Passage and Survival of Juvenile Chinook Salmon Migrating from the Snake River Basin

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Survival of Juvenile Salmon Passing through Bonneville Dam and Tailrace

E. M. Dawley, R. D. Ledgerwood, L. G. Gilbreath, B. P. Sandford, P. J. Bentley, M. H. Schiewe, and S. J. Grabowski

National Marine Fisheries Service, Northwest Fisheries Science Center
2725 Montlake Boulevard East, Seattle, Washington 98112

Introduction

The efficacy of bypass systems as a safe means of passing juvenile salmon (Oncorhynchus spp.) around dams has generally been established by site-specific testing as each system goes into operation. Virtually all of this testing focused on the portion of the system beginning at interception of out-migrant juvenile salmonids by submersible travelling screens, and ending just prior to release into a conduit or channel through which fish were carried to the tailrace below the dam. There have been few rigorous assessments of fish survival through an entire bypass system, from forebay to tailrace or beyond, at any of the dams.

The principal constraint in conducting such tests is the difficulty of obtaining a statistically unbiased sample of fish exiting a bypass system prior to reaching the next dam downstream. Assessment downstream is often complicated by the uncertainties of collection efficiency. This is not the case at Bonneville Dam, the lowermost hydroelectric project on the Columbia River, where approximately 157 km of free-flowing river separate the dam from the estuary. An established sampling station is located at the head of the estuary at Jones Beach (River Kilometer 75; Figure 1). More than 20 years of sampling, using beach and purse seines to collect out-migrating juvenile salmon, has demonstrated that an unbiased estimate can be made at this site (Dawley et al. 1986).

There are several compelling reasons for focusing research on fish passage at Bonneville Dam. As the last dam on the Columbia River, Bonneville Dam is in the critical position of passing more juvenile salmon than any other dam in the system. Moreover, no thorough assessment of passage survival has been conducted at the dam since completion of the spillway flow deflectors in 1975, the Second Powerhouse in 1983, and the two downstream migrant bypass systems in 1981 and 1984. Information specific to each of these separate passage routes is needed for management of fish passage relative to power production.

Passage Route Survival Comparisons

In 1987, the National Marine Fisheries Service (NMFS), in cooperation with the U.S. Army Corps of Engineers (COE), began a multiyear study to evaluate survival of subyearling fall chinook salmon O. tshawytscha passing Bonneville Dam. During June, July, and August, 1987 through 1990, groups of differentially marked chinook salmon were simultaneously released to pass Bonneville Dam via the spillway, the Second Powerhouse turbines, or the Second Powerhouse bypass system (Figure 2). Additional releases were made in the tailrace at the downstream edge of the turbine boil, about 2 km downstream from the dam. To date, about 8 million fish have been released. Estimates of short-term relative survival were based on recoveries of juveniles by beach and purse seines at Jones Beach. Estimates of long-term relative survival were based on recoveries of tagged adult fish from the fisheries and from hatchery escapement.

The most striking finding of this study was that differences in estuarine recoveries of juvenile salmon from turbine and bypass release groups suggested little survival benefit associated with the bypass system. In 1987 and 1988, recoveries of bypass-released groups were significantly less than recoveries of turbine-released groups; mean differences were 13.3 and 16.6%, respectively. In 1989 and 1990, recoveries of bypass-released groups were also less than recoveries of turbine-released groups, though not significantly; mean differences were 3.1 and 2.6%, respectively. The difference between data sets may be associated with river flow, resulting in higher tailwater elevation during tests conducted in the last 2 years (Figure 3).
Figure 1. The lower Columbia River showing locations of Bonneville Dam and the estuarine sampling site at Jones Beach, Oregon.
Figure 2. Schematic of Bonneville Dam and vicinity showing release locations for subyearling chinook salmon during 1987-90 studies.
Increased survival of bypass-released groups relative to increased tailwater surface elevation; survival % = (Bypass recovery %) / (Lower turbine recovery % x 100). Only the last half of the annual releases were used to provide uniform survival data for comparing low tailwater test conditions.
Higher tailwater elevation has diminished turbulence and reduced water velocity from 8.1 to 7.6 m/sec within the 1-m diameter bypass conduit. In addition, it has diminished shear forces at the conduit terminus.

Comparisons of recovery differences between bypass-released and other release groups were also made, but include fewer years of comparison (Table 1). On the basis of 3 years of releases, recoveries of bypass-released groups averaged 8.3% less than recoveries of tailrace-released groups. From 2 years of releases, recoveries of bypass-released groups averaged 17.4% less than recoveries of downstream-released groups. On the basis of data from a single year (1989), bypass-released groups averaged 16.6% less than spillway-released groups. This latter comparison is noteworthy since spillway passage has long been believed to be the safest route of dam passage and was considered similar to bypass passage.

