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[Management Brief]

Evaluation of a Surface Flow Bypass System for Steelhead Kelt Passage at Bonneville Dam, Washington

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Abstract.—A surface flow bypass system for juvenile Pacific salmon *Oncorhynchus* spp. began operation at the second powerhouse (B2) of Bonneville Dam on the lower Columbia River in spring 2004. This surface bypass, called the "B2 corner collector," is the result of extensive modification of the original B2 sluice chute. Because steelhead *O. mykiss* are iteroparous, the effect of this bypass and the unmodified sluiceway at the older first powerhouse (B1) on downstream migration of postspawn steelhead (i.e., kelts) may be an important factor in the rate of iteroparity. As such, passage at Bonneville Dam (river kilometer [rkm] 234, measured from the mouth of the Columbia River) was examined to understand the efficiency of surface bypass in passing kelts. Steelhead kelts were collected, radio-tagged, and volitionally released from the juvenile bypass facilities at McNary Dam (rkm 465) and John Day Dam (rkm 345) on the Columbia River during spring 2004. Forebay residence times for kelts passing via B2 (with the corner collector operating) were significantly reduced relative to residence times published from a prior period with similar water flows at B2 (2002). Passage efficiency (nonturbine passage) at B2 significantly increased in relation to this same period. Over 80% of kelts at B2 and nearly the same percentage at B1 were routed away from turbines via surface flow routes passing up to 5% of total discharge at each powerhouse, indicating that relatively small amounts of surface flow are needed to pass kelts via nonturbine routes. Providing surface flow passage routes may provide an efficient means of bolstering iteroparity rates by increasing the number of kelts that successfully navigate Bonneville Dam during the spring.

Population declines of Columbia River basin steelhead *Oncorhynchus mykiss* have led to listings under the U.S. Endangered Species Act (ESA) of threatened for Snake River and lower and mid-Columbia River stocks and endangered for upper Columbia River stocks (NMFS 2004). Causes for these declines include but are not limited to exploitation rates, land use practices, hatchery supplementation, ocean conditions, and hydroelectric impoundment effects (Raymond 1979, 1988; Waples 1991; ISG 1999; Wertheimer and Evans 2005). Before development of the federal Columbia River power system (FCRPS) in the Columbia River basin, 7.5–8.9 million salmon and steelhead returned annually (Chapman 1986). Current runs are about 25% of the lower estimated range and are composed of as much as 90% hatchery fish (Brannon et al. 2004).

The historical number of steelhead kelts (i.e., adults that spawn more than once) in the Columbia River basin is not known (Evans et al. 2004a). However, iteroparity rates of steelhead varieties in the Kalama River (a tributary to the unimpounded reach below Bonneville Dam [BON]) were estimated at over 15% for summer (stream maturing) steelhead and over 21% for winter (ocean maturing) steelhead (Withler 1966; Leider et al. 1986). In comparison, iteroparity rates in the Hood River (a tributary discharging into the reservoir created by BON) have been reported at over 9% for summer steelhead and over 13% for winter steelhead (Olsen 2004). In contrast, iteroparity rates of summer steelhead populations above McNary Dam (the fourth furthest downstream hydroelectric facility on the main-stem Columbia River at river kilometer [rkm] 465, measured from the mouth of the Columbia River) have been reported between 2% and 4% (Whitt 1954; Hockersmith et al. 1995; Busby et al. 1996). Decreasing iteroparity rates for the more inland steelhead stocks are not particularly surprising, as the frequency of iteroparity in steelhead varies inversely with migration distance (Meehan and Bjornn 1991; Behnke 1992). Some other factors affecting iteroparity rates in salmonids include genetic constraints, environmental conditions, geographic location, sex, size at maturity, harvest, and hydroelectric impoundment effects (Withler 1966; Fleming 1998; Wertheimer and Evans 2005).

Hydroelectric dams have been shown to affect repeat spawning through both direct and indirect effects (Long and Griffin 1937; Carscadden and Leggett 1975; Kynard and O'Leary 1993). Mortality associated with dam passage is a direct effect, whereas indirect effects of hydroelectric dams (e.g., high temperatures, low flows) may be compounded in kelts because of the fish's postspawn atrophied state (Wertheimer and Evans 2005). Since iteroparity is an important component of steelhead life history, management actions should consider maintaining such diversity in the population. As such, it is important to understand

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FIGURE 1.—Map of the study area showing locations of federal Columbia River power system dams on the lower Columbia River, Washington and Oregon, and the lower Snake River, Washington, including McNary and John Day dams, where steelhead kelts were radio-tagged and released in spring 2004.

both the sensory and behavioral mechanisms by which out-migrating kelts navigate through hydropower projects. This understanding should provide insight into dam configurations and operations that increase the survival of kelts migrating downstream through hydroelectric projects.

