Relative Survival of Juvenile Salmon Passing through the Spillway of The Dalles Dam, 1997-2000

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EXECUTIVE SUMMARY

High rates of spill are presumed to increase passage survival for juvenile salmonid migrants because passage survival through spillways at Columbia and Snake River dams is generally higher than through turbines. However, two conditions at The Dalles Dam may decrease spill passage survival under high spill conditions: 1) a short stilling basin and shallow tailrace result in severe turbulence and lateral currents that may cause physical injury to juvenile salmon; and 2) a large proportion of spilled water moves through shallows and islands downstream, where salmonids may be more susceptible to predation by gulls (*Larus* spp.) and northern pikeminnow (*Ptychocheilus oregonensis*) than in the main river channel.

In 1997, the National Marine Fisheries Service initiated a study at The Dalles Dam to evaluate the relative survival of juvenile Pacific salmon (*Oncorhynchus* spp.) through the spillway when 64% of river flow was spilled. Equal numbers of fish were released during the day and night. Fish were tagged with passive integrated transponder (PIT) tags at Bonneville Dam and transported to The Dalles Dam about 24 hours prior to release. Treatment groups of fish were released into the forebay of The Dalles Dam directly in front of the spillway, and reference groups were released from a boat downstream from the dam at the proposed site of the new bypass system outfall. This site is about 70 m from the Washington shore, about 0.7 km downstream from the spillway, and about 30 m downstream from the Highway 197 bridge in an area of high water velocity.

Recapture information was collected at both the first and second powerhouses at Bonneville Dam, from the estuary pair trawl off Jones Beach (Columbia River RKm 74), and from piscivorous bird colonies on Rice Island (RKm 34) and East Sand Island (RKm 8). A total of 43,362 coho salmon (*O. kisutch*) and 53,192 subyearling chinook salmon (*O. tshawytscha*) were released for the spring and summer evaluations respectively. Results of the 1997 tests suggested passage mortality of about 13% for coho salmon and 8% for subyearling chinook salmon at 64% spill. No significant differences in survival were noted between daytime and nighttime releases or among north, middle, and south spillway release sites in either the spring or summer test periods.

In 1998, we expanded the research objectives to include assessment of passage survival through the spillway at high flow (64% of river flow) and moderate flow (30% of river flow) during both day and night and through the ice and trash sluiceway during daytime periods at moderate flow. Methods were similar to those used in 1997 with the exception that toward the end of the summer evaluation, fish were collected at McNary Dam because fish were no longer available at Bonneville Dam. A total of 63,994 coho salmon and 80,498 subyearling chinook salmon were released for the spring and summer evaluations respectively.

Results of the 1998 tests suggested losses of about 11% for coho salmon during the spring migration and 25% for subyearling chinook salmon during the summer migration at 64% spill. At the 30% spill level, losses were reduced to about 3% for coho salmon during the spring migration and 11% for subyearling chinook salmon during the summer migration (significantly higher survivals than at 64% spill in the summer). At 30% spill, losses through the sluiceway were similar to those through the spillway, at 4% for coho salmon and 11% for subyearling chinook salmon.

In spring 1998, daytime spillway passage survival at 64% spill was substantially lower than survival at 30% spill, but the difference was not significant. Also, there were no significant differences between spillway release locations (north, middle/north, middle/south, and south). In the summer, there were no significant differences in survival between diel release periods or spillway locations, although daytime spillway passage survival was higher at 30% than at 64% spill, and survival was generally higher for the north than for the south spillway release groups.

In 1999, we continued passage survival tests comparing 30 and 64% spill conditions, but excluded the sluiceway component of the study in order to increase test fish numbers, and thus precision in survival estimates, for the spillway passage evaluations. Test fish were collected from the fish collection facility at John Day Dam and PIT tagged before transport and release at The Dalles Dam. Approximately 139,000 yearling chinook and coho salmon were tagged in April and May (spring migrants) and 167,000 subyearling chinook salmon were tagged in June and July (summer migrants).

Results of the 1999 tests suggested losses of about 7% for yearling chinook and coho salmon during the spring migration and 4% for subyearling chinook salmon during the summer migration at 64% spill. At the 30% spill level, losses were about 4% for yearling chinook and coho salmon during the spring migration and 0% for chinook salmon during the summer migration. In the spring, nighttime survival estimates were significantly higher than daytime estimates for both 30 and 64% spill levels. No differences in spillway release location (north, middle, and south) were noted in either the spring or summer. In the summer, nighttime survival estimates were again significantly higher than daytime survival estimates with differences greater at the 30% spill level.

In 2000, we expanded the research to include assessment of passage survival through the spillway at a single moderate spill level (40% of river flow), the ice/trash sluiceway, and turbine units. Test fish were again collected from the fish collection facility at John Day Dam and PIT tagged. Approximately 135,000 yearling chinook and coho salmon were tagged in April and May and 161,000 subyearling chinook salmon were tagged in June and July. Point estimates of dam passage survival were calculated for juvenile salmon during the spring and summer migration periods and for both day and night diel periods. The spillway was operated 24 hours per day using the juvenile salmon flow pattern, which concentrates spill toward the northernmost spillbays. In previous

study years, the juvenile pattern was used during the night, and the adult pattern (spill distributed across all spillbays) was used during daytime.

Test fish were released in approximately equal numbers in each of four release locations at every release. Half of the test fish were released at night, and the other half in daylight. The tailrace groups were released in the same location as previous years, at a site away from turbulence and areas of suspected predation, and at a time intended to coincide with passage of treatment groups. The spillway releases were apportioned as equally as possible to two lateral locations (north and south) in the spillway forebay, approximately 200 meters upstream from the spillbays.

Sluiceway groups were released from the intake deck of The Dalles Dam through a fixed 10-cm hose to a point just above the sluiceway water level. Turbine releases were also made from the intake deck, through a flexible 10-cm hose. The hose was contained in a steel pipe, which was in turn held in a frame; the frame was lowered by a crane until the hose end projected into the turbine intake about 4 m below the intake ceiling. Releases were made into the center gate slot of the selected turbine unit. During both spring and summer test periods, turbine releases were made across the entire powerhouse.

After migrating through 74 km of reservoir, a similar distance to previous years, a portion of the test fish passed through the Bonneville Dam PIT-tag interrogation equipment located in the juvenile fish bypass systems at RKm 235. About 17.5% of yearling chinook and coho salmon (spring migrants) and 3.2% of subyearling chinook salmon (summer migrants) released at The Dalles Dam were detected in the bypass systems at Bonneville Dam in 2000. Additionally, 3.2% of spring migrants and 2.1% of summer migrants were detected in the estuary off Jones Beach or on piscivorous bird colonies on Rice and East Sand Island in the Columbia River estuary.

Point estimates of relative passage survival for daytime and nighttime releases during spring and summer 2000 are summarized below.

Spring	Location	Daytime (%)	Nighttime (%)
	Sluiceway	94.5	94.0
	North spillway	102.6	91.8
	South spillway	90.9	92.4
	Turbine	79.0	83.0

Summer	Location	Daytime (%)	Nighttime (%)
	Sluiceway	95.5	97.2
	North spillway	84.2	100.6
	South spillway	87.4	94.3
	Turbine	79.1	88.9

There were no differences in estimated relative survival between diel release periods for sluiceway, south spillway, and turbine releases during either the spring or summer test periods. However, estimates of relative survival for daytime releases at the north spillway during spring were significantly higher than those for nighttime releases, but estimates from releases during summer at the same location showed significantly higher survival for nighttime than for daytime releases.

These point estimates of survival were designed to represent passage survival of mixed fish stocks throughout the spring and summer migration periods; during daytime and nighttime; through spillbays across the width of the spillway; and through the turbines across the powerhouse, with ambient spill gate openings, river flows, tailwater elevations, and water temperatures.

Median travel time from release to detection at Bonneville Dam averaged 1.9 days for both spring and summer migrants. Travel time was consistently shorter for tailrace-released groups than for spillway, sluiceway, and turbine released groups.

For spring tailrace groups, median travel time averaged 1.7 days (combined first and second powerhouse data), while travel time averaged 1.9 days for sluiceway and spillway groups and 2.0 days for turbine groups. Average median travel time to detection at Bonneville Dam was 0.2 days shorter at the second powerhouse than at the first powerhouse for all four release locations combined over the spring test period.

For summer tailrace groups, median travel time averaged 1.8 days (combined first and second powerhouse data), while travel time averaged 1.9 days for sluiceway groups and 2.0 for spillway and turbine groups. Average median travel time to detection at Bonneville Dam was 0.2 days shorter at the first powerhouse than at the second powerhouse for all four release locations combined over the summer test period--the opposite of the trend observed from spring data.

Tests of passage distribution homogeneity at Bonneville Dam for corresponding spillway- and tailrace-released groups of yearling spring and subyearling summer migrants suggested that daily release groups were not mixed on 20 of 63 test dates. To assess these distribution differences, we compared the number of fish detected from spillway- and tailrace-release groups in relation to powerhouse operation and river flow. We found negligible differences in powerhouse operation between mixed and non-mixed groups. Analyses of survival estimates showed no significant differences between groups that were mixed upon arrival at Bonneville Dam and those that were not mixed .

Relative survival estimates calculated from PIT-tag detections at Bonneville Dam were consistently lower than those calculated from detections at abandoned bird colonies. Detections at bypass systems and avian predator colonies are obtained using different PIT-tag detection methods; these methods may bias estimates from either or both sites. We used combined data from all recovery sites for passage survival analyses.

During the 2000 study periods, spring flows ranged from 187,600 to 342,600 ft^3/second and summer flows ranged from 136,500 to 274,600 ft^3/second. Spring flows in 2000 were much lower than those in 1997, and although the lower end of the flow range in 2000 was similar to the lower end of the ranges in1998 and 1999, the upper end of the range was much lower than the upper ends in 1998 and 1999. During summer 2000, both ends of the flow range were lower than in the other three years.

Based on data collected through four years of study, we arrived at the following conclusions:

1) Detection rates at Bonneville Dam for fish released through The Dalles spillway at 64% spill were significantly lower than for fish released downstream from The Dalles Dam.

2) Based on data from the two years of direct comparison between spill rates, point estimates of relative survival for fish passing at 64% spill have been lower, but not significantly different, than for fish passing at 30% spill. However, when annual data from 1998 and 1999 were combined for analysis, the differences were significant for spring migrants in 1998, but not for summer migrants in 1999. Respective point estimates for passage survival at 64 and 30% spill were 90.5 and 95.5% for spring migrants in 1998, 73.4 and 89.0% for summer migrants in 1998, and 95.9 and 99.5% for summer migrants in 1999.

3) The combined data from three years of research (1997-1999) indicated that for summer migrants passing via the spillway, lower survival was estimated for those passing during daytime (adult spill patterns) than nighttime hours (juvenile spill patterns), with respective daytime vs. nighttime estimates of 87.6 and 89.7%. The combined data indicated that for spring migrants there was no difference between daytime and nighttime passage in 1997 and 1998 (89.8 day vs. 88.8% night, but there was a difference in 1999 (86.9 day vs. 102.1 night).

4) Data from one year of research (2000) in the spring where the juvenile spill pattern was used throughout the entire study period produced significantly higher survival during the day than night through the north spillbays. South spillbays showed no difference between night and daytime releases. Point estimates of survival through north spillbays were 102.6 and 91.8% for day and nighttime releases, respectively. Point estimates of survival through south spillbays were 90.9 and 92.4% for daytime and nighttime releases, respectively.

5) Data from one year of research (2000) in the summer where the juvenile spill pattern was used throughout the entire study period produced significantly higher survival during the night than day through the north spillbays. South spillbays showed no difference between daytime and nighttime releases. Point estimates of survival through north spillbays were 84.2 and 100.6% for daytime and nighttime releases, respectively. Point estimates of survival through south spillbays were 87.4 and 94.3% for daytime and nighttime releases, respectively.

6) Point estimates of survival during the spring 2000 evaluation showed no significant difference between daytime and nighttime releases for fish released to the ice/trash sluiceway (94 and 95%, respectively) or turbine units (78 and 84%, respectively).

7) Point estimates of survival from the summer 2000 evaluation showed no significant difference in survival between daytime and nighttime releases for fish released into the ice/trash sluiceway (96 and 97% respectively) or into turbine units (79 and 89%, respectively).

8) Data from the 1998 spring evaluation of sluiceway passage (one year of testing) indicated that for daytime passage at 30% spill, relative survival for daytime fish passage through the sluiceway (point estimate = 96.0%) was similar to that of daytime fish passage through the spillway (point estimate = 97.8%).

9) Data from the 2000 spring test period showed significantly lower survival for turbine released fish than either spillway or sluiceway released fish for both daytime and nighttime releases. Point estimates of survival for daytime releases were 79.0, 102.6, 90.9, and 94.5% for turbine, north spillway, south spillway, and sluiceway respectively. Point estimates of survival for nighttime releases were 83.0, 91.8, 92.4, and 94.0 for turbine, north spillway, south spillway, and sluiceway respectively.

10) Data from the 2000 summer test period showed significantly lower survival for turbine released fish than sluiceway fish released during the day. Because of the low detection rates and resultant high variability no other differences between release sites were significant though some were quite close. Point estimates of survival for daytime releases were 79.1, 84.2, 87.4, and 95.5% for turbine, north spillway, south spillway and sluiceway respectively. Point estimates of survival for nighttime releases were 88.9, 100.6, 94.3, and 97.2% for turbine, north spillway, south spillway, and sluiceway respectively.

11) Analysis of survival in relation to tailwater elevation, spill volume, river flow, and water temperature have produced poor correlations in both spring and summer tests, in all years of the study.

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INTRODUCTION

Based on the 1995 National Marine Fisheries Service (NMFS) Biological Opinion (NMFS 1995), the U.S. Army Corps of Engineers (COE) selected the spillway as the best passage route for migrating juvenile salmon (*Oncorhynchus* spp.) at The Dalles Dam. NMFS recommended increasing spill volumes to 64% of river flow to attain 80% fish passage efficiency (FPE). High volumes of spill at The Dalles Dam produce levels of total dissolved gas (TDG) that are lower than those produced at other dams: during 1996, high volumes of spill at The Dalles Dam produced levels of TDG which were less than 120% of saturation, the maximum approved by state water quality agencies. Because TDG is not a factor that limits spill operations at The Dalles Dam, implementation of alternatives for increasing FPE, such as surface collectors or turbine intake screens with an upgraded sluiceway or bypass system, were deferred in lieu of increased spill.

However, observations at The Dalles Dam and hydraulic model studies at the COE Waterways Experiment Station have raised concerns about the safe passage of juvenile salmonids during high spill. Heavy turbulence, back eddies, and lateral flow in the spillway stilling basin may be severe enough to injure fish, and spillway flow passing through the Bridge and Basin Islands downstream from the dam might cause higher-than-expected mortality due to predation (Fig. 1).

Substantial predation by northern pikeminnow *(Ptychocheilus oregonensis*) and gulls (*Larus* spp.) is suspected in the Bridge and Basin Islands area, based upon northern pikeminnow abundance and stomach-content evaluations (Hansel et al. 1993, Ward et al. 1995) and upon observations of salmonid smolts carried off by gulls (Jones et al. 1997, Dawley et al. 2000a). Survival tests conducted in 1995 (Normandeau Associates et al. 1996) corroborated concerns that heavy turbulence in the spillway stilling basin might cause unacceptable increases in mortality.

In 1996, we began discussions with the COE on means to test the premise that high spill levels at The Dalles Dam increase passage survival of migrating juvenile salmonids. A comprehensive review of potential methodologies indicated that assessments of spill passage survival at The Dalles Dam could be conducted using balloon tags, coded-wire tags, or passive integrated transponder (PIT) tags. Balloon tags are appropriate for evaluations of immediate and direct injury and mortality from shear currents and high-velocity impact with structures during dam passage, but not for evaluation of indirect mortality from predation during passage through the tailrace and downstream reservoir. Coded-wire-tag technology provides the ability to effectively evaluate both direct and indirect mortality; however, results are dependent on adult returns, and thus the number of fish necessary for the study would be unacceptably large. Therefore, we selected PIT tags because they provided the only method to evaluate both direct and indirect mortality using feasible numbers of test fish.

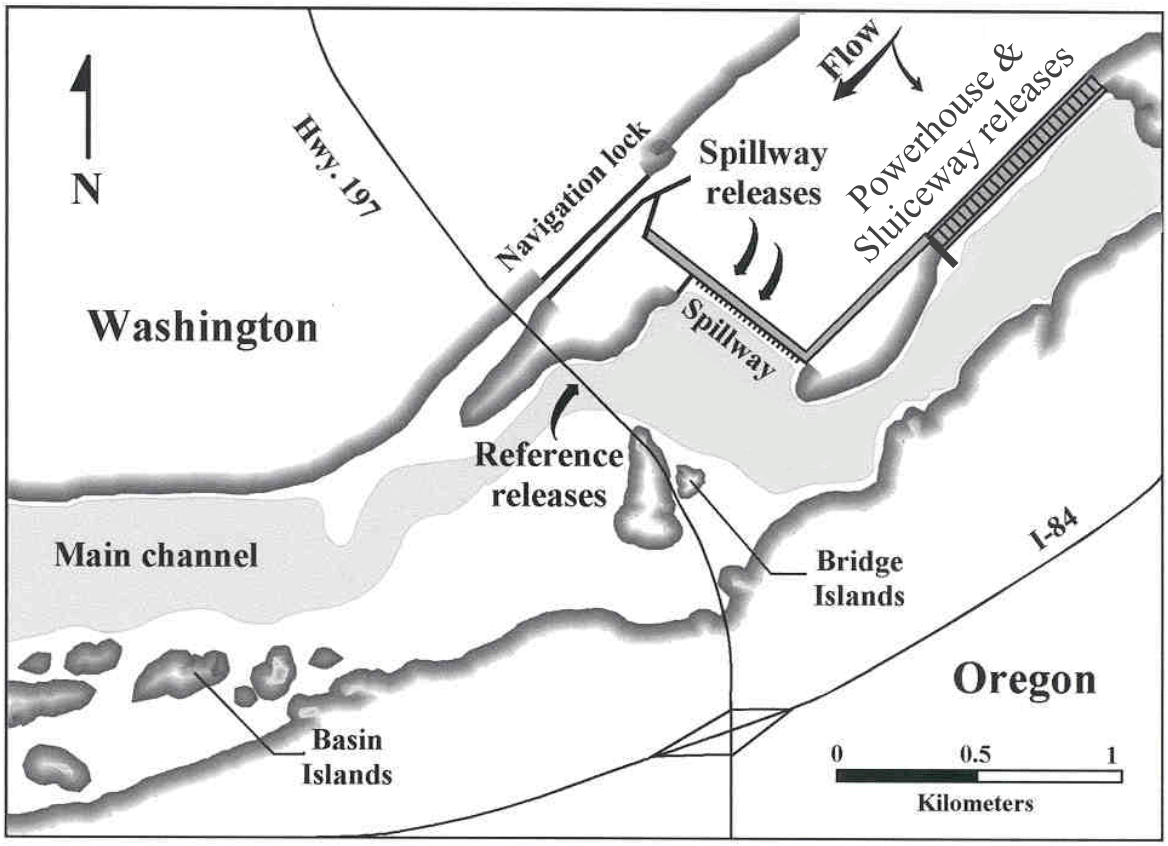

Figure 1. Overview of The Dalles Dam and tailrace area. Reference, spillway, sluiceway, and powerhouse group release locations used in the 2000 evaluation of relative survival of juvenile coho salmon, yearling chinook salmon, and subyearling chinook salmon are shown, as well as the position of the main channel in relation to the shallow island areas downstream from the dam.