Although several years remain before data on adult returns are complete, preliminary results suggest that returns of bypass-released fish are not significantly different from those of turbine-released fish. Again, this suggests a lack of benefit from bypass passage (Ledgerwood et al. 1990, 1991).

**Evaluation of the Bypass System**

Results of passage survival tests prompted us to focus research efforts on detrimental impacts to out-migrating juvenile salmon using the bypass system. Decreased survival may be a consequence of physical damage, occurring during passage through the system; increased predation after egress from the bypass discharge conduit; or a combination of both.

The design and location of the bypass conduit terminus were engineered to provide out-migrants the best possible protection against predation by birds and fish. The supporting structure for the 1-m diameter conduit is a teardrop-shaped column projecting 9 m upward from the river bottom, the top of which is 7-14 m below the water surface. The terminus is located in relatively high-velocity water about 76 m downstream from the dam, 85 m from the north shore, and 30 m downstream from the turbine discharge boil. The river bottom is smooth and the distance from any geologic relief was thought to eliminate predator sanctuary near out-migrating juvenile salmon.

**Initial Investigations**

Initial investigations of the physical features of the bypass system by NMFS and COE provided little evidence of problems. A video inspection of the discharge conduit revealed no structural problems sufficient to cause injuries to fish. At operating conditions identical to those of survival tests, water velocities adjacent to the discharge monolith varied from 1 to 1.6 m/sec, similar to model-predicted velocities. Northern squawfish *Ptychocheilus oregonensis* are thought to be the primary piscivore on juvenile salmon in the Columbia River (Poe et al. 1991; Vigg et al. 1991). Literature regarding habitat suitability for northern squawfish suggested that velocities of that magnitude would be exclusionary (Faler et al. 1988). Purse seining at the bypass outlet produced little evidence of injury or mortality, but insufficient fish were recovered to allow rigorous assessment.

**Trap-Net Method**

In 1990, researchers began using a trap-net recovery system to assess the physical condition of out-migrants following passage through the bypass system (Figure 4). The trap net was attached directly to a steel carriage permanently affixed to the outlet monolith. The objective was to identify which segment of the system was detrimental to juvenile salmonids and to assess any differences at various tailwater elevations. Marked hatchery and run-of-the-river fish were released at various locations in the bypass system and trap net. Fish were then recovered and evaluated for stress, scale loss, injury, mortality, and 48-h delayed mortality. To assess whether the trap net captured live and moribund fish in the same percentages, recently killed fish were released through the bypass system in conjunction with live fish.
TABLE 1.—Differences in relative survival between fish passing through the bypass system and other passage routes at Bonneville Dam based upon juvenile recovery data from estuarine sampling.

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<tr>
<td>Turbine:</td>
<td>-10.8*</td>
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<td>-3.3</td>
<td>-2.5*</td>
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<td>Passage through the turbine and through the PH-2 tailrace.</td>
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<td>Tailrace:</td>
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<td>-14.1*</td>
<td>-7.3</td>
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<td>Passage through the PH-2 tailrace.</td>
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<td>Spillway:</td>
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<td>-16.6*</td>
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<td>Passage over the spillway, through stilling basin and spillway tailrace.</td>
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<td>Downstream:</td>
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<td>-23.1*</td>
<td>-11.6*</td>
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<td>-17.4*</td>
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<td>Released downstream from dam and tailraces, at a swift-water site.</td>
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* Calculated using annual means for recovery percent of treatment groups, where:
  \( BY = \text{bypass, and TR = other treatment groups/passage routes} \) \( \left[ \left( BY\% - TR\% \right) + TR\% \right] \times 100 \).

* Abbreviation for Second Powerhouse.

* Only the mid-depth release site was used, to provide increased numbers of replicates.

* Significant at \( P = 0.05 \).
Figure 4. Schematic of the downstream migrant bypass system at Bonneville Dam Second Powerhouse; fish release sites are numbered.
Trapping Results

The trap net recovered 80-100% of live test fish and 93-100% of killed fish released into the bypass channel. The high recovery rate of killed fish allowed us to assume that injured, moribund, and dead test fish exiting the bypass were proportionally represented in recovery data.

Tests conducted during the juvenile migration period at moderate tailwater elevations (4.9-6.1 m) showed some impacts from bypass passage, primarily increased stress and scale loss, with slight increases of injury and mortality. However, some groups showed substantial impacts from bypass passage. Run-of-the-river yearling and subyearling chinook salmon and coho salmon *O. kisutch* incurred high percentages of scale loss (9-29%; Figure 5) and individual fish suffered severe scale loss. In tests with subyearling chinook salmon, hatchery fish incurred 0.3% injury, 5.6% direct mortality, and 2.1% delayed mortality; and run-of-the-river fish incurred 3.8% injury, 2.4% direct mortality, and 7.6% delayed mortality.