Because BON is the lowermost hydroelectric project on the Columbia River, it passes a larger number and more diverse variety of anadromous migrants than any of the other main-stem dams; thus, it has the potential to have the most deleterious impact on anadromous fishes (Kynard and O'Leary 1993). For instance, both ESA-listed winter and summer steelhead varieties spawn in tributaries that discharge into the reservoir created by BON, the sole FCRPS reservoir affecting both steelhead varieties (Busby et al. 1996). Thus, enhancement of the in-river passage and survival of steelhead kelts passing BON by providing more efficient passage options should help minimize hydroelectric impoundment effects for some ESA-listed lower Columbia River steelhead stocks (Wertheimer and Evans 2005).

Due to postspawn atrophy, kelts probably are subject to indirect hydroelectric dam effects (e.g., forebay residence times) (Wertheimer and Evans 2005); therefore, a reduction in residence times due to dam passage events is particularly important. Development of the ice and trash sluice chute at the second powerhouse of BON (B2) into a surface flow passage route—termed the B2 corner collector (B2CC)—provided an opportunity to evaluate the efficacy of surface bypass in reducing dam passage residence times for steelhead kelts. Forebay residence and passage efficiency (nonturbine passage) data from B2 in 2004 were compared with published information from a period with similar discharge levels at B2 (2002) to provide information on the effects of a surface flow route for passing steelhead kelts (Wertheimer and Evans 2005). The objectives of this brief are to (1) demonstrate forebay residence time of kelts passing B2 and (2) demonstrate the efficiency and effectiveness (fish-to-flow) of a surface flow bypass in passing steelhead kelts at BON. Results from this study were used to assess how different dam configurations and operations may be used to reduce residence times, improve passage efficiency and ultimately contribute to enhancing iteroparity rates of steelhead kelts that pass hydroelectric dams in the lower Columbia River.

Study Area

Downstream-migrating steelhead kelts were captured at juvenile bypass systems, radio-tagged, and returned to the bypass systems at two hydroelectric dams located on the Columbia River: (1) McNary Dam (rkm 465) and (2) John Day Dam (rkm 345; Figure 1). Steelhead kelts arriving at these facilities are composed of ESA-listed steelhead populations from evolutionarily significant units within the middle and upper Columbia and Snake River basins (NMFS 2004). The downstream limit of the study area (i.e., Exit Station)

