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Effect of Dietary Salt on Migration and Survival of Yearling Steelhead Produced at Iron Gate Hatchery, Klamath River, 2009

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Effect of dietary salt on migration and survival of yearling steelhead produced at Iron Gate Hatchery, Klamath River, 2009

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Abstract. We surgically implanted radio transmitters into 30 hatchery yearling steelhead (*Oncorhynchus mykiss*) released from Iron Gate Hatchery during the spring of 2009 to improve our understanding of the effect of dietary salt on their out-migration and survival. Steelhead yearlings were divided into two feed treatments to test the efficacy of a salt-enriched feed in promoting out-migration. Fish were fed either their regular diet (control treatment) or a salt-enriched diet (test treatment) for 38 d prior to their release. We implanted 15 fish of each treatment with radio transmitters for a total of 30 tagged individuals. Nine of the radio-tagged steelhead (four of the control treatment; five of the test treatment) completed their downstream migration to the estuary within the 60-d operational period of the tags. Tagged fish migrated from the hatchery release site to the estuary in an average of 45 d. Neither migration nor survival differed between diet treatments, but small sample size and the relatively short duration of this study limit the conclusiveness of our findings.

INTRODUCTION

Iron Gate Hatchery (IGH), operated by the California Department of Fish and Game (CDFG) with funding from PacifiCorp, produces Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead (*O. mykiss*) to mitigate for population losses resulting from Klamath Hydropower Project operations. This hydropower project consists of six dams that extend from Iron Gate Dam (IGD) at river kilometer (rkm) 310 to Link Dam at the outlet of Upper Klamath Lake (rkm 399). The hatchery is located at the base of IGD, and is required to release 200,000 yearling steelhead each year to mitigate the construction of IGD in 1961-1962 and the loss of habitat from this dam to the Copco Dam complex approximately 18 rkm upstream. This goal has not been achieved since 1991 due to extremely low returns of adult steelhead to the hatchery (Appendices A and B; K. Rushton, IGH manager, unpublished data). This population decline has motivated research concerning the survival and out-migration of juvenile steelhead produced at the hatchery.

Oncorhynchus mykiss is the most abundant and widespread native species of salmonid in western North America, ranging north from the Kuskokwim River in Alaska south to Baja California (Moyle 2002). Like many salmonids, the species exhibits a phenomenon known as partial migration, having populations that exhibit both migratory and resident life histories (Jonsson and Jonsson 1993). The migratory anadromous form of *O. mykiss* is commonly called steelhead whereas the resident freshwater form is referred to as rainbow trout. However, life history patterns of *O. mykiss* are more complex than this simple division, with the species exhibiting varying degrees of anadromy and plasticity in the expression of anadromy between generations. Anadromous steelhead can produce resident offspring, and vice versa (Ruzycki et al. 2003; Kostow 2003). Anadromous and resident life history forms of *O. mykiss* coexist in the Klamath River and the relationship between the two forms is not well understood. In this report we will use the term steelhead to describe all *O. mykiss* produced at IGH, regardless of their future life history.

There is concern that a high percentage of juvenile steelhead released from IGH are residualizing in the Klamath River. Residual hatchery steelhead never migrate to the ocean and instead, complete their lifecycle in freshwater. Studies in other river systems have documented hatchery-produced steelhead residualizing (Viola and Schuck 1995; McMichael and Pearsons 2001; Naman 2008). A scale analysis of adult steelhead returning to IGH in 1993 found that only three of the 12 fish examined exhibited ocean growth patterns (Jong 1994 in Chesney 2003). Otolith microchemisty analysis of 19 adult steelhead returning to IGH in 2002 found that eight were anadromous, eight were resident, and three had intermediate life histories that could not be classified (Chesney 2003). In a separate otolith microchemistry study, Donohoe et al. (2008) found that 36 of 76 adult steelhead sampled upon return to IGH were resident fish, and 50% of those identified as resident fish were progeny of anadromous females.

Iron Gate Hatchery personnel, with the support of CDFG biologists, have investigated methods to increase the out-migration rate of yearling steelhead. In 2001, hatchery release techniques for yearling steelhead production changed from a forced to volitional release to promote anadromy. Higher emigration rates may increase abundance of hatchery returns by increasing juvenile survival and therefore, subsequent adult returns. An increase in emigration rates may also benefit wild salmonid populations in the Klamath River by minimizing competition for space, food (McMichael et al. 1997), and predation (Naman 2008). When hatchery fish remain permanently in freshwater (i.e. residualization) the potential for negative interactions with juvenile wild fish is greatest.

In the spring of 2009 hatchery personnel experimented with a new method thought to increase smoltification and out-migration of juvenile salmonids: a salt-enriched diet. Several studies indicate that a salt-enriched diet prepares juvenile salmonids for the freshwater-to-saltwater osmoregulatory transformation (Zaugg et al. 1983; Staurnes and Finstand 2000; Perry et al. 2006). Hatchery staff divided production yearling steelhead into two diet treatments; one treatment was fed the standard (control) diet and the other a salt-enriched (test) diet. We were asked to evaluate the migration and survival of these steelhead using radio telemetry, because we had stationary radio telemetry receivers installed along the Klamath River for a multi-year study of juvenile coho salmon outmigration (Beeman 2007, 2008; Beeman and Juhnke 2009; Beeman et al. 2007, 2008, 2009; Stutzer et al. 2006). The main objectives of this study are to investigate: 1) if yearling hatchery steelhead survive and emigrate to the ocean; 2) emigration rate of yearling hatchery steelhead; 3) if there is a difference in survival or rate of emigration between the control and test diet treatments of yearling hatchery steelhead.

STUDY AREA

The Klamath River and its watershed encompass more than 40,403 km^2 in northern California and southern Oregon. This study took place on the lower 310 rkm of the mainstem Klamath River from Iron Gate Dam to the estuary near the river's mouth at the Pacific Ocean (Figure 1). Principal tributaries to the lower Klamath River include the Trinity, Salmon, Scott, and Shasta Rivers. Stationary radio telemetry detection sites were located near the confluences of major tributaries and near the estuary (Figure 1).

