model removed from consideration due to similar deviance and delta AICc ≤2 units from a model with one fewer parameters.

Table N5. Model selection results from analyses of selected covariates on the survival of hatchery and wild fish in the Salmon River to Trinity River reach in 2009.

[Models with four combinations of intercept and slope hypotheses are compared to a model without the covariates. Model hypotheses are: model 0=no covariate effect; model 1= both origins have the same survival at basal levels of the covariate, but the covariate affects the two origins differently; model 2= both origins have the same survival over all values of the covariate; model 3= origins have different survivals at basal levels of the covariate, and the covariate affects the two origins differently; model 4= origins have different survivals at basal levels of the covariate, but the covariate affects survival of both origins the same. AICc=the Akaike Information Criterion with a sample size adjustment; K=number of parameters]

Model No.	Intercept	Slope	AICc	Delta AICc	AICc Weight	Model Likelihood	K	Deviance
	---------- Covariate = River Discharge ----------							
3	Different	Different	61.905	0.000	0.897	1.000	5	55.770
0	None	None	66.651	4.746	0.084	0.093	3	60.516
2	Same	Same	71.057	9.152	0.009	0.010	3	64.922
1	Same	Different	72.142	10.237	0.005	0.006	4	63.916
4	Different	Same	72.565	10.660	0.004	0.005	4	64.339
	---------- Covariate = Water Temperature ----------							
0	None	None	66.651	0.000	0.821	1.000	3	60.516
3	Different	Different	71.346	4.695	0.079	0.096	5	61.005
2	Same	Same	71.596	4.946	0.069	0.084	3	65.461
4	Different	Same	73.208	6.558	0.031	0.038	4	64.982
1	Same	Different	73.382	6.731	([1])	([1])	4	65.156
	---------- Covariate = Fish Weight ----------							
0	None	None	66.651	0.000	0.785	1.000	3	60.516
2	Same	Same	70.594	3.943	0.109	0.139	3	64.459
3	Different	Different	71.853	5.203	0.058	0.074	5	61.512
1	Same	Different	72.273	5.622	0.047	0.060	4	64.047
4	Different	Same	72.633	5.983	([1])	([1])	4	64.407

[1]Model removed from consideration due to similar deviance and delta AICc ≤2 units from a model with one fewer parameters.

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Beeman and others—**Effects of Iron Gate Dam Discharge and Other Factors on the Survival and Migration of Juvenile Coho Salmon, Lower Klamath River, Northern California, 2006–09**—Open-File Report 2012–1067