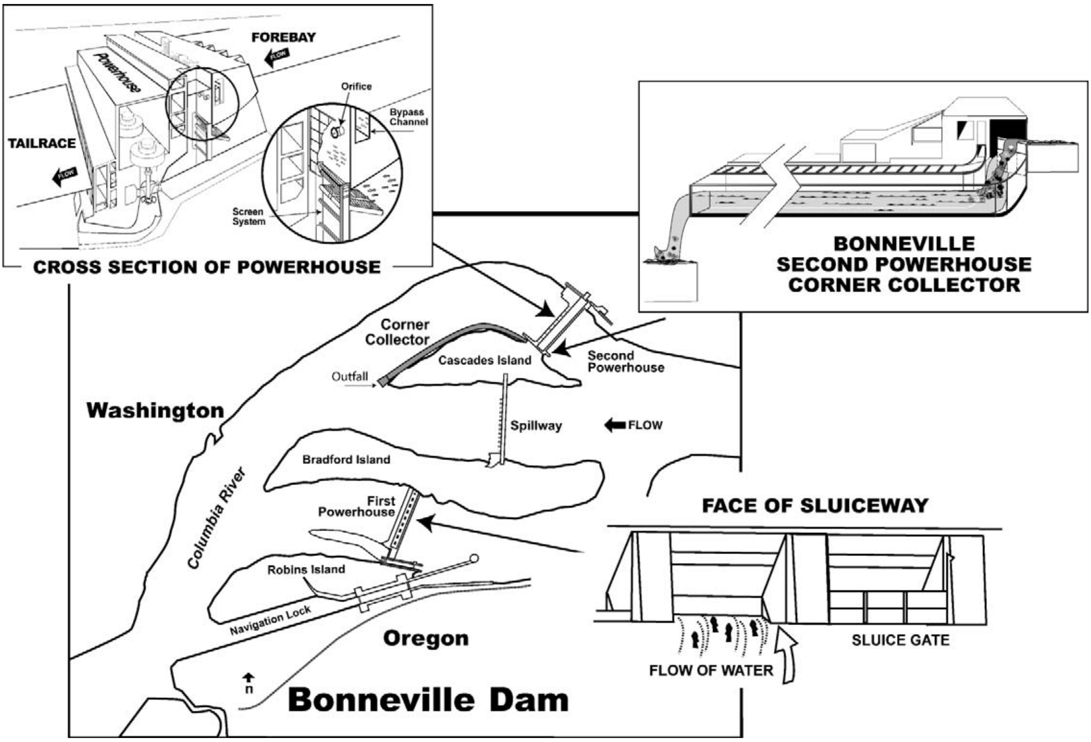

FIGURE 2.—Schematic showing downstream passage routes (i.e., spillway, bypass system, ice and trash sluiceway, and the second powerhouse corner collector), the forebay, and the tailrace at Bonneville Dam on the Columbia River, Washington and Oregon.

was at Government Island (rkm 181), roughly 53 km below BON (Figure 1).

Fish passing downstream through BON have several passage options that differ across the four primary dam structures (Figure 2). The first powerhouse (B1) contains 10 unscreened turbine units with a hydraulic capacity of 3,850 m^3/s and connects Robins Island on the south side and Bradford Island on the north side. Fish entering B1 either pass deep through turbine units or pass shallower over lowered gates into a debris-type sluiceway, which routes up to 23 m^3/s of river discharge to the tailrace of the dam. The spillway, sited between Bradford and Cascades islands, has 18 vertical liftgates that have a capacity of 45,307 m^3/s and are used for smolt passage and for passing excess powerhouse discharge. Powerhouse B2 is separated from the spillway on the south end by Cascades Island and connects to the Washington shore on the north end. It contains eight screened turbine units (i.e., juvenile bypass system) with a hydraulic capacity of 4,332 m^3/s. The B2CC is in the south forebay corner at the southern end of B2 and has an entrance area measuring 4.6 m wide and 6.7 m deep at normal pool elevation. A conveyance channel extends downstream beyond the tip of Cascades Island and discharges up to 155 m^3/s of water flow at the B2CC outfall (Figure 2). The navigation lock can provide passage for both upstream and downstream migrants, although the numbers are not substantial (Boggs et al. 2004).

Methods

Sampling, tagging, and monitoring.—Steelhead adults were obtained from the U.S. Army Corps of Engineers' (USACE) juvenile salmon bypass facilities at McNary and John Day dams following established protocols during spring 2004 (Wertheimer and Evans 2005). Adult steelhead were diverted (at John Day Dam) or directly dipnetted (at McNary Dam) from the bypass separator and transferred to a nearby sampling tank that contained aerated river water with a buffered solution of clove oil at 30 mg/L (Prince and Powell 2000; Pirhonen and Schreck 2003). The ultrasound imaging techniques of Evans et al. (2004b) were used to distinguish prespawn (i.e., mature) steelhead from kelts based on the presence or absence of gonads. Data on fork length (cm), external condition (rated by degree of damage as "good," "fair," or "poor"; Evans et al. 2004a), and rearing type (hatchery or naturally produced) were also recorded. Rearing type was determined based upon the presence or absence of fin clips.

To avoid interfering with the kelts' ability to return during repeat spawning migrations, radio tags (Lotek Wireless, Inc., Newmarket, Ontario; Model MCFT-3HM) designed for juvenile salmon were affixed to the dorsal fin base of each kelt based on the methods of Wertheimer and Evans (2005). Attached radio tags were 9.2 mm in diameter and 20 mm long, weighed 1.3 g in air, and transmitted once every 5 s for a period of approximately 36 d. Tags were attached to the outside of each kelt's body using a wrap of polyolefin that had a 0.05-cm tube underneath to accommodate a size-1 nylon suture. The suture ends were attached to sterilized needles and passed through the cartilage at the base of the dorsal fin (posterior to the third and sixth dorsal fin rays), and a surgical knot was tied on the distal cartilage surface. After tagging, fish were placed in a recovery area within the bypass and allowed to exit to the river volitionally. Recovery and exit times were about 15 min. Releases of radio-tagged kelts began on 20 April at McNary Dam and on 21 April at John Day Dam. Although kelts of all sizes, conditions, and rearing types were tagged, a smaller proportion of kelts in poor condition were tagged than the proportion in the captured sample to make the most efficient use of the available transmitters.

