STEELHEAD (*ONCORHYNCHUS MYKISS*) KELT ABUNDANCE, CONDITION, PASSAGE, AND SURVIVAL IN THE LOWER SNAKE AND COLUMBIA RIVERS, 2003

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EXECUTIVE SUMMARY

Steelhead (*Oncorhynchus mykiss*) may exhibit an iteroparous life history, returning to the ocean between spawning episodes. In the Snake River, post-spawn steelhead (kelts) must pass up to eight dams during out-migration and each year thousands are observed falling back over dams via juvenile bypass systems. Between 12 April and 15 June 2003, we sampled 1,774 steelhead from the Lower Granite Dam separator and used ultrasound imagery to distinguish post-spawn kelts from spring migrating pre-spawn steelhead. Of steelhead sampled, 96.8% were determined to be kelts. Kelts were predominantly female (82.7%) and of wild origin (~50%). The majority (72.6%) of kelts were in good or fair physical condition and were best distinguished from pre-spawn steelhead by a thin, imploded abdomen (72.4%). We estimate that at least 4,026 kelts were bypassed from the Lower Granite Dam separator during this study period.

We PIT-tagged a total of 1,254 kelts and randomly assigned 701 to an in-river/transport paired release experiment. A total of 372 kelts were transported to the estuary in conjunction with the juvenile transport effort, and 329 were released in the tailrace of Lower Granite Dam. Tagged kelts from this study are expected to begin returning to the Columbia River in the fall of 2003, though the majority will probably reascend during summer and fall of 2004. Data from PIT detectors located at Bonneville, McNary, Ice Harbor, and Lower Granite dams will be used to compare return rates of the experimental groups.

We radio-tagged an additional 212 kelts, released them in the Lower Granite tailrace, and monitored their migration rates and survival through the hydrosystem. Telemetry receivers detected 142 kelts (67.0%) downstream from Ice Harbor Dam and 73 (34.4%) were recorded passing Bonneville Dam. Radio-tagged kelts in good condition were more likely to successfully exit the hydrosystem than those in fair condition (χ^2 test, P=0.003). Migration rates through Snake River inter-dam reaches (tailrace to tailrace) averaged 32.4 km/d (*range* 22.6-42.6); migration rates through Columbia River reaches were generally higher (*mean*=55.3 km/d, *range* 39.5-80.1). Regression analysis revealed pooled migration rates through all reaches were positively related to river discharge ($P < 0.0001$, r^2=0.63), though when examined individually this relationship was not significant for three of the eight reaches. We calculated both inter-dam and daily survival rate estimates using Program MARK and a Cormack-Jolly-Seber 'recaptures only' model. Estimates of inter-dam survival in the three Snake River reaches averaged 0.885 (*range* 0.840-0.970) and estimates for the four Columbia River reaches averaged 0.846 (*range* 0.706-0.936). Daily survival estimates averaged 0.935 (*range* 0.897-0.991) for Snake River reaches and 0.883 (*range* 0.788-0.952) for Columbia River reaches. Both inter-dam and daily survival estimates showed a general downward trend as kelt migration progressed downstream, although the trend was significant only for daily estimates (Bonferroni P=0.058).

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1.0 INTRODUCTION

Steelhead (*Oncorhynchus mykiss*), unlike other anadromous Pacific salmonids, are capable of spawning more than once and each year thousands of post-spawn steelhead (kelts) attempt to out-migrate through the Snake and Columbia River hydrosystem. This iteroparous life history has been documented for decades (Whitt 1954). However, there is a paucity of information concerning kelt abundance, return rates or the possible contribution kelts could make to rebuilding ESA-listed steelhead populations. Steelhead kelts that return to spawn a second time increase the total number of individual spawners and may increase genetic heterozygosity and diversity. Repeat spawning steelhead have already survived an entire reproductive cycle and may have traits that confer higher survival and success within the hydrosystem than first attempt spawners.

As steelhead kelts migrate downriver toward the ocean, thousands are incidentally collected in the juvenile bypass systems (JBS) of mainstem dams, where they are intermingled with spring-migrating pre-spawn steelhead that are falling back over dams (Wagner and Hillsen 1993). All adult fish are removed from juvenile separators and returned to the river to continue migration. Until recently, kelts and pre-spawn steelhead were differentiated visually by USACE separator personnel using coloration and physical condition as discriminate factors. Research conducted at Lower Granite and Little Goose dams in 1999 and 2000 (Evans and Beaty 2000) developed methods for using ultrasound imaging to distinguish pre-spawn from post-spawn steelhead based on the presence of an egg mass in females and by the cross-sectional diameter of male testes. This technique proved to be a highly accurate method for determining maturation status and allowed researchers to gather information on the abundance and general condition of kelts in JBS facilities. Research at Little Goose and Lower Granite dams in past years revealed that the majority of adult steelhead in juvenile separators were kelts, the majority of kelts (>75%) examined were in good or fair physical condition and the kelt run was disproportionately female (>80%) and of wild origin (~50%). In fact, it was estimated that about 23% of the 2000 wild steelhead run (2,780 wild fish) and 21% of the 2001 wild steelhead run (4,695 wild fish) passed through the Lower Granite Dam bypass facility after likely spawning (Evans and Beaty 2000; 2001) though this proportion dropped to 8.6% (Hatch et al. 2003) in 2002.

In 2001 and 2002, in an effort to obtain information on kelt outmigration survival rates, radio tags were affixed externally to 422 kelts and their migration through the hydrosystem was monitored from release at Lower Granite Dam to the tailrace of Bonneville Dam (Evans 2002; Hatch et al. 2003). Near-record low river flows occurred in 2001, with no spill at Snake River dams and drastically reduced spill at Columbia River dams. Of the 212 radio-tagged kelts released at Lower Granite Dam that year, only 8 (3.8%) were detected in the Bonneville Dam tailrace (Evans and Beaty 2001). River flow in 2002 was about 80% of the 10 year mean with spill occurring at all Snake and Columbia river dams. Twenty-eight (13.3%) of 210 radio-tagged kelts released at Lower Granite Dam in 2002 were detected in the Bonneville tailrace (Hatch et al. 2003). Differences in river flow and dam passage conditions are generally believed to be responsible for the differences in hydrosystem survival between the two years. In both years, the physical condition of kelts at tagging was also correlated to migration success: kelts in good condition were more likely to successfully migrate out of the hydrosystem than those in fair or poor condition. As part of the 2002 study, researchers used a randomly assigned paired release experiment to estimate return rates of kelts and to evaluate the efficacy of transporting kelts collected at Lower Granite Dam through the hydrosystem in conjunction with the smolt barging effort. After ultrasound examination, kelts were PIT tagged and randomly assigned to two treatments. The 'transport' group was loaded into submerged pens within a hold on a juvenile barge and released in the Columbia River estuary with the smolts. The 'in-river' group was released in the tailrace of Lower Granite Dam and allowed to out-migrate through the hydrosystem. Return rates of these two experimental groups (transported and in-river) continue to be monitored.

In spring of 2003, we continued to evaluate steelhead kelt abundance and condition using ultrasound imaging, to compare return rates using the paired release study design and to estimate hydrosystem survival and migration rates using radio-telemetry.

2.0 METHODS

2.1 Study Site

Research was conducted at the juvenile bypass facility (JBS) of Lower Granite Dam (LGR) on the Snake River. This facility is the first collection point encountered by downstream migrating steelhead kelts and more adult steelhead are counted at the LGR bypass than at any other bypass facility on the Snake or Columbia rivers (Evans and Beaty 2001). Steelhead are present in the separator throughout its operational period but numbers historically peak between 15 April and 15 May. Adult steelhead were collected from the LGR separator daily (between 6:00 am and 2:00 pm) from 12 April to 13 June. We attempted to examine every steelhead bypassed from the LGR separator.