In 1997, the National Marine Fisheries Service initiated a study at The Dalles Dam to evaluate the relative survival of juvenile Pacific salmon passed through the spillway when 64% of the river flow was spilled. Equal numbers of fish were released during the day and at night. Fish were tagged with PIT tags at Bonneville Dam and transported to The Dalles Dam about 24 hours prior to release. Treatment groups of fish were released from the spillway intake deck into the forebay of The Dalles Dam directly in front of the spillbays. Reference groups were released from a boat downstream from the dam at the proposed site of the new bypass system outfall. This site is about 70 m from the Washington shore, about 0.7 km downstream from the spillway, and about 30 m downstream from the Highway 197 bridge in an area of high water velocity.

Recapture information was collected at both the first and second powerhouses at Bonneville Dam, the estuary pair trawl off Jones Beach (Columbia River Kilometer [RKm] 74), and from the piscivorous bird colonies at Rice Island (RKm 35) and East Sand Island (RKm 8). A total of 43,362 coho salmon (*O. kisutch*) and 53,192 subyearling chinook salmon (*O. tshawytscha*) were released for the spring and summer evaluations respectively. Results of the 1997 tests suggested losses of about 13% for coho salmon and 8% for subyearling chinook salmon passing at 64% spill. No significant differences in survival were noted between daytime and nighttime releases or between north, middle, and south spillway release sites in either the spring or summer test periods (Dawley et al. 1998).

In 1998, we expanded the research objectives to include assessment of passage survival through the spillway at high flow (64% of river flow) and moderate flow (30% of river flow) during both day and night and through the ice and trash sluiceway during daytime periods at moderate flow. Methods were similar to those used in 1997 with the exception that toward the end of the summer evaluation, fish were collected at McNary Dam because fish were no longer available at Bonneville Dam. A total of 63,994 coho salmon and 80,498 subyearling chinook salmon were released for the spring and summer evaluations respectively.

Results of the 1998 tests suggested losses of about 11% for coho salmon during the spring migration and 25% for subyearling chinook salmon during the summer migration at 64% spill. At the 30% spill level, losses were much lower, at about 3% for coho salmon during the spring migration and 11% for chinook salmon during the summer migration (significantly higher survival than at 64% spill). At 30% spill, losses through the sluiceway were similar to those through the spillway, at 4% for coho salmon and 11% for subyearling chinook salmon.

In spring 1998, daytime spillway passage survival at 64% spill was substantially lower than survival at 30% spill, but the difference was not significant. There were also no significant differences between spillway release locations. In the summer, there were no significant differences between diel release periods or spillway release locations, although survival estimates for fish passing through the north spillways were generally higher than for fish passing through the south spillways. Daytime passage survival through the spillways was lower at 64% than at 30% spill (Dawley et al. 2000b).

In 1999, we continued passage survival tests comparing 30 and 64% spill conditions, but we excluded the sluiceway component of the study in order to increase the number of test fish available for, and thus the precision of, the spillway evaluations. Test fish were collected from the smolt monitoring facility at John Day Dam, PIT-tagged, and transported for release at The Dalles Dam. We released spillway (test) fish from a boat in the forebay. Approximately 139,000 yearling chinook and coho salmon were tagged in April and May (spring migrants) and 167,000 subyearling chinook salmon were tagged in June and July (summer migrants).

Results of the 1999 tests at 64% spill suggested losses of about 7% for yearling chinook and coho salmon during the spring migration and 4% for subyearling chinook salmon during the summer migration. At the 30% spill level, losses were at about 4% for yearling chinook and coho salmon during the spring migration and 0% for subyearling chinook salmon during the summer migration. In the spring, nighttime survival estimates were significantly higher than daytime estimates and were observed in data for both 30 and 64% spill levels. No differences in spillway release location were noted in either the spring or summer. In the summer, nighttime survival estimates were again significantly higher than daytime survival estimates, with the differences greater at the 30% spill level (Dawley et al. 2000a).

In 2000, we expanded the research to include assessment of passage survival through the spillway at moderate spill (40% of river flow), the ice and trash sluiceway, and turbine units. Point estimates of dam passage survival were calculated for juvenile salmon during the spring and summer migration periods and for both day and night diel periods. The spillway was operated 24 hours per day with the juvenile salmon flow pattern which concentrates spill toward the northernmost spillbays. In previous study years, the juvenile pattern was used during the night, and the adult pattern (spill distributed across all spillbays) was used during daytime.

METHODS

During the 2000 spring migration, we captured run-of-the-river juvenile yearling chinook and coho salmon 5-7 days/week at the smolt monitoring facility at John Day Dam (RKm 347) in late April and May. During the summer migration in June and July, we captured run-of-the-river subyearling chinook salmon 5-7 days/week at the same facility. We PIT tagged approximately 6,000 fish daily in both the spring and summer test periods and divided them proportionally among spillway, turbine, and ice/trash sluiceway treatment groups and the tailrace reference group on a daily basis (Fig. 1, Appendix Table A5).

Tagged fish groups were then transported to The Dalles Dam (RKm 308) and held for one day before release. Analyses of relative survival rates were based on subsequent PIT-tag detections from the juvenile bypass systems at Bonneville Dam first and second powerhouses (RKm 235), from the PIT-tag detector trawl used in the estuary off Jones Beach (RKm 75; Ledgerwood et al. 2000), and from flat-plate and pole-mounted detections on abandoned bird colonies at RKm 8 and 35 (Ryan et al. 2001).

Generally, juvenile salmon for each day of marking were captured during a 6- to 10-hour period from the fish bypass system at John Day Dam. As migrants passed out of the corrugated flume, they slid across a dewatering screen onto the wetted separator, which segregates juvenile salmon from larger fish and debris. Upon separation, juvenile fish were directed through a 25-cm-diameter PIT-tag detector tunnel to a 3-way rotating gate, where previously PIT-tagged fish were returned to the river and non-tagged fish were diverted through a 25-cm pipe to the juvenile-fish sampling room. At the sampling room, fish were collected in a 6.1-m-long by 152-cm-wide by 107-cm-deep tank. Fish were sorted and tagged during the night as they were collected.

Marking began each evening at 2000 h, when the smolt monitoring sample rate was increased to collect the target number of fish for tagging. The sample rate was initially increased to 100%. Adjustments to the sample rate were made every one-half hour as needed to collect the required number of fish for tagging, and ranged from 5 to 100%.

After fish were anesthetized, target fish were sorted, scanned for PIT tags, and tagged in approximately equal numbers for spillway, turbine, ice/trash sluiceway (treatment), and tailrace (reference) groups. Tagging personnel were alternated between the treatment and reference groups throughout the study period. Non-target fish and the occasional PIT-tagged target fish not diverted back to the river at the 3-way rotating gate were allowed to recover from anesthetic and were then released into the exit flume and returned to the river.

Tagged fish were routed to 950-L insulated aluminum holding tanks and held at maximum densities of less than 19 g/L for mixed coho and spring/summer chinook salmon (800 fish/tank, assuming 23 g average fish weight) and less than 11 g/L for subyearling chinook salmon (1,000 fish/tank, assuming 10.5 g average fish weight). Tanks were maintained near ambient river temperature and oxygen concentration with about 75 L/minute water flow.

Holding tanks were transported by truck to The Dalles Dam in the morning. During the 40-minute transport, oxygen was metered into tanks through air stones. When water temperatures approached 20°C, ice was added to each tank to prevent further temperature increases during the transport period. At The Dalles Dam, water was distributed to each tank at a rate of about 45 L/minute. Fish were generally held until the following morning or night, then released. Before release, tanks were inspected for mortalities and loose PIT tags. Tanks were then loaded onto trailers supplied with oxygen and taken to the release location. Turbine and ice/trash sluiceway releases were made directly from the trailer. Tanks designated for spillway and tailrace releases were set on boats for transport to release locations.

Test Conditions

Tests were designed to evaluate passage survival at a spill level of 40% of river flow; however, actual spill levels varied as much as 11% in the spring (after the initial release) and 3% in the summer with averages of 40.4% (SD 2.3%) and 40.8% (SD 0.9%; Appendix Tables A1-A4) for the spring and summer, respectively. Passage conditions through each spillbay were different and changed through time in association with changes in river flow and hour of the day, following the COE Fish Passage Plan (USACE 2000). The juvenile spill pattern was utilized throughout the test periods in spring and summer 2000 so that estimates of relative survival by diel release period would not be influenced by the spill pattern.

Releases were made through the duration of the yearling chinook salmon migration (spring migrants) and at the beginning and through the peak of the subyearling chinook salmon migration (summer migrants). The experimental design called for releases to be evenly divided between daytime and nighttime on a daily basis (Appendix Table A5).

Release Methods, Locations, and Times

Daily releases were made from 21 April to 1 June for yearling chinook and coho salmon (spring migration), and from 10 June to 18 July for subyearling chinook salmon (summer migration). Turbine groups were released first, followed by ice/trash sluiceway, spillway, and tailrace groups. Releases were generally paired, with a daytime and nighttime release each made every other day throughout both spring and summer tests.

Turbine groups were released from the intake deck through a 4-in rubber hose directly into the turbine intake about 4 m below the intake ceiling. A steel frame was lowered into the selected gate slot with a crane to hold the release hose in the desired location. Turbine releases were randomized across the entire powerhouse during both the spring and summer test periods. Turbine unit operations were not specified for releases. A turbine unit was randomly picked for each release, and if that unit was not on line, an adjacent unit was selected (Appendix Table A5). All releases were made into the center slot of the selected turbine unit. Ice/trash sluiceway releases were made from the intake deck through a 4-in flexible hose held in place just above the water surface with an adjustable steel frame. Both spillway and tailrace releases were made from a boat, which placed the tanks at an elevation of about 0.5 m above the water surface.

Spillway releases were evenly distributed between the north and south portions of the spillway, with all groups released from a boat about 200 m upstream from the spill gates (Fig. 1). The order of spillway releases was randomized (Appendix Table A5). Tailrace releases were made from a boat downstream from the dam at the proposed site of the new bypass system outfall, which is the same release location used in previous years (Fig. 1). At this location, released fish are thought to generally pass down the north side of the river, away from predator sanctuary areas (Snelling and Mattson 1998).

We attempted to make all test fish releases during peak periods of daily passage for naturally migrating fish (based on hydroacoustic data; BioSonics 1997). Release times varied, but the mean daytime release time was 1202 h for the spring migration and 1110 h for the summer migration, while the mean nighttime release time was 2132 h for the spring migration and 2157 h for the summer migration (Appendix Tables A1-A4). The average time from the first to last daily release was about 1 hour.

To accurately evaluate relative survival differences in exclusive relation to the effects of dam passage, it is important that treatment and reference groups migrate together (mixed) past the sampling and detection sites: homogeneity in passage ensures that physical conditions other than passage route are comparable. Fish passing a river reach at differing times or by differing migration routes could experience differences in predation and PIT-tag detection rates that are not directly attributable to dam passage.

To achieve mixing of test fish exiting the tailrace, treatment and reference groups were released sequentially in relation to travel time from release location to the tailrace exit. Unfortunately, the passage route taken by fish through the dam (i.e., powerhouse, ice/trash sluiceway, proposed new bypass system, or spillway) affects the lateral location of fish in the tailrace, which in turn affects its passage route and movement rate downstream (Snelling and Mattson 1998). Therefore, some differences in timing from The Dalles Dam to Bonneville Dam were likely related to route of passage through The Dalles Dam. Different arrival timing at Bonneville Dam and in the estuary may affect the comparability of detection rates between groups because of temporal differences in river flow, Bonneville Dam operations, and predator activity in the estuary.

PIT-Tag Detection Methods and Locations

For this study, detection data from three general areas were downloaded from a regional PIT-tag database (PSMFC 1996). The majority of these detections came from the smolt bypass systems in the first and second powerhouses of Bonneville Dam. Detections were also recorded in the estuary off Jones Beach using a surface trawl fitted with a PIT-tag detector in its cod end (Ledgerwood et al. 2000). Finally, land-based detections were recorded with flat-plate and pole-mounted PIT-tag detectors on abandoned piscivorous bird colonies. These colonies were on East Sand and Rice Island (RKm 8 and 34, respectively), and on channel markers in the estuary upstream from Rice Island (RKm 34 and 37; Ryan et al. 2001).

Land-based detections on gull colonies upstream from The Dalles Dam were recorded but were not used for survival estimates because of low numbers of detections and differences in proximity to gull feeding areas between reference and test releases. Tags detected in the estuary were far downstream from the areas between The Dalles and Bonneville Dams, and thus represented test fish that survived passage through Bonneville Dam and migration through an additional 200 km of river.

Test Fish

Juvenile yearling chinook and coho salmon were used to evaluate spill passage survival at The Dalles Dam during the spring 2000 migration. To limit handling impacts to fish listed under the Endangered Species Act, we did not separate hatchery and wild fish but used both as they arrived at the collection facility. Sorting out wild fish and tagging only hatchery fish would have necessitated the handling of, and consequent stress to, many more wild fish. Subyearling fall chinook salmon were used as test fish during the summer migration period.

Based on previous work, we estimated that detection rates at Bonneville Dam from PIT-tagged fish released in The Dalles Dam tailrace would average 15% for the spring migration and 10% for the summer migration (Dawley et al. 1999). To obtain the desired sensitivity of an 8 and 10% detectable difference between treatment and reference groups, the calculated numbers (Cochran and Cox 1957) of test fish needed were 140,000 spring fish and 168,000 summer fish.

Data Analyses

The primary null hypothesis tested was:

$H_{0(1)}$: Detection rates of treatment groups released to the spillway, ice/trash sluiceway, and turbines at 40% spill do not differ from those of reference groups released to the tailrace of The Dalles Dam.

Additional null hypotheses, which were not necessarily expected to be rejected with one year of data (because of limited test fish numbers) were as follows:

$H_{0(2)}$: There are no differences in relative survival estimates between spillway, ice/trash sluiceway, and turbine release groups.

$H_{0(3)}$: There are no differences in relative survival between treatment groups associated with release time (day or night) and lateral release location in the spillway (north to south segments).

$H_{0(4)}$: Relative survival for groups released through the spillway, ice/trash sluiceway, and turbines is not correlated with river volume, spill volume, tailwater elevation, or water temperature.

$H_{0(5)}$: Relative survival does not differ with size at release between small and large fish, where the threshold between small and large is defined at 125 mm for yearling fish and 110 mm for subyearling fish.

$H_{0(6)}$: Detection proportions (treatment to reference release groups) did not differ with site of detection between Bonneville Dam first powerhouse, Bonneville Dam second powerhouse, Jones Beach, and the estuarine bird rookeries.

$H_{0(7)}$: Arrival timing and passage distributions at Bonneville Dam do not differ between treatment and reference groups.

Detection percentages of daily release groups passing the spillway, sluiceway, and turbines at 40% spill were compared to those of reference groups released in the tailrace. Relative survival was the detected proportion of treatment fish released divided by the detected proportion of tailrace fish released, and was calculated in relation to the following passage variables: Julian date (blocking factor); diel release period (indexed as 1 for daytime and 2 for nighttime); and spillway release location (indexed as 1 for north spillbays, 2 for south spillbays).

Assessments were made using analysis of variance (ANOVA) of log-transformed detection ratios (treatment/reference). Means and 95% confidence intervals were calculated on this scale and then back transformed. We assessed the appropriateness of using ANOVA as an approximation to more theoretically accurate models by examination of normality assessment plots and other residual diagnostic plots. We found no evidence to suggest that other statistical models were needed to accurately analyze these data.

Correlation coefficients were calculated for the relative survival estimates in independent variables (tailwater elevation, total river volume, spill volume, and water temperature) and stepwise linear regressions were conducted to evaluate the predictive potential of log-transformed survival ratios. Day and night data from 1997, 1998, and 1999 used for this evaluation were pooled. Correlation coefficients were also calculated to assess temporal trends in median travel time.

Relative survival in relation to body size at release was evaluated to provide information regarding the effects of size selection on survival. Information from this analysis will be useful in future research activities, when a full range of fish sizes may not be available. Fish were divided into two groups: fish smaller than the size necessary for radio-transmitter implantation and fish larger than this size. The size thresholds presently utilized as minimum for radio tagging are 125 mm for yearling chinook and coho salmon and 110 mm for subyearling chinook (Dawley et al. 2000a). Student's *t*-test distributions were used to evaluate relative survival in relation to fork length. Paired *t*-tests were used for evaluating survival differences separated by site of detection (Bonneville Dam first and second powerhouse, the estuary off Jones Beach, and the bird colonies).

We tested the assumption of mixing between treatment and reference groups (i.e., homogeneity of passage distributions at Bonneville Dam) with chi-square tests for each release date, using a Monte Carlo approximation of the exact method to calculate *P*-values (Mehta and Patel 1992). Significance was established at $P \leq 0.05$. Relative survival estimates for groups identified as not mixed were compared to those of mixed groups using a two-sample *t*-test.

We evaluated whether differences among arrival times at Bonneville Dam might impart systematic differences to detection ratios of spillway, turbine, sluiceway (treatment groups), and tailrace (reference) fish passing via the first powerhouse, second powerhouse, or by inference, the spillway. For each day or nighttime release, the proportion of reference fish and treatment fish passing hourly at the first or second powerhouses was compared to the hourly proportions of total powerhouse flow and total river flow. Average powerhouse flow percentages were then calculated for spillway, sluiceway, turbine (treatment), and tailrace (reference) groups and compared by paired *t*-test.

RESULTS

Spring Migration: Yearling Chinook and Coho Salmon

On test days 21 April-1 June 2000, river flow during hours of release ranged from 5,312 to 9,701 m^3/second (187,600-342,600 ft^3/second), and average spill ranged from 2,152 to 5,522 m^3/second (76,000-195,000 ft^3/second) at the average 40% spill level (Appendix Tables A1-A2). Of the 135,373 PIT-tagged chinook and coho salmon released, 20.2% (27,288 unique tags) were detected at one or more downstream sites (Table 1; Appendix Table A5). Of 34,200 PIT-tagged salmon released as tailrace (reference) groups at a site downstream from the Highway 197 bridge, 21.8% (7,461 unique tags) were detected. Proportions of total detections from spring migrants were 35.7% at Bonneville Dam first powerhouse, 48.8% at Bonneville Dam second powerhouse, 3.4% in the estuary off Jones Beach, and 12.0% from abandoned bird colonies in the estuary.

The PIT-tag detection data were separated by detection site to evaluate variability of relative survival estimates between sites. Average survival estimates for spillway passage calculated from detections at Bonneville Dam first powerhouse (90%) were lower than those calculated from detections at Bonneville Dam second powerhouse (96%). They were also lower than estimates calculated from detections of the trawl off Jones Beach (108%)* or detections from the bird colonies (103%). Survival estimates from detections at Bonneville Dam first and second powerhouse combined averaged 9.1% lower than those from detections on bird colonies. Release data are presented in Appendix Table A5, and statistical analyses of the pooled recovery data are presented in Appendix Table B1.

Paired *t*-tests of the natural log of relative survival ratios indicated nearly significant differences between survival ratios from Bonneville Dam first powerhouse and those from Bonneville Dam second powerhouse for turbine and spillway releases ($P = 0.055$ and 0.064, respectively). Sluiceway survival ratios from Bonneville Dam first powerhouse were significantly different from that at Bonneville Dam second powerhouse ($P = 0.003$). Comparisons between the combined detections at Bonneville Dam and those from the surface trawl off Jones Beach were not significantly different for turbine releases ($P = 0.130$) but were significantly different sluiceway and spillway releases ($P = 0.050$ and 0.005, respectively).

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* Relative survival estimates often exceeded 100% when variability was high.

Table 1. Numbers and percentages of PIT-tagged fish released and detected at various locations by treatment and condition for The Dalles Dam survival study, 2000.

