U.S. Army Corps of Engineers
Portland District

Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam, 2004
Revised for Corrected Spill

Annual Report

Prepared by:

Scott D. Evans, Lisa S. Wright, Rachel E. Reagan,
Noah S. Adams, and Dennis W. Rondorf
U.S. Geological Survey
Columbia River Research Laboratory
5501 A Cook-Underwood Road
Cook, Washington 98605

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U.S. Army Corps of Engineers
Portland District
Planning and Engineering Division
Environmental Resources Branch
Robert Duncan Plaza
333 S.W. 1st. Avenue
Portland, Oregon 97204-3495

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Executive Summary

Flow augmentation, spill, surface collection, and improved turbine guidance systems have been identified as potential management actions to improve passage efficiency and survival of outmigrating juvenile salmonids. The U.S. Army Corps of Engineers (USACE), along with regional, state, and federal resource agencies, has designed and implemented studies to determine which management actions would provide significant biological benefits to juvenile salmonids. From 1994 to 2004, the USACE has contracted the U.S. Geological Survey to evaluate juvenile salmonid behavior in relation to passage improvement tests at Lower Granite, John Day, The Dalles, and Bonneville Dams.

In 2004, we used radio telemetry to examine the movements and behavior of subyearling Chinook salmon *Oncorhynchus tshawytscha* in the forebay of Bonneville Dam. The objectives of this research were to: 1) determine the behavior, distribution, and approach patterns of fish in the forebay areas of Bonneville Dam, 2) determine the timing and route of dam passage of fish, 3) estimate fish passage efficiency for the entire Bonneville Dam complex, fish guidance efficiency for powerhouses I and II, and efficiency and effectiveness for the spillway and corner collector, and 4) provide data to estimate survival of radio tagged fish released above and at Bonneville Dam.

From 18 June to 27 July 2004, we radio-tagged and released 11,683 subyearling Chinook salmon upstream of Bonneville Dam at The Dalles Dam and John Day Dam. We detected our last radio-tagged fish on 4 August 2004. Mean river discharge at Bonneville Dam during the study period was 146 kcfs, with 37% of flow discharged at the spillway, 56% at the second powerhouse (B2), and 6% at the first powerhouse (B1). Fish were exposed to two different spill conditions during the study: 1) A Biop spill condition, with a discharge of 55 kcfs (original goal was 75 kcfs) during the day and up to 120% of the total dissolved gas cap at night, and 2) a mean discharge of 32 kcfs (original goal was 50 kcfs) during both day and night. The Biop spill treatment occurred for a total of 599 h (448 h day, 151 h night) over 32 d and averaged 81.8 kcfs overall, 58.2 kcfs during the day, and 117.4 kcfs at night. The 32 kcfs treatment occurred for a total of 481 h (320 h day, 161 h night) over 27 d and averaged 32.1 kcfs overall, 31.9 kcfs during the day, and 32.4 kcfs at night. The median travel rates of radio-tagged fish from release to Bonneville Dam was 2.0 km/h for fish released from John Day Dam and for fish released from The Dalles Dam. Median travel times from the release site to Bonneville Dam were 55.9 h for John Day fish and 38.5 h for The Dalles fish. Of the fish released, we detected 75% at Bonneville Dam. Median forebay residence time was shortest at B2 (11 min), compared to 34 min at the spillway and 1.6 h at B1.

Passage routes were determined for 99.9% of fish detected at Bonneville Dam. The second powerhouse passed the most fish (60%), followed by the spillway (35%) and B1 (5%). Of the fish that passed at B1, 48% passed through the turbines (unguided), 47% passed through the sluiceway, and 5% passed through the navigation lock. Of the fish that passed at B2, 49% passed unguided through the turbines, 37% passed through the corner collector, and 14% were guided into the DSM. Passage rates at both powerhouses were higher during the night than the day and about the same during both day and night at the spillway.

Overall fish passage efficiency (FPE: the proportion of fish that passed the dam via non-turbine routes) at Bonneville Dam in summer 2004 was 68% (SE = 0.5). During the Biop spill condition, when spill discharge averaged 58.2 kcfs during the day and 117.4 kcfs at night, FPE was 79% (SE = 0.6). During the 32 kcfs spill treatment, when spill discharge averaged about 32 kcfs during both day and night, subyearling Chinook salmon had an FPE of 57% (SE = 0.7). At B1, FPE was 52% (SE = 2.5) and at B2, FPE was 50% (SE = 0.7). Fish guidance efficiency (FGE: the proportion of powerhouse-entrained fish that are guided by screens into the bypass system) was calculable only at B2 since no guidance system operated at B1 during 2004. Fish Guidance Efficiency was 22% (SE = 0.7) overall, 24% (SE = 1.3) during Biop spill, and 20% (SE = 0.9) during 32 kcfs spill. Spillway efficiency (proportion of fish passing all routes that passed via spill) was 35% (SE = 0.9) overall, 50% (SE = 1.1) during Biop spill, and 21% (SE = 1.3) during 32 kcfs spill. Spillway effectiveness (spillway efficiency divided by the proportion of total discharge through the spillway) was 0.94 overall, 0.92 during Biop spill, and 0.94 during 32 kcfs spill. Corner collector efficiency (CCE: the number of fish that passed through the corner collector divided by the number of fish that passed through all routes at B2) was 37% (SE = 0.7) overall, 45% (SE = 1.1) during Biop spill, and 32% (SE = 0.8) during 32 kcfs spill. Corner collector effectiveness (CCF: corner collector efficiency divided by the proportion of discharge at B2 that went through the corner collector) was 5.6 overall, 5.2 during Biop spill, and 5.8 during 32 kcfs spill.

Like in previous years, the proportion of discharge allocated among B1, B2, and the spillway affected which dam area fish entered and passed, as well as the time fish spent in the forebay before passing. Since the greatest discharge occurred at B2, more than half of the radio-tagged subyearling Chinook salmon entered the forebay of B2 and spent the least amount of time relative to the other forebays before passing. Of the two spill conditions, Biop spill (mean = 81.8 kcfs) was the most efficient, passing 50% (SE = 1.1) of Chinook salmon through the spillway relative to all other passage routes. Similarly, passage through the corner collector was significantly higher during Biop spill (45%) than during 32 kcfs spill (32%) for Chinook salmon. Another shallow surface flow type passage route, the sluiceway, was also more efficient during Biop spill (50%) than during 32 kcfs spill (46%).

Of the two spill conditions tested at Bonneville Dam in 2004, the Biop treatment had higher passage metrics than the 32 kcfs treatment. The only metrics that were higher during 32 kcfs spill were sluiceway and corner collector effectiveness. This can be attributed to the increase in discharge through the turbines at both powerhouses during 32 kcfs spill, decreasing the proportion of total powerhouse discharge that went through the sluiceway or corner collector, thereby increasing effectiveness.

Passage metrics for subyearling Chinook salmon were generally lower in 2004 than in 2002. The only passage metrics that were higher in 2004 were FPE_{B2} and sluiceway efficiency $_{B1}$. If guidance screens had been deployed at B1 in 2004, FPE_{B1} and $FPE_{project}$ would have been higher. However, due to low discharge at B1 in 2004, relatively few fish passed there and the increase would have been minimal. Fish guidance efficiency at B2 in 2004 was the lowest of all study years. We hypothesize that low FGE_{B2} in 2004 was due to the corner collector passing the majority of the shallow fish that otherwise may have been guided. Spillway efficiency decreased in 2004 because more fish passed at B2, specifically through the corner collector. The increased passage at B2 through the corner collector is reflected in increased $FPE_{B2.}$ Although the addition of the corner collector did not increase $FPE_{project}$, it did achieve an $FPE_{project}$ of 68% with far less water than would have been necessary to attain the same $FPE_{project}$ without the corner collector. The spillway discharged an average 14 times more water than the corner collector. Consequently, effectiveness of the corner collector (5.9) relative to the project was far greater than effectiveness of the spillway (0.9). Our results indicate that although the intake screen guidance systems at Bonneville Dam have poor guidance efficiency, project FPE of nearly 80% can be attained for subyearling Chinook salmon under a Biop spill condition in conjunction with the operation of the B2 corner collector. Additionally, by strategically optimizing discharge patterns at the project, passage of juvenile salmonids can be increased temporally and spatially.

1.0 Introduction

Years of research have been allocated to ensure the long-term survival of salmon and steelhead stocks in the Columbia River basin. Much of this effort has focused on the effects of dams and reservoirs on juvenile salmonids as they migrate from their natal waters to the ocean. Raymond (1968, 1979) and Park (1969) showed migration times increased after dam construction and suggested this may be detrimental to juvenile salmonid survival.

Flow augmentation, spill, surface collection, and improved turbine intake guidance systems have been identified as potential management actions to improve juvenile salmonid passage and survival, thereby assisting the recovery of anadromous fish stocks in the Snake and Columbia rivers. Options currently being evaluated at Bonneville Dam are the improvement of turbine intake guidance systems and a new corner collector surface-flow bypass system.

In 2000, we conducted the first evaluation of species-specific FPE for the entire Bonneville Dam project and estimated that FPE was between 73% and 91%, depending on species (Evans et. al. 2001a and 2001b). The National Marine Fisheries Service Biological Opinion (2000) states, "The dam passage survival rate at Bonneville Dam is currently one of the lowest of any U.S. Army Corps of Engineers Federal Columbia River Power System (FCRPS) project, and is therefore the highest priority relative to the need for improvements," and that the Corps should "continue intake screen guidance improvement investigations and implement as warranted." The U.S. Army Corps of Engineers (USACE) addressed these concerns in 2001 by field-testing a prototype screen system at turbine unit 15 at Bonneville's second powerhouse (Monk et al. 2002). In 2002, Monk et al. (2004) evaluated intake screen modifications at turbine unit 17 and a minimum gap runner (MGR) turbine at Bonneville's first powerhouse was tested (Counihan et al. 2002). In 2004, studies of the MGR turbine continued and evaluations were also conducted for the ice and trash sluiceway at the first powerhouse and the corner collector surface-flow bypass system at the second powerhouse. To determine whether these management actions are effective, it is necessary to estimate passage efficiencies and survival and compare those estimates to pre-improvement passage efficiencies and survival.

During summer 2004, we used radio telemetry to examine the movements and behavior of subyearling Chinook salmon *Oncorhynchus tshawytscha* at Bonneville Dam. Our objectives were to:

- Determine the timing and route of passage for subyearling Chinook salmon at Bonneville Dam relative to spill, powerhouse operations, and corner collector tests.

- Monitor all passage routes at Bonneville Dam to determine route-specific and project survival for subyearling Chinook salmon.

- Estimate fish passage efficiency for the project, fish guidance efficiency for the second powerhouse, and efficiency and effectiveness for the spillway, corner collector, and sluiceway.

- Provide data to estimate route-specific and project survival of radio-tagged fish released above Bonneville Dam (reported by Counihan et al. 2004).

2.0 Methods

2.1 Study Area

Bonneville Dam is located on the Columbia River at rkm 233. The dam consists of two powerhouses and a single spillway, each separated by an island. The first powerhouse (B1) consists of 10 turbine units and is located at the south side of the river, spanning from the Oregon shore to Bradford Island. The second powerhouse (B2) consists of eight turbine units and is located at the north side of the river, spanning from Cascades Island to the Washington shore. The spillway (SPI) lies between Cascades and Bradford islands and has 18 spill gates. A navigation lock is located at the south end of B1 (Figure 1).

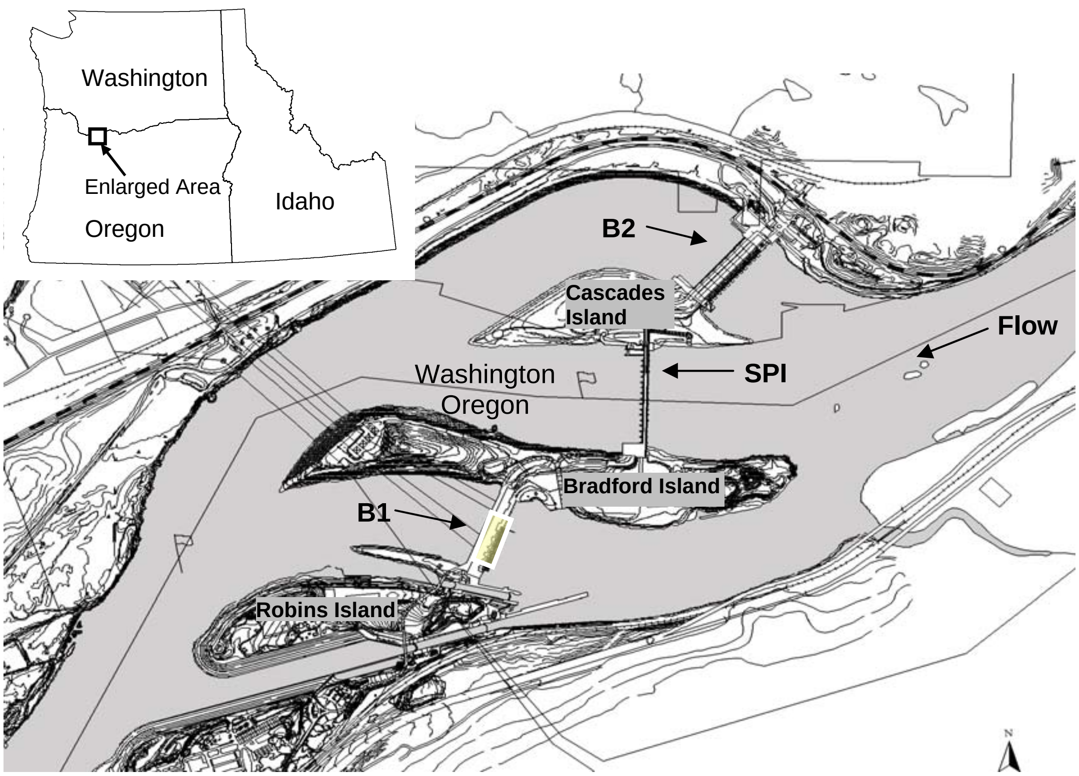

Figure 1.—Plan view of Bonneville Dam on the Columbia River, showing first powerhouse (B1), the spillway (SPI), and second powerhouse (B2). Image source: U.S. Army Corps of Engineers.

2.2 Water quality

We monitored water temperature (±0.2ºC), dissolved oxygen (DO; ± 0.2 ppm), and electrical conductivity (EC; 0.5%) throughout the study using a Stevens-Greenspan

CS304 multi-parameter sensor (Stevens Water Monitoring Systems, Inc, Beaverton, Oregon). The CS304 was deployed 1.5 m below the water surface in the forebay of the Bonneville Dam spillway and was programmed to record water temperature, DO, and EC measurements every minute.

2.3 Fixed Receiving Equipment

We used four types of data acquisition equipment to monitor underwater and aerial antennas at Bonneville Dam in 2004. Ninety-seven aerial antennas, 35 stripped coax antennas, and 124 underwater dipole antennas were linked to 34 Lotek SRX-400 receivers (SRX; Lotek Engineering, Newmarket, Ontario), five Lotek DSP-500 digital spectrum processors (DSP; Lotek Engineering, Newmarket, Ontario), three Orion DSP receivers (Grant Systems Engineering, King City, Ontario, Canada), and three Multiprotocol Integrated Telemetry Acquisition Systems (MITAS; Grant Systems Engineering, King City, Ontario, Canada). Each SRX monitored a maximum of six aerial antennas. Orions, DSPs, and MITASs were used to monitor underwater antennas. Orions and DSPs were also used to monitor aerial antennas in some areas. The combination of these technologies allowed us to monitor approach behavior and passage through all routes at Bonneville Dam.

Aerial antennas were positioned in three locations: 1) along the periphery of the forebay, 2) along the tailrace shoreline, and 3) along the corner collector flume (Figure 2). Aerial antennas were located in the forebay to detect fish within 100 m of the dam, in the tailrace to confirm fish passage, and in the corner collector flume to detect fish passing through the corner collector. Aerial antennas were connected to SRX receivers programmed to monitor seventeen frequencies in random order. Two aerial antenna monitoring configurations were used depending on location: auxiliary/master switching or combined antennas. The auxiliary/master switching configuration was used in the forebay of both powerhouses and at entrance stations where signal acquisition time was longer and more spatial resolution was required. Combined antenna configurations were used in the spillway forebay and all tailraces where signal acquisition time was limited and less spatial resolution was needed. In addition to combining antennas to reduce scan time (a function of the number of frequencies being monitored), scan time was reduced by half by using an extra receiver at all locations. Reducing scan time is beneficial because it increases the probability of detecting transmitters. Underwater dipole and stripped coax antennas had limited ranges (about 6 m) compared to aerial antennas (100 to 300 m depending on transmitter depth, receiver gain, and number of antenna elements). Underwater antennas allowed us to obtain fine scale fish behavior information by limiting the range of signal detection. Two SRX receivers in the B2 tailrace, two SRX receivers in the corner collector flume, and one SRX receiver at the B2 sampling facility were each coupled with DSPs. These receivers had essentially no scan time because a DSP acquires signals over a 1 MHz bandwidth almost instantaneously. Using DSPs, rather than a stand-alone SRX, was necessary to document fish passage in high flow hydraulic environments because signal acquisition time is limited.

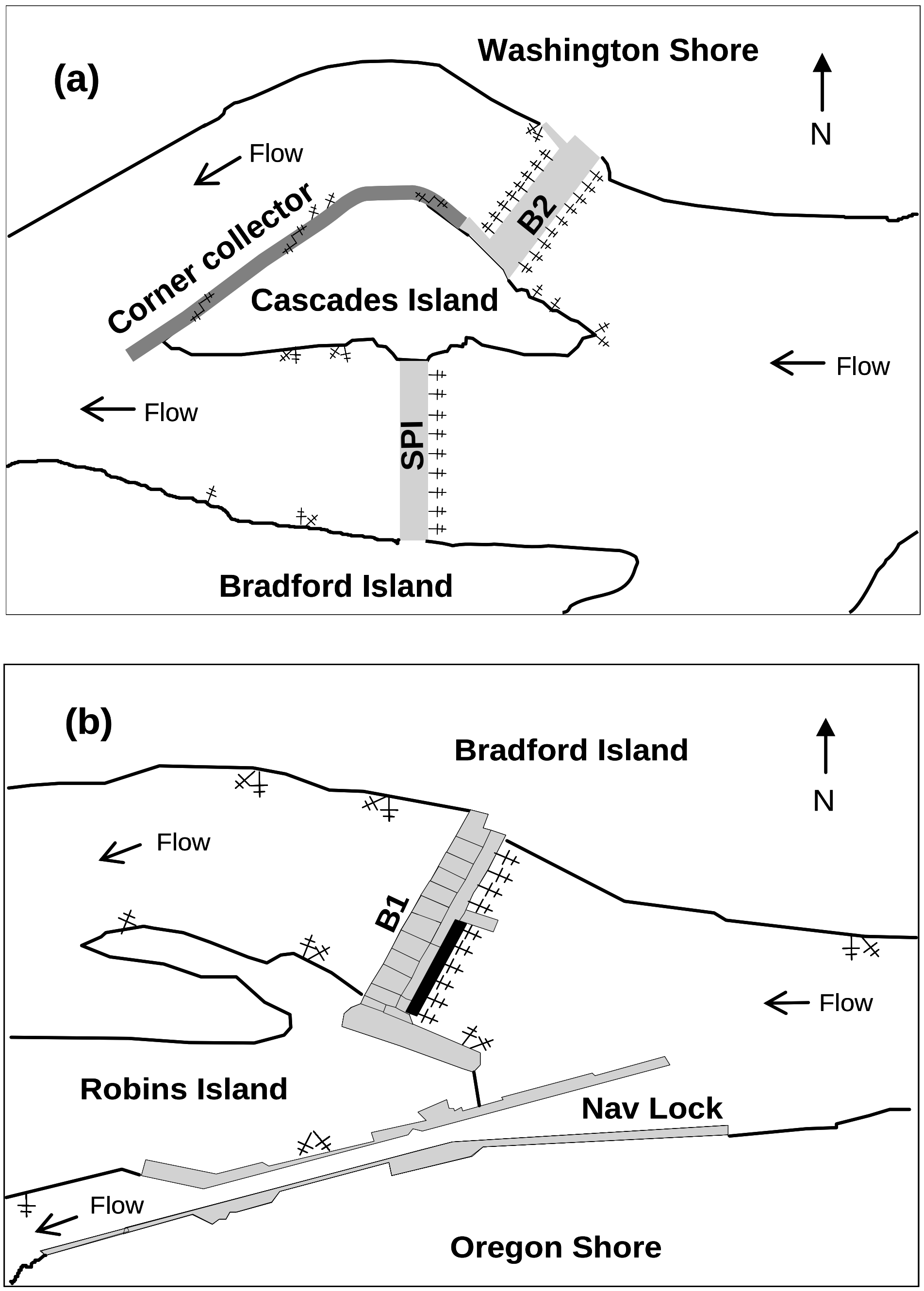

Figure 2.—Plan view of aerial antenna coverage during summer 2004 at Bonneville Dam's: (a) second powerhouse (B2) and spillway (SPI); and (b) first powerhouse (B1).

One Orion receiver at the B2 sampling facility and two Orion receivers in the corner collector flume were also used. Since this was the first year that Orion receivers were operational, they were placed in conjunction with DSPs. All three of the Orion receivers were monitoring the same frequencies and antennas as the DSPs.
The Orion receiver also has essentially no scan time because signals are acquired over a 1 MHz bandwidth.

Three MITAS systems were incorporated at B1, B2, and the spillway (Figure 3). Each MITAS was capable of simultaneously monitoring up to 50 inputs with greater multiple transmitter recognition than the SRX, DSP, or Orion. Although each MITAS was limited to a maximum of 50 inputs, each input could be a horizontal or vertical combination of multiple underwater dipole or stripped coax antennas. In addition to enhanced signal recognition, the MITAS's data displays and on-screen diagnostics allowed the user to identify problems in real-time and avoid potential data loss that otherwise would not have been apparent until post-processing.

