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Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam, 2001

Annual Report

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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 (COE), 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 2001, the COE 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 2001, 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 spillway efficiency and effectiveness, and 4) provide data to estimate survival of radio tagged fish released above Bonneville Dam (reported by Counihan et al. *in prep).* This report covers the study of subyearling chinook salmon during the summer of 2001. Study activities on yearling chinook salmon conducted in spring 2001 were reported by Evans et al. (2001a).

From 1 July to 19 July 2001, we radio-tagged and released 647 subyearling chinook salmon upstream of Bonneville Dam near Hood River, Oregon. We detected our last radio-tagged fish on July 24, 2001. Mean river discharge at Bonneville Dam during the study period was 81.1 kcfs, with 94.2% of flow discharged at powerhouse II (B2), 3.4% at powerhouse I (B1), and 2.4% at the spillway. Median travel rate of radio-tagged fish from release to Bonneville Dam was 1.5 km/h, resulting in a median travel time of 26.8 h. Of the fish released, we detected 90% at Bonneville Dam. Median forebay residence time was shortest at B2 (0.7 h) compared to 2.4 h at B1 and 1.5 h at the spillway.

Passage routes were determined for 90% of fish detected at Bonneville Dam. B2 passed the most fish (92%), followed by B1 (6%) and the spillway (2%). Of the fish that passed at B1, 70% passed into the sluiceway, 13% were diverted into the turbine bypass system by turbine intake screens (guided), 10% passed through the turbines (unguided), and 7% passed through the adult ladder located on Bradford Island. All fish that passed at B2 entered the turbine intakes; 65% were unguided and 35% were guided. At all dam areas, a higher proportion of fish passed during night compared to day.

Fish passage efficiency (FPE; the proportion of total fish that passed through non-turbine routes) at Bonneville Dam in summer 2001 was 40% overall, 89% at B1 and 35% at B2. Fish guidance efficiency (FGE; the proportion of powerhouse-entrained fish that are guided by screens into bypass systems) was higher at B1 (57%) than B2 (35%). However, sample size was small at B1 (n = 7). Spillway efficiency (SE), which is the proportion of total fish passing the project that pass through the spillway, was 2%. Spillway effectiveness (SF; SE divided by the proportion of total discharge through the spillway) was 0.8.

The proportion of discharge allocated at B1, B2, and the spillway affected which dam area fish entered and passed, as well as the time spent in the forebay before passing. All passage metrics except FGE (at B1 and B2) were lower in 2001 than 2000, largely due to low river flows experienced in 2001. Although low discharge negatively affected passage metrics in general, at B1, it was likely responsible for fewer fish becoming entrained in turbine flow, thereby increasing the number of fish available to the surface-oriented sluiceway. Our results indicate that, during a low flow year, the current intake screen guidance systems at B1 and B2 do not divert sufficient numbers of subyearling chinook salmon to meet the project FPE goal of 80%.

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. One option being evaluated is the improvement of turbine intake guidance systems. The National Marine Fisheries Service and the Northwest Power Planning Council have established goals of 80% fish passage efficiency (FPE) for Columbia and Snake River dams (Whitney et al. 1997). To achieve this goal, migrant salmonids are diverted from turbines via intake screen guidance systems. However, at Bonneville Dam, the present intake screen guidance systems do not divert enough fish to meet the 80% FPE goal.

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. 2001b). The draft Biological Opinion, July 27, 2000 states " The dam passage survival rate at Bonneville Dam is currently one of the lowest of any Corps 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". To address these concerns, in 2001, the COE field-tested a prototype screen system at unit 15 at powerhouse II (Monk et al. *in prep*). In 2002, tests will be conducted on a new minimum gap runner turbine at Powerhouse I and on new and old flow deflector bays at the spillway. To determine whether these management actions are effective, it is necessary to estimate passage efficiency metrics such as FPE, fish guidance efficiency (FGE), spillway efficiency (SE) and effectiveness (SF), and survival.

During summer 2001, we used radio telemetry to examine the movements and behavior of subyearling chinook salmon *Oncorhynchus tshawytscha* in the forebay of Bonneville Dam. Our objectives were to:

- Determine the behavior, distribution, and approach patterns of subyearling chinook salmon in the forebay areas of Bonneville Dam.
- Determine the time and route of dam passage of subyearling chinook salmon.
- Estimate fish passage efficiency for the entire Bonneville Dam complex, fish guidance efficiency for powerhouses I and II, and spillway efficiency and effectiveness.
- Provide data to estimate survival of radio tagged fish released above Bonneville Dam (reported by Counihan et al. *in prep).*

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. Powerhouse one (B1) consists of 10 turbine units and is located at the south side of the river, spanning from the Oregon shore to Bradford Island. Powerhouse two (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 lies between Cascades and Bradford islands and has 18 spill gates. A navigation lock is located at the south end of B1 (Figure 1).

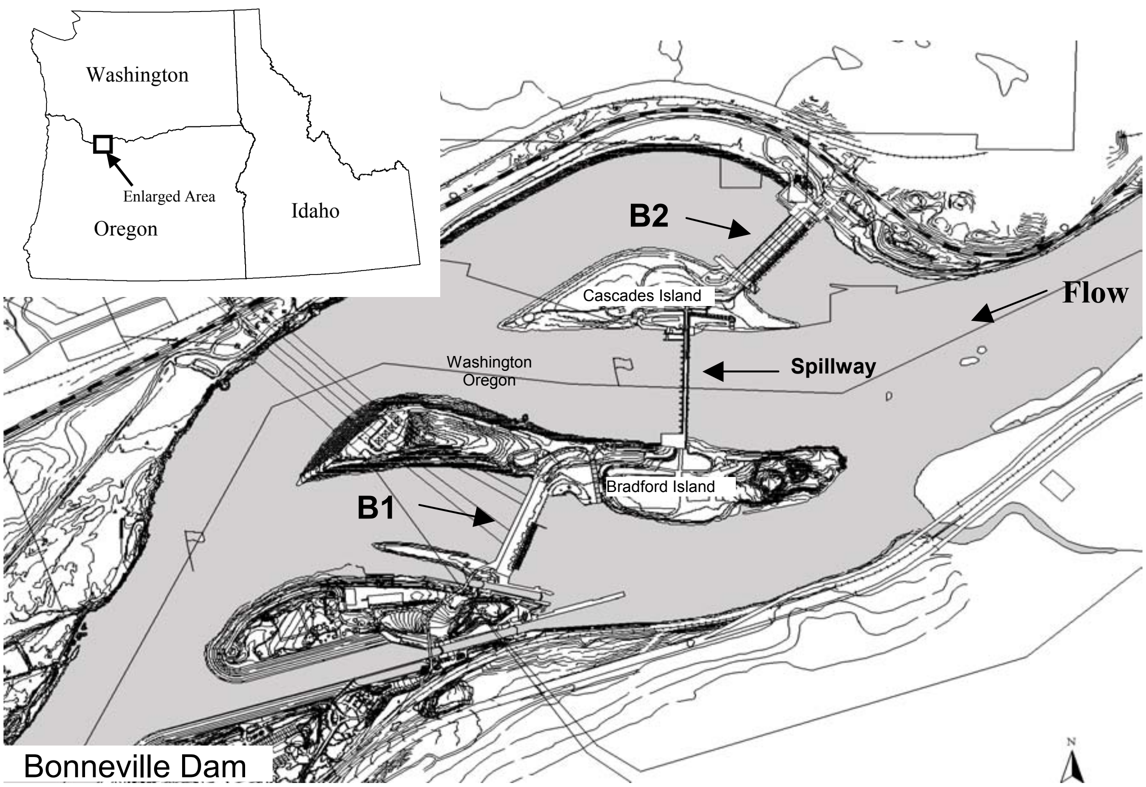

Figure 1. Plan view of Bonneville Dam on the Columbia River, showing the first powerhouse (B1), spillway, and second powerhouse (B2).

2.2 Fixed Receiving Equipment

Sixty-four aerial antennas, 45 stripped co-ax antennas, 32 balanced loop-vee antennas, and 180 underwater dipole antennas were linked to 31 Lotek SRX-400 receivers (SRX; Lotek Engineering, Newmarket, Ontario), three Lotek DSP-500 digital spectrum processors (DSP; Lotek Engineering, Newmarket, Ontario), and three Multiprotocol Integrated Telemetry Acquisition Systems (MITAS; Grant Systems Engineering, Newmarket, Ontario, Canada). Each receiver monitored a maximum of eight aerial antennas. Digital spectrum processor/receiver combinations and MITAS were used to monitor underwater antennas. The combination of these technologies allowed us to monitor approach behavior and passage through all routes at Bonneville Dam.

Aerial antennas were positioned along the periphery of the forebay to detect fish within about 100 m of the dam face (Figures 2 and 3). Aerial antennas were connected to Lotek SRX-400 data logging receivers, programmed to monitor 23 frequencies split between two receivers. 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 at the spillway and tailrace exit stations where signal acquisition time was limited and less spatial resolution was needed. In addition to combining antennas to reduce scan time, the scan time (a function of the number of frequencies being monitored) was reduced by half by using an extra receiver at each of the aerial sites. Reducing scan time is beneficial because it increases the probability of detecting transmitters. Underwater dipole, stripped co-ax, and loop-vee antennas had limited ranges (about 6, 6, and 15 m, respectively) compared to aerial antennas (100 to 300 m depending on transmitter depth, receiver gain, and number of

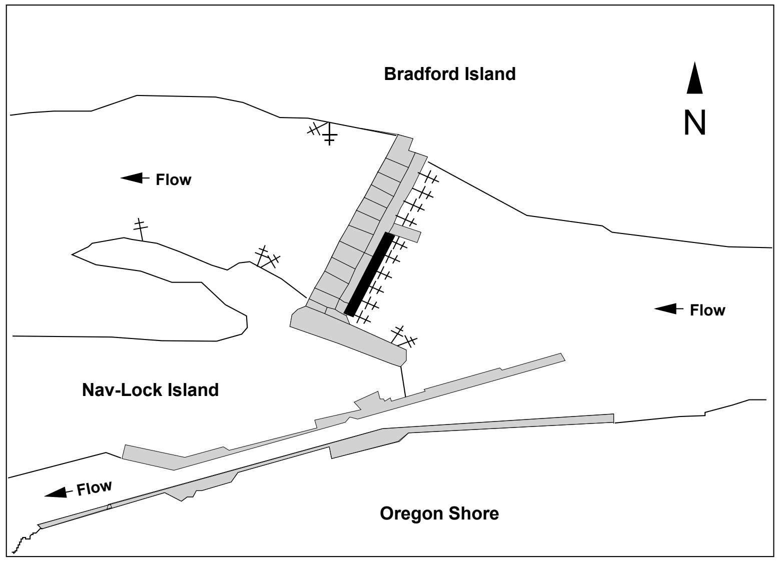

Figure 2. Plan view of aerial antenna coverage at Bonneville's first powerhouse (B1) during summer 2001.

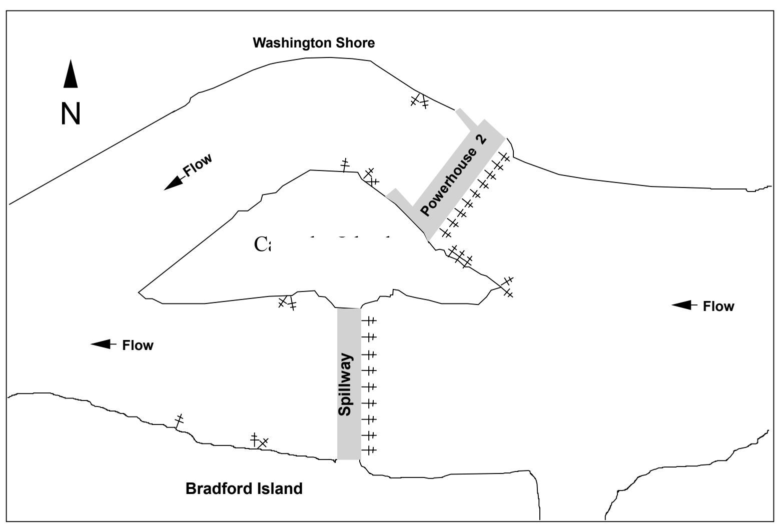

Figure 3. Plan view of aerial antenna coverage at Bonneville's second powerhouse (B2) and spillway during summer 2001.

antenna elements). Underwater antennas allowed us to obtain fine scale fish behavior information by limiting the range of signal detection.

