Evaluation of a Surface Flow Bypass System for Steelhead Kelt Passage at the Second Powerhouse, Bonneville Dam, 2004

Monitoring Report
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EXECUTIVE SUMMARY

Steelhead (*Oncorhynchus mykiss)*, the sea-run form of the rainbow trout are iteroparous, having the ability to repeat spawn (Long and Griffin 1937). Some factors affecting repeat spawning rates in salmonids include, phylogenic constraints, environmental conditions, geographic location, sex, size at maturity, harvest, and impoundment effects (Withler 1966; ISG 1996; Fleming 1998; Wertheimer and Evans 2005). Reduced genetic contributions from post-spawn steelhead attempting repeat spawning runs – referred to as ‘kelts’ – may be a component in the declines of Columbia Basin steelhead stocks. As a result of these declines the upper Columbia River steelhead Evolutionarily Significant Unit (ESU) is currently listed as ‘endangered’, whereas the Snake, mid-Columbia and lower Columbia River ESU’s are listed as ‘threatened’ under the Endangered Species Act (ESA; NMFS 2004). Because steelhead are iteroparous, a better understanding of kelt migration behaviors through the Federal Columbia River Power System (FCRPS) could provide insight into dam structural configurations (e.g., surface flow bypass systems) and operations (e.g., spill) that are germane to the recovery of listed steelhead stocks.

This report describes kelt passage through lower Columbia River (LCR) dams where modifications occurred. For instance, at The Dalles Dam (TDA), a spillway tailrace training-wall was placed. Further, at the second powerhouse (B2) of Bonneville Dam (BON) the sluice chute was modified into a surface passage route, termed the B2 Corner Collector (B2CC). The objective of this study is to compare the fish passage efficiency (FPE) metrics from kelts passing LCR dams, to metrics seen during previous studies and during a similar water flow year (2002) to assess dam modifications on kelt passage.

From 8 April to 24 May 2004, 516 kelts were radio-tagged and released from McNary (McN; n=123) and John Day (JDA; n=393) dams. Average water discharge at TDA was 74% (201.6 kcfs ± 45.1) of the 2002 average (271.0 kcfs ± 58.6), with 39% of river flow passed via spill. At TDA, 99% of kelts passed via non-turbine routes; most, passing via the spillway. Over 90% of kelts at the TDA powerhouse passed with surface water away from turbine intakes into the sluiceway, generating a high effectiveness ratio (~ 30:1).

Average river discharge at BON was 81% (203.3 kcfs ± 37.0) of the 2002 average (252.2 kcfs ± 53.8), with 35% of river flow discharged as spill, 53% at B2, and 12% at Powerhouse I (B1). Over 58% of kelts passed via sluiceway’s (B1 & B2CC), 28% spill, 9% turbine, and 4% via bypass systems. At B2, fish passage efficiency (non-turbine passage) significantly increased from 2002 to 2004 (from 62% to 88%; chi-square test; $P < 0.0001$), with 82% of kelts passing the B2CC (~ 16:1 effectiveness ratio), while median forebay residence times at B2 decreased significantly (chi-square test; $P < 0.0001$).

Summary

In 2004, passage and residence data from kelts passing the LCR and BON indicate innovations deployed to enhance the passage, survival, and return rates from juvenile Pacific salmon (*O. spp*.) proved beneficial to steelhead kelts. These kelt passage data stand as confirmation that steelhead kelts can be rapidly and effectively (fish-to-flow) passed away from turbine intakes using surface flow bypass systems.

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INTRODUCTION

Some natural causes that affect respawning rates among iteroparous salmonids include environmental conditions, geographic location of natal stream, sex, size at maturity, and differences in the energy investment of spawning among different stocks & species (Fleming 1998). For example, winter run steelhead varieties enter the freshwater in a sexually mature state, and typically have higher respawning rates than summer run varieties which sexually mature while in the freshwater (Withler 1966). Impacts of impoundments to repeat spawning rates include, but are not limited to, direct (mortality associated with dam passage) and indirect (e.g., bioenergetic exhaustion associated with passage through multiple dams and reservoirs) components (Whitt 1954; Withler 1966; NPPC 1986; ISG 1996; Wertheimer and Evans 2005).

The number of post-spawn steelhead (kelts) in the Columbia Basin that historically survived to spawn again is not well known (Evans et al. 2004a). Scale analysis from Columbia River steelhead, prior to the construction of BON, indicated repeat spawning rates ranged from 2% in the summer run to 12% in the winter run (Long and Griffin 1937). Scale analysis from steelhead of the Clearwater River, a tributary of the Snake River (SnR), in the 1950s indicated a repeat spawning rate of roughly 2% to 4% when only two mainstem dams impeded their migration (Whitt 1954). Current return data from steelhead kelts tagged with passive integrated transponders (PIT) indicates less than 1% of migrating SnR kelts have been contacted on repeat spawning migrations (Boggs and Peery 2004). However, repeat spawning rates typically decline with increasing distance from the ocean (Fleming 1998); thus, it is difficult to discern impoundment affects relative to what would be the natural level of repeat spawning in the system.

Due to their post-spawned atrophic state, steelhead kelts have a finite amount of time to resume feeding – a behavior believed to take place primarily in the ocean – or they will die. Thus, reducing delays in kelt migrations due to dam passage events are particularly important. Currently, renovations in the FCRPS are focusing on reducing migration delays at dams for juvenile salmon through using the natural surface orientation of smolts (Andrew and Geen 1960) to use surface flow bypass (SFB) systems to pass these fish (Ferguson et al. 1998; Johnson et al. 2005). Wertheimer and Evans (2005) reason that due to relatively short distances to the ocean, rapid LCR migrations rates, and high passage efficiencies from kelts passing overflow routes (i.e., sluiceways), surface bypass systems being deployed for smolts at LCR dams may also benefit kelts. One such route is at BON B2, where the sluice chute was internally modified and the outfall was extended to an area of greater water depth and higher river flow to form a SFB.

As the lowermost Columbia River dam, BON passes a more diverse array and larger number of migrants than other main-stem dams; thus, having the potential to have the most deleterious impact on these fish (Kynard and O’Leary 1993). For instance, both ESA listed winter (ocean maturing) and summer (stream maturing) steelhead varieties (Withler 1966) spawn in tributaries located in the reservoir created by BON (Lake Bonneville), the sole Columbia River basin reservoir affecting both steelhead varieties. Development of the ice and trash sluice chute at BON B2 into a surface flow bypass system (B2CC) provides a unique opportunity to evaluate effects of a surface bypass on the passage behaviors of these fish. The results from this study are being used to assess how different operational (i.e., spill) and configuration strategies at dams (i.e., providing surface flow passage routes), may reduce delay, improve passage, and potentially enhance iteroparity rates of steelhead kelts passing through LCR dams.

Methods

Study Sites

This report focuses on kelt travel between and passage through LCR dams, which are described and depicted below (Figure 1). Migrating steelhead kelts were captured, radio tagged, and released at McN (located on the Columbia River, rkm 470), and JDA (rkm 347). Kelts arriving at these facilities comprise an aggregate population from several ESU's including ESA listed Columbia (mid & upper) and Snake river steelhead stocks (NMFS 2004). The migration rate and downstream passage of each tagged kelt was monitored from release through the study area Exit Station which was located in the free-flowing reach beyond BON.

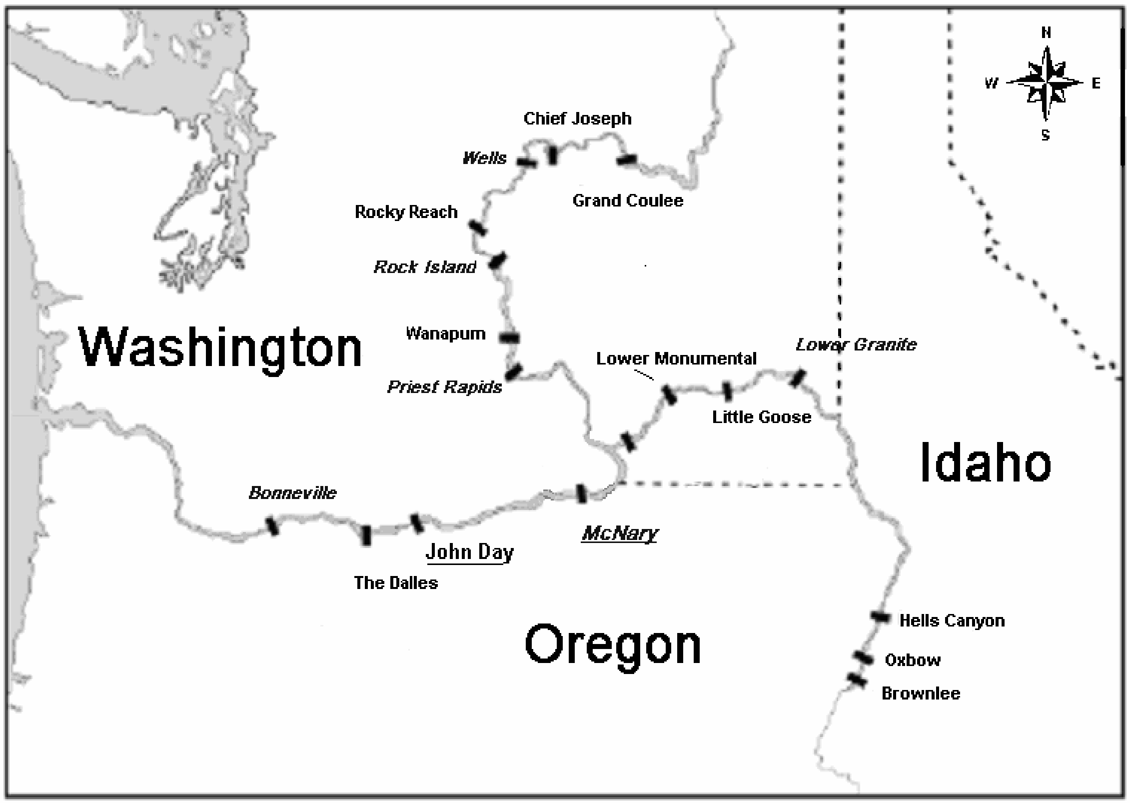

Figure 1. Hydroelectric projects of the Federal Columbia River Power System FCRPS (Lower Granite to Bonneville Dam), including some other Columbia Basin projects. Sample collection sites on the Columbia River are underlined.

Downstream migrants and fish falling back through FCRPS projects have several passage options, and in the LCR these options often differ by project. In general, a fish can either pass the dam by way of the spillway (if in operation) or by way of the powerhouse (Figure 2). Fish entering the powerhouse deep in the water column typically pass through the turbine units, whereas those higher in the water column may either: 1) pass with river water over lowered gates and be routed in a debris sluiceway to the tailrace, or 2) be diverted via screen systems that are positioned to guide fish out of the upper portion of the turbine intake into gate wells, and subsequently pass through gatewell orifices into the juvenile bypass system (JBS). Some adult upstream migrants that 'fallback' through a project, individuals that overshoot their natal stream of origin, and kelts are also known to pass downstream through navigation locks, and also via fishways designed to pass migrants upstream (Boggs et al. 2004). A description of LCR dams including bypass systems are described and depicted below (Figure 2).