Conditions		Released No.	PIT-tag detections by location Bon. 1	Bon. 2	Jones B.	Bird col.	Total*	Detect (%)*
			Spring					
Tailrace	Day	17,133	1,373	1,840	109	442	3,656	21.3
	Night	17,067	1,467	1,870	124	435	3,805	22.3
40% Spill	Day	17,217	1,295	1,769	136	439	3,522	20.5
	Night	16,339	1,258	1,684	124	407	3,374	20.6
Sluiceway	Day	17,025	1,221	1,783	115	427	3,439	20.2
	Night	16,524	1,211	1,751	132	488	3,470	21.0
Turbine	Day	17,503	1,029	1,498	123	342	2,927	16.7
	Night	16,565	1,171	1,525	102	402	3,096	18.7
	Total*	135,373	10,025	13,720	739	3,382	27,289	20.2
	Release (%)		7.4	10.1	0.7	2.5		
	Detections (%)		35.7	48.8	3.4	12.0		
			Summer					
		No.	Bon. 1	Bon. 2	Jones B.	Bird col.	Total*	Detect (%)*
Tailrace	Day	21,058	564	115	16	439	1,122	5.3
	Night	19,728	643	86	13	396	1,127	5.7
40% Spill	Day	20,880	526	70	16	387	993	4.8
	Night	19,114	580	115	8	435	1,119	5.9
Sluiceway	Day	19,901	467	86	20	392	955	4.8
	Night	19,970	607	100	7	415	1,115	5.6
Turbine	Day	21,041	461	73	8	357	886	4.2
	Night	20,156	546	105	8	411	1,056	5.2
	Total	161,848	4,394	750	96	3,232	8,373	5.2
	Release (%)		2.7	0.5	0.1	2.0		
	Detections (%)		51.9	8.9	1.1	38.1		

* Total observed (used for combined analysis) is the number of unique tags observed at any of the sites. Multiple observations of a tag are not counted. Numbers observed at individual sites may include tags observed at other sites, and these data were used to make the inter-site comparisons.

Comparisons between combined Bonneville Dam detections and those from bird colonies were not significant for turbine, spillway, or sluiceway releases ($P = 0.109$, 0.401, and 0.066 respectively). Finally, a paired *t*-test of the natural log of relative survival for detections measured at Jones Beach vs. those measured on abandoned bird colonies indicated no significant difference for turbine and sluiceway releases ($P = 0.339$ and 0.542, respectively) and a significant difference for spillway releases at $P = 0.011$. We utilized the combined data from all recovery sites for all further analyses.

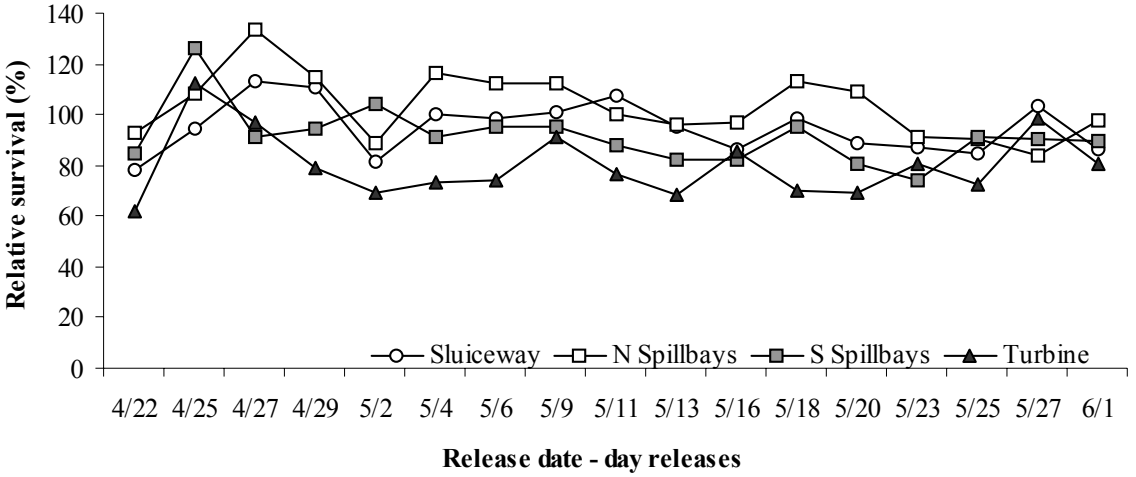
Survival Estimates

Survival was estimated for combined releases of coho and spring chinook salmon to the tailrace (reference fish), the north spillway at night, the south spillway during day and night, the sluiceway during daytime, and the turbine during both day and night. Survival estimates were significantly lower fish released through all of these sites than for fish released to the tailrace of The Dalles Dam. Only the survival estimates of fish that passed through the north spillway during the daytime and through the sluiceway at night were not significantly different from those of the reference fish.

Point estimates of relative passage survival during spring 2000 are summarized in Table 2 and Appendix Table A5. These estimates ranged from 103% through the north spillway during the daytime to 79% through the turbine during daytime.

There were no significant differences in relative survival between estimates of daytime and nighttime releases for fish passing either the sluiceway, turbines, or south spillway. Estimates of relative survival for fish passing through the north spillway were significantly higher for daytime than for nighttime releases. Relative survival of daytime releases through the turbines was also significantly lower than survival of daytime and nighttime releases through the sluiceway and north and south spillways. Nighttime releases through the turbines resulted in relative survival estimates that tended to be lower than daytime and nighttime releases through the sluiceway and north and south spillway, although the differences were not significant (Fig. 2). The geometric mean of nighttime turbine relative survival estimates also tended to be higher than for daytime turbine releases, but not significantly higher.

Relative survival estimates of fish released to Turbine Units 1-7, 8-14, and 15-21 were 77, 89, and 79%, respectively. The estimated relative survival of fish released to Units 8-14 was significantly higher than that of fish released to either Units 1-7 or 15-21. There are two different capacity ratings for the turbines at The Dalles Dam: Turbine Units 1-14 are rated at 78 megawatts, and Units 15-22 are rated at 88 megawatts (Richard Harrison, U.S. Army Corps of Engineers, personal communication).



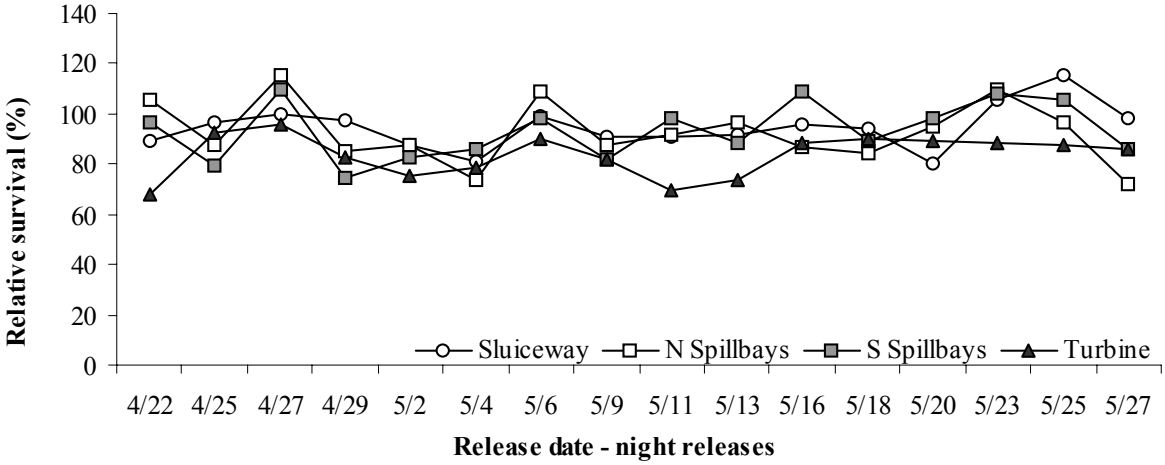


Figure 2. Daily relative survival estimates for daytime and nighttime releases to the ice/trash sluiceway, the north and south spillway, and the turbines at The Dalles Dam, spring 2000.

Table 2. Relative survival estimates and 95% confidence intervals (CI) of coho and chinook salmon released at each site, The Dalles Dam 1997-2000.

Year	Location	Diel	Mean	95% Lo CI	95% Hi CI
		Spring			
1997	Spillway -64%	Day	82.1	74.3	90.7
	Spillway-64%	Night	86.7	80.1	93.9
1998	Spillway-30%	Day	97.8	90.3	105.8
	Spillway-30%	Night	91.8	80.5	104.7
	Spillway -64%	Day	89.4	82.9	96.4
	Spillway-64%	Night	87.7	79.9	96.2
	Sluiceway (at 30% spill)	Day	96.0	87.4	105.4
1999	Spillway-30%	Day	88.4	83.1	94.0
	Spillway-30%	Night	103.8	98.5	109.4
	Spillway -64%	Day	85.4	80.6	90.4
	Spillway-64%	Night	100.4	95.1	105.9
2000	Sluiceway	Day	94.5	89.5	99.8
	Sluiceway	Night	94.0	88.9	99.5
	Spillway north-40%	Day	102.6	97.2	108.4
	Spillway north-40%	Night	91.8	86.8	97.1
	Spillway south-40%	Day	90.9	86.1	96.0
	Spillway south-40%	Night	92.4	87.4	97.8
	Turbine	Day	79.0	74.8	83.4
	Turbine	Night	83.0	78.5	87.8
		Summer			
1997	Spillway -64%	Day	87.7	76.5	100.5
	Spillway-64%	Night	96.4	84.1	110.5
1998	Spillway-30%	Day	86.1	77.0	96.3
	Spillway-30%	Night	84.0	72.6	97.2
	Spillway -64%	Day	76.8	68.4	86.3
	Spillway-64%	Night	70.1	61.6	79.7
	Sluiceway (at 30% spill)	Day	88.9	80.6	98.0
1999	Spillway-30%	Day	94.7	87.0	103.0
	Spillway-30%	Night	104.6	96.1	113.8
	Spillway -64%	Day	93.9	86.3	102.1
	Spillway-64%	Night	98.0	90.1	106.6
2000	Sluiceway	Day	95.5	84.9	107.4
	Sluiceway	Night	97.2	86.4	109.4
	Spillway north-40%	Day	84.2	74.9	94.8
	Spillway north-40%	Night	100.6	89.4	113.1
	Spillway south-40%	Day	87.4	77.7	98.4
	Spillway south-40%	Night	94.3	83.8	106.1
	Turbine	Day	79.1	70.3	89.0
	Turbine	Night	88.9	79.0	100.0

If relative survival were strongly related to the capacity of the turbine unit into which fish were released, were would expect the survival estimates from releases to Units 1-7 to be similar to those of Units 8-14. The difference in survival was likely related to conditions encountered by fish after they exited the powerhouse, while a component of the difference could be related to operational differences of the turbine units at the time of release.

Relative survival estimates for individual releases ranged from 72.2 to 133.3% for spillway releases, 72.2 to 133.3% for north spillway releases, 74.0 to 126.1% for south spillway releases, 60.4 to 112.8% for turbine releases, and 63.0 to 121.6% for sluiceway releases. These point estimates represent passage survival of mixed fish stocks by way of all tested passage routes throughout the migration period and include daytime and nighttime releases at ambient river flows, tailwater elevations, and water temperatures.

Numbers of test fish were sufficient during spring 2000 to accurately estimate relative survival differences between the three treatment releases and the reference group, but these numbers were not sufficient to fully evaluate survival effects related to other controlled and uncontrolled variables. However, we examined the data for survival trends related to other variables.

Through the period of testing, there was a trend of slightly increasing survival for turbine releases, almost no change in survival for sluiceway groups, and a slight decrease in survival for spillway groups; however, none of these trends were significant (Fig. 3; Appendix Table B1). There was no difference in relative survival between daytime and nighttime releases for the sluiceway, turbines, and south spillway releases. There was a significant difference between daytime and nighttime releases from the north spillway, with higher survival estimates for the daytime releases (Appendix Table B1).

The mean survival rate estimated for fish passing the north spillway was 102.6% (CI 97.2-108.4%) for daytime releases and 91.8% for nighttime releases ($P = 0.009$, CI 86.8-97.1%; Table 2, Appendix Table B1). Relative survival was not strongly correlated to change in river flow, spill flow, water temperature, or tailwater elevation ($R^2 = 0.002$, 0.017, 0.039, and 0.010, respectively; Figs. 4-5).

In addition to these analyses, we calculated survival and looked for trends and relationships in the data from coho and yearling chinook salmon separately. Relative survival proportions for coho salmon were similar to those for chinook salmon (Appendix Tables A6-A7). A paired *t*-test comparing survival estimates between these species found no significant difference ($P = 0.52$).

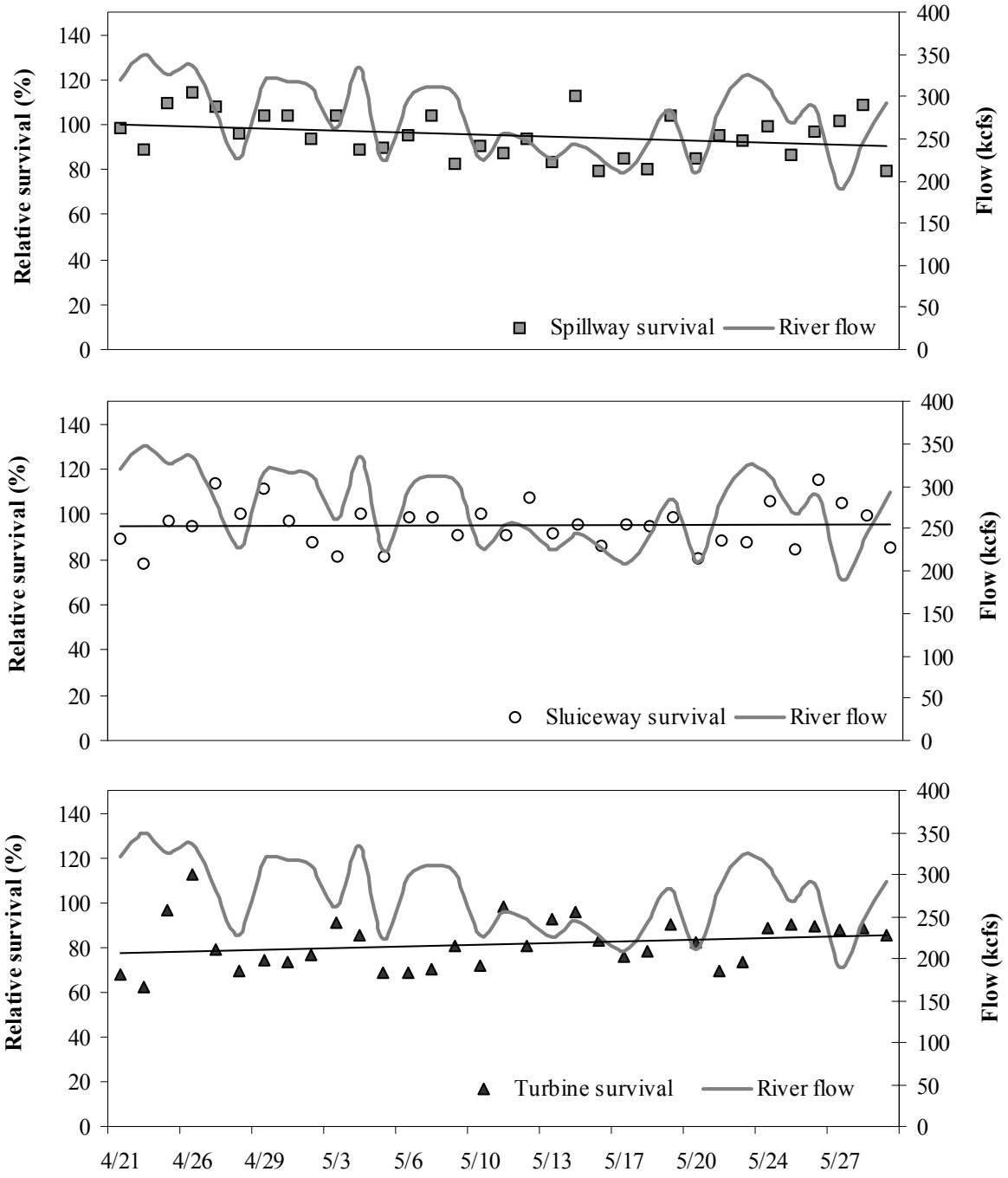


Figure 3. Relative spillway, sluiceway, and turbine passage survival of yearling chinook and coho salmon in relation to river flow during the test period at The Dalles Dam, spring 2000.

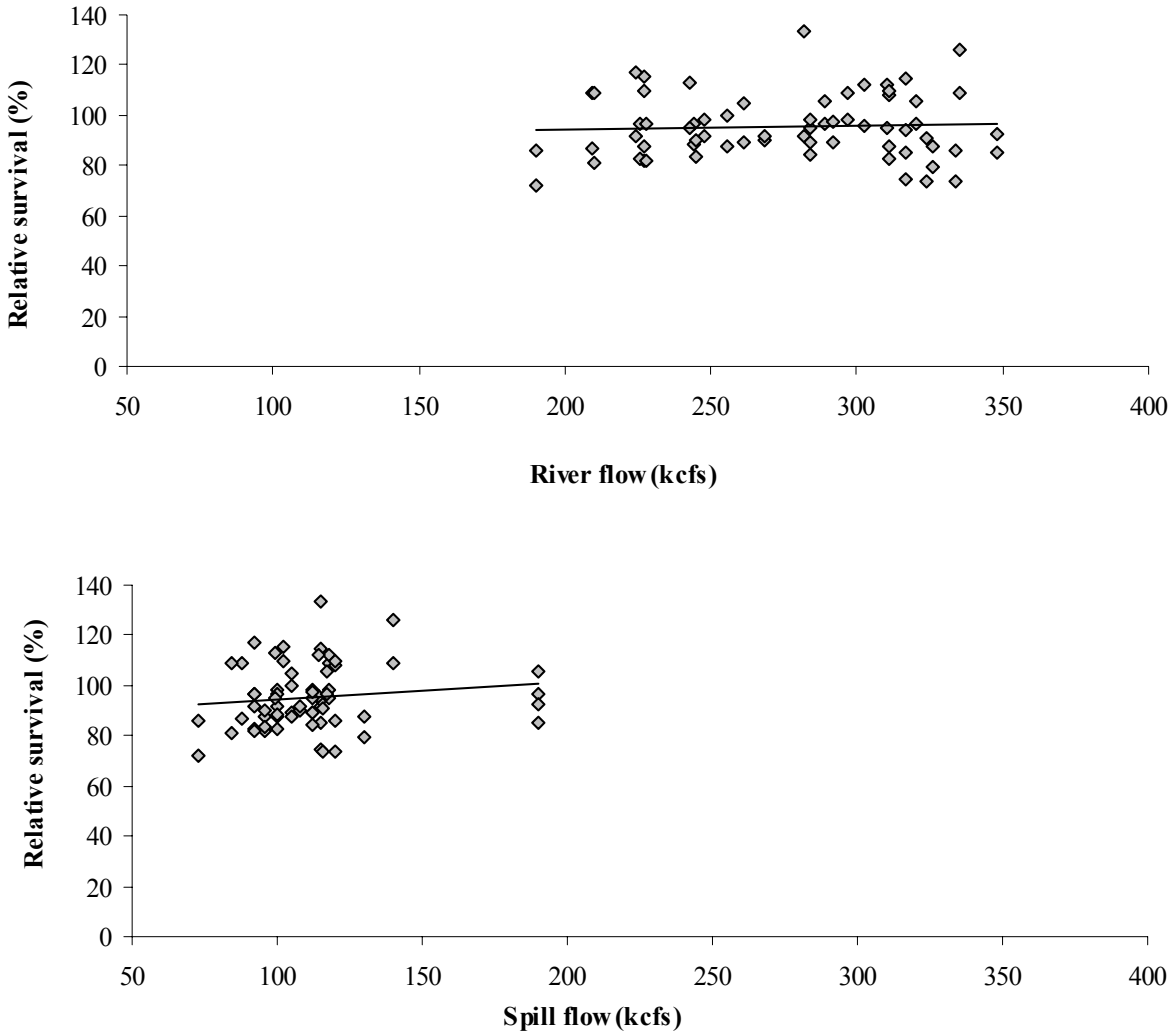


Figure 4. Relative spillway passage survival in relation to river flow and spill flow for yearling chinook and coho salmon during testing at The Dalles Dam, spring 2000.