Two receivers in the B2 tailrace and one receiver at the B2 sampling facility were coupled with digital spectrum processors. These receivers had essentially no scan time because a DSP acquires signals over a 1 MHz bandwidth almost instantaneously. Although antennas monitored by DSPs could have been monitored by a MITAS, we chose to use DSPs due to wiring logistics. Using DSPs was necessary to document fish passage in turbulent hydraulic environments because signal acquisition time is limited.

Three MITASs were incorporated at B1, B2, and the spillway. Each MITAS was capable of simultaneously monitoring up to 50 inputs with greater multiple transmitter recognition than either the SRX-400 or SRX/DSP combination. 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 co-ax antennas. In addition to its enhanced signal recognition, the MITAS's data displays and on screen diagnostics increased the robustness of the system. These features 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 comprised of 90 underwater antennas. Sixty dipole underwater antennas monitored turbine passage and were attached to the standard length traveling screens (STS) at units 1-7, and units 9 and 10, as well as the extended submerged bar screens (ESBS) at unit 8. Two dipole antennas were mounted on the bottom frame of each STS and the backside of the lower portion of the extended screen on each ESBS. Screen antennas were then combined to provide turbine unit-specific passage information. Twenty stripped co-axial antennas were positioned mid-channel in the sluiceway, two at each unit, to monitor unit-specific sluiceway passage. Ten stripped co-axial antennas were located inside the DSM (one at each "C-slot" gatewell orifice) to measure guided fish passage (i.e., fish directed by guidance screens).

The MITAS located at B2 was comprised of 59 underwater antennas and one aerial antenna. Forty-eight dipole underwater antennas monitored turbine passage and were attached to the standard length traveling screens. Eight stripped co-ax antennas located at each "C-slot" turbine gatewell orifice and one additional stripped co-ax antenna located at the terminus of the DSM, monitored guided fish passage through the DSM. A single aerial and two stripped co-ax antennas positioned at the entrance to the sluice chute measured fish passage in the chute. Although aerial antennas are not typically used with a MITAS due to noise sensitivity,

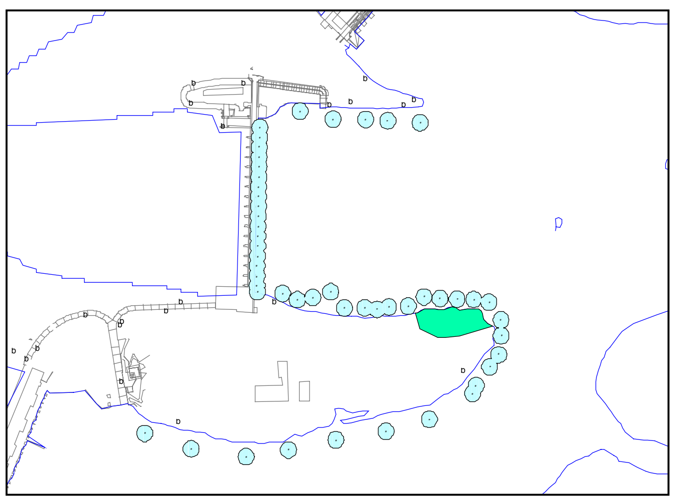

Figure 4. Plan view of underwater antenna coverage at the Bonneville spillway and Cascades and Bradford Islands during summer 2001.

the quiet environment of the sluice chute enabled the successful use of an aerial antenna with the MITAS at B2.

The spillway MITAS consisted of 104 underwater antennas. Seventy-two dipole underwater antennas monitored spillway passage and were attached to the forebay pier noses about 4.5 and 10.5 m below mean pool level. Four antennas in each of the 18 spillbays were combined to one per spillbay to monitor spillbay specific passage. We used balanced loop-vee underwater antennas at Cascades Island (n = 5) and Bradford Island (n = 27) to monitor fish approach behavior (Figure 4). Antennas at Cascades and Bradford Islands were deployed as part of an adult salmonid study conducted by USGS and Battelle. Although they were intended for another study, the loop-vee antennas provided valuable information regarding juvenile salmonid behavior in the forebay of Bonneville Dam.

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 antennas on Cascades and Bradford Islands were amplified within a waterproof antenna housing. Underwater amplification was not used on the B1 or B2 MITAS; however, 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.

2.3 Transmitters

Pulse-coded transmitters developed by Lotek Engineering Inc., (Lotek) were implanted in subyearling chinook salmon. The transmitters were 6.8 mm (diameter) x 15 mm and weighed 0.85 g in air and 0.5g in water. The antenna length was 30 cm and the pulse rate was 2.0 s, resulting in an estimated minimum tag life of 8 d.

2.4 Tagging, Handling, and Release of Fish

Subyearling chinook salmon *Oncorhynchus tshawytscha* were collected from the Bonneville Dam’s Juvenile Bypass System (JBS) located downstream of B2. Employees form the Pacific States Marine Fisheries Commission’s (PSMFC) Smolt Monitoring Program sorted and identified fish. Fish were collected 24 h/d at a collection rate between 2 and 6 percent depending on the quantity of fish that were needed. Fish were sorted and identified using methods developed by PSMFC. Fish were held 24 h before tagging in 127 L plastic holding cans. Fish were held at a density no greater than 30 fish/container and were supplied with flow-through river water.

All fish were gastrically implanted with a radio transmitter using procedures similar to those described in Adams et al. (1998). Fish were anesthetized using tricaine methanosulfate (MS-222) at 50 mg per one-liter of fresh water. Once a fish started to lose equilibrium it was weighed, measured and tagged. Immediately following, fish were placed in a 19 L recovery bucket and supplied with bottled oxygen. After about 10 min, fish were transferred into a 127 L plastic recovery container at a density no greater than 4 fish/container and were supplied with flow-through river water. Fish were held between 18 and 24 h before release.

Before transportation to the release site, each holding container was checked for mortalities, regurgitated tags, and tag functionality. Fish were transported from the juvenile bypass facility to the Hood River Marina and loaded onto a boat. All fish were released at mid-channel just below the Hood River Bridge (rkm 273). Transportation time from the facility to the marina was about 35 minutes. Releases occurred during day (1000-1100 hours) and night (2200-2300 hours) to enable tagged fish to mix spatially and temporally with untagged fish in the river prior to passing the dam. The release location 40 km upstream allowed fish about 12-36 h to adjust to temperature and hydraulic conditions in the reservoir before reaching the forebay and encountering the dam.

2.5 Data Management and Analysis

Fixed receivers were typically downloaded every other day. All data was backed up daily and imported into SAS (version 8.1, SAS Institute Inc., Cary, North Carolina, USA) for subsequent proofing and analysis. Data were manually 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 that had been predated 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.

Entrance into the near-dam 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, or within either DSM or 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 which dam area fish passed (i.e., B1, B2, or spillway). However, exit stations were excluded when identifying more specific passage locations (e.g., DSM, turbine, and sluiceway). If a fish was detected in the DSM it was identified as being guided. Guided fish are powerhouse-entrained fish that are diverted by turbine intake screens. If a fish was detected at the turbine guidance screens and subsequently in the tailrace, it was identified as an unguided fish. Unguided fish are powerhouse-entrained fish that are not diverted by turbine intake screens. If a fish was detected in the sluiceway and subsequently in the tailrace, it was identified as passing through the sluiceway.

Residence time in the near-dam area, 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 near-dam area. Residence times are a minimum estimate of the actual time that radio-tagged fish spend in the near-dam area 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.

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

- Spillway efficiency (SE) = $\dfrac{SP}{(B1 + SP + B2)}$
- Spillway effectiveness (SF) = $\dfrac{SE}{F_{sp} / F_{tot}}$
- Fish guidance efficiency (FGE) = $\dfrac{G_{tot}}{(G_{tot} + UG_{tot})}$
- Fish passage efficiency (FPE) = $\dfrac{Non-turbine\,passage}{TOT_{pass}}$

Where:

SP = Total number of fish passing spillway
B1 = Total number of fish passing B1
B2 = Total number of fish passing B2
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 period.
F_{tot} = Average discharge (kcfs) through the project (B1+SP+B2) during the study period

3.0 Results

3.1 Tagging

From 1 July to 19 July 2001, we radio-tagged and released 647 subyearling chinook salmon. The release period coincided with the central portion of the “in river” seaward migration of chinook smolts (Figure 5). Forty percent (258 of 647) were released during the day (1000-1100 hours) and 60% were released at night (2200-2300 hours). Mean fork length was 122 mm and the mean weight was 20 g. The radio tag represented 4.1% of mean fish body weight. Fish length increased and weight decreased during the study (Appendix 1). Of the 673 subyearling chinook salmon collected, 14 (2.1%) regurgitated their tags, 9 (1.3%) had their tag pulled due to premature tag failure, and 3 (0.5%) died during the 24 h holding period.

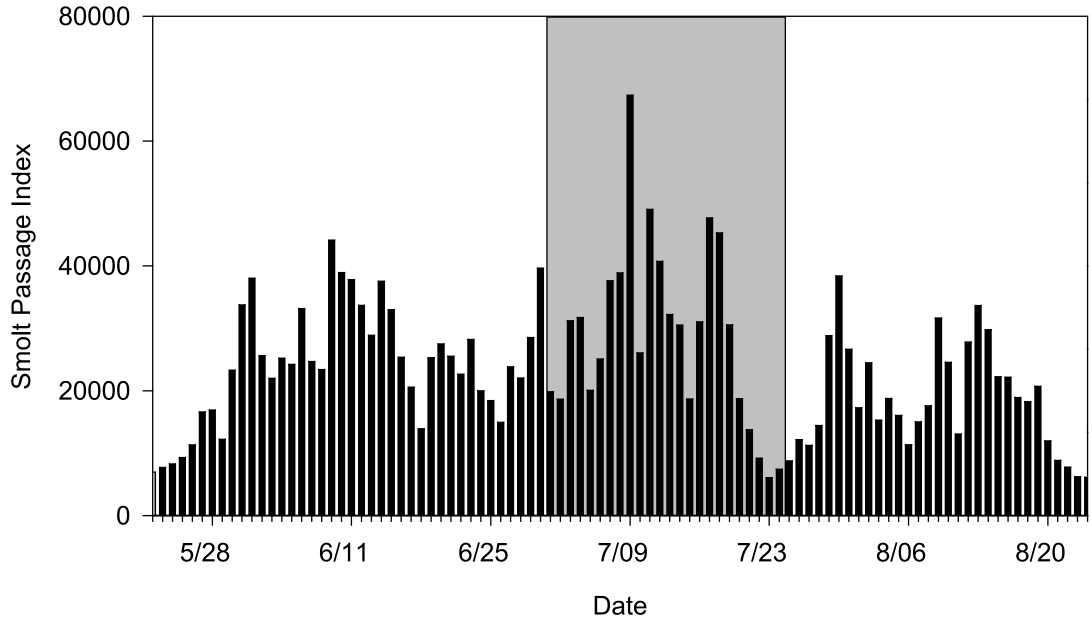

Figure 5. Smolt Passage index for subyearling chinook salmon at Bonneville Dam's Second Powerhouse (B2) fish collection facility during summer 2001. Shaded area represents study period. Smolt index data were acquired from the Fish Passage Center web page at www.fpc.org.

3.2 River Discharge and Project Operations

During summer 2001 (July 1 – 24), mean river discharge at Bonneville Dam was 81.1 kcfs, and ranged from 66.1 kcfs to 114.3 kcfs. Allocation of mean river discharge among dam areas (i.e., B1, B2, and spillway) during the study period was 3.4% through B1, 94.2% through B2, and 2.4% through spill (Figure 6 and Table 1). Mean daily discharge at B1 (turbines 1–10) was 2.8 kcfs and ranged from 0 to 22.1 kcfs. B2 displayed the greatest fluctuation in mean daily discharge with a mean of 76.4 kcfs, minimum of 64.3 kcfs and a maximum of 94.1 kcfs. Mean daily spill was 2.0 kcfs and ranged from 1.8 to 2.4 kcfs (Figure 7). Spill was discharged only through bays 1 and 18 and occurred from 0500-2000 hours during the day and from 2100-2300 hours during the night.