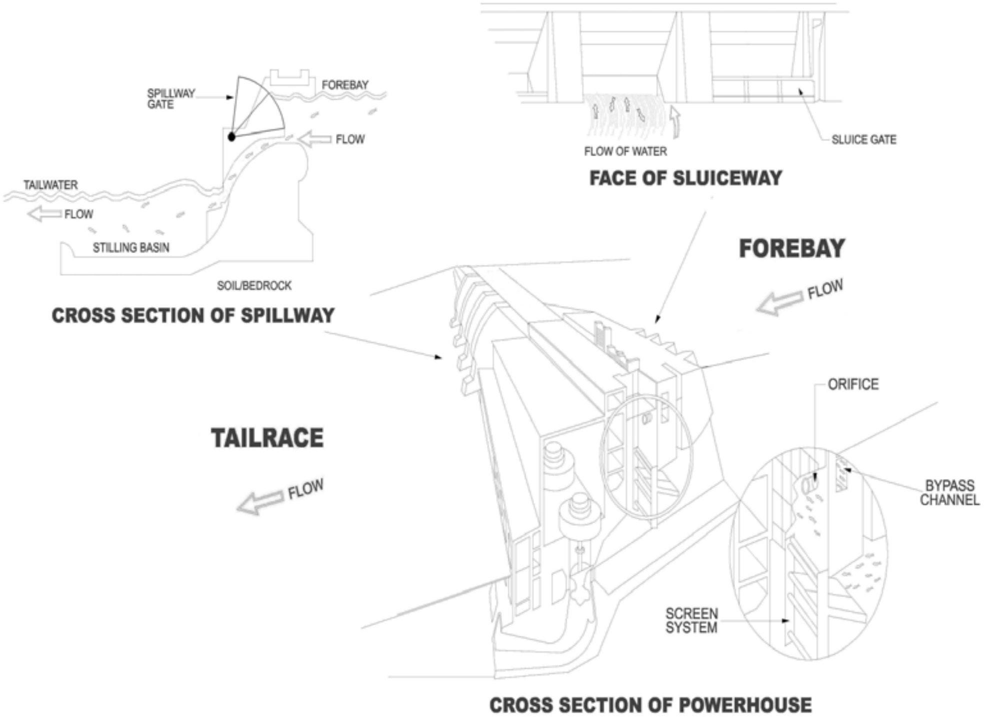

Figure 2. Schematic showing downstream passage routes (i.e., spillway, bypass system, turbine unit, and ice and trash sluiceway) at Federal Columbia River Power System (FCRPS) dams.

Kelt sampling initiated at McN, the lowermost juvenile fish collector facility on the Columbia River (rkm 470). The McN powerhouse contains 14 screened turbine units with a hydraulic capacity of 232 thousand cubic feet per second (kcfs). The JBS of McN contains a 'wet separator', which separates juveniles by size and from adults (Merchant and Barilla 1988). The spillway consists of 22 vertical lift gates. The navigation lock is on the Washington shore - with the spillway and powerhouse side by side - perpendicular to river flow. There are two fish ladders at the dam, one sited on each shore.

After passing McN, fish must navigate Lake Umatilla (123 km) and next encounter JDA (rkm 347), where the powerhouse has 16 turbine units with a capacity of approximately 322 kcfs. Fish are guided by screen systems into a JBS, equipped with a pneumatic switch-gate to allow for collection of adult specimens. Manually operating the switch-gate allowed monitoring personnel to divert adult steelhead into an adult holding tank. The spillway has 20 tainter gates. The navigation lock is sited on the Washington shore with the spillway and powerhouse spanning the river to the Oregon shore. There are two fish ladders at the dam, one on each shore.

After passing JDA, fish must navigate Lake Celilo (36 km) and next encounter TDA (rkm 310), where 22 unscreened turbine units, are positioned parallel to river flow, with a hydraulic capacity of approximately 375 kcfs. Orifices within gatewells lead into a debris type sluiceway that also has multiple overflow type entrances (20 ft. wide, 7 ft. deep) allowing fish to pass above lowered gates into a sluiceway. The sluiceway discharges approximately 4.5 kcfs of water flow over a weir into the tailrace. The spillway, which is perpendicular to river flow, has 23 tainter gates (numbered 1-23 from north to south). A training wall was placed extending out into the stilling basin between spill bays 6 and 7. The intent of this modification is to concentrate river flow discharged via the spillway in the northern portion of the tailrace, to avoid known juvenile salmon predator habitat (Shively et al. 1996). Fish ladders at TDA are on each side of the river.

After passing TDA, fish must navigate Lake Bonneville (74 km), next encountering BON (rkm 235) the lowermost FCRPS dam. Two separate powerhouses and an unattached central spillway comprise the BON project. The Navigation lock connects the Oregon shore on the south side and Robins Island on the north side. The first powerhouse (B1) connects Robins Island on the south side and Bradford Island on the north and contains ten unscreened turbine units with a hydraulic capacity of 136 kcfs. Fish at B1 were passed above lowered gates into a sluiceway, routing approximately 750 cfs of river discharge to the southern-most corner of the B1 tailrace.

The second powerhouse (B2) contains eight screened turbine units with a hydraulic capacity of approximately 153 kcfs and is separated from the spillway on the south end by Cascades Island and connects to the Washington shore on the north. At B2, the sluice-chute or ‘B2CC’ entrance is sited in the southernmost forebay corner and remained unchanged (15 feet across, and typically 22 feet deep at normal pool elevation). Internally, a smooth concrete ogee replaced a 50-ft drop onto a flat surface, and a conveyance channel extended the outfall beyond the tip of Cascades Island discharging approximately 5.5 kcfs of water away from predator habitat into an area of greater depth and higher river flow. At BON, each powerhouse has its own fish ladder system. The spillway has 18 vertical lift gates and lies between Bradford and Cascades Islands.

Kelt Sampling

Steelhead were obtained from the U.S. Army Corps of Engineers (Corps) JBS systems at McN and JDA dams. Adult steelhead were removed via dip-net from the bypass wet separator at McN, or diverted from the bypass into an adult holding tank at JDA, and transferred to a nearby sampling tank containing river water with a buffered solution of clove oil at 30 mg/L (Prince and Powell 2000). To differentiate between emigrating kelts and prespawn fallbacks, adult steelhead were scanned with an Aloka®[1] ultrasound machine to assess gonadal maturation and sex (Evans et al. 2004a). Male specimens with testis area < 1.25 cm^2 were considered kelts, whereas, those specimens with testis areas ≥ 1.25 cm^2 were classified as pre-spawners (Evans et al. 2004b). Condition status of steelhead (good, fair, poor, dead) were evaluated and recorded concurrent with the ultrasound spawning status identification. Guidelines for rating kelt condition can be observed in Appendix A. Data on fork length, coloration (bright, intermediate, dark), fin wear, fungus, hatchery or wild lineage (based upon adipose fin clips), physical anomalies (e.g., head burn see Elston 1996), and abdominal appearance (fat, intermediate, imploded/thin) were also recorded. After sampling/tagging, fish were placed in the recovery tank and allowed to exit back to the river of their own volition. Recovery and exit times approximated 15 minutes.

Radio Tags

We did not want to interfere with the ability of kelts to return on repeat spawning migrations; thus, radio-tags (~ 36 d; Lotek®[2] Engineering, Inc.) that were designed for juvenile salmon were externally affixed to the dorsal fin base of each kelt. Attached radio tags were 9.2 mm (diameter) x 20.0 mm, weighed 1.3 g in air, and transmitted once every five seconds. Retention rates of kelts tagged using this methodology are typically high (>95%; *in vivo & in vitro*) during the period (i.e., 36 d) in which radio-tags were transmitting (Wertheimer and Evans 2005). Attachment of the radio tags are more thoroughly described by Wertheimer et al. (2001). Radio-tag releases began 15 April 2004, however as USGS telemetry arrays were only available to detect tags from 23 April 2004, passage route histories for the early portion of the kelt-run were not completely represented. Reported passage data are from the completely represented period.

[1 & 2] Use of trade name does not imply endorsement by the USACE.

Telemetry Monitoring

Radio signal receptions or “contacts” from kelts tagged and released at McN were initially monitored by fixed-station aerial arrays located in McN tailrace and the JDA forebay. Arrays located in forebay areas are referred to as “entrance” stations, whereas arrays located in tailrace areas are referred to as “exit” stations. Projects downstream of JDA (i.e., TDA and BON) were equipped with entrance, and exit stations including underwater fixed station arrays located in and around dam passage structures (Appendix B). Tagged kelts were detectable to 8 m in depth directly below aerial antenna arrays, while underwater antennas had a range of about 6 m (Venditti et al. 2000). Data were collected based upon contacts from these arrays through three sets of exit arrays in the free-flowing reach beyond BON. The initial exit array was located on and around Reed Island (rkm 200), followed by an array sited near the mouth of the Washougal River (rkm 193), with the study area ‘Exit Station’ at the western end of Government Island (rkm 181) roughly 53 rkm below BON. Fixed stations were operated and maintained by U.S. Geological Survey (USGS) researchers with systems at TDA described by Hansel (et al. 2005), whereas, systems at and beyond BON are described by Reagan (et al. 2005).

Telemetry “contacts” from radio-tagged kelts were chronologically arranged for each individual coded tag, creating a sequential history for each fish. Data were then manually proofed with maps showing zones of coverage of each telemetry array. Manual proofing of the data allowed for rapid recognition of a kelt’s arrival at a telemetry array, route specific passage determination, and removal of noise. Criteria used in verifying the presence of a tagged kelt included the signal’s power level, the period of signal reception, and the distribution of contacts within and among arrays. Telemetry records were only accepted if the record of a tag’s plausible passage history was supported by telemetry contacts before and after each contact. We calculated radio-tag detection efficiency for each location based on the number of tagged specimens that were not detected at a site (i.e., dam or exit array) but were later confirmed at a downstream site.

Data Management and Analyses

Forebay residence times and migration rates were calculated to describe kelt migration delays through the study area Exit Station. Forebay residence times are the amount of time between the first and last contacts in the forebay from which a kelt passed. Migration rates through the pools were calculated as the amount of time from first tailrace contact at the upstream project to first forebay contact at the downstream project. Migration rates were calculated by dividing the length of the pool by the amount of time within the pool (tailrace-forebay). Migration rates were only calculated for kelts that were contacted by consecutive telemetry arrays, resulting in smaller sample sizes than the actual number of kelts passing each river-reach.

Migration success rates were calculated as a ‘proxy’ for kelt survival, because we were unable to address assumptions fundamental for validating the use of radio telemetry to determine survival rates (e.g., tagged individuals have the same probability of surviving as non-tagged individuals, survival and capture probabilities not affected by sampling; Burnham et al. 1987; Skalski et al. 2001). Migration success was determined based on the total number of kelts released minus the number detected within a given river-reach. As with many telemetry studies, fish loss within and among river-reaches cannot always be attributed to specific causes (e.g., loss can be attributed to mortality, tag loss, or missed detection).

The distributions of kelt migration rate data (km/h) were non-normal due to the presence of outliers. Therefore a distribution free and outlier sensitive test (e.g., Wilcoxon rank-sum) was used to compare travel times among river-reaches. Passage efficiency metrics were typically compared using chi-square tests. To ensure that assumptions of sample independence were not temporally violated (i.e., that kelt release groups or 'clusters' behaved similarly throughout the passage season) results from within season kelt releases (i.e., passage metrics, residence data) were compared using Kruskal-Wallis or chi-square tests. Means are expressed as x ± SD. Statistical significance was set at $\alpha < 0.05$. Statistical analyses were run with SAS®[3] software (version 8.0, SAS Inc., N.C., USA).

