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Summary of Survival Data from Juvenile Coho Salmon in the Klamath River, Northern California, 2009



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Cover: Photograph of the Klamath River looking downstream near its confluence with the Salmon River, northern California.
(Photograph taken by Steve Juhnke, U.S. Geological Survey, Cook, Washington, October 20, 2009).

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Abstract

A study of the effects of the discharge from Iron Gate Dam on the Klamath River on juvenile coho salmon during their seaward migration began in 2005. Estimates of fish survival through various reaches of the river downstream of the dam were completed in 2006, 2007, 2008, and 2009. This report describes the estimates of survival during 2009, and is a complement to similar reports for 2006, 2007, and 2008. For each year, a series of numerical models were evaluated to determine apparent survival and recapture probabilities of radio-tagged fish in several river reaches between Iron Gate Hatchery at river kilometer 309 and a site at river kilometer 33. The evaluations indicate that the primary differences among years are in the survivals through reaches upstream of the confluence of the Scott River with the Klamath River. Data from 2009, one of two years when fish from both hatchery and wild origins were available for analysis, indicate that survival of wild and hatchery fish are similar.

Introduction

In 2006, the U.S. Geological Survey (USGS) entered into a cooperative study with the Karuk Tribe of California, the Yurok Tribe, and the U.S. Fish and Wildlife Service to estimate the effects of the discharge of Iron Gate Dam on survival of juvenile coho salmon (*Oncorhynchus kisutch*) in the lower Klamath River, northern California. Funding for this study was provided by the Bureau of Reclamation, Klamath Basin Area Office. The purpose of the study was to provide information about the relation between survival of juvenile coho salmon and river water discharge in the Klamath River downstream of Iron Gate Dam [river kilometer (rkm) 310]. The study fish were part of the Southern Oregon/Northern California Coasts Evolutionary Significant Unit of coho salmon listed under the Endangered Species Act (ESA) in 1997. In 2006, both hatchery and wild fish were tagged, but in 2007 and 2008, the numbers of wild juvenile coho salmon in nearby tributaries were low and only hatchery fish were tagged. In 2009, we again tagged both hatchery and wild fish.

This report describes results from the 2009 study to date and is a complement to similar reports describing survival estimates in 2006, 2007, and 2008 (Beeman, 2007, 2008; Beeman and others, 2007, 2009). The design and methods of the studies were similar in each year, and are briefly described below.

The study design was based on a need to estimate apparent survival probabilities of juvenile coho salmon in the Klamath River downstream of Iron Gate Dam. The analytical approach, described in Burnham and others (1987), is based on Cormack-Jolly-Seber capture-mark-recapture models (Cormack, 1964; Jolly, 1965; Seber, 1965). Apparent survival is the probability that an animal remains available for recapture. In the context of this study, it is the joint probability that the animal is both alive and migrates through the study area. As such, fish that stop migrating within the study area, travel to areas outside the mainstem Klamath River and do not return, or those that remain within the study area after the radio tags deplete their battery and cease transmitting, are counted as mortalities. All references to ‘survival’ in this document refer to apparent survival. Survival through all but the last of eight river reaches delineated (fig. 1) was estimated from data obtained by telemetry receiving equipment. Survival could not be estimated in the last reach because only the joint probability of survival and recapture is known in the last reach in Cormack-Jolly-Seber models.