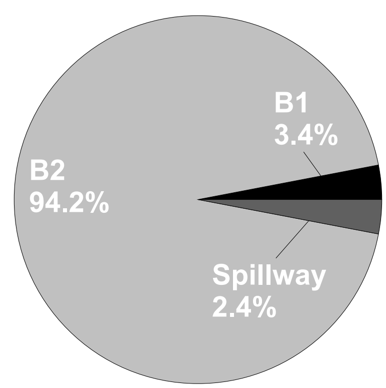

Figure 6. Discharge allocation between dam areas at Bonneville Dam during summer 2001.

Table 1. Mean project discharge (kcfs) for Bonneville Dam during summer 2001. Values have been rounded to the nearest tenth.

Dam Area	Mean	Median	Min	Max
B1	2.8	0.0	0.0	22.1
B2	76.4	73.6	64.3	94.1
Spillway	2.0	1.8	1.8	2.4
Total	81.1	75.4	66.1	114.3

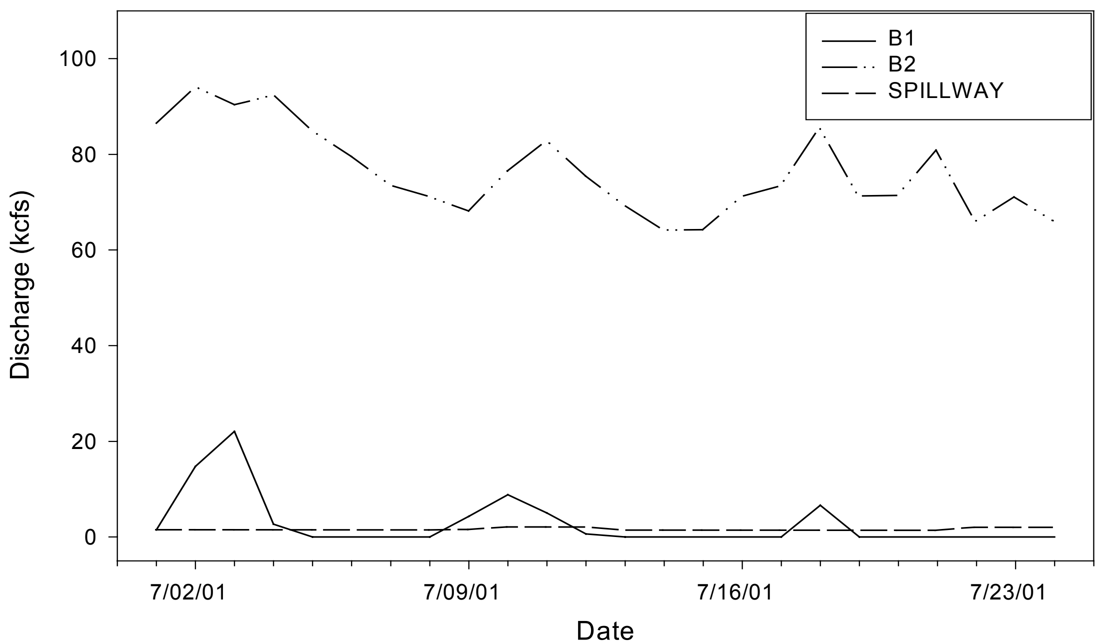

Figure 7. Mean daily discharge at Bonneville Dam by dam area during summer 2001.

Specifically at B1, turbines 1-6 represented 20% and turbines 7-10 represented 80% of mean discharge (Figure 8). At B2, turbines 11-14 represented 49% and turbines 15-18 represented 51% of mean discharge (Figure 9). There were considerable differences in discharge between turbine units, although fluctuations in mean daily discharge of turbines 11-18, 11-14, and 15-18, corresponded with mean daily river discharge. Differences in daily turbine discharge were observed for multiple turbines throughout the study (Figures 10, 11, 12, and 13). We found that discharge at B1 and B2 were essentially the same during day (0500 to 2159 hours) and night (2200 to 0459 hours; Table 2). However, at the spillway, 2.4 kcfs was discharged every hour through bays 1 and 18 from 2100-2300 hours (2 h) at night compared to 0500-2000 hours (16 h) during the day.

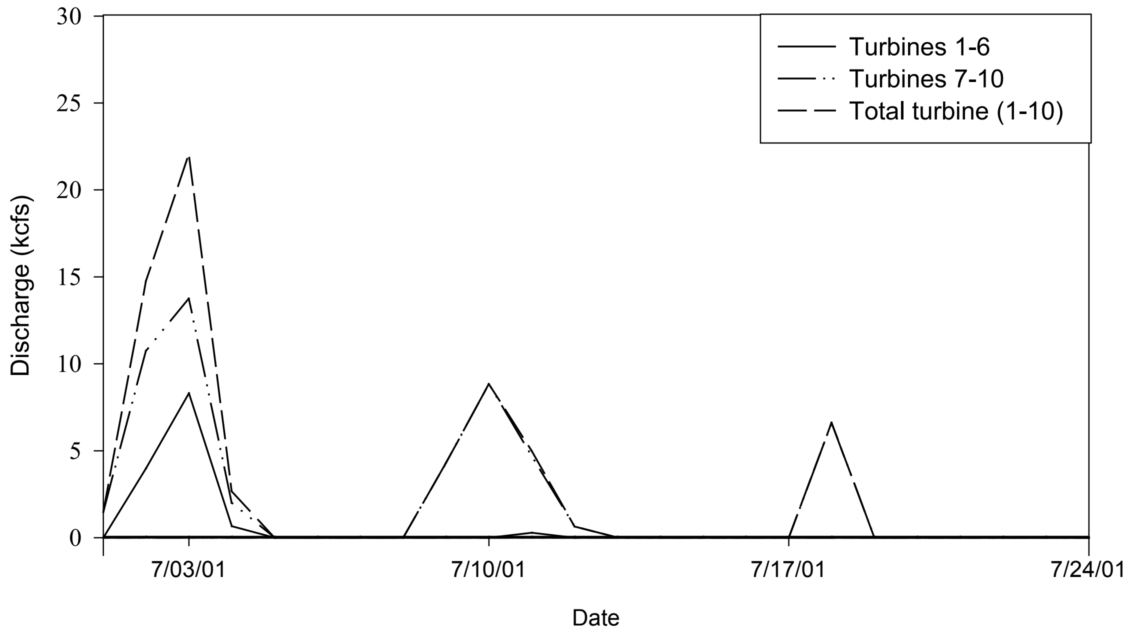

Figure 8. Mean daily discharge through turbines 1-6 and turbines 7-10 during summer 2001.

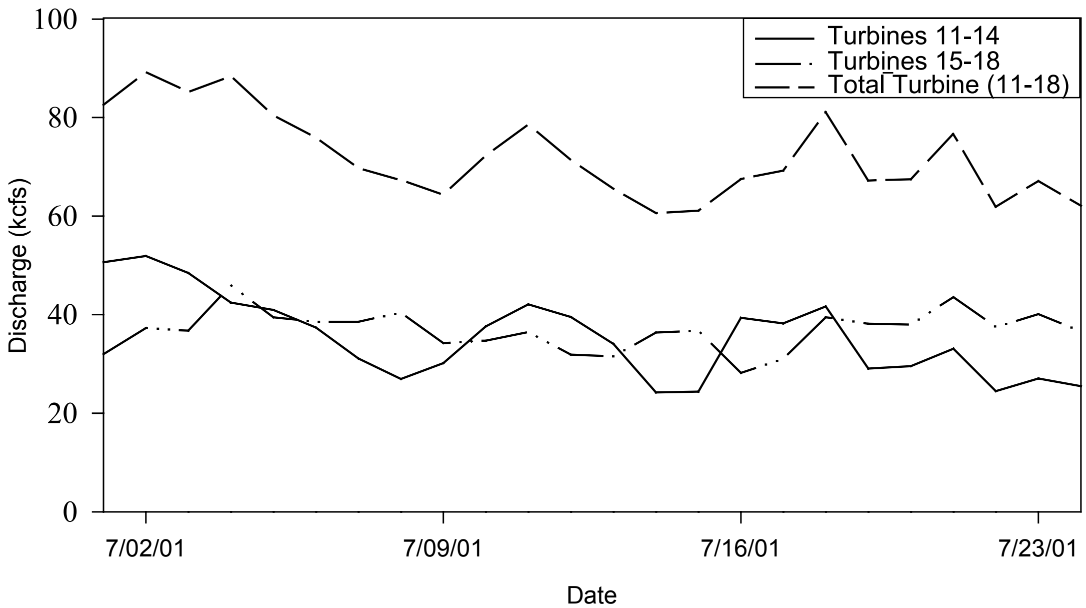

Figure 9. Mean daily discharge through turbines 11-14 and turbines 15-18 during summer 2001.

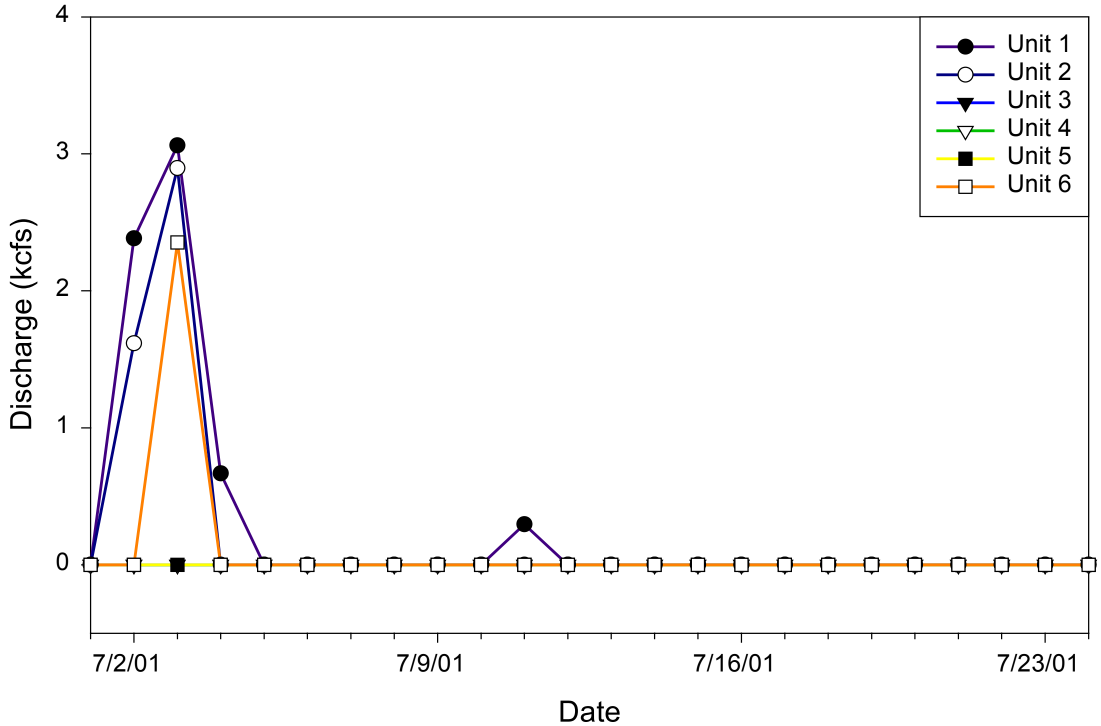

Figure 10. Mean daily discharge by unit for units 1-6 at Bonneville Dam during summer 2001.