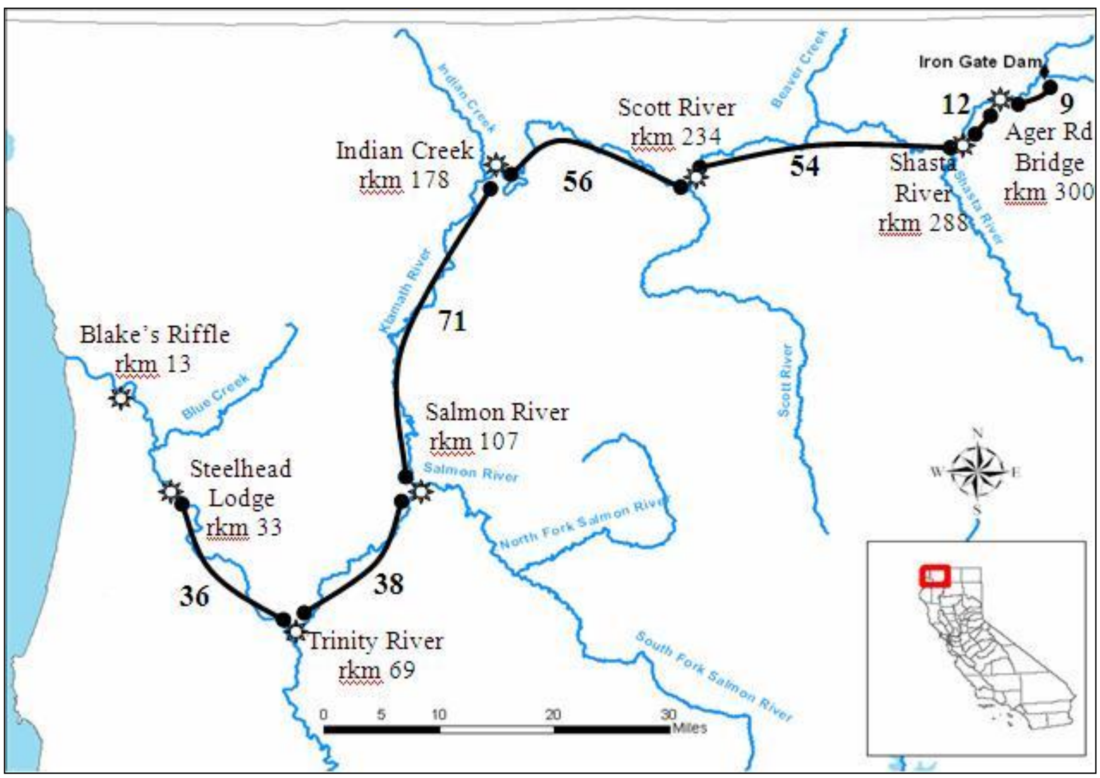

Figure 1. Map showing study area of the Klamath River hatchery yearling steelhead survival study, northern California, 2009. Stationary radio telemetry detection sites are indicated by ☼. Bold numbers indicate reach lengths in kilometers.

METHODS

Diet Treatments

Yearling steelhead were divided into two groups of approximately 15,000 fish each by hatchery personnel on March 10, 2009. Fish were held in the same raceway with the control treatment positioned upstream of the test treatment. The control treatment was Nelson and Sons' Silver Cup Slow Sinking Salmon diet (2.0 mm pellet size) and the test treatment was Bio-Oregon's BioTransfer diet (2.5 mm pellet size), which were relatively similar in composition to one another with the exception of salt content (Table 1). The test diet is a saltwater preparation feed containing a proprietary salt amount. Fish were treated for 38 d prior to release on April 17, 2009.

Tagging Procedure

Thirty hatchery steelhead (15 of each diet treatment) were implanted with radio transmitters on April 16, 2009. We used Lotek model NTC-M-2 transmitters, which have dimensions of 13 mm x 5 mm x 3 mm in size, weigh 0.43 g in air and 0.29 g in water, and have a 16 cm trailing antenna. The transmitter's weight in air represented 0.81% of the mean body weight of the fish and ranged from 0.38 to 2.9% of each individual's body weight, well under the recommended 5% maximum recommended by Adams et al. (1998). Mean weight of the fish before tagging was 53.3 g (SD = 19.4) and mean fork length was 166 mm (SD = 20.9). The life of this transmitter using a coded burst rate of 8 seconds was guaranteed for 45 d, and 24 transmitters tested in 2009 lasted a mean of 65.3 d and ranged from 58.3 to 69.5 d (S. Juhnke, personal communication). The transmitters operated at frequencies of 164.360, 166.620, and 167.280 MHz.

The procedure used to surgically implant the radio transmitters was similar to that used by Adams et al. (1998). Before surgery each steelhead was anesthetized in a bath of tricaine methanesulfonate (70 mg/L Finquel MS-222, Argent Chemical Laboratories, Redmond, Washington) until loss of equilibrium occurred. A foam pad with a central groove shaped to fit the dorsal surface of a small fish was covered with a chamois soaked in PolyAqua (Novalek, Inc., Hayward, California) and used to support the fish's body during surgery. Fish were placed ventral side up on the surgical support pad, and the gills were flushed with anesthetic solution (20 mg/L MS-222) for the duration of the surgery through tubing placed in fish's mouth. The mean (± 1 SD) time to complete each surgical procedure was 3 min 02 s (± 30 s).

Table 1. Percent composition of control (Nelson and Sons' Silver Cup Slow Sinking Salmon diet) and test (Bio-Oregon's BioTransfer diet) treatments used at Iron Gate Hatchery, 2009. Analyses of feed composition were performed by the manufacturers.

Diet Treatment	Protein Minimum	Oil Minimum	Moisture Maximum	Fiber Maximum	Ash Maximum	Digestible Energy (MJ/kg)
Control	45%	19%	<10%	3%	12%	19.5
Test	50%	20%	8.5%	1%	12%	18.9

Surgical tools and equipment were disinfected according to the procedures described by Summerfelt and Smith (1990). To reduce the likelihood of infection, the transmitters were disinfected prior to insertion using a 0.5% solution of chlorohexidine diacetate (Nolvasan Fort Dodge Animal Health, Fort Dodge, Iowa) and then rinsed twice in sterile water. Sterile surgical gloves were worn during each surgery.

To implant the transmitter, an approximately 7 mm incision was made 5 mm anterior to the pelvic girdle and 3 mm away from and parallel to the mid ventral line. The incision was made only deep enough to penetrate the peritoneum, using extra care so as not to damage vital organs (Summerfelt and Smith 1990). A shielded needle (Nipro I.V., 20-gauge x 5 cm) was used to guide the antenna through the body wall of the fish as described by Ross and Kleiner (1982). Once the transmitter was in position, one simple, interrupted absorbable suture (Ethicon coated vicryl braided suture 5-0, reverse cutting P-3 needle) was used to close the incision.

Following surgery, each fish was placed in a recovery bath of fresh river water until it regained equilibrium. Fish were then transferred to net pens (1.2 x 0.61 x 0.61 m with 5 x 5 mm bar mesh) moored in the Klamath River near the IGH adult ladder entrance and held overnight for at least 13 h (range 13-18 h) to monitor recovery and ensure proper functioning of the radio transmitter. Radio-tagged steelhead were released at the same time as the 29,683 production hatchery yearling steelhead on the morning of April 17, 2009.