The MITAS at B1 was composed of 22 underwater stripped coax antennas and one aerial antenna. Twenty stripped coax antennas were positioned mid-channel in the sluiceway, two at each unit, to monitor unit-specific sluiceway entrance and passage through the sluiceway. In addition, two stripped coax antennas and one aerial antenna were placed at the outfall of the sluiceway to confirm sluiceway passage.

The MITAS at B2 was composed of 61 underwater antennas. Forty-eight dipole underwater antennas attached to the submersible traveling screens monitored unguided turbine passage. Two dipole antennas were mounted to the bottom of each of three submersible traveling screens in front of each of eight turbine units. Antennas from each of the three gatewell slots per unit were combined to provide turbine unit specific passage information. Nine stripped coax antennas placed within the downstream salmonids migrant channel (DSM) monitored guided fish passage. One antenna was located just downstream of each "C-slot" gatewell orifice and one additional antenna was located at the terminus of the DSM. Four dipole underwater antennas monitored approach and entrance of fish to the corner collector.

The spillway MITAS consisted of 72 underwater antennas. Seventy-two dipole underwater antennas monitored spillway passage and were attached to the forebay pier noses. Each spillbay had four antennas attached to the pier nose, two antennas at about 4.5 m below mean pool level and two antennas at about 10.5 m below mean pool level. All four antennas in each spillbay were combined to one input to provide spillbay-specific passage.

Regardless of the type of monitoring technology used, a standard input signal of known value was used to determine the signal strength reaching each receiver. All aerial antennas were amplified in close proximity to the receiving antenna and transmission line amplification was used as needed to insure signal quality. Underwater antenna transmission lines were amplified as soon as they reached the deck elevation. Over-amplified signals were attenuated down to a standard level. These efforts insured that all antennas within and among arrays were equally sensitive and resulted in a balanced receiving system.

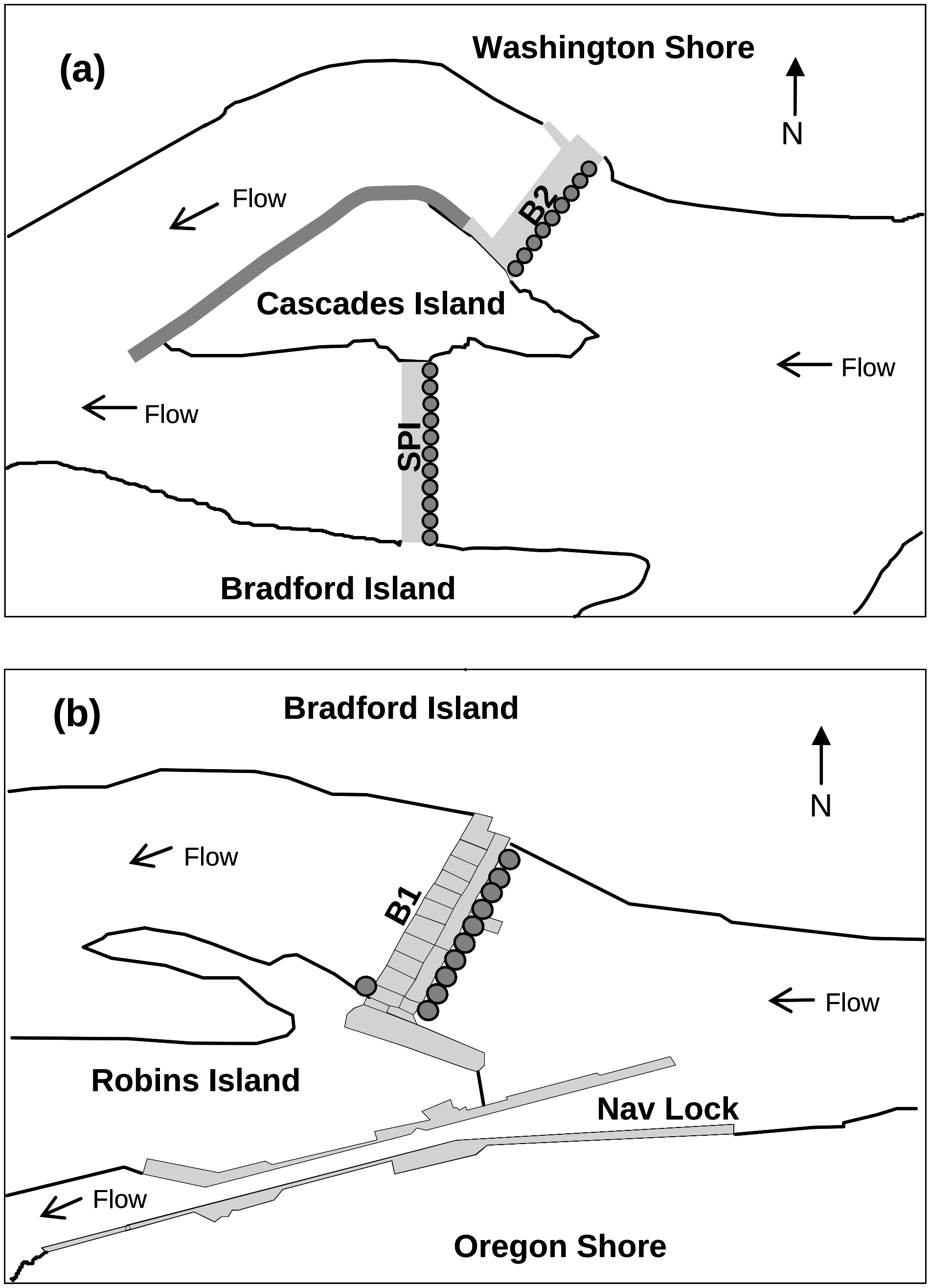

Figure 3.—Plan view of underwater antenna coverage during summer 2004 at Bonneville Dam's: (a) second powerhouse (B2) and spillway (SPI); and (b) first powerhouse (B1).

2.4 Transmitters

Coded microprocessor transmitters (model NTC-3-1) manufactured by Lotek Engineering Inc. were implanted in subyearling Chinook salmon. The transmitters were 6.3 mm wide x 4.5 mm high and weighed 0.85 g in air. The antenna length was 30 cm and the pulse rate was 2.0 s, resulting in an estimated minimum tag life of 8 d.

2.5 Tagging, Handling, and Release of Fish

Subyearling Chinook salmon were collected at the Smolt Monitoring Facility (SMF) at John Day Dam. Employees from the Pacific States Marine Fisheries Commission's Smolt Monitoring Program and U.S. Geological Survey employees sorted and identified study fish. Fish were weighed at the time of collection to ensure they met the minimum weight criteria of 13.0 g, keeping the tag weight to fish weight ratio below 6.5%. Fish collected at John Day Dam were tagged and released into the Columbia River at John Day Dam and at The Dalles Dam. Although fish were tagged and released at different locations, the fish handling, tagging, transport, and release methods were standardized.

Subsequent to collection, fish to be tagged and released at John Day Dam were held for 12-24 h at the SMF in 303 L circular fiberglass tanks supplied with flow-through river water at a maximum density of 120 fish per tank (≤ 20 g fish body weight per 1 L of water). Fish to be tagged and released at The Dalles Dam were collected, loaded into 265 L plastic tanks and transported to The Dalles Dam in temperature-controlled trucks at a maximum density of 100 fish per tank. The tanks were supplied with oxygen throughout transport. Once at The Dalles Dam, the tanks were supplied with flow-through river water and fish were held for 12-24 h before tagging. The holding times for fish prior to tagging allowed the fish to attain a post-absorptive state, helping to minimize stress throughout the tagging procedure.

All fish were gastrically implanted with a radio transmitter using procedures described by Adams et al. (1998). Fish were anesthetized using tricaine methanosulfate (MS-222) at a concentration of 50 mg/L of fresh water. An equal amount of buffer solution ($NaHCO_3$) was added, along with stress coat at a concentration of 0.25 ml/L. Fish were netted from the holding tanks into the prepared anesthesia bucket with a maximum density of 5 fish in anesthesia at one time. Timers were used to ensure that no fish remained in the anesthesia for longer than 5 min. Fish were carefully observed to determine when adequate sedation occurred (evident by loss of equilibrium), then removed from anesthesia and examined for overall condition. Fish that met criteria for size and condition were weighed, measured and tagged, then placed in an oxygenated recovery bucket for 5 min. A maximum of two fish were held in each recovery bucket and oxygen was supplied at a minimum flow rate of 50 ml/min. Following the recovery period, fish were checked for regurgitated tags or mortalities. Each bucket was then covered with a locking lid and held for 18-24 h in a 3.6 m x 1.2 m x 1.2 m aluminum tank supplied with flow-through river water to a depth of 27.5 cm. Recovery buckets were modified 19 L buckets, designed to hold 5 L of water while simultaneously allowing adequate flow-through of water through numerous drilled holes. Prior to transporting the fish to the release site, each recovery bucket was checked for mortalities, regurgitated tags and tag functionality. Releases occurred during day and night (0600 and 1800 hours at John Day Dam, 0100-0700 and 1300-1900 hours at The Dalles Dam) to enable tagged fish to mix spatially and temporally with untagged fish in the river before reaching Bonneville Dam. The upstream release locations allowed fish an average of 39 to 56 h, depending on release site, to adjust to temperature and hydraulic conditions in the reservoir before reaching the forebay and encountering Bonneville Dam.

2.6 Data Management and Analysis

Fixed receivers were typically downloaded every day. All data were backed up daily and imported into SAS (version 8.1, SAS Institute Inc., Cary, North Carolina, USA) for subsequent proofing and analysis. This was the first year that we implemented an automated proofing program, designed specifically for Bonneville Dam data. The automated proofing program was written in SAS and allowed us to proof and process our data with increased speed. Data were proofed to eliminate non-valid records, including environmental noise, single records of a particular channel and code, records collected prior to a known release date and time, and records suspected to be fish consumed by avian or aquatic predators. To consider a detection of a radio-tagged fish as valid, we required at least two detections within 1 min of each other. All data records for fish that fell outside of our set criteria for travel time, residence time, and geographical area were flagged and subsequently proofed manually. Additionally, a 10% sub-sample of each auto-proofed file was proofed manually as a quality assurance measure of the auto-proofing program and to ensure accurately proofed data.

Entrance into the forebay area was determined by the location and time an individual fish was first detected by aerial or underwater antennas on the dam face. Similarly, the last detection of a fish by aerial or underwater antennas on the dam face, on the traveling screens, at the corner collector, within the B2 DSM, or in the B1 sluiceway, was considered to be the route and time of passage through the dam. If a fish was not detected in the forebay or within the dam, the tailrace exit stations were used to determine the passage location (DSM, corner collector, turbine, or sluiceway).

Residence time in the forebay, defined as the duration of time between the first and last detections in the forebay, was calculated for each radio-tagged fish detected in the forebay. Residence times are a minimum estimate of the actual time that radio-tagged fish spent in the forebay because of receiver limitations and detection probabilities. For example, fish may enter the forebay before they are first detected and may remain following their last detection. Additionally, fish that approach very deep may have a low probability of detection and thus pass the dam undetected.

We calculated the standard error (SE), as described by Zar (1999), for all fish passage proportions (efficiencies) to provide a measure of precision of our estimate. We tested for equality of proportions between passage efficiencies during spill treatments using a chi-square test (Zar 1999).

The following are definitions of metrics used to measure passage behavior of radio-tagged fish at Bonneville Dam:

- Spillway efficiency $(SPE) = \dfrac{SP}{(B1 + SP + B2)}$

- Spillway effectiveness $(SPF) = \dfrac{SPE}{F_{SP} / F_{tot}}$

- Fish guidance efficiency (FGE) = $\dfrac{G_{tot}}{(G_{tot} + UG_{tot})}$

- Fish passage efficiency (FPE) = $\dfrac{Non-turbine\ passage}{TOT_{pass}}$

- Corner collector efficiency (CCE) = $\dfrac{CC}{B2}$

- Corner collector effectiveness (CCF) = $\dfrac{CCE}{F_{CC} / F_{B2}}$

- Sluiceway efficiency (SLE) = $\dfrac{SL}{B1}$

- Sluiceway effectiveness (SLF) = $\dfrac{SLE}{F_{SL} / F_{B1}}$

Where:

SP = Total number of fish passing spillway.
CC = Total number of fish passing through corner collector.
B1 = Total number of fish passing first powerhouse.
B2 = Total number of fish passing second powerhouse.
SL = Total number of fish passing through B1 sluiceway.
G_{tot} = Total number of guided fish.
UG_{tot} = Total number of unguided fish.
TOT_{pass} = Total number of fish passing the project (B1+SP+B2).
F_{SP} = Average discharge (kcfs) through the spillway during the study.
F_{CC} = Average discharge (kcfs) through the corner collector during the study.
F_{B1} = Average discharge (kcfs) through first powerhouse during the study.
F_{B2} = Average discharge (kcfs) through second powerhouse during the study.
F_{tot} = Average discharge (kcfs) through the project (B1+SP+B2) during the study.

3.0 Results

3.1 Water Quality

Water temperature in the spillway forebay increased over the course of the study, averaging 20.5 ºC and ranging from 17.14 to 22.74 ºC. Dissolved oxygen in the spillway forebay gradually decreased over the course of the study, averaging 8.4 ppm and ranging from 7.50 to 9.95 ppm. Electrical conductivity increased gradually over the course of the study, averaging 114.3 μS/cm and ranging from 103.8 to 128.8 μS/cm (Appendix 1). Dissolved oxygen, temperature, and electrical conductivity all were higher during the day than during the night (Appendix 2).

3.2 Tagging

From 18 June to 27 July 2004, we radio-tagged and released 11,683 subyearling Chinook salmon (Appendix 3). Of the fish tagged, 2,210 were released from John Day Dam and 9,473 were released from The Dalles Dam. The release period coincided with the central portion of the "in river" seaward migration of subyearling Chinook salmon (Figure 4). Of the fish released from John Day Dam, 43% (955 of 2,210) were released during the day and 57% (1,255 of 2,210) were released at night. Of the fish released from The Dalles Dam, 52% (4,905 of 9,473) were released during the day and 48% (4,568 of 9,473) were released at night. The mean fork length for subyearling Chinook salmon released from all sites was 115.6 mm and the mean weight was 17.1 g. The radio tag represented an average of 5.0% of mean fish body weight.

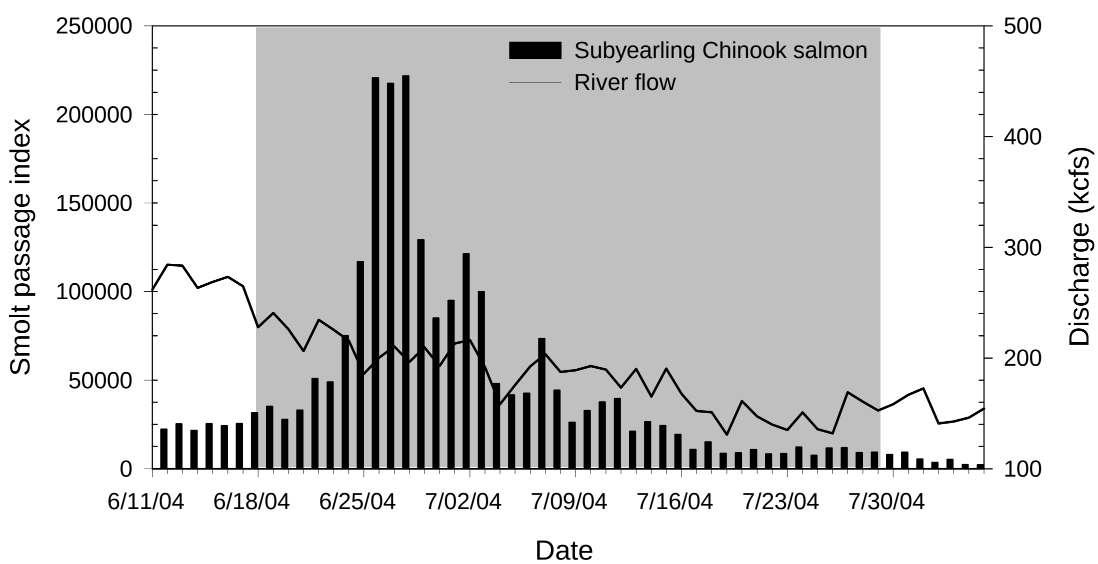

Figure 4.—Smolt Passage Index for subyearling Chinook salmon at Bonneville Dam's second powerhouse (B2) fish collection facility during summer 2004. Shaded area represents study period. Smolt index data were acquired from the Fish Passage Center web page at www.fpc.org.

3.3 River Discharge and Project Operations

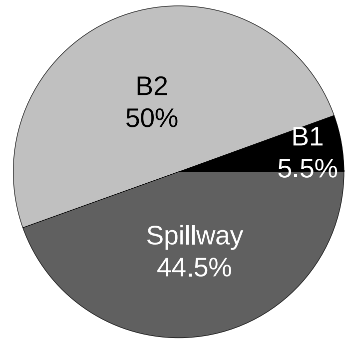

Figure 5.—Discharge allocation between dam areas at Bonneville Dam, summer 2004.

In July of 2004, the U.S. Army Corps of Engineers identified a discrepancy in the amount of water reported to be spilled at Bonneville Dam. An error in the calibration of spill gate openings installed in the early 1970's resulted in up to 30% less water discharged through the spillway than was reported to regional fish and water management officials. Updated spill measurements were received in June 2006 and are used in this revised report.

During summer 2004 (21 June – 4 August), mean river discharge at Bonneville Dam was 145.9 kcfs, and ranged from 102.0 kcfs to 216.9 kcfs. Allocation of mean river discharge among dam areas (i.e., B1, B2, and spillway) during the study period was 6% through B1, 56% through B2, and 37% through spill (Figure 5 and Table 1). Mean daily discharge at B1 (turbines 1–10) was 9.1 kcfs and ranged from 0.4 to 45.9 kcfs. B2 displayed the greatest fluctuation in mean daily discharge with a mean of 82.2 kcfs, a minimum of 38.0 kcfs and a maximum of 114.8 kcfs. Mean daily spill was 54.6 kcfs and ranged from 30.9 to 81.2 kcfs (Table 1). Spill occurred from 0400-2059 hours during the day and from 2100-0359 hours during the night. Discharge at both powerhouses decreased as the season progressed and daily discharge fluctuated more at B1 and B2 than at the spillway (Figure 6).

Two spill conditions were tested in 2004: 1) a Biop test condition of 58 kcfs spilled during daytime hours (0400-2059) and spill to the 120% total dissolved gas (TDG) cap during nighttime hours (2100-0359), and 2) a test condition of 32 kcfs spilled 24 h per day. Spill during the Biop treatment occurred for a total of 599 h over 32 d. During daytime hours, Biop spill occurred for a total of 448 h, averaged 58.2 kcfs, and ranged from 55.8 to 66.3 kcfs. During nighttime hours, Biop spill occurred for a total of 151 h, averaged 117.4 kcfs, and ranged from 73.0 to 158.8 kcfs. Spill during the 32 kcfs treatment occurred for a total of 481 h (320 h during the day and 161 h at night) over 27 d, averaged 32.1 kcfs, and ranged from 30.9 to 32.9 kcfs. Mean discharge at B1 went primarily through turbines 1-6 (77%), with the remainder of discharge going through turbines 7-10 (10%) and the sluiceway (13%; Figure 7). Mean discharge at B2 was distributed through the turbines more equally than at B1: 54% through turbines 11-14 and 39% through turbines 15-18. The remaining 7% was discharged through the corner collector (Figure 8). There were considerable differences in discharge between turbine units, although fluctuations in mean daily discharge at B2 and the spillway corresponded with mean daily river discharge. Differences in daily turbine discharge were observed for multiple turbines throughout the study (Figures 9-12). Mean discharge at both powerhouses was higher during day than night (57% of B1 and 55% of B2) and mean discharge at the spillway was higher at night compared to day (61% of SPI). During the day, 68% of water discharged at Bonneville Dam went through the powerhouses (61% at B2 and 7% at B1) and 32%

was discharged through the spillway (Table 2). During the night, a mean 71 kcfs was discharged through both the spillway and B2 and a mean 7.5 kcfs was discharged at B1.

Table 1.—Descriptive statistics for discharge (kcfs) at Bonneville Dam during summer 2004. Values have been rounded to the nearest tenth and are based on daily totals. Discharge for the sluiceway and corner collector are included in discharge for first powerhouse and second powerhouse, respectively.