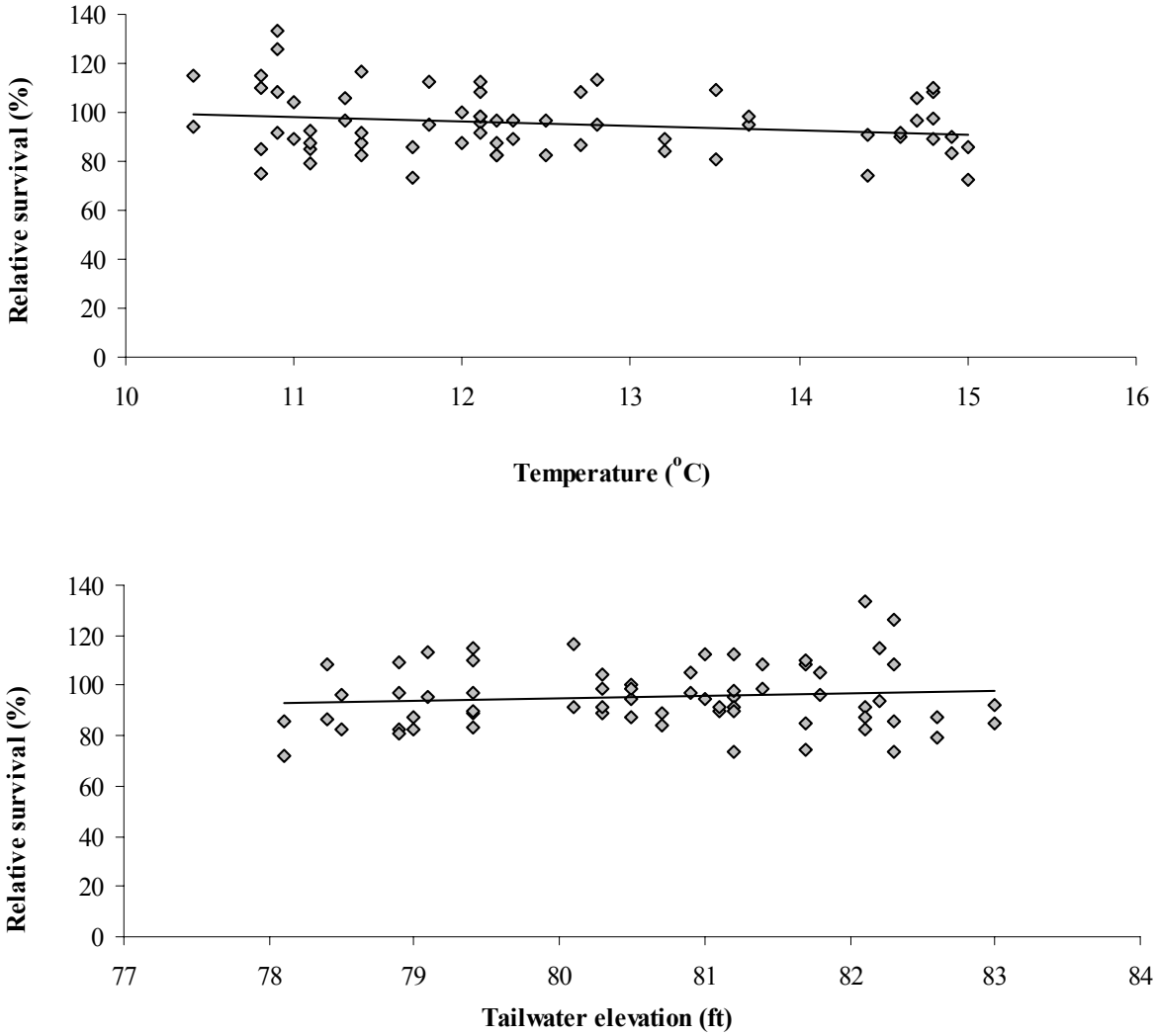


Figure 5. Relative spillway passage survival in relation to river temperature and tailwater elevation for yearling chinook and coho salmon during testing at The Dalles Dam, spring 2000.

Test-fish body size at release was also evaluated as a variable affecting survival. We examined length distributions for daily release groups separated into two fork-length categories: 125 mm or less and greater than 125 mm. Of the 36,490 yearling chinook salmon measured at John Day Dam during the spring test period, 97% were large enough to be radio tagged (>125 mm), while only 3% were too small to radio tag (Appendix Table B2; Fig. 6). A direct comparison of survival estimates between large and small fish was not practical because too few small fish were recaptured (n = 316).

Variability Associated with the Experimental Process

To assess differences in temporal distribution among treatment groups (mixing), we compared travel time and daily detection distributions at Bonneville Dam for daily release groups.

Travel time—The simplest method to evaluate whether mixing occurred among treatment groups was to assess travel time differences between treatment groups released during the same time period. Travel time was measured from time of release at The Dalles Dam to time of PIT-tag detection at Bonneville Dam (either first or second powerhouse). Median travel times through the 74-km river reach from The Dalles Dam to Bonneville Dam averaged 2.1 days, with 80% of detections occurring within 2.4 days of release (Appendix Table B3). Travel time generally decreased through the test period for the tailrace, spillway, sluiceway, and turbine release locations (R^2 = 0.678, 0.793, 0.850, and 0.652, respectively; Fig. 7). Also, river flow did not appear to affect travel time for the tailrace, spillway, sluiceway, or turbine releases (R^2 = 0.425, 0.527, 0.447, and 0.433, respectively; Fig. 8).

Median travel time was 1.8 days for daytime releases and 2.0 days for nighttime releases at all four release locations combined; the difference was significant (P <0.01). Median travel times for tailrace-released reference groups averaged 0.2 days (5 hours) less than spillway, sluiceway, and turbine groups; the difference was significant (P <0.01, 0.01, and 0.01, respectively; Appendix Table B3). We have no explanation for the differences in travel time to Bonneville Dam. Spillway and tailrace fish appeared to exit the tailrace of The Dalles Dam at about the same time, while sluiceway and turbine groups exited later as measured by radiotelemetry data (Theresa Liedtke, U.S. Geological Survey, personal communication).

If exit from the area of The Dalles Dam indicated arrival timing at Bonneville Dam, tailrace and spillway groups should have arrived before sluiceway and turbine groups. While the tailrace groups did arrive before sluiceway and turbine groups, spillway groups arrived at the same time as the tailrace groups. Median travel time to Bonneville second powerhouse averaged 0.2 days less for all release sites combined than to Bonneville first powerhouse.

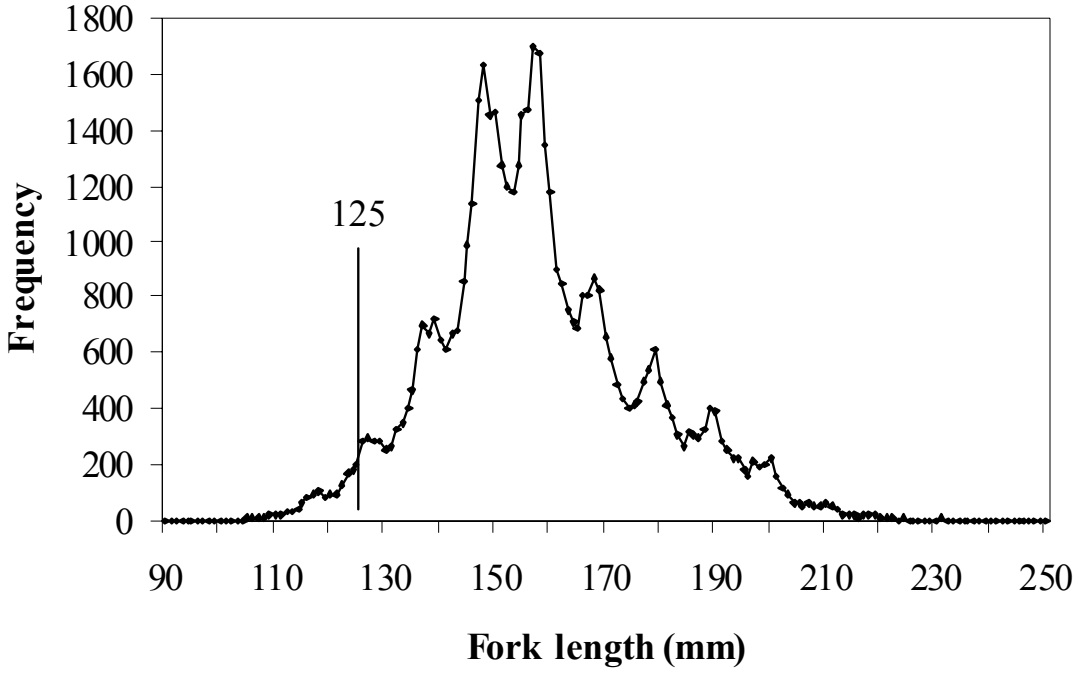


Figure 6. Size distribution of yearling chinook and coho salmon (mean = 158.0 mm) released during spring testing at The Dalles Dam, 2000. Vertical line shows the 125-mm size threshold for radio tagging yearling chinook and coho salmon.

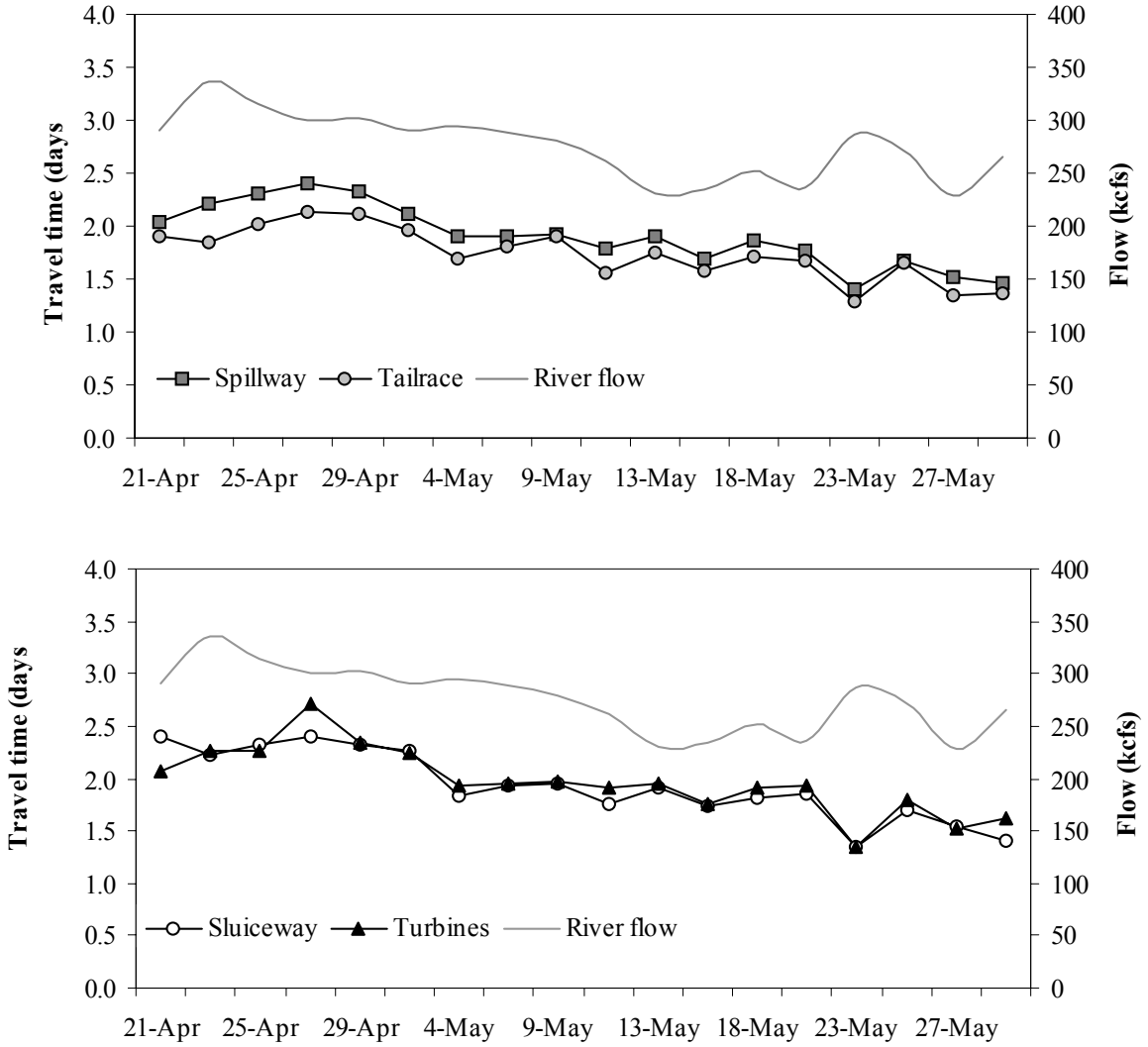


Figure 7. Median travel time and total river flow from The Dalles Dam to Bonneville Dam (powerhouse 1 and 2 combined) for daily release groups (day and night combined) of yearling chinook and coho salmon by release date, spring 2000.

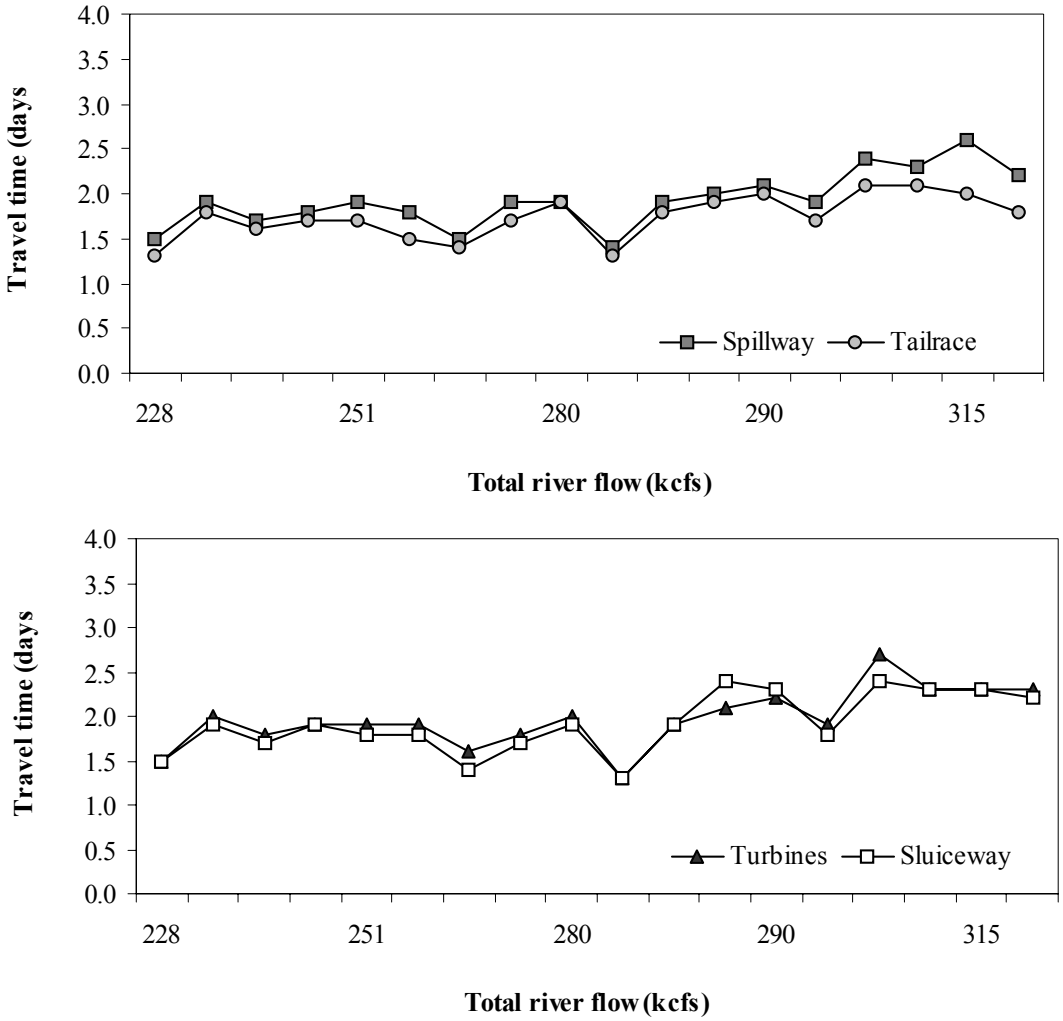


Figure 8. Median travel time from The Dalles Dam to Bonneville Dam (powerhouse 1 and 2 combined) for daily release groups (day and night combined) of yearling chinook and coho salmon in relation to average river flow during spring 2000.

Temporal detection distributions—The homogeneity of passage distributions at Bonneville Dam (detection through time) for corresponding release groups of chinook and coho salmon suggested many violations of the mixing assumption. We used a chi-square test to compare passage distribution between releases of spring migrants from all 34 release periods. These tests indicated temporal differences in passage distribution at Bonneville Dam for 12 of the 34 periods (Appendix Table B4). Although the statistical analysis indicated that these arrival timing differences were significant, overall passage distributions for all release groups were quite compact, with spillway, sluiceway, and turbine releases arriving only slightly later than tailrace releases.

To assess the importance of distribution differences, we compared the number of fish detected from spillway- and tailrace-release groups in relation to river flow and Bonneville Dam powerhouse operation. For each release period, hourly fish counts at the first or second powerhouse and the percentages of powerhouse flow, in relation to total powerhouse flow or total river flow at the time of passage, were calculated separately for treatment and reference fish.

For each release period, the average flow percentage/fish for treatment and for reference fish was compared (Appendix Table B5). Differences between treatment and reference groups appeared negligible. Paired *t*-test comparisons of the three treatment groups vs. tailrace groups for powerhouse and total river flow/fish are summarized below. Comparisons showed no significant differences for either the first or second powerhouse at Bonneville Dam or total river flow for fish detected at each powerhouse.

Bonneville Dam detections	Spillway vs. tailrace (*P*)	Turbine vs. tailrace (*P*)	Sluiceway vs. tailrace (*P*)
First powerhouse			
Powerhouse flow	0.397	0.504	0.633
Total river flow	0.346	0.068	0.076
Second powerhouse			
Powerhouse flow	0.904	0.152	0.492
Total river flow	0.661	0.085	0.425

Comparison with 1997, 1998, and 1999 Results and Trends for Combined Data

Detection site differences—Estimates of relative survival through the spillway based on surface-trawl detections off Jones Beach and on land-based detections on bird colonies were compromised by low numbers of detections and resultant high variability among the daily releases (Appendix Tables A5, B1, C1, C3, C5, and C8). In 1997-2000, survival estimates from detections at Bonneville Dam first powerhouse were 1-5% higher (not significant) than those from Bonneville Dam second powerhouse, while in 2000, the estimates from detections at the second powerhouse were 5% higher.

Estimates from detections at Bonneville Dam (combined) were 0-19% lower (significant in two of four years) than at the bird colonies. During 1997-1999, estimates of survival for spillway releases based on detections off Jones Beach were 12-14% lower than those based on detections at the bird colonies (significant in one year), but were 6% higher than estimates based on bird colony detections in 2000 (non-significant). In addition, the estimates based on detections off Jones Beach were 14% lower than those based on detections at Bonneville Dam in 1998, 7% higher in 1999 (non-significant), and 15% higher (significant) in 2000.