Additional Sampling Procedures

The 30 steelhead implanted with radio transmitters were sampled for size, gill ATPase, and assigned a smoltification ranking based upon external examination. We also randomly sampled 60 steelhead yearlings of each treatment from the total population in the hatchery raceway. From these fish we collected a tissue sample for genetic archival, size, gill ATPase, and blood hormone information and assigned a smoltification ranking based on external examination (Table 2).

Table 2. Sampling plan for yearling steelhead at Iron Gate Hatchery, April 16, 2009.

Fish Source	Sample Type	Reason	Number per Treatment	Total
Radio-tagged	Length and weight	Size	All	30
Radio-tagged	Gill tissue	ATPase	All	30
Radio-tagged	External visual examination	Smolt ranking	All	30
Population	Fin clip	Genetics	60	120
Population	Length and weight	Size	60	120
Population	External visual examination	Smolt ranking	60	120
Population	Gill tissue	ATPase	20 (every third fish)	40
Population	Plasma	Hormones	30 (every other fish)	60

Genetics. Caudal fin clips were collected and preserved in 95% ethyl alcohol for future genetic testing when funds become available.

Size. The fork length of each sampled steelhead was measured to the nearest millimeter and recorded. Each fish's weight was measured and recorded to the nearest tenth of a gram. Condition factor for each fish was calculated using Fulton's formula, $K = 10^5 * W/L^3$, where K is the condition factor, W is the weight of the fish in grams, and L is the fork length of the fish in millimeters.

Smoltification ranking index. All fish were visually examined and assigned a smoltification ranking following Prentice et al. (1981). Details of the smoltification index can be viewed in Table 3.

Gill ATPase. Non-lethal micro-clip samples of gill tissue were collected to determine the level of Na^+-K^+ gill ATPase activity as a measure of smoltification. Martinelli-Liedtke et al. (1999) found that non-lethal gill biopsies did not affect subsequent health, growth, or survival of radio-tagged juvenile salmonids.

After fish were anesthetized for surgery, a 3 x 4 mm section of gill filaments was clipped from the center section of the first gill arch on the left side of the fish. This sample was immediately placed in a vial with 0.5 mL of a chilled preservative solution of sucrose, EDTA (ethelynediaminetetraacetic acid), and imidazole, which was immersed in liquid nitrogen and then stored at -80º C. These gill samples will be held for processing at an undetermined future date when funds become available.

Table 3. Smoltification index used to rank yearling steelhead at Iron Gate Hatchery, April 16, 2009.

Smoltification Rank	External physical characteristics
Parr (P)	Light brown to yellowish overall color, yellow to brownish-orange fin color, parr marks dark and clearly evident, little or no silvering of scales, and relatively robust in appearance. The ratio of eyeball diameter to its total length (E:L) is usually greater in parr stage fish than in other smoltification stages.
Transitional (T)	Parr marks partly obscured because of guanine deposition in the scales, although not completely silvery; fin color becoming clear or uniform light gray; relatively robust in appearance; E:L ratio decreasing from that of a parr.
Smolt (S1)	Parr marks almost completely obscured by the silvery appearance of the scales, fins are clear with slight intensification of black pigment (melanin) at outer edge of dorsal fin and extremities of caudal fin lobes, and fish are relatively thinner in appearance. E:L decreasing.
Smolt (S2)	Parr marks completely absent, fins clear with greater intensification of black pigment at outer edges of dorsal fin and caudal fin lobes, and fish are slender in appearance.
Smolt (S3)	Parr marks completely absent, fins clear with very intense black (almost fluorescent) pigment at outer extremities of dorsal fin and caudal fin lobes, and fish are slender in appearance.

Blood plasma. Thirty fish of each diet treatment were euthanized with an overdose of MS-222. The caudal fin of each fish was cut off and blood was drawn from the dorsal aorta using a heparinized microhematocrit tube (1.1-1.2 mm diameter, 75 mm length). The microhematocrit tubes were spun in a centrifuge for 1-2 minutes at approximately 6,000 rpm to separate plasma from blood. Plasma was transferred into a 1.5 mL vial which was then immersed in liquid nitrogen and stored at -80º C for future analysis when funds become available.

Mobile Detection Systems

Mobile tracking was conducted to locate tagged fish between stationary detection stations. Mobile tracking surveys were made from inflatable rafts and automobiles using a Lotek SRX-400 receiver connected to a three-element Yagi antenna. A Global Positioning System receiver (Garmin model Global Positioning System Map 76S) was used to record the location when radio-tagged fish were detected. Using a geographic information system database, these locations were overlaid on a map of the Klamath River and converted into river kilometer locations.

Stationary Detection Systems

Eight automated radio telemetry stations were installed along the mainstem Klamath River in the study reach from Iron Gate Dam to the estuary (Figure 1). The location and dates of operation of each station are listed in Table 4. These stations were established for a juvenile coho salmon radio telemetry study and were in operation in excess of the tag life expectancy of the radio transmitters implanted in the yearling steelhead (Beeman and Juhnke 2009). Each station consisted of two to four Yagi aerial antennas (three- and six-element versions) mounted on a 3 m mast, connected to two data-logging receivers. These receivers were powered by a 12 V system (two 180 amp hour batteries) charged by a 170 W photovoltaic bank. Two types of receivers were used at each site (SRX-400, Lotek Wireless, Newmarket, Ontario, Canada; Orion, Grant Systems Engineering, Newcastle, Ontario, Canada). Stations were configured to maximize the detection of tagged fish. When a fish was detected, the data-logging receivers recorded transmitter channel (frequency), code, signal strength, time, and date.

Table 4. Summary of automated radio telemetry stations deployed on the Klamath River, 2009.

Site location	rkm	Site coordinates	Receiver type	Dates of operation
Ager Bridge	300	41°53’51”N - 122°30’14”W	SRX-400 & Orion	03/21/09 – 08/05/09
Shasta River	288	41°49’48”N - 122°35’36”W	SRX-400 & Orion	03/21/09 – 08/05/09
Scott River	234	41°47’14”N - 123°01’49”W	SRX-400 & Orion	03/21/09 – 08/05/09
Indian Creek	178	41°48’31”N - 123°21’39”W	SRX-400 & Orion	03/20/09 – 08/05/09
Salmon River	107	41°22’37”N - 123°29’34”W	SRX-400 & Orion	03/20/09 – 08/05/09
Trinity River	69	41°11’13”N - 123°42’09”W	SRX-400 & Orion	03/20/09 – 08/05/09
Steelhead Lodge	33	41°22’47”N - 123°54’45”W	SRX-400 & Orion	03/19/09 – 08/05/09
Blake’s Riffle	13	41°30’40”N - 123°58’33”W	SRX-400 & Orion	03/19/09 – 08/05/09

Migration Analysis

Migration of radio-tagged fish was analyzed using time-to-event methods. We calculated 'travel time,' the length of time taken to migrate through reaches of known length, for radio-tagged fish through each study reach. Travel time was calculated as the time from the last detection at the upstream end of the reach (or the release time in the case of the first reach) to the first detection at the downstream end of the reach. Migration rates were calculated as distance traveled divided by travel time.