River flow and spill at Lower Granite Dam during the study period was 92% and 106% of the 1994-2002 averages, respectively. Dam spill at Lower Granite was manipulated experimentally from 14 April to 29 May to evaluate juvenile fish passage through the removable spillway weir (RSW). Spill treatments consisted of 24 h RSW operation in conjunction with approximately 14 kcfs “training” spill, and 12 h of no spill followed by 12 h of spill to the gas cap at night (Figure 1).

2.2 Sampling Procedures

The sampling procedure used at the bypass facility was similar to that of Evans and Beaty (2000; 2001). USACE personnel removed steelhead from the juvenile separator and placed them in a flume leading to a concrete holding tank (1.2m × 1.8m × 3.0m). Steelhead were then individually dip-netted from the holding tank and placed in a 190-L sampling tank containing river water and a solution of clove oil (eugenol) at ~ 20 ppm. Once steelhead were anesthetized, we used an Aloka® SDD-500v ultrasound machine equipped with a 7.5 MHz linear probe to assess sex and maturation status. The ultrasound probe was placed on the abdomen of steelhead and moved anterior to posterior to view the egg mass or testes. Determination of maturation status (pre- or post-spawn) was based on the size, location and echogeneity (tissue density) of the gonads (described in detail in Evans and Beaty 2000). All sampled steelhead were classified either as female kelt, male kelt, female pre-spawn, male pre-spawn or of unknown maturation status (no visible eggs or testes) based on the ultrasound imagery. Concurrent with this examination, we collected data on the likely origin of the steelhead (hatchery or presumed wild), overall fish condition (good, fair, or poor), general coloration (bright, intermediate or dark), a caudal fin rating based on severity of wear, fish fork length and abdomen size (fat, fat-medium, slim-medium, and slim). Any injuries or physical conditions (e.g. cuts, fungal infections, headburn) were also noted. All steelhead examined were scanned for PIT tags. Steelhead determined to be pre-spawn were immediately released into the river after examination (< 1 min). All steelhead classified as kelts in good or fair condition had a PIT tag inserted into the pelvic girdle via hypodermic needle if they did not already have a PIT tag. All PIT tagging information was uploaded to the Pacific States Fisheries Marine Council’s PITAGIS database (www.psmfc.org/pittag/). Scale and tissue samples were taken from a subset of the kelts (every tenth fish sequentially regardless of condition) for age classification and genetic analysis. These samples were inventoried and archived for future analysis. After examination, all kelts were allowed to recover briefly in a tank of fresh river water, then returned to the river or loaded onto a juvenile transportation barge.

2.3 Transportation Evaluation

If a juvenile transportation barge was being loaded at the LGR juvenile collection facility at the time of examination, PIT tagged kelts were assigned (using a randomizing computer program) to one of two release groups. Kelts were either released in-river (at the same site as all other fish bypassed from the LGR juvenile separator) and allowed to continue their downstream migration or they were placed in a pen (1.2m × 1.8m × 2.4m) within one of the juvenile barge holds to be transported out of the hydrosystem and released with smolts. Subsequent PIT tag detections of kelts from each release group at sites along the Columbia and Snake rivers were used to evaluate and compare return rates (possible repeat spawning attempts) of the two treatment groups. All steelhead examined while transportation was not an option were released at the in-river site and were not used in the paired-release comparison.

2.4 Kelt Abundance Estimates

The total proportion of kelts present in the LGR juvenile collection facility was estimated based on a weighted average of kelt proportions from all sampling weeks. Kelt proportions identified by ultrasound each sampling week were applied to the total number of steelhead bypassed from the juvenile separator during that week. Weekly and total estimates of proportions were calculated.

2.5 Radio Telemetry

To evaluate migration rates and times, dam passage routes and hydrosystem survival, we radio-tagged 212 kelts determined to be in good or fair physical condition. We radio-tagged kelts from 5 May to 5 June and tagged an average of 7 kelts/d. Due to a delay in the delivery of radiotags from the manufacturer, our radiotagging effort in 2003 began about one month later than the previous two study years.

Anesthetized kelts were placed in a surgery trough and a 1 cm × 2 cm uniquely coded radio tag weighing ~ 3 grams (Lotek® Engineering) was sutured to the base of the dorsal fin using a #2 monofilament suture harness developed by the USACE-FFU in 2000 (Wertheimer et al. 2002). All radio-tags transmitted on the 149.760 MHz frequency with a 5 sec repeat rate. After radio-tagging, kelts were allowed to recover briefly in a tank containing fresh river water and were then released into the LGR tailrace to continue downstream migration.

2.6 Telemetry Monitoring

Telemetry monitoring was conducted using the extensive array of radio-telemetry receivers operated by the University of Idaho to monitor adult salmon upstream migrations (Figure 2, Table 5). Radio-tagged kelts were detected at fixed telemetry sites at the mouths of major tributaries and other mainstem sites and in the forebay and tailrace areas of all mainstem dams. At McNary, John Day and Bonneville dams, telemetry coverage was sufficient to determine some routes of dam passage by kelts. Mobile tracking of radio-tagged kelts was conducted in the Bonneville, The Dalles and John Day dam pools. Approximately two weeks after the last radio-tagged kelt was released, the entire Snake River from LGR to the confluence of the Snake and Columbia rivers was also tracked by boat. Kelts were monitored from release (rkm 694.1) to the tailrace receiver site at Bonneville Dam (rkm 232.3). These telemetry data were processed using the coding protocol developed by the University of Idaho before analysis was conducted.

2.7 Survival Estimates

Estimates of kelt survival were calculated using Program MARK (White and Burnham 1999) and a Cormack-Jolly-Seber "recaptures only" model. Telemetry receivers located in the tailraces of Snake and Columbia river dams were used to demarcate river reaches (e.g. Lower Granite tailrace receiver to Little Goose tailrace receiver). Detections at tailrace receivers were used to generate binary encounter histories for the complete migration of all radio-tagged kelts. Encounter histories were entered into Program MARK and inter-dam reach survival estimates, daily survival estimates and detection efficiencies of telemetry receivers (recapture probabilities) were generated. The inter-dam reach survival was the probability of an individual kelt that entered a reach surviving migration through that reach. Daily survival estimates used the mean time (d) of all kelts to successfully migrate through an inter-dam reach as a factor in the survival estimate calculation for that reach. Therefore, daily survival estimates for inter-dam reaches are comparable even though inter-dam reaches are of different lengths.

3.0 RESULTS

3.1 Kelt Abundance

USACE separator personnel enumerated and bypassed 2,023 steelhead between 26 March when the separator began operating and 12 April when we began examinations and tagging (Figure 1). Between 12 April and 15 June 2003, we examined 1,774 of the 4,157 steelhead (42.6%) bypassed from the juvenile separator between those dates and on average examined 42.1% of steelhead bypassed each week (Table 2). Ultrasound imagery revealed 1,714 (96.6%) of examined fish were post-spawn and 54 (3.0%) were pre-spawn fallbacks. We were unable to visually locate gonads in six (0.3%) steelhead. In general, the proportion of kelts in the run increased as the sampling period progressed (Table 2).

Visual determinations of steelhead maturation status by USACE personnel were consistent with ultrasound examinations. Differences in estimated weekly kelt proportions by USACE personnel and by ultrasound examination averaged 2.0% (*range* 0.3 – 5.7%). Using visual discriminant factors, USACE personnel estimated 4,035 kelts were bypassed during the study period, a difference of only 7 kelts from our ultrasound estimate.