Survival trends—The point estimate for spillway passage survival at 64% spill in 1999 (94%) was higher than in 1998 and 1997 (89 and 87%, respectively). Survival trend lines for 64% spill showed a slight increase through time in 1999, whereas in 1998 and 1997, they showed decreases through time (Fig. 9). The point estimate for spillway passage survival at 30% spill in 1999 (95%) was similar to that in 1998 (97%), but the trend line for spillway passage survival at 30% spill increased through the test period in 1999 but decreased through the test period in 1998 (Fig. 7). At the 40% spill volume tested in 2000, the spillway passage survival (point estimate 95%) trend line decreased through time while the turbine and sluiceway survival (point estimates 81 and 94%, respectively) trend lines increased (Fig. 3).

ANOVA of combined 1997, 1998, and 1999 data indicated a significant difference in relative passage survival between 64 and 30% spill ($P = 0.01$) and a nearly significant difference in estimated survival between daytime and nighttime releases ($P = 0.08$). Mean relative survival was 88.9% at 64% spill and 97.0% at 30% spill.

Mean relative survival for daytime releases was 86.7 at 64% spill and 93.8% at 30% spill. These estimates were substantially lower than those for nighttime releases, which averaged 91.2% at 64% spill and 100.2% at 30% spill ($P = 0.08$; Appendix Table C11). In general, survival estimates from all releases during 1997-1999 showed greater survival at 30% spill than at 64% spill and greater survival for spillway passage at night, with the juvenile spill pattern, than during day, with the adult spill pattern (Table 2).

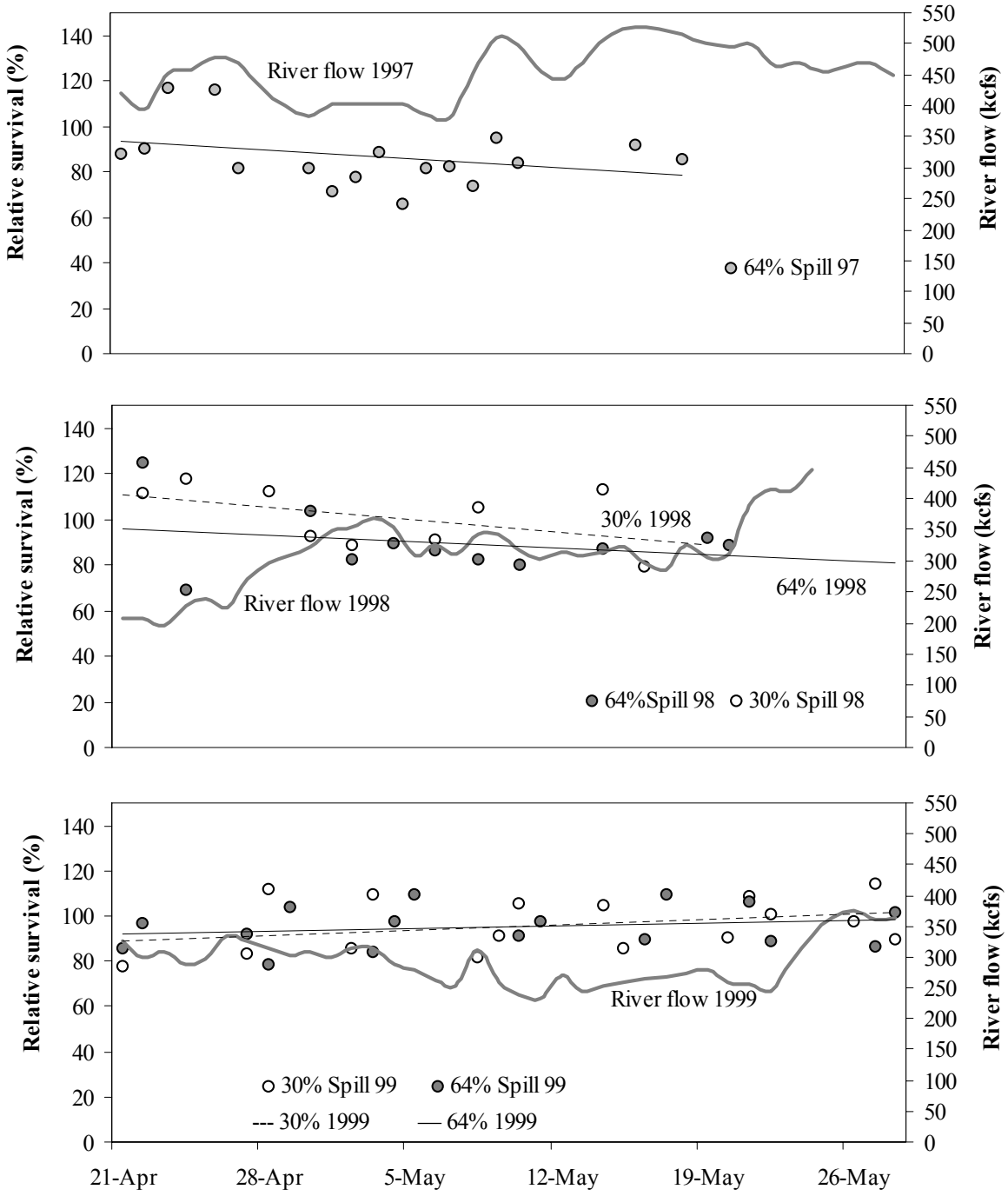


Figure 9. Relative spillway passage survival of yearling chinook and coho salmon in relation to spill level and river flow at The Dalles Dam during spring testing from 1997 to 1999.

The juvenile spill pattern was used throughout the entire test period in 2000, which must be considered when comparing the results of this year's study to the results from previous years when daytime releases were made under the adult (evenly distributed) spill pattern. In 2000, the mean relative survival for daytime releases through the north spillways was significantly higher than nighttime releases. There was no significant difference between daytime and nighttime releases for fish released through the south spillways. There was also no difference between daytime and nighttime releases of fish through the sluiceway or turbines in 2000.

Because comparisons between high and moderate spill rates were not conducted in 1997, we analyzed the combined data from 1998 and 1999 only. These data indicated a significant difference in relative survival between 64 and 30% spill ($P = 0.039$). Mean relative survival was 90.5% at 64% spill and 95.5% at 30% spill (Appendix Table C10).

Comparisons of combined 1997-1999 data for analysis of diel differences indicated a significant interaction between year/spill and diel factors ($P = 0.011$). The nature of the interaction was that the difference in relative survival estimates between day and night was small in 1997 and 1998 (2-6%) and large in 1999 (14-15%; Appendix Table C11).

Travel times—Travel times to Bonneville Dam for tailrace (reference) groups were slightly less than those of corresponding treatment groups in all four years of the study. In 1997 and 1998, differences were not significant ($P = 0.22$); however, in 1999, travel times between treatment and reference groups were significantly different ($P < 0.01$). In 2000, travel time differences were significant for tailrace groups compared to spillway, sluiceway, and turbine groups ($P \leq 0.01$ for all comparisons).

Uncontrolled variables—Evaluations of survival in relation to the following individual dependent variables showed poor correlation in springtime tests using yearling chinook and coho salmon: water temperature, spill flow, river flow, and tailwater elevation ($R^2 < 0.05$ for all variables; Figs. 10-11). Stepwise regression of dependent variables, including Julian date, also provided poor predictive capability, whether utilizing data from single or multiple study years ($R^2 = 0.05$; Appendix Table C7).

Powerhouse operations—Examination of the data on powerhouse operations for each of the four study years showed that differences at Bonneville Dam during passage of tailrace and spillway releases appeared to be minor, with no notable trends between years. Average river flows per fish and average powerhouse flows per fish showed no discernable pattern at either powerhouse for any of the treatments (Appendix Tables B5, C2, C4, and C6).

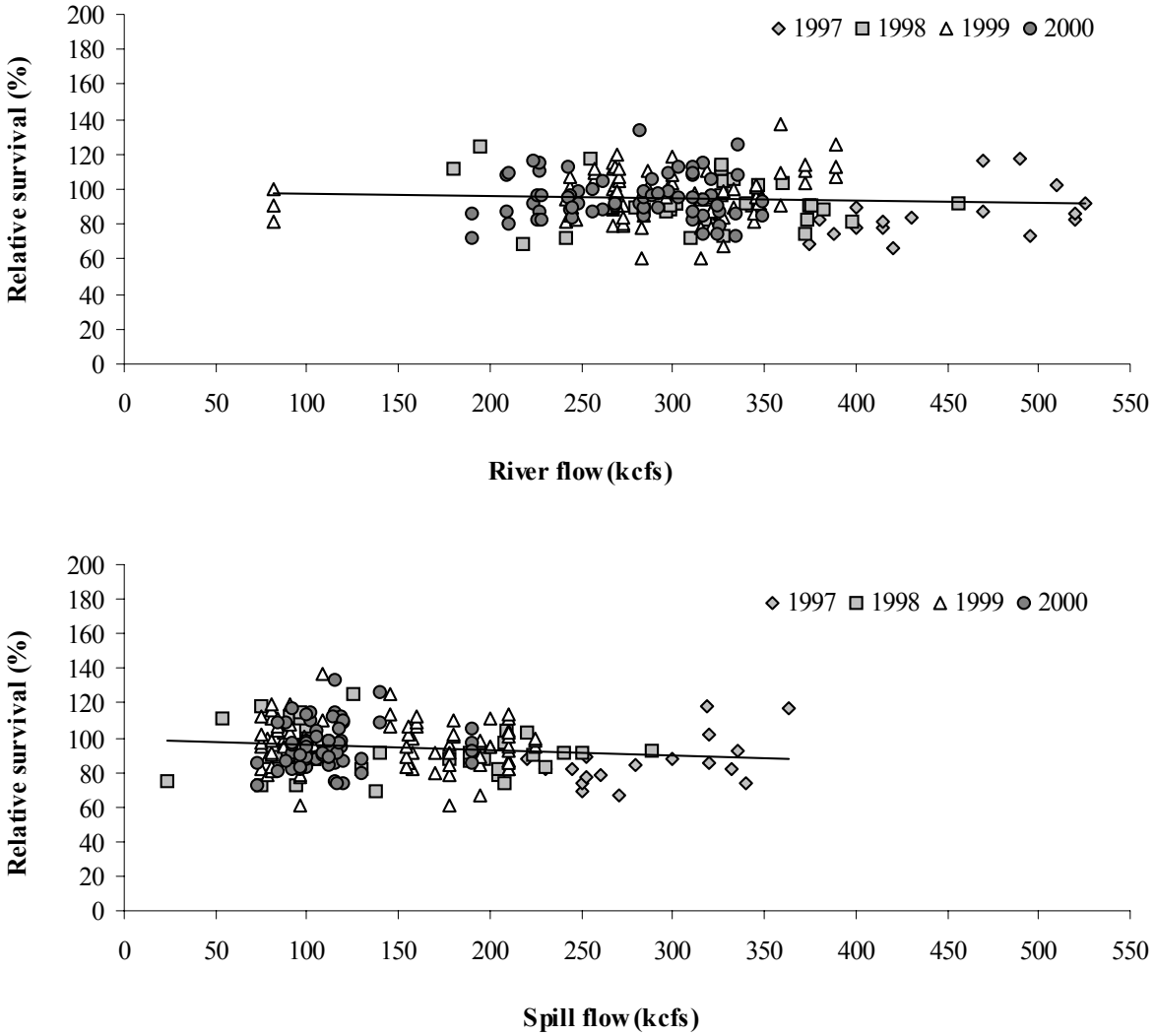


Figure 10. Relative survival of yearling chinook and coho salmon in relation to river flow and spill volume during spring test periods at The Dalles Dam, 1997-2000.

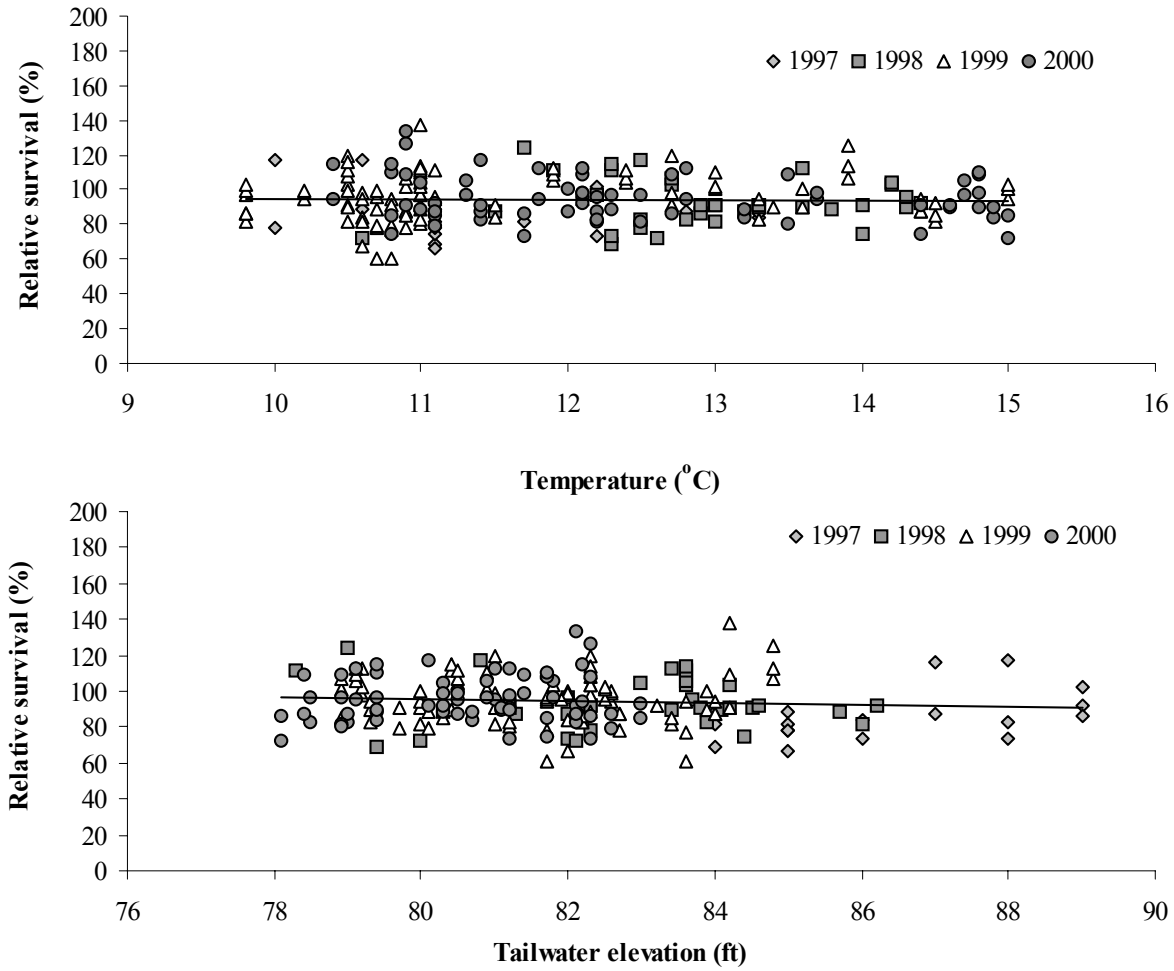


Figure 11. Relative survival of yearling chinook and coho salmon in relation to water temperature and tailwater elevation at The Dalles Dam during spring test periods, 1997-2000.

Upstream gull colonies—Tags from spring migrants were detected during land-based surveys of gull colonies upstream from The Dalles Dam on Little Memaloose and Little Miller Islands. Approximately 0.2% of tags from all spring migrants released at The Dalles Dam were detected on gull colonies in both 1997 and 1998, 0.08% in 1999, and 0.14% in 2000. Spillway-released fish comprised 90% of these detections in both 1997 and 1998 and 84% of the detections in 1999. In 2000, only 50% of gull colony detections were from spillway-released fish, while 16, 8, and 26% were from the sluiceway, tailrace, and turbine releases, respectively (Brad Ryan, National Marine Fisheries Service, personal communication). This difference can be attributed to the lower percentage of fish released into the spillway in 2000 (25% in 2000, 50% in previous years). Also, the COE installed gull lines between the spillway and the Highway 197 bridge prior to the 2000 migration season. This moved gulls out of their preferred feeding area and probably contributed to a lower rate of predation on spillway fish. Detections at the gull colonies represent a minimum estimate of predation: detection efficiency on the colonies is not 100%, and the proportion of tags deposited at other locations by predators is unknown.

Summer Migration: Subyearling Chinook Salmon

During hours of release on 10 June-18 July 2000, river flow ranged from 3,865 to 7,776 m^3/second (136,500-274,600 ft^3/second), and average spill ranged from 1,586 to 3,171 m^3/second (56,000-112,000 ft^3/second) at 40% spill (Appendix Tables A3-A4). Of the total 161,848 PIT-tagged subyearling chinook salmon released at all locations, 5.2% (8,374 unique tags) were detected at one or more downstream sites (Table 1; Appendix Table A8). The 5.2% detection rate observed this year was lower than previous years primarily because of the lower rate of detections at Bonneville Dam second powerhouse. In 2000, detections of subyearling chinook salmon released at the second powerhouse comprised only 8.9% of the total, compared to 74% in 1999.

For the 40,786 PIT-tagged subyearling chinook salmon released at the reference location just downstream from the Highway 197 bridge, 5.5% (2,249 unique tags) were detected. The proportions of total detections during the summer migration by location were about 51.9% at the first powerhouse, 8.9% at the second powerhouse, 1.1% at the estuary trawl, and 38.1% at the bird colonies.

Operation of the sluice chute at Bonneville Dam second powerhouse contributed to lower detection rates. PIT-tag detection data were separated by detection site to evaluate relative survival differences between sites. Mean spillway survival estimates from detections at Bonneville first powerhouse were lower than those from detections at the second powerhouse or from the bird colonies (96, 98, and 97%, respectively). Mean survival estimates from all detections at Bonneville Dam were 3% lower than those from detections at the bird colonies. Statistical analyses of the separated data are shown in Appendix Table B6.

Paired *t*-tests were used to compare the natural log of relative survival estimates by PIT-tag detection location and method. For sluiceway releases, these tests indicated a significant difference in relative survival to Bonneville Dam between fish detected at the first and the second powerhouse ($P = 0.025$). For turbine and spillway releases, differences between relative survival estimates from detections at the first and second powerhouse were not significant ($P = 0.525$ and 0.385, respectively; Appendix Table A8).

Survival estimates calculated from combined detections at Bonneville Dam were compared to those calculated from land-based detections at piscivorous bird colonies. In these comparisons, no significant differences in relative survival were found for either turbine, sluiceway, or spillway release locations ($P = 0.955$, 0.458, and 0.683, respectively). Comparison of survival estimates calculated from combined detections at Bonneville Dam vs. those calculated from the Jones Beach pair trawl indicated no significant difference for either turbine, sluiceway, or spillway release locations ($P = 0.851$, 0.563, and 0.751, respectively).

Finally, a paired *t*-test of the natural log of relative survival between detections measured at Jones Beach and those measured on abandoned bird colonies indicated no significant differences for turbine or sluiceway locations ($P = 0.339$ and 0.542, respectively) and a significant difference for spillway releases ($P = 0.011$). We utilized combined data from all recovery sites for all other analyses.

Survival Estimates

Survival for north spillway and turbine releases during the day was significantly lower than survival of reference fish released downstream from the dam. Survival of nighttime releases through the north spillway, daytime and nighttime releases from the south spillway and sluiceway, and nighttime releases through the turbine were not significantly different from reference fish released downstream from the dam. Point estimates (unweighted geometric mean) of relative survival are presented in Table 2 and Appendix Table A5 and are summarized below.

Location	Daytime	95% CI (%)	Nighttime	95% CI (%)
Sluiceway	95.5	84.9-107.4	97.2	86.4-109.4
North spillway	84.2	74.9-94.8	100.6	89.4-113.1
South spillway	87.4	77.7-98.4	94.3	83.8-106.1
Turbine	79.1	70.3-89.0	88.9	79.0-100.0

These point estimates represent passage survival of mixed fish stocks throughout the migration period; during day and night; through spillbays across the width of the spillway; and at ambient spill-gate openings, river flows, tailwater elevations, and water temperatures.