Information is provided on kelt diel activities and passage behaviors to provide insight into operational strategies that may reduce delay and provide for more effective kelt passage. We consulted the sunrise/set calendar to best select the period of visible daylight from 15 April to 30 May. The period of daylight (time) hours is defined as between 0700 and 1959 hours, roughly the inverse of that defined as nighttime spill at JDA (between 1900 and 0659 hours).

Metrics that illustrate the efficacies of spill and mechanical structures in passing juveniles away from turbines were calculated to describe kelt passage efficiencies (Whitney et al. 1997). Due to biotic variability, statistical comparisons of passage efficiency metrics across study years are typically not appropriate (Johnson et al. 2005). Despite this, we provide some comparisons as an indication of the relative performance changes between systems among years, primarily when similar water flows passed a given dam or powerhouse, with the caveat that these analyses be cautiously interpreted. As a result of the fluctuating nature of water levels in forebay areas, and the fixed positions of sluiceway gates, sluiceway effectiveness values are approximations and should be considered 'best estimates' of fish-to-flow ratios. The Corps initially reported incorrect flow data for the BON spillway (COE 2004), corrected flow data are reported herein. The employed metrics are defined:

- Kelt passage efficiency (PE) = (non-turbine / [non-turbine + turbine])
- Kelt guidance efficiency (GE) = (guided / [guided + turbine])
- Kelt sluice passage efficiency (SLE) = (sluice / [sluice + turbine])
- Kelt sluice effectiveness (SLF) = (SLE / [sluice discharge / powerhouse discharge])
- Spillway efficiency (SPE) = (spill / [non-turbine + turbine])
- Spillway effectiveness (SPF) = (SPE / [spill discharge / project discharge])
- B2 passage efficiency (B2FPE) = (CC + guided / [CC + guided + turbine])
- B2CC efficiency (B2CCE) = (CC / [CC + guided + turbine])
- B2CC effectiveness = (B2CCE / [CC discharge / B2 discharge])

RESULTS & DISCUSSION

Telemetry Sample & Detection efficiency

Kelts were tagged and released from McN (n=123; Appendix C-1) and JDA (n=393; Appendix C-2). Most tagged kelts were of wild origin (77%; n=397) and of good condition (58%; n=299), however, kelts of fair (33%; n=171) and poor conditions (9%; n=46) were also tagged.

Condition and origin data collected in 2004 from all kelts sampled at JDA (i.e., not just those selected for tagging) indicated that 70% of sampled kelts were wild (n=1,257) with an average of 46% of kelts passing JBS' in good, 21% fair, 27% of poor conditions, and roughly, 6% of kelts passing JBS were moribund or deceased (Appendix D). Our estimates of kelt migration success

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[3] Use of trade name does not imply endorsement by the USACE.

probably overestimate the success rates of the kelt populations passing these facilities, because good and fair condition kelts are disproportionately represented in our telemetry sample. Detection efficiencies were at or above 98% for the monitored sites (Table 1). High project detection efficiencies resulted from the enhanced probability of contact as kelts moved through multiple contiguous 'site' arrays (i.e., entrance, passage route, and exit 'arrays').

Table 1. Estimated detection efficiency of telemetry systems (forebay, passage route, and tailrace) of radio-tagged kelts released from the McN and JDA bypasses, 2002 v 2004.

Reach & Location	Estimated Detection Efficiency 2002	Estimated Detection Efficiency 2004	Detections (n) 2002	Detections (n) 2004	Missed Detections (n) 2002	Missed Detections (n) 2004
John Day	88%	98%	210	104	29	2
The Dalles	94%	99%	206	480	14	1
Bonneville	96%	99%	192	378	8	1
Gate One	90%	63%	156	224	17	131
Gate Two	66%	81%	106	287	37	68

Project Operations

Mean river flow discharges during 2001, 2002, and 2004 (Table 2; COE).

Table 2. Average flows through the Columbia River at John Day, The Dalles, and Bonneville dams in 2001, 2002, and 2004.

Project	2001	2002	2004
John Day	127 kcfs	278 kcfs	198 kcfs
The Dalles	128 kcfs	271 kcfs	202 kcfs
Bonneville	126 kcfs	252 kcfs	203 kcfs

Migration rates

Significantly higher migration rates were observed in the one non-impounded reach – the free-flowing area below BON– relative to each of the impounded reaches (Table 3. Wilcoxon rank-sum; P< 0.0001 for all within year reach comparisons relative to the free-flowing reach).

Table 3. Median, first (25th percentile), and third (75th percentile) quartile migration rates (km/hr) exhibited by tagged kelts passing river-reaches (tailrace-to-forebay) in the Lower Columbia River. Flows (1000 ft^3/s) are based on discharge measurements from the tailrace of the upstream dam.

	2002			2004		
Reach	N	Average Flows in kcfs (SD)	Median, 1st, and 3rd quartile Migration Rates	N	Average Flows in kcfs (SD)	Median, 1st, and 3rd quartile Migration Rates
JDA Pool (123 km)	201	275.0 (63.9)	1.5, 1.1, 1.9	104	184.9 (53.4)	1.4, 1.2, 1.7
TDA Pool (38 km)	156	277.8 (61.1)	3.3, 2.7, 4.0	384	197.8 (43.9)	1.4, 0.9, 2.1
BON Pool (73 km)	140	271.0 (58.6)	2.9, 2.3, 3.3	269	201.6 (45.1)	2.2, 1.8, 2.6
Free-flow (53 km)	163	252.2 (50.8)	4.7, 3.7, 5.7	213	203.3 (33.7)	4.6, 4.0, 5.3

John Day Dam – River Discharge and Operations

Average discharge at JDA was 71% (197.8 ± 43.9) of the 2002 average (277.8 ± 61.1). Spilling water usually occurred during night only periods at JDA in 2004 (from ~ 1900 to 0659 hours), typically, at 54% of total project discharge.

John Day Dam – Forebay Residence time

Median forebay residence times of kelts passing during continuous spill in 2004 (n=18) were significantly shorter than kelts in 2002 (n=85) whose residence included non-spill hours (chi-square test; $P < 0.0001$; 1:24 vs. 17:13; hh:mm). Median forebay residence time in 2004 at JDA were significantly longer than in 2002 (chi-square test; $P = 0.036$; 14:40 vs. 09:45; Figure 3).

Operational tests at JDA in 2002 (continuous vs. night only spill) may provide insight into the passage behaviors of kelts that help explain this delay. For instance, during both continuous and night only spill in 2002 at JDA, passage was mainly via the spillway. Similarly, during night-only spill in 2004 passage was again mainly via the spillway.

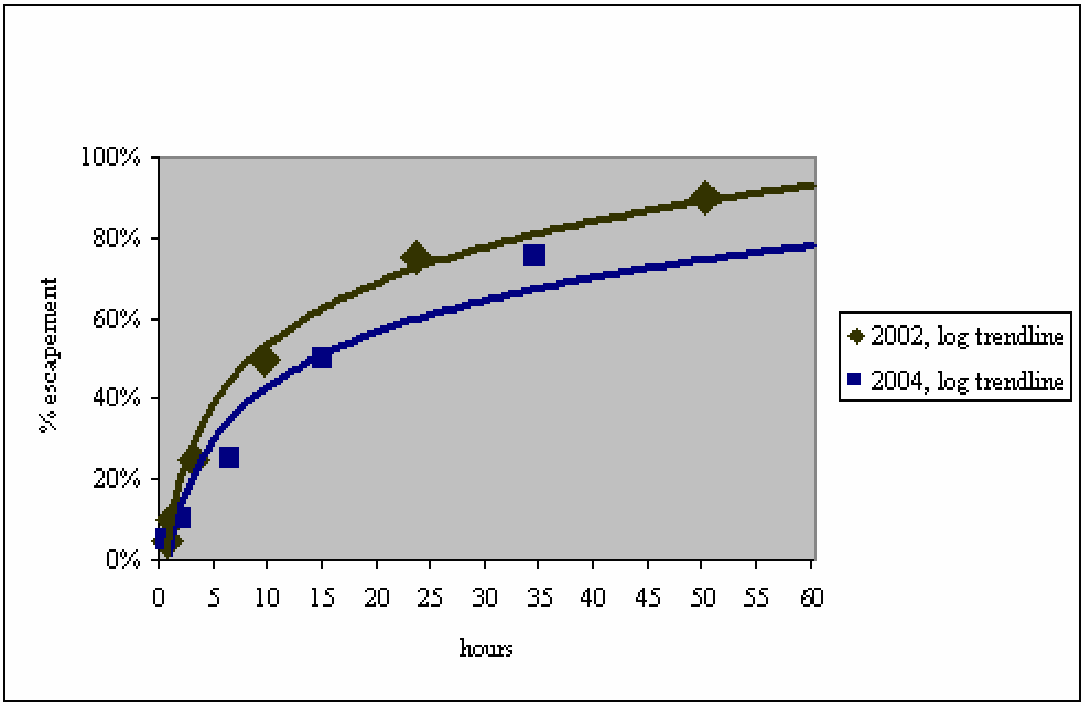

Figure 3. Median forebay residence times of radio-tagged kelts (hours) vs. the percentage of kelts exiting the forebay of John Day Dam (percent escapement; 2002 and 2004).

John Day Dam – Passage Routes

Based upon the last reception of telemetry signals or ‘contacts’ from fixed station forebay aerial telemetry arrays we estimate that over 87% (89 of 103) of kelts passed via the spillway.

John Day Dam – Time of Passage (diel)

Data suggests the forebay residence times of kelts were increased in 2004 due to the lack of an alternative daytime passage route to turbine intakes. For example, nearly 80% (81/103) of kelt first contacts in forebay areas occurred during daylight hours. Patterns of contacts from telemetry arrays suggest kelts were moving across the face of the dam during daylight hours, presumably, searching for a passage route. During the first hour after the onset of spill almost 25% (21 of 89) of kelts that had accumulated during daytime hours passed via the spillway. On the final hour of night-only spill (between 0600 and 0659 hours) an average of one kelt exited via spill, a passage pattern that was unlikely to have occurred through chance alone (chi-square test; $P < 0.01$). Evidently, kelts that had accumulated in forebay areas during daylight hours were reluctant to enter turbine intakes (or did not discover turbine flows), and readily discovered river discharge passing via the spillway, once, river-flow was allocated via this route.

The Dalles Dam – River Discharge and Operations
Average discharge at TDA was 74% (201.6 kcfs ± 45.1) of the 2002 average (271.0 kcfs ± 58.6). Roughly, 39% of river flow was discharged at the spillway, and 2.0% (~ 3.9 kcfs) passed via the ice and trash sluiceway.

The Dalles Dam – Forebay Residence Time
Forebay residence times at TDA remained minimal. In 2004, median forebay residence was approximately one half hour (00:32), similar to 2002 (00:34; Figure 3). As the percentage of water allocated through the spillway was unaffected by the presence of the spillway tailrace wall, forebay residence data are reasonable.