Survival Analysis

The apparent survival of juvenile steelhead was estimated using Cormack-Jolly-Seber mark-recapture methods (Cormack 1964; Jolly 1965; Seber 1965). These methods are based on separately estimating the probabilities of detection and survival, because detection of an animal is their joint probability. The methods used in this analysis were nearly identical to those described by Beeman and Juhnke (2009). In studies of animals detected remotely, such as with the radio transmitters used in this study, the estimated survival is called apparent survival. Fish that stop migrating within the study area, travel to areas outside the mainstem Klamath River and do not return, or 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.

Estimates of survival were based on model-averaging a-priori models representing several hypotheses of factors affecting survival or recapture probabilities. Models of survival probabilities included river reach and hatchery feed type as well as various combinations of the two, including one model with a constant survival over all reaches and diets. Models of recapture probabilities were based on stationary detection site or a constant value for all sites. The entire suite of models was averaged prior to estimating survival using methods of Burnham and Anderson (2002).

RESULTS

Fish Size

The mean fork lengths, weights, and condition factors of radio-tagged and population steelhead in control and test feed treatments are shown in Table 5. There was no difference between the means of radio-tagged feed treatments in terms of FL ($t_{0.05\,(2),\,28}$ = 0.405, P = 0.688), weight ($t_{0.05\,(2),\,28}$ = 0.571, P = 0.573), or condition factor ($t_{0.05\,(2),\,28}$ = 0.425, P = 0.674). The hatchery steelhead we tagged were not different in terms of FL ($t_{0.05\,(2),\,148}$ = 1.28, P = 0.202), weight ($t_{0.05\,(2),\,148}$ = 1.51, P = 0.134), or condition factor ($t_{0.05\,(2),\,148}$ = 0.730, P = 0.466) compared to supplemental fish sampled from the raceway population.

Table 5. Mean fork length (FL), mean weight, and mean condition factor of hatchery yearling steelhead, Iron Gate Hatchery, Klamath River, 2009. Standard deviations of the means are given in parentheses.

Sample source	Diet treatment	n	Mean FL (mm)	Mean weight (g)	Mean condition factor (K)
Radio-tagged	Control	15	168 (23.3)	55.3 (21.8)	1.12 (0.0655)
Radio-tagged	Test	15	165 (18.7)	51.2 (17.3)	1.11 (0.0572)
Population	Control	60	159 (22.8)	47.0 (17.5)	1.11 (0.0570)
Population	Test	60	162 (19.5)	48.6 (17.1)	1.10 (0.0553)

Smoltification Ranking Index

All yearling steelhead we sampled were visually examined and assigned a smoltification ranking (Table 6). Percentages in the tagged fish showed no differences between treatments, however the fish sampled from the population did exhibit some difference between treatments. The majority of the fish were transitional.

Mobile Detection Systems

Eleven mobile tracking surveys were conducted to locate tagged steelhead between stationary receiver systems (Table 7). These surveys began on May 14, 2009, which was 28 d after the radio tags began transmitting (27 d after tagged steelhead were released), and ended on June 25, 2009, 70 d after the radio tags began transmitting (69 d after tagged steelhead were released). There were 16 unique detections of radio-tagged steelhead within the survey area from Iron Gate Hatchery to Sluice Box (rkm 309.8 to 211.0).

Fish were classified as migrants or non-migrants depending on their detection history (Table 8). Six tagged steelhead (four of the control treatment and two of the test treatment) were never detected by mobile tracking or stationary receivers after their release. Migrant steelhead were either first detected in one location and then not present on subsequent surveys that included that location, or were detected further downstream on subsequent mobile tracking surveys or by stationary receivers. Two migrants were detected on subsequent surveys 18.1 and 21.5 rkm downstream from their previous location. Six fish located during mobile tracking were later detected by a downstream stationary receiver. Non-migrant steelhead did not move more than 0.3 rkm between surveys and were detected on each survey of that area. Surveys 10 and 11 took place after the tag life had expired, and were not used to evaluate whether tagged fish had migrated out of the survey area.

Stationary Detection Systems

Migration and survival analyses were performed using the capture histories of fish recorded passing stationary detection systems (Appendix C). Capture probabilities of fish passing the stationary detection systems averaged 0.9394 (range 0.9253–0.9470).

Table 6. Percentages of hatchery yearling steelhead exhibiting parr, transitional, or smolt characteristics, Iron Gate Hatchery, Klamath River, 2009.

Sample source	Diet treatment	n	Parr	Transitional	Smolt (S1)	Smolt (S2)	Smolt (S3)
Radio-tagged	Control	15	0	73.3	26.7	0	0
Radio-tagged	Test	15	0	73.3	26.7	0	0
Population	Control	60	6.7	71.7	21.7	0	0
Population	Test	60	0	75.0	21.7	3.3	0

Table 7. Summary of mobile tracking surveys and number of tagged steelhead detected, Klamath River, 2009. Tag life day is the number of days since tags began transmitting.

			Upper boundary		Lower boundary		Number of
Survey	Date	Tag life day	Location	rkm	Location	rkm	steelhead detected
1	14-May-09	28	Shasta River	288.4	Skeahan Bar	274.9	5
2	26-May-09	40	Iron Gate Hatchery	309.8	Deliverance Camp	287.2	10
3	27-May-09	41	Interstate 5 Bridge	293.5	Community Center	257.8	6
4	28-May-09	42	Community Center	257.8	Sarah Totten Campground	232.2	1
5	29-May-09	43	Sarah Totten Campground	232.2	Sluice Box	211.0	1
6	3-Jun-09	48	Iron Gate Hatchery	309.8	Interstate 5 Bridge	293.5	5
7	4-Jun-09	49	Interstate 5 Bridge	293.5	Deliverance Camp	287.2	2
8	11-Jun-09	56	Deliverance Camp	287.2	Beaver Creek	261.9	3
9	12-Jun-09	57	Fish Hook Restaurant	307.1	Ager Bridge	300.7	2
10	24-Jun-09	69	Deliverance Camp	287.2	Community Center	257.8	0
11	25-Jun-09	70	Fish Hook Restaurant	307.1	Ager Bridge	300.7	0

Table 8. Number of tagged steelhead from each diet treatment that exhibited migrant or non-migrant behavior based upon mobile tracking data, Klamath River, 2009.

