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An Evaluation of Adult Chinook Salmon Behavior in the Presence of Pinniped Exclusion Gates, Hazing, and Acoustic Deterrents at Bonneville Dam: 2005-2006

M.A. Jepson, M.L. Keefer, K.R. Tolotti, and C.A. Peery
University of Idaho
Department of Fish and Wildlife Resources
Moscow, ID 83844-3141

and

B. J. Burke
Fish Ecology Division, Northwest Fisheries Science Center,
National Marine Fisheries Service
2725 Montlake Blvd. East, Seattle, WA 98112

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Abstract

We used radiotelemetry to evaluate the behavior of adult summer Chinook salmon in the presence of sea lion exclusion devices (SLEDs) intermittently deployed at four fishway openings at Powerhouse 2 of Bonneville Dam during 2005. Radio-tagged salmon that first approached at a SLED had the highest median time from first approach to first entry (1.3 h) among groupings (i.e., spillway, Powerhouse 1, and Powerhouse 2 w/ no SLED), suggesting the SLEDs mildly impeded fishway entry for some tagged salmon. However, we found no significant difference in the spatial distribution of first approaches or first entrances of radio-tagged salmon in the presence or absence of SLEDs during 2005. Based on time-to-event analyses and Cox Proportional Modeling, tagged salmon were 21% more likely to first approach Powerhouse 2 entrances at any given time when the SLEDs were deployed than when they were not. In contrast, tagged salmon were 19% less likely to first enter a Powerhouse 2 fishway at any given time when the SLEDs were deployed than when they were not. Neither difference was statistically significant.

Significantly higher total PIT and total visual counts recorded on days when SLEDs were deployed at Powerhouse 2 but we concluded that using daily count data to make inferences about any effects of the SLEDs, ADDs, or hazing was not robust when we used passage histories of radio-tagged salmon as surrogates.

In 2006, SLEDS were deployed at all main fishway openings and we evaluated the behavior of radio-tagged spring Chinook salmon in response to sea lion hazing and acoustic deterrent treatments. Deterrents were applied in a paired-treatment, randomized block design during 2006. Blocks were four days long and consisted of two days each with or without hazing and ADD applications. We considered both hazing and ADD applications to be parts of a single treatment for these analyses.

We ln-transformed passage times from a) first tailrace record to first approach, b) first tailrace record to first entry, c) first approach to first entry, and d) first tailrace record to last record at the ladder top to meet the normality assumption of ANOVA. We tested for any treatment and/or block effects using the model: Passage time = Treatment + Block + error. We found no significant treatment effects but the block term was significant for all passage time metrics except the time from first approach to first entry. Passage times were typically higher

during late April and early May than during the latter part of May, likely a reflection of faster fish passage when water temperatures were higher.

We also used Cox Proportional Hazard Modeling to test for any effects of the ADDs/Hazing on passage times from the tailrace to first fishway approach and first fishway entry. Fish were 10% and 17% more likely to first approach and first enter fishways, respectively, at any given time during the ADD/Hazing treatment than during the No ADD/Hazing treatment, but neither difference was statistically significant. In summary, both parametric and non-parametric analyses suggested that the combined effect of hazing and ADDs did not impede the passage of radio-tagged adult spring Chinook salmon during 2006.

Finally, we performed an *ad hoc* evaluation of any SLED effects by comparing passage times from April-May 2006 during periods with no ADDs/Hazing, to passage times from April-May in 2003 and 2004, when no SLEDs were deployed. Median passage times from 2006 were consistently lower than those from the years with no SLEDs, circumstantially suggesting the SLEDs alone did not impede the passage of radio-tagged adult spring Chinook salmon during 2006.