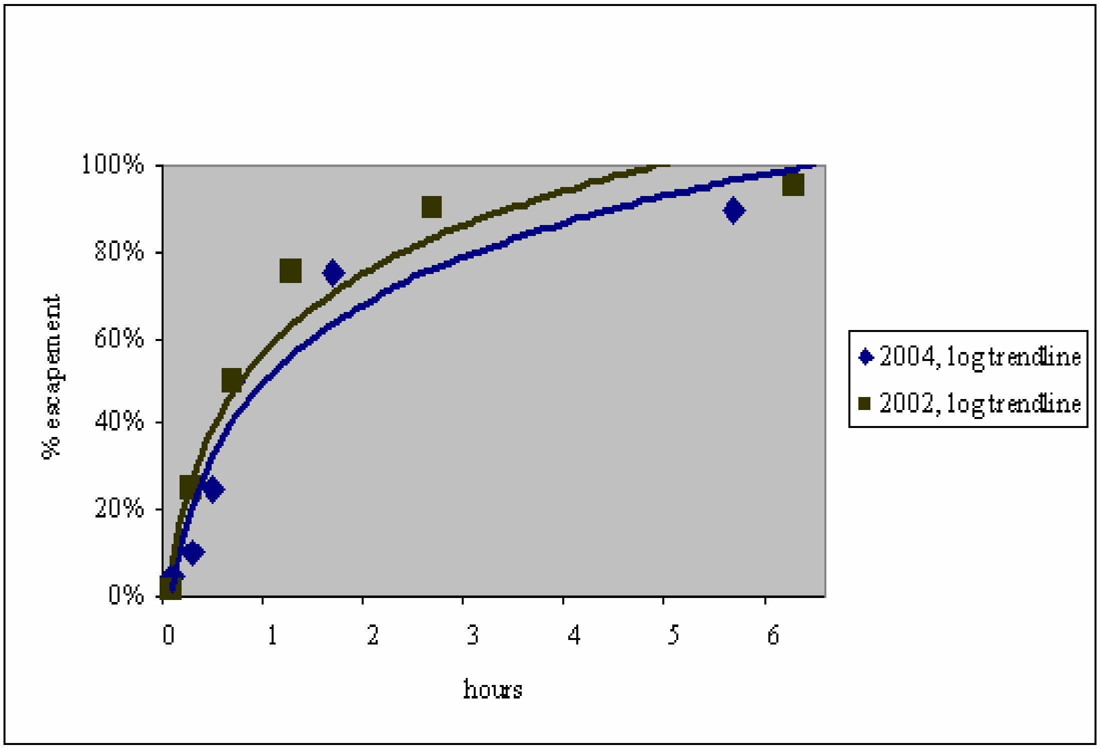

Figure 4. Median forebay residence times from kelts (hours) vs. the percentage of kelts exiting the forebay of The Dalles Dam (percent escapement; 2002 and 2004).

The Dalles Dam – Passage Routes
At TDA, 99% (473 of 476) of kelts passed via non-turbine routes, with the majority of these (93%; 443 of 476) passing via the spillway. Similar near perfect project passage efficiency (i.e., 99%) was documented at TDA during the spill portion of 2001 at a lower spill rate (30%) than the 40% spill rate used in 2004 (Wertheimer and Evans 2005). Most kelts (91%; 30 of 33) at the powerhouse passed with surface water flow into the sluiceway (~ 3% of powerhouse discharge), generating a high sluiceway effectiveness or fish-to-flow ratio (~ 30:1). Recall, sluiceway effectiveness is calculated using powerhouse discharge (not project discharge as is spillway effectiveness). Calculating sluiceway effectiveness in this manner allows for direct comparison to the BON sluiceways, where the powerhouses are separate from the spillway.

The Dalles Dam – Time of Passage (diel)
Most kelts (72%; 320 of 443) passed the spillway during the daylight hours; however sluiceway passage was higher during the nighttime period (67%; 20 of 30).

Bonneville Dam – River Discharge and Operations

Average river discharge at BON in 2004 was 81% (203.3 kcfs ± 37.0) of the 2002 average (252.2 kcfs ± 53.8). In 2004, roughly 35% of river flow discharged as spill, 53% at B2, and 12% at B1. Two spill levels were tested during spring 2004: 1) during daytime hours (between 0500 and 2059 hours) spill averaged 50.8 kcfs (± 13.2), and 2) during the nighttime period (between 2100 and 0459 hours) spill averaged 95 kcfs (± 29.9). In 2002, roughly 41% of river flow was discharged at the spillway, 42% at B2, and 17% at B1.

Bonneville Dam – Forebay Residence Time

Median forebay residence at B2 were significantly reduced (chi-square test; $P < 0.0001$) from 2002 (06:30; n=50) to 2004 (00:19; n=218; Figure 5). Data are supported by the fact that residence times showed 'no evidence' of cluster effects in 2002 (Kruskal-Wallis test; $P = 0.3889$) or 2004 (Kruskal-Wallis test; $P = 0.2627$). That is, consistent behaviors were observed at B2 from the groups of kelts released at both McN and John Day throughout each passage season.

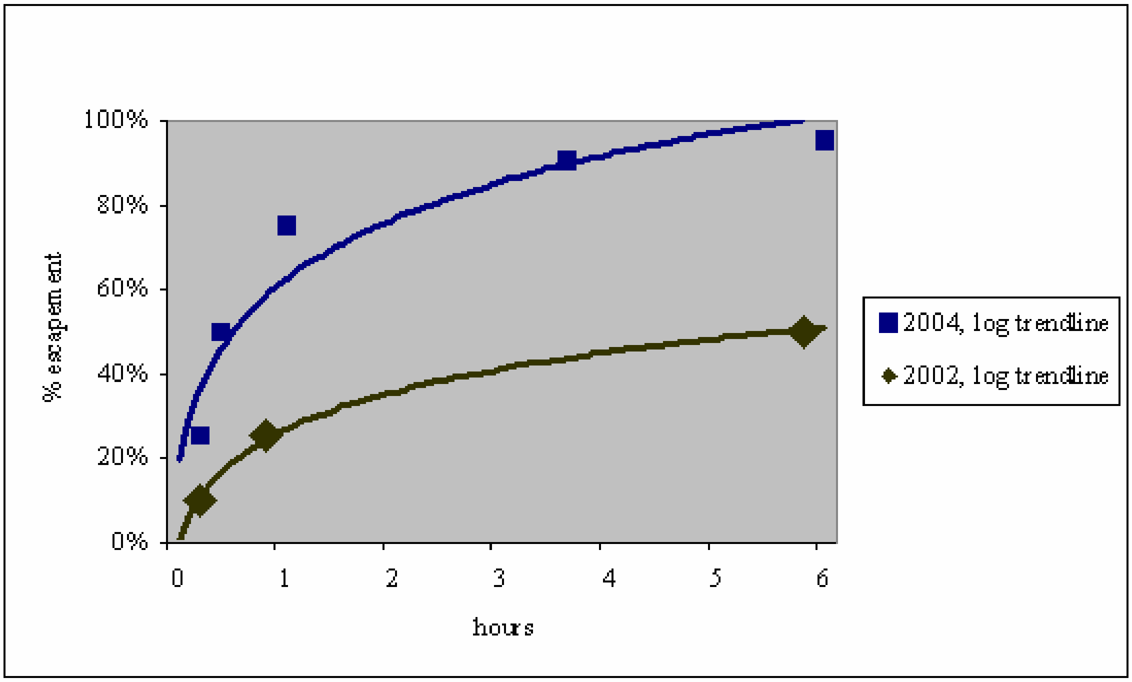

Figure 5. Median forebay residence times of radio-tagged kelts (hours) vs. the percentage of kelts exiting the forebay of Powerhouse II (B2) Bonneville Dam (percent escapement; 2002 and 2004).

Median forebay residence times at the spillway in 2004 (00:54) were over twice those times documented in 2002 (00:24; Table 4). This may not prove overly alarming as median spillway forebay residence time remained brief (< 1.0 h). Median forebay residence time at B1 also increased from 2002 (05:18) to 2004 (19:46), with similar kelt sample sizes (Table 4). Data from Wertheimer et al. (2002, 2003) suggest the lack of an open chain gate on the north side of the B1 wing-wall may have protracted forebay residence times at B1. Willis and Uremovich (1981) documented high rates of juvenile steelhead passage north of the wing-wall at gate 7A, and believed that steelhead were attracted to the water current pattern caused by the wing-wall.

Bonneville Dam – Passage Routes

Kelt passage distributions were 66% via B2 (n=235), 28% spillway (n=101), and 5% via B1 (n=19). Nearly 60% of kelts (207 of 356) passed surface routes at B1 and B2, 28% spill, 9% via turbine units, 4% via juvenile bypass systems, and one kelt passed via the Navigation Lock.

Table 4. Median and first (25th percentile) and third (75th percentile) quartile forebay residence times (hours) exhibited by kelts passing John Day Dam, The Dalles Dam, and Bonneville Powerhouse 2 (B2), the spillway (Spill), and Powerhouse 1 (B1) during the periods in which kelts passed in 2002 (April 15 through June 30) and in 2004 (April 15 through May 31).

	2002			2004		
Site	N	Average Flows in kcfs (SD)	Median, 1st, and 3rd quartile Forebay Residence Times	N	Average Flows in kcfs (SD)	Median, 1st, and 3rd quartile Forebay Residence Times
JDA	183	277.8 (63.9)	9.1, 2.3, 23.4	90	197.8 (53.4)	15.6, 6.4, 42.1
TDA	197	271.0 (61.1)	0.5, 0.3, 1.6	372	201.6 (42.0)	0.5, 0.3, 1.1
B1	18	43.0 (31.3)	4.4, 3.5, 19.5	19	24.8 (25.5)	19.9, 7.2, 34.5
Spill	125	103.5 (41.6)	0.4, 0.1, 4.1	100	70.8 (29.2)	0.9, 0.3, 3.2
B2	48	105.7 (21.9)	6.1, 0.7, 23.1	218	107.7 (22.8)	0.3, 0.1, 1.0

At B2, passage efficiency significantly increased (chi-square test; P < 0.0001) from 2002 to 2004 (Table 5). Statistical comparison between years is supported by the similar water flow levels passing B2 in 2002 (~106 kcfs) and 2004 (~ 108 kcfs). Moreover, passage data showed 'no evidence' of cluster effects within each study year (chi-square test; P = 0.2256). Over 80% (192 of 235) of kelts passed B2 in the ~ 5 kcfs of surface water passed via the B2CC, generating an effectiveness value of ~ 16:1. Roughly, 66% of our kelt sample at BON migrated in the 53% of water discharged at B2. Guidance efficiency of screen systems was low (35%; 15 of 43), perhaps due to kelts in the upper portion of the water column discovering the B2CC surface exit.

At the spillway, there was a significant reduction in passage efficiency between 2002 and 2004 (from 65% to 28%; chi-square test P < 0.0001); thus, spillway effectiveness was reduced from 1.6:1 (2002) to 0.9:1 (2004; Table 5). However, mean water flow through the spillway was greater in 2002 (~104 kcfs) than 2004 (~ 71 kcfs). Approximately, 28% of our kelt sample at BON migrated in the 35% of water discharged past the project via the spill.