Dam Area	Mean	Median	Min	Max
First powerhouse	9.1	3.3	0.4	45.9
Sluiceway	1.2	1.3	0.4	1.3
Second powerhouse	82.2	82.0	38.0	114.8
Corner collector	5.4	5.6	4.4	5.8
Spillway	54.6	57.4	30.9	81.2
Total	145.9	146.6	102.0	216.9

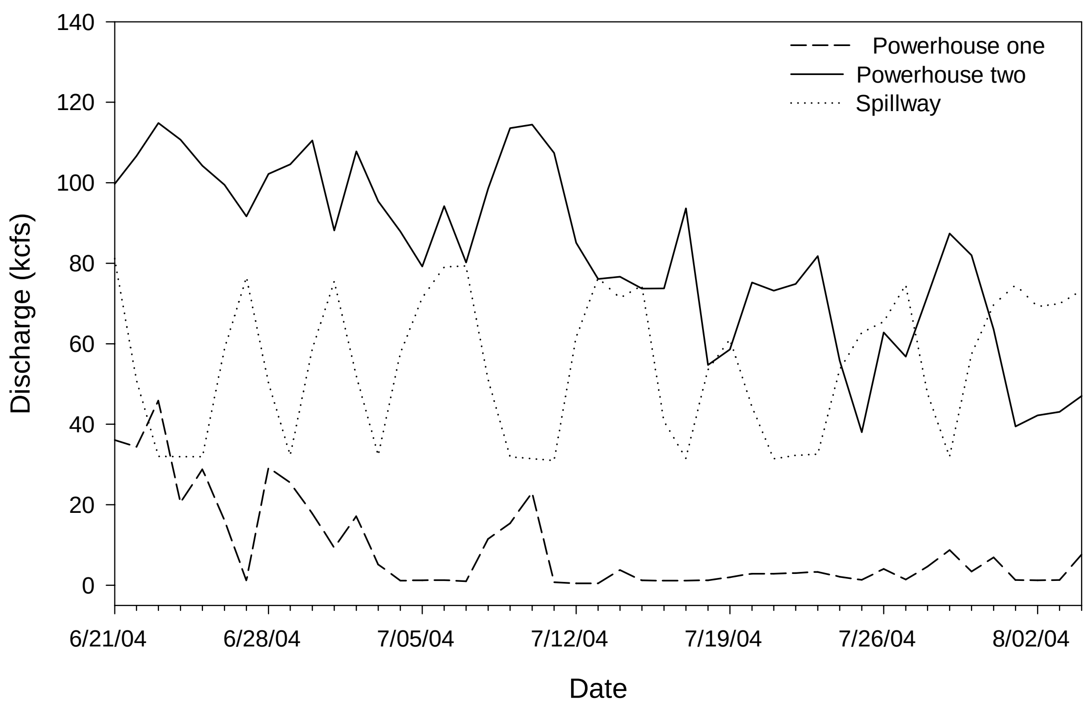

Figure 6.—Mean daily discharge by dam area at Bonneville Dam, summer 2004

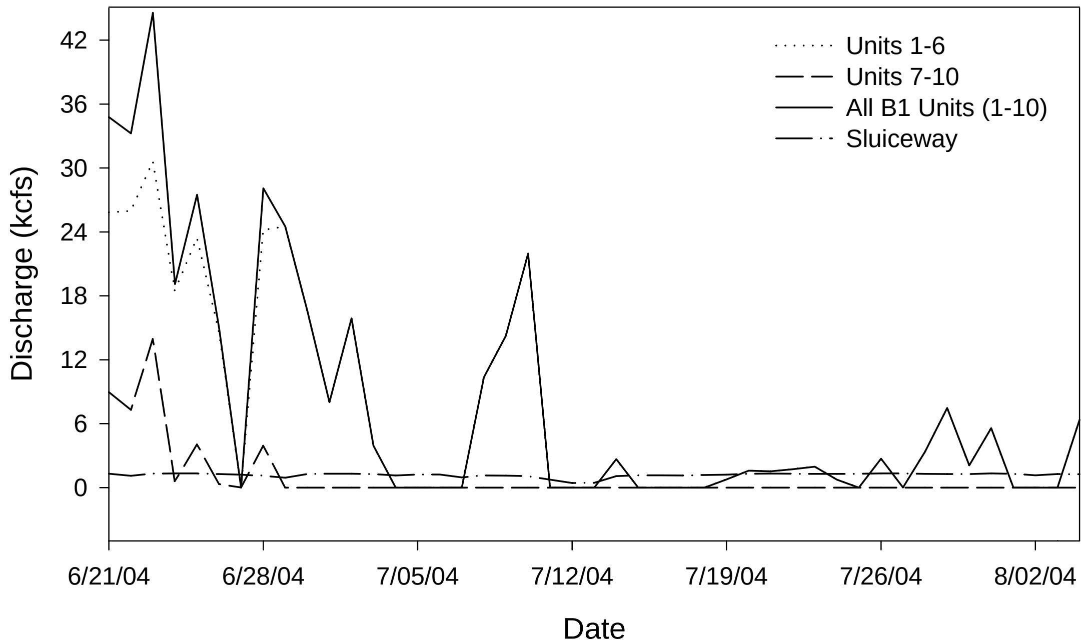

Figure 7.—Mean daily discharge through turbines 1-6, 7-10, and the sluiceway at Bonneville Dam's first powerhouse (B1), summer 2004.

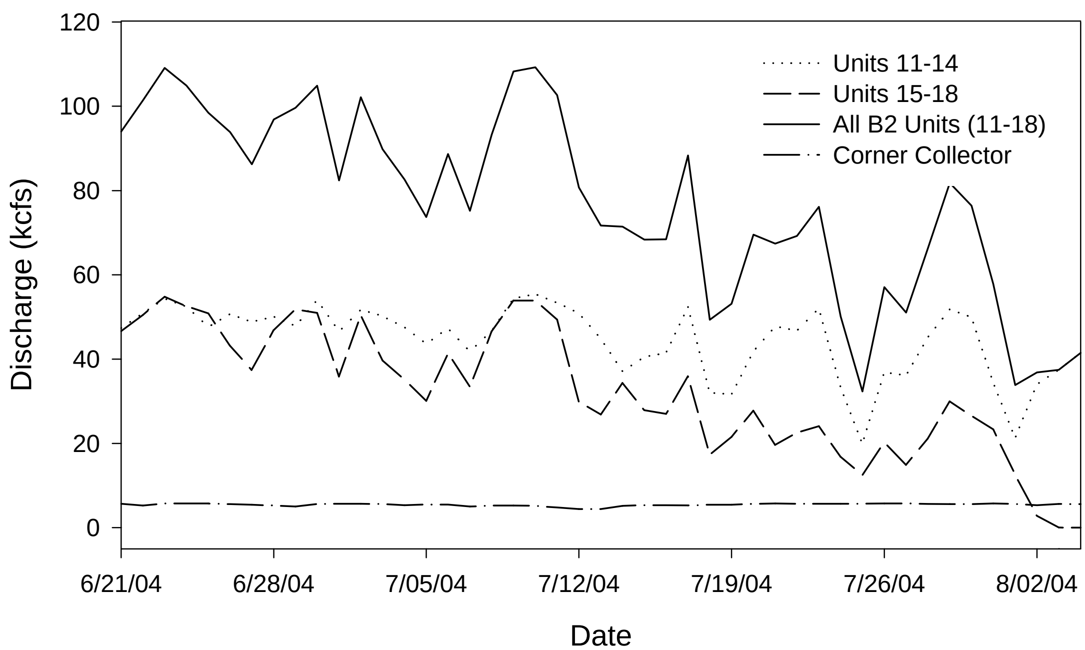

Figure 8.—Mean daily discharge through turbines 11-14, 15-18, and the corner collector at Bonneville Dam's second powerhouse (B2), summer 2004.

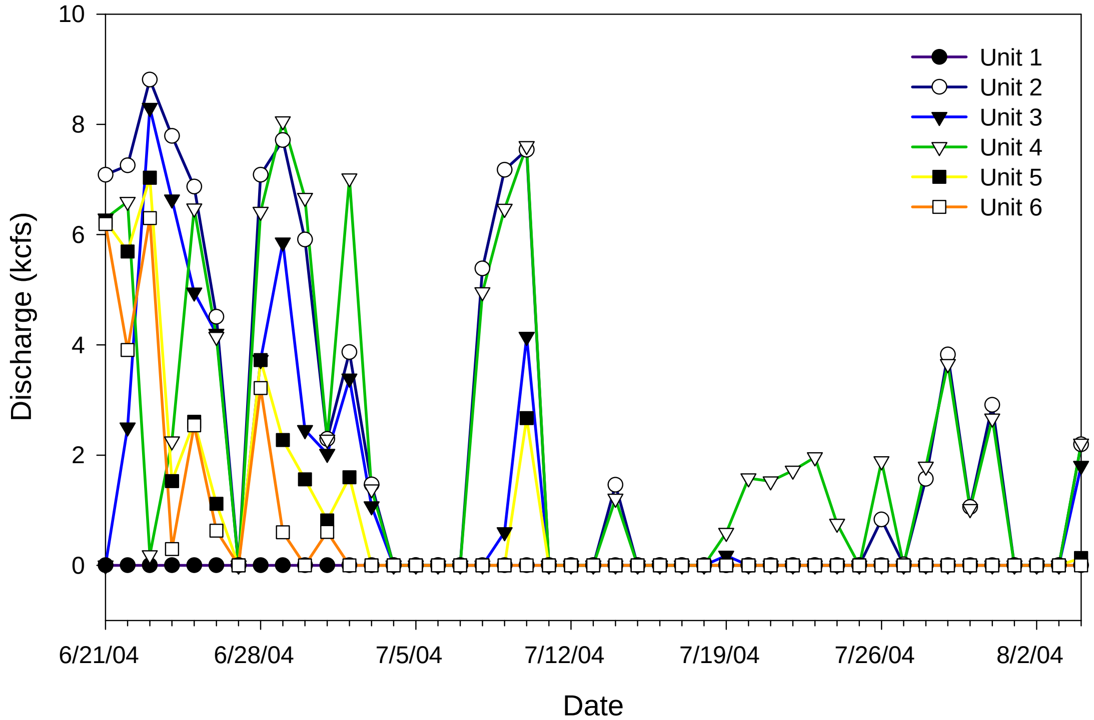

Figure 9.—Mean daily discharge by unit for turbines 1-6 at Bonneville Dam, summer 2004.

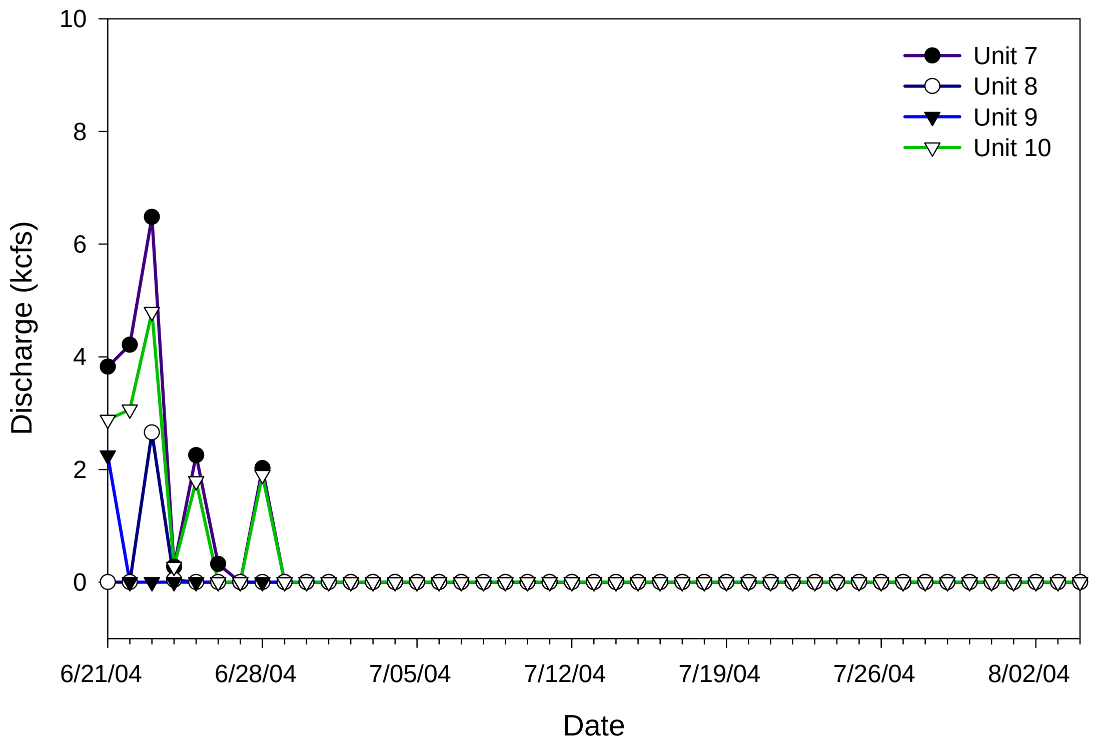

Figure 10.—Mean daily discharge by unit for turbines 7-10 at Bonneville Dam, summer 2004.

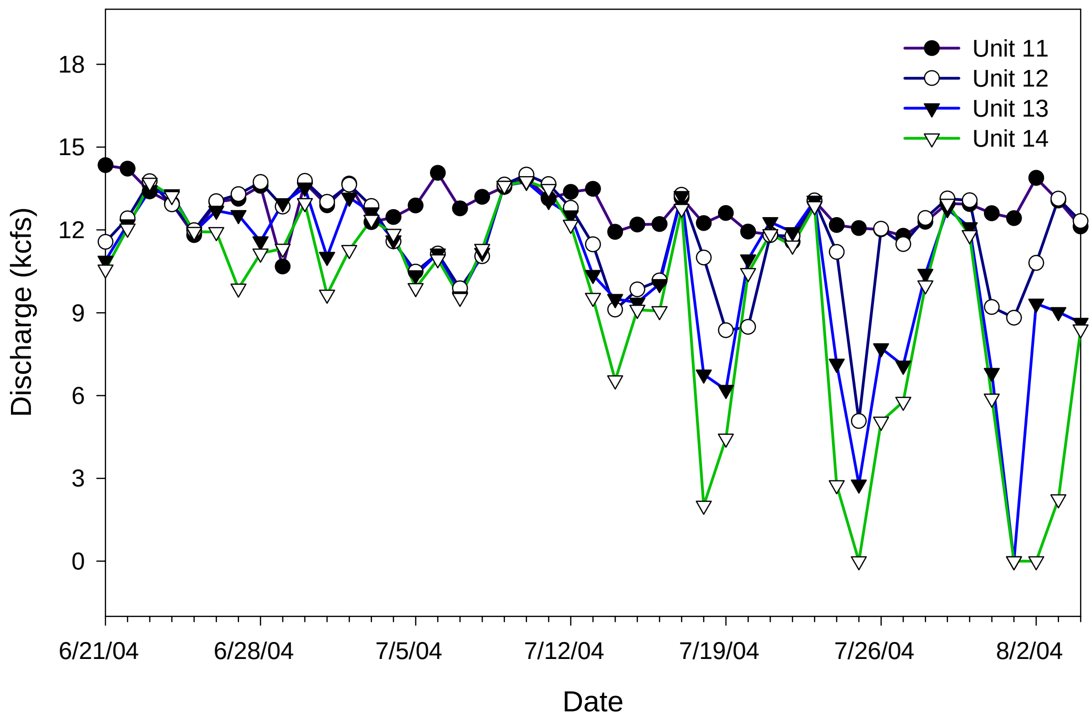

Figure 11.—Mean daily discharge by unit for turbines 11-14 at Bonneville Dam, summer 2004.

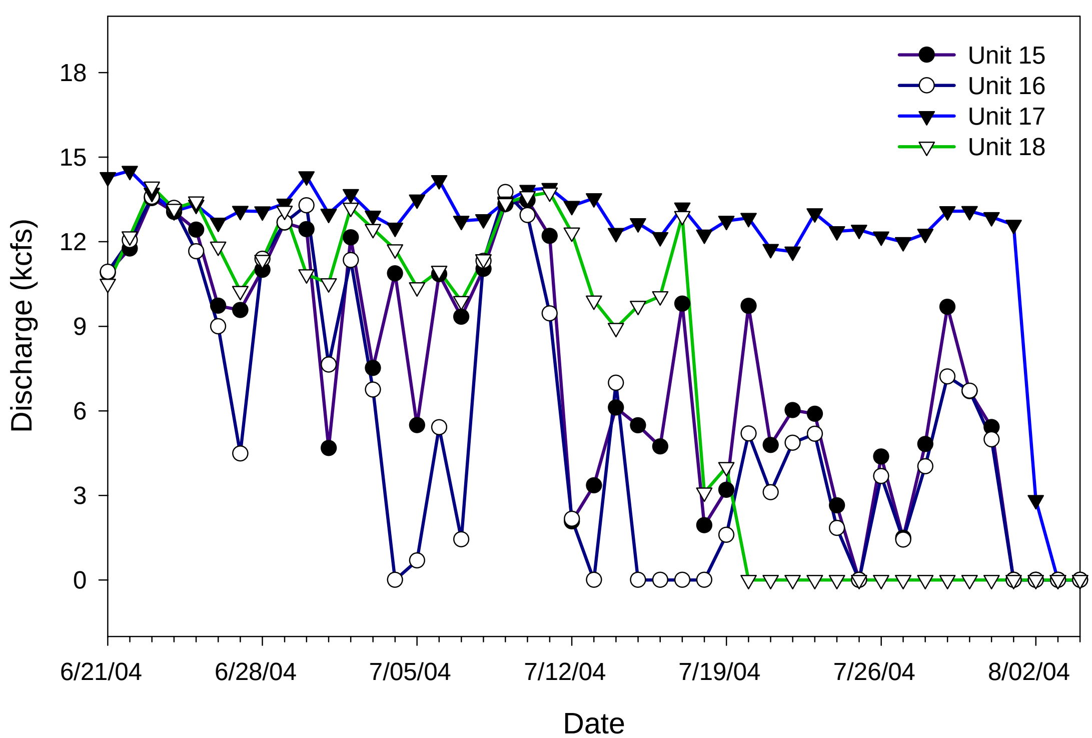

Figure 12.—Mean daily discharge by unit for turbines 15-18 at Bonneville Dam, summer 2004.

Table 2.—Mean discharge (kcfs) during day spill (0400-2059 hours) and night spill (2100-0359 hours) by dam area at Bonneville Dam, summer 2004.

Period and dam area	Percent (of period)	Mean	Median	Min	Max
Day					
First powerhouse	7%	9.9	2.1	0.3	52.2
Second powerhouse	61%	87.6	90.9	38.8	123.8
Spillway	32%	46.3	56.0	30.8	66.3
Total	100%	143.7	142.5	96.2	227.4
Night					
First powerhouse	5%	7.5	3.4	0.6	33.2
Second powerhouse	48%	71.4	70.4	33.2	115.8
Spillway	47%	71.2	70.4	31.2	131.2
Total	100%	150.1	152.0	110.0	200.4

3.4 Travel to and Arrival at Bonneville Dam

At Bonneville Dam, we detected 75% (8,748 of 11,683) of the subyearling Chinook salmon that were released from all of the upstream sites. The median travel rates from release to first detection at Bonneville Dam were 2.1 km/h for fish released from John Day Dam and 2.0 km/h for fish released from The Dalles Dam. The median travel times from release to first detection at Bonneville Dam were 53.9 h from John Day Dam and 37.0 h from The Dalles Dam (Table 3).

Table 3.—Descriptive statistics for travel time (h) and travel rate (km/h) to Bonneville Dam for subyearling Chinook salmon, summer 2004. Travel rate statistics are represented in parentheses.

Release site	Mean	Median	Min	Max
John Day Dam	56.1 (2.1)	53.9 (2.1)	30.4 (0.8)	144.2 (3.7)
The Dalles Dam	38.8 (2.0)	37.0 (2.0)	21.5 (0.6)	133.5 (3.4)

Fish did not enter dam areas (i.e., B1, B2, and spillway) in equal proportions. Of the fish detected at Bonneville Dam, 60% (5,214 of 8,748) first entered the B2 forebay, 35% (3,104 of 8,748) first entered the spillway forebay, and 5% (418 of 8,748) first entered the B1 forebay. Differences in the number of fish entering the forebay of each dam area appeared to be related to allocation of river discharge among dam areas. Discharge allocation at B1, B2, and the spillway was 6%, 56%, and 37%, respectively. To further investigate this relation, we compared the proportion of mean daily discharge through each dam area to the daily proportion of radio-tagged fish that entered each dam area. The daily arrival of fish fluctuated with daily discharge. At all three dam areas, when discharge increased, fish arrival increased. Likewise, when discharge decreased at a dam area, the number of fish entering that dam area decreased (Figure 13).

Similarly, we compared the hourly proportion of fish entering each dam area to the hourly proportion of mean discharge through each dam area. At all three dam areas, fish entrance did not change relative to fluctuations in hourly discharge (Figure 14).

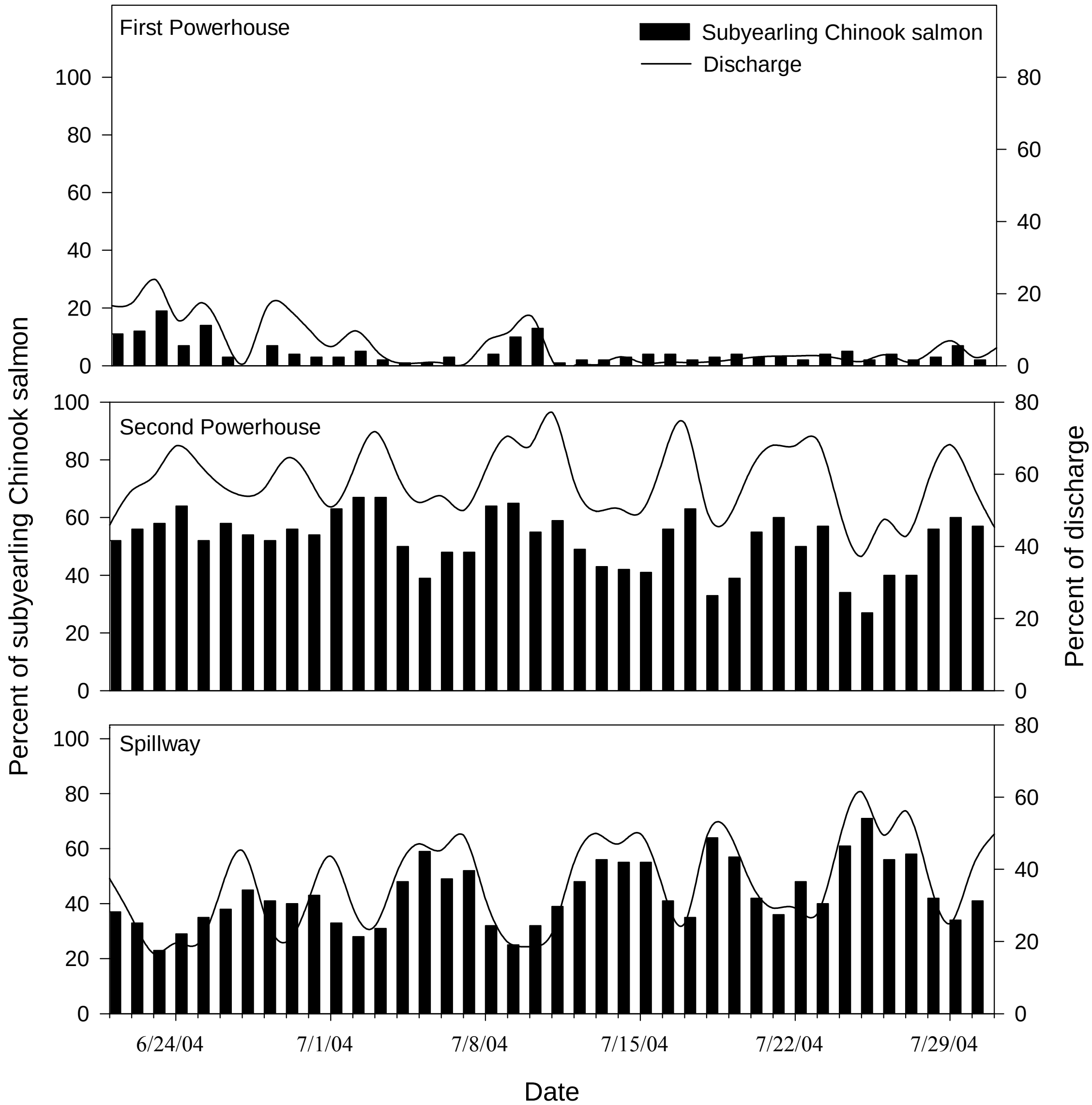

Figure 13.—The percentage of subyearling Chinook salmon that entered each dam area versus the percentage of mean daily discharge at each dam area at Bonneville Dam, summer 2004.