Assessment of blood plasma cortisol, glucose, and lactate—used to evaluate stress—indicated significantly greater stress to bypass-released fish than to controls. Concentrations of plasma cortisol were high for an 18-h period following passage (Figure 6). Test fish stressed in the laboratory by dip netting to establish comparison points of known stress showed cortisol levels of similar magnitude to those produced from bypass passage.

Additional tests conducted at low tailwater elevations (2.7-3.2 m) may indicate high variability in passage conditions, causing intermittent high mortality. The high velocity and turbulence within the system during tests was similar to conditions that migrants would encounter during years of low river flow. Mortality ranged from 6 to 51% for subyearling chinook salmon and from 0 to 32% for subyearling coho salmon (Figure S). Impacts to fish released at the midpoint of the bypass system were less, 2-40% mortality for subyearling chinook salmon and 0.19% mortality for subyearling coho salmon.

Two potential sources of hazard within the bypass discharge conduit were identified by NMFS biologists and engineers: entrained air may be causing severe pressure fluctuations throughout the conduit, and a short radius elbow at the upstream end of the conduit may be producing negative pressures. Biological evaluation is in progress.

Aspects of Bypass Systems That May Cause Decreased Survival

Coincidental studies of northern squawfish in the tailrace of Bonneville Dam indicated greater predation on fish leaving the bypass system than at other locations at the dam. Ward et al. (1992) stated that trolling with lures at the bypass outlet produced substantially higher catches of northern squawfish than at any other location in the forebay or tailrace of the dam. In 1990, passage survival tests indicated that northern squawfish consumed greater percentages of bypass-released fish than tailrace- or turbine-released fish (Ithomas Poe, unpublished report, U.S. Fish and Wildlife Service, Columbia River Field Station).

Reduced survival of test fish released through the Bonneville Dam Second Powerhouse bypass system in 1987-90 probably resulted from both physical impacts of passage through the bypass discharge conduit and predation during migration through the tailrace. Physical problems within the bypass conduit will be remedied insofar as possible, but since the conduit is 287 m long, mostly 1 meter in diameter, and partially submerged, it may be difficult to identify and correct all problem areas. However, the inherent impact from predation following egress from the system cannot easily be remedied.

Predation may be an insurmountable problem as a result of (1) increased stress from passage causing diminished avoidance reactions [laboratory studies showed that severe stress or severe turbulence caused loss of equilibrium and abnormal avoidance behavior (Groves 1972; Sigismondi and Weber 1988)];
IMPACTS FROM BYPASS PASSAGE

Figure 5. Average descaling and mortality percentages of test fish in relation to tailwater (TW) elevation during tests (RR = run-of-the-river, H = hatchery, Yr = yearling, Sy = subyearling, and Chin = chinook salmon).
Cortisol levels of yearling and subyearling chinook salmon before and after bypass passage compared to counterparts released into the trap-net (Net) and to laboratory test fish stressed by dipnetting (Acute) and by continuous crowding (Chronic).
(2) point-source release from the bypass allowing predators to congregate; 3) migration through a low-velocity tailrace basin providing a large area of suitable habitat for northern squawfish; and (4) a bypass outlet location on the north side of a tailrace that angles to the south about 90°, tending to direct out-migrants shoreward toward rip-rap areas-prime habitat for northern squawfish.

In the passage survival tests of 1987-90, estimated survival for test fish released 2.5 km downstream from the dam was significantly higher than for fish released into the bypass system. The physical conditions at the downstream release location that most probably allowed higher survival were (1) high water velocity-1.5 to 2.1 m/sec; (2) long distance from shore-about 100 m; (3) rapid downstream dispersal of fish, resulting in decreased juvenile salmon density in the migration route and increased time for orientation prior to encountering predators; (4) release where current direction was parallel to the shoreline; (5) lack of predator attraction from a continuous egress of juvenile salmon at a single location or along a localized migration route; and (6) nighttime releases that minimized avian predation.

Summary and Conclusions

1. Trends observed in the juvenile recovery data suggest that bypass passage has not substantially improved survival as compared to turbine passage for summer-migrating juvenile chinook salmon at Bonneville Dam; however, the final conclusions regarding differences in passage survival must await analyses of all adult returns.

2. Bypass passage appears to cause significant stress, loss of scales, and some direct mortality. During summertime low river flows, the resulting low tailwater elevations appear to aggravate mortality during passage.

3. Survival of fish leaving the bypass system appears to be diminished by northern squawfish predation.

4. Conditions that appear to increase survival of downstream-released fish over bypass-released fish include high water velocity, long distance to predator habitat, current direction parallel to the shoreline, low level of stress for migrants at river entry, lack of predator attraction from continuous availability of juvenile salmonids, and nighttime release of fish to limit avian predation.

5. Conditions thought to decrease survival of out-migrating juvenile salmonids at the Bonneville Dam Second Powerhouse bypass system may be important at other dams, and should be investigated.

References


155