At B1, 79% (15 of 19) of kelts at the powerhouse passed with the surface water overflow discharged into the sluiceway, generating a high sluiceway effectiveness ratio (~ 26:1). Roughly, 5% (19 of 356) of kelts at BON migrated in the 12% of the water flow discharged via B1. Water flow levels passing B1 were greater in 2002 (~ 43 kcfs) than 2004 (~ 25 kcfs).

Bonneville Dam – Time of Passage (diel)

At B2, roughly two-thirds (67%) of kelts passed during daylight hours; the same proportion passed the B2CC during this period (i.e., 67%). Similarly, 73% of kelts passed the B1 sluiceway during daylight hours. Spillway passage was almost equally divided between daytime (49%) and nighttime periods (recall, daytime spill was ~ 51 kcfs, whereas nighttime spill was ~ 95 kcfs).

Migration Success

Of kelts released on or after 20 April 2004 from McN, 73% (82/113) were contacted passing the exit arrays (as the exit arrays were not operational until on or after 23 April 2004). Of kelts released on or after 21 April 2004 from JDA (n=279), 92% were contacted passing the exit-arrays; suggesting, success rates from McN and JDA were typically at, or above 70% and 90%, respectively. For comparison, Wertheimer and Evans (2005) found that of those kelts tagged and released from McN in 2001 and 2002, 59.6% (n=52) and 62.3% (n=273) were contacted at these same exit arrays, respectively. Of kelts tagged and released from JDA, 63.6% (n=154) and 80.0% (n=10) were contacted at these exit arrays during the same two years.

Table 5. Passage (PE), guidance (GE), sluiceway (SLE), and spillway (SPE) efficiencies and Sluiceway (SLF) and Spillway Effectiveness (SPF), at The Dalles Dam (TDA), and BON, including the first Powerhouse (B1) and second Powerhouses (B2) in 2002 & 2004, where: 1) Passage efficiency (PE) = (non-turbine / [non-turbine + turbine]), 2) Guidance efficiency (GE) = (guided / [guided + turbine]), 3) Sluice efficiency (SLE) = (sluice / [sluice + turbine]), 4) Sluice effectiveness (SLF) = (SLE / [sluice discharge / project discharge]), 5) Spillway efficiency (SPE) = (spill / [non-turbine + turbine]), and 6) Spill effectiveness (SPF)=(SPE / [spill discharge / project discharge]).

Project	Year	N	Spill (%)	PE (%)	GE (%)	SLE (%)	SLF	SPE (%)	SPF
TDA	2002	207	37	95	NA	59	26:1	89	2.5:1
TDA	2004	476	39	99	NA	91	30:1	93	2.4:1
BON	2002	207	41	90	62 (B2)	100 (B1)	71:1	65	1.6:1
BON	2004	356	32	91	35 (B2)	NA	NA	28	0.9:1
B1	2002	18	41	100	NA	100	71:1	NA	NA
B1	2004	19	32	79	NA	79	26:1	NA	NA
B2	2002	50	41	62	62	NA	NA	NA	NA
B2	2004	235	32	88	35	82	16:1	NA	NA

SUMMARY & CONCLUSIONS

For systems such as the Columbia River with a diversity of anadromous and resident species making downstream migrations, bypass systems of use to all migrants, not structures specific to a particular species or life stage are needed (Kynard and O'Leary 1993). This study provides such data for the post-spawn steelhead population migrating through the LCR with particular emphasis on the B2CC of BON. Fish-to-flow or 'effectiveness' ratios generated from kelts passing BON, at the B1 sluiceway and B2CC confirm the hypothesis that steelhead kelts can be effectively passed away from turbine intakes using surface flow water bypass systems. Summary findings from our study include:

- Indirect impoundment effects significantly slowed the migration rates of kelts.

- Forebay Residence times at John Day Dam were prolonged due to the lack of an alternative passage route to the turbine intakes (i.e., spill, or surface bypass) during daylight hours.

- Kelts were rapidly and effectively passed away from B2 turbines with surface water flow discharged via the B2CC.

- Data indicate optimal kelt passage routes are via surface flow bypass systems.

Spillways at FCRPS dams were not designed to pass fish. The 'water value' attained from passing kelts via surface flow bypass systems is accentuated when B2CC and sluiceway efficiency and effectiveness ratios are calculated directly in relation to the spillway's (recall, spillway efficiency and effectiveness are generated using total project passage and project discharge). Calculating B2CC efficiency in relation to 'project-wide' passage generates an efficiency of 53% (192 of 356). These data produce a B2CC effectiveness or fish-to-flow ratio in excess of 26:1 (~ 2% of BON discharge was passed via the B2CC); indicating, the B2CC was at least 26 times more effective in passing kelts than was the BON spillway. Calculating B1 sluiceway efficiency in this manner produces an efficiency of 4% (15 of 356), generating an effectiveness of 10:1 (~ 0.4% of BON discharge was passed via the B1 sluiceway). Finally, calculating TDA sluiceway effectiveness in relation to spillway effectiveness generates a value of 46:1 (~ 2% of TDA discharge was passed via the sluiceway), indicating the TDA sluiceway was roughly 19 times more effective in passing kelts than the TDA spillway. These results together support the on-going retrofitting of FCRPS spillways (e.g., Removable Spillway Weirs or 'RSW') to provide for surface passage in assisting outmigrating juvenile salmon and kelts.

The success of passing steelhead kelts at the B2CC was probably realized as this system was designed to pass their conspecifics and congeners, though of a differing life stages. Despite this success, the effectiveness of surface bypass systems are typically site, species, and life stage specific; thus, systems under development should take into account knowledge on the behaviors of salmon smolts (Johnson et al. 2005) and steelhead kelts. Further, to better our understanding of impoundment affects on repeat spawning rates in the contemporary hydro-system, the return rates of kelts migrating from upriver locations (e.g., upper Columbia and Snake rivers) should be better established and integrated into a cumulative evaluation of the entire Columbia Basin.

Hydro-dam configurations and operations in the LCR that expedite the downstream passage of kelts may prove a cost effective means of conserving genetic diversity in some Columbia Basin steelhead stocks. Structural modifications to main-stem dams can reduce delays associated with passage for kelts, as indicated by performance of the B2CC. Limited access to steelhead kelts in the LCR, relatively short distances to the ocean, and the present level of iteroparity suggests that kelts from these locations will be best aided through continued in-river passage improvements such as the development and earlier onset of surface spill, surface bypass routes through powerhouse areas, and turbine modifications (Cada 2001). Recommendations in this paper should be cautiously applied in relation to the management of upriver steelhead stocks. It is beyond the scope of this paper to address impoundment affects (both indirect and direct) on stocks from the Snake and mid to upper Columbia rivers, or make recommendations for the management of these stocks

It is of particular importance that the lowermost hydro-facility on the Columbia River provides a surface flow passage route at each powerhouse. Kelt passage rates at both powerhouses could probably be enhanced through operations criteria providing a surface passage route prior to the onset of operations for juvenile salmon (from December to March). Hydro-acoustic and PIT evaluations could provide insight into periods, where operation of the B2CC and existing LCR surface overflow routes (TDA and B1 sluiceways) would be advantageous to the return rates from these fish. More quantitative field studies of kelt behaviors would be beneficial to our understanding of kelt movements in relation to flows and other stimuli.

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REFERENCES

Andrew, F. J. and G. H. Geen. 1960. Sockeye and pink salmon production in relation to proposed dams in the Fraser River system. International Pacific Salmon Fisheries Commission Bulletin 11.

Boggs, C.T., M.L. Keefer, C.L. Peery, T.C. Bjornn, and L.C. Struehrenberg. 2004. Fallback, reascension, and adjusted fishway escapement estimates for adult Chinook salmon and steelhead at Columbia and Snake river dams. Transactions of the American Fisheries Society 133:932-949.

Boggs, C.T. and C.A. Peery. 2004. Steelhead (Oncorhynchus mykiss) kelt abundance, condition, passage, and survival in the lower Snake and Columbia rivers. Prepared by the U.S. Idaho Cooperative Fish and Wildlife Research Unit for the U. S. Army Corps of Engineers, Portland District, contract DACW68-02-D-0002.

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5; ISSN 0362-1715.

Cada, G.F. 2001. The development of advanced hydroelectric turbines to improve fish passage survival. Fisheries 26:14–23.

COE (U.S. Army Corps of Engineers), 2004. River Data. ONLINE. U.S. Army Corps of Engineers, Portland Oregon, USA. Available: http://www.nwd-c.usace.army.mil/tmt/wcd/tdg/months.html [Accessed July, 2004].

Elston, R. 1996. Investigation of Head Burns in Adult salmonids. Phase 1: Examination of fish at Lower Granite Dam, July 2, 1996. 12p. Final report prepared for the Bonneville Power Administration. Contract number 96AP95973 (NWPPC 1986, ISG 1996).

Evans, A.F., R.E. Beaty, M.S. Fitzpatrick, and K. Collis. 2004a. Identification and enumeration of steelhead kelts at Lower Granite Dam. Transactions of the American Fisheries Society 133:1089-1099.

Evans, A.F., M.S. Fitzpatrick, and L.K. Siddens. 2004b. Use of ultrasound imaging and steroid concentrations to identify maturational status in adult steelhead. North American Journal of Fisheries Management 24:967–978.

Ferguson, J.E., T.P. Poe, and T.J. Carlson. 1998. Surface-oriented bypass systems for juvenile salmonids on the Columbia River, USA. Pages 281–299 i*n* M. Jungwirth, S. Schmutz, and S. Weiss, editors. Fish Migration and Fish Bypasses, Portland, OR.

Fleming, I.A. 1998. Pattern and variability in the breeding system of Atlantic salmon (*Salmo salar*), with comparisons to other salmonids. Canadian Journal of Fisheries and Aquatic Sciences 55(Supplement 1): 59-76.

Hansel, H. C., S. D. Juhnke, P. V. Haner, L. Dingmon, and J. W. Beeman. 2005. Estimates of fish-, spill-, and sluiceway-passage efficiencies of radio-tagged juvenile Chinook salmon at The Dalles Dam during the spring and summer of 2004. Prepared by the U.S. Geological Survey for the U. S. Army Corps of Engineers, Portland District, contract W66QKZ40369586.

ISG (Independent Science Group). 1996. Return to the river: restoration of salmonid fishes in the Columbia River. ISG, Report 96-6, for NPPC Portland, Oregon.

Johnson, G.E., S.M. Anglea, N.S. Adams, and T.O. Wik. 2005. Evaluation of a prototype surface flow bypass for juvenile salmon and steelhead at the powerhouse of Lower Granite Dam, Snake River, Washington, 1996-2000. North American Journal of Fisheries Management 25: 138-151.

Kynard, B. and J. O'Leary. 1993. Evaluation of a bypass system for spent American Shad at Holyoke Dam, Massachusetts. North American Journal of Fisheries Management 13:782-789.

Long, J.B. and L.E. Griffin. 1937. Spawning and migratory habits of the Columbia River steelhead trout as determined by scale studies. Copeia 1:62.

Merchant, A. and T. Barilla. 1988. Improving salmon passage on the Columbia River. Hydro Review 9:22-30.

NMFS (National Marine Fisheries Service). 2004. Endangered Species Act status of west coast salmonids, June 17, 2004. NMFS, Northwest Region, Portland, OR. Available: http://www.nwr.noaa.gov (accessed 30 September 2004).