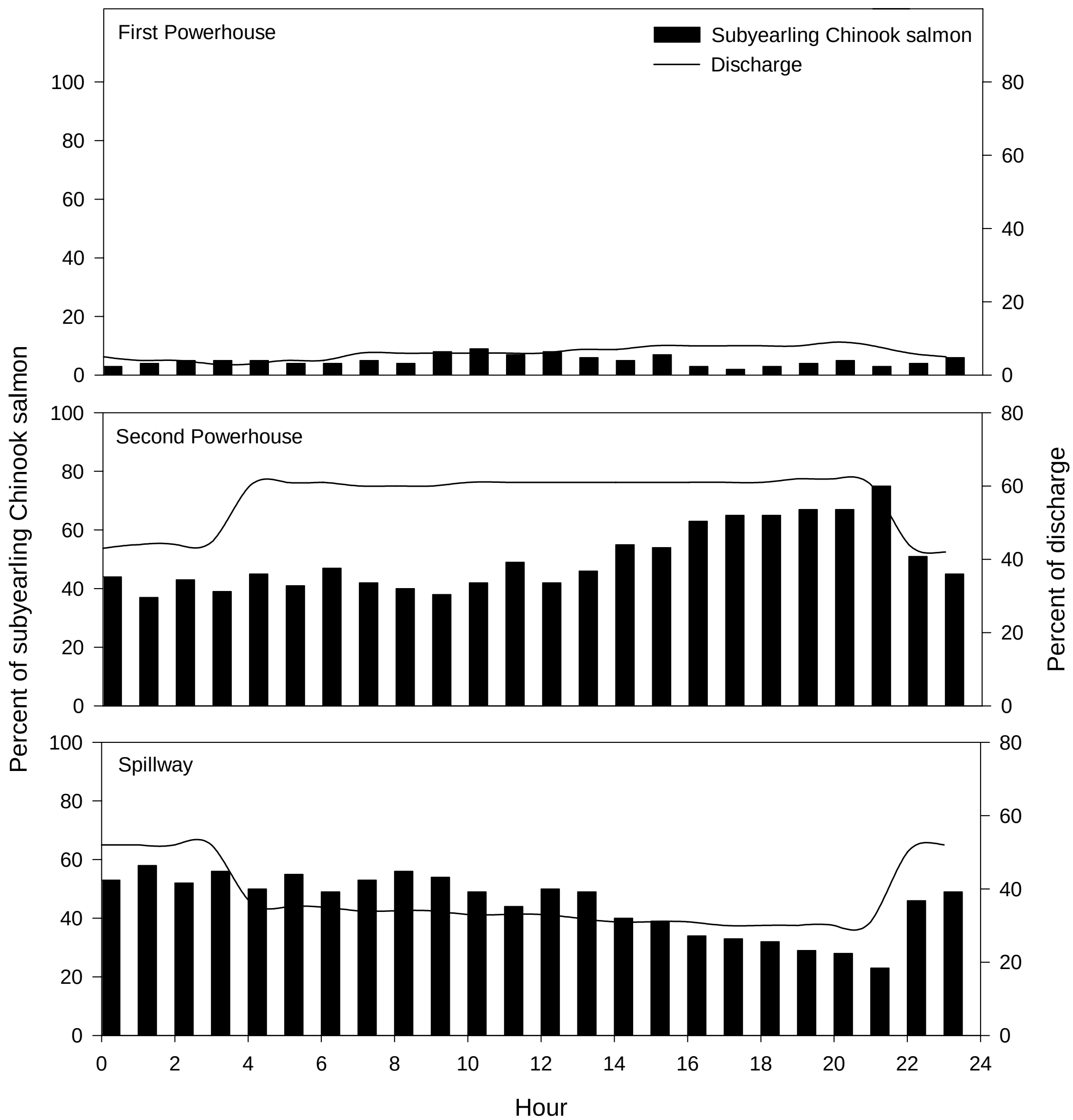

Figure 14.—The percentage of subyearling Chinook salmon that entered each dam area versus the percentage of mean hourly discharge at each dam area at Bonneville Dam, summer 2004.

3.5 Residence Time in the Forebay

Forebay residence time (time from first detection until time of passage) differed between dam areas. Subyearling Chinook salmon resided considerably longer in the forebay of B1 (median = 1.5 h) than in the forebays of B2 (median = 12 min) or the spillway (36 min; Table 4). We compared median forebay residence time by day of passage, by hour of passage, and by hour of arrival to mean discharge and found that residence times generally decreased as discharge increased (Appendices 4-6).

Table 4.—Descriptive statistics of forebay residence time (h) by dam area for subyearling Chinook salmon at Bonneville Dam, summer 2004.

Dam area	N	Mean	Median	Min	Max
First powerhouse	398	5.7	1.5	0.0	134.9
Second powerhouse	3,639	2.1	0.2	0.0	159.0
Spillway	3,062	2.0	0.6	0.0	158.6
All Areas	7,099	2.3	0.4	0.0	159.0

3.6 Route and Time of Passage through Bonneville Dam

We determined the route of passage through Bonneville Dam for nearly 100% (8,739 of 8,748) of subyearling Chinook salmon detected at the dam. Of the nine fish that a passage route could not be determined for, seven were detected upstream of Bonneville Dam after being detected in the forebay and two were likely predated while in the forebay. Not included in the number of fish detected at Bonneville dam are 47 fish detected downstream of the dam but at no other locations. Among the three dam areas, B2 passed the most fish (60%), 35% passed at the spillway, and 5% passed at B1 (Figure 15). The distribution of passage among dam areas was identical to the distribution of approach (based on first detection of fish) among dam areas.

Passage of subyearling Chinook salmon at B1 was distributed relatively equally among the two main routes of passage. Of the 416 fish with known passage routes, 48% (200) passed unguided through the turbines and 47% (196) passed through the sluiceway. The remaining 5% (20) passed through the navigation lock. Passage at B2 was not as equally distributed as at B1. Of the 5,240 fish that passed at B2, 49.6% (2,598) passed unguided through the turbines, 36.8% (1,928) passed through the corner collector, and 13.6% (714) were guided into the DSM (Figure 15).

Passage of subyearling Chinook salmon peaked at sunset (2200 hours) and was lowest at 0300 hours (Figure 16). Overall, during both day and night, more fish passed B2 (60%) than through the spillway (35-36%) and B1 (4-5%; Table 5). During Biop spill, passage increased at the spillway during both diel periods and during 32 kcfs spill, passage increased at B2 during both day and night (Table 5). Of the total number of fish that passed each dam area, a higher number of fish passed during the day for all spill treatments (Table 6). However, since there was a difference in the number of hours in each diel period (16 for day, 8 for night), we also calculated passage rates (fish/hour) for each dam area and diel period. Passage rates were slightly higher during the day and B1. At B2 and the spillway, passage rates were highest at night except during 32 kcfs spill when passage rates were higher during the day at the spillway (Table 7). Hourly passage data for all fish by route of passage and by spill treatment are provided in appendices 7-19.

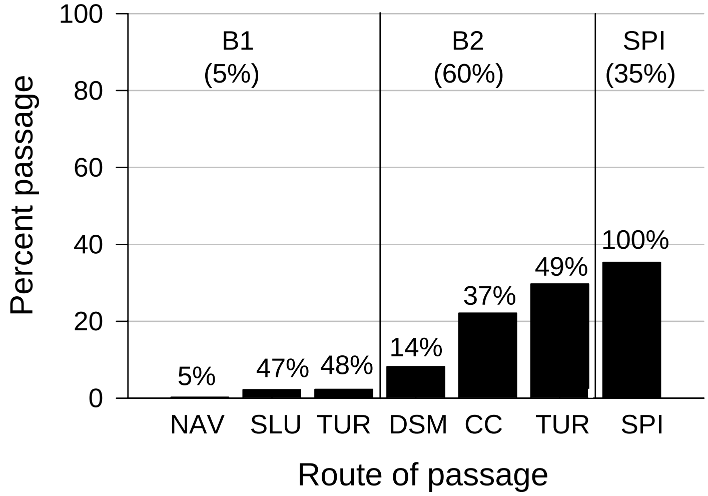

Figure 15.—Percent fish passage by dam area and route of passage for subyearling Chinook salmon at Bonneville Dam, summer 2004. B1 = first powerhouse, B2 = second powerhouse, SPI = spillway, NAV = navigation lock, SLU = sluiceway, TUR = turbine, DSM = downstream salmonid migrants channel, and CC = corner collector. Percentages in parentheses designate proportions among dam areas, percentages without parentheses designate proportions within each dam area, and the percent value of each bar represents proportions of all routes at Bonneville Dam.

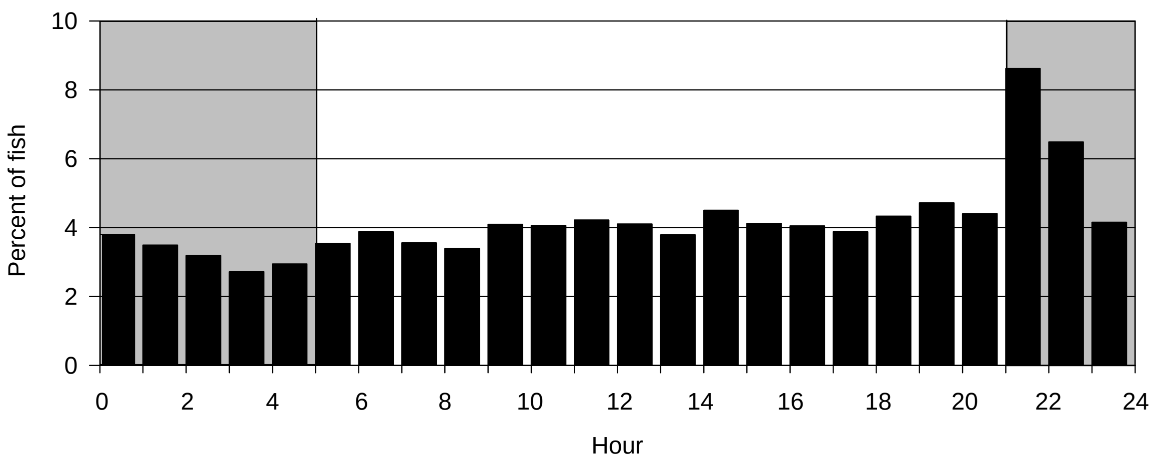

Figure 16.—Percent passage during daytime hours (0500-2059; unshaded) and nighttime hours (2100-0459; shaded) for subyearling Chinook salmon at Bonneville Dam, summer 2004.

Table 5.—Percentage of subyearling Chinook salmon that passed each area of Bonneville Dam during day (0500-2059) and night (2100-0459), summer 2004. Percentages are based on the total number of fish that passed each route during each diel period.

Treatment and	Route of passage		
Diel Period	First powerhouse	Second powerhouse	Spillway
Overall			
Day	5% (298 of 5,637)	60% (3,370 of 5,637)	35% (1,969 of 5,637)
Night	4% (118 of 3,102)	60% (1,870 of 3,102)	36% (1,114 of 3,102)
Biop			
Day	3% (85 of 2,857)	51% (1,466 of 2,857)	46% (1,306 of 2,857)
Night	1% (17 of 1,447)	40% (573 of 1,447)	59% (857 of 1,447)
32 kcfs			
Day	8% (213 of 2,780)	68% (1,904 of 2,780)	24% (663 of 2,780)
Night	6% (101 of 1,655)	78% (1,297 of 1,655)	16% (257 of 1,655)

Table 6.—Percentage of subyearling Chinook salmon that passed each area of Bonneville Dam during day (0500-2059) and night (2100-0459), summer 2004. Percentages are based on the total number of fish that passed each dam area.

Treatment and	Route of passage		
Diel Period	First powerhouse	Second powerhouse	Spillway
Overall			
Day	72% (298 of 416)	64% (3,370 of 5,240)	64% (1,969 of 3,083)
Night	28% (118 of 416)	36% (1,870 of 5,240)	36% (1,114 of 3,083)
Biop			
Day	83% (85 of 102)	72% (1,466 of 2,039)	60% (1,306 of 2,163)
Night	17% (17 of 102)	28% (573 of 2,039)	40% (857 of 2,163)
32 kcfs			
Day	68% (213 of 314)	59% (1,904 of 3,201)	72% (663 of 920)
Night	32% (101 of 314)	41% (1,297 of 3,201)	28% (257 of 920)

Table 7.—Passage rates for subyearling Chinook salmon that passed Bonneville Dam during daytime hours (0500-2059) and nighttime hours (2100-0459), summer 2004. Rates are based on 16 h per 24 h over 40 d for overall day passage and 8 h per 24 h over 40 d for overall night passage. During the 32 kcfs treatment, spill occurred for a total of 320 h during the day and 161 h during the night. During the Biop treatment, spill occurred for a total of 448 h during the day and 151 h during the night.

Treatment and	Route of passage		
Diel Period	First powerhouse	Second powerhouse	Spillway
Overall			
Day	0.5 fish/h	5.3 fish/h	3.1 fish/h
Night	0.4 fish/h	5.8 fish/h	3.5 fish/h
Biop			
Day	0.2 fish/h	3.3 fish/h	2.9 fish/h
Night	0.1 fish/h	3.8 fish/h	5.7 fish/h
32 kcfs			
Day	0.7 fish/h	6.0 fish/h	2.1 fish/h
Night	0.6 fish/h	8.1 fish/h	1.6 fish/h

3.7 Passage Metrics

3.7.1 Spillway Efficiency

Spillway efficiency is the number of fish that passed through the spillway divided by the number of fish that passed through all routes at all dam areas (spillway, B1, and B2). Overall, 35% of subyearling Chinook salmon passed through the spillway. Spillway efficiency was significantly higher ($\chi^2 = 832.2$, df = 1, $P < 0.0001$) during the Biop spill condition, when spill was discharged at 75 kcfs during the day and up to the total dissolved gas cap (mean = 121 kcfs) at night, than during the 32 kcfs treatment, when spill was discharged at 32 kcfs day and night (Table 8).

Table 8.—Spillway Efficiency at Bonneville Dam for subyearling Chinook salmon during summer 2004. Mean discharge spilled during each period is shown in parentheses. SE = standard error of spillway efficiency estimate, B1 = first powerhouse, and B2 = second powerhouse.

Treatment	Spillway efficiency	SE	B1 passage	B2 passage	SPI passage
Overall (54.6)	35%	0.9	416	5,240	3,083
Biop (81.8)	50%	1.1	102	2,040	2,163
32 kcfs (32.1)	21%	1.3	314	3,200	920

3.7.2 Spillway Effectiveness

Spillway effectiveness is the proportion of fish that passed through spill relative to the proportion of project discharge spilled. Overall spillway effectiveness was 0.94 for subyearling Chinook salmon (Table 9). Spill effectiveness during the Biop spill condition (0.92) was similar to spill effectiveness during the 32 kcfs spill condition (0.94).

Table 9.—Spillway effectiveness and efficiency at Bonneville Dam for subyearling Chinook salmon during summer 2004. Mean discharge spilled during each period is shown in parentheses. F_{sp} = mean spillway discharge (kcfs). F_{tot} = mean project discharge (kcfs).

Treatment	Spillway effectiveness	Spillway efficiency	F_{sp}	F_{tot}
Overall (54.6)	0.94	35%	54.6	145.9
Biop (81.8)	0.92	50%	81.8	149.3
32 kcfs (32.1)	0.94	21%	32.1	145.3

3.7.3 Fish Guidance Efficiency

Fish guidance efficiency at B2 (FGE: proportion of fish entering turbine intakes that were guided by turbine intake screens) was 22% for subyearling Chinook salmon overall (Table 10). Since no guidance screens were deployed at B1 in 2004, we could not calculate FGE at B1. Fish guidance efficiency at B2 was significantly higher ($\chi^2 = 8.1$, df = 1, $P = 0.0045$) during Biop spill (24%) than during 32 kcfs spill (20%).

Turbine unit 16 was the most efficient (30%) at guiding Chinook salmon (Table 11). Over twice as many fish passed at the southern half of B2 through units 11-14 than at the northern half through units 15-18. Unit 13 had the lowest guidance efficiency (21%) but guided the most fish (164) and unit 18 guided the least amount of fish (12).

Table 10.—Estimates of fish guidance efficiency (FGE) and corresponding standard error at Bonneville Dam's second powerhouse for subyearling Chinook salmon during summer 2004. Mean discharge spilled during each period and numbers of fish guided of total guided plus unguided are shown in parentheses.

Treatment	Fish guidance efficiency	Standard error
Overall (54.6)	22% (714 of 3,312)	0.7
Biop (81.8)	24% (275 of 1,128)	1.3
32 kcfs (32.1)	20% (439 of 2,184)	0.9

Table 11.—Estimates of fish guidance efficiency (FGE) by turbine unit at Bonneville Dam's second powerhouse for subyearling Chinook salmon, summer 2004.

Turbine Unit	FGE
11	27% (87 of 324)
12	25% (121 of 477)
13	21% (164 of 776)
14	22% (136 of 622)
15	29% (100 of 342)
16	30% (44 of 145)
17	23% (43 of 188)
18	23% (12 of 52)

3.7.4 Fish Passage Efficiency

Fish passage efficiency (FPE: the proportion of fish that passed the dam via non-turbine routes) at Bonneville Dam was 68% (SE = 0.5) overall for subyearling Chinook salmon (Table 12). Fish passage efficiency was significantly higher ($\chi^2 = 492.5$, df = 1, $P < 0.0001$) during the Biop treatment (79%) than during the 32 kcfs treatment (57%).

Table 12.—Fish passage efficiency (FPE) at Bonneville Dam for subyearling Chinook salmon during summer 2004. Passage numbers shown that were used to calculate FPE do not include 20 Chinook salmon that passed through the navigation lock. However, those fish were included in calculations of FPE. B1 = first powerhouse and B2 = second powerhouse.

Treatment	FPE	Sluiceway	B2 guided	Corner collector	Spillway	B1 unguided	B2 unguided
Overall	68%	196	714	1,928	3,083	200	2,598
Biop	79%	51	275	912	2,163	42	853
32 kcfs	57%	145	439	1,016	920	158	1,745

3.7.5 Corner Collector Efficiency

Corner collector efficiency (CCE) is the number of fish that passed through the corner collector divided by the number of fish that passed through all routes at B2. Overall, more than one-third of subyearling Chinook salmon that passed at B2 went through the corner collector (Table 13). Passage through the corner collector was significantly higher ($\chi^2 = 90.6$, df = 1, $P < 0.0001$) during the Biop treatment (45%) than during the 32 kcfs treatment (32%).

Table 13.—Corner collector efficiency (CCE) and effectiveness (CCF) at Bonneville Dam for subyearling Chinook salmon during summer 2004. SE = standard error of corner collector efficiency estimate. F_{cc} = mean corner collector discharge (kcfs). F_{B2} = mean second powerhouse discharge (kcfs).

Treatment	CCE	SE	CCF	F_{cc}	F_{B2}
Overall	37%	0.7	5.6	5.4	82.2
Biop	45%	1.1	5.2	5.4	63.6
32 kcfs	32%	0.8	5.8	5.4	99.3

3.7.6 Corner Collector Effectiveness

Corner collector effectiveness (CCF) is the proportion of fish that passed through the corner collector relative to the proportion of discharge at B2 that went through the corner collector. Overall effectiveness of the corner collector was 5.6 and was higher during the 32 kcfs treatment (5.8) than during the Biop treatment (5.2; Table 13).

3.7.7 Sluiceway Efficiency

Sluiceway efficiency is the number of fish that passed through the B1 sluiceway divided by the number of fish that passed through all routes at B1. Overall, just under half of the subyearling Chinook salmon that passed at B1 passed through the sluiceway (Table 14). Passage through the sluiceway was not significantly different between Biop spill (50%) and 32 kcfs spill (46%; $\chi^2 = 0.45$, df = 1, $P = 0.5017$).

Table 14.—Sluiceway efficiency (SLE) and effectiveness (SLF) at Bonneville Dam for subyearling Chinook salmon during summer 2004. SE = standard error of sluiceway efficiency estimate. F_{SL} = mean sluiceway discharge (kcfs). F_{B1} = mean first powerhouse discharge (kcfs).

Treatment	SLE	SE	SLF	F_{SL}	F_{B1}
Overall	47%	2.5	3.7	1.2	9.1
Biop	50%	5.0	1.7	1.2	3.9
32 kcfs	46%	2.8	5.5	1.2	13.9

3.7.8 Sluiceway Effectiveness

Sluiceway effectiveness (SLF) is the proportion of fish that passed through the B1 sluiceway relative to the proportion of discharge at B1 that went through the sluiceway. Chinook salmon had an overall sluiceway effectiveness of 3.7 (Table 14). Effectiveness of the sluiceway was higher during the 32 kcfs spill treatment (5.5) than during the Biop spill treatment (1.7).