Diet treatment	Migrant	Non-migrant
Control	6	2
Test	3	5

Migration Analysis

Nine of the thirty radio-tagged yearling steelhead successfully migrated downstream to the estuary during the battery life of the radio transmitters: four from the control treatment and five from the test treatment. The travel times of these individuals through the 296 km study area ranged from 37.2 to 54.5 d with a median of 43.4 d. Mean total migration time (from release to final detection at rkm 13) was 43.4 d (SD = 5.7) for the control treatment, and 45.6 d (SD = 7.5) for the test treatment. There was no difference in mean total travel duration between the two treatments ($t_{0.05\,(2),\,7} = -0.48$, $P = 0.648$).

Travel time spent within each study reach tended to decrease as steelhead moved downstream (Table 9). Migration rate (distance traveled per day) increased as fish moved downstream from release to the last detection site at Blake's Riffle (Figure 2). This does not necessarily mean that fish were swimming more quickly through downstream reaches since migration rate is a function of fish movement as well as water velocity. As the river flowed downstream, tributary inputs added to the main stem river volume and increased flow rate. Overlapping confidence intervals around mean migration rates indicate little difference between diet treatments. The dates that fish of the two diet treatments passed the detection sites overlapped at all sites (Figure 3). Kaplan-Meier curves of fish passage between detection sites show similar fish migration rates between diet treatments (Figure 4).

Table 9. Length of time radio-tagged juvenile steelhead spent in each study reach, Klamath River, 2009. Steelhead were divided into two treatments: each group of 15 fish was fed either the control diet or the test diet. Numbers in parentheses below each reach designation are reach lengths.

	Release Site to Ager Bridge (9 km)	Ager Bridge to Shasta River (12 km)	Shasta River to Scott River (54 km)	Scott River to Indian Creek (56 km)	Indian Creek to Salmon River (71 km)	Salmon River to Trinity River (38 km)	Trinity River to Steelhead Lodge (36 km)	Steelhead Lodge to Blake's Riffle (20 km)
Control diet								
N	9	4	5	5	4	4	4	4
Median (d)	1.43	18.09	1.16	0.82	0.69	0.38	0.26	0.14
Min (d)	0.47	0.12	0.58	0.56	0.51	0.24	0.22	0.12
Max (d)	44.07	40.06	40.53	4.05	0.93	0.60	0.27	0.15
SD	14.66	21.95	17.26	1.49	0.19	0.15	0.03	0.01
Test diet								
N	11	6	5	5	5	5	5	5
Median (d)	2.48	0.31	1.14	0.63	0.67	0.34	0.34	0.14
Min (d)	0.58	0.14	0.60	0.50	0.56	0.28	0.24	0.12
Max (d)	48.33	1.02	48.84	1.11	1.00	0.82	0.71	0.45
SD	18.42	0.34	23.95	0.28	0.18	0.24	0.19	0.14

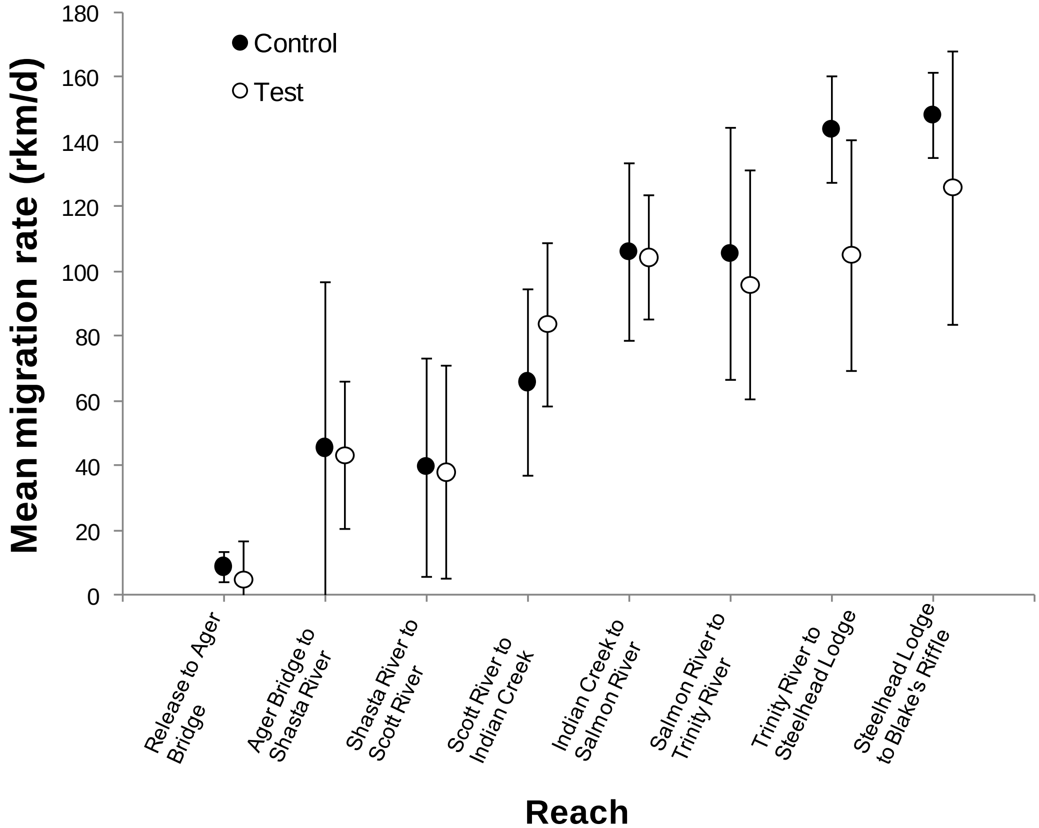

Figure 2. Mean downstream migration rates (rkm/d) of control and test treatment fish through study reaches after release at Iron Gate Hatchery, Klamath River, 2009. Error bars represent 95% confidence intervals around the mean. Reach locations are shown on horizontal axis from upstream (L) to downstream (R).