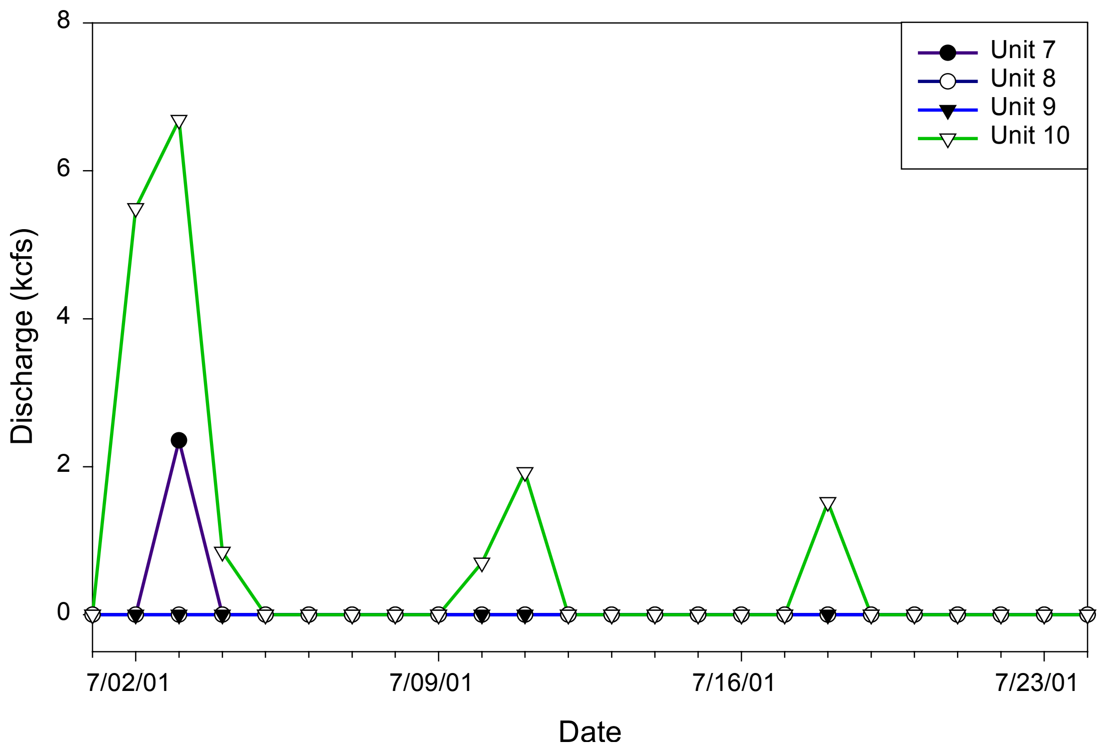

Figure 11. Mean daily discharge by unit for units 7-10 at Bonneville Dam during summer 2001.

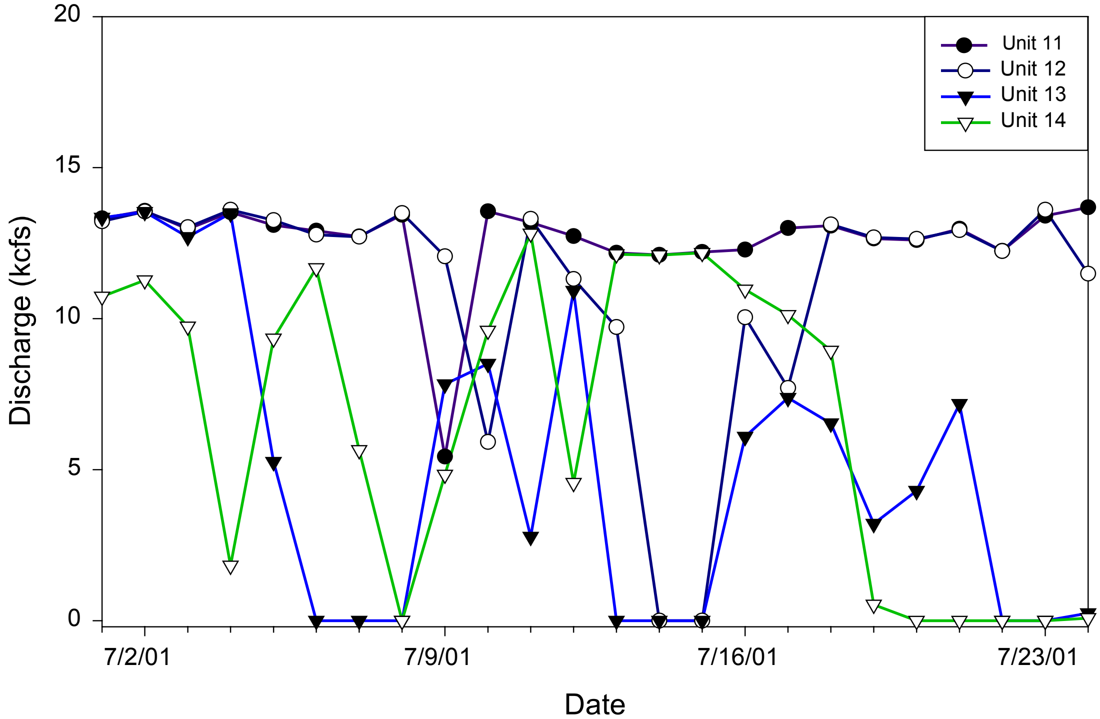

Figure 12. Mean daily discharge by unit for units 11-14 at Bonneville Dam during summer 2001.

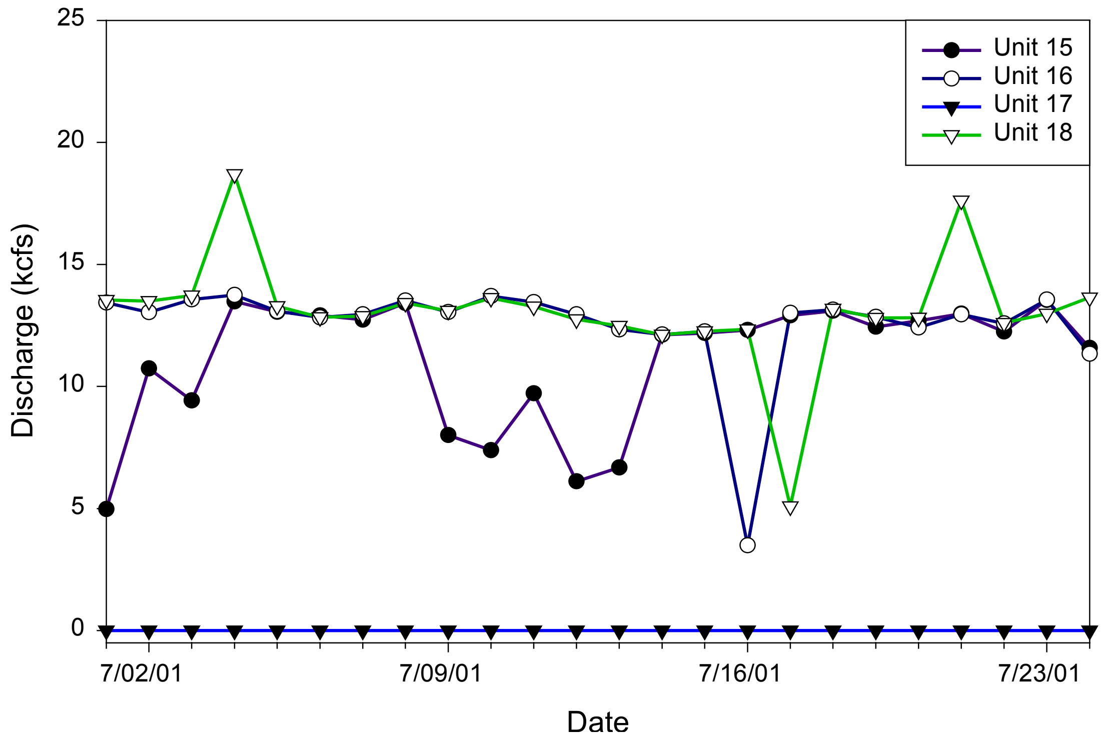

Figure 13. Mean daily discharge by unit for units 15-18 at Bonneville Dam during summer 2001.

Table 2. Mean discharge (kcfs) during day (0500-2059 hours) and night (2100-0459 hours) by dam area during summer 2001.

Dam Area	Period	Percent (of mean)	Mean	Median	Min	Max
B1	Day	3.5%	2.9	0	0	51.7
B2	Day	93.5%	77.7	76.1	60.7	192.7
Spillway	Day	3.0%	2.4	2.4	2.4	2.4
B1	Night	3.0%	2.4	0	0	50.9
B2	Night	95.5%	74.0	70.5	30.0	201.9
Spillway	Night	1.5%	1.1	0	0	2.4

3.3 Travel to and Arrival at Bonneville Dam

At Bonneville Dam, we detected 90% (582 of 647) of the subyearling chinook salmon that were released near the Hood River Bridge. The median travel rate from release at Hood River to first detection at Bonneville Dam was 1.5 km/h. The corresponding median travel time from release to first detection at Bonneville Dam was 26.8 h (Table 3).

Table 3. Descriptive statistics for travel time (h) and travel rate (km/h) to Bonneville Dam for radio-tagged subyearling chinook salmon during summer 2001. Travel rates are represented within parenthesis.

Release Site	Mean	Median	STD	Min	Max
Hood River Bridge	29.9 (1.4)	26.8 (1.5)	13.3 (0.4)	12.5 (0.2)	196.6 (3.1)

Fish did not enter dam areas (i.e., B1, B2, and spillway) in equal proportions. Of the fish detected at Bonneville Dam, 9% (50 of 577) first entered B1 forebay, 67% (388 of 577) first entered B2 forebay, and 24% (139 of 577) first entered the spillway 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. B1, B2, and the spillway represented 3.4%, 94.2%, and 2.4%, respectively, of mean river discharge. 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. At B1 and B2, daily proportions of fish fluctuated somewhat with the proportion of daily discharge (Figure 14). The higher proportion of discharge at B2 compared to B1 and the spillway was likely the largest contributing factor to the higher number of fish that entered the B2 forebay. Extremely low discharge at B1 resulted in very few fish entering that dam area. Although discharge was also low at the spillway, a comparatively high number of fish entered the spillway forebay, possibly due to its close proximity to the high discharge at B2.

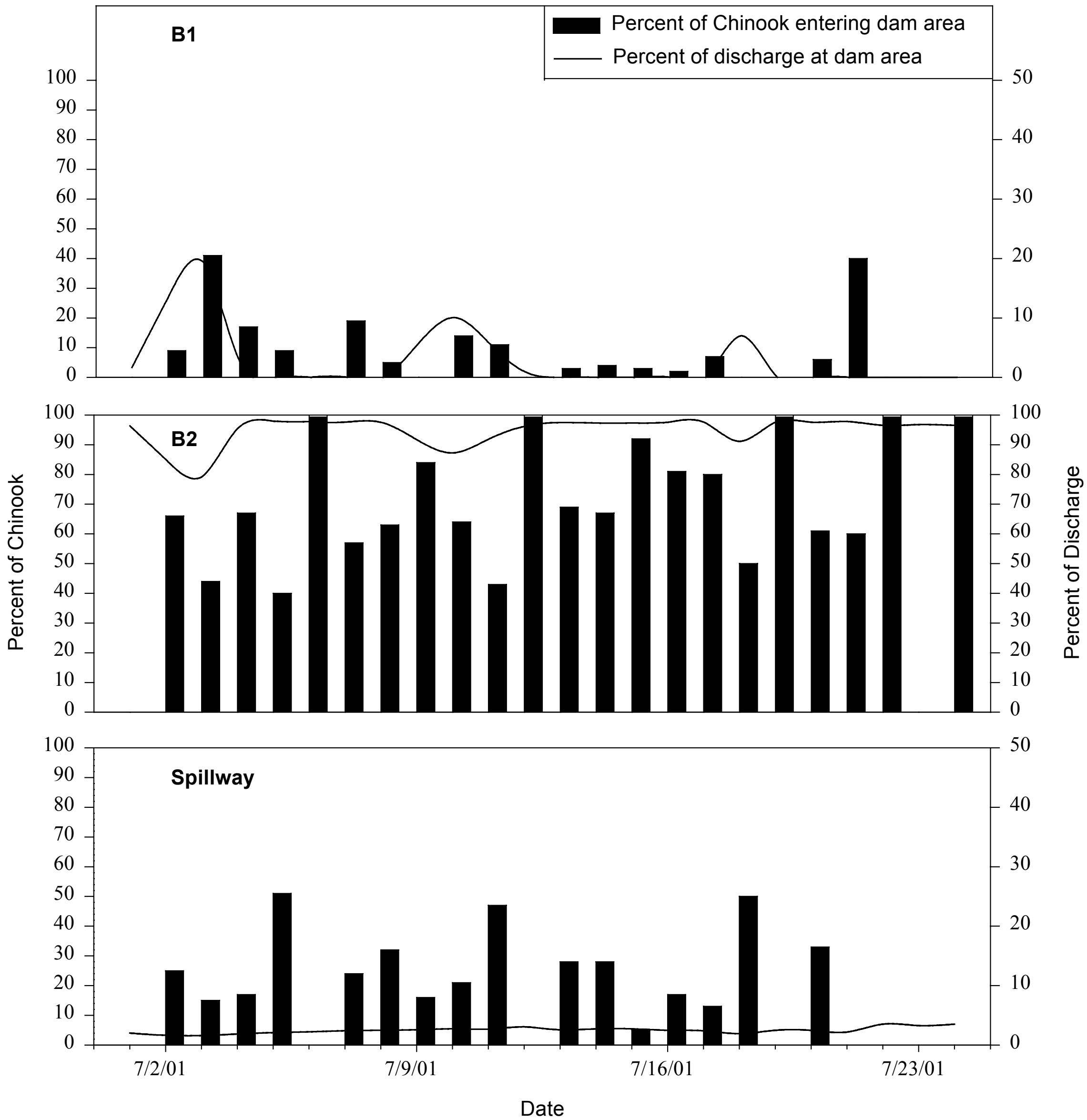

Figure 14. The percentage of subyearling chinook salmon that entered each dam area versus the percentage of mean discharge at each dam area by day during summer 2001.