Northwest Power Planning Council (NPPC). 1986. Council Staff Compilation of Information on Salmon and Steelhead Losses in the Columbia River Basin. Appendix D, 1987 Columbia River Basin Fish and Wildlife Program. 252 pp. Portland, OR.

Prince, A. and C. Powell. 2000. Clove oil as an anesthetic for invasive field procedures on adult rainbow trout. North American Journal of Fisheries Management 20: 1029-1032.

Reagan, R., S. Evans, L. Wright, M. Farley, N. Adams, and D. Rondorf. 2005. Movement, distribution, and passage behavior of radio-tagged yearling Chinook salmon and steelhead at Bonneville Dam, 2004. Prepared by the U.S. Geological Survey, Cook Washington for the U.S. Army Corps of Engineers, Portland District, Portland, OR, USA.

Shively, R.S., T.P. Poe, and M.B. Sheer. 1996. Criteria for reducing predation by northern squawfish near juvenile salmonid bypass outfalls at Columbia River dams. Regulated Rivers and Management 12:493-500.

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

Venditti, D.A., D.W. Rondorf, and J.M. Kraut. 2000. Migratory behavior and forebay delay of radio-tagged juvenile fall chinook salmon in a lower Snake River impoundment. North American Journal of Fisheries Management 20:41–52.

Wertheimer, R.H., J.T. Dalen, and P.L. Madson. 2001. Evaluation of Steelhead Kelt Passage Routes at Bonneville Dam, *in* 2000. U.S. Army Corps of Engineers, Portland District Fish Field Unit, Bonneville Lock and Dam, Cascade Locks, OR. 26 pp. available at: https://www.nwp.usace.army.mil/pm/e/home.asp

Wertheimer, R.H., P.L. Madson, M.R. Jonas, and J.T. Dalen. 2002. Evaluation of Steelhead Kelt Project Abundance, Condition, Passage, and Conversion Rates through Lower Columbia River dams, *in* 2001. U.S. Army Corps of Engineers, Portland District Fish Field Unit, Bonneville Lock and Dam, Cascade Locks, OR. 31pp. available at: https://www.nwp.usace.army.mil/pm/e/home.asp

Wertheimer, R.H., P.L. Madson, and M.R. Jonas. 2003. Evaluation of Steelhead Kelt Project Abundance, Condition, Passage, and Conversion Rates through Lower Columbia River dams, *in* 2002. U.S. Army Corps of Engineers, Portland District Fish Field Unit, Bonneville Lock and Dam, Cascade Locks, OR. 31pp. available at: https://www.nwp.usace.army.mil/pm/e/home.asp

Wertheimer, R.H. and A.F. Evans. 2005. Downstream passage of steelhead kelts through hydroelectric dams on the lower Snake and Columbia Rivers. Transactions of the American Fisheries Society 134: 853-865.

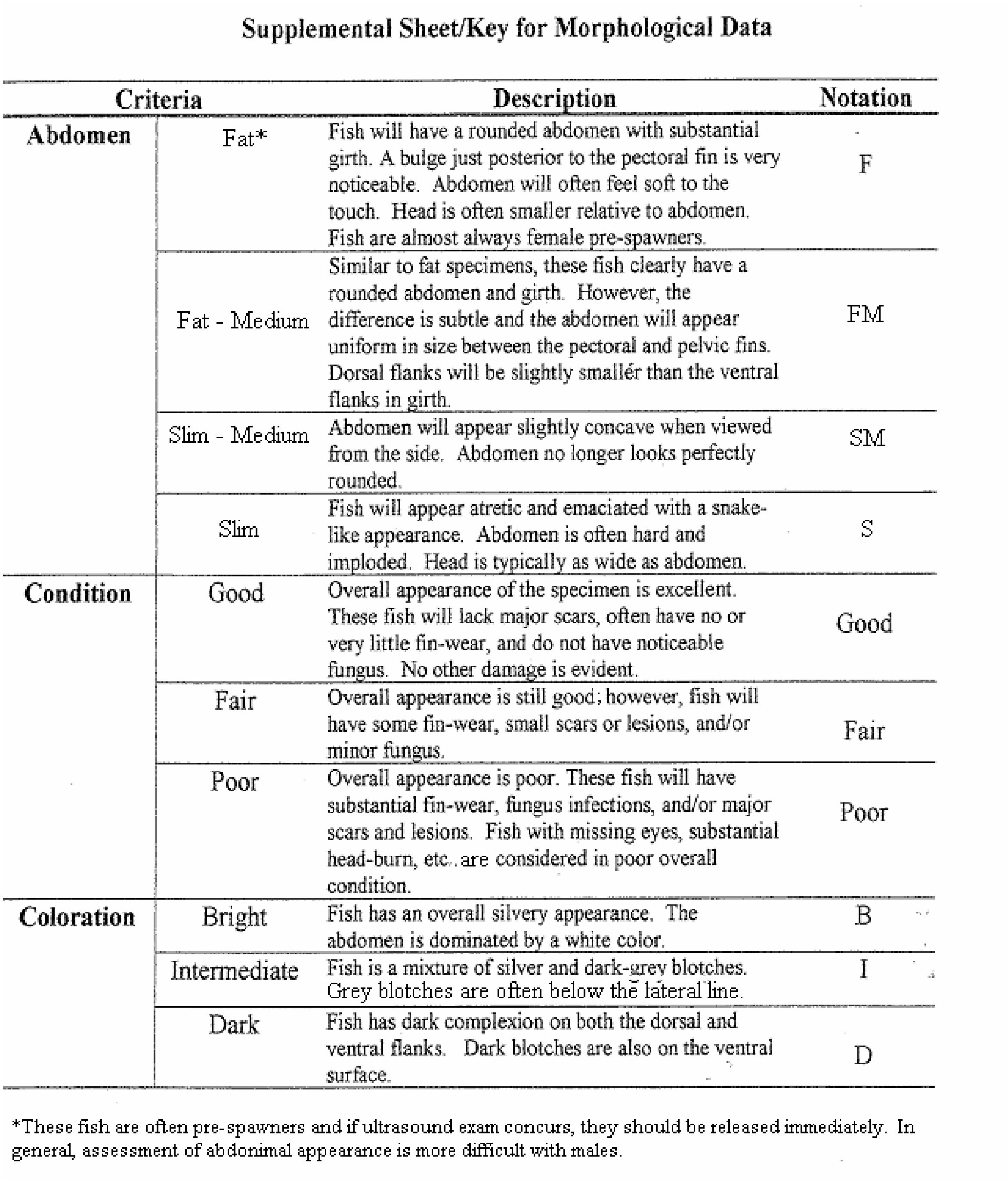
Whitney, R. R., L.D. Calvin, M. W. Erho. Jr., and C.C. Coutant. 1997. Downstream passage for salmon at hydroelectric projects in the Columbia River basin: development, installation, and evaluation. Final report to Northwest Power Planning Council. Independent Scientific Advisory Board, Portland, OR. ISAB 97-15.

Whitt, C. R. 1954. The age, growth, and migration of steelhead trout in the Clearwater River, Idaho. Master's thesis, University of Idaho, Moscow.

Willis, C.F. and B.L. Uremovich. 1981. Evaluation of the ice and trash sluiceway at Bonneville Dam as a bypass system for juvenile salmonids, 1981. Progress reported 34 pp. Oregon Department of Fish and Wildlife Division, Fish Division, Portland, Oregon.

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.