3.8 Comparison of Passage Performance Metrics as Measured by Radio Telemetry and Hydroacoustics

In addition to the radio telemetry evaluation we conducted, Pacific Northwest National Laboratory (PNNL) used fixed hydroacoustics to monitor fish passage and estimate passage performance metrics for the run-at-large. The summer monitoring period for hydroacoustics (June 1 – July 15) was slightly different than it was for our radio telemetry study (June 21 – August 4). We therefore calculated passage metrics during the overlapping period of June 21 – July 15 to directly compare estimates and minimize the effects of variables such as discharge that may have differed during non-overlapping time periods. Differences in passage performance metrics, as estimated by radio telemetry and hydroacoustics, ranged from 2-12% (Table 15). Estimates by both research methods for spillway efficiency, corner collector efficiency$_{Project}$, sluiceway efficiency$_{Project}$, and FPE$_{B1}$, were within 3% of each other. Estimates for FGE$_{B2}$ and FPE$_{B2}$ had the greatest disparity between the two methods. Estimates of FGE by unit at B2 were most similar for the southern units and differed considerably at the northern units (Table 16). Although sample sizes for radio-telemetry estimates were relatively small compared to those for hydroacoustics, standard errors of radio telemetry passage metric estimates ranged from only 0.2% to 2.5%. Standard errors for FGE by unit ranged from 1.5% to 5.9%.

Table 15.—Comparison of passage performance metrics for subyearling Chinook salmon, as measured by radio telemetry (RT), and the run-at-large, as measured by hydroacoustics (HA) during the overlapping period of June 21-July 15, 2004, at Bonneville Dam. Hydroacoustic data were provided by Gene Ploskey, Pacific Northwest National Laboratory (November 20, 2004).

Passage Metric	RT estimate	HA estimate	Difference
Corner Collector Efficiency$_{B2}$	32%	39%	7%
Corner Collector Effectiveness $_{B2}$	5.8	7.1	1.3
Corner Collector Efficiency$_{Project}$	21%	23%	2%
Corner Collector Effectiveness$_{Project}$	6.5	7.1	0.6
Spillway efficiency	29%	33%	4%
Spillway effectiveness	0.9	1.0	0.1
Sluiceway efficiency$_{B1}$	48%	55%	7%
Sluiceway effectiveness$_{B1}$	6.1	7.2	1.1
Sluiceway efficiency$_{Project}$	3%	5%	2%
Sluiceway effectiveness$_{Project}$	4.7	7.8	3.1
FGE$_{B2}$	24%	35%	11%
FPE	63%	73%	10%
FPE$_{B1}$	52%	55%	3%
FPE$_{B2}$	48%	60%	12%

Table 16.—Estimates of Fish Guidance Efficiency (FGE), by turbine unit, at Bonneville Dam's second powerhouse (B2) for subyearling Chinook salmon, as measured by radio telemetry (RT), and for the run-at-large, as measured by hydroacoustics (HA), during the overlapping period of June 21-July 15, 2004. Hydroacoustic data were provided by Gene Ploskey, Pacific Northwest National Laboratory (November 20, 2004).

Location	RT FGE	HA FGE	Difference
Unit 11	31%	40%	9%
Unit 12	25%	27%	2%
Unit 13	23%	30%	7%
Unit 14	22%	37%	15%
Unit 15	31%	49%	18%
Unit 16	35%	41%	6%
Unit 17	23%	41%	18%
Unit 18	25%	16%	9%

3.9 Residence Times at Areas of Potential Delay

According to survey data gathered by the USACE in early 2002, the second powerhouse Juvenile Bypass System (B2 JBS) conveyance pipe had become out-of-round (exceeded the maximum allowable ovality of 8.5%) in two locations and there was concern that these areas may cause delay in travel times of fish. The B2 JBS conveyance pipe transported juvenile salmonids rather quickly in 1999-2001 (Holmberg et al. 2001a, 2001b; Evans et al. 2001a, 2001b) and again in 2002, after the discovery of the ovality issue (Evans et al. 2003a, 2003b). Travel times of juvenile salmonids through the conveyance pipe were monitored again in 2004. The median travel time of guided subyearling Chinook salmon through the B2 JBS conveyance pipe in 2004 was slightly less than travel times through the pipe in 1999-2002, indicating that fish were not delayed in the pipe (Table 17).

Table 17.—Median travel times (min) for subyearling Chinook salmon passing through Bonneville Dam's second powerhouse juvenile bypass system conveyance pipe during summer study periods of 1999-2004.

	1999	2000	2001	2002	2004
Chinook salmon	41.3[a]	36.5	38.1	35.9	35.0

[a]Residence times in 1999 were based on travel from the top of the pipe to the outfall. Residence times in 2000-2004 were based on travel from the top of the pipe to the fish sampling facility, which was not yet completed in 1999.

4.0 Discussion

The proportion of discharge allocated to each dam area was likely the determining factor for which forebay fish entered and subsequently passed. Based on our analysis of percent discharge per dam area by day related to percent of fish that entered each dam area, fish appeared to follow the bulk flow, entering the dam area with the highest proportion of discharge. Since B2 discharged the greatest amount of water during the study (56%), most fish entered the B2 forebay (60%). Since flows were lowest at B1 (6% of project discharge), only 5% of Chinook salmon entered that dam area.

Forebay residence times were also affected by discharge. Subyearling Chinook salmon spent the least amount of time (12 min) in the forebay of B2, the structure with the highest project discharge. Residence time was longest in the forebay of B1, which had the lowest project discharge. No relation was apparent between daily discharge patterns, hour of arrival, or hour of passage and residence time. Therefore, total discharge per dam area seemed to be the primary factor affecting residence times of subyearling Chinook salmon. These observations indicate that project operations and the resulting discharge per dam area influence approach paths of migrating subyearling Chinook salmon and consequently determine which dam area smolts enter and pass. Likewise, discharge per dam area affected how long fish resided in the forebay of Bonneville Dam before passing.

Of all radio-tagged subyearling Chinook salmon with known passage routes, 76% passed Bonneville Dam through relatively deep routes of passage (the spillway or the turbine intakes). More than one-third of all Chinook salmon that passed Bonneville Dam went through the spillway, where fish must descend about 15 m to pass. At B2, subyearling Chinook salmon passed more readily through the deeper turbine intakes (50% unguided, 14% guided) than through the surface-oriented corner collector (37%). At B1, the proportion of radio-tagged fish that passed through specific routes was more evenly distributed between the deeper turbine intakes (48% unguided) and the shallow, weir-type entrances of the sluiceway (47%). These data indicate that subyearling Chinook salmon were probably distributed relatively deep in the water column and were less likely to pass Bonneville Dam using one of the surface-oriented passage structures.

Passage distributions reflected discharge allocation when comparing the two spill treatments. During the Biop spill treatment, most radio-tagged subyearling Chinook salmon (50%) passed the spillway, which had the highest proportion of project discharge (55%) at times of Biop spill. Likewise, during the 32 kcfs spill condition, most fish (72%) passed at B2, which had the highest proportion of project discharge (68%) at times of 32 kcfs spill. Passage distributions fluctuated with diurnal periods but were confounded because discharge also varied diurnally. Passage distributions were highest at B2 during both day and night. Discharge was also highest (54% of project flow) at B2 during the day but at the spillway during the night (53% of project flow). Thus, it is difficult to determine whether diurnal periods or discharge were more responsible for fluctuating passage distributions. During summer 2002, when discharge was nearly equal during day and night for all dam areas and when the only passage route through B2 was through the turbines or bypass system, fish passage increased during the night at all dam areas (Evans et al. 2003a). Daytime passage during summer 2004 at both powerhouses was primarily through the shallow sluiceway (49% of B1) and corner collector (47% of B2), while nighttime passage at both powerhouses was primarily through the deeper turbines (B1 = 58% unguided and B2 = 56% unguided, 26% guided). Therefore, past and present research at Bonneville Dam shows that fish passage increases at night through deep routes of passage like the turbines and spillway, and increases during the day through shallow routes of passage like the sluiceway and corner collector. These findings concur with numerous studies regarding juvenile salmonid behavior at hydroelectric projects. Coutant and Whitney (2000) reported in a review of literature on fish behavior relative to passage of fish through hydropower turbines that emigrating salmonids descend, mostly at night, to pass the dam through the turbines or turbine intake bypass system. Surface-oriented passage of juvenile salmonids has been shown to increase during the day at Bonneville Dam (Willis and Uremovich 1981; Magne et al.1989; Evans et al. 2001a) as well as at other Columbia River Basin projects (Nichols et al. 1978; Raymond and Sims 1980; Ransom and Ouellette 1991). These data suggest that since fish tend to follow flow and pass in a diurnal pattern, discharge and diurnal period can have a synergistic effect on fish passage if discharge is allocated to the right dam area at the right time.

Of the two spill conditions tested at Bonneville Dam in 2004, the Biop treatment had generally higher passage metrics than the 32 kcfs treatment. The only metrics that were higher during 32 kcfs spill were sluiceway and corner collector effectiveness. This can be attributed to the increase in discharge through the turbines at both powerhouses during 32 kcfs spill, decreasing the proportion of total powerhouse discharge that went through the sluiceway or corner collector, thereby increasing effectiveness.

Passage metrics for subyearling Chinook salmon were generally lower in 2004 than in 2002 (Table 18). The only passage metrics that were higher in 2004 were FPE_{B2} and sluiceway $efficiency_{B1}$. If guidance screens had been deployed at B1 in 2004, FPE_{B1} and $FPE_{project}$ would have been higher. However, due to low discharge at B1 in 2004, relatively few fish passed there and the increase would have been minimal. Fish guidance efficiency at B2 in 2004 was the lowest of all study years. We hypothesize that low FGE_{B2} in 2004 was due to the corner collector passing the majority of the shallow fish that may otherwise have been guided. Spillway efficiency decreased in 2004 because more fish passed at B2, specifically through the corner collector. The increased passage at B2 through the corner collector is reflected in increased $FPE_{B2.}$ Although the addition of the corner collector did not increase $FPE_{project}$, it did achieve an $FPE_{project}$ of 68% with far less water than would have been used to attain the same FPE without the corner collector. The spillway discharged an average of 10 times more water than the corner collector. Consequently, effectiveness of the corner collector relative to the project (5.9) was far greater than effectiveness of the spillway (0.9). Our results indicate that although the intake screen guidance systems at Bonneville Dam have poor guidance efficiency, project FPE of nearly 80% can be attained for subyearling Chinook salmon under a Biop spill condition in conjunction with the operation of the B2 corner collector. Additionally, by strategically optimizing discharge patterns at the project, passage of juvenile salmonids can be increased temporally and spatially.

The comparison of our estimates of passage metrics with those obtained with hydroacoustics demonstrates the importance of having more than one independent estimate of passage performance. Although each research tool has its strengths, each tool also has its weaknesses. Radio telemetry is useful because it enables the investigator to obtain information on a species-specific basis and it has a relatively wide range of spatial resolution in terms of coverage area. However, radio telemetry sample size is often restricted by costs of tags and the number of radio-tagged fish that can be tracked concurrently. Hydroacoustic sampling is an effective means of obtaining information on numerous fish, but deciphering fish species or obtaining information on individual fish is not currently possible. Therefore it can be advantageous to utilize both technologies to overcome the limitations of each method. We do not have a clear explanation of why differences in passage metric estimates for radio telemetry and hydroacoustics were, in some instances, so great (up to 18%). The smaller sample sizes utilized by radio telemetry may have contributed to these differences. However, standard errors for radio telemetry estimates were very low (≤ 2.5%). Equally plausible is the possibility that because hydroacoustics sampled the run-at-large, passage estimates may have been based on a mixture of species with different passage behavior than subyearling Chinook salmon.

Table 18.—Passage performance metrics for subyearling Chinook salmon at Bonneville Dam during summer study periods of 2000, 2001, 2002, and 2004. B1 = first powerhouse and B2 = second powerhouse.

Passage Metric	2000	2001	2002	2004
Spillway efficiency	65%	2%	58%	35%
Spillway effectiveness	1.2	0.8	1.3	0.9
FGE_{B1} [a]	29%	57%	43%	-----
FGE_{B2}	25%	35%	47%	22%
$FPE_{Project}$	91%	40%	82%	68%
FPE_{B1}	77%	89%	72%	52%
FPE_{B2}	25%	35%	47%	50%
Sluiceway $efficiency_{B1}$	29%	77%	35%	53%
Sluiceway $effectiveness_{B1}$ [b]	-----	-----	18.6	14.5
Corner collector $efficiency_{B2}$	-----	-----	-----	37%
Corner collector $effectiveness_{B2}$	-----	-----	-----	5.6
Corner collector $efficiency_{Project}$	-----	-----	-----	22%
Corner collector $effectiveness_{Project}$	-----	-----	-----	5.9

[a] In 2004, FGE_{B1} could not be estimated due to the absence of guidance screens.
[b] In 2000 and 2001, sluiceway effectiveness could not be estimated due to the absence of sluiceway discharge data.

5.0 Acknowledgements

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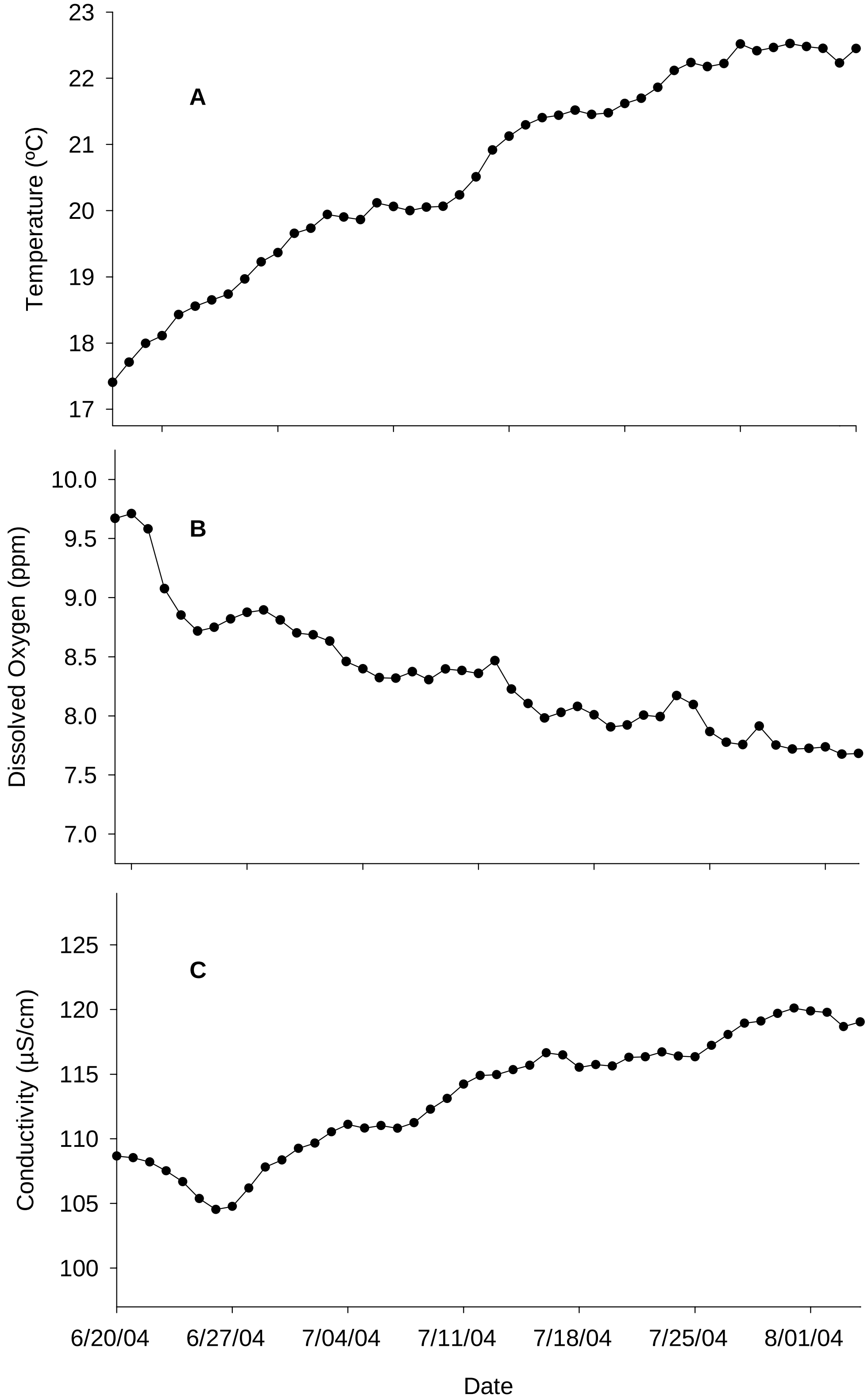
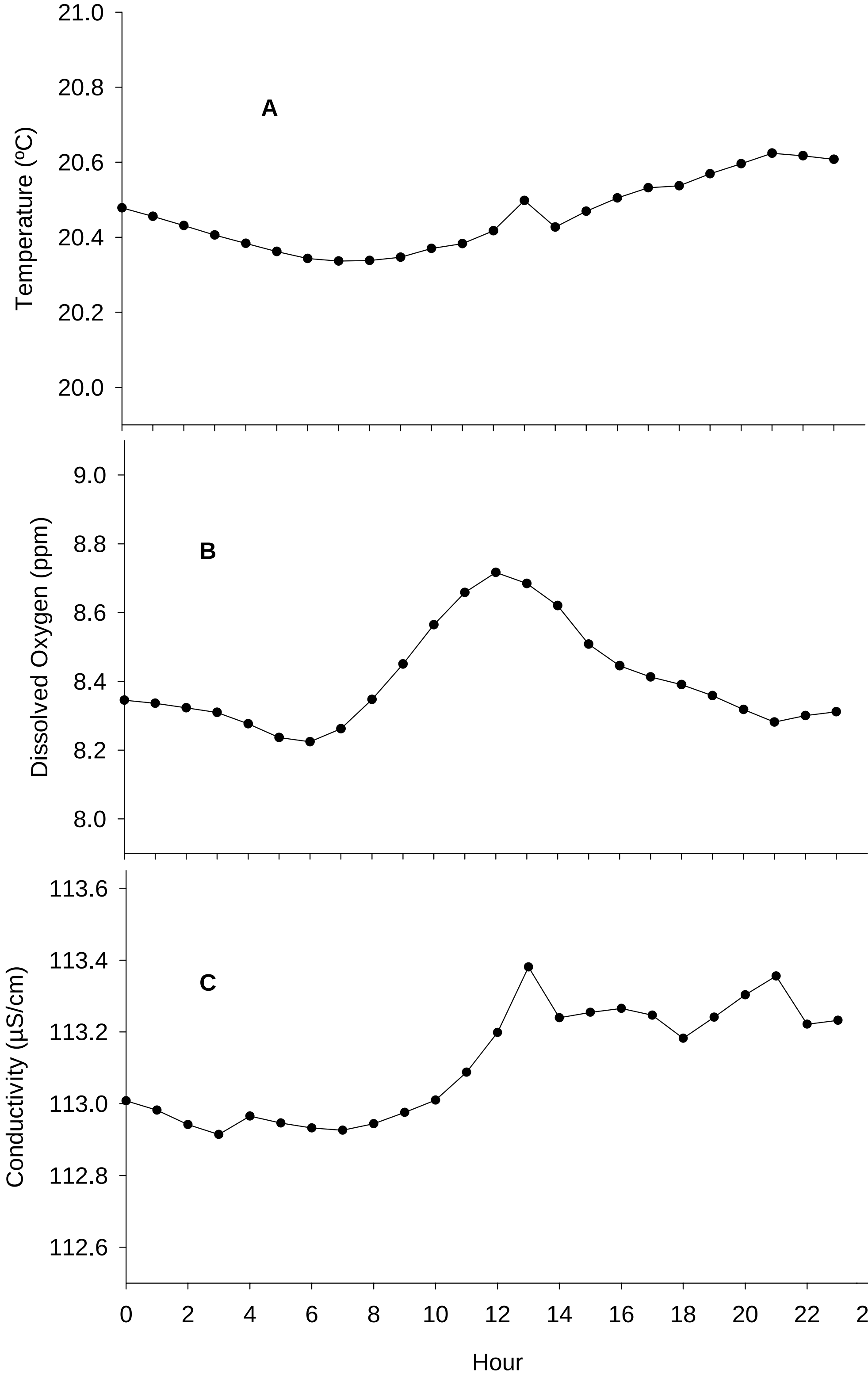
7.0 Appendices



Appendix 1.—Mean daily temperature (A), dissolved oxygen (B), and conductivity (C) at Bonneville Dam 1.5 m below water surface in the forebay of the spillway from 20 June to 4 August 2004.



Appendix 2.—Mean hourly temperature (A), dissolved oxygen (B), and conductivity (C) at Bonneville Dam 1.5 m below water surface in the forebay of the spillway from 20 June to 4 August 2004.

Appendix 3.—Mean weight and fork length, and their associated standard deviations (SD), for subyearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDT), summer 2004.