Acknowledgements

Many people assisted with the field work and data compilation for this report and its successful completion was made possible through their efforts. They include: Steve Lee for overseeing the radiotagging of adult salmon, Travis Dick, Carol Morat, and Mark Morasch for downloading receivers, Kinsey Frick for administering the database in Seattle, Dan Joosten for interpreting and summarizing the telemetry data, and Dr. Christopher Williams for asistance with the statistical portions of this report. This study was funded by the U.S. Army, Corps of Engineers (USACE), Portland District, with assistance provided by David Clugston, Tammy Mackey, Jon Rerecich, and Robert Stansell.

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Introduction

Archeological data from the Lower Columbia River region show that members of the Order Pinnipedia were in the river downstream from Celilo Falls during much of the last 10,000 years and it has been suggested that these pinnipeds were pursuing salmon and lamprey up the Columbia River (Lyman et al. 2002). Adult salmon are vulnerable to pinniped predation during the spawning migration through estuaries and river mouths, especially where salmon concentrate or passage may be constricted (NMFS 1997a). Because most salmonids must pass through relatively narrow fishways to pass Bonneville Dam, the most downstream dam on the Columbia River, fish managers are concerned that unrestricted pinniped access to Bonneville's fishways may make salmonids particularly vulnerable to predation or may cause inordinately high dam passage times for adults migrating to upstream spawning sites.

For most years between 1980 and 2000, one to two sea lions (both *Zalophus californianus* and *Eumetopias jubatus*) were observed in the tailrace of Bonneville Dam. Since 2001, increasing numbers of sea lions and harbor seals (*Phoca vitulina richardii*) have been observed there and some were observed inside the Washington-shore fishway at the counting window during 2005 (Figure 1). Surveys conducted from 2002 through 2006 suggest there has been a general increase in the proportion of the spring Chinook salmon (*Oncorhynchus tshawytscha*) run being preyed upon by pinnipeds (Stansell 2004; R. Stansell, personal communication). During these years, predations rates have averaged 1.5% annually; years with relatively high proportionate predation have been years with low salmon abundance. In absolute terms, a range of 1,010 – 3,533 adult salmon were estimated to have been preyed upon by pinnipeds each year from 2002 through 2006, with an average of 2,563 salmon annually.

During 2005, barred gates (or sea lion exclusion devices (SLEDs)) were intermittently placed at four main fishway openings of Powerhouse 2 to block pinniped access. Barred gates were similarly placed at all main fishway openings at the dam during 2006. Active hazing (e.g., rubber bullets and firecrackers) and the use of acoustic deterrent devices (ADDs) were evaluated as means of coercing pinnipeds to leave or avoid the Bonneville fishways in 2006. If ADD treatments were effective at keeping pinnipeds away from fishway openings, one might expect salmon passage times to be lower when hazing and ADD treatments were applied. However, if these treatments were detectable by salmon, one might expect higher passage times. We used radiotelemetry to monitor the movements of adult Chinook salmon at Bonneville Dam in both years to evaluate whether the barred gates, hazing activities, and/or acoustic deterrents impeded adult Chinook salmon passage.

Figure 1. Photograph of sea lion viewed from Washington-shore viewing window during 2005 (courtesy of U.S. Army, Corps of Engineers).

Methods

We collected adult summer Chinook salmon in the Adult Fish Facility adjacent to the Washington-shore at Bonneville Dam during June of 2005 and adult spring Chinook salmon during April and May of 2006. During the day, a picketed lead weir was lowered into the ladder and adult migrants were unselectively diverted into the trap. We made no attempt to representatively (proportionately) sample the run as a whole. Fish swam from the trap into exit chutes and were diverted into an anesthetic tank [20 mg/l clove oil] (Peake 1998) via electronically-controlled guide gates. Anesthetized fish were moved to a smaller tank where they were tagged after having their lengths, marks, and injuries recorded.