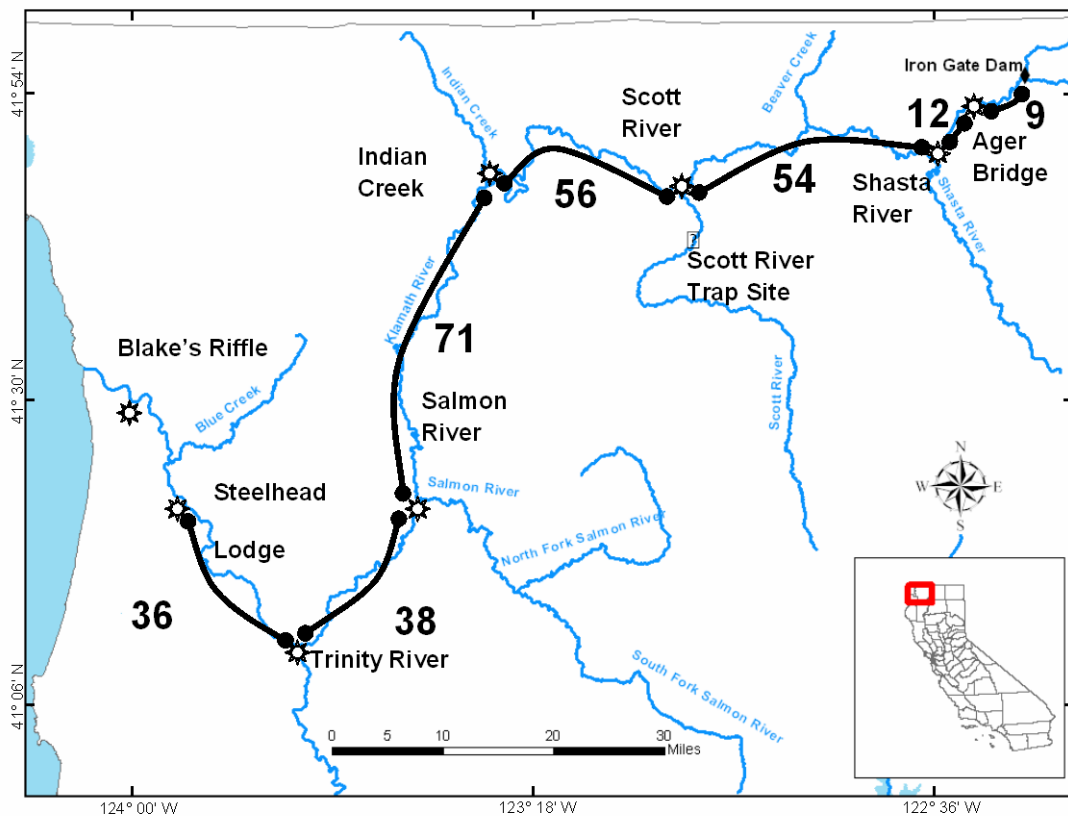


Figure 1. Map showing study area of the Klamath River juvenile coho salmon survival study, northern California, 2009. Detection sites are indicated by ☼. Large, bold numbers indicate reach lengths in kilometers. Figure modified from U.S. Fish and Wildlife Service, Arcata, CA, 2006.

In 2009, we surgically implanted radio tags into yearling coho salmon of hatchery origin from Iron Gate Hatchery, as well as into yearling coho salmon of wild (or natural) origin from the Scott River. The radio tags weighed 0.43 grams in air and had dimensions of 13.5 mm length, 5.3 mm width, and 3.3 mm height and had a 16 cm long trailing antenna. The hatchery fish ($n = 189$ fish) were taken directly from a tank at the hatchery. The wild fish ($n = 60$ fish) were taken from the catch of a rotary trap located at approximately rkm 8 of the Scott River, operated by the California Department of Fish and Game. In 2006, the wild fish were taken from a similar trap on the Shasta River. The intent of using both hatchery and wild groups was to determine if hatchery fish could be used as surrogates for the limited supply of wild fish to study factors affecting the survival of juvenile coho salmon. All fish were released into the Klamath River near the hatchery (rkm 309) at nautical twilight during several dates each week beginning on April 16, 2009, and ending on May 28, 2009. There were no mortalities of study fish during the holding, tagging, or releasing periods. No fish were released downstream as in some previous years due to differences in migratory behaviors and survivals of fish released near the hatchery and fish released near the Tree of Heaven campground (rkm 280) in 2007 (Beeman and others, 2008). Data were analyzed several months after the last fish was released; the last fish detection was on June 22, 2009. Twenty-five transmitters were held in a laboratory setting (submerged in water) to measure transmitter life. The tested radio transmitters lasted between 58 and 70 days, and the longest travel time recorded from a fish was 41.5 d.

Survival of Juvenile Coho Salmon Through River Reaches

The survival of fish through each reach and over multiple reaches was estimated using the single-release design (Burnham and others, 1987). The modeling approach was similar to that used in previous years. A series of *a-priori* models was created and ordered in terms of parsimony using program MARK (White and Burnham, 1999). The analysis included a suite of models describing recapture probabilities and survival probabilities of fish from the two origins (hatchery and wild) in each of the common reaches. The models were ranked using a variant of Akaike's Information Criterion adjusted for small sample sizes (AICc) to determine which models were best supported by the data. Recapture probability and survival were then estimated from one or more of the models depending on the level of support each received. The general methods are described in Burnham and Anderson (2002). Because recapture probabilities were at or near 1.0, overdispersion—the presence of greater sampling variance than model-based variance—could not be estimated, but was believed to be negligible.