3.2 Kelt Origin, Sex, and Condition

Of those steelhead determined by ultrasound to be kelts, 860 (50.2%) were of hatchery origin and 854 (49.8%) were presumed to be wild. Comparatively, of the 54 pre-spawn steelhead, 39 (72.2%) were of hatchery origin and 15 (27.8%) were presumed wild (Table 3). Similar to previous years, the kelt run was predominantly female (82.7%) and in good (46.2%) or fair (26.4%) physical condition. Most kelts were of intermediate (46.4%) or dark (32.6%) coloration and were likely to have a slim abdomen (72.4%). The majority of both kelts and pre-spawn steelhead exhibited no caudal fin wear. Fork length of wild kelt and wild pre-spawn steelhead averaged about 7 cm greater than those of hatchery origin (Table 3).

The proportion of male kelts in the run increased as the migration season progressed. During week 1 of sampling, males constituted about 11% of all kelts but by week 8 nearly one third of all kelts were males (Figure 3). Similarly, the proportion of wild origin fish to hatchery origin fish also increased throughout sampling. During weeks 2 through 4, more than 60% of examined kelts were from hatcheries. By week 7, hatchery fish comprised about 26% of kelts examined (Figure 3).

3.3 PIT Tagging Effort and 2003 Transportation Evaluation

After ultrasound examination, all fish were scanned for PIT tags and non-tagged kelts considered in good or fair condition received a PIT tag implanted in the pelvic girdle. We PIT tagged a total of 1,254 kelts and randomly assigned 701 PIT-tagged kelts to the in-river/transport paired release study. An additional 341 non-experiment PIT-tagged kelts were released in the tailrace. All radio-tagged kelts also received a PIT as secondary tag (Table 4). These PIT-tagged kelts would be expected to begin returning to the Columbia River drainage in fall of 2003, though the majority will probably reascend during summer and fall of 2004 (see *2002 Transportation Evaluation* below). As such, return rates from these releases will be evaluated in future progress reports.

3.4 2002 Transportation Evaluation

During the 2002 out-migration 1,410 kelts were PIT tagged and randomly assigned to in-river/transport paired release study. In total, 751 kelts were transported to release sites downstream from Bonneville Dam and 659 were released in the Lower Granite tailrace. Researchers also released 965 non-experiment PIT-tagged kelts in the tailrace of Lower Granite Dam. These kelts were treated identically to the in-river group but were not used in the comparison (Table 5).

Return rates to Bonneville Dam and to Lower Granite Dam were significantly different for the in-river and transport groups (χ^2 test, $P < 0.05$). Return rates for the in-river treatment were 0.6% to Bonneville Dam and 0.5% to Lower Granite Dam; rates for the transport treatment were 2.3% and 1.7%, respectively. PIT tagged kelts from the Snake River were twice as likely to spend another full year at sea before returning to the Columbia River Basin (Table 5).

3.5 Previously PIT Tagged Kelts

In 2003, we captured 12 kelts that had been PIT tagged previous to our examination. Eleven steelhead had been PIT tagged as smolts at the Lower Granite juvenile collection facility (eight in 2000 and three in 2001). Two of these eleven steelhead were recaptured as returning adults at the Adult Fish Facility (AFF) at Bonneville Dam and radiotagged by the University of Idaho in 2002. Additionally, we captured one kelt that had been PIT and radio-tagged as a returning adult at the AFF in 2002. Radio-tags were removed from kelts during our examinations.

Telemetry data indicated two of these kelts (one hatchery female and one wild origin female) had likely spawned in the Salmon River drainage upstream from Riggins, Idaho. One wild female kelt had likely spawned in the Grande Ronde River drainage.

In 2003, we did not recapture any previously PIT tagged kelts with detection histories consistent with multiple spawning events.

3.6 Radio Telemetry

We released 212 radio-tagged kelts at the outflow of the juvenile collection facility of Lower Granite Dam between 5 May and 5 June and monitored their outmigration between release and the telemetry receiver site (1BO) located 2.8 km downstream from Bonneville Dam (Figure 2, Table 1). We estimate about 70% of the total kelt run had already passed LGR by the time radio tagging began on 5 May.

Migration rates through inter-dam reaches in the Snake River were generally lower than those in the Columbia River (Figure 4, Table 6). Mean rates through Snake River reaches ranged from 22.6 km/d for the Lower Granite-Little Goose reach to 42.6 km/d for the Lower Monumental-Ice Harbor reach (Figure 5, Table 6). Mean rates through Columbia River inter-dam reaches ranged from 39.5 km/d for the McNary-John Day reach to 80.1 km/d for the John Day-The Dalles reach. Migration rates were similar for kelts of hatchery and wild origin and for kelts in good and fair physical condition (Figure 6).

Detection efficiencies of tailrace telemetry receivers (recapture probabilities) were calculated using Program MARK. Efficiencies on the Snake River ranged from 0.651 at Little Goose Dam to 0.957 at Lower Monumental Dam (Table 1). On the Columbia River, efficiencies ranged from 0.533 at

McNary Dam to 0.933 at The Dalles Dam (Table 6). Mean detection efficiency for all tailrace receiver sites was 0.805.

Regression analysis of individual kelt migration rates through inter-dam reaches (dependent variable) and river discharge at the dam that demarcated the upstream end of the reach on the date individual kelts entered that reach (independent variable) indicated a significant relationship existed between discharge and migration rates ($P < 0.0001$, r^2=0.63) when all data were pooled. When inter-dam reaches were examined individually, the relationship was significant for all Snake River reaches ($P <$ 0.0001, r^2 range=0.43 -0.73), the Ice Harbor-McNary reach (P=0.01, r^2=0.34) and nearly so for the John Day-The Dalles reach (P=0.065, r^2=0.22). Models were not significant for the McNary-John Day reach and for The Dalles-Bonneville reach.

Radio-tagged kelts that successfully outmigrated through the hydrosystem took an average of 14.3 d. Radio-tagged kelts that passed Ice Harbor Dam on or prior to 9 June and passed Bonneville Dam on or prior to 29 June.

3.7 Dam Passage Routes

Telemetry coverage permitted assignment of kelt passage routes at McNary (limited coverage), John Day and Bonneville dams (Table 7). At McNary Dam, 8.1% of all kelts that passed the dam did so via the juvenile bypass, 2.4% were detected passing downstream through fishways and none was detected by antennas in the navigation lock. Passage by kelts at John Day Dam was primarily through the spillway (76.1%) and the navigation lock (12.0%) with 2.2% of kelts detected in the juvenile bypass. Telemetry coverage was most complete at Bonneville Dam where 49.3% of kelts likely passed the dam via the spillway and smaller proportions used the ice and trash sluiceway (19.2%) and juvenile bypass (17.8%) (Table 7).

Antennas in fishways did detect fallbacks via this route at some dams. One kelt passed Little Goose Dam via the fishway as did two kelts at Lower Monumental and three kelts at Ice Harbor Dam. No kelts were detected passing The Dalles Dam fishways.

3.8 Kelt Survival

Of the 212 radio-tagged kelts released at Lower Granite Dam, 142 (67.0%) were detected by receivers downstream from Ice Harbor Dam and 70 (33.0%) were detected by receivers downstream from Bonneville Dam. Three additional kelts were detected by receivers within the juvenile bypass system of Bonneville Dam but were not detected by tailrace receivers. Radio-tagged kelts in good condition were more likely to successfully out-migrate through the hydrosystem. Of 141 kelts in good condition when radio-tagged, 62 (44.0%) were determined to have passed Bonneville Dam while 11 of 71 (15.5%) kelts in fair condition when tagged survived the same migration (χ^2 test, P=0.003). There was no difference in the proportion of radio-tagged hatchery origin (35.5%) and wild origin (33.8%) kelts to survive out-migration. Twenty-one kelts were documented with headburn at the time of radio-tagging, 8 (38.1%) were detected downstream of Ice Harbor Dam. Only one (4.8%) headburned kelt was detected downstream of Bonneville Dam. The distributions of radio-tagging dates for kelts that did or did not survive out-migration were not significantly different (Kolmolgorov-Smirnov two sample test).