Radio signal receptions or "contacts" from individual radio-tagged kelts were monitored by fixed-station aerial arrays located in the forebay entrance and tailrace exit areas of BON; these included combinations of aerial and underwater arrays at potential passage routes. Tagged kelts were detectable to a depth of 8 m directly below aerial antenna arrays, while underwater antennas had a range of about 6 m (Venditti et al. 2000). Data were composed of contacts from these arrays through three sets of exit arrays that culminated at the downstream limit of the study area at Government Island. Radio tag detection efficiencies at BON were calculated based on the number of tagged specimens that were not detected passing the dam but were subsequently confirmed at a downstream location. For instance, a kelt that was not contacted passing BON but was confirmed at the exit arrays was considered a missed detection.

Data management and analyses.—Passage rates through a surface flow bypass are related to the opportunity a fish has to discover water flow passing via the structure (Johnson et al. 2000, 2005). To examine the relation between water flow discharged through each dam area (i.e., B1, spill, B2) and kelt passage distributions, a Pearson's correlation coefficient was calculated (Robinson et al. 1988).

Forebay residence times were calculated and used as a metric of potential migrational delay (Venditti et al. 2000; Wertheimer and Evans 2005). Forebay residence times are defined as the amount of time between the first and last radio signal contacts in the near-dam (~100 m) areas of the forebay. The distribution of kelt forebay residence data (h) were nonnormal owing to the presence of outliers; therefore, a distribution-free and outlier-sensitive test (i.e., Wilcoxon rank-sum test) was used to compare residence times at each forebay area between study years.

The passage efficiency metrics of Whitney et al. (1997) were used to assess the effects of bypass structures on kelt nonturbine passage rates. Using a chi-square test to assess the effects of the B2CC on kelt passage (Wertheimer and Evans 2005), nonturbine passage rates (passage efficiency) from kelts passing B2 in 2004 were compared with rates published from a period with similar water flows at B2 (i.e., spring 2002). Passage efficiency data from spill between these same 2 years were also compared with a chi-square test, though results should be cautiously interpreted because of lesser spill flows in 2004 than in 2002 (Johnson et al. 2005). Finally, sample independence—an assumption that might have been violated by spatial and temporal differences in behaviors from kelt releases throughout the season—was tested by comparing forebay residence times and passage efficiency of kelts released early and later within each of the passage seasons using a ranked approach (Kruskal–Wallis *k*-sample test).

Ice and trash sluiceways are surface conduits located above turbine intakes and are designed to route debris out of powerhouse forebay areas to the dam tailrace. Because the BON powerhouses are separate from the spillway (Figure 2), sluiceway effectiveness values were calculated from powerhouse discharges (rather than from project discharges), as were spill effectiveness values. Due to the static nature of sluiceway gates and varying forebay water levels, sluiceway effectiveness values are based upon maximum discharge of the B1 sluiceway and B2CC in 2004, rather than upon estimated discharges. Calculating effectiveness based upon maximum discharges provides a conservative estimate of sluiceway effectiveness values because a greater water volume could not have passed than was estimated. Means are reported with SEs. Statistical significance level α was set at 0.05. The employed metrics are defined as follows:

1. Passage efficiency = estimated proportion of downstream-migrating fish that pass a dam via nonturbine routes;
2. Spill efficiency = estimated proportion of down-

TABLE 1.—Number of steelhead kelts radio-tagged and released at the bypass facilities at Lower Granite (Snake River), McNary (Columbia River), and John Day (Columbia River) dams during the spring of 2002 (15 April–21 June) and 2004 (15 April–31 May).