Appendix A

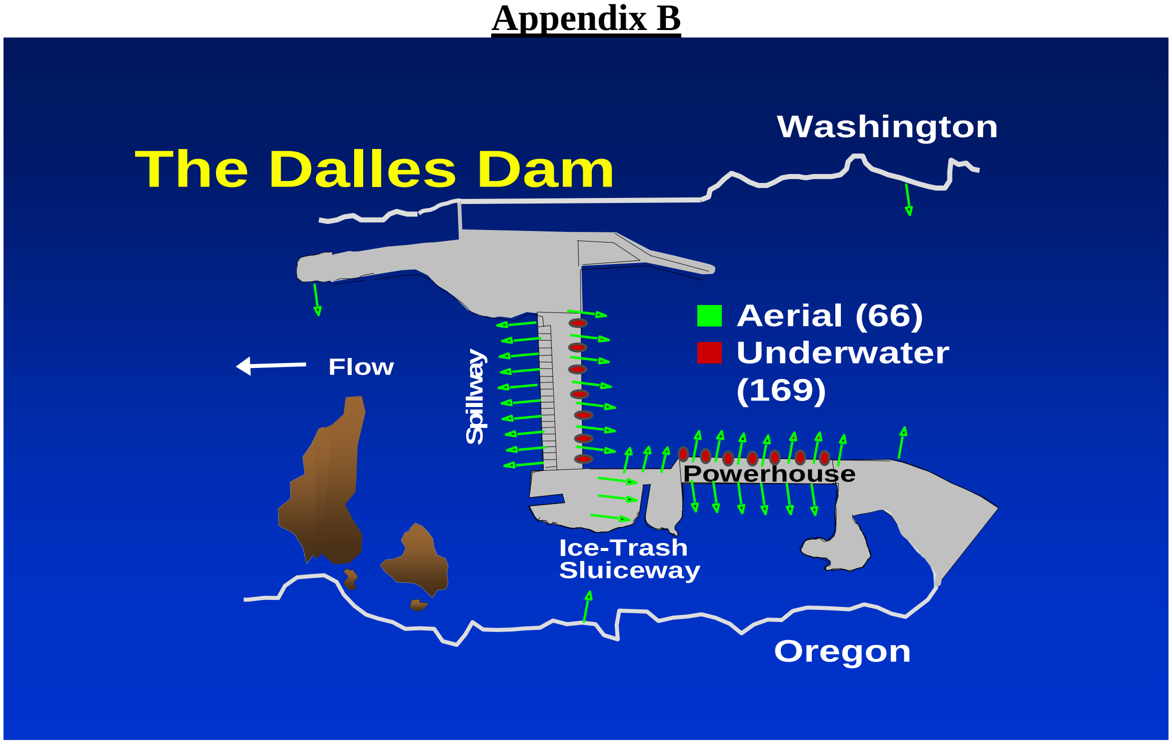


Supplemental Sheet/Key for Morphological Data

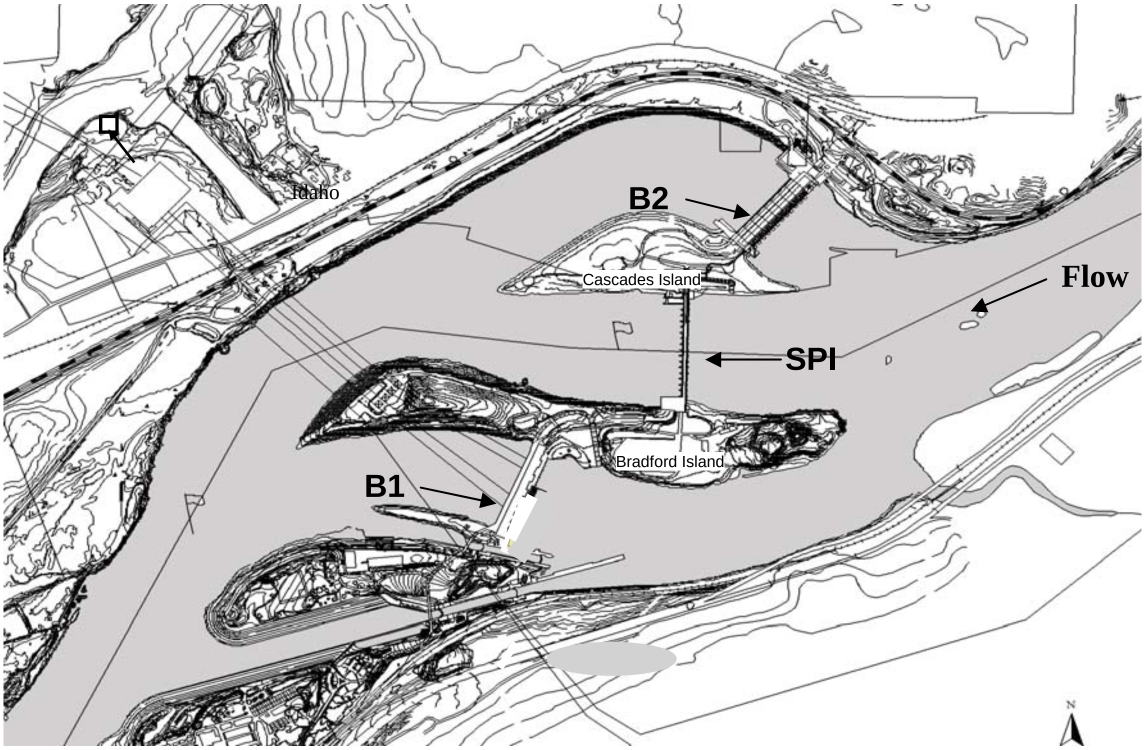
Criteria		Description	Notation
Abdomen	Fat*	Fish will have a rounded abdomen with substantial girth. A bulge just posterior to the pectoral fin is very noticeable. Abdomen will often feel soft to the touch. Head is often smaller relative to abdomen. Fish are almost always female pre-spawners.	F
	Fat - Medium	Similar to fat specimens, these fish clearly have a rounded abdomen and girth. However, the difference is subtle and the abdomen will appear uniform in size between the pectoral and pelvic fins. Dorsal flanks will be slightly smaller than the ventral flanks in girth.	FM
	Slim - Medium	Abdomen will appear slightly concave when viewed from the side. Abdomen no longer looks perfectly rounded.	SM
	Slim	Fish will appear atretic and emaciated with a snake-like appearance. Abdomen is often hard and imploded. Head is typically as wide as abdomen.	S
Condition	Good	Overall appearance of the specimen is excellent. These fish will lack major scars, often have no or very little fin-wear, and do not have noticeable fungus. No other damage is evident.	Good
	Fair	Overall appearance is still good; however, fish will have some fin-wear, small scars or lesions, and/or minor fungus.	Fair
	Poor	Overall appearance is poor. These fish will have substantial fin-wear, fungus infections, and/or major scars and lesions. Fish with missing eyes, substantial head-burn, etc. are considered in poor overall condition.	Poor
Coloration	Bright	Fish has an overall silvery appearance. The abdomen is dominated by a white color.	B
	Intermediate	Fish is a mixture of silver and dark-grey blotches. Grey blotches are often below the lateral line.	I
	Dark	Fish has dark complexion on both the dorsal and ventral flanks. Dark blotches are also on the ventral surface.	D

*These fish are often pre-spawners and if ultrasound exam concurs, they should be released immediately. In general, assessment of abdonimal appearance is more difficult with males.

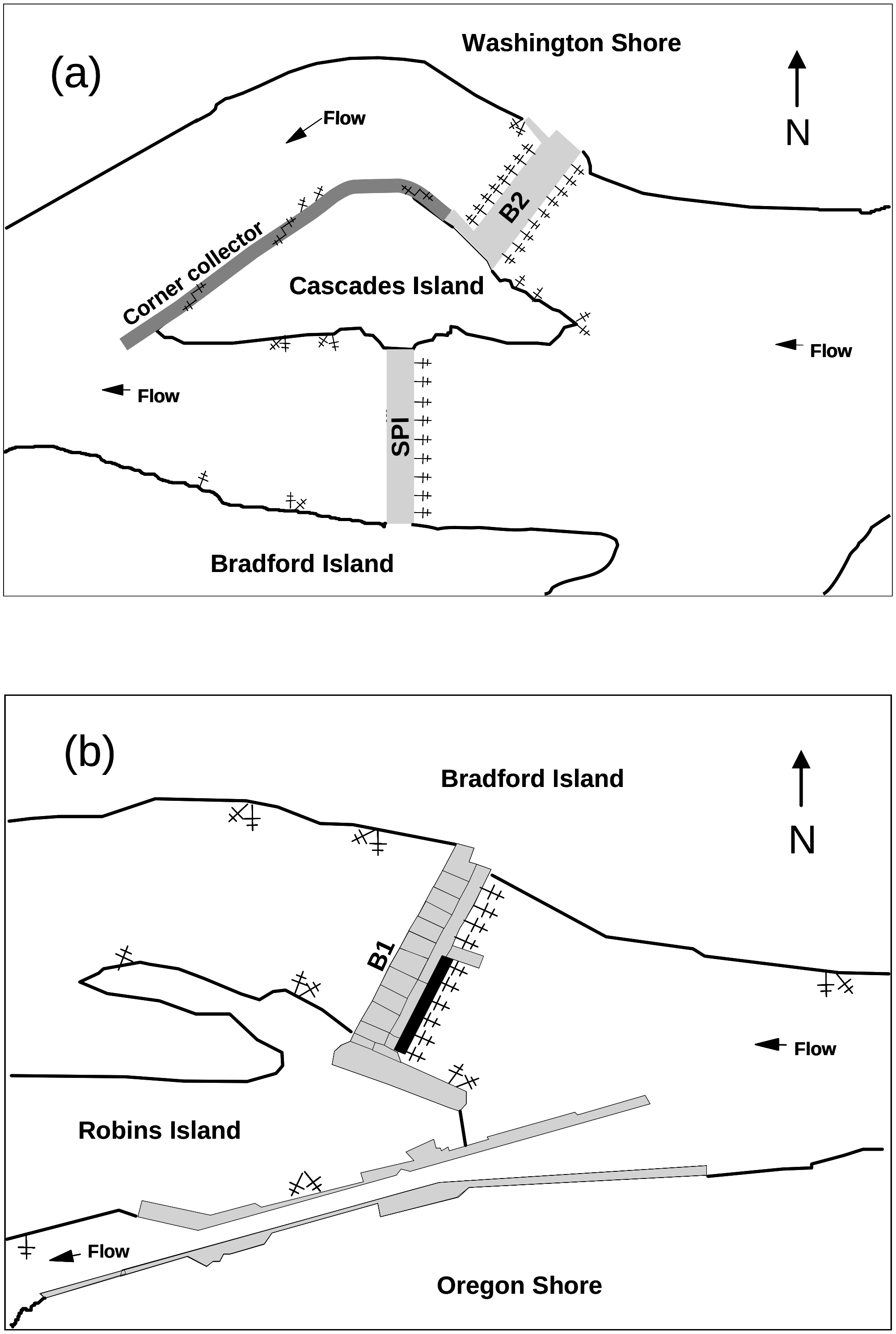
Appendix B



Plan view of The Dalles Dam aerial antenna coverage during spring 2004.



Plan view of Bonneville Dam on the Columbia River showing the first powerhouse (B1), spillway (SPI), and second powerhouse (B2). Image source: U.S. Army Corps of Engineers.



Plan view of aerial antenna coverage during spring 2004 at Bonneville Dam's: (a) second powerhouse (B2) and spillway (SPI); and (b) first powerhouse (B1). Antenna array setup and operated by the U.S. Geological Survey.

Appendix C

Table C-1. Summary of the sample date, sample size (N), sample mean, standard deviation (SD), range of the fork lengths (cm), sex, origin, and condition categories (i.e., G&F for good and fair condition kelts summed) of kelt steelhead radio-tagged at McNary Dam, spring 2004.

		Fork Length (mm)				Sex			Origin		Cond
Date	N	Mean	SD	Range	M	F	Un	Wild	Hatch	G&F
4/8/04	1	550.0	0.0	550 - 550	0	1	0	0	1	1
4/14/04	8	680.0	110.6	540 - 830	1	7	0	7	1	8
4/16/04	1	670.0	0.0	670 - 670	0	1	0	1	0	1
4/20/04	14	630.8	96.3	495 - 770	1	13	0	11	3	14
4/22/04	6	588.3	51.2	540 - 670	0	5	1	4	2	6
4/24/04	4	672.5	64.0	600 - 740	0	4	0	4	0	4
4/26/04	10	567.0	25.8	520 - 610	1	9	0	9	1	10
4/28/04	18	617.2	74.7	500 - 760	2	14	2	11	7	15
4/30/04	6	551.7	44.5	490 - 600	1	4	1	4	2	5
5/2/04	9	558.9	61.3	450 - 680	2	3	4	4	5	9
5/3/04	6	583.3	41.3	540 - 640	1	5	0	3	3	6
5/4/04	4	575.0	20.8	550 - 600	0	0	4	3	1	3
5/6/04	3	553.3	28.9	520 - 570	0	2	1	2	1	3
5/10/04	3	600.0	85.4	510 - 680	0	1	2	2	1	2
5/12/04	6	600.0	37.4	540 - 640	1	5	0	4	2	6
5/14/04	1	580.0	0.0	580 - 580	0	1	0	0	1	1
5/18/04	11	570.9	45.9	510 - 680	7	3	1	10	1	11
5/19/04	3	573.3	25.2	550 - 600	1	1	1	3	0	3
5/20/04	5	558.0	42.1	510 - 620	1	3	1	4	1	4
5/21/04	2	550.0	14.1	540 - 560	0	1	1	2	0	2
5/24/04	2	585.0	21.2	570 - 600	0	2	0	2	0	1
Totals	123	-	-	-	19	85	19	90	33	115

Table C-2. Summary of the sample date, sample size (N), sample mean, standard deviation (SD), range of the fork lengths (cm), sex, origin, and condition categories (i.e., G&F for good and fair condition kelts summed) of kelt steelhead radio-tagged at John Day Dam, spring 2004.