A radio transmitter dipped in glycerin was inserted into the stomach through the mouth of each fish tagged. We used 3- and 7-volt transmitters (Lotek Wireless, (Newmarket, Ont.) that emitted a digitally-coded signal (containing the frequency and code of the transmitter) every 5 s. All transmitters were cylindrical with 43-47 cm antennas. Seven volt tags weighed 29 g in air (8.3 by 1.6 cm), three volt tags weighed 11 g in air (4.3 by 1.4 cm), and Data Storage Tags (9.0 by 2.0 cm) weighed 34 g in air. Code sets allowed us to monitor up to 212 fish on each frequency. Lithium batteries powered the transmitters which had a rated operating life of more than nine months. We used passive integrated transponder (PIT) tags as secondary tags. After tagging, fish were placed in an aerated transport tank where they were held until release.

2005 Studies

We radiotagged a total of 96 fish and released 95 of them (*mean FL* = 82.2 cm, *range* = 69-108 cm) at the Hamilton Island boat ramp, approximately one kilometer downstream from Powerhouse 2 on the Washington shore (Figure 2). One adult Chinook salmon died prior to release. Because adult salmon tend to migrate close to river shores (Daum and Osborne 1998; Hinch et al. 2002), radio-tagged salmon were released at the Hamilton Island boat ramp on the Washington shore in hopes of maximizing the number of tagged salmon first approaching Powerhouse 2 sites where barred gates were deployed. Passage times from the tailrace to any event (e.g., first fishway approach or first fishway entry) during 2005 were not comparable to similar metrics from other years because radio-tagged salmon were released within the range of tailrace receivers.

SLEDs were intermittently deployed at the four main Powerhouse 2 fishway openings during 2005 (Figure 3). SLEDs were constructed of 5 inch (outside diameter), circular, vertical bars with 16 inch gaps. A schedule for deploying and removing the SLEDS for 2-day intervals was initiated in June of 2005 and planned to be run for 80 days. However, significant cracks in the gates were found after eighteen days were completed and the 2005 evaluation was stopped. Turbulence from water passing around the round bars was thought to have caused the cracks to form. During the 18-day test, four-day periods consisted of two days each with or without the SLEDs in place while radio-tagged Chinook salmon were monitored as they passed the dam (Figure 2). The order of two-day SLED deployments within four-day periods was randomized. Because salmon are typically less active at dams at night (Burke et al. 2005; Naughton et al. 2005; Keefer et al. *in review*), SLEDS were deployed or removed at approximately 2000 hrs on each day preceding the nominal date for each SLED change. Openings without SLEDs were always available for use by salmon during periods when SLEDs were deployed; permanently available openings included unmonitored orifice gates at Powerhouse 2, openings to the Powerhouse I fishway, and fishway openings adjacent to the spillway. SLEDs were deployed for a total of eight days during 2005.