Release				Weight (g)		Fork Length (mm)	
Date	Dam	Time	N	Mean	SD	Mean	SD
6/19/2004	JDT	18:00	29	16.2	2.4	116	6
6/19/2004	JDT	6:00	31	16.2	2.0	115	5
6/20/2004	TDA	13:00	106	16.6	3.1	117	7
6/20/2004	JDT	18:00	29	17.8	3.3	118	7
6/20/2004	TDA	1:00	117	18.6	4.1	119	9
6/20/2004	JDT	6:00	30	17.4	2.9	119	7
6/20/2004	TDA	7:00	61	17.8	3.6	119	7
6/21/2004	TDA	13:00	172	18.2	3.8	121	8
6/21/2004	JDT	18:00	32	15.7	1.7	114	3
6/21/2004	TDA	1:00	117	18.1	3.5	118	7
6/21/2004	JDT	6:00	31	18.2	3.4	120	8
6/22/2004	TDA	13:00	65	17.4	3.1	119	7
6/22/2004	JDT	18:00	30	15.7	1.8	115	4
6/22/2004	TDA	1:00	175	17.5	3.3	119	7
6/22/2004	JDT	6:00	30	20.9	4.4	124	8
6/23/2004	TDA	13:00	118	17.1	3.4	118	8
6/23/2004	JDT	18:00	31	15.0	1.7	114	4
6/23/2004	TDA	19:00	61	16.9	2.7	116	6
6/23/2004	TDA	1:00	116	18.5	3.2	119	7
6/23/2004	JDT	6:00	31	18.0	3.2	118	7
6/24/2004	TDA	13:00	118	16.4	3.4	116	7
6/24/2004	JDT	18:00	29	14.6	1.0	112	2
6/24/2004	TDA	19:00	59	14.8	2.1	114	5
6/24/2004	TDA	1:00	117	16.5	2.4	115	5
6/24/2004	JDT	6:00	31	15.7	1.9	115	4
6/25/2004	TDA	13:00	105	16.0	3.3	116	7
6/25/2004	JDT	18:00	31	14.5	1.0	112	2
6/25/2004	TDA	1:00	88	15.3	3.0	115	6
6/25/2004	JDT	6:00	30	15.8	3.6	116	7
6/26/2004	TDA	13:00	46	16.5	4.9	117	9
6/26/2004	JDT	18:00	23	17.4	6.5	119	11
6/26/2004	TDA	1:00	89	15.6	3.2	115	7
6/26/2004	JDT	6:00	22	15.6	5.9	115	10
6/26/2004	TDA	7:00	58	16.3	4.7	115	8
6/27/2004	TDA	13:00	35	19.2	6.5	121	11
6/27/2004	JDT	18:00	17	15.4	1.2	114	2
6/27/2004	TDA	1:00	47	17.6	4.1	118	8
6/27/2004	JDT	6:00	25	16.9	5.4	118	10
6/28/2004	TDA	13:00	14	16.2	3.3	116	6
6/28/2004	JDT	18:00	29	15.8	1.9	115	4
6/28/2004	TDA	1:00	32	17.5	4.3	118	9
6/28/2004	JDT	6:00	16	15.2	1.5	113	1
6/28/2004	TDA	7:00	27	16.5	3.2	116	6
6/29/2004	TDA	13:00	81	16.1	3.7	115	7
6/29/2004	JDT	18:00	20	15.9	2.6	115	6

Appendix 3 (continued) .—Mean weight and fork length, and their associated standard deviations (SD), for subyearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDT), summer 2004.

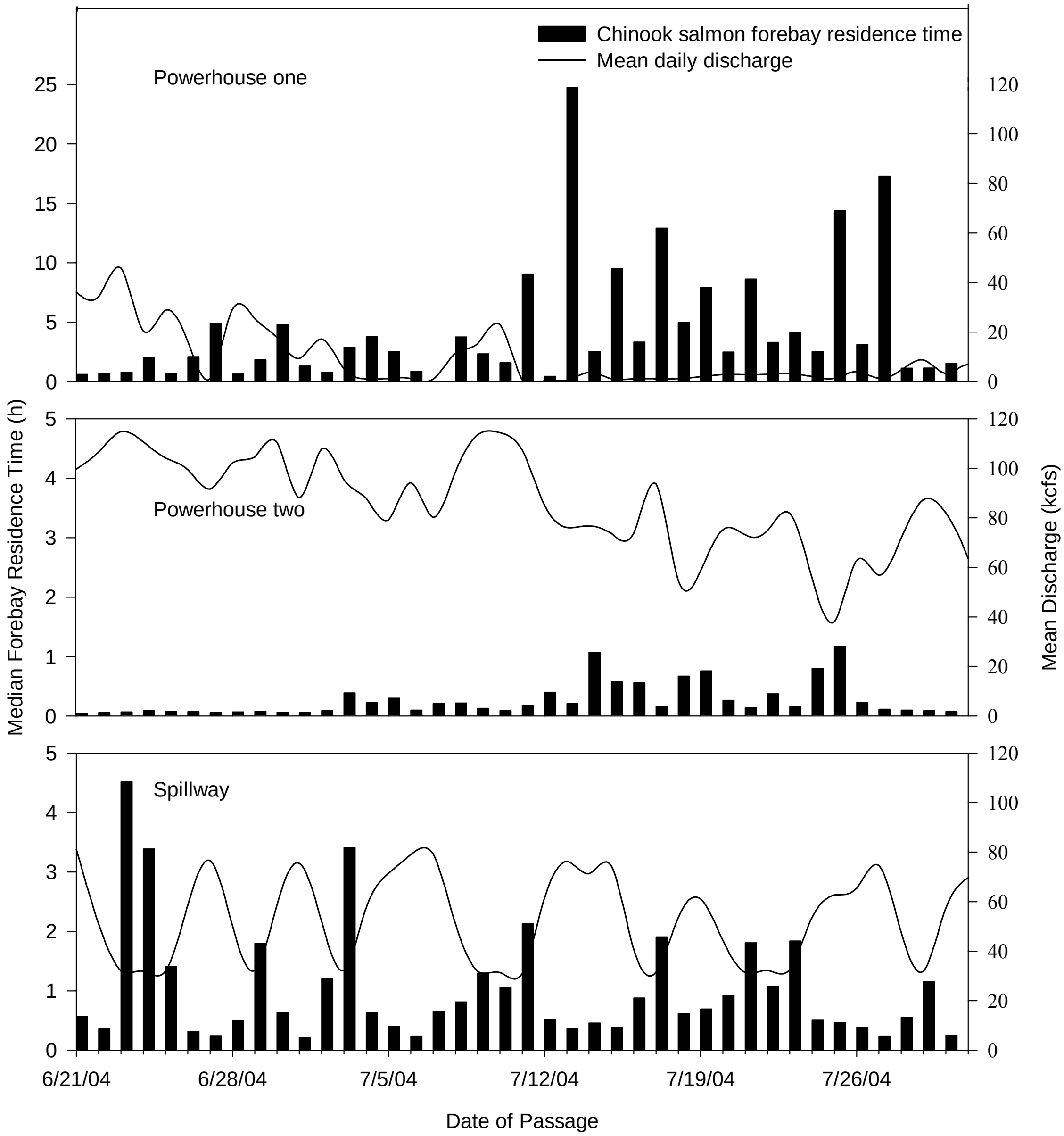
Release				Weight (g)		Fork Length (mm)	
Date	Dam	Time	N	Mean	SD	Mean	SD
6/29/2004	TDA	19:00	25	15.7	2.7	114	6
6/29/2004	TDA	1:00	58	16.3	2.3	114	4
6/29/2004	JDT	6:00	29	17.3	4.4	117	9
6/30/2004	TDA	13:00	165	16.2	3.9	115	8
6/30/2004	JDT	18:00	28	17.5	4.1	116	9
6/30/2004	TDA	1:00	65	16.6	4.1	116	8
6/30/2004	JDT	6:00	20	14.7	1.5	113	3
7/1/2004	TDA	13:00	185	16.2	3.7	115	7
7/1/2004	JDT	18:00	20	16.3	3.0	116	7
7/1/2004	TDA	1:00	101	15.5	3.6	115	8
7/1/2004	JDT	6:00	27	15.8	3.5	115	7
7/2/2004	TDA	13:00	53	16.0	3.5	115	7
7/2/2004	JDT	18:00	21	17.3	4.6	116	8
7/2/2004	TDA	1:00	61	16.0	3.6	116	8
7/2/2004	JDT	6:00	20	14.7	1.1	112	3
7/3/2004	TDA	13:00	50	16.1	3.9	115	8
7/3/2004	JDT	18:00	20	16.6	3.9	114	6
7/3/2004	TDA	19:00	39	16.0	2.9	115	6
7/3/2004	TDA	1:00	73	16.7	5.6	115	10
7/3/2004	JDT	6:00	22	17.2	4.0	116	8
7/4/2004	TDA	13:00	48	17.4	4.8	117	10
7/4/2004	JDT	18:00	17	20.2	7.2	123	15
7/4/2004	TDA	1:00	40	15.9	3.3	114	7
7/4/2004	JDT	6:00	19	16.7	5.5	116	11
7/5/2004	TDA	13:00	27	16.8	5.1	116	9
7/5/2004	JDT	18:00	18	15.3	1.3	113	3
7/5/2004	TDA	1:00	64	18.6	5.9	117	11
7/5/2004	JDT	6:00	17	18.9	5.6	120	11
7/5/2004	TDA	7:00	32	17.5	6.4	116	12
7/6/2004	TDA	13:00	100	17.6	6.1	116	11
7/6/2004	JDT	18:00	19	15.7	2.4	111	4
7/6/2004	TDA	1:00	67	19.0	6.2	119	12
7/6/2004	JDT	6:00	18	16.3	3.9	115	8
7/7/2004	TDA	13:00	184	17.1	4.2	116	9
7/7/2004	JDT	18:00	22	16.1	4.7	114	8
7/7/2004	TDA	1:00	43	16.2	3.1	114	7
7/7/2004	JDT	6:00	19	17.9	6.6	118	11
7/8/2004	TDA	13:00	79	15.7	3.6	113	8
7/8/2004	JDT	18:00	19	15.1	2.3	111	5
7/8/2004	TDA	19:00	26	17.1	5.2	116	11
7/8/2004	TDA	1:00	82	16.2	4.4	114	9
7/8/2004	JDT	6:00	20	18.3	6.6	120	13
7/9/2004	TDA	13:00	39	15.3	2.8	111	6
7/9/2004	JDT	18:00	19	18.6	7.6	118	14
7/9/2004	TDA	1:00	36	18.7	6.4	119	13

Appendix 3 (continued) .—Mean weight and fork length, and their associated standard deviations (SD), for subyearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDT), summer 2004.

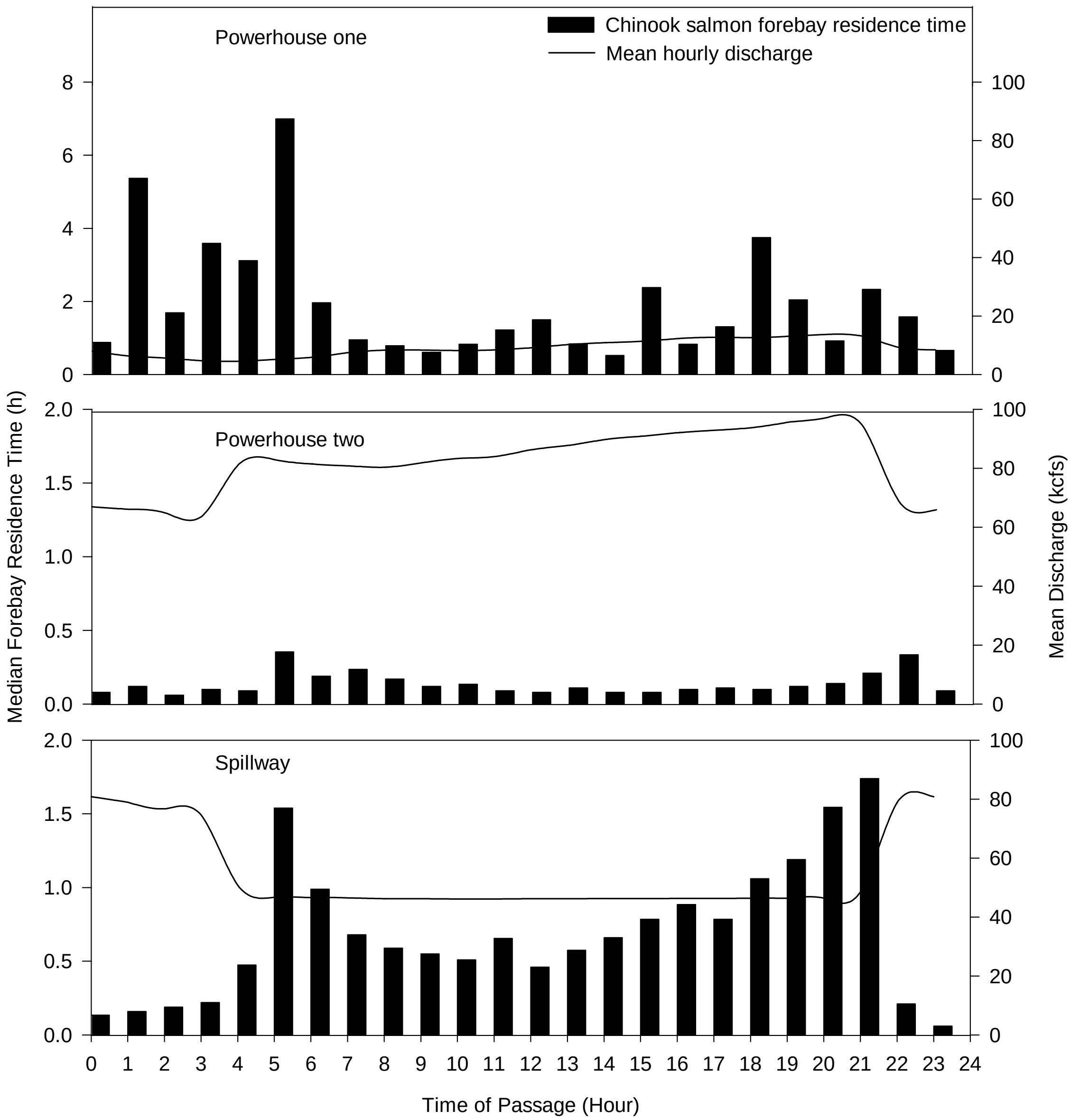
Release				Weight (g)		Fork Length (mm)	
Date	Dam	Time	N	Mean	SD	Mean	SD
7/9/2004	JDT	6:00	13	16.9	3.9	116	9
7/10/2004	TDA	13:00	92	18.0	6.6	118	13
7/10/2004	JDT	18:00	23	19.6	7.4	121	14
7/10/2004	TDA	1:00	78	17.6	5.1	115	11
7/10/2004	JDT	6:00	14	15.7	5.5	114	10
7/11/2004	TDA	13:00	60	22.9	10.5	127	17
7/11/2004	JDT	18:00	20	16.0	3.6	115	9
7/11/2004	TDA	1:00	58	21.3	7.5	124	14
7/11/2004	JDT	6:00	23	20.6	8.5	125	13
7/11/2004	TDA	7:00	55	20.3	6.4	124	13
7/12/2004	TDA	13:00	59	18.7	6.4	119	12
7/12/2004	JDT	18:00	16	17.2	5.1	116	10
7/12/2004	TDA	1:00	101	19.8	7.1	120	13
7/12/2004	JDT	6:00	20	16.7	4.6	117	10
7/13/2004	TDA	13:00	49	21.4	8.5	125	17
7/13/2004	JDT	18:00	20	19.7	5.8	124	12
7/13/2004	TDA	19:00	42	25.6	9.8	133	16
7/13/2004	TDA	1:00	63	21.6	9.2	125	16
7/13/2004	JDT	6:00	14	20.3	4.2	126	10
7/14/2004	TDA	13:00	21	18.1	4.9	120	12
7/14/2004	JDT	18:00	28	17.4	4.0	115	10
7/14/2004	TDA	1:00	25	23.1	8.6	129	14
7/14/2004	JDT	6:00	18	26.1	11.8	131	18
7/14/2004	TDA	7:00	47	22.5	8.6	128	15
7/15/2004	TDA	13:00	62	17.6	4.6	119	11
7/15/2004	JDT	18:00	22	16.1	5.1	115	10
7/15/2004	TDA	1:00	162	17.8	5.2	118	11
7/15/2004	JDT	6:00	24	17.2	4.4	116	10
7/16/2004	TDA	13:00	110	17.9	5.2	118	11
7/16/2004	JDT	18:00	29	17.4	3.8	117	9
7/16/2004	TDA	1:00	68	17.5	4.7	118	10
7/16/2004	JDT	6:00	24	18.7	5.7	118	10
7/17/2004	TDA	13:00	106	19.1	5.9	121	12
7/17/2004	JDT	18:00	33	17.1	3.2	116	7
7/17/2004	TDA	19:00	56	16.5	2.5	115	7
7/17/2004	TDA	1:00	101	19.6	7.6	121	14
7/17/2004	JDT	6:00	31	22.5	8.1	129	15
7/18/2004	TDA	13:00	167	17.7	5.2	117	10
7/18/2004	JDT	18:00	30	17.2	3.0	114	8
7/18/2004	TDA	1:00	79	16.9	4.7	114	8
7/18/2004	JDT	6:00	20	17.0	4.2	117	11
7/19/2004	TDA	13:00	158	17.2	5.0	116	10
7/19/2004	JDT	18:00	33	16.7	4.4	115	10
7/19/2004	TDA	1:00	162	16.5	3.7	115	8
7/19/2004	JDT	6:00	33	17.7	3.5	117	8

Appendix 3 (continued) .—Mean weight and fork length, and their associated standard deviations (SD), for subyearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDT), summer 2004.

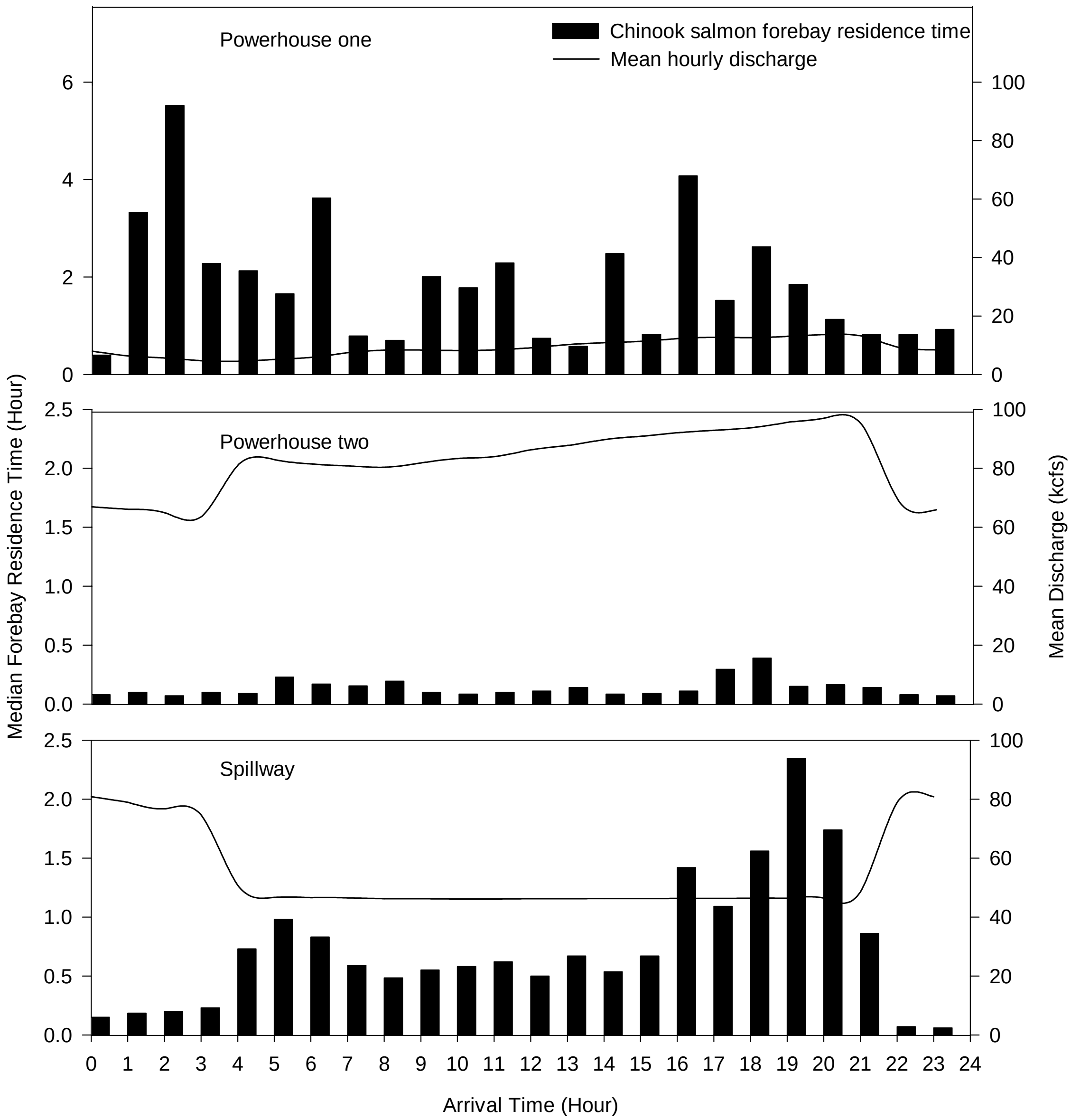
Release				Weight (g)		Fork Length (mm)	
Date	Dam	Time	N	Mean	SD	Mean	SD
7/19/2004	TDA	7:00	67	16.0	2.0	113	6
7/20/2004	TDA	13:00	193	16.3	3.3	114	8
7/20/2004	JDT	18:00	32	19.3	8.7	116	13
7/20/2004	TDA	1:00	166	16.1	2.9	113	7
7/20/2004	JDT	6:00	31	16.1	3.4	115	8
7/21/2004	TDA	13:00	134	17.3	6.0	115	10
7/21/2004	JDT	18:00	35	15.2	2.3	111	6
7/21/2004	TDA	19:00	66	18.7	7.6	118	14
7/21/2004	TDA	1:00	154	16.2	3.9	114	8
7/21/2004	JDT	6:00	35	18.3	5.2	118	10
7/22/2004	TDA	13:00	214	16.6	3.3	113	8
7/22/2004	JDT	18:00	34	16.6	4.7	113	11
7/22/2004	TDA	1:00	155	15.6	2.2	112	6
7/22/2004	JDT	6:00	34	17.7	5.9	116	11
7/23/2004	TDA	13:00	167	17.4	4.2	114	10
7/23/2004	JDT	18:00	21	15.4	1.9	111	6
7/23/2004	TDA	1:00	154	16.3	4.8	112	9
7/23/2004	JDT	6:00	36	16.8	4.1	114	9
7/23/2004	TDA	7:00	64	17.2	4.5	114	10
7/24/2004	TDA	13:00	161	15.9	2.7	112	6
7/24/2004	JDT	18:00	52	15.8	2.1	110	5
7/24/2004	TDA	19:00	60	17.1	3.2	113	7
7/24/2004	TDA	1:00	152	16.4	3.5	112	8
7/24/2004	JDT	6:00	31	17.9	3.4	115	8
7/25/2004	TDA	13:00	163	16.5	3.6	114	8
7/25/2004	JDT	18:00	50	16.2	2.7	113	7
7/25/2004	TDA	1:00	218	17.0	2.9	113	7
7/25/2004	JDT	6:00	50	17.0	3.2	112	8
7/26/2004	TDA	13:00	193	16.0	2.6	112	6
7/26/2004	JDT	18:00	57	17.6	3.0	111	7
7/26/2004	TDA	1:00	161	16.3	2.9	111	6
7/26/2004	JDT	6:00	63	16.5	2.9	113	7
7/27/2004	TDA	13:00	161	17.3	3.9	114	8
7/27/2004	JDT	18:00	35	15.5	2.4	110	6
7/27/2004	TDA	1:00	205	16.1	2.5	111	6
7/27/2004	JDT	6:00	60	16.7	3.7	112	8
7/28/2004	TDA	13:00	164	16.9	3.5	113	8
7/28/2004	JDT	18:00	46	16.5	2.7	109	6
7/28/2004	TDA	1:00	159	16.4	3.2	111	7
7/28/2004	JDT	6:00	32	16.4	3.7	112	9
7/28/2004	TDA	7:00	44	15.3	2.0	109	5
7/29/2004	TDA	13:00	170	17.3	3.1	115	7
7/29/2004	TDA	19:00	49	17.2	3.0	114	7
7/29/2004	TDA	1:00	154	16.6	2.6	113	6