Similarly, we compared the hourly proportion of fish entering each dam area to the hourly proportion of mean discharge through each dam area. Although we found no relation between hourly discharge and fish entrance, we did see a relation between fish entrance and time of day. Hourly discharge was fairly constant at each dam area; however, most fish entered B2 at night and the spillway during midday (Figure 15).

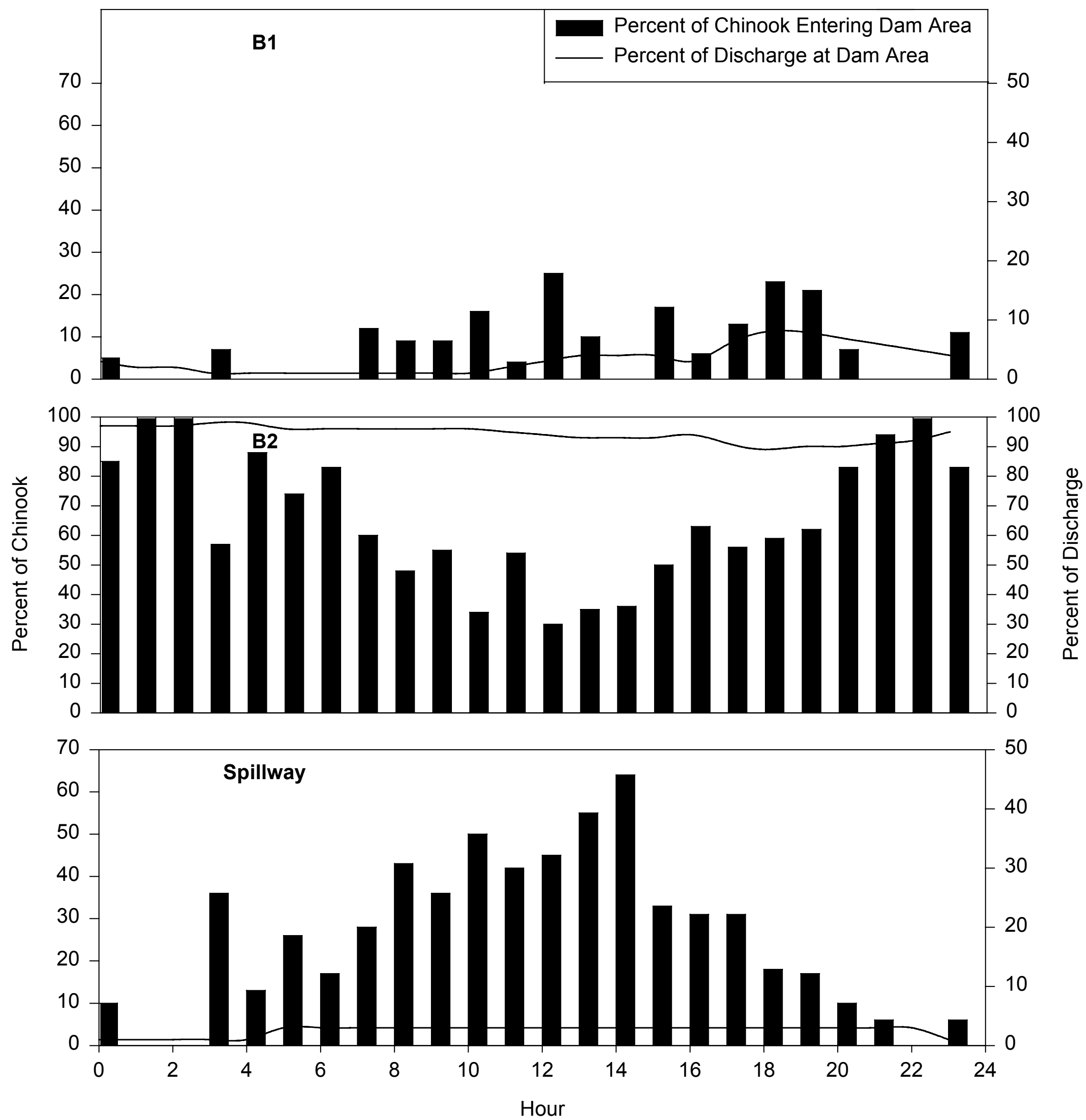

Figure 15. The percentage of subyearling chinook salmon that entered each dam area versus the percentage of mean discharge at each dam area by hour of day during summer 2001.

3.4 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 = 2.4 h) than the forebay of B2 (median = 0.6 h). Fish resided a median 1.3 h in the forebay of the spillway (Table 4). We compared median forebay residence time by day of passage, by hour of passage, and by hour of arrival to mean daily discharge and found no relation (Appendix 2, 3, and 4).

Table 4. Descriptive statistics of forebay residence time (h) for radio-tagged subyearling chinook salmon at Bonneville Dam during summer 2001. Note 92 fish that passed at a dam area different than the one they first entered and 159 fish with one or no detections in the forebay were excluded from calculations of forebay residence time.

Dam Area	N	Mean	Median	Std	Min	Max
B1	25	3.8	2.4	4.6	0.02	17.5
B2	238	2.1	0.6	4.2	0.01	34.5
Spillway	7	8.0	1.3	15.0	0.24	41.1
All areas	270	2.5	0.7	4.9	0.01	41.1

3.5 Route and Time of Passage Through Bonneville Dam

We determined the route of passage through Bonneville Dam for 90% (521 of 582) of subyearling chinook salmon detected at the dam. Three percent (20 of 582) passed the dam but a passage route could not be determined and 7% (41 of 582) were not detected below the dam. Among the three dam areas, B2 passed the most (92%; 479 of 521) subyearling chinook salmon, followed by B1 (6%; 30 of 521) and the spillway (2%; 12 of 521); Figure 16). These percentages differ from percentages of fish that first entered each dam area: 67% at B2, 24% at the spillway, and 9% at B1. Therefore, of the fish that first entered the spillway (24%), 22% eventually passed at B2. Similarly, of the fish that first entered B1 (9%), 3% eventually passed at B2.

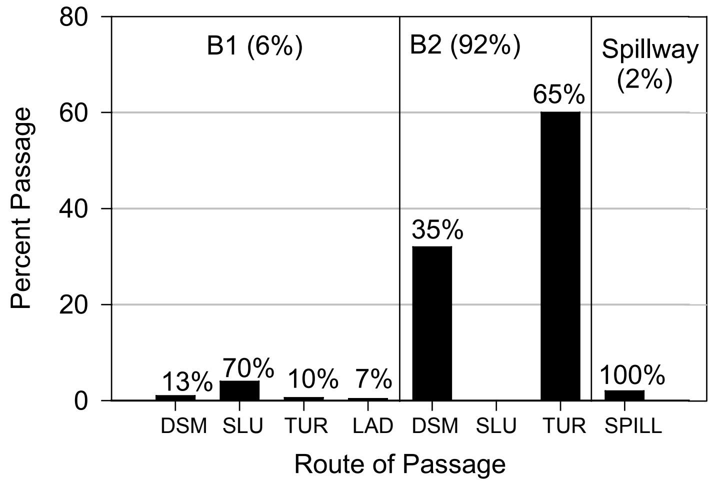

Figure 16. Percent fish passage by dam area and route of passage through Bonneville Dam for radio-tagged subyearling chinook salmon during summer 2001. Percentages in parenthesis designate proportions between dam areas, percentages without parenthesis designate proportions within dam area, and the percent value of the bars represent proportions of all routes.

At B1, of the fish with known passage routes, 70% (21 of 30) passed via the sluiceway, 13% (4 of 30) were guided into the DSM, 10% (3 of 30) passed unguided through the turbines, and 7% (2 of 30) passed through the adult ladder located on Bradford Island. An additional 15 fish passed B1 through undetermined routes. At B2, of the fish with known passage routes, 65% (310 of 479) passed unguided through the turbines and 35% (169 of 479) were guided into the DSM (Figure 16). Twelve fish passed through the spillway and 5 fish passed through an unknown dam area.

Passage of subyearling chinook salmon peaked at 2200 hours and was lowest at 0500 hours (Figure 17). At all dam areas, a higher number of fish passed during day (275) compared to night (246; Table 5). However, based on the number of hours in each diel period (16 for day, 8 for night), a higher proportion of fish passed at night at B2. Passage rates were higher during the day at the spillway and equal during day and night at B1 (Table 6).

Route-specific passage in regard to the diel cycle also indicated the majority of fish passed during day. Regardless of route, more fish passed during day than night at each dam area (Figure 18). At the spillway, 92% (11 of 12) of fish passed during the day. At B1, 100% of fish that passed through the adult ladder, 75% of guided fish, 67% of unguided fish, and 62% of fish that passed through the sluiceway, passed Bonneville Dam during the day. At B2, 58% of unguided fish passed during the day. However, 63% of guided fish passed B2 at night.

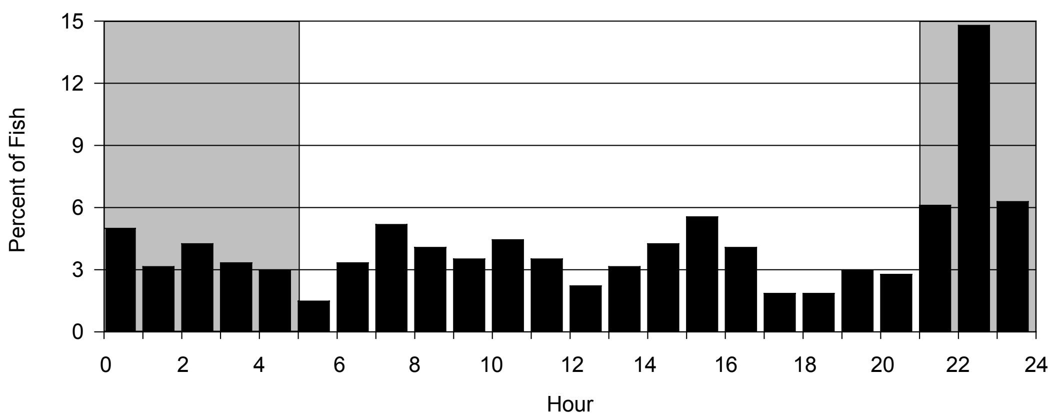

Figure 17. Percentage of subyearling chinook salmon that passed Bonneville Dam by hour during summer 2001. Shaded areas represent night (2100-0459 hours) and unshaded areas represent day (0500-2059 hours).

Table 5. The proportion of radio-tagged subyearling chinook salmon that passed each dam area of Bonneville Dam by day (0500-2059 hours) versus night (2100-0459 hours) during summer 2001.

Period	B1 Passage	B2 Passage	Spill Passage
Day	7% (20 of 275)	89% (244 of 275)	4% (11 of 275)
Night	4% (10 of 246)	95.5% (235 of 246)	0.5% (1 of 246)

Table 6. Passage rates for radio-tagged subyearling chinook salmon at each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during a 24 d test period in summer 2001. Spill occurred for only 2 h during the night.