Fish of Hatchery Origin

Survival was estimated from the data collected on hatchery fish on all release dates (April 16 to May 28, 2009). The dataset included information for 189 fish after censoring from the analysis one animal that was found dead in a rotary screw trap between the Shasta and Scott Rivers. Three models were compared to evaluate various hypotheses of factors affecting recapture and survival probabilities. These models were based on differences in these probabilities among reaches as well as a common value of each parameter fitted to all reaches. The model based on differences in survival and recapture probabilities among reaches received nearly 95 percent of the model weight, indicating that it was clearly the most supported hypothesis of those evaluated (model 1, table 1). To incorporate model selection uncertainty, the estimates of recapture and survival probabilities were based on model-averaged results of all models in the set listed in table 1. In this procedure, the coefficients for each

effect in each model are averaged across all models after weighting by the AICc weights (Burnham and Anderson, 2002). The model-averaged results indicated that recapture probabilities ranged from 0.77 [standard error (SE) 0.032] at the Ager Bridge site to 0.98 (SE 0.011) or greater at all other sites. The estimate of recapture probability at most sites was 1.0. The low estimate at the Ager Bridge site relative to that at the other sites was due to equipment failure over several days. The estimates of survival ranged from 0.870 (SE 0.031) through the 71-km reach from Indian Creek to the Salmon River, to 0.961 (SE 0.019) through the 9-km reach from Iron Gate Hatchery (the release point) to the Ager Road Bridge (table 2). The survival estimate through the 276 km reach from release at Iron Gate Hatchery to Steelhead Lodge was 0.555 (SE 0.038). Overall, the reach-specific estimates of survival from hatchery fish in 2009 were most similar to those from 2006, particularly upstream of the Scott River junction.

Table 1. Summary of models used to estimate apparent survival (Φ) and recapture probabilities (P) of hatchery-origin juvenile coho salmon in study reaches of the Klamath River during spring 2009.

[Models are based on data from 189 hatchery fish from Iron Gate Hatchery. All fish were released in the Klamath River near the hatchery between April 16 and May 28, 2009. Rankings are based on AICc, a modification of the Akaike's Information Criterion for small samples. A '.' indicates a single value fitted to all reaches]

Model No.	Model	AICc	Delta AICc	AICc weights	Model likelihood	Number of parameters	Deviance
1	{ Φ (reach), P (reach)}	840.839	0.000	0.948	1.000	15	8.586
2	{ Φ (.), P (reach)}	846.644	5.806	0.052	0.055	9	26.662
3	{ Φ (reach), P (.)}	958.441	117.602	0.000	0.000	9	138.458

Table 2. Estimated apparent survivals of radio-tagged juvenile hatchery-origin coho salmon in study reaches of the Klamath River during spring 2009.

[Results are based on data from 189 fish released from Iron Gate Hatchery. All fish were released in the Klamath River near the hatchery between April 16 and May 28, 2009. Results are based on model-averaging the models in table 1. Estimates over multiple reaches were calculated as the product of the individual reach estimates with variances estimated using the delta method]

Reach No.	Description	Reach length (km)	Apparent survival	Standard error	95-percent confidence interval	
					Lower	Upper
1	Release to Ager Road Bridge (rkm 300)	9	0.961	0.019	0.902	0.985
2	Ager Road Bridge to Shasta River (rkm 288)	12	0.930	0.021	0.875	0.962
3	Shasta River to Scott River (rkm 234)	54	0.904	0.023	0.848	0.941
4	Scott River to Indian Creek (rkm 178)	56	0.940	0.019	0.890	0.968
5	Indian Creek to Salmon River (rkm 107)	71	0.870	0.031	0.797	0.920
6	Salmon River to Trinity River (rkm 69)	38	0.912	0.025	0.849	0.950
7	Trinity River to Steelhead Lodge (rkm 33)	36	0.921	0.025	0.856	0.958
	Release to Shasta River	21	0.894	0.027	0.841	0.947
	Release to Scott River	75	0.808	0.032	0.746	0.871
	Release to Steelhead Lodge	276	0.555	0.038	0.481	0.630

Fish of Hatchery Origin Compared to Fish of Wild Origin

Numerical models developed with and without accounting for the effect of fish origin on recapture and survival probabilities were evaluated to determine if the data supported differences in survival based on fish origin. The comparisons were based on dates in which at least four fish from each origin were released (April 16 through April 30, 2009), providing 57 fish from each origin for analysis. A model of recapture probability based on differences between origins and among reaches received 71 percent of the AICc weight and was used in all models of survival. A model of recapture probability varying among reach, but not between origins, received 21 percent of the model weight. The use of either model produced trivial differences in survivals.

The data provided moderate support for differences in survival based on fish origin (table 3). A model based on differences in survival among reaches received 60 percent of the AICc model weight (model 4) and a competing model with the added effect of origin received 26 percent of the model weight (model 5), for a delta AICc value of 1.7. A model based on a common survival for all origins and reaches received 8 percent of the AICc model weight (model 6). Estimates of recapture and survival probabilities were based on model-averaged results of the set of models in table 3 to incorporate model selection uncertainty into the estimates.