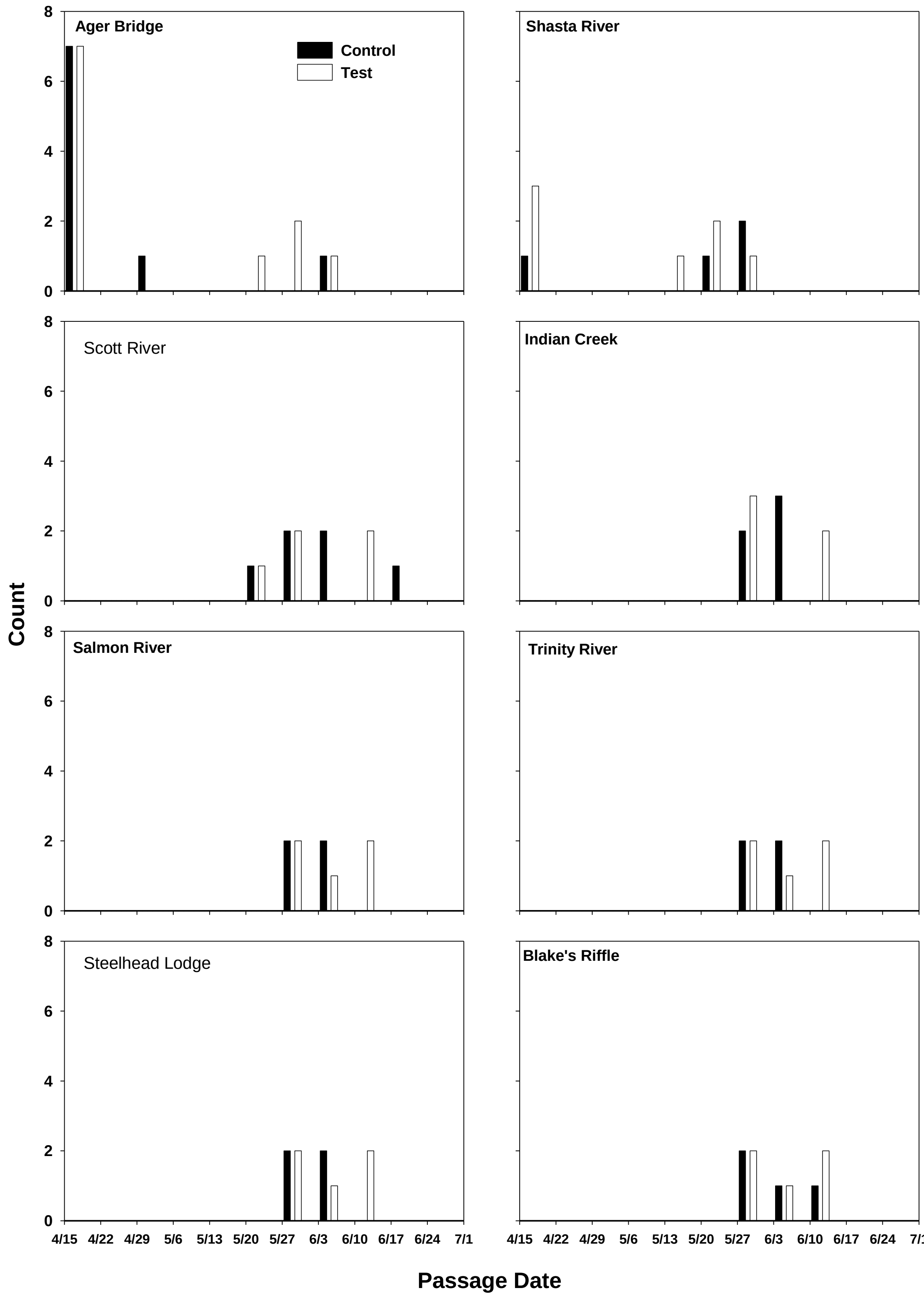

Figure 3. Fish passage timing by treatment at each detection site, Klamath River, 2009.