Damarea	Day	Night
B1	$20 \text{ fish} \div (16\text{h/d} \times 24\text{d}) = 0.05 \text{ fish/h}$	$10 \text{ fish} \div (8\text{h/d} \times 24\text{d}) = 0.05 \text{ fish/h}$
B2	$244 \text{ fish} \div (16\text{h/d} \times 24\text{d}) = 0.64 \text{ fish/h}$	$235 \text{ fish} \div (8\text{h/d} \times 24\text{d}) = 1.22 \text{ fish/h}$
Spillway	$11 \text{ fish} \div (16\text{h/d} \times 24\text{d}) = 0.03 \text{ fish/h}$	$1 \text{ fish} \div (2\text{h/d} \times 24\text{d}) = 0.02 \text{ fish/h}$

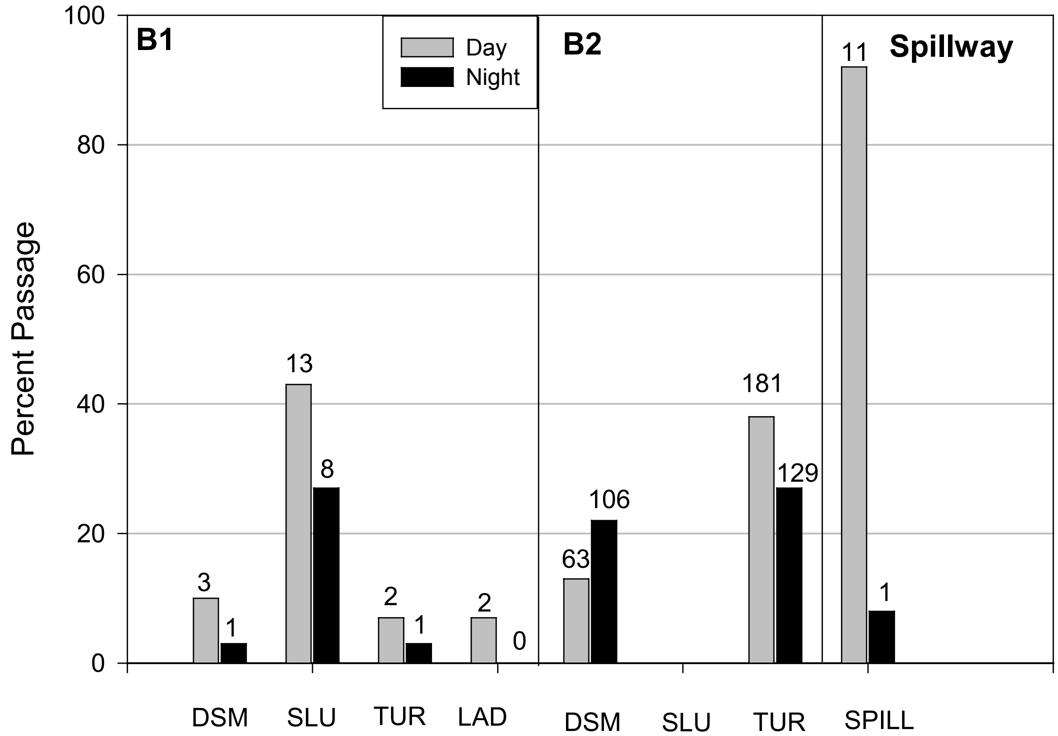

Figure 18. Percent passage by route of passage during day (0500-2059 hours) and night (2100-0459 hours) for radio-tagged subyearling chinook salmon at Bonneville Dam during summer 2001.

3.6 Passage Metrics

3.6.1 Spillway Efficiency

Spillway efficiency (SE) is the number of fish that passed through spill divided by the number of fish that passed through all routes (spill, B1 and B2). Spillway efficiency at Bonneville Dam was 2% for subyearling chinook salmon (Table 7).

Table 7. Spillway Efficiency (SE) at Bonneville Dam for subyearling chinook salmon during summer 2001. Number passed at B1 includes 15 fish that passed through unknown routes at B1.

SE	B1 Passage	B2 Passage	Spill Passage
0.2	45	479	12

3.6.2 Spillway Effectiveness

The proportion of fish that passed through spill relative to the proportion of water spilled (spillway effectiveness; SF) was 0.8, indicating that the percentage of fish that passed through spill was less than the percentage of water spilled (Table 8).

Table 8. Spillway Effectiveness (SF) at Bonneville Dam for subyearling chinook salmon during summer 2001.

SF	SE	F_{sp}	F_{tot}
0.8	0.2	2.0	81.1

3.6.3 Fish Guidance Efficiency

Fish guidance efficiency (FGE; number of fish guided divided by number guided plus number unguided) was higher at B1 (57%) than B2 (35%). However, sample size was small at B1 (n = 7). FGE was slightly higher at units 15-18 (37%), at the northern half of B2, than at units 11-14 (32%; Table 9). Turbine unit 16 was the most efficient at guiding fish (46%) at B2 (Table 10). At B1, sample sizes were too small (n = 7) to calculate FGE by unit.

Table 9. Estimates of Fish Guidance Efficiency (FGE) at Bonneville Dam for subyearling chinook salmon during summer 2001. Estimates for units 11-14 and units 15-18 do not include 101 unguided fish and 58 guided fish that passed through an unknown unit.

B1	B2	Units 11-14	Units 15-18
57% (4 of 7)	35% (169 of 479)	32% (54 of 167)	37% (57 of 153)

Table 10. Estimates of Fish Guidance Efficiency (FGE) by turbine unit at Bonneville's second powerhouse (B2) for radio-tagged subyearling chinook salmon during summer 2001. These estimates do not include 101 unguided fish and 58 guided fish that passed through an unknown unit.

Turbines at B2							
11	12	13	14	15	16	17	18
33% (27 of 83)	22% (7 of 32)	36% (9 of 25)	39% (11 of 28)	30% (13 of 43)	46% (41 of 90)	n/a (0 of 0)	15% (3 of 20)

3.6.4 Fish Passage Efficiency

Fish passage efficiency (FPE; number guided, sluiced, and spilled divided by total number passed B1, B2 and spill) at Bonneville Dam was 40% (Table 11).

Table 11. Numbers used to calculate Fish Passage Efficiency (FPE) at Bonneville Dam for radio-tagged subyearling chinook salmon during summer 2001.

Non-Turbine Routes				Turbine Routes	
B1 Guided	B1 Sluiceway	B2 Guided	Spillway	B1 Unguided	B2 Unguided
4	21	169	12	3	310

3.7 Comparison of Passage Performance Metrics as Measured by RadioTelemetry and Hydroacoustics

In addition to the radio telemetry evaluation we conducted, the Waterways Experiment Station of the U.S. Army Corps of Engineers (WES) used fixed hydroacoustics to monitor fish passage and estimate passage performance metrics for the run-at-large. Although the hydroacoustic summer monitoring period started earlier and finished later than did radio telemetry, passage metrics were calculated for each research tool using data from overlapping time periods (July 1 – July 15) to facilitate comparison of the two techniques. All passage metrics were 4-9% higher for hydroacoustics than for radio telemetry, except FGE at B1, which was 10% higher for radio telemetry (Table 12).

A comparison of unit-specific estimates of FGE for B2 (units 11-18), as measured by radio telemetry and hydroacoustics, revealed further disparity: 7-21% (Table 13). Except at unit 11, estimates of FGE by unit were higher for hydroacoustics than for radio telemetry. Differences in FGE between hydroacoustics and radio telemetry were under 10% for only two units (units 11 and 16). Radio telemetry estimates of unit 11 FGE may have been overestimated due to unit 15 FGE tests during which fish were sampled out of unit 15 and then returned to unit 11. Any unreported radio-tagged fish returned to unit 11 could have been counted as a guided fish at unit 11.

We also compared diurnal passage results between radio telemetry and hydroacoustics. Diurnal trends in project passage were similar for both research methods except that radio telemetry data indicated a slight peak in passage at 0700 hours and another at 1500 hours (Figure 19). Hydroacoustics data showed a peak in passage at 0800 hours but not in the afternoon (Figure 20). Diurnal passage patterns relative to individual dam areas and passage routes did not indicate whether a specific passage route was responsible for the peak in project diurnal passage (Appendix 5).

Table 12. 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), at Bonneville Dam during summer (overlapping period of July 1-July 15) 2001. Hydroacoustic data were provided by Carl Schilt, Waterways Experiment Station (January 9, 2001).

Metric	RT	HA
SE	2.6%	N/A[a]
SF	1.1	N/A[a]
FGE_{B1}	57%	47%
FGE_{B2}	35%	44%
FPE	40%	44%
FPE_{B1}	89%	N/A[b]
FPE_{B2}[c]	35%	44%

[a]Spillbays 1 and 18 were not monitored by hydroacoustics so SE and SF could not be estimated.
[b]The sluiceway at B1 was not monitored by hydroacoustics so FPE_{B1} could not be estimated.
[c]$FPE_{B2} = FGE_{B2}$ since no fish could pass through closed sluice chute at B2.

Table 13. Estimates of Fish Guidance Efficiency (FGE), by turbine unit, at Bonneville'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 summer (overlapping period of July 1- July 15) 2001. Hydroacoustic data were provided by Carl Schilt, Waterways Experiment Station (January 9, 2001).

Location	RT FGE	HA FGE	Difference
Unit 11	33%	26%	7% (RT>HA)
Unit 12	19%	40%	21% (HA>RT)
Unit 13	38%	48%	10% (HA>RT)
Unit 14	32%	53%	21% (HA>RT)
Units 11-14	31%	39%	8% (HA>RT)
Unit 15	34%	52%	18% (HA>RT)
Unit 16	46%	53%	7% (HA>RT)
Unit 17	N/A	N/A	N/A
Unit 18	7%	19%	12% (HA>RT)
Units 15-18	39%	50%	11% (HA>RT)
Units 11-18	35%	44%	9% (HA>RT)

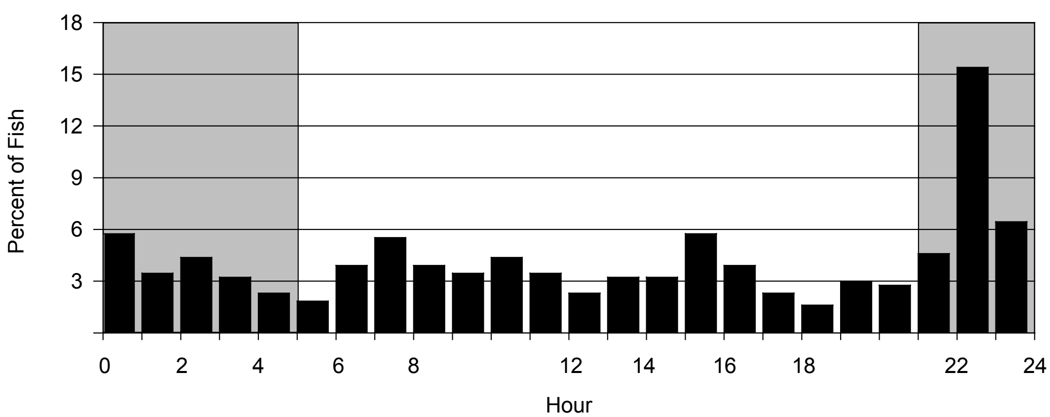

Figure 19. Percentage of subyearling chinook salmon that passed Bonneville Dam by hour of day as measured by radio telemetry during summer (7/1-7/15) 2001. Shaded areas represent night (2100-0459 hours) and unshaded areas represent day (0500-2059 hours).