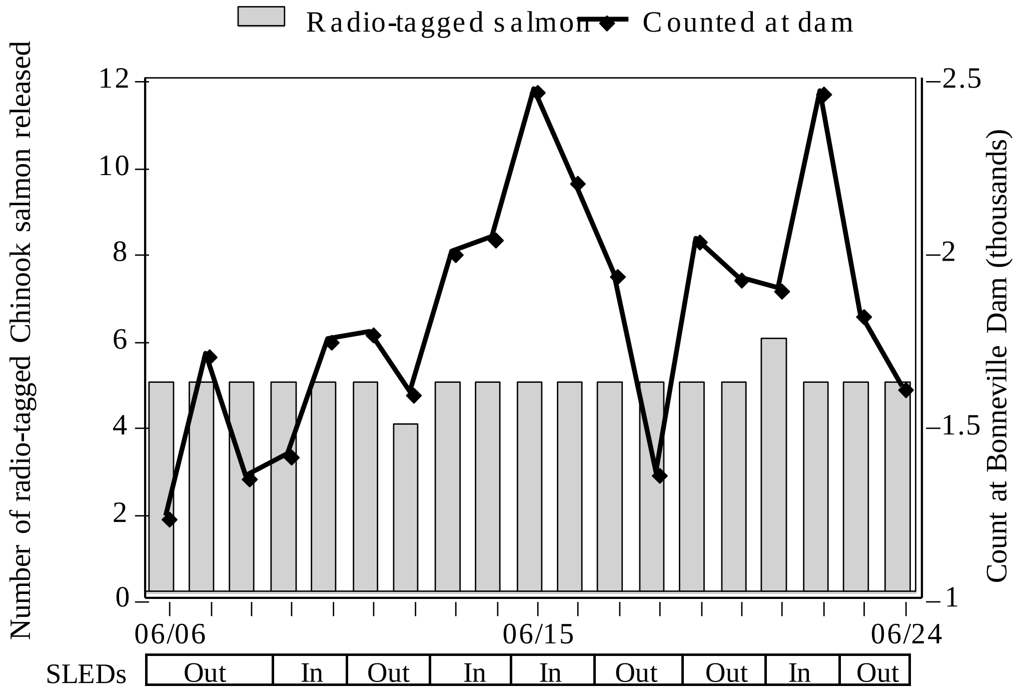

Figure 2. Counts of adult summer Chinook salmon passing Bonneville Dam and the numbers collected and radiotagged at the dam during 2005 SLED evaluations. SLED deployments are depicted below the x-axis.

Distributions of first approaches and first entrances

Observations of radio-tagged salmon at fishway openings with SLEDs were opportunistic in the sense that openings without SLEDs were always available for use by salmon during periods when SLEDs were deployed and we could not control which opening(s) a radio-tagged salmon approached. We therefore compared the distributions of first approaches and first entrances of radio-tagged salmon in the presence and absence of SLEDs at Powerhouse 2. We additionally evaluated times from first fishway approach to first fishway entry for radio-tagged salmon that first approached at a fishway opening with a SLED versus tagged salmon that first approached openings without a SLED.

Daily Dam and PIT-tag Counts

Daily counts of salmon passing via fish ladders and numbers of unique PIT-tag detections could potentially be used to estimate any effects of the SLED treatment on passage rates, assuming passage routes remained similar between SLED treatments. We ln-transformed ladder-specific and total PIT- and visual count data to better meet the assumption of normality and evaluated any effects of the SLED deployments using the (ANOVA) general linear model: Ln (daily PIT or visual count) = treatment + error.

We also used the dates of dam passage events by radio-tagged salmon to estimate the percentages of daily ladder-specific (Bradford Island or Washington shore) visual and PIT-tag counts that could be directly attributable to a particular SLED treatment during 2005. Of the number of passage events recorded at each ladder by radio-tagged salmon, we estimated the number of tagged salmon that first approached a fishway opening with a SLED, the number that first entered a fishway opening using a SLED, and the number that last entered a fishway using a SLED. We then evaluated what effect these percentages might have on any meaningful comparison of the SLED treatment using ladder-specific visual counts and PIT-tag counts of salmon.

Time-to-Event Analysis

We used R statistical software (version 2.3.1) and Cox Proportional Hazard models (Castro-Santos and Haro 2003; Caudill et al. 2006) to compare time to approach or enter between treatments. We restricted comparisons to Powerhouse 2, where the treatment was being applied. Comparisons were between times from first detection in the tailrace to first approach or first entrance when SLEDs were deployed versus times when SLEDs were not deployed. This analytical technique takes into consideration fish that entered the area during one treatment but did not approach or enter until treatments were switched. It also accounted for fish that entered the area, but never approached or entered a fishway. For approach times, we included only tagged fish that first approached at Powerhouse 2 (n = 60). For entrance times, we included only those tagged fish that first approached and first entered at Powerhouse 2 (n = 52). We evaluated the statistical power of this test using methods described in Schoenfeld (1983).