Estimates of inter-dam survival in the three Snake River reaches averaged 0.885 (*range* 0.840-0.970) and estimates for the four Columbia River reaches averaged 0.846 (*range* 0.706-0.936) (Table 8). Daily survival estimates for Snake River reaches averaged 0.935 (*range* 0.897-0.991) and estimates for Columbia River reaches averaged 0.883 (*range* 0.788-0.952) (Table 8).

Daily survival estimates were significantly and negatively related to the progression of downstream migration through inter-dam reaches (Bonferroni P=0.058). No relationship existed between inter-dam survival estimates and the progression of downstream migration (Figure 7).

4.0 DISCUSSION

The majority of steelhead present in the Lower Granite Dam separator in the spring of 2003 were kelts, as was observed in previous years. During the nine weeks of this study, between 93 and 100% of steelhead examined by ultrasound were determined to be kelts. Most (73%) were in good or fair physical condition. The kelt out-migration was disproportionately female (83%) and of wild origin (50%). As in past years, kelts were best characterized by thin, imploded abdomens. The relative proportion of male kelts and of wild kelts in the run increased as the run progressed. Hatchery steelhead have been selectively bred (Busby et al. 1996) for early returns and it is likely this influences the higher proportion of hatchery kelts present early in the run. The change in sex ratio throughout the run is likely due to male steelhead remaining in spawning areas longer than females. Male steelhead aggressively compete for females and comparatively higher male spawning mortality has been noted in other iteroparous salmonid populations (Fleming 1998).

Based on the nine weeks of ultrasound examinations, total kelt abundance at the Lower Granite Dam separator was estimated to be 96.8% (weighted average). This proportion is slightly higher than abundance estimates in 2001 and 2002 (94.3% and 91.0%, respectively), and may have been caused by our sampling effort in 2003 beginning later than in previous years. Pre-spawn steelhead that have over-wintered in the Snake River are passing and falling back over Lower Granite Dam in late winter and early spring, and so higher proportions of pre-spawn steelhead are bypassed from the separator during the early portion of the kelt out-migration. As the spawning season progresses, fewer pre-spawn steelhead pass the dam and the proportion of kelts bypassed increases. This pattern has been observed in all study years. By applying the kelt abundance estimate (0.968) and the proportion of wild steelhead in the kelt run (0.50) to the total number of steelhead bypassed from the separator (6,248), we estimate that 3,024 wild steelhead were bypassed from the Lower Granite Dam separator. This constitutes 5.6% of the 53,893 wild steelhead counted passing Lower Granite Dam between 1 June and 15 December of 2002. In 2000, 2001 and 2002, it was estimated that 23%, 21% and 8.6% of the previous years' wild steelhead runs were bypassed from the Lower Granite Dam separator. Differences in river flow and dam operation among years likely affected these proportions. There was no spill at Snake River dams in 2001, forcing all kelts to fallback via juvenile bypasses, turbine units or navigation locks which would be expected to increase the total number of fish bypassed from separators. Researchers have speculated that some of the difference in these estimates could be attributed to operation of the removable spillway weir (RSW) in 2002, though we found no evidence of this in 2003. There was no significant difference in the number of steelhead bypassed during RSW operation (mean=74 steelhead/day) and during gas cap spill (mean=79 steelhead/day). However, use of the RSW by downstream migrating adults has not been specifically evaluated.

During the 2002 upstream migration, the University of Idaho radio-tagged 1,345 steelhead at Bonneville Dam as part of the adult passage study. We recorded 591 of these fish passing Lower Granite Dam, of which 80 (13.5%) had telemetry records consistent with kelt outmigration behavior in spring of 2003 and 54 (9.1%) were known to have successfully passed downstream from Lower Granite Dam. These are likely minimum estimates of the proportion of the steelhead run to attempt post-spawn outmigration because 1) some receiver sites are not operational in late winter and early spring allowing kelts to move downstream undetected, 2) steelhead have an estimated transmitter regurgitation rate of 4% (Keefer et al. 2004), and 3) radiotagged adult steelhead have slightly lower survival rates than untagged fish (University of Idaho, unpublished data). We examined over 40% of the steelhead bypassed from the separator and recovered three of the 42 radio-tags known to have passed the dam during this time frame. We estimate that eight radio-tagged kelts probably passed Lower Granite through the separator and 36 passed via other routes, a 1 to 4.5 ratio. If radio-tagged steelhead kelts are good surrogates for the run as a whole and this ratio is applied to the estimated number of kelts present in the Lower Granite Dam separator, it is possible that more than 13,000 wild steelhead kelts passed the dam in spring of 2003, approximately 25% of the wild steelhead counted passing the dam in the previous fish-year.

Visual determinations of steelhead maturation status by USACE personnel was quite accurate with differences between visual determinations and ultrasound examinations averaging only 2% throughout all sample weeks. Total estimates of kelt abundance during the study period differed by only seven fish. There was no discernible pattern to the small weekly discrepancies between visual and ultrasound determinations and it is possible differences were attributable to personnel.

In 2003, we were able to PIT tag and assign release treatments to 701 kelts (41% of all kelts examined during the study period), of which 379 were transported. Several factors limited the number of kelts we were able to transport, and primary among these were the timing and size of the kelt run. About one third of the 6,248 steelhead bypassed during the study (26 March to 15 June) passed Lower Granite Dam before juvenile barging operations began on 14 April. These kelts could not be transported. In addition, the total number of kelts bypassed in 2003 was about 28% fewer than in 2002 and 50% fewer than in 2001.

We queried the PTAGIS database on 12 March 2004 for detections of PIT tagged kelts assigned to the transport/in-river experiment in 2002. Return rates of kelts in the transport treatment were significantly higher (χ^2 test, $P < 0.05$) to Bonneville Dam (2.3%) and to Lower Granite Dam (1.7%) than kelts in the in-river treatment (0.6% and 0.5%, respectively). Non-experiment PIT tagged kelts returned at the same rate as kelts in the in-river treatment. The only other published estimate of iteroparity rates for Snake River basin steelhead we could find is an estimate of about 2% for steelhead returning to the Clearwater River in 1952 when only two dams impeded their migration (Whitt 1954). It is likely that iteroparity rates for steelhead of the Snake River basin have always been modest (e.g. latitudinal effect, length of spawning migration effect; Withler 1966, Fleming 1998). However, because Snake River steelhead kelts are predominantly female and disproportionately of wild origin, even small increases in return rates through transportation could result in a substantial contribution to wild steelhead production.

Due to technical constraints, our radio-tagging effort did not begin until 5 May, after an estimated 70% of the kelt run had already passed LGR. River discharge during the kelt run prior to the 2003 spring spike in the hydrograph (1 April to 23 May) remained stable (mean flow=72.7 kcfs, s.d.=7.8) and about half of all radio-tagged kelts were released during these flows. On 24 May, Snake River discharge increased to 124.1 kcfs and remained comparatively high (mean=131.2 kcfs, s.d.=35.4) for the remainder of the study period. Radio-tagged kelts released during these high flows experienced near optimal outmigration conditions, which would be expected to positively influence migration rates and survival.

Migration rates through inter-dam reaches were generally lower in Snake River reaches than in Columbia River reaches, and in all but three reaches were significantly related to river flow. Similar relationships between river flow and downstream migration rates and travel times have been described for juvenile chinook and sockeye salmon and steelhead (Giorgi et al. 1997, Berggren and Filardo, 1993). The highest mean migration rates we observed were for the John Day-The Dalles (80.1 km/d) and from The Dalles-Bonneville (56.7 km/d) reaches. Interestingly, migration rates in these two reaches were not significantly related to river flow. Each of these inter-dam reaches contain one dam passage, it is possible that differential dam passage conditions, whether operational or physical, could affect overall reach migration rates. These two reaches are also the most downstream in the hydrosystem and out-migrating adults that have survived out-migration thus far may be better able to negotiate passage at dams. Due to restrictions in telemetry coverage, however, we could not compare forebay residence time of kelts. Muir (1994) reported that the degree of smoltification can positively influence migration rates of juvenile salmonids. As steelhead kelts are also preparing for saltwater entry during outmigration, similar physiological effects on migration rates are possible.