The estimates of survival for fish of hatchery and wild origins were almost identical (table 4). Differences in reach-specific survivals between origins were less than 1 percent and the estimated survival through the 276 km reach from release to Steelhead Lodge was 0.659 (SE 0.049) for hatchery fish and 0.641 (SE 0.051) for wild fish.

Table 3. Summary of models used to estimate apparent survival (Φ) and recapture probabilities (P) of hatchery- and wild-origin juvenile coho salmon in study reaches of the Klamath River during spring 2009 on dates at least four of each group were released.

[Models are based on data from 57 fish released 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. Rankings are based on AICc, a modification of the Akaike's Information Criterion for small samples. A '+' between factors indicates an additive effect, a '*' between factors indicates a multiplicative effect, and a '.' indicates a single value fitted to all levels of origin and reach]

Model No.	Model	AICc	Delta AICc	AICc weights	Model likelihood	Number of parameters	Deviance
4	{ Φ (reach), P (origin+reach)}	390.178	0.000	0.605	1.000	16	22.918
5	{ Φ (origin+reach), P (origin+reach)}	391.899	1.721	0.256	0.423	17	22.538
6	{ Φ (.), P (origin+reach)}	394.227	4.050	0.080	0.132	10	39.448
7	{ Φ (origin), P (origin+reach)}	395.665	5.488	0.039	0.064	11	38.821
8	{ Φ (origin*reach), P (origin+reach)}	397.067	6.890	0.019	0.032	24	12.820
9	{global model}	403.994	13.817	0.001	0.001	30	6.739

Table 4. Estimated apparent survivals of radio-tagged juvenile coho salmon of hatchery- and wild-origin in study reaches of the Klamath River during 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 table 3. Estimates over multiple reaches were calculated as the product of the individual reach estimates with variances estimated using the delta method]

Reach No.	Description	Reach length (km)	Apparent survival	Standard error	95-percent confidence interval	
					Lower	Upper
----- Origin = Hatchery -----						
1	Release to Ager Road Bridge (rkm 300)	9	0.919	0.029	0.840	0.960
2	Ager Bridge to Shasta River (rkm 288)	12	0.890	0.039	0.787	0.946
3	Shasta River to Scott River (rkm 234)	54	0.933	0.027	0.857	0.970
4	Scott River to Indian Creek (rkm 178)	56	0.963	0.020	0.894	0.988
5	Indian Creek to Salmon River (rkm 107)	71	0.962	0.021	0.893	0.987
6	Salmon River to Trinity River (rkm 69)	38	0.961	0.021	0.889	0.987
7	Trinity River to Steelhead Lodge (rkm 33)	36	0.970	0.021	0.890	0.992
	Release to Shasta River	21	0.817	0.044	0.731	0.904
	Release to Scott River	75	0.763	0.047	0.671	0.854
	Release to Steelhead Lodge	276	0.659	0.049	0.562	0.756
----- Origin = Wild -----						
1	Release to Ager Road Bridge (rkm 300)	9	0.912	0.031	0.830	0.957
2	Ager Bridge to Shasta River (rkm 288)	12	0.881	0.042	0.773	0.942
3	Shasta River to Scott River (rkm 234)	54	0.931	0.028	0.851	0.970
4	Scott River to Indian Creek (rkm 178)	56	0.961	0.022	0.888	0.987
5	Indian Creek to Salmon River (rkm 107)	71	0.959	0.022	0.885	0.986
6	Salmon River to Trinity River (rkm 69)	38	0.959	0.023	0.883	0.986
7	Trinity River to Steelhead Lodge (rkm 33)	36	0.969	0.022	0.884	0.992
	Release to Shasta River	21	0.804	0.047	0.713	0.896
	Release to Scott River	75	0.749	0.049	0.653	0.845
	Release to Steelhead Lodge	276	0.641	0.051	0.541	0.742

Summary

This report is a brief summary of the results from the fourth and final year of a study of the survival of juvenile coho salmon in the Klamath River, northern California, downstream of the Iron Gate Dam. Summaries such as this have been provided for each year of the study. The survival probability of hatchery-origin fish from Iron Gate Hatchery (at river kilometer 309) to Steelhead Lodge (at river kilometer 33) in 2009 (0.555, SE 0.038) was slightly greater than in 2008 (0.406, SE 0.032; hatchery tank group) and 2007 (0.497, SE 0.044), but lower than in 2006 (0.653, SE 0.039). The survivals of hatchery-origin and wild fish were similar in 2006 and 2009, the only years for which adequate numbers of wild fish were available for analysis.

Acknowledgments

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