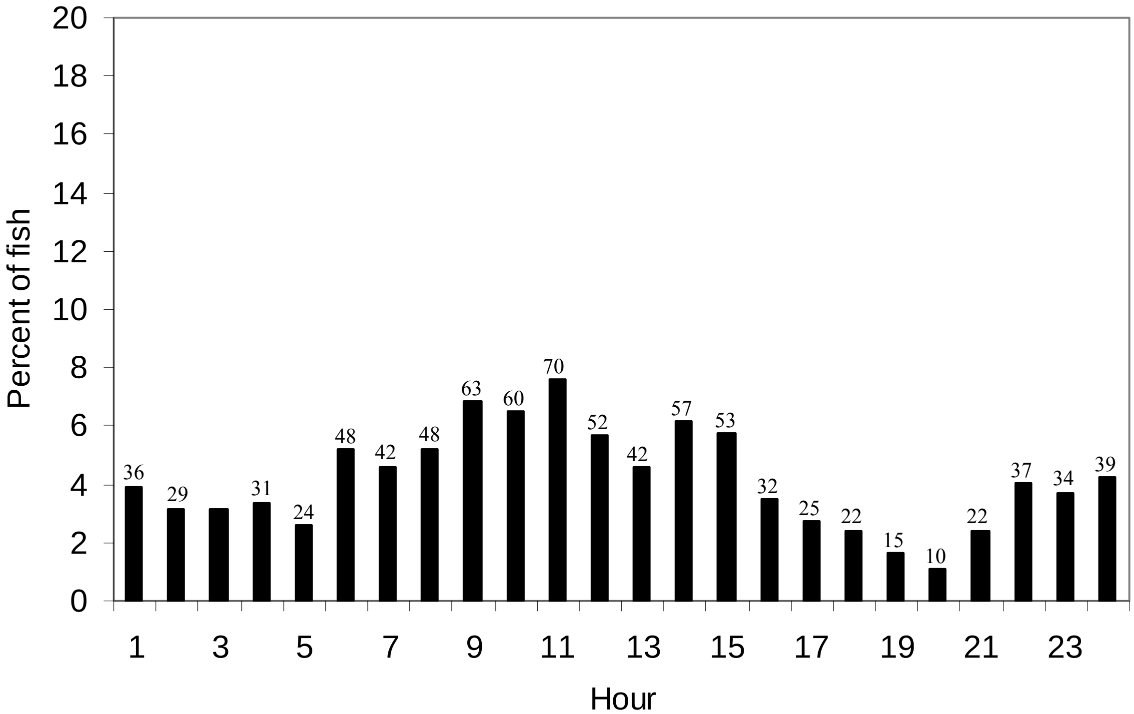
Appendix 4.—Median forebay residence time by day of passage versus mean discharge by dam area for subyearling Chinook salmon at Bonneville Dam, summer 2004. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



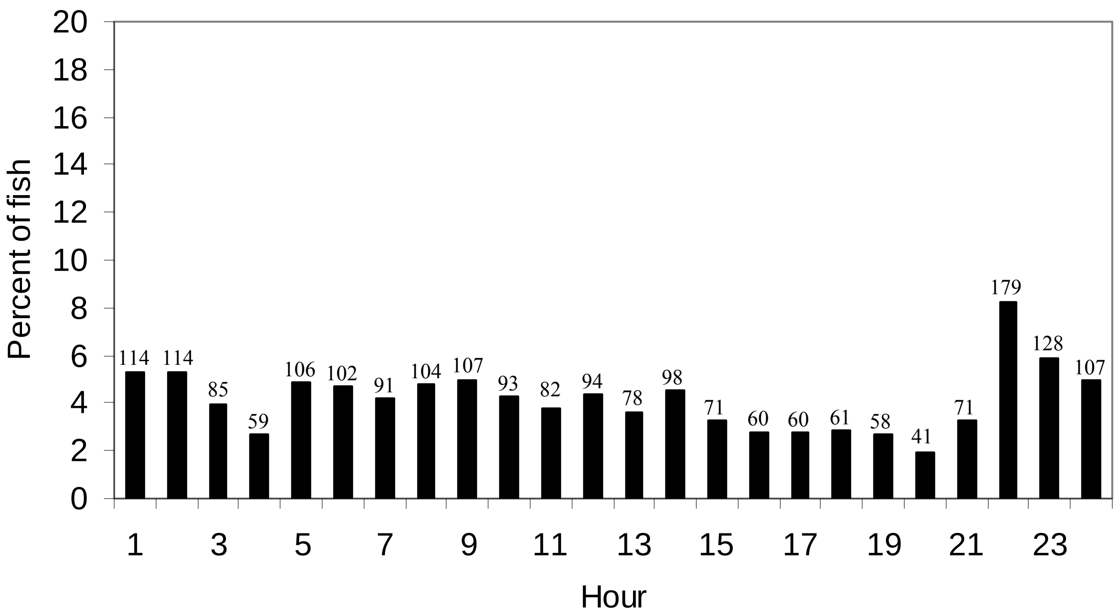
Appendix 5.—Median forebay residence time by hour of passage versus mean discharge by dam area for subyearling Chinook salmon at Bonneville Dam, summer 2004. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



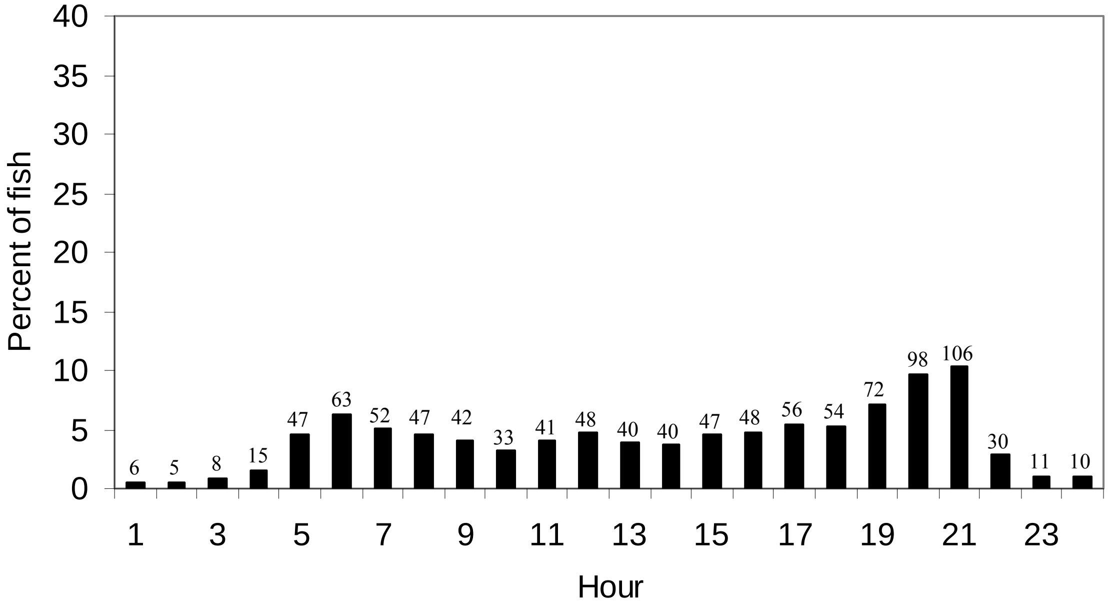
Appendix 6.—Median forebay residence time by hour of arrival versus mean discharge by dam area for subyearling Chinook salmon at Bonneville Dam, summer 2004. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



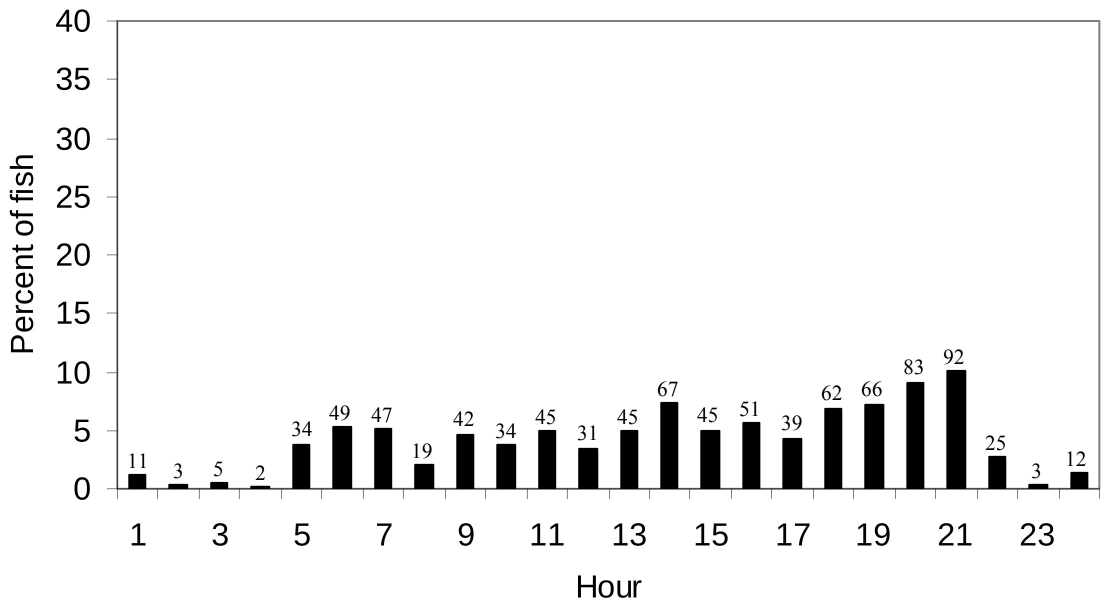
Appendix 7.—Hourly spillway passage of subyearling Chinook salmon at Bonneville Dam during 32 kcfs spill treatment blocks, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



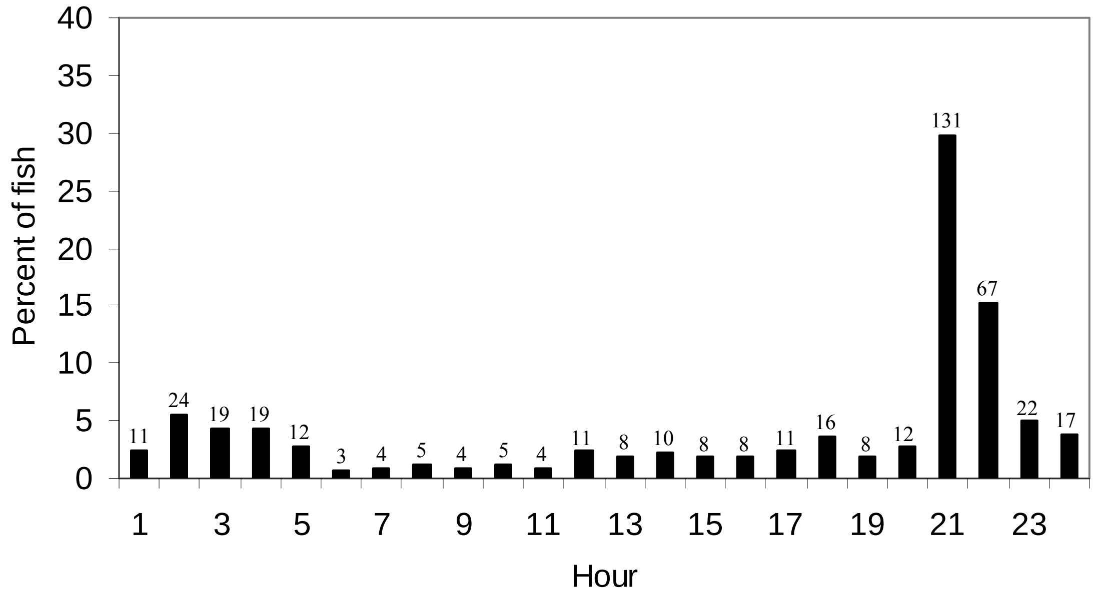
Appendix 8.—Hourly spillway passage of subyearling Chinook salmon at Bonneville Dam during Biop spill treatment blocks, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



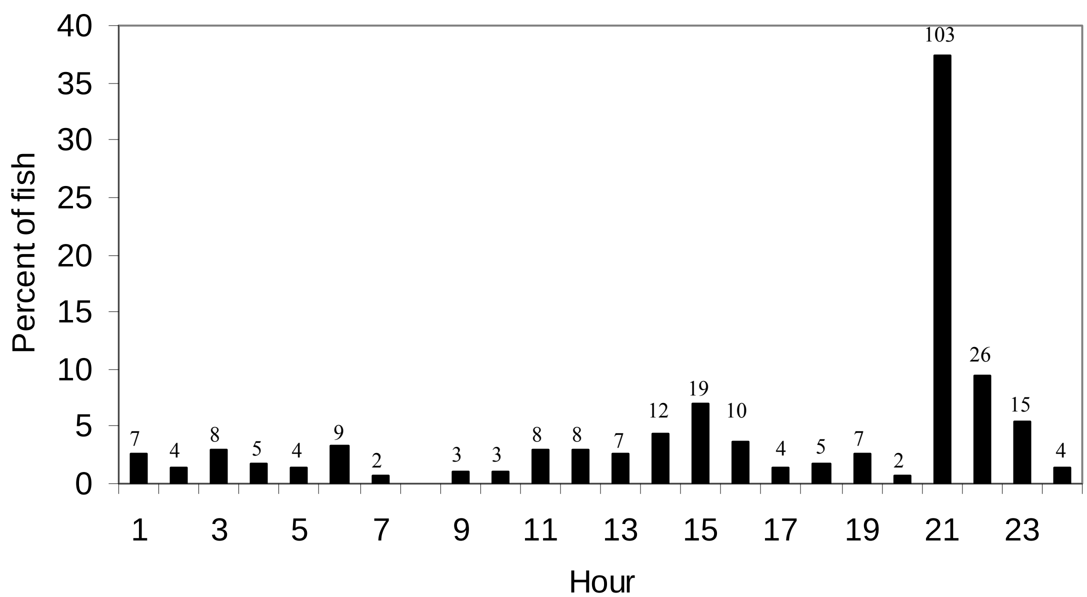
Appendix 9.—Hourly corner collector passage of subyearling Chinook salmon at Bonneville Dam's second powerhouse during 32 kcfs spill treatment blocks, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



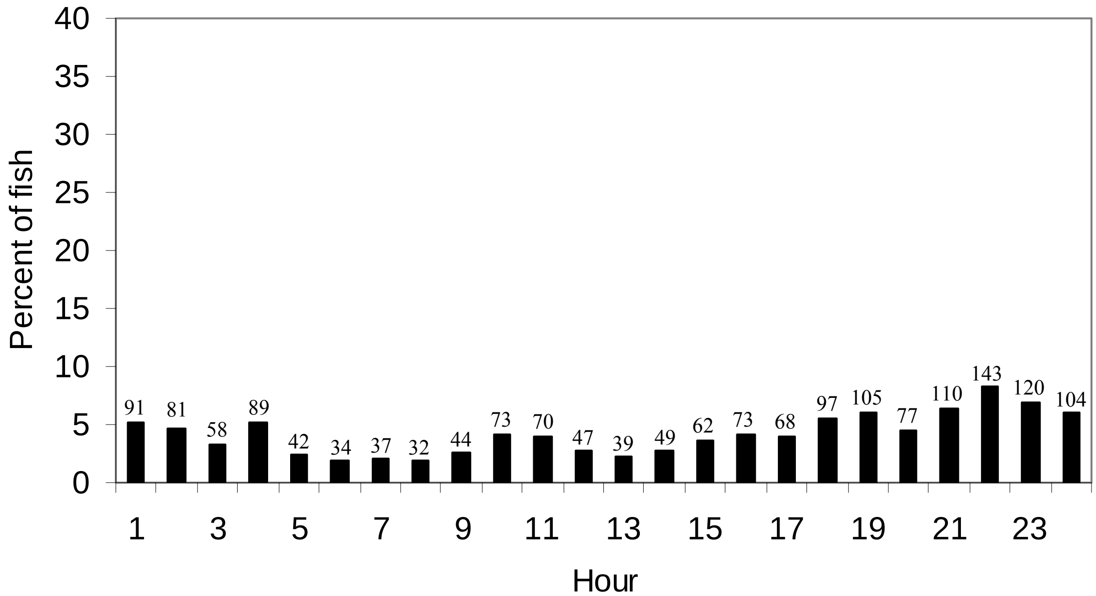
Appendix 10.—Hourly corner collector passage of subyearling Chinook salmon at Bonneville Dam's second powerhouse during Biop spill treatment blocks, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



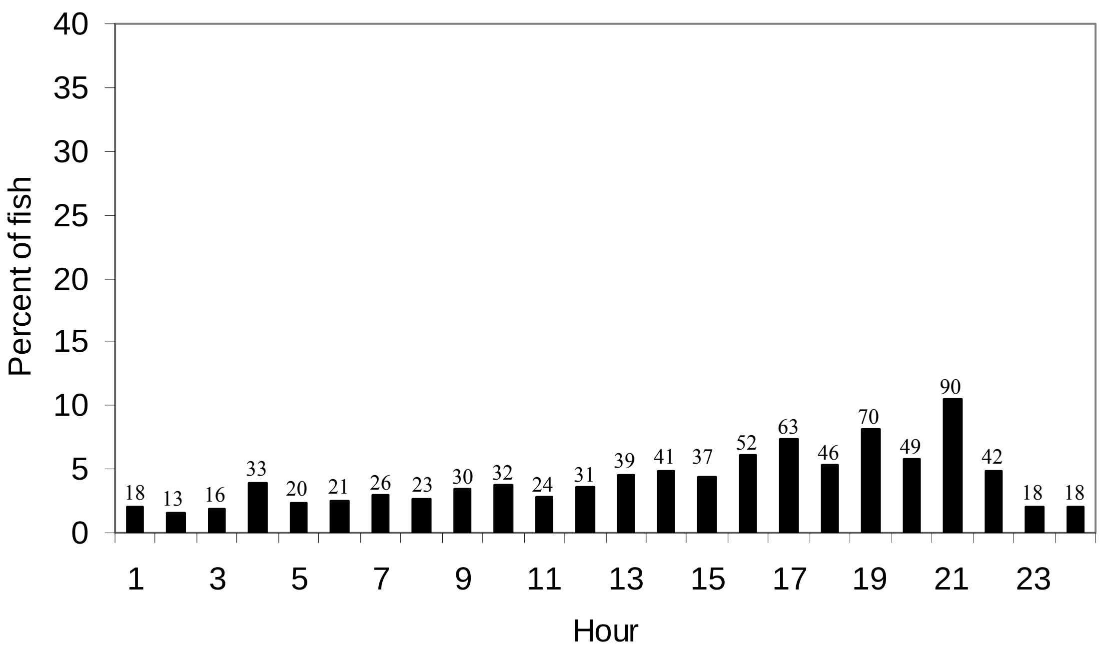
Appendix 11.—Hourly guided passage of subyearling Chinook salmon at Bonneville Dam's second powerhouse during 32 kcfs spill treatment blocks, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



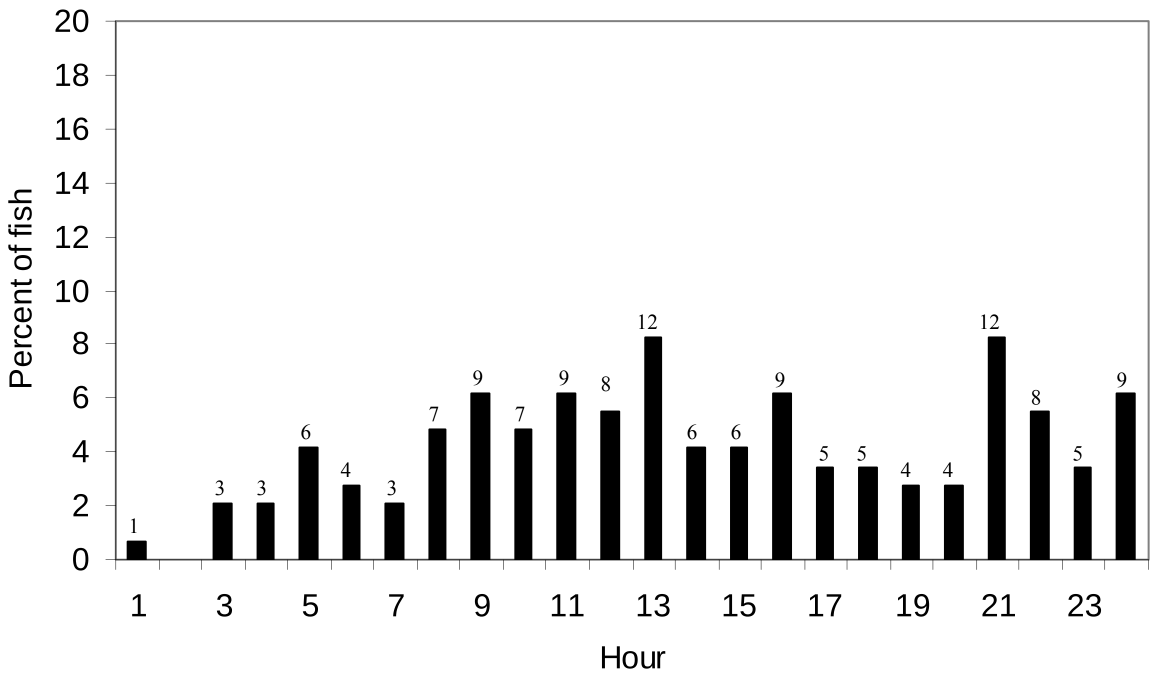
Appendix 12.—Hourly guided passage of subyearling Chinook salmon at Bonneville Dam's second powerhouse during Biop spill treatment blocks, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