We observed differences in dam passage routes used by kelts at McNary, John Day and Bonneville dams, though telemetry coverage was limited for some routes. Only the juvenile bypass and navigation lock at McNary Dam were monitored and ten kelts (8%) were detected using the bypass facility. Passage at John Day was primarily via the spillway (76%) and navigation lock (12%) with only two kelts detected passing the dam via the juvenile bypass system. At Bonneville Dam, about half of all kelts were detected passing the spillway and thirteen (18%) passed the dam via the juvenile bypass. Bonneville Dam has two powerhouses with juvenile bypass structures and a higher proportion of kelts bypassed would be expected, though eight times as many kelts used this route at Bonneville Dam than at John Day Dam. Proportions of kelts to use bypass structures also differed between McNary and John Day dams (χ^2 test, P=0.06). If juvenile collection and bypass facilities at different dams collect downstream migrating kelts at different efficiencies, estimates of the kelt population based on separator counts may be biased.

Telemetry data in 2003 indicated 73 of 212 kelts (34%) successfully exited the hydrosystem. In 2001, Evans (2002) reported only 3.8% (8/212) of kelts radio tagged and released at Lower Granite Dam survived to the Bonneville Dam tailrace. This survival rate estimate increased to 13.3% (28/210) in 2002 (Hatch et al. 2003). When these estimates are calculated using only kelts in good or fair condition (we did not radio-tag poor conditioned kelts in 2003), hydrosystem survival increases to 4.1% (8/197) in 2001 and 17.0% (28/164) in 2002, still substantially lower than the 2003 estimate. Passage conditions during outmigration are likely responsible in part for these differences in migration success. In 2003, the Snake River experienced a sharp peak in flow in early June when most kelts had passed downstream of Lower Granite Dam and were actively moving through the hydrosystem. Spill occurred at all dams throughout the kelt run and the spillway is assumed to be the most benign route of downstream egress for fish. During years without spill such as 2001, kelts must pass dams via juvenile bypass structures, turbines and debris sluiceways which likely have higher rates of injury than spillway passage, though quantitative information on this is lacking.

Both inter-dam and daily survival estimates for radio-tagged kelts exhibited a general downward trend through progressively downstream reaches. However, inter-dam estimates do not account for the length of time kelts spent migrating through a reach, and were not significantly related to this progression. The McNary-John Day reach had the lowest estimated inter-dam survival (0.706). This reach is nearly twice as long as the next longest reach (The Dalles-Bonneville), which had the second lowest inter-dam survival estimate. Daily survival estimates were negatively and significantly related to downstream progression through the hydrosystem. Daily survival estimates were corrected for the time period between detection at the upstream and downstream dam tailraces that demarcate a river reach, effectively making survival estimates from reaches of different lengths comparable. Kelts have limited bioenergetic reserves and the downward trend of daily survival estimates suggest that during outmigration some kelts may be exhausted before reaching the ocean and reinitiating feeding. Injuries and infections incurred during spawning and subsequent outmigration would be expected to accelerate this attrition rate through bioenergetic exhaustion. In this and past years of research, radio-tagged kelts in good physical condition were more likely to survive outmigration than kelts in fair or poor condition.

Data on pre-hydrosystem kelt abundance and return rates is virtually non-existent though recent research at Lower Granite Dam and in the Yakima sub-basin have provided Columbia Basin fisheries managers with a basic understanding of the kelt life stage of steelhead and the potential for bolstering steelhead populations through transportation and reconditioning. The research has revealed that the vast majority of steelhead present in juvenile separators are post-spawn and are disproportionately female and of wild origin. It appears that many factors that affect smolt migration rates and success may have the same effect on steelhead kelts, and so efforts to aid smolt passage (spill patterns, mechanical passage devices) may also benefit kelts. There is very little data on the true proportion of steelhead that attempt outmigration after spawning and estimates of outmigration success have differed substantially in the three years of estimates. Therefore, we would expect that return rates of PIT-tagged kelts will also differ among years and continued monitoring of kelt return rates is necessary to fully evaluate their impact on steelhead populations.

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6.0 LITERATURE CITED

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

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. NOAA Technical Memo NMFS-NWFSC-27, U.S. Department of Commerce, Washington, DC, USA.

Evans, A. F and R. E. Beaty. 2000. Identification and enumeration of steelhead (*Onchorhynchus mykiss)* kelts at Little Goose Dam juvenile bypass separator, 1999 Ann. Rep. to U.S. Army Corps of Engineers, Walla Walla District, for Contract No. DACW68-99-M-3102. Prepared by the Columbia River Inter-tribal Fish Commission, Portland, Or.

Evans, A. F and R. E. Beaty. 2001. Identification and enumeration of steelhead (*Onchorhynchus mykiss)* kelts in the Juvenile Collection Systems of Lower Granite and Little Goose dams, 2000. Ann. Rep. to U.S. Army Corps of Engineers, Walla Walla District, for Contract No. DACW68-99-M-3102. Prepared by the Columbia River Inter-tribal Fish Commission, Portland, Or.

Evans, A. F. 2002. Steelhead (*Onchorhynchus mykiss)* kelt outmigration from Lower Granite Dam to Bonneville Dam: Abundance, downstream conversion rates, routes of passage and travel times. To U.S. Army Corps of Engineers, Walla Walla District, for Contract No. DACW68-01-0016. Prepared by the Columbia River Inter-tribal Fish Commission, Portland, Or.

Giorgi, A. E., T. W. Hillman, J. R. Stevenson, S. G. Hays and C. M. Peven. 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 17: 268-282.

Hatch, D. R., R. Branstetter and S. Narum. 2003. Evaluate steelhead(*Onchorhynchus mykiss)* kelt outmigration from Lower Granite Dam to Bonneville Dam and test the use of transportation to increase returns of repeat spawners. Ann. Rep. to U.S. Army Corps of Engineers, Walla Walla District, for Contract No. DACW68-00-C-0027. Prepared by the Columbia River Inter-tribal Fish Commission, Portland, Or.

Keefer, M. L., C. A. Peery, R .R. Ringe, and T. C. Bjornn. 2004. Regurgitation rates of intragastric radio transmitters by adult chinook salmon and steelhead during upstream migration in the Columbia and Snake rivers. North American Journal of Fisheries Management 24:47-54.

Muir, W. D., S. G. Smith, J. G. Williams and E. E. Hockersmith. 2001. Survival estimates for migrant yearling chinook salmon and steelhead tagged with passive integrated transponders in the Lower Snake and Lower Columbia rivers, 1993-1998. North American Journal of Fisheries Management 21: 269-282.

Wagner, P. and T. Hillson. 1993. 1991 Evaluation of adult fallback through the McNary Dam juvenile bypass system. Report for U.S. Army Corps of Engineers, Portland District, Contract No. DACW68-82-C-0077. Prepared by Washington Department of Fisheries, Habitat Management Division, Olympia, Washington.

Wertheimer, R. H., J. Dalen, P. Madson, M. Jones. 2002. Evaluation of steelhead kelt project abundance, condition, passage, and conversion through Lower Columbia River dams. 2001 Draft Ann. Report to US army Corps of Engineers, Portland District. Prepared by USACE Fisheries Field Unit, Cascade Locks, OR.

Withler, I. L. 1966. Variability in life history characteristics of steelhead trout (*Salmo gairdneri*) along the Pacific Coast of North America. Journal of the Fisheries Research Board of Canada 23:365-393.

White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement:120-139.