There were no significant differences in relative survival estimates between daytime and nighttime release periods for the sluiceway, turbines, or south spillway groups. Relative survival of groups released through the north spillway at night was significantly higher than for releases from the same location during the day. This was the opposite of what occurred in the spring 2000 releases. Relative survival estimates for nighttime releases were also higher than those of daytime releases to the sluiceway, south spillway, and turbine, but because of the low detection rates and resultant higher variability in the data, none of the other day-night differences was significant (Fig. 12). There were also no significant differences between the sluiceway, north or south spillway, and turbine release locations.

Relative survival estimates for turbine-released groups of summer migrants were evaluated in the same manner as described for spring migrants. Survival estimates of fish released into Turbine Units 1-7, 8-14, and 15-21 were 79, 89, and 86%, respectively. Because of the relatively low detection rates and resultant higher variability in the data, none of these differences were significant. Trends were the same as seen in the spring, with survival tending to be higher in fish released into Turbine Units 8-14. We again concluded that if the survival estimates above were strongly related to the turbine capacity in units where fish were released, the estimate for Units 1-7 would be similar to those of Units 8-14. We believe the difference in survival is likely related to conditions encountered by fish after they have exited the powerhouse, although a component of this difference could be related to operational differences between turbine units at the time of release.

The range of relative survival estimates for individual releases by location is shown below:

Location	Range of survival estimates (%)
spillway	47.4- 166.9
north spillway	69.5-166.9
south spillway	47.4-124.0
turbine	46.4-143.0
sluiceway	69.4-171.0

These point estimates represent passage survival of mixed fish stocks by way of all tested passage routes throughout the migration period—during daytime and nighttime releases, at ambient river flows, tailwater elevations, and water temperatures.

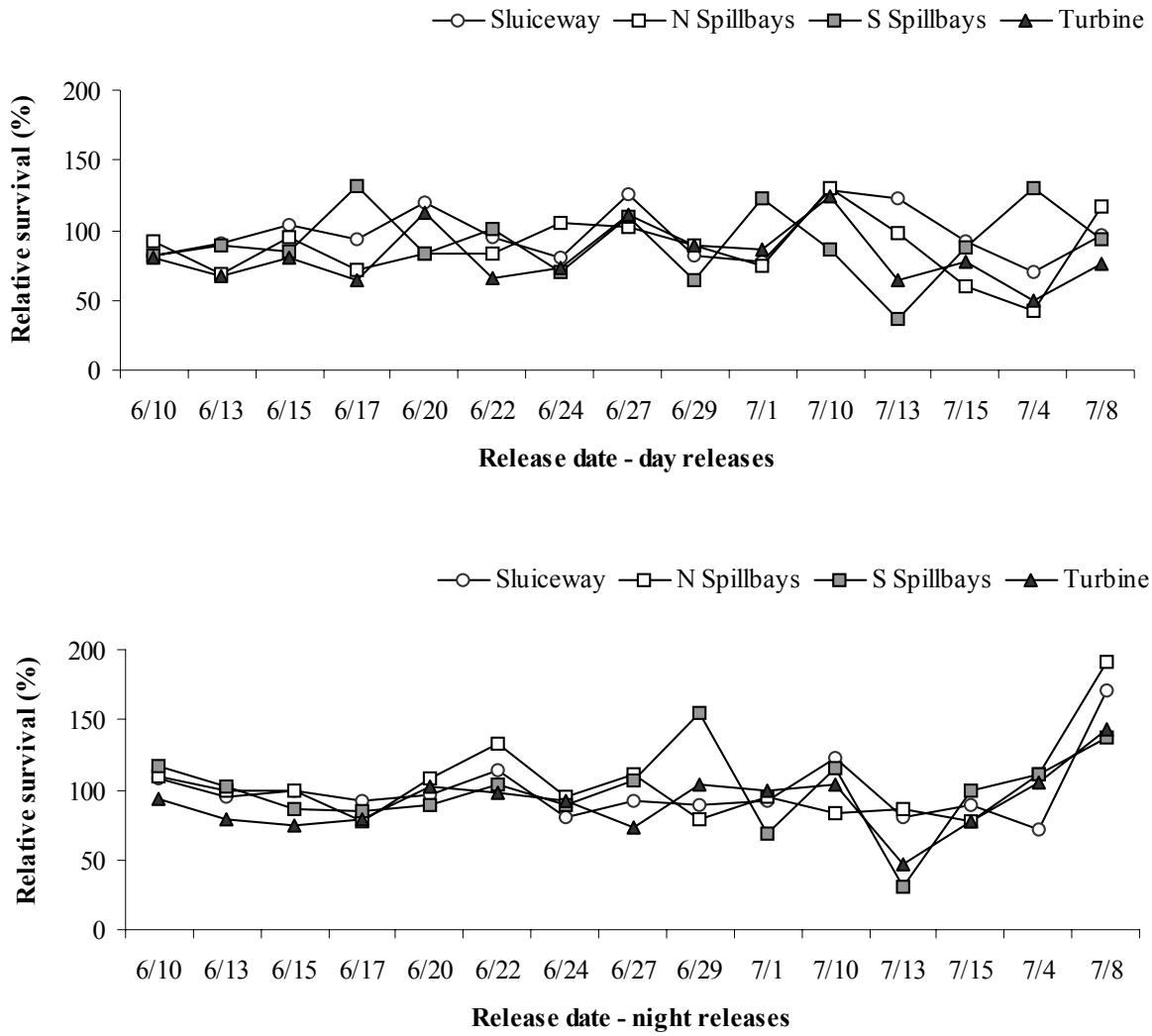


Figure 12. Relative survival estimates for daytime and nighttime releases to the ice/trash sluiceway, north and south spillways, and turbine at The Dalles Dam, summer 2000.

Sufficient numbers of test fish were available to accurately assess differences in relative survival between spillway, ice and trash sluiceway, turbine (treatment), and tailrace (reference) groups at 40% spill during summer tests. The juvenile (north) spill pattern was again utilized throughout the study period. We examined the data for survival trends or relationships with other controlled and uncontrolled variables; however, the numbers of test fish were not sufficient for these evaluations.

Differences in passage survival between the north and south spillways were not significant, although survival estimates for releases to the north spillways were significantly higher for nighttime than for daytime releases (Appendix Table B1). Through the period of testing there appeared to be a trend of slightly decreasing survival for spillway groups and slightly increasing survival for sluiceway groups, while turbine survival was relatively constant (Fig. 13). Point estimates of relative survival from all release locations were higher for nighttime than for daytime releases, but were significantly different only in releases through the north spillway. Mean relative survival was 86.6% for daytime passage and 94.9% for nighttime passage, (Appendix Table B1). We saw no strong correlations between spillway relative survival and changes in river flow, spill flow, tailwater elevation, or water temperature (R^2 = 0.037, 0.044, 0.043, and 0.004, respectively; Figs. 14-15).

Test-fish body size at release was evaluated as a variable affecting survival. We examined fork-length distributions of daily release groups separated into two fork-length categories: 110 mm or less and greater than 110 mm. Of the 147,803 subyearling chinook salmon fish measured at John Day Dam, 44% were large enough to be radio tagged (>110 mm), while 56% were too small (Fig. 16).

Combined detections from Bonneville Dam showed that the proportion of larger fish detected was twice (mean = 1.99) that of smaller fish for all four release locations combined. The proportion of larger fish detected in the estuary (combined Jones Beach and piscivorous bird colonies) was more than twice (mean = 2.29) the proportion of smaller fish detected in the estuary for all four release locations combined (Appendix Table B7).

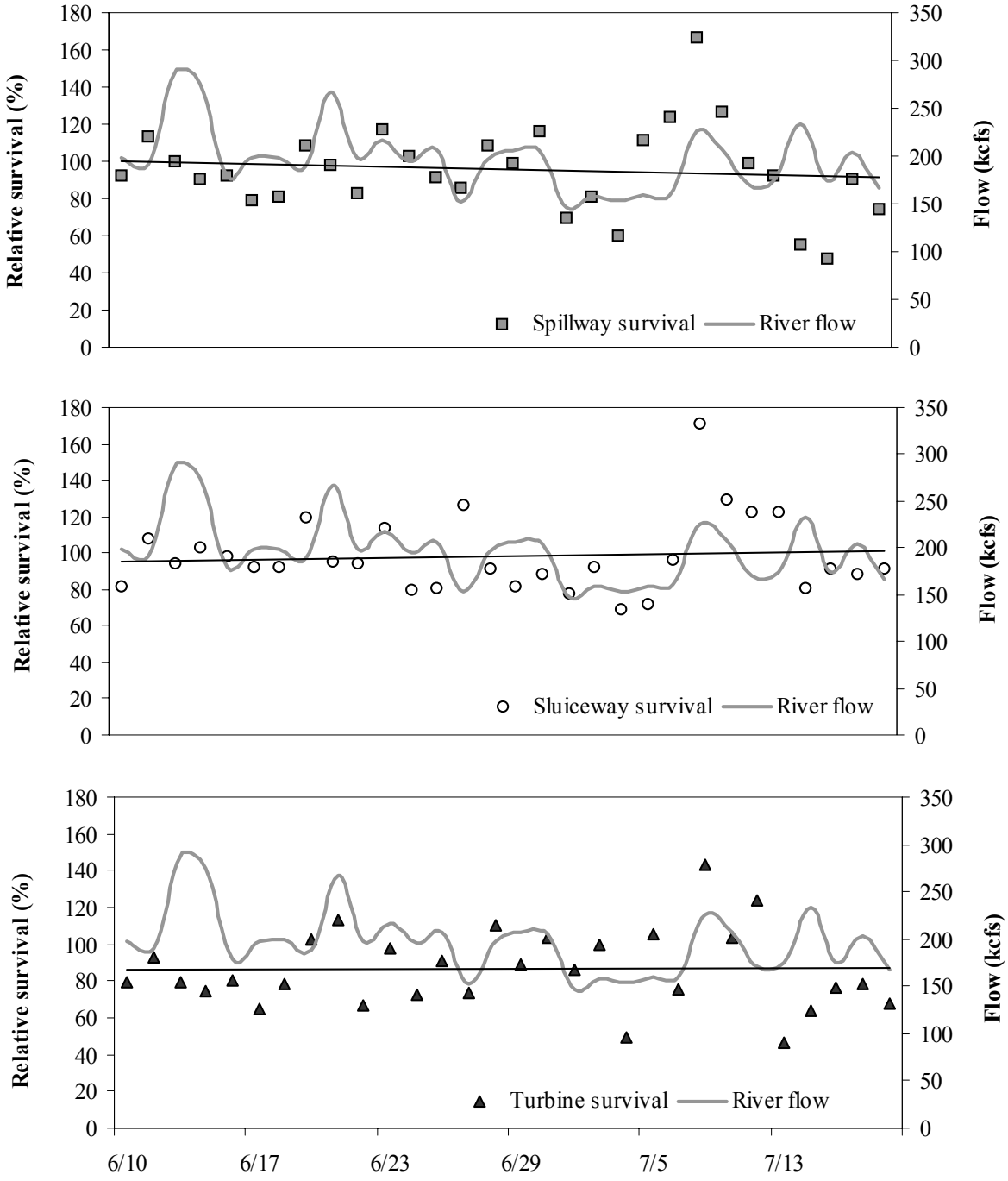


Figure 13. Relative spillway, sluiceway, and turbine passage survival of subyearling chinook salmon and river flow at The Dalles Dam through the test period in summer, 2000.

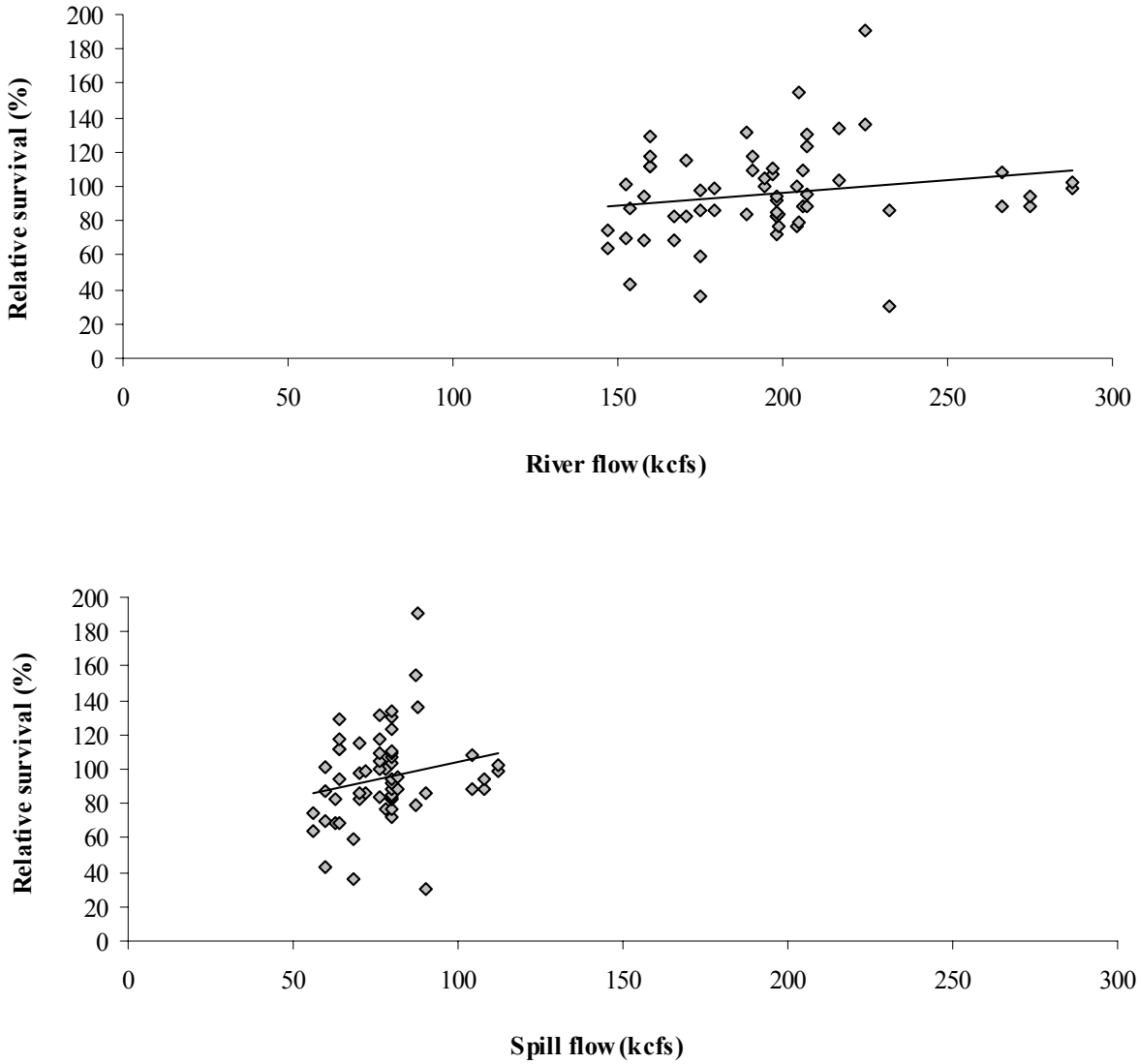


Figure 14. Relative survival of spillway-released subyearling chinook salmon in relation to river flow and spill flow at The Dalles Dam, summer 2000.

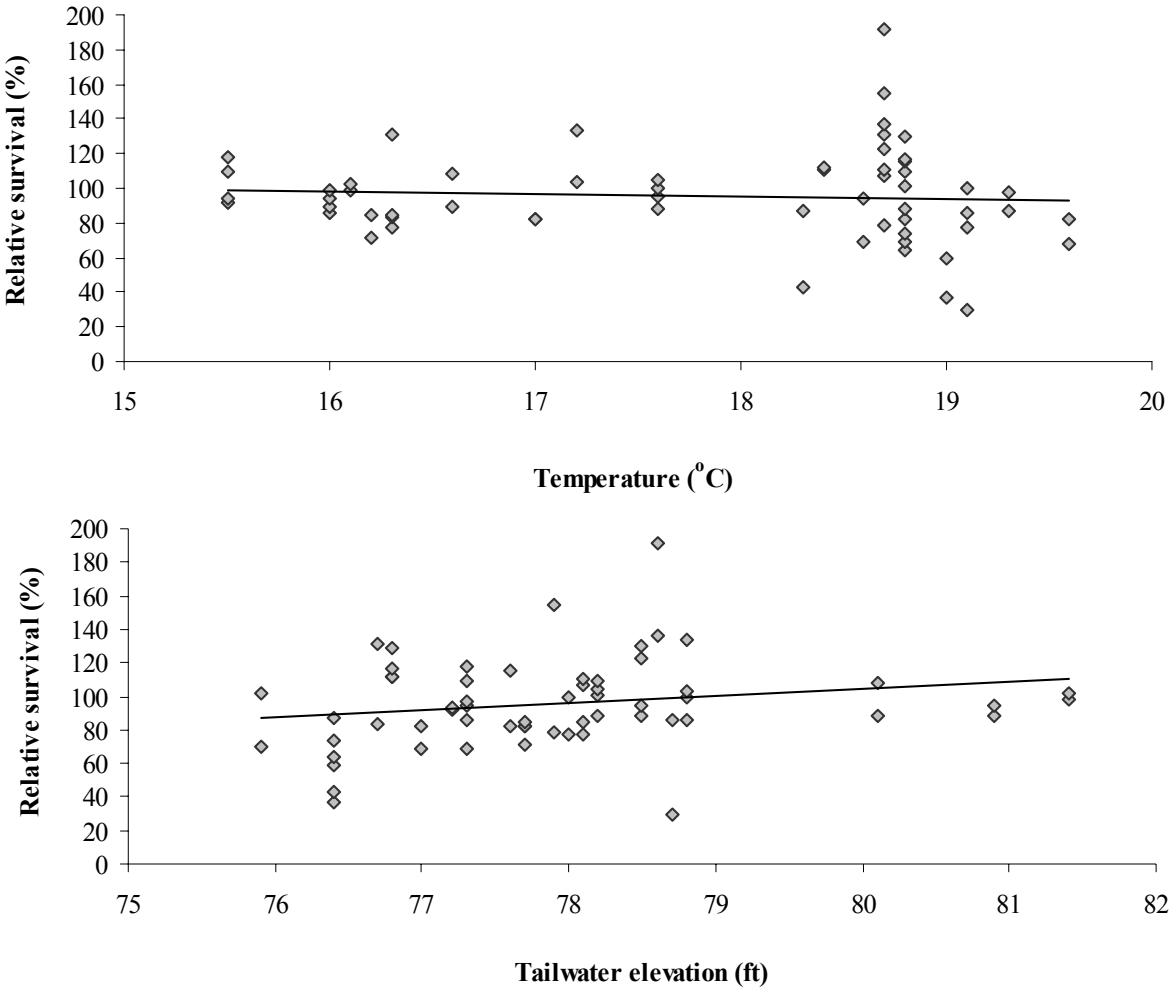


Figure 15. Relative survival of spillway-released subyearling chinook salmon in relation to temperature and tailwater elevation at The Dalles Dam, summer 2000.