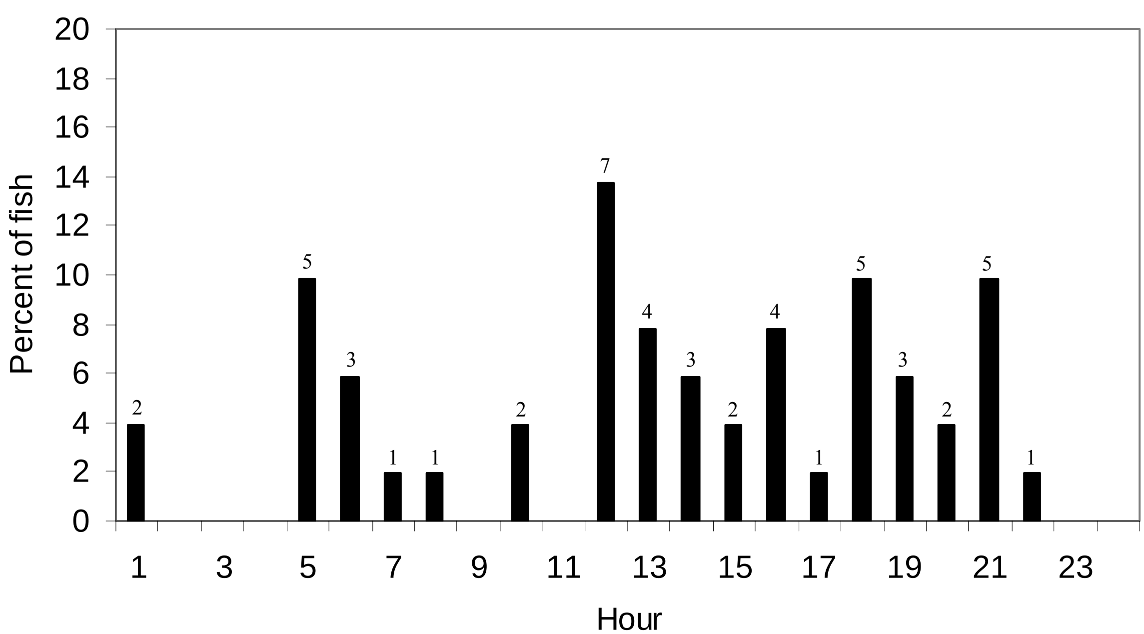
Appendix 13.—Hourly unguided passage of subyearling Chinook salmon at Bonneville Dam's second powerhouse during 32 kcfs spill treatment blocks, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



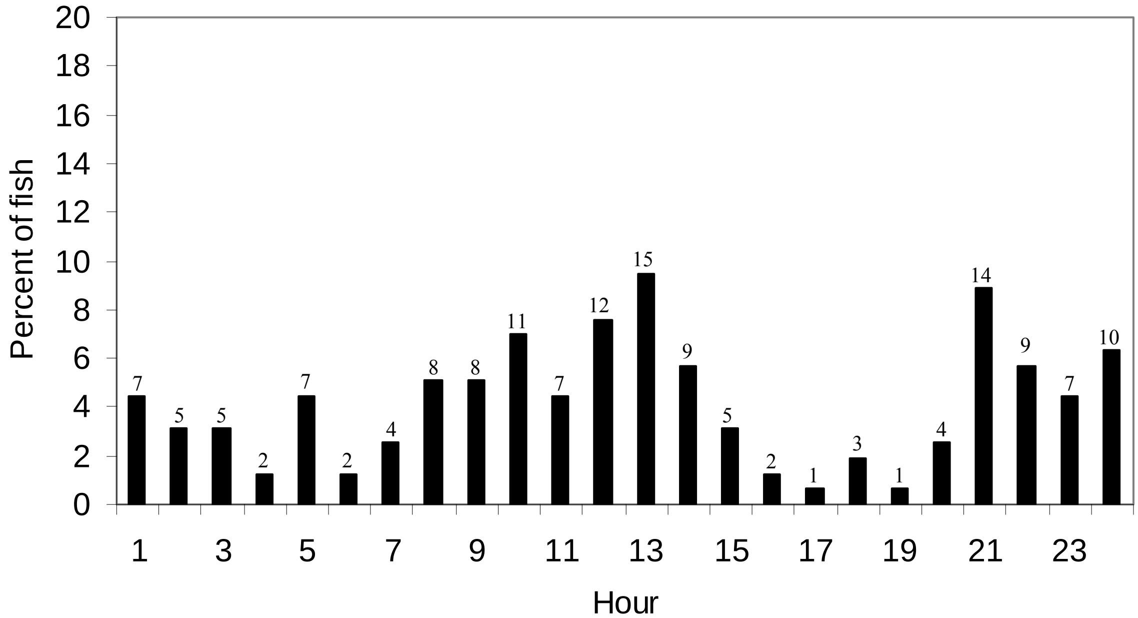
Appendix 14.—Hourly unguided passage of subyearling Chinook salmon at Bonneville Dam's second powerhouse during Biop spill treatment blocks, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



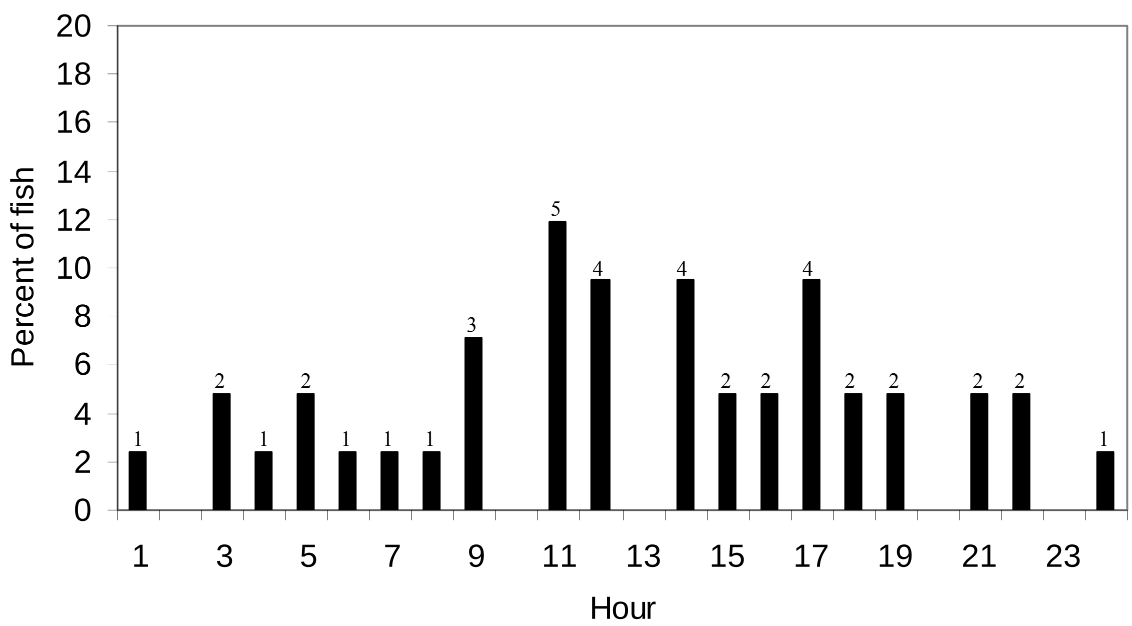
Appendix 15.—Hourly sluiceway passage of subyearling Chinook salmon at Bonneville Dam's first powerhouse during 32 kcfs spill, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



Appendix 16.—Hourly sluiceway passage of subyearling Chinook salmon at Bonneville Dam's first powerhouse during Biop spill, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



Appendix 17.—Hourly unguided passage of subyearling Chinook salmon at Bonneville Dam's first powerhouse during 32 kcfs spill, summer 2004. Numbers above the bars represent number of fish that passed during that hour.



Appendix 18.—Hourly unguided passage of subyearling Chinook salmon at Bonneville Dam's first powerhouse during Biop spill, summer 2004. Numbers above the bars represent number of fish that passed during that hour.

Appendix 19.—Numbers of subyearling Chinook salmon that passed Bonneville Dam by spill treatment, passage route, and hour of passage during summer, 2004.

Treatment	Passage Route	Hour of Passage	Number Passed
32KCFS	B1NAV	3	1
32KCFS	B1NAV	6	1
32KCFS	B1NAV	7	1
32KCFS	B1NAV	12	2
32KCFS	B1NAV	14	1
32KCFS	B1NAV	15	2
32KCFS	B1NAV	16	1
32KCFS	B1NAV	17	1
32KCFS	B1NAV	19	1
32KCFS	B1SLU	1	1
32KCFS	B1SLU	2	0
32KCFS	B1SLU	3	3
32KCFS	B1SLU	4	3
32KCFS	B1SLU	5	6
32KCFS	B1SLU	6	4
32KCFS	B1SLU	7	3
32KCFS	B1SLU	8	7
32KCFS	B1SLU	9	9
32KCFS	B1SLU	10	7
32KCFS	B1SLU	11	9
32KCFS	B1SLU	12	8
32KCFS	B1SLU	13	12
32KCFS	B1SLU	14	6
32KCFS	B1SLU	15	6
32KCFS	B1SLU	16	9
32KCFS	B1SLU	17	5
32KCFS	B1SLU	18	5
32KCFS	B1SLU	19	4
32KCFS	B1SLU	20	4
32KCFS	B1SLU	21	12
32KCFS	B1SLU	22	8
32KCFS	B1SLU	23	5
32KCFS	B1SLU	24	9
32KCFS	B1TUR	1	7
32KCFS	B1TUR	2	5
32KCFS	B1TUR	3	5
32KCFS	B1TUR	4	2
32KCFS	B1TUR	5	7
32KCFS	B1TUR	6	2
32KCFS	B1TUR	7	4
32KCFS	B1TUR	8	8
32KCFS	B1TUR	9	8
32KCFS	B1TUR	10	11
32KCFS	B1TUR	11	7
32KCFS	B1TUR	12	12
32KCFS	B1TUR	13	15

Appendix 19 (continued).—Numbers of subyearling Chinook salmon that passed Bonneville Dam by spill treatment, passage route, and hour of passage during summer, 2004.

Treatment	Passage Route	Hour of Passage	Number Passed
32KCFS	B1TUR	14	9
32KCFS	B1TUR	15	5
32KCFS	B1TUR	16	2
32KCFS	B1TUR	17	1
32KCFS	B1TUR	18	3
32KCFS	B1TUR	19	1
32KCFS	B1TUR	20	4
32KCFS	B1TUR	21	14
32KCFS	B1TUR	22	9
32KCFS	B1TUR	23	7
32KCFS	B1TUR	24	10
BIOP	B1EAT	7	1
BIOP	B1NAV	5	2
BIOP	B1NAV	6	1
BIOP	B1NAV	11	1
BIOP	B1NAV	12	3
BIOP	B1NAV	16	2
BIOP	B1SLU	1	2
BIOP	B1SLU	2	0
BIOP	B1SLU	3	0
BIOP	B1SLU	4	0
BIOP	B1SLU	5	5
BIOP	B1SLU	6	3
BIOP	B1SLU	7	1
BIOP	B1SLU	8	1
BIOP	B1SLU	9	0
BIOP	B1SLU	10	2
BIOP	B1SLU	11	0
BIOP	B1SLU	12	7
BIOP	B1SLU	13	4
BIOP	B1SLU	14	3
BIOP	B1SLU	15	2
BIOP	B1SLU	16	4
BIOP	B1SLU	17	1
BIOP	B1SLU	18	5
BIOP	B1SLU	19	3
BIOP	B1SLU	20	2
BIOP	B1SLU	21	5
BIOP	B1SLU	22	1
BIOP	B1SLU	23	0
BIOP	B1SLU	24	0
BIOP	B1TUR	1	1
BIOP	B1TUR	2	0
BIOP	B1TUR	3	2
BIOP	B1TUR	4	1
BIOP	B1TUR	5	2

Appendix 19 (continued).—Numbers of subyearling Chinook salmon that passed Bonneville Dam by spill treatment, passage route, and hour of passage during summer, 2004.

Treatment	Passage Route	Hour of Passage	Number Passed
BIOP	B1TUR	6	1
BIOP	B1TUR	7	1
BIOP	B1TUR	8	1
BIOP	B1TUR	9	3
BIOP	B1TUR	10	0
BIOP	B1TUR	11	5
BIOP	B1TUR	12	4
BIOP	B1TUR	13	0
BIOP	B1TUR	14	4
BIOP	B1TUR	15	2
BIOP	B1TUR	16	2
BIOP	B1TUR	17	4
BIOP	B1TUR	18	2
BIOP	B1TUR	19	2
BIOP	B1TUR	20	0
BIOP	B1TUR	21	2
BIOP	B1TUR	22	2
BIOP	B1TUR	23	0
BIOP	B1TUR	24	1
BIOP	B1UPS	10	1
32KCFS	B2CC	1	6
32KCFS	B2CC	2	5
32KCFS	B2CC	3	8
32KCFS	B2CC	4	15
32KCFS	B2CC	5	47
32KCFS	B2CC	6	63
32KCFS	B2CC	7	52
32KCFS	B2CC	8	47
32KCFS	B2CC	9	42
32KCFS	B2CC	10	33
32KCFS	B2CC	11	41
32KCFS	B2CC	12	48
32KCFS	B2CC	13	40
32KCFS	B2CC	14	38
32KCFS	B2CC	15	47
32KCFS	B2CC	16	48
32KCFS	B2CC	17	56
32KCFS	B2CC	18	54
32KCFS	B2CC	19	72
32KCFS	B2CC	20	98
32KCFS	B2CC	21	106
32KCFS	B2CC	22	30
32KCFS	B2CC	23	11
32KCFS	B2CC	24	10
32KCFS	B2DSM	1	11
32KCFS	B2DSM	2	24

Appendix 19 (continued).—Numbers of subyearling Chinook salmon that passed Bonneville Dam by spill treatment, passage route, and hour of passage during summer, 2004.

Treatment	Passage Route	Hour of Passage	Number Passed
32KCFS	B2DSM	3	19
32KCFS	B2DSM	4	19
32KCFS	B2DSM	5	12
32KCFS	B2DSM	6	3
32KCFS	B2DSM	7	4
32KCFS	B2DSM	8	5
32KCFS	B2DSM	9	4
32KCFS	B2DSM	10	5
32KCFS	B2DSM	11	4
32KCFS	B2DSM	12	11
32KCFS	B2DSM	13	8
32KCFS	B2DSM	14	10
32KCFS	B2DSM	15	8
32KCFS	B2DSM	16	8
32KCFS	B2DSM	17	11
32KCFS	B2DSM	18	16
32KCFS	B2DSM	19	8
32KCFS	B2DSM	20	12
32KCFS	B2DSM	21	131
32KCFS	B2DSM	22	67
32KCFS	B2DSM	23	22
32KCFS	B2DSM	24	17
32KCFS	B2TUR	1	91
32KCFS	B2TUR	2	81
32KCFS	B2TUR	3	58
32KCFS	B2TUR	4	89
32KCFS	B2TUR	5	42
32KCFS	B2TUR	6	34
32KCFS	B2TUR	7	37
32KCFS	B2TUR	8	32
32KCFS	B2TUR	9	44
32KCFS	B2TUR	10	73
32KCFS	B2TUR	11	70
32KCFS	B2TUR	12	47
32KCFS	B2TUR	13	39
32KCFS	B2TUR	14	49
32KCFS	B2TUR	15	62
32KCFS	B2TUR	16	73
32KCFS	B2TUR	17	68
32KCFS	B2TUR	18	97
32KCFS	B2TUR	19	105
32KCFS	B2TUR	20	77
32KCFS	B2TUR	21	110
32KCFS	B2TUR	22	143
32KCFS	B2TUR	23	120
32KCFS	B2TUR	24	104

Appendix 19 (continued).—Numbers of subyearling Chinook salmon that passed Bonneville Dam by spill treatment, passage route, and hour of passage during summer, 2004.

Treatment	Passage Route	Hour of Passage	Number Passed
32KCFS	B2UPS	8	1
32KCFS	B2UPS	16	1
BIOP	B2CC	1	11
BIOP	B2CC	2	3
BIOP	B2CC	3	5
BIOP	B2CC	4	2
BIOP	B2CC	5	34
BIOP	B2CC	6	49
BIOP	B2CC	7	47
BIOP	B2CC	8	19
BIOP	B2CC	9	42
BIOP	B2CC	10	34
BIOP	B2CC	11	45
BIOP	B2CC	12	31
BIOP	B2CC	13	45
BIOP	B2CC	14	67
BIOP	B2CC	15	45
BIOP	B2CC	16	51
BIOP	B2CC	17	39
BIOP	B2CC	18	62
BIOP	B2CC	19	66
BIOP	B2CC	20	83
BIOP	B2CC	21	92
BIOP	B2CC	22	25
BIOP	B2CC	23	3
BIOP	B2CC	24	12
BIOP	B2DSM	1	7
BIOP	B2DSM	2	4
BIOP	B2DSM	3	8
BIOP	B2DSM	4	5
BIOP	B2DSM	5	4
BIOP	B2DSM	6	9
BIOP	B2DSM	7	2
BIOP	B2DSM	8	0
BIOP	B2DSM	9	3
BIOP	B2DSM	10	3
BIOP	B2DSM	11	8
BIOP	B2DSM	12	8
BIOP	B2DSM	13	7
BIOP	B2DSM	14	12
BIOP	B2DSM	15	19
BIOP	B2DSM	16	10
BIOP	B2DSM	17	4
BIOP	B2DSM	18	5
BIOP	B2DSM	19	7
BIOP	B2DSM	20	2

Appendix 19 (continued).—Numbers of subyearling Chinook salmon that passed Bonneville Dam by spill treatment, passage route, and hour of passage during summer, 2004.

Treatment	Passage Route	Hour of Passage	Number Passed
BIOP	B2DSM	21	103
BIOP	B2DSM	22	26
BIOP	B2DSM	23	15
BIOP	B2DSM	24	4
BIOP	B2TUR	1	18
BIOP	B2TUR	2	13
BIOP	B2TUR	3	16
BIOP	B2TUR	4	33
BIOP	B2TUR	5	20
BIOP	B2TUR	6	21
BIOP	B2TUR	7	26
BIOP	B2TUR	8	23
BIOP	B2TUR	9	30
BIOP	B2TUR	10	32
BIOP	B2TUR	11	24
BIOP	B2TUR	12	31
BIOP	B2TUR	13	39
BIOP	B2TUR	14	41
BIOP	B2TUR	15	37
BIOP	B2TUR	16	52
BIOP	B2TUR	17	63
BIOP	B2TUR	18	46
BIOP	B2TUR	19	70
BIOP	B2TUR	20	49
BIOP	B2TUR	21	90
BIOP	B2TUR	22	42
BIOP	B2TUR	23	18
BIOP	B2TUR	24	18
BIOP	B2UPS	13	1
BIOP	B2UPS	20	1
BIOP	B2UPS	22	1
32KCFS	SPILL	1	36
32KCFS	SPILL	2	29
32KCFS	SPILL	3	29
32KCFS	SPILL	4	31
32KCFS	SPILL	5	24
32KCFS	SPILL	6	48
32KCFS	SPILL	7	42
32KCFS	SPILL	8	48
32KCFS	SPILL	9	63
32KCFS	SPILL	10	60
32KCFS	SPILL	11	70
32KCFS	SPILL	12	52
32KCFS	SPILL	13	42
32KCFS	SPILL	14	57
32KCFS	SPILL	15	53

Appendix 19 (continued).—Numbers of subyearling Chinook salmon that passed Bonneville Dam by spill treatment, passage route, and hour of passage during summer, 2004.

Treatment	Passage Route	Hour of Passage	Number Passed
32KCFS	SPILL	16	32
32KCFS	SPILL	17	25
32KCFS	SPILL	18	22
32KCFS	SPILL	19	15
32KCFS	SPILL	20	10
32KCFS	SPILL	21	22
32KCFS	SPILL	22	37
32KCFS	SPILL	23	34
32KCFS	SPILL	24	39
BIOP	SPILL	1	114
BIOP	SPILL	2	114
BIOP	SPILL	3	85
BIOP	SPILL	4	59
BIOP	SPILL	5	106
BIOP	SPILL	6	102
BIOP	SPILL	7	91
BIOP	SPILL	8	104
BIOP	SPILL	9	107
BIOP	SPILL	10	93
BIOP	SPILL	11	82
BIOP	SPILL	12	94
BIOP	SPILL	13	78
BIOP	SPILL	14	98
BIOP	SPILL	15	71
BIOP	SPILL	16	60
BIOP	SPILL	17	60
BIOP	SPILL	18	61
BIOP	SPILL	19	58
BIOP	SPILL	20	41
BIOP	SPILL	21	71
BIOP	SPILL	22	179
BIOP	SPILL	23	128
BIOP	SPILL	24	107