Year	Dam	Sampling weeks	Kelts		
			Wild	Hatchery	Total
2002[a]					
	Lower Granite	7	88	79	167
	McNary	8	181	92	273
	John Day	2	10	0	10
2004					
	McNary	6	82	31	113
	John Day	6	228	51	279

[a] Data from 2002 are from Wertheimer and Evans (2005).

stream-migrating fish that pass a dam via the spillway;

3. Spill effectiveness = spill efficiency divided by the proportion of total dam discharge passed via the spillway;
4. Project sluice efficiency = B1 sluice passage plus B2CC passage, divided by the estimated number of downstream-migrating fish that pass the dam;
5. Project sluice effectiveness = project sluice efficiency divided by the proportion of total dam discharge that can pass via the B1 sluiceway and B2CC;
6. Sluice passage efficiency = estimated proportion of fish passing a powerhouse via the sluiceway;
7. Sluice effectiveness = sluice passage efficiency divided by the proportion of total powerhouse discharge that can pass through the sluiceway; and
8. B2 guidance efficiency = estimated proportion of downstream-migrating fish passing B2 turbine intakes that were guided into the bypass system by intake screens.

Results

Telemetry Sample and Detection Efficiency

In 2004, 392 kelts were radio-tagged and released from McNary ($n = 113$) and John Day ($n = 279$) dams (Table 1). The majority of tagged kelts were of natural origin (79.1%) and of good external condition (55.6%); however, kelts of fair (33.2%) and poor (11.2%) condition were also tagged. Condition and origin data collected in 2004 from all kelts sampled at McNary and John Day dams (i.e., not just those selected for tagging; $n = 1{,}257$) indicated that 69.9% of these kelts were naturally produced and that 46.9% of passing kelts were in good condition, 21.2% were in fair condition, and 31.9% were in poor condition.

Maximum detection efficiency during the study period was estimated to be 99.9% at BON. High detection efficiency from forebay areas (~94.6%) suggested that most kelts migrated through these areas in the upper 8 m of the water column, the maximum depth at which fish could be detected by fixed aerial arrays.

Bonneville Dam River Discharge and Operations

River discharge at BON was greater in 2002 than in 2004. Analysis of flow records from BON (USACE, unpublished data) indicates that average river discharge during spring 2004 was 80.6% (5,753 ± 32 m^3/s) of the 2002 average (7,136 ± 43 m^3/s).

Despite this reduction, average river discharge at B2 in 2004 was 101.9% (3,048 ± 19 m^3/s) of the 2002 average (2,991 ± 15 m^3/s). Turbines passed 57.2% and 61.5% of total project discharge in 2002 and 2004, respectively. Water flows discharged via spill and B1 were greater in 2002 than in 2004 (Table 2).

Bonneville Dam Passage Distributions

Kelt passage distributions were 66.0% via B2 ($n = 235$), 28.4% via spill ($n = 101$), and 5.3% via B1 ($n = 19$); one kelt passed via the navigation lock. Kelt passage distributions were correlated with discharge through each dam area (Pearson's correlation: $r = 0.60$, df = 307, $P < 0.0001$), indicating that passage distributions were related to area discharge.

Bonneville Dam Forebay Residence Time

Median forebay residence times at B2 were significantly shorter in 2004 than in 2002 (Wilcoxon rank-sum test: $P < 0.0001$). Median forebay residence times at the spillway in 2004 were significantly longer (Wilcoxon rank-sum test: $P < 0.05$) and over twice those reported in 2002. This may not prove overly alarming, however, as median spillway forebay residence times remained brief (<1.0 h). There is some evidence that B1 forebay residence times increased for kelts between 2002 and 2004 (Wilcoxon rank-sum test: $P = 0.0535$), although sample sizes for this comparison were small and residence times routinely exceeded 20 h for individuals in both years (Table 2). Some kelts (~5.3%) were not contacted in forebay areas before dam passage, which resulted in unknown residence times.

Bonneville Dam Passage Routes

Overall project passage efficiency (nonturbine passage) increased from 2002 (89.8%) to 2004 (90.7%). The majority of kelts (58.1%) in 2004 passed surface flow routes (B2CC and B1 sluiceway); the remaining passed through spill (28.4%), turbine (9.0%), and screened bypass systems (4.2%). Surface passage rates divided by the combined discharge of the

TABLE 2.—Median, first-quartile (25th percentile) and third-quartile (75th percentile) forebay residence times (*h*) exhibited by telemetered steelhead kelts passing the Bonneville Dam (Columbia River) first powerhouse (B1), spillway (Spill), and second powerhouse (B2) during springs of 2002 and 2004. The number of kelts contacted in the forebay area (sample) is also reported. Values in parentheses are SEs. In 2004, a corner collector was installed at B2. *P*-values are for comparisons between 2002 and 2004.