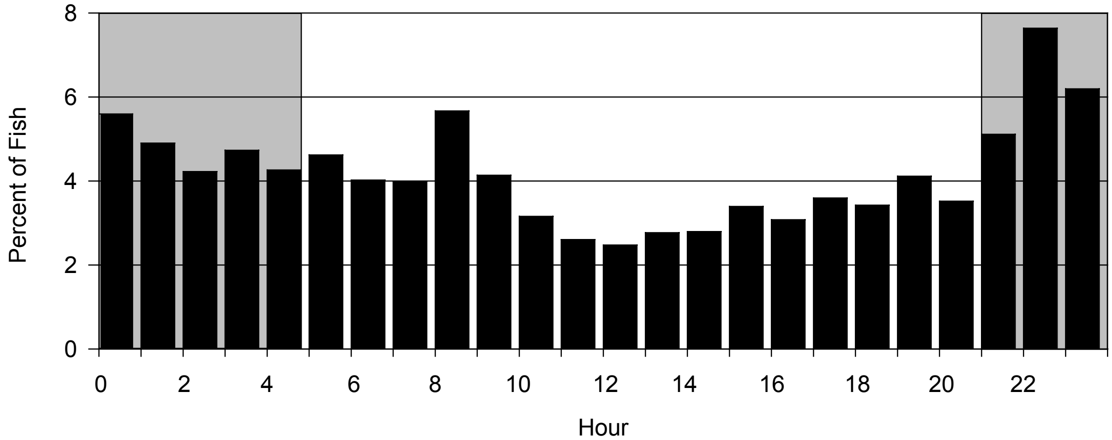

Figure 20. Percentage of run-of-river fish that passed Bonneville Dam by hour of day as measured by hydroacoustics during summer (7/1-7/15) 2001. Shaded areas represent night (2100-0459 hours) and unshaded areas represent day (0500-2059 hours). Data were provided by Carl Schilt, Waterways Experiment Station (January 9, 2002).

4.0 Discussion

The proportion of discharge at each dam area was likely the determining factor for which forebay fish entered. 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 largest amount of water during the study (94.2%) most fish entered the B2 forebay (67%). Low discharge at B1 (3.4% of project discharge) resulted in only 9% of subyearling chinook salmon entering that dam area. However, discharge at the spillway (2.4% of project discharge) was even lower than at B1, yet 24% of fish that approached Bonneville Dam first entered the spillway forebay. Although our analysis of the data did not provide a reason for the relatively high number of fish that entered the spillway during low discharge, the observation suggests that factors other than, or in addition to, flow may cause fish to enter the spillway forebay at Bonneville Dam.

Forebay residence times of subyearling chinook salmon differed considerably depending on dam area. B2 and the spillway provided the quickest routes of passage as residence times there were substantially less than at B1. No relation was apparent between daily discharge patterns, hour of arrival, or hour of passage and residence time. Total discharge per dam area seemed to be the primary factor affecting residence times of subyearling chinook salmon at B2. However, at the spillway, where discharge was low, residence times were also relatively short. This indicated that the quality of discharge, rather than just the quantity, might have also affected residence times. The flow cues provided by spilling at the outermost spillbays (1 and 18) may have been sufficient enough for fish to recognize and pass relatively quickly. These observations indicate that project operations and the resulting discharge per dam area influence approach paths of migrating subyearling chinook salmon and may determine which dam area they enter. Likewise, discharge per dam area affected how long fish resided in the forebay of Bonneville Dam before passing.

Although some movement occurred between the three dam areas (B1, B2, and the spillway), most fish passed through the dam area they first entered. Twenty-five percent of the fish that first entered B1 and the spillway, eventually passed at B2. Therefore, project discharge was the primary factor in affecting not only approach behavior but also which dam area fish ultimately passed.

At B1, the proportions of radio-tagged fish that passed through specific routes indicated that fish were generally shallow in the water column. The greatest percentage of fish passed through the shallow, weir-type entrances of the sluiceway (70%) and adult ladder exit (7%), followed by the deeper guided (13%) and unguided (10%) routes of passage. At B2, where a shallow, surface-oriented route of passage was unavailable because of the closure of the sluice chute, more fish passed directly through the turbines (65%) than were guided into the DSM (35%). The high rate of passage through the sluiceway at B1 was likely due to the low amount of discharge at B1. Since few turbines were operated at B1 due to low river flow, less fish were entrained into turbine intakes and thus were available to the shallow entrances of the sluiceway.

Passage distributions during day and night did not appear to be influenced by discharge, which was nearly equal during day and night at all dam areas. The higher proportion of fish that passed B2 at night (based on the number of hours in each diel period) concurs with the findings of 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.

All passage metrics directly related to spill (SE, SF, and project FPE) were lower in 2001 than in 2000 (Table 14). Passage metrics not directly related to spill (FGE_{B1}, FGE_{B2}, FPE_{B1} and FPE_{B2}) were all higher in 2001 than in 2000. Decreased passage metric values in 2001 can be attributed to low river flows. Due to B2 FGE tests, turbine operation at B2 was prioritized over turbine operation at B1. Additionally, extremely limited spill (3% of project discharge through 2 spillbays) occurred during the study. The resulting high discharge at B2, compared to the other dam areas, attracted and passed a majority of the fish. Since fewer fish entered B1 and the spillway, fewer fish passed at those locations, resulting in low passage metrics, especially those related to spill.

Table 14. Passage performance metrics for radio-tagged subyearling chinook salmon at Bonneville Dam during summer 2000 and summer 2001.

Metric	Subyearling Chinook	
	2000	2001
Spillway Efficiency	65%	2%
Spillway Effectiveness	1.2	0.8
FGE_{B1}	29%	57%
FGE_{B2}	25%	35%
FPE	91%	40%
FPE_{B1}	77%	89%
FPE_{B2}	25%	35%

5.0 Acknowledgements

We thank our colleagues of the U.S. Geological Survey who assisted with field operations, data analysis, and administrative support throughout the study. We thank Blaine Ebberts, Rock Peters, Jennifer Sturgill, and other COE personnel for their efforts in managing our contract and assisting in planning and executing this research. Many thanks go to Dean Ballinger, Bruce Mills, John Barton and Rick Martinson at the Pacific States Marine Fisheries Commission for their assistance in collecting fish for this study. We would also like to thank Gene Ploskey and Carl Schilt, of the U.S. Army Corps of Engineer's Waterways Experiment Station, for providing hydroacoustic data and information that enabled our comparison of radio telemetry and hydroacoustic results.

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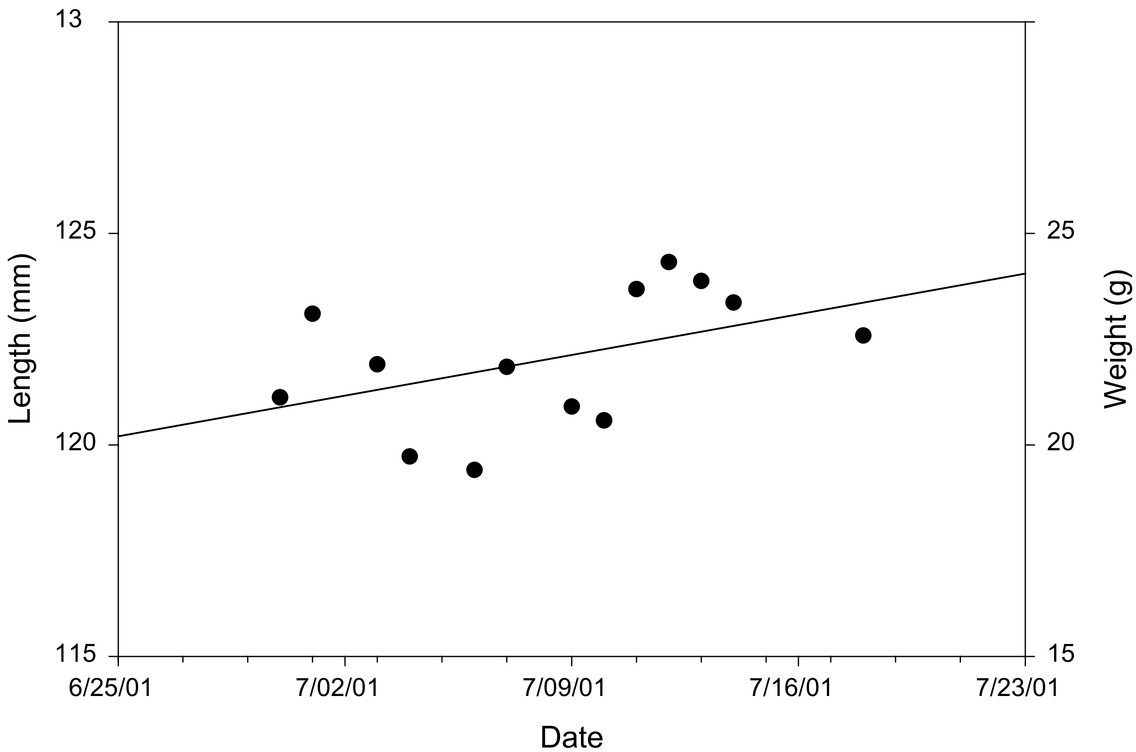
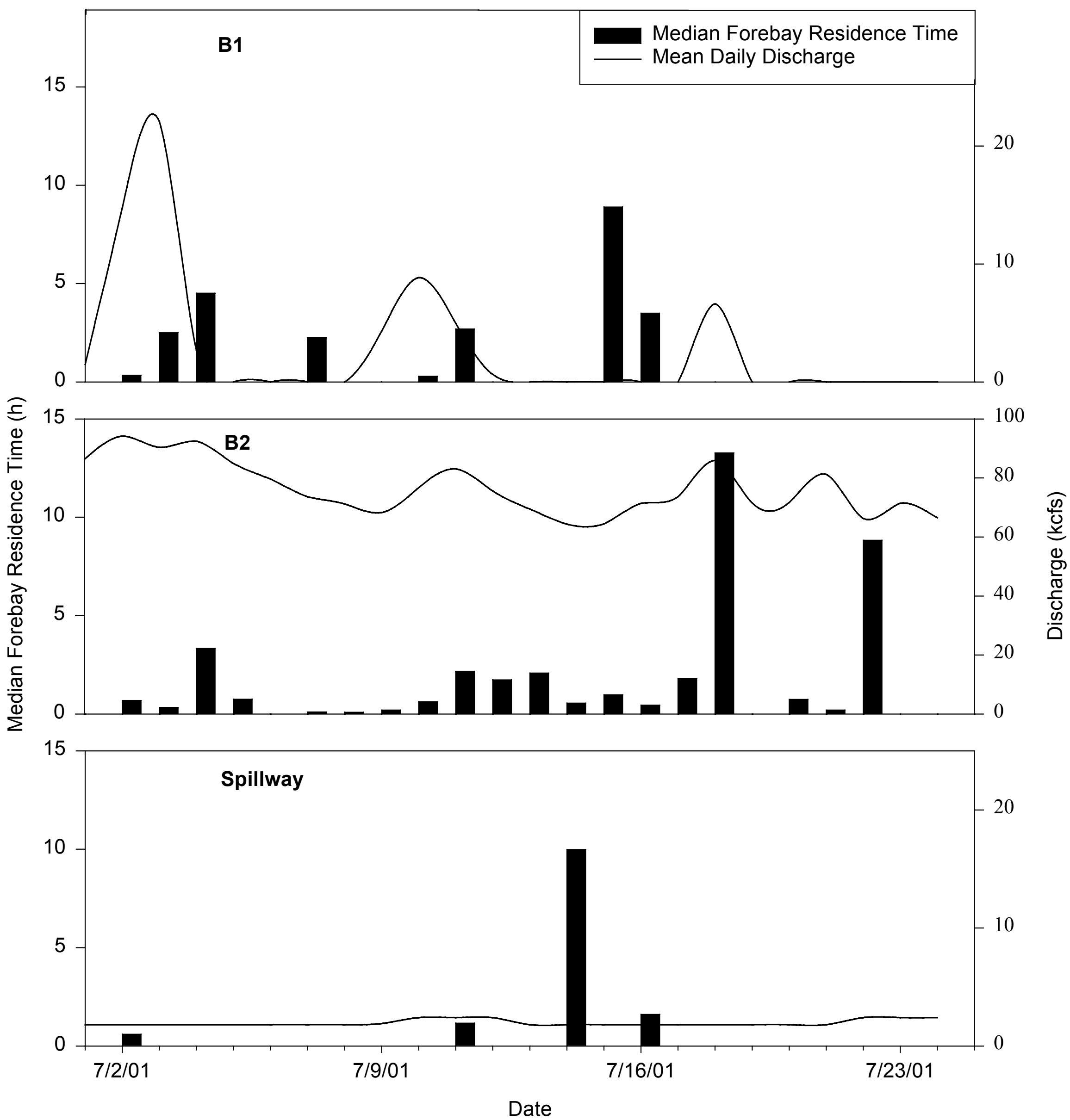
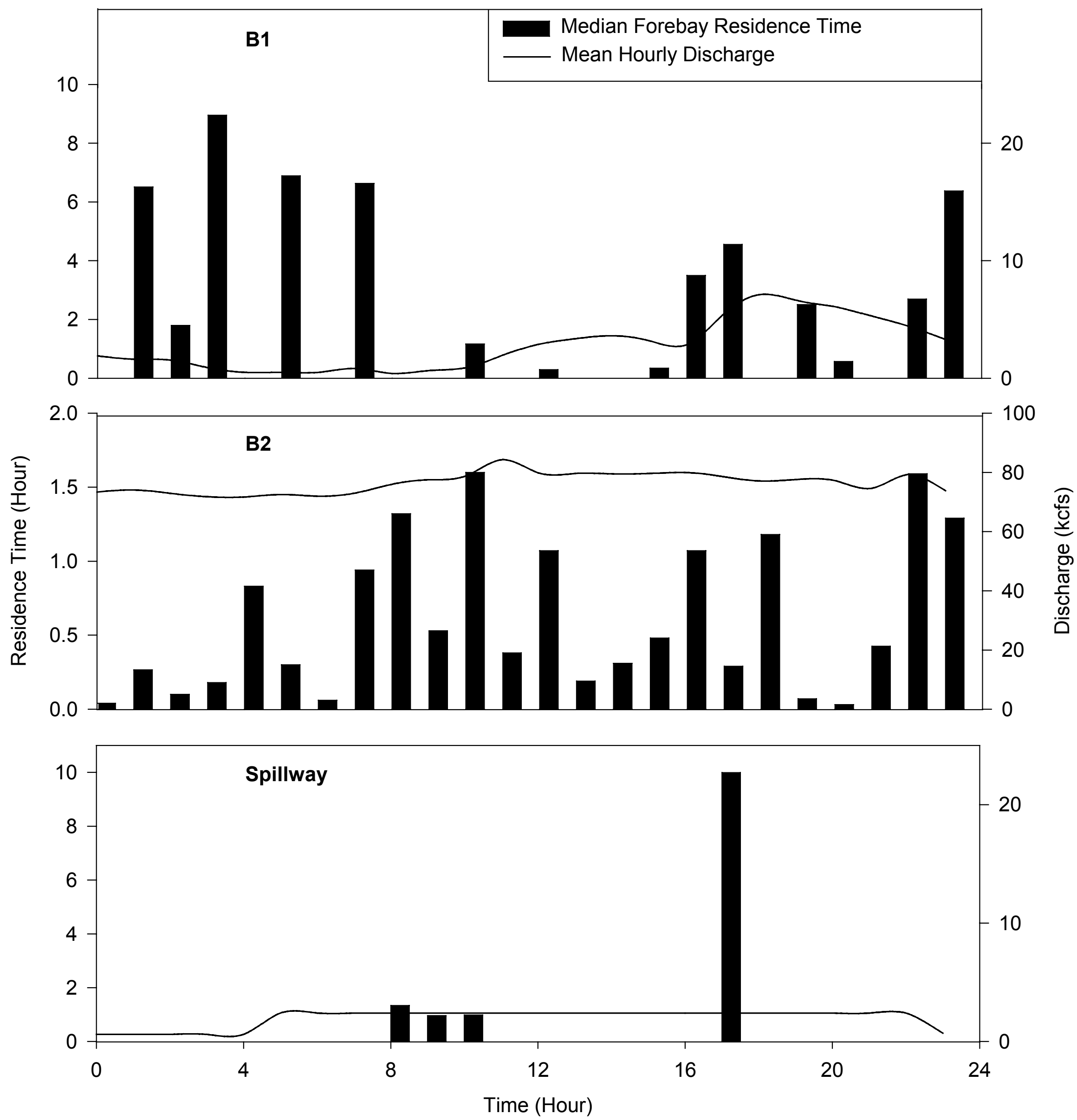
7.0 Appendices