Whitt, C. 1954. The age, growth, and migration of steelhead trout in the Clearwater River, Idaho. M.S. Thesis, University of Idaho, Moscow, ID.

TABLES

Table 1

Receiver sites, river kilometer and number of unique radio-tagged kelts detected by each site in 2003 (see Figure 1).

Receiver Site	Site Code	River kilometer	Unique Detections
Lower Granite Dam Tailrace	1GR	693.8	172
Willow Landing	SWL	658.8	183
Little Goose Dam Tailrace	1GO	634.3	132
Lyon's Ferry	LFR	615.2	94
Ayer's Landing	AYL	603.5	100
Lower Monumental Dam Tailrace	1LM	587.6	163
Fishhook Park	FHK	549.7	55
Ice Harbor Dam Tailrace	1IH	537.1	116
McNary Dam Tailrace	1MN	467.3	70
Alder Creek	ALD	415.1	5
Roosevelt	RVT	390.0	7
John Day Dam Forebay Boat Ramp	NJD	347.0	67
John Day Dam Tailrace	1JD	345.0	84
Wishram	WSM	325.3	73
The Dalles Dam Tailrace	1TD	304.9	81
Mayer State Park	MSP	293.0	55
Bingen Marina	BMA	276.4	35
Bridge of the Gods	BOG	238.6	35
Bonneville Dam Tailrace	1BO	232.3	69

Table 2

Number of steelhead bypassed from the separator, number examined by ultrasound, proportion determined to be kelts with ultrasound, weighted proportion of kelts and kelt abundance estimates for the nine sample weeks at Lower Granite Dam in 2003.

Week	Dates	Steelhead Bypassed	Ultrasound Kelts	Ultrasound Pre-spawn	Kelt Proportion	Weighted Proportion	Abundance Estimate
1	12-18Apr	844	285	13	0.956	0.194	807
2	19-25Apr	716	274	15	0.948	0.163	679
3	26Apr-2May	770	308	10	0.969	0.179	746
4	3-9May	457	233	3	0.987	0.109	451
5	10-16May	354	164	4	0.976	0.083	346
6	17-23May	380	182	3	0.984	0.090	374
7	24-30May	313	159	1	0.994	0.075	311
8	31May-6Jun	156	67	5	0.931	0.035	145
9	7-13Jun	167	48	0	1.000	0.040	167
	Totals	4157	1720*	54		0.968	4026

*includes six steelhead of undetermined maturation status

Table 3

Physical condition (% of total) of all kelts and pre-spawn steelhead examined at Lower Granite Dam in 2003. Six steelhead of unknown maturation status are excluded.

	Kelts		Pre-spawn	
	Hatchery Origin	**Presumed Wild**	**Hatchery Origin**	**Presumed Wild**
Total	860	854	39	15
Females	695 (80.8)	723 (84.7)	26 (66.7)	11 (73.3)
Males	165 (19.2)	131 (15.3)	13 (33.3)	4 (26.7)
Condition				
Good	352 (40.9)	440 (51.5)	15 (38.5)	3 (20.0)
Fair	218 (25.3)	235 (27.5)	11 (28.2)	3 (20.0)
Poor	290 (33.7)	179 (21.0)	13 (33.3)	9 (60.0)
Coloration				
Bright	120 (14.0)	240 (28.1)	4 (10.3)	1 (6.7)
Intermediate	394 (45.8)	402 (47.1)	21 (53.8)	3 (20.0)
Dark	346 (40.2)	212 (24.8)	14 (35.9)	11 (73.3)
Abdomen				
Slim	610 (70.9)	631 (73.9)	5 (12.8)	4 (26.7)
Slim-medium	228 (26.5)	207 (24.2)	17 (43.6)	2 (13.3)
Fat-medium	22 (2.6)	16 (1.9)	11 (28.2)	7 (46.7)
Fat	0	0	6 (15.4)	2 (13.3)
Caudal fin wear				
< 5%	472 (54.9)	444 (52.0)	27 (69.2)	10 (66.6)
5- 25%	314 (36.5)	312 (36.5)	8 (20.5)	3 (20.0)
> 25%	74 (8.6)	98 (11.5)	4 (10.3)	2 (13.3)
Fork length (cm)				
Minimum	50.8	48.3	53.3	55.9
Maximum	86.4	94.0	81.3	81.3
Mean	61.9	68.6	61.2	68.4

Table 4

Origin and condition of kelts PIT tagged and radio-tagged at Lower Granite Dam and released in the dam tailrace and those PIT tagged and transported by barge and released downstream of Bonneville Dam.

	Hatchery Origin	Presumed Wild
Paired Release		
In Tailrace*		
Good Condition	86	112
Fair Condition	60	64
Transported		
Good Condition	120	142
Fair Condition	63	54
Tailrace Release**		
Good Condition	90	105
Fair Condition	76	70
Radiotagged		
Good Condition	56	85
Fair Condition	20	51

*Includes one kelt in poor condition

**Includes four kelts in poor condition

Table 5

Number of kelts PIT tagged and assigned to each treatment, number to return in the fall of 2002 or the summer and fall of 2003, and number and percentage of kelts from each treatment detected at Bonneville and Lower Granite dams.

2002 Releases		Paired release	
	Non-experiment	In-river	Transport
Number per Treatment	956	659	751
Returned in 2002	3	0	6
Returned in 2003	3	4	11
Detected at Bonneville Dam	6	4	17
Percent Return to Bonneville Dam	0.6	0.6*	2.3*
Detected at Lower Granite Dam	5	3	13
Percent Return to Lower Granite Dam	0.5	0.5*	1.7*

* χ^2 test, $P < 0.05$

Table 6

Length of river reaches (tailrace receiver to tailrace receiver), number of radio-tagged kelts detected entering and exiting each reach, mean time to pass each reach and mean and median rates of passage in the Snake and Columbia rivers in 2003.

River Reach	Reach Length (km)	N	Mean Time to Pass (d)	Mean Rate (km/d)	Median Rate (km/d)
Release to 1GR	0.8	169	0.28	45.2	8.0
1GR to 1GO	59.5	110	3.63	22.6	20.1
1GO to 1LM	46.7	106	2.01	32.1	26.8
1LM to 1IH	50.5	111	1.55	42.6	39.5
1IH to 1MN	69.8	57	1.87	44.7	46.4
1MN to 1JD	122.3	45	3.61	39.5	39.5
1JD to 1TD	40.1	74	0.55	80.1	80.3
1TD to 1BO	72.6	56	1.52	56.7	60.0

Table 7

Passage routes (number and percentage) of radio-tagged kelts at McNary, John Day and Bonneville dams on the Columbia River in 2003.

	McNary Dam		John Day Dam		Bonneville Dam	
Passage Route	**N**	**%**	**N**	**%**	**N**	**%**
Spillway	*	-	70	76.1	36	49.3
Ice and Trash	*	-	*	-	14	19.2
Juvenile Bypass	10	8.1	2	2.2	13	17.8
Turbine Unit	*	-	0	0	1	1.4
Navigation Lock	0	0	11	12.0	0	0
Fishway	3	2.4	0	0	0	0
Unknown	111	89.5	9	9.8	9	12.3
Total known to pass	124		92		73	

*route not monitored

Table 8

Inter-dam and daily survival rate estimates with 95% confidence intervals calculated with telemetry data by Program MARK. Included are detection efficiencies for the receiver site at the terminus of each reach.