	2002[b]					2004					
			Forebay residence time (h)					Forebay residence time (h)			
Area	N^a	Mean flow (m^3/s)	Median	First quartile	Third quartile	*N*	Mean flow (m^3/s)	Median	First quartile	Third quartile	*P*
B1	18	1,216 (22)	4.4	3.5	19.5	19	701 (21)	19.9	7.2	34.5	0.0535
Spill	125	2,929 (27)	0.4	0.1	4.1	100	2,003 (23)	0.9	0.3	3.2	<0.05
B2	48	2,991 (15)	6.1	0.7	23.1	218	3,048 (19)	0.3	0.1	1.0	<0.0001

[a] Data from 2002 are from Wertheimer and Evans (2005).
[b] Reported *N* is limited to kelts within known residence times only and does not represent all tagged kelts detected passing each dam area during the study period.

B1 sluiceway and B2CC (3% of project discharge) produced a project sluice effectiveness of 19 (Table 3).

At B2, passage efficiency significantly increased (chi-square test: $P < 0.0001$) between 2002 (58.0%) and 2004 (88.1%). Most kelts (81.7%) passed B2 in the approximately 5% of surface discharge routed via the B2CC, generating a powerhouse sluiceway effectiveness of 16. Despite success in increasing nonturbine passage at B2 in 2004, guidance efficiency of screen systems was low (34.8%), perhaps a result of shallowly distributed kelts discovering the surface flow discharge passing into the B2CC (Table 3). It is plausible that kelts migrating at water depths beneath intake screen systems (>20 m) may have been attracted to or entrained by turbine flows. Data supporting this premise are provided from kelts passing B2, where forebay residence times were not obtained ($n = 17$), suggesting these fish migrated through the forebay at depths greater than 8 m.

At the spillway, there was a significant reduction in passage efficiency between 2002 (66.6%) and 2004 (28.4%; chi-square test: $P < 0.0001$); thus, spillway effectiveness was reduced from 1.6 to 0.8. At B1, 78.9% of kelts passed via the sluiceway, generating a powerhouse effectiveness of 20 (<4% of B1 discharge passed via the sluiceway); yet, turbine passage increased in relation to 2002 (Table 3). Data showed no evidence of grouping effects from kelt releases between 2002 (Kruskal–Wallis test: $P = 0.3889$) and 2004 (Kruskal–Wallis test: $P = 0.2627$), indicating that the passage behaviors of kelts were consistent throughout each of the passage seasons.

Discussion

For systems such as the Columbia River that have resident and anadromous fish populations making upstream and downstream migrations, bypass systems that benefit all species and life history stages are desired (Kynard and O'Leary 1993; Northcote 1997). This study provides forebay residence and passage data for the postspawn steelhead population passing via surface flow bypass systems at BON. Results demonstrate that kelts were attracted to the greater proportion of river discharge passing via B2. Forebay residence

TABLE 3.—Steelhead kelt passage efficiency, sluice efficiency, spill efficiency, sluice effectiveness, spill effectiveness, and guidance efficiency at Bonneville Dam (Columbia River) in 2002 and 2004. The percent of total water flow discharged via each dam area are followed by the sample percent and size (*n*) detected passing. Note that sluice efficiency and effectiveness are for individual powerhouses, whereas project sluice passage efficiency and effectiveness, including spill passage efficiency and effectiveness, are calculated for the entire project (NA = not applicable).

Area and measurement	2002[a]	2004
Project		
Passage efficiency (%)	90	91
Sluice efficiency (%)	NA	58
Sluice effectiveness	NA	19
Powerhouse I (B1)		
Flow (%)	17	12
Sample (%; *n*)	9 (18)	5 (19)
Sluice efficiency (%)	1.0	79
Sluice effectiveness	71	20
Spill[b]		
Flow (%)	41	35
Sample (%; *n*)	67 (138)	28 (101)
Spill efficiency (%)	67	28
Spill effectiveness	1.6	0.8
Powerhouse II (B2)		
Flow (%)	42	53
Sample (%; *n*)	24 (50)	66 (235)
Passage efficiency (%)	58	88
Guidance efficiency (%)	58	35
Corner collector efficiency (%)	NA	82
Corner collector effectiveness	NA	16