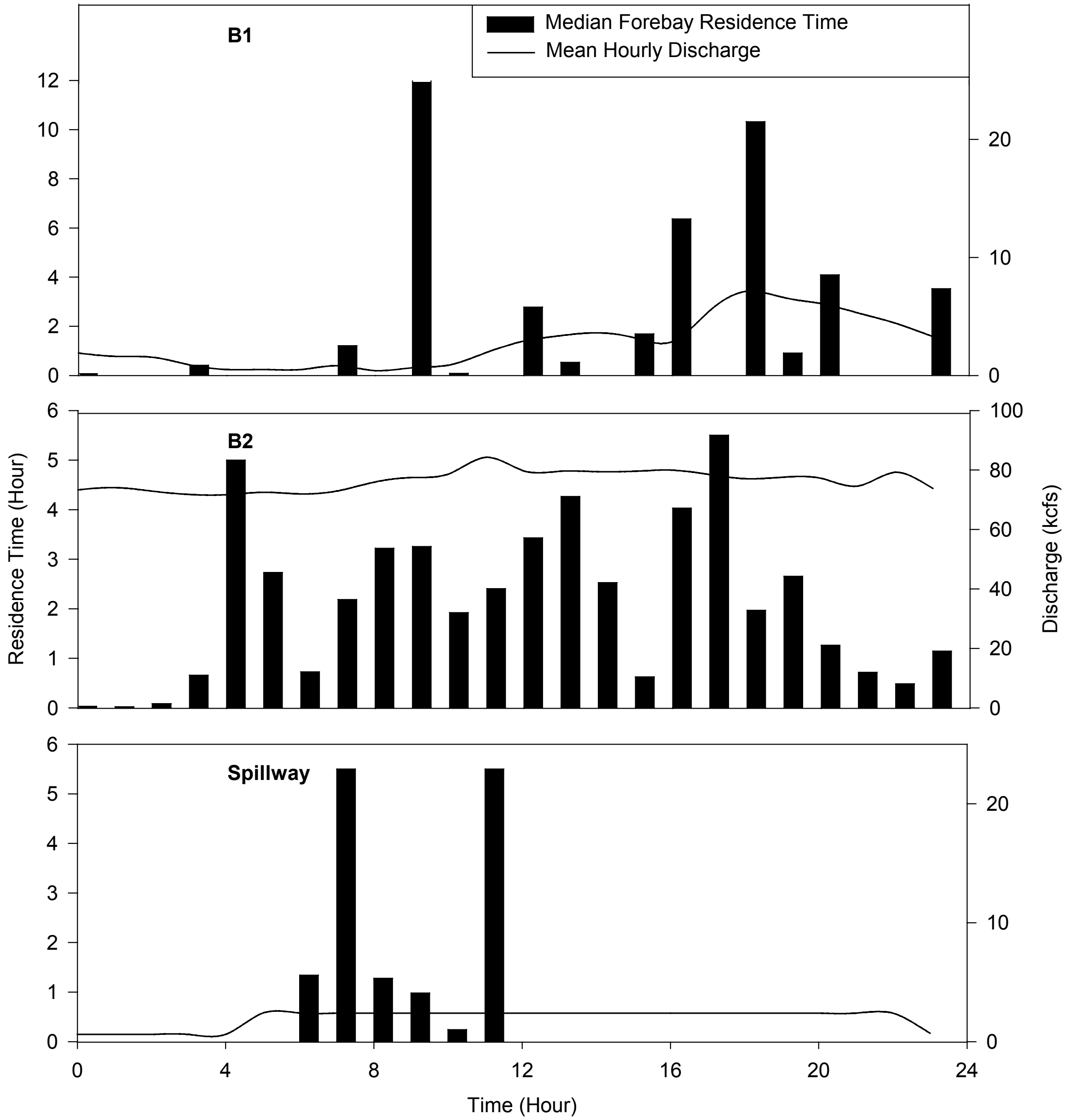
Appendix 1. Mean length and weight by date for subyearling chinook salmon collected at Bonneville Dam during summer 2001.



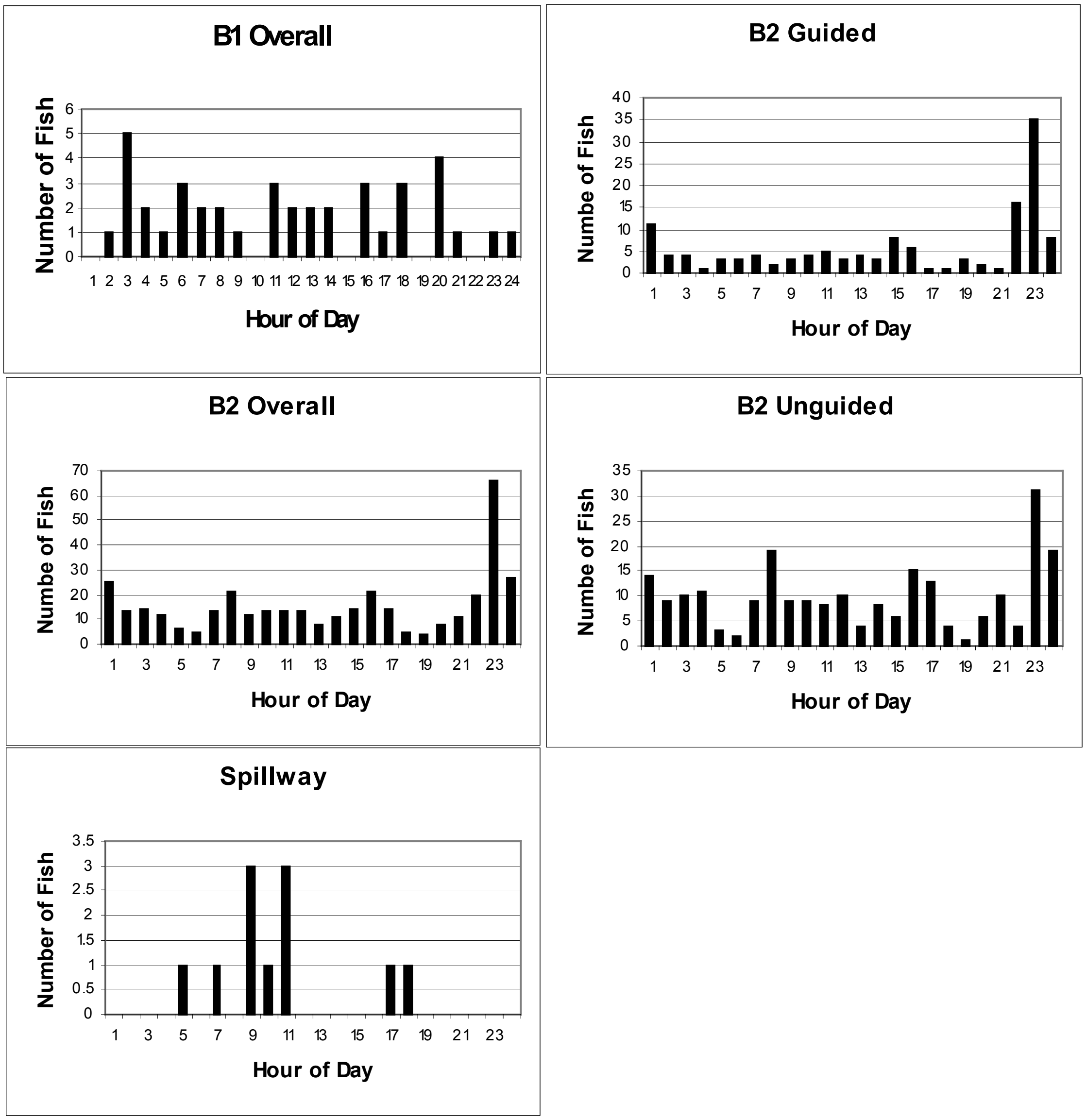
Appendix 2. Median forebay residence time by day of passage versus mean discharge by dam area for radio-tagged subyearling chinook salmon at Bonneville Dam during summer 2001.



Appendix 3. Median forebay residence time by hour of passage versus mean discharge by dam area for radio-tagged subyearling chinook salmon at Bonneville Dam during summer 2001.



Appendix 4. Median forebay residence time by hour of arrival versus mean discharge by dam area for radio-tagged subyearling chinook salmon at Bonneville Dam during summer 2001.



Appendix 5. Diurnal passage of radio-tagged yearling chinook salmon at Bonneville Dam during spring 2001. Note the y-axis scales differ among graphs.