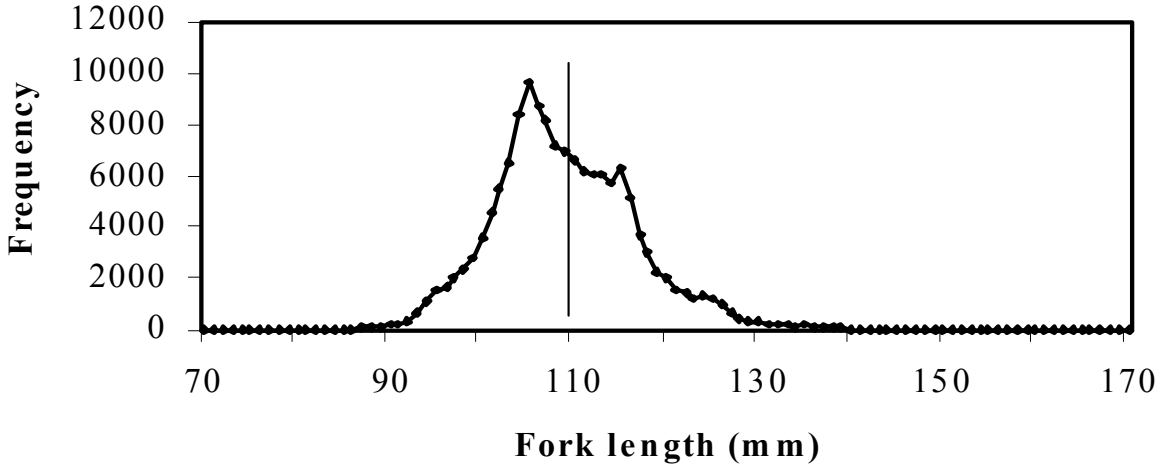


Figure 16. Size distribution of subyearling chinook salmon released during summer testing at The Dalles Dam, 2000 (mean = 109.1 mm). Vertical line shows the 110-mm size threshold for radio tagging of subyearling chinook salmon.

Variability Associated with the Experimental Process

To assess differences in temporal distribution between treatment and reference groups (mixing), we compared travel times over the 74-km reach from the release sites to Bonneville Dam as well as daily detection distributions at Bonneville Dam.

Travel times—The simplest method to evaluate whether mixing occurred among treatment groups was to assess travel time differences between treatment and reference groups released during the same time period. Travel time was measured from time of release at The Dalles Dam to time of PIT-tag detection at Bonneville Dam. Median travel times for the summer test period through the 74-km river reach from The Dalles Dam to Bonneville Dam averaged 1.9 days (Appendix Table B8). Travel times showed a slight decrease through the test period for tailrace, spillway, sluiceway, and turbine release locations (R^2 = 0.206, 0.277, 0.114, and 0.172, respectively, Fig. 17).

River flow during the test period was generally unchanging (R^2 = 0.154; Fig. 13), while travel time tended to decrease for tailrace, spillway, sluiceway, and turbine release locations (R^2 = 0.058, 0.065, 0.032, and 0.020, respectively; Fig. 18). Median travel time from all four release locations combined was 1.8 days for daytime releases and 2.0 days for nighttime releases; the difference was significant (P = 0.004).

Median travel time of tailrace release groups averaged 0.2 days (5 hours) less than that of spillway and turbine groups ($P \leq 0.01$ and < 0.01, respectively) and 0.1 days (2.4 hours) less than that of sluiceway groups (P = 0.02; Appendix Table B8). We have no explanation for these differences in travel time to Bonneville Dam. Spillway and tailrace fish appeared to exit the tailrace of The Dalles Dam at about the same time, while sluiceway, and turbine groups exited later, as measured by radiotelemetry data (Theresa Liedtke, U.S. Geological Survey, personal communication).

If exit from the area of The Dalles Dam was predictive of arrival timing at Bonneville Dam, tailrace and spillway groups would have arrived first, followed by sluiceway, and turbine groups. The data indicate that tailrace groups did indeed arrive first, but were closely followed by sluiceway groups, with spillway and turbine groups arriving later.

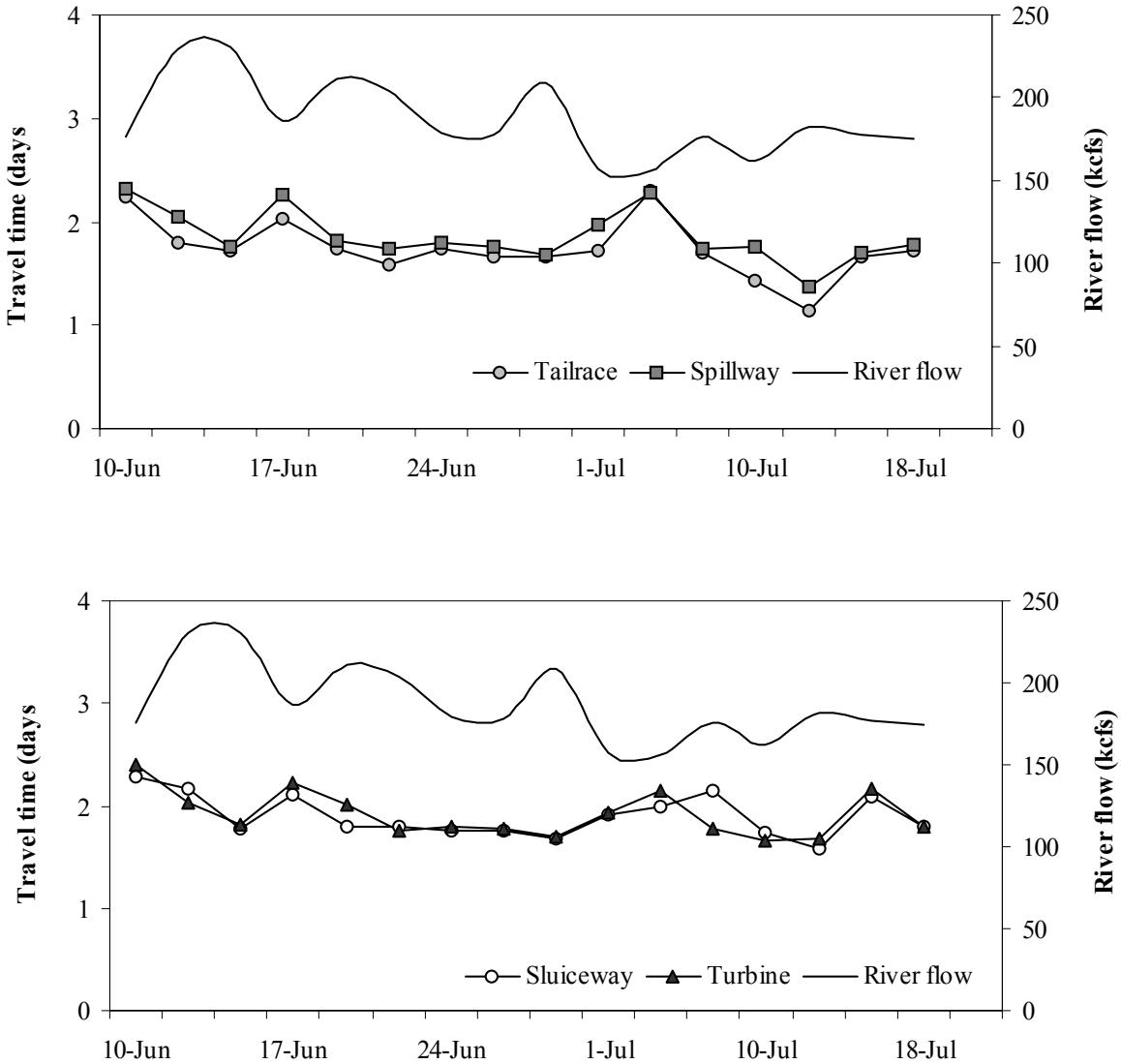


Figure 17. Median travel time from The Dalles Dam to Bonneville Dam (powerhouse 1 and 2 combined) for daily release groups (day and night combined) of subyearling chinook salmon by release date, summer 2000.

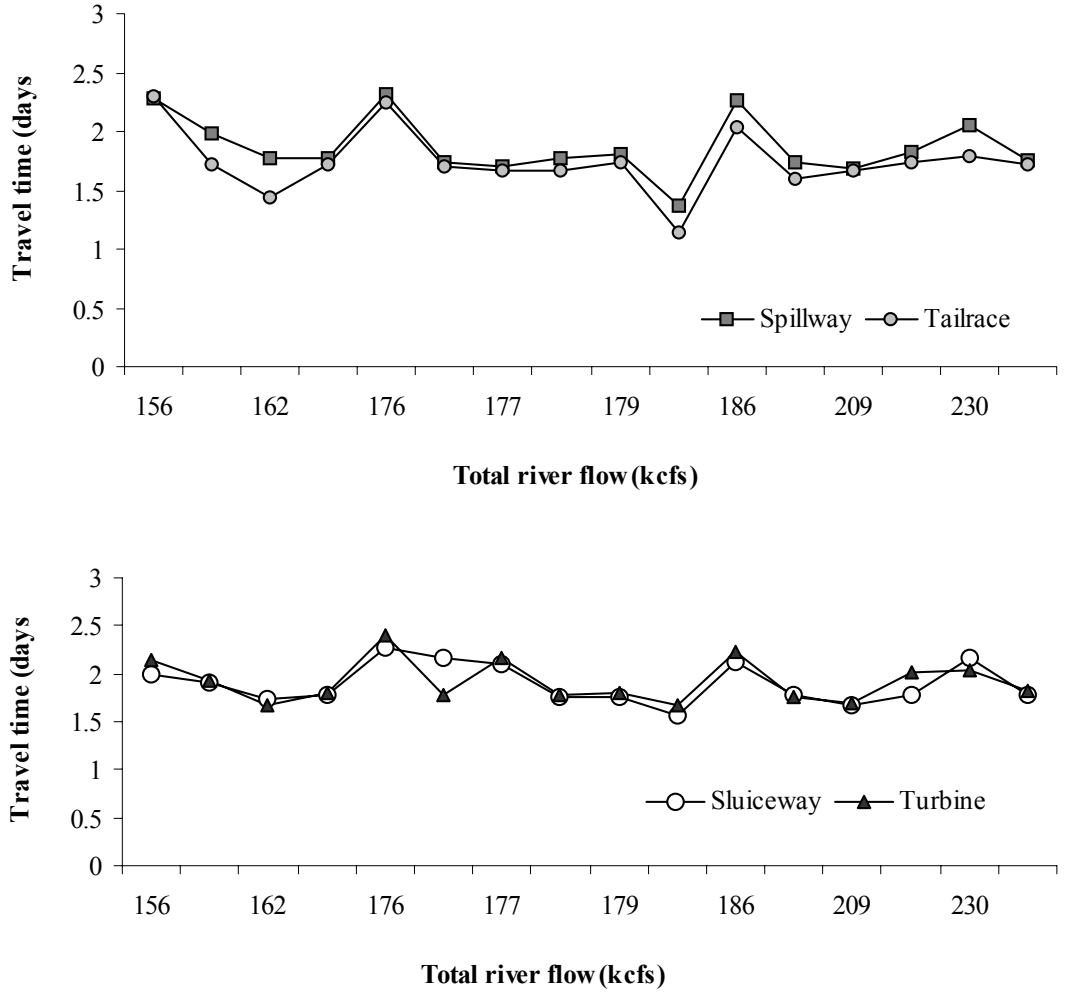


Figure 18. Median travel time from The Dalles Dam to Bonneville Dam (powerhouse 1 and 2 combined) for daily release groups (day and night combined) of subyearling chinook salmon compared to average river flow, summer 2000.

Temporal detection distributions—We evaluated the homogeneity of passage distributions at Bonneville Dam (PIT-tag detections through time) for corresponding release groups of subyearling chinook salmon. Using a chi-square test of the homogeneity of passage distributions, we found significant differences in temporal distribution between treatment and reference groups in 11 of 28 release periods (Appendix Table B4). However, in spite of statistical evidence that the two groups did not mix, passage distributions for both spillway and tailrace groups were quite compact, with spillway, sluiceway, and turbine groups generally arriving only slightly later.

To assess the biological importance of these distribution differences, we compared detections of fish from spillway vs. tailrace release groups in relation to powerhouse operation and river flow. For each release period, we calculated hourly fish counts at the first or second powerhouses and the percentages of powerhouse flow and total river flow per fish at the time of passage for treatment fish vs. reference fish.

We then compared average flow percentages per fish by release period for treatment and reference fish (Appendix Table B9). The data indicated negligible differences in passage conditions between treatment and reference groups. Paired *t*-test comparisons for each of the three treatments vs. the reference groups are summarized below for both powerhouses by powerhouse flow and total river flow (per fish). No significant differences were found between first and second powerhouses or between powerhouse flow and total river flow (Appendix Table B9).

Bonneville Dam detections	Spillway vs. tailrace (*P*)	Turbine vs. tailrace (*P*)	Sluiceway vs. tailrace (*P*)
First powerhouse			
Powerhouse flow	0.809	0.722	0.213
Total river flow	0.580	0.279	0.157
Second powerhouse			
Powerhouse flow	0.872	0.460	0.406
Total river flow	0.715	0.553	0.346

Comparison with 1997, 1998, and 1999 Results and Trends for Combined Data

Detection site differences—Estimates based on detections at the bird colonies were compromised by low numbers of detections and resultant high variability among daily releases (Appendix Tables A8, C1, C3, C5 and C8). Spillway relative survival estimates measured at Bonneville Dam first powerhouse were 2-5% lower (significant in two of four years) than estimates measured at Bonneville Dam second powerhouse. Estimates at Bonneville Dam (combined) were 3-26% lower (significant in two of four years) than at the bird colonies (Appendix Table C8).

Survival trends—The point estimate for passage survival at 64% spill in 1999 (96%) was higher than those in 1997 and 1998 (92 and 75%, respectively). Survival trend lines at 64% spill showed a decrease through time during 1997 and 1998, but a slight increase during 1999 (Fig. 14). The point estimate for passage survival at 30% spill in 1999 was substantially higher than in 1998 (100 and 89%, respectively). In 1999 and 1998, survival at 30% spill decreased through the test period (Fig. 19). At the 40% spill level tested in 2000, the trend line for spillway passage survival (point estimate 91%) decreased slightly over the test period; the trend line for sluiceway passage survival (point estimate 96%) increased slightly; the trend line for turbine passage survival (point estimate 84%) showed no change (Fig. 12).

ANOVAs of combined 1997, 1998, and 1999 data indicated significant differences in relative survival between 64 and 30% spill ($P = 0.04$) and between daytime and nighttime releases ($P < 0.01$). Relative survival means were 88.2% at 64% spill and 96.0% at 30% spill. Relative survival means for daytime releases at 64 and 30% spill (84.8 and 87.8%, respectively) were lower ($P < 0.01$) than for nighttime releases (91.8 and 105.1%, respectively; Appendix Table C11).

In general, estimates at all sites through years 1997-1999 showed greater survival at 30% spill than at 64% spill and greater survival for spillway passage at night with the juvenile spill pattern than during day with the adult spill pattern (Table 2).

The juvenile spill pattern was used throughout the entire test period in 2000, which must be considered when comparing the results of this year's study to the results from previous years, when daytime releases were made under the adult (evenly distributed) spill pattern. In 2000, the mean relative survival for nighttime releases through the north spillways was significantly higher than daytime releases. There was no significant difference between day and nighttime releases for fish released through the south spillways. There was also no difference between daytime and nighttime releases of fish through the sluiceway or turbines in 2000, though survival of nighttime releases tended to be higher than daytime releases in all release locations.

Because comparisons between 64 and 30% spill rates were not conducted in 1997, we analyzed the combined data from 1998 and 1999 only. These data indicate significant interactions between year and spill ($P = 0.019$) and between year and diel factors ($P = 0.012$) for point estimates of survival. The nature of the interaction between year and spill was that in 1998, survival point estimates at the 64% spill level were lower than those at the 30% spill level (15.6% difference between means), while in 1999 they were not different (3.6% difference between means). The interaction between year and diel factor was that the survival point estimate for daytime passage was 8.4% higher than for nighttime passage in 1998 but 6.9% lower than for nighttime passage in 1999 (Appendix Table C10).

Comparisons of combined 1997-1999 data for analysis of diel differences indicated no significant interactions between year/spill and diel factors ($P = 0.395$) or the diel factor ($P = 0.505$). Mean relative survival for combined 1997-1999 data for day and night releases are 87.6 and 89.7% respectively. There was a significant interaction between year and spill factors ($P < 0.001$). The nature of this interaction was that the 64% spill level in 1998 was lower than all other groups, and the 30% spill level in 1998 was lower than both the 30 and 64% spill levels in 1999 (Appendix Table C11).

Travel times—Travel times to Bonneville Dam for groups of tailrace released subyearling chinook salmon were slightly less than those of their spillway-released cohorts in all four years, with differences of 0.3, 0.1, and 0.1 days in 1997, 1998, and 1999, respectively (Dawley et al. 2000a). In 2000, travel times for tailrace releases were 0.1 days shorter than those of sluiceway releases and 0.2 days shorter than those of spillway and turbine releases (Appendix Table B8).

Uncontrolled variables—Evaluations of relative survival estimates for subyearling chinook salmon summer migrants showed poor correlation with the following individual dependent variables: water temperature, spill flow, river flow, and tailwater elevation ($R^2 = 0.110$, 0.002, 0.066, and 0.064, respectively; Figs. 14-15, 20-21). Linear regressions of dependent variables including Julian date provided poor predictive capability, utilizing data from either individual years or multiple years; for 1997-2000 combined data ($R^2 = 0.18$; Appendix Table C9).

Powerhouse operations—Examination of the data on powerhouse operations for each of the four years of study showed that differences during passage at Bonneville Dam appeared to be minor, with no discernable trends for either tailrace- or spillway-released fish groups. Variation in average flows per fish appeared to be random in both direction and magnitude at both Bonneville Dam powerhouses for all daily release groups (Appendix Tables B9, C2, C4, and C6).

Upstream gull colonies—Land-based PIT-tag surveys of the gull colonies upstream from The Dalles Dam (Little Memaloose and Little Miller Islands) detected approximately 0.05% of all tags from summer migrants released in both 1997 and 1998, 0.06% of all tags from summer migrants released in 1999, and 0.10% of all tags from summer migrants released in 2000. Spillway released (treatment) fish comprised 90% of all detections on these colonies in 1997, 1998, and 1999. In 2000, spillway-released fish made up 45% of the total, with 17, 3, and 35% of the detections from sluiceway, tailrace, and turbine releases, respectively (Brad Ryan, National Marine Fisheries Service, personal communication).

This lower proportion of spillway detections in 2000 can be attributed to the lower percentage of fish released into the spillway in that year (25% of total in 2000 vs. 50% in previous years). Also, the COE installed gull lines between the spillway and the Highway 197 bridge prior to the 2000 outmigration. This moved gulls out of their preferred feeding area and probably contributed to a lower percentage of spillway fish being taken by gulls. The total proportion of tags detected at gull colonies represent minimum estimates of predation: land surveys do not detect 100% of tags present on the colonies, and the proportion of tags that may have been dropped by predators at other locations is unknown.