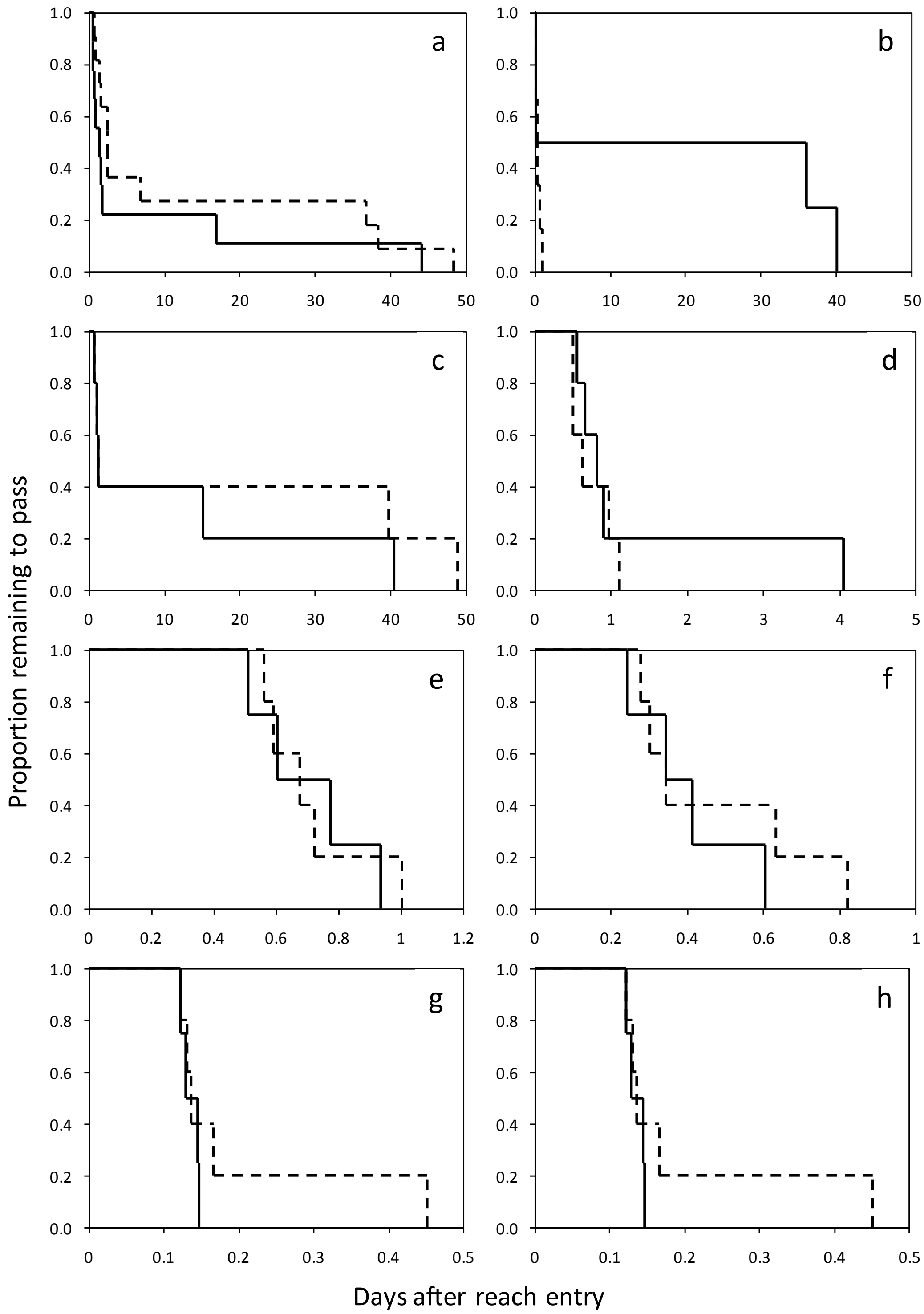

Figure 4. Kaplan-Meier curves describing travel times of control (black line) and test treatment (dotted line) radio-tagged steelhead from a) release site to Ager Bridge, b) Ager Bridge to Shasta River, c) Shasta River to Scott River, d) Scott River to Indian Creek, e) Indian Creek to Salmon River, f) Salmon River to Trinity River, g) Trinity River to Steelhead Lodge, and h) Steelhead Lodge to Blake's Riffle in 2009.

Survival Analysis

Estimates of survival were restricted to the reaches between release at the hatchery and the detection site near the confluence of the Klamath River and Indian Creek. All fish detected at the Indian Creek site were also detected at all downstream sites, indicating all fish lived through the reaches from Indian Creek to Steelhead Lodge, so there was no need to estimate their survival. As such, the data from all sites downstream from Indian Creek were collapsed in to a single detection site and estimates of recapture and survival probabilities were restricted to the first four reaches.

Several of the models evaluated received support from the data (Table 10). Models representing hypotheses of no differences in survivals among river reaches and diets (Model 1), differences among reaches (Model 2), and differences among diets (Model 3) were all similarly supported by the data. Models of recapture probabilities varying by site and equal among sites were also evaluated. Model-averaged estimates of recapture probabilities averaged 0.9394 (range 0.9253–0.9470). The model-averaged estimates of survivals among reaches and diets are listed in Table 11 and presented in Figure 5. The small sample sizes resulted in large confidence intervals around the estimates. The data and models indicate little support for differences in survival between fish fed the different diet types or among the four river reaches

DISCUSSION

We found that approximately one-third (30%) of the radio-tagged steelhead migrated downstream and survived to reach the estuary within the approximate 60-d tag life. Survival to the estuary is the joint probability of migration, survival, and detection. Apparent survival rates through each of the four upstream study reaches ranged from 0.690 to 0.792 for fish of each diet treatment. All fish that survived to reach the Indian Creek site lived through the four downstream reaches. The mean travel time for these fish was 45 d from release to the last detection site at Blake's Riffle.

The impetus of this study was to evaluate the use of a salt-enriched feed in promoting steelhead out-migration. Our results suggest that a salt-enriched diet did not affect the joint probability of migration and survival of hatchery-reared yearling steelhead within the 60-d duration of this study. No difference was found between control and test treatments in terms of out-migration, migration rate, or survival. It is important to note that this study was based on a small number of fish, and that the results should be considered in that light.

It should also be noted that a fish detected at any one of the sites is a result of the joint probability of migration and survival as well as detection at the site. We were able to separately estimate detection from the other probabilities. Thus, the apparent survivals we present are the joint probabilities of migration and survival. It is possible that some fish were migrants and did not survive to some of the sites.

Certain limitations of this study, such as the number of mobile tracking surveys and tag life of the radio transmitters, make it difficult to conclusively determine the fate of the

Table 10. Model summary from analyses of apparent reach survival (Phi) and capture probabilities (p) of two groups of juvenile steelhead fed different diets and released at Iron Gate Hatchery, Klamath River. Models are based on 15 juvenile fish fed the control diet and 15 juvenile fish fed test diet. All fish were released April 17, 2009. Rankings are based on AICc, a modification of Akaike Information Criterion for small samples. A '+' between factors indicates an additive effect. A '*' between factors indicates a multiplicative effect. A '.' indicates no factor effects (a single value fitted to all observations).

Model number	Model	Delta AICc	AICc	Model weights	Model likelihood	Number of Parameters	Deviance
1	Phi (.), p (.)	120.958	0.000	0.396	1.000	2	23.094
2	Phi (reach), p (.)	122.046	1.089	0.230	0.580	6	15.202
3	Phi (diet), p (.)	122.979	2.022	0.144	0.364	3	22.958
4	Phi (diet + reach), p (.)	124.324	3.366	0.074	0.186	7	15.080
5	Phi (reach), p (site)	124.555	3.597	0.066	0.166	9	10.311
6	Phi (.), p(site)	125.153	4.196	0.049	0.123	6	18.309
7	Phi (diet + reach), p (site)	127.039	6.081	0.019	0.048	10	10.187
8	Phi (diet), p (site)	127.416	6.459	0.016	0.040	7	18.173
9	Phi (diet * reach), p (.)	129.230	8.272	0.006	0.016	11	9.694
10	Phi (diet * reach), p (site)	132.616	11.658	0.001	0.003	14	4.543

Table 11. Model-averaged apparent reach survival estimates for two groups of juvenile steelhead released at Iron Gate Hatchery, Klamath River, April 17, 2009. Each group of 15 fish was fed either the control or test diet. Model-averaged results are based on the 10 models in Table 10. Stderr = unconditional standard error; 95% CI = 95% confidence interval for the weighted-average estimate.

		Control Diet				Test Diet			
				95% Cl				95% CI	
River Reach	Description	Apparent Survival	Stderr	Lower	Upper	Apparent Survival	Stderr	Lower	Upper
1	Hatchery to Ager Bridge	0.737	0.075	0.568	0.856	0.746	0.073	0.580	0.862
2	Ager Bridge to Shasta River	0.690	0.112	0.444	0.861	0.700	0.110	0.455	0.867
3	Shasta River to Scott River	0.787	0.094	0.552	0.917	0.792	0.091	0.564	0.918
4	Scott River to Indian Creek	0.772	0.095	0.542	0.907	0.782	0.092	0.555	0.912