[a] Data from 2002 are from Wertheimer and Evans (2005).
[b] USACE (unpublished data) initially reported incorrect volumes of water passing via spill. Corrected data are presented here.

times at B2 were negligible relative to those of kelts passing B2 in 2002. Furthermore, over 80% of kelts entering the B2 forebay passed via the B2CC, significantly improving passage efficiency in relation to this same period. Increased residence times and decreased passage efficiency at B1 were probably related to lesser B1 flows in 2004 than in 2002. It should also be remembered that the B1 sluiceway was not configured with design criteria of a surface bypass system (Johnson et al. 2005). Despite this, B1 sluiceway efficiency (78.9%) and effectiveness (20) remained high, providing additional evidence that kelts can be efficiently routed away from turbine intakes with the use of surface bypass.

Conventional spillways at FCRPS dams (i.e., where flow passes beneath raised spill gates) were not designed as fish passage systems. Sluiceway passage efficiency was near or above 80% for the monitored powerhouses. Due to comparatively low volumes of surface discharge, these data resulted in powerhouse effectiveness values of at least 16. The value of passing kelts via surface bypass is highlighted when sluiceway effectiveness is calculated directly in relation to the spillway (recall, spill effectiveness is generated using total project passage and project discharge). Project-wide sluice passage data indicate that these structures were at least 19 times as effective as spill in passing kelts in 2004. Spillway efficiency and effectiveness at BON were probably reduced because of lower spill flows in 2004 than in 2002. Despite this reduction, the highest published spill effectiveness value for kelts in the FCRPS was 2.9 at The Dalles and John Day dams (Wertheimer and Evans 2005), indicating that results presented here are not an anomaly and are related to kelt passage behaviors. Passing juvenile salmon using a surface flow bypass, as compared with spill, screened bypass systems, or turbine passage, is hypothesized to reduce stress as a result of decreases in pressure changes and turbulence (ISG 2000; Budy et al. 2002). Due to their postspawn atrophied state, kelts would probably receive the same physiological benefits acquired by juveniles passing via surface bypass, but specific studies are needed to provide empirical evidence.

Structural modifications to main-stem dams can increase passage efficiency for kelts, as indicated by performance of the B2CC, potentially providing a more benign passage system for these fish. During kelt sampling at FCRPS facilities (2000–2004), fresh injuries (e.g., head scrapes, damaged fin rays, descaling) were identified on some sampled kelts (R.H.W., unpublished data). Presumably, some of these injuries were associated with passage through screen systems and orifices designed to pass juvenile salmonids, not adult prespawn fallbacks (Boggs et al. 2004) or steelhead kelts. Passage at B2 for kelts could probably be enhanced by providing surface bypass attraction flows, especially early in the kelt passage season from December to April (Shapovalov and Taft 1954; Leider et al. 1984; Olsen 2004) and before the onset of B2CC operations for juvenile salmon passage. The seasonal timing of such operations to enhance iteroparity rates by decreasing forebay residence times and increasing passage efficiency at BON merits future investigation.

In the Pacific Northwest, providing surface flow passage routes at dams may provide an optimal means of conserving population-specific life histories and aid in the persistence of steelhead stocks spawning upstream of dams by bolstering downstream kelt survival rates. Due to proximity to the Pacific Ocean and limited access to kelts caused by a lack of juvenile salmon collector facilities (see Figure 1), results from this study support the ongoing development and evaluation of surface bypass systems in the lower Columbia River. Moreover, these data indicate that kelts passing lower Columbia River dams could be aided through the development of surface spill, surface bypass routes through powerhouse areas, and turbine modifications (Cada 2001). Factoring the orientations of adult prespawn fallbacks and kelts when developing a more fish-friendly turbine unit would be beneficial because larger fish suffer greater mortality during turbine passage than smaller fish (Coutant and Whitney 2000).

Despite the success of the B2CC in passing kelts, the efficiency of surface bypass systems is typically site and species specific. Systems under development should be designed with attention to all existing knowledge on the behaviors of juvenile salmon (Johnson et al. 2005) and steelhead kelts. Results from this study phase provide useful information on the behavior and passage routes of steelhead kelts at a lower Columbia River dam (Wertheimer and Evans 2005). More quantitative field studies of behavior are needed to understand kelt movements in relation to flows and other stimuli. The use of acoustic telemetry systems being developed at dams within the Columbia River basin for juvenile salmon may be one means of obtaining such data for steelhead kelts.

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