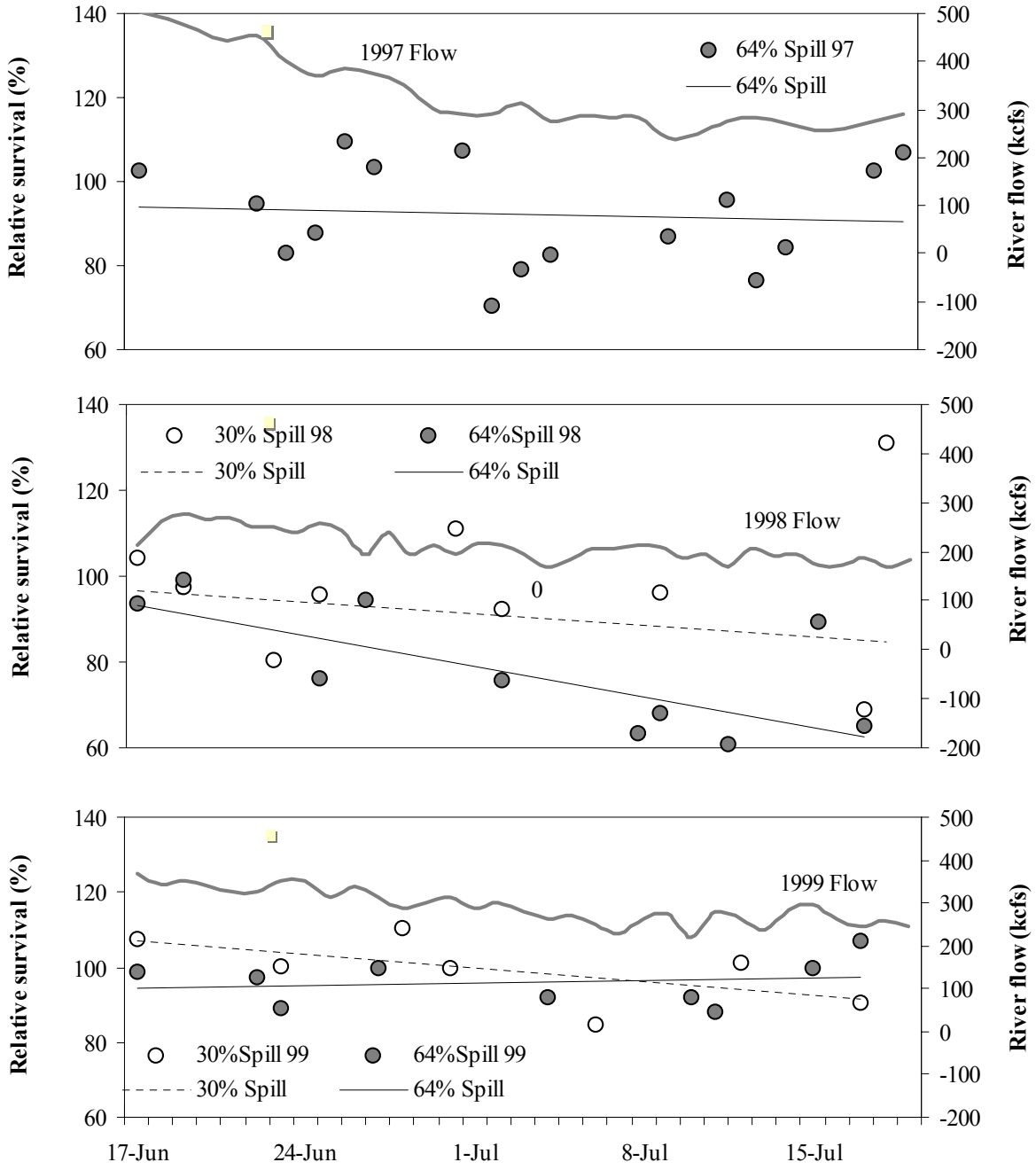


Figure 19. Relative spillway passage survival of subyearling chinook salmon at The Dalles Dam through the period of testing, 1997, 1998, and 1999.

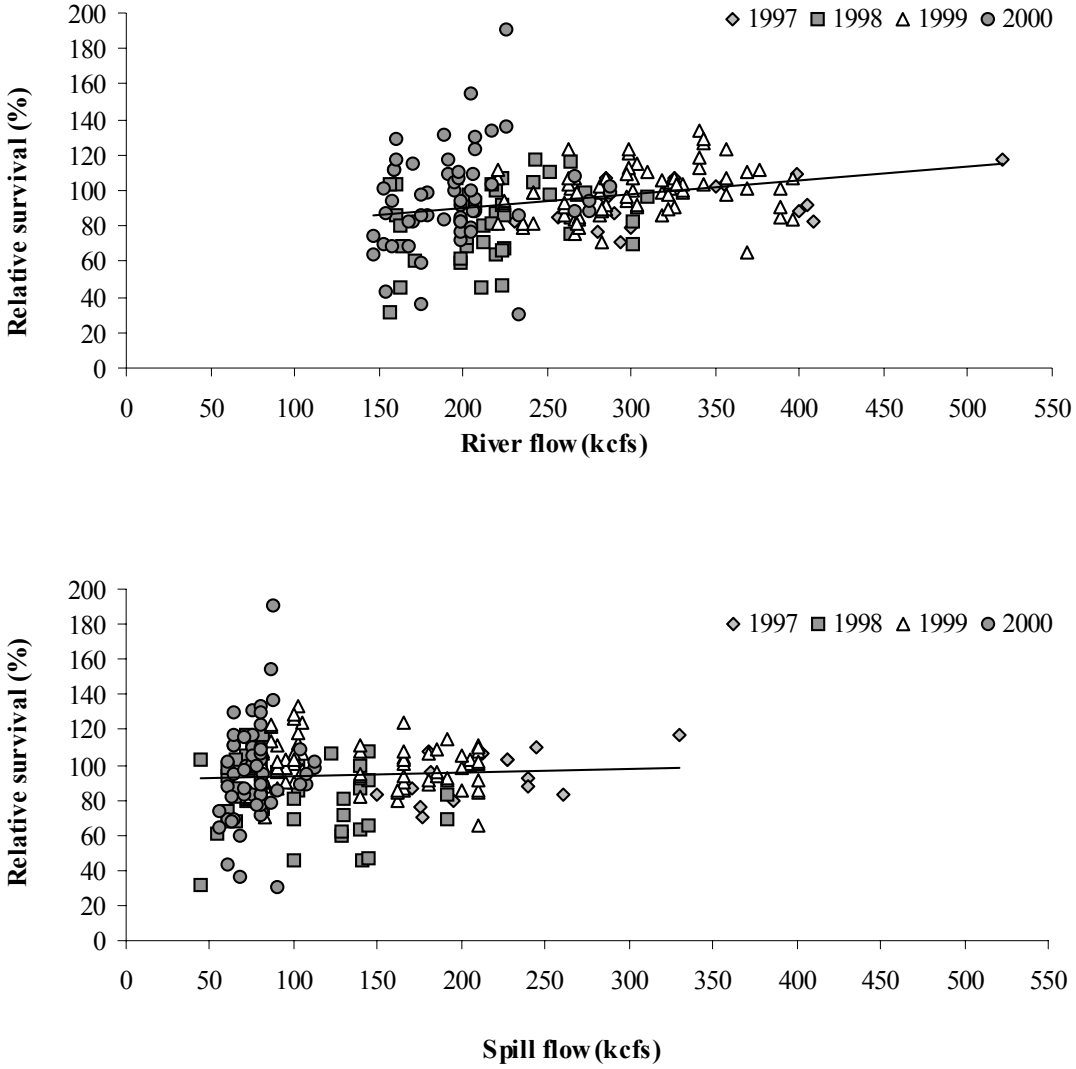


Figure 20. Relative survival of spillway-released subyearling chinook salmon in relation to total river flow and spill flow during summer testing at The Dalles Dam from 1997 to 2000.

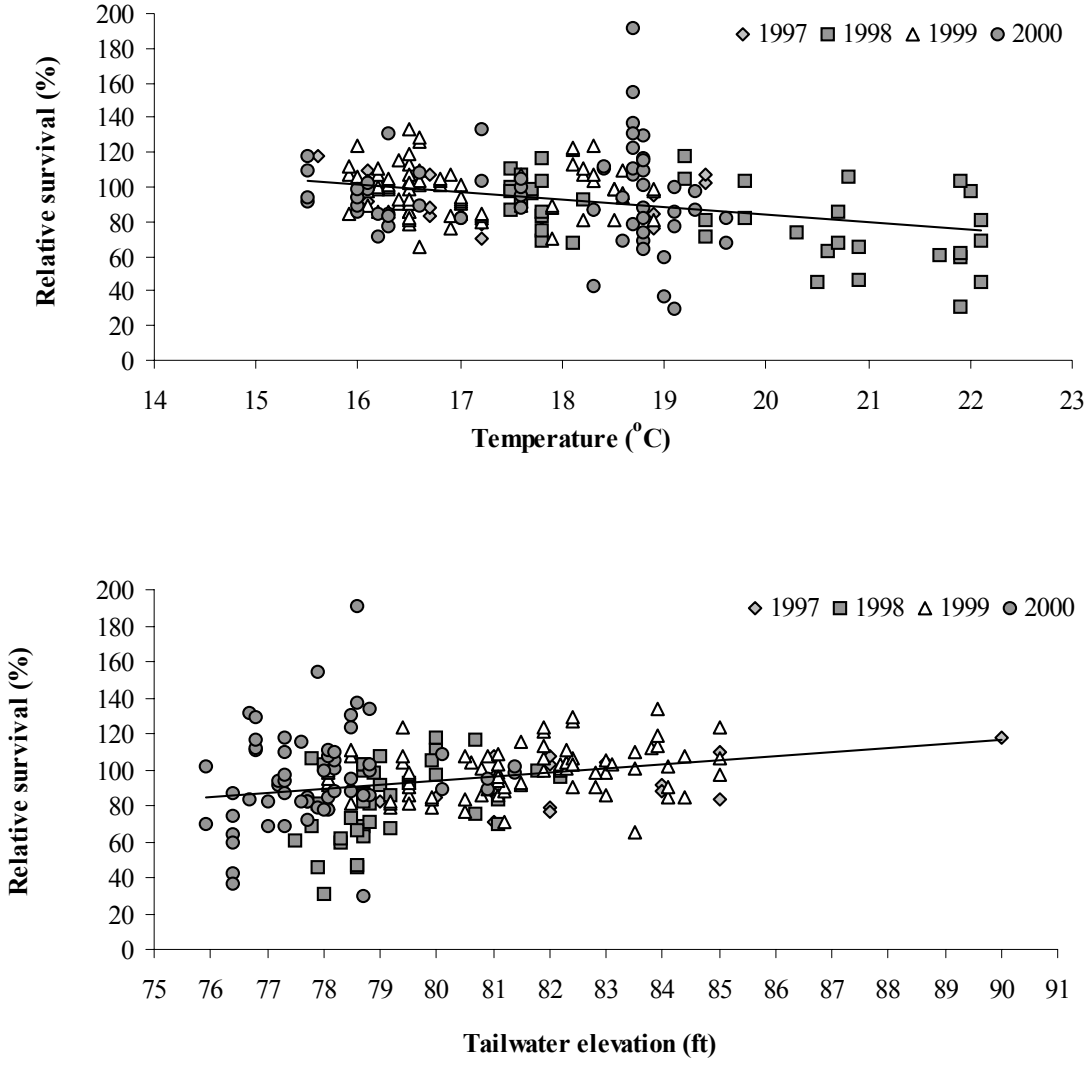


Figure 21. Relative survival of spillway-released subyearling chinook salmon in relation to water temperature and tailwater elevation during summer testing at The Dalles Dam from 1997 to 2000.

DISCUSSION

We found that in every year of the study, average survival estimates differed in relation to whether detections from Bonneville Dam, the surface trawl off Jones Beach, or the island surveys were used in the analyses. These differences were not surprising because each detection site used fundamentally different methods, and each was subject to sampling bias associated with those methods. Survival estimates based on detections at Bonneville Dam were generally lower than those based on detections at other sites throughout the four-year study period.

Differences in detection probabilities between the two powerhouses at Bonneville Dam could be related to poor spatial mixing of reference and treatment fish groups, with fish oriented to the side of the river on which they were released. For example, survival estimates calculated for each powerhouse would be higher at the first powerhouse and lower at the second powerhouse if treatment-fish detections were more likely at the first powerhouse and reference-fish detections were more likely at the second powerhouse. This pattern was in fact observed in spring but not in summer in the first three years of the study. In 2000, spring and summer point estimates of survival were higher at the second powerhouse for all three treatment release locations.

Differences in detection probabilities between treatment and reference groups may also have been related to diel changes in test-fish depth distribution at Bonneville Dam (which affects the number of fish guided) and differences in arrival timing (which is affected by changes in project operations). In addition, survival estimates based on PIT-tag detections from bird colonies are influenced by whether the treatment and reference groups were completely mixed (pass the islands at the same time and at the same depth) and by hourly variation in the foraging behavior of avian predators.

Due to these uncertainties, and because we had no basis for selecting one recovery site over the others, we based survival estimates on pooled PIT-tag detections from all three sites. This provided the largest number of detections and incorporated any potential biases associated with each of the three recovery sites.

Based on pooled recoveries, survival estimate comparisons between 30 and 64% spill and between day and nighttime releases generally trended in the same direction, with detections of fish released at 30% spill and during nighttime hours consistently producing the highest relative survival estimates through the first three years of the study. During the first three years of the study, the juvenile spill pattern was used at night and the adult pattern used during the day. The juvenile spill pattern concentrates spill toward the north spillbays.

In spring 2000, when the juvenile spill pattern was used throughout the test period, nighttime survival point estimates were slightly higher than daytime point estimates for fish released into the sluiceway, turbines, and south spillway. Fish released into the north spillway showed significantly higher relative survival for daytime releases. The summer 2000 results show the same trend as the first three years of the study where nighttime survival estimates trend higher than daytime. Sluiceway, turbine, and north and south spillway point estimates all showed higher relative survival estimates for nighttime releases, with the north spillway estimate being significantly higher than the daytime release estimate.

We believe that hourly powerhouse operations at Bonneville Dam had no systematic affect on our estimates based on our evaluation of the data on powerhouse operations, defined in terms of the ratios between average river flow per fish and average powerhouse flow per fish. Variations in these ratios were minor, with no notable trends within or among the four years; thus we conclude that valid estimates can be derived using combined data from all detection sites. Environmental conditions throughout the study varied by year, season, and day. For example, during the study period for all four years, spring flows ranged from 5,312 to 15,763 m^3/second (187,600-557,000 ft^3/second) and summer flows ranged from 3,865 to 14,235 m^3/second (136,500-503,000 ft^3/second).

During the first year of the study (1997), we estimated relative survival of spillway released fish at only the 64% spill level due to the large volume of runoff that year. In 1998 and 1999, we were able to compare survival between 30 and 64% spill levels. In both years for both spring and summer migrants, point estimates of relative survival were higher for fish released at the 30% spill level. The difference was significant for summer migrants when both years data were combined. In addition, in 1998 sluiceway releases were made during the day at the 30% spill level. The point estimate of relative survival for these releases was very similar to that of spillway releases at 30% spill levels (Table 3).

In 2000, a single spill level (40%) and spill pattern (juvenile) was utilized during the entire test period. Spillway survival was estimated as well as relative survival of fish released into the sluiceway and into turbine units. Point estimates of survival through these passage routes indicated significantly lower survival during both the spring and summer test periods for turbine releases compared to both spillway and sluiceway releases. Point estimates of survival of sluiceway and spillway releases were not significantly different from each other. In the spring test period, spillway and sluiceway survival point estimates were the same, and in the summer the point estimate of sluiceway survival was higher than that of spillway survival (Table 4).

Table 3. River flow and point estimates with 95% confidence intervals for relative passage survival of juvenile salmon at The Dalles Dam, 1997, 1998, and 1999.

	River flow (kcfs)		64% Spill	30% Spill	
Year	Median	Range	Spillway survival (95% CI)	Spillway survival (95% CI)	Sluiceway survival (95% CI)
			Spring migration (coho or chinook and coho salmon)		
1997	455	379-557	87% (80-94)		
1998	347	196-445	89% (82-95)	97% (88-107)	96% (87-105)
1999	273	239-376	94% (90-97)	95% (91-98)	
			Summer migration (subyearling chinook salmon)		
1997	301	213-503	92% (86-99)		
1998	212	167-279	75% (68-83)	89% (80-99)	89% (81-98)
1999	300	221-369	96% (92-100)	100% (96-104)	

Table 4. River flow and point estimates with 95% confidence intervals for relative passage survival of juvenile salmon at The Dalles Dam, 2000.

	River flow (kcfs)		Mean (95% CI)		
Year	Median	Range	Spillway at 40% spill	Sluiceway	Powerhouse
			Spring migration (coho and yearling chinook salmon)		
2000	273	158-348	95% (91-97)	94% (89-99)	81% (76-85)
			Summer migration (subyearling chinook salmon)		
2000	194	138-277	92% (85-98)	96% (87-106)	84% (76-93)

Relative survival estimates for spillway passage from this study at 64% spill are also lower than those obtained in studies conducted at Lower Monumental Dam in 1994. In that study, the point estimate of relative survival of PIT-tagged yearling chinook salmon passing through spillbays without flow detectors was 98.4% (NMFS 2000, Muir et al. 2001).

Survival estimates for turbine passage were also determined for yearling chinook salmon at Lower Granite Dam in 1995, Little Goose Dam in 1993, and Lower Monumental Dam in 1994 (Muir et al. 2001). Point estimates of relative survival for those studies were 92.7, 92.0, and 86.5%, respectively. These estimates were all higher than the 81% point estimate for turbine survival obtained at The Dalles Dam in 2000 (Table 4).

CONCLUSIONS

1) Comparisons from three years of data (1997-1999) indicate that survival estimates for juvenile salmon passing the spillway at The Dalles Dam under 64% spill are lower than estimates for juvenile spillway passage at other dams, and are similar to or lower than survival estimates for turbine passage at Snake River dams.

2) Analysis of the combined annual data on spill levels from 1998 and 1999 showed that differences between spill rates were significant for spring migrants ($P = 0.039$). Respective point estimates for passage survival at 64 and 30% spill were 90.5 and 95.5 for spring migrants. For summer migrants, the combined data from 1998 and 1999 indicated a significant interaction between both year and spill ($P = 0.019$) and year and diel passage time ($P = 0.012$). At spill levels of 64 and 30%, respective point estimates for passage survival of summer migrants were 73.4 and 89.0% in 1998 and 95.9 and 99.5% in 1999.

3) For spring migrants, analyses of three years of combined data (1997-1999) indicated a significant interaction between diel period, year, and spill ($P = 0.011$) for fish passing the spillway. Point estimates of survival for diel periods at 64 and 30% spill levels are shown below.

Diel release		Relative survival for spillway passage (%)		
period	Spill level (%)	1997	1998	1999
day	64	82.1	89.4	85.4
	30		97.8	88.4
night	64	86.7	87.7	100.4
	30		91.8	103.8

4) For summer migrants, analyses of three years of combined data (1997-1999) indicated a significant interaction between year and spill ($P < 0.001$) for summer migrants passing via the spillways. Point estimates of survival for diel periods at 64 and 30% spill are shown below.

Diel release		Relative survival for spillway passage (%)		
period	Spill level (%)	1997	1998	1999
day	64	87.7	76.8	93.9
	30		86.1	94.7
night	64	96.4	70.1	98.0
	30		84.0	104.6

5) Data from research during 2000 produced significantly lower survival estimates for turbine releases than for sluiceway or spillway releases in both the spring and summer test periods, as shown in the point estimates summarized below.

	Relative survival estimates, 2000 (%)		
	Turbine	Sluiceway	Spillway
Spring releases	81.0	94.4	94.7
Summer releases	83.9	96.3	92.4

6) Analysis of data from spring 2000, when the juvenile spill pattern was used throughout the study period, indicated a significant interaction between diel period and release location (ANOVA, $P = 0.027$). The nature of the interaction is indicated by the 10.8% difference between day and night relative survival estimates through the north spillbays shown in the summary below.

	Relative survival estimates, spring 2000 (%)			
Diel release period	North spillbays	South spillbays	Sluiceway	Turbine
day	91.8	90.2	94.5	79.0
night	102.6	92.4	94.0	83.0

7) Analysis of the data from summer 2000, when the juvenile spill pattern was used throughout the study period, indicated no significant interaction between diel period and release location (ANOVA, $P = 0.585$).

	Relative survival estimates, summer 2000 (%)			
Diel release period	North spillbays	South spillbays	Sluiceway	Turbine
day	84.2	87.4	95.5	79.1
night	100.6	94.3	97.2	88.9

8) Data from the 1998 evaluation showed that relative survival estimates of daytime releases through the sluiceway were similar to those of daytime releases through the spillway at 30% spill.

9) For both spring and summer migrants throughout all four years of study, correlations between relative survival through the spillway and physical variables such as tailwater elevation, spill volume, river flow, and water temperature were analyzed. These analyses indicated poor correlations and no relationships between spillway survival and these variables.

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