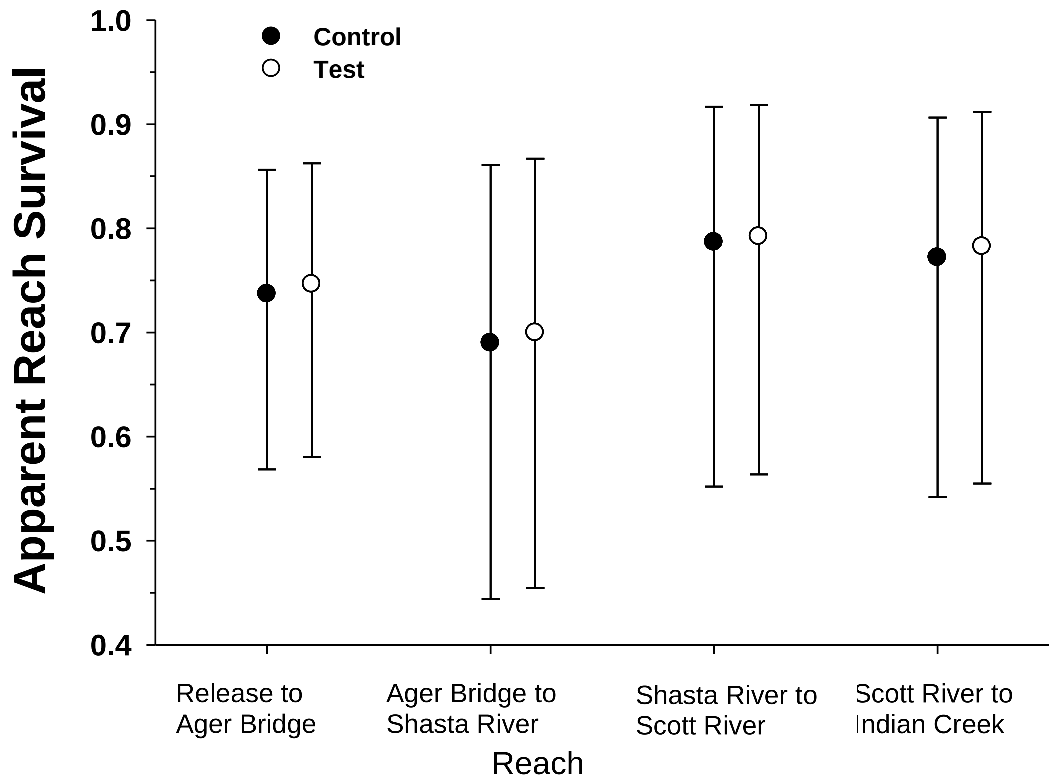

Figure 5. Klamath River juvenile steelhead apparent survival estimates for four river reaches between Iron Gate Hatchery and Indian Creek, 2009. Model-averaged survival estimates are for 15 steelhead fed the control diet and 15 steelhead fed the test diet released at Iron Gate Hatchery on April 17, 2009.

radio-tagged individuals. More extensive mobile tracking and diving surveys would have helped to differentiate between mortality and holding behavior. Six tagged fish were never detected by the stationary receivers or mobile tracking, suggesting that fish migrated into tributaries out of the study area, the transmitters were removed from the study area, or the transmitters failed. This level of transmitter failure would be inconsistent with our previous studies of transmitter failure under controlled conditions.

This study's time frame was restricted by the tag life of the transmitters, which may have been shorter than the time required for fish to migrate. Hopelain (1998) found that based on scales of 119 adult fall-run steelhead returning to IGH 74.8% of the fish had remained in freshwater for two years prior to emigrating to the ocean. It is therefore possible that some of the tagged steelhead may have emigrated well after the batteries of the transmitters were drained. Increasing transmitter tag life by implanting larger transmitters in yearling steelhead would allow a longer study period and would help to distinguish migrants from non-migrants. It is unlikely that a transmitter small enough for use in juvenile steelhead could emit radio pulses continuously for two years, but they could be programmed to turn off until the following spring, which may allow use during two migration seasons.

While feeding steelhead a salt-enriched diet does not appear to promote out-migration, other management practices tested in Washington hatcheries, such as decreasing condition factor before release and setting a minimum size at release, may be good alternatives. Tipping et al. (1995) found that emigration rates of hatchery steelhead decreased as condition factor increased. In their study, steelhead with K-values from 0.90-0.99 emigrated at a rate of 81.7% while steelhead with condition factors 1.15 or greater emigrated only 66.6% of the time. The condition factors of steelhead sampled at IGH averaged 1.10 (ranging from 0.97-1.29). Tipping and Byrne (1996) recommend restricting feed during the last month of hatchery rearing to lower the condition factor and increase emigration and adult returns. Studies have also suggested a minimum size at release of 190 mm for hatchery steelhead, having found increased emigration rate and adult return rate above this length threshold (Tipping et al. 1995; Tipping 1997). Of the 150 steelhead sampled at IGH, only 4.67% were above that minimum size recommendation (average FL=162 mm, range 80-222 mm).

In summary, this study found that a salt-enriched diet had no effect on the joint probability of outmigration and survival of yearling steelhead. We caution readers to interpret this result with consideration given to the study's small sample size and other limitations.

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Appendix A. Summary of adult steelhead returning to Iron Gate Hatchery, 1969 to 2009.

Season	Number of returning steelhead
1969-70	1,194
1970-71	2,365
1971-72	3,757
1972-73	1,286
1973-74	1,865
1974-75	3,227
1975-76	1,523
1976-77	1,941
1977-78	4,411
1978-79	2,079
1979-80	1,657
1980-81	1,247
1981-82	2,261
1982-83	2,703
1983-84	832
1984-85	1,385
1985-86	3,165
1986-87	2,834
1987-88	3,770
1988-89	3,343
1989-90	759
1990-91	268
1991-92	207
1992-93	126
1993-94	163
1994-95	271
1995-96	12
1996-97	97
1997-98	127
1998-99	91
1999-00	112
2000-01	532
2001-02	631
2002-03	495
2003-04	554
2004-05	417
2005-06	209
2006-07	212
2007-08	195
2008-09	140

Appendix B. Summary of yearling steelhead released from Iron Gate Hatchery, 1969 to 2009.

Year	Number of yearling steelhead released
1991	200,000
1992	188,201
1993	63,000
1994	0
1995	74,000
1996	163,000
1997	10,702
1998	35,802
1999	37,080
2000	51,324
2001	31,897
2002	141,362
2003	192,770
2004	148,991
2005	195,698
2006	83,034
2007	21,208
2008	18,461
2009	29,683

Appendix C. Capture histories of radio-tagged yearling steelhead released at Iron Gate Hatchery, Klamath River, 2009. Steelhead were divided into two diet treatments, each treatment of 15 fish was fed either the control or test diet. Histories begin with a '1' for release and are '1' if they were detected and '0' if they were not at Ager Bridge, Shasta River, Scott River, Indian Creek, Salmon River, Trinity River, Steelhead Lodge, and Blake's Riffle, California.

Diet treatment	Capture history	Observed
$R_{control}$ = 15	100000000	5
	110000000	4
	111100000	1
	111110000	1
	101111111	1
	110111111	1
	111111111	2
R_{test} = 15	100000000	3
	110000000	5
	111000000	2
	101111111	1
	111111111	4