	Inter-dam	95% C. I.		Daily Survival	95% C. I.		Detection
Reach	**Survival Estimate**	**Lower**	**Upper**	**Estimate**	**Lower**	**Upper**	**Efficiency**
Release to 1GR	0.986	0.921	0.997	0.953	0.757	0.992	0.827
1GR to 1GO	0.970	0.841	0.995	0.991	0.952	0.998	0.651
1GO to 1LM	0.840	0.765	0.895	0.917	0.875	0.946	0.957
1LM to 1IH	0.845	0.767	0.901	0.897	0.842	0.935	0.805
1IH to 1MN	0.912	0.717	0.997	0.952	0.833	0.988	0.533
1MN to 1JD	0.706	0.587	0.801	0.907	0.861	0.940	0.906
1JD to 1TD	0.936	0.835	0.977	0.887	0.724	0.959	0.933
1TD to 1BO	0.831	*	*	0.788	*	*	0.831

*Program MARK was unable to calculate confidence intervals for the last inter-dam reach.

FIGURES

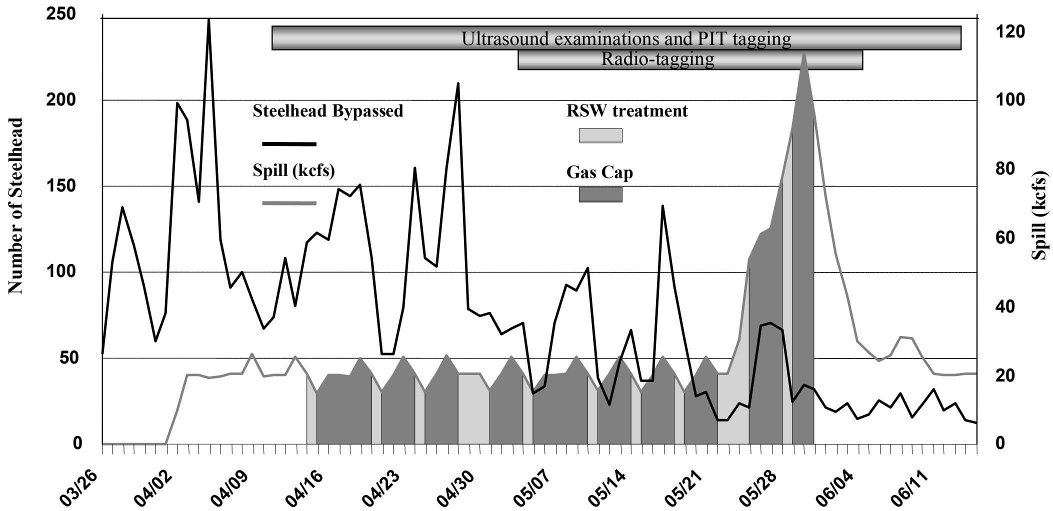

Figure 1. Number of steelhead bypassed from the juvenile separator at Lower Granite Dam with spill volume and spill test treatments. Included is the timing of ultrasound examinations and PIT and radiotagging effort.

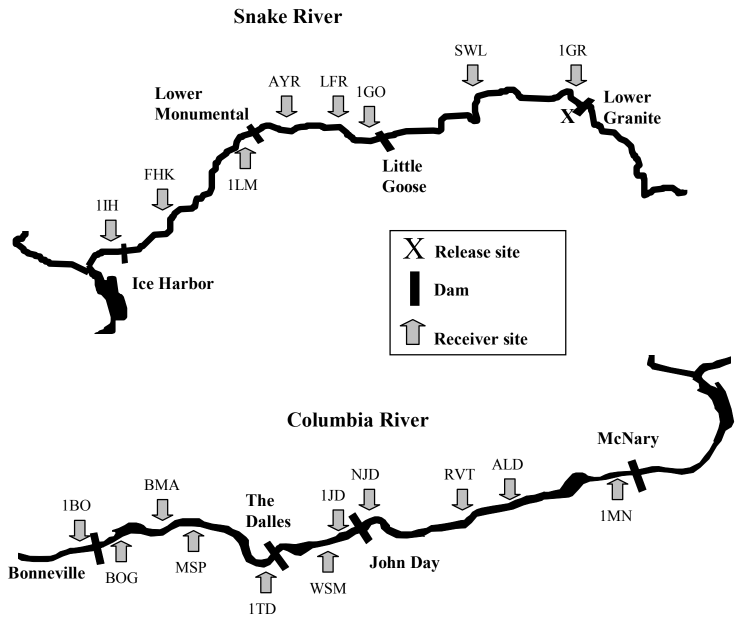

Figure 2. Location of release site, Columbia and Snake river dams and selected telemetry receivers used to estimate passage rates, passage times and inter-dam reach and daily survival rates of outmigrating Snake River steelhead kelts in 2003 (see Table 5 for receiver site code definitions).

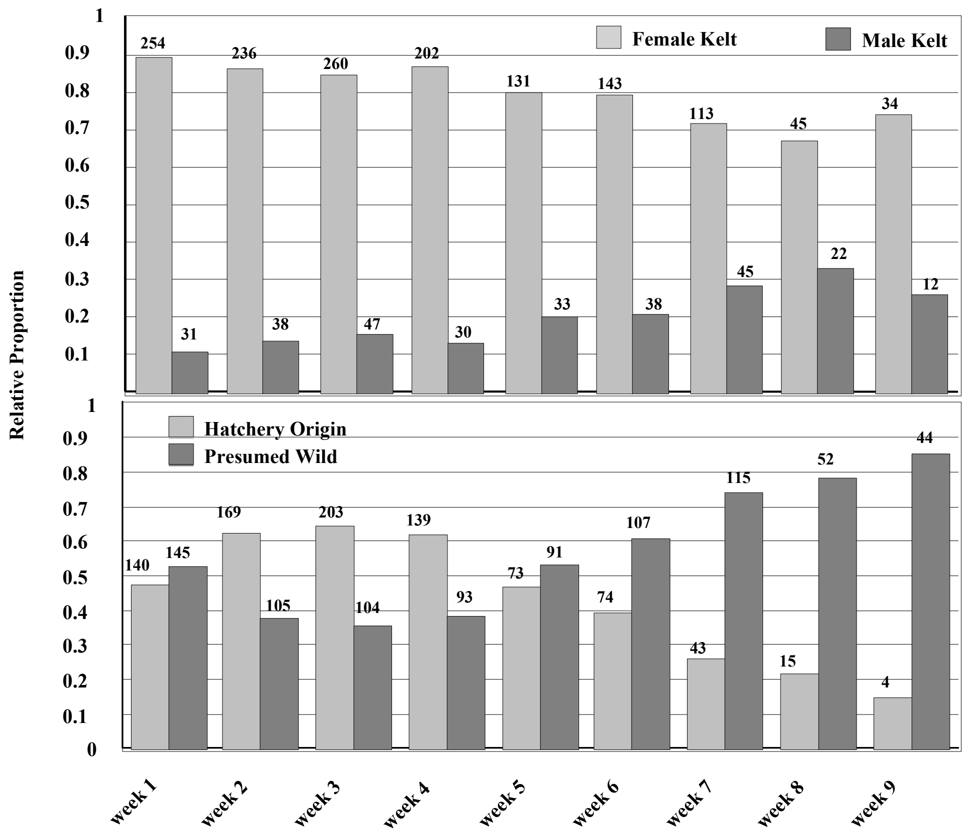

Figure 3. Relative proportion of female and male, and hatchery and wild origin steelhead kelts examined by ultrasound throughout the 2003 study period.