		Fork Length (mm)			Sex			Origin		Cond	
Date	N	Mean	SD	Range	M	F	Un	Wild	Hatch	Poor	G&F
4/12/04	43	614.2	85.6	500 - 880	3	23	17	26	17	0	43
4/13/04	18	617.2	102.5	520 - 850	2	12	4	11	7	0	18
4/14/04	14	611.4	100.6	490 - 800	0	10	4	13	1	0	14
4/15/04	4	617.5	22.2	590 - 640	0	3	1	3	1	0	4
4/16/04	5	652.0	83.5	560 - 770	2	2	1	3	2	0	5
4/17/04	10	584.0	72.6	490 - 690	3	6	1	6	4	1	9
4/18/04	7	621.4	100.1	510 - 730	1	4	2	6	1	1	6
4/19/04	3	560.0	36.1	530 - 600	0	3	0	3	0	0	3
4/20/04	10	589.0	63.8	520 - 720	1	9	0	8	2	0	10
4/21/04	8	632.5	72.3	540 - 720	0	5	3	6	2	0	8
4/22/04	11	577.3	38.2	520 - 660	1	7	3	7	4	2	9
4/23/04	6	555.0	20.7	520 - 580	1	3	2	5	1	1	5
4/24/04	6	571.7	41.7	530 - 650	0	3	3	4	2	0	6
4/25/04	4	602.5	81.8	530 - 720	0	4	0	3	1	2	2
4/26/04	4	532.5	32.0	500 - 560	0	1	3	3	1	0	4
4/27/04	10	601.0	66.2	530 - 750	1	4	5	7	3	0	10
4/28/04	8	633.8	70.3	540 - 710	0	8	0	5	3	1	7
4/29/04	11	570.9	50.9	500 - 650	0	8	3	7	4	3	8
4/30/04	3	546.7	30.6	520 - 580	0	1	2	3	0	0	3
5/1/04	9	596.7	25.0	560 - 640	2	7	0	7	2	0	9
5/2/04	9	576.7	36.7	500 - 640	2	7	0	7	2	2	7
5/3/04	6	570.0	48.6	480 - 610	0	4	2	3	3	0	6
5/4/04	8	598.8	63.8	550 - 730	1	5	2	8	0	1	7
5/5/04	14	621.4	81.7	520 - 750	3	10	1	13	1	0	14
5/6/04	13	581.5	57.9	520 - 700	2	9	2	9	4	0	13
5/7/04	14	573.6	40.3	520 - 640	5	7	2	10	4	0	14
5/8/04	9	614.4	68.6	520 - 720	1	4	4	8	1	0	9
5/9/04	5	564.0	28.8	530 - 600	1	2	2	5	0	1	4
5/10/04	6	585.0	37.8	540 - 620	0	2	4	5	1	1	5
5/11/04	3	546.7	25.2	520 - 570	1	2	0	0	3	2	1
5/12/04	2	595.0	7.1	590 - 600	0	2	0	2	0	0	2
5/13/04	8	596.3	76.5	530 - 720	0	7	1	5	3	3	5
5/14/04	11	592.7	68.6	520 - 730	1	7	3	11	0	3	8
5/15/04	3	608.3	82.5	540 - 700	0	2	1	3	0	0	3
5/16/04	4	572.5	78.9	520 - 690	1	2	1	3	1	1	3
5/17/04	4	600.0	29.4	570 - 630	0	3	1	4	0	0	4
5/18/04	9	565.6	19.4	530 - 590	1	5	3	9	0	2	7
5/19/04	4	640.0	117.5	520 - 790	1	3	0	3	1	1	3
5/20/04	5	572.0	23.9	540 - 600	1	3	1	5	0	1	4
5/21/04	7	578.6	23.4	550 - 620	0	4	3	6	1	0	7
5/22/04	11	580.0	87.4	510 - 830	3	7	1	11	0	2	9
5/23/04	12	624.2	74.6	550 - 780	2	10	0	11	1	2	10
5/24/04	14	560.0	35.7	480 - 650	1	10	3	14	0	1	13
5/25/04	6	573.3	44.6	500 - 620	1	4	1	6	0	3	3
5/26/04	12	594.2	92.2	510 - 780	3	8	1	10	2	1	11
Totals	393				48	252	93	307	86	38	355

Appendix D

Table D-1. Summary of the sample date, sample size (N), sample mean, standard deviation (SD), range of the fork lengths (cm), sex, origin, status (i.e., kelt or pre-spawn [Pre]), and condition categories (i.e., G&F for good and fair condition kelts summed) of steelhead kelts sampled at McNary Dam, spring 2004.

		Fork Length (mm)			Sex			Origin		Status		Cond	Recap
Date	N	Mean	SD	Range	M	F	Un	Wild	Hatch	Kelt	Pre	G&F	n
4/8/04	7	555.7	70.4	480 - 680	1	6	0	5	2	2	5	1	0
4/14/04	11	676.4	108.1	540 - 830	1	10	0	8	3	10	1	8	0
4/16/04	6	625.0	49.3	550 - 680	1	4	1	5	1	3	3	1	1
4/20/04	16	630.7	89.8	495 - 770	1	15	0	12	4	16	0	15	2
4/22/04	12	585.8	36.5	540 - 670	1	10	1	8	4	9	3	6	0
4/24/04	6	663.3	56.1	600 - 740	0	6	0	4	2	6	0	4	0
4/26/04	11	581.8	54.9	520 - 730	1	10	0	10	1	11	0	10	0
4/28/04	21	606.7	74.0	500 - 760	3	16	2	13	8	21	0	15	0
4/30/04	7	590.0	109.2	490 - 820	2	4	1	5	2	7	0	5	0
5/2/04	10	572.0	71.1	450 - 690	2	4	4	5	5	10	0	9	0
5/3/04	6	583.3	41.3	540 - 640	1	5	0	3	3	6	0	6	0
5/4/04	7	572.9	22.9	540 - 600	0	2	5	6	1	5	1	3	0
5/6/04	7	544.3	42.0	470 - 600	0	3	4	5	2	7	0	3	0
5/10/04	6	566.7	68.9	500 - 680	1	3	2	4	2	6	0	2	0
5/12/04	10	595.5	87.8	450 - 790	2	7	1	7	3	9	1	6	0
5/14/04	3	551.7	24.7	535 - 580	1	2	0	1	2	2	1	1	1
5/18/04	16	563.8	43.8	500 - 680	8	7	1	14	2	16	0	11	1
5/19/04	4	582.5	27.5	550 - 610	1	2	1	3	1	4	0	3	0
5/20/04	6	553.3	39.3	510 - 620	1	4	1	5	1	6	0	4	0
5/21/04	2	550.0	14.1	540 - 560	0	1	1	2	0	2	0	2	0
5/24/04	4	627.5	96.0	570 - 770	0	4	0	3	1	4	0	1	0
Totals	178	-	-	-	28	125	25	128	50	162	15	116	5

Table D-2 Summary of the sample date, sample size (N), sample mean, standard deviation (SD), range of the fork lengths (cm), sex, origin, status (i.e., kelt or pre-spawn [Pre]), and condition categories (i.e., G&F for good and fair condition kelts summed) of steelhead kelts sampled at John Day Dam, spring 2004.

		Fork Length (mm)			Sex			Origin		Status		Cond	Recap
Date	N	Mean	SD	Range	M	F	Un	Wild	Hatch	Kelt	Pre	G&F	N
4/6/04	19	645.8	104.6	530 - 880	6	11	2	11	8	12	7	4	0
4/7/04	8	675.0	106.1	530 - 850	0	8	0	3	5	6	2	2	0
4/12/04	75	614.9	82.0	500 - 880	11	41	23	47	28	71	4	47	0
4/13/04	36	622.8	112.0	450 - 870	3	26	7	21	15	33	3	21	1
4/14/04	20	614.0	88.8	490 - 800	2	11	7	18	2	18	2	15	1
4/15/04	14	620.0	45.2	530 - 680	2	9	3	7	7	10	4	4	0
4/16/04	10	620.0	74.7	530 - 770	4	5	1	4	6	9	1	5	0
4/17/04	13	596.9	74.7	490 - 730	3	9	1	8	5	10	3	9	1
4/18/04	11	621.8	93.7	510 - 760	2	6	3	8	3	10	1	6	0
4/19/04	7	566.4	37.7	525 - 630	0	6	1	5	2	6	1	4	0
4/20/04	21	603.8	76.1	520 - 790	2	19	0	15	6	18	3	10	0
4/21/04	22	604.5	63.8	520 - 740	5	13	4	14	8	21	1	11	3
4/22/04	14	540.0	134.0	90 - 660	2	8	4	7	7	13	1	9	0
4/23/04	10	573.0	40.3	520 - 670	3	4	3	7	3	8	2	5	0
4/24/04	11	601.4	73.9	530 - 730	2	5	4	6	5	9	2	6	0
4/25/04	6	605.0	74.0	530 - 720	0	6	0	4	2	5	1	2	0
4/26/04	9	565.6	58.3	500 - 700	1	5	3	7	2	9	0	4	0

Date	N	Mean	SD	Range	M	F	Un	Wild	Hatch	Kelt	Pre	G&F	N
4/27/04	14	592.1	58.5	530 - 750	3	6	5	10	4	12	2	10	0
4/28/04	13	645.4	79.5	540 - 760	0	13	0	9	4	10	3	8	1
4/29/04	15	578.0	70.2	500 - 770	1	9	5	10	5	14	1	8	1
4/30/04	8	618.8	74.7	520 - 730	0	4	4	5	3	7	1	4	1
5/1/04	10	594.0	25.0	560 - 640	3	7	0	7	3	10	0	9	1
5/2/04	11	572.7	34.1	500 - 640	2	9	0	9	2	11	0	7	0
5/3/04	14	572.9	54.0	480 - 690	4	6	4	10	4	13	1	6	0
5/4/04	11	610.0	68.8	540 - 730	1	6	4	10	1	10	0	7	0
5/5/04	18	615.6	85.1	460 - 750	6	11	1	17	1	17	1	14	0
5/6/04	16	587.5	53.6	520 - 700	3	11	2	10	6	16	0	13	0
5/7/04	18	576.1	42.9	520 - 670	6	10	2	12	6	18	0	14	0
5/8/04	10	624.0	71.4	520 - 720	1	4	5	9	1	10	0	9	0
5/9/04	10	570.0	36.2	520 - 640	4	4	2	10	0	9	1	5	1
5/10/04	8	583.8	32.5	540 - 620	1	2	5	6	2	7	1	5	0
5/11/04	6	553.3	18.6	520 - 570	2	4	0	3	3	5	1	1	0
5/12/04	7	572.9	34.0	530 - 620	1	4	2	5	2	7	0	2	0
5/13/04	11	587.3	67.4	530 - 720	1	9	1	8	3	11	0	5	0
5/14/04	17	581.8	56.9	520 - 730	1	10	6	16	1	17	0	8	0
5/15/04	4	598.8	70.0	540 - 700	0	2	2	3	1	4	0	3	1
5/16/04	6	570.0	61.3	520 - 690	1	3	2	4	2	5	1	3	0
5/17/04	7	598.6	25.4	570 - 630	1	4	2	6	1	6	1	4	0
5/18/04	15	565.3	21.7	530 - 600	3	8	4	12	3	13	2	7	1
5/19/04	7	641.4	118.2	520 - 810	2	5	0	5	2	7	0	3	1
5/20/04	11	601.8	66.5	530 - 760	3	5	3	8	3	9	2	4	0
5/21/04	10	577.0	30.9	530 - 630	0	7	3	8	2	9	1	7	0
5/22/04	15	574.7	76.2	510 - 830	3	11	1	13	2	15	0	9	1
5/23/04	16	605.6	87.1	430 - 780	3	13	0	15	1	16	0	10	1
5/24/04	15	560.7	34.5	480 - 650	1	10	4	15	0	15	0	13	0
5/25/04	10	578.0	38.2	500 - 630	2	7	1	9	1	10	0	3	0
5/26/04	22	588.2	75.9	470 - 780	6	14	2	19	3	21	1	14	1
5/27/04	9	595.6	49.3	520 - 680	3	3	3	8	1	7	2	5	0
6/1/04	2	570.0	28.3	550 - 590	2	0	0	2	0	2	0	0	0
Totals	672				118	413	141	485	187	611	60	384	17