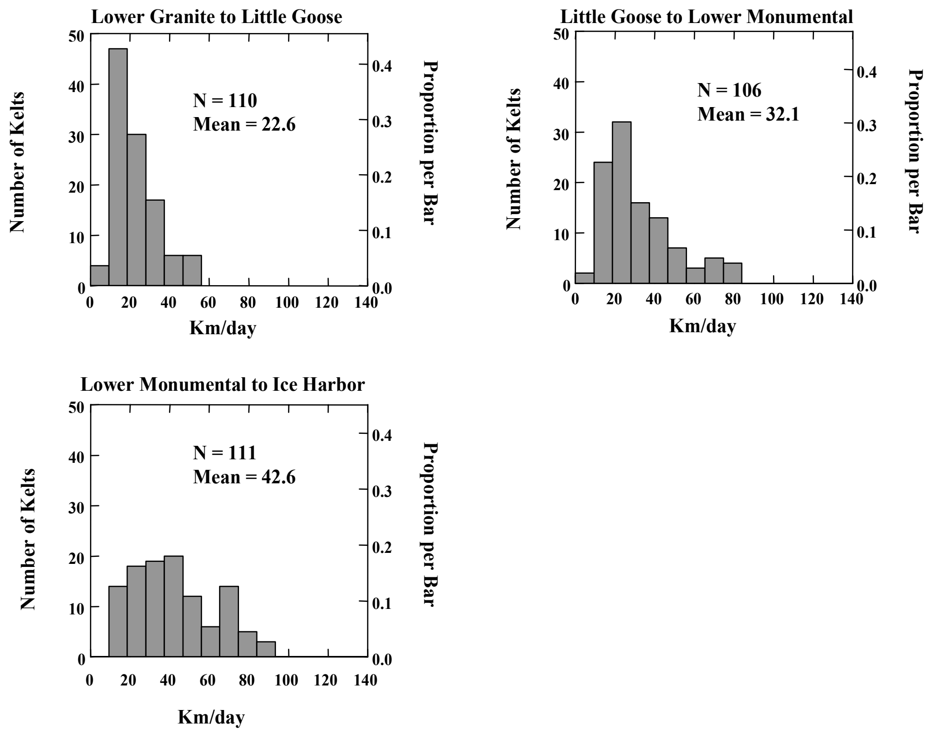

Figure 4. Distributions of migration rates (km/d) of radio-tagged steelhead kelts through inter-dam reaches of the Snake River in 2003.

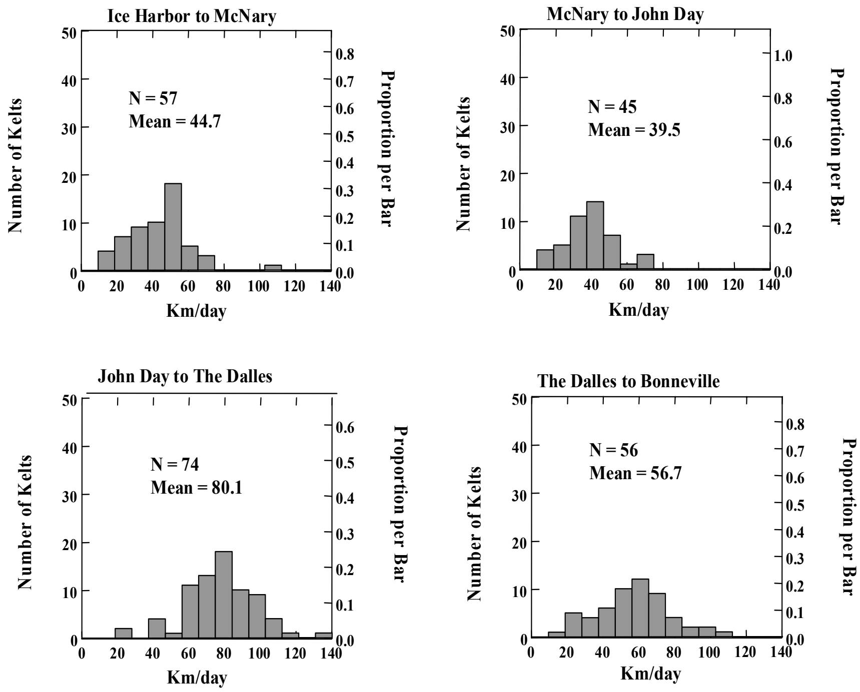

Figure 5. Distributions of migration rates (km/d) of radio-tagged steelhead kelts through inter-dam reaches in the Columbia River in 2003.

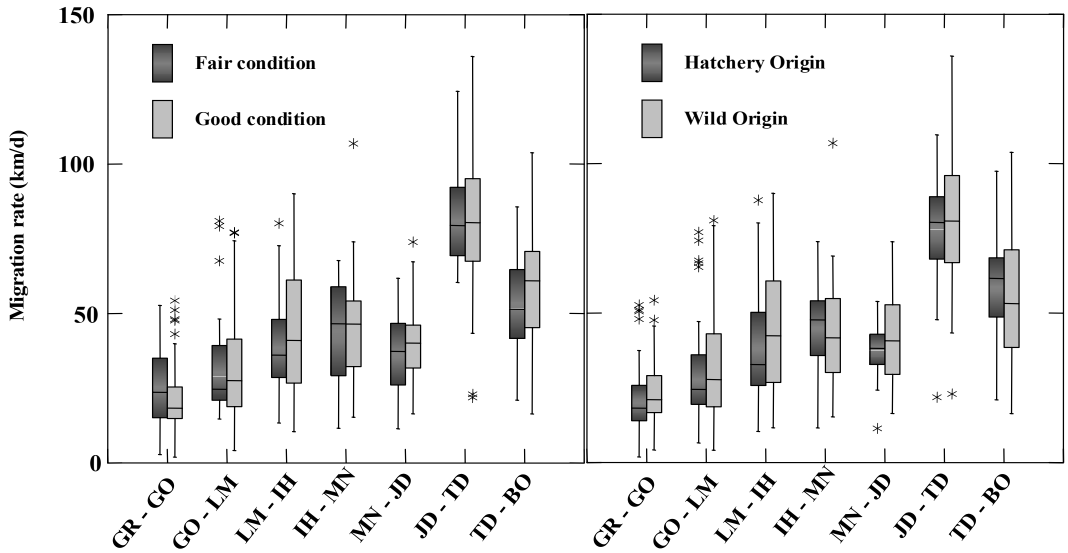

Figure 6. Migration rates (km/d) of kelts in fair and good physical condition and of hatchery and wild origin through inter-dam reaches of the Snake and Columbia rivers in 2003.

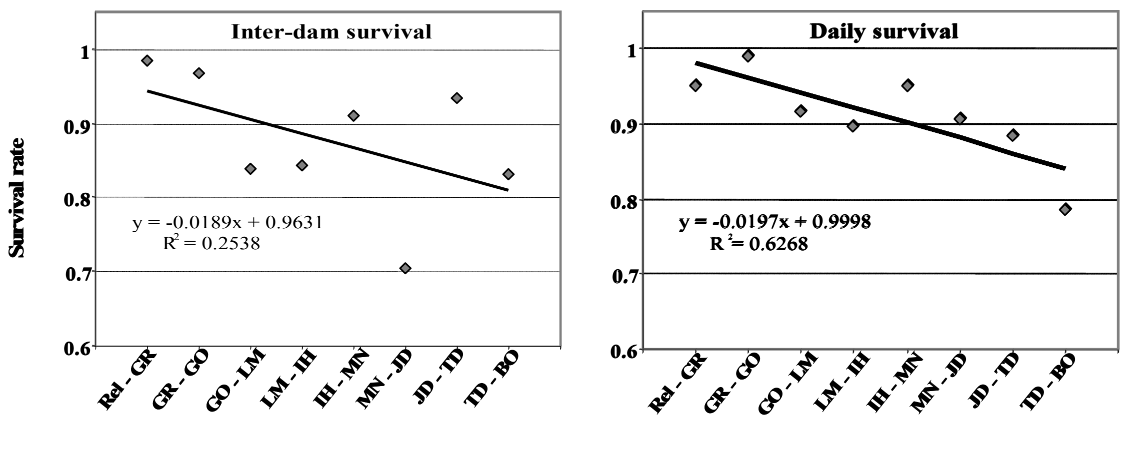

Figure 7. Inter-dam and daily survival rate estimates through Snake and Columbia river reaches for steelhead kelts released in the Lower Granite Dam tailrace in 2003.