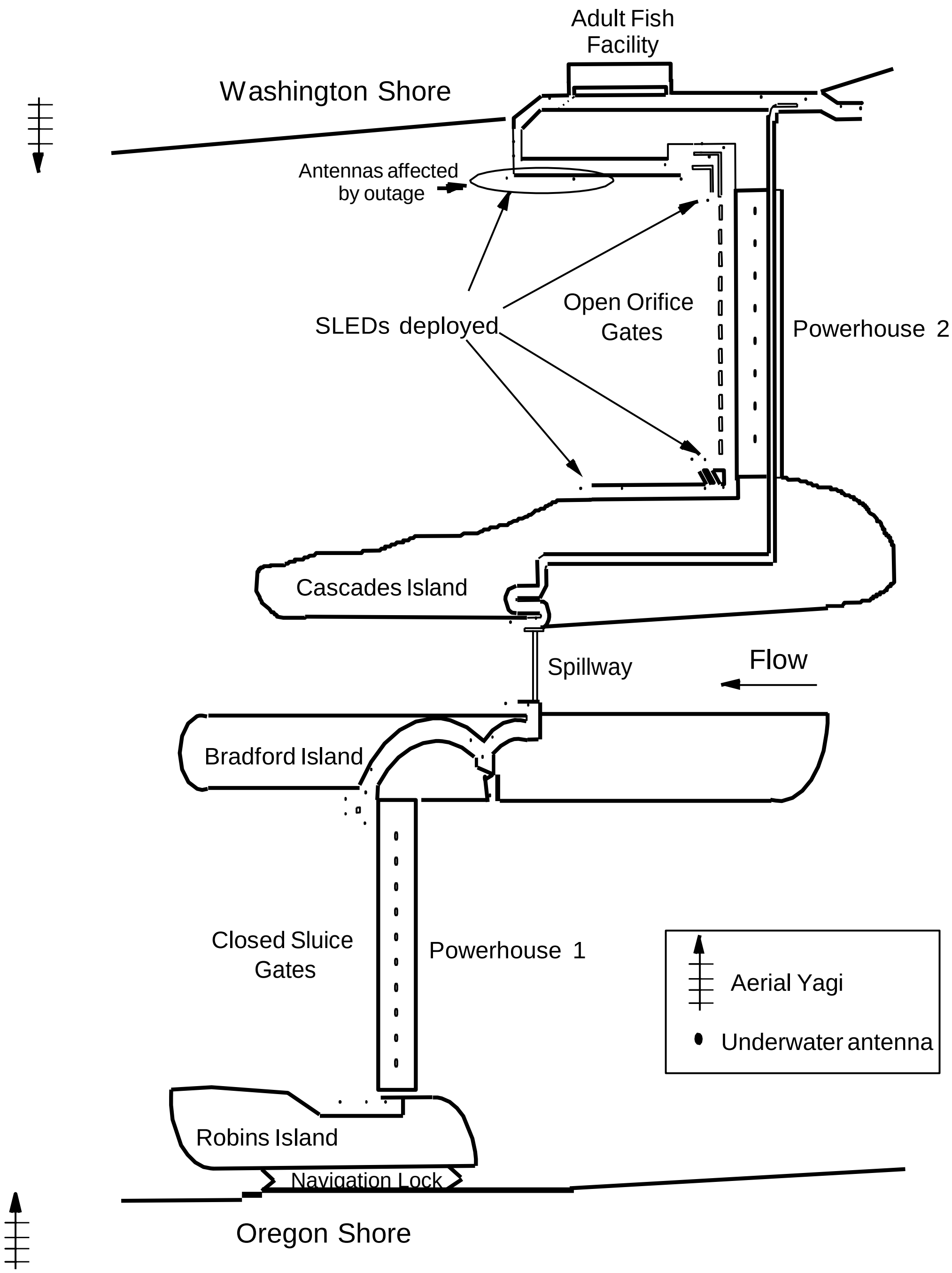

Figure 3. Aerial view of radio antenna and SLED deployments at Bonneville Dam during 2005.

2006 Studies

We radiotagged 358 adult Chinook salmon (*mean FL* = 73.8 cm, *range* = 63.0-96.5 cm) and alternately released them approximately nine kilometers downstream from the dam on either side of the river during 2006. SLEDs were deployed at all eight main fishway openings. As during 2005, the orifice gates at Powerhouse 2 were not monitored with radiotelemetry during 2006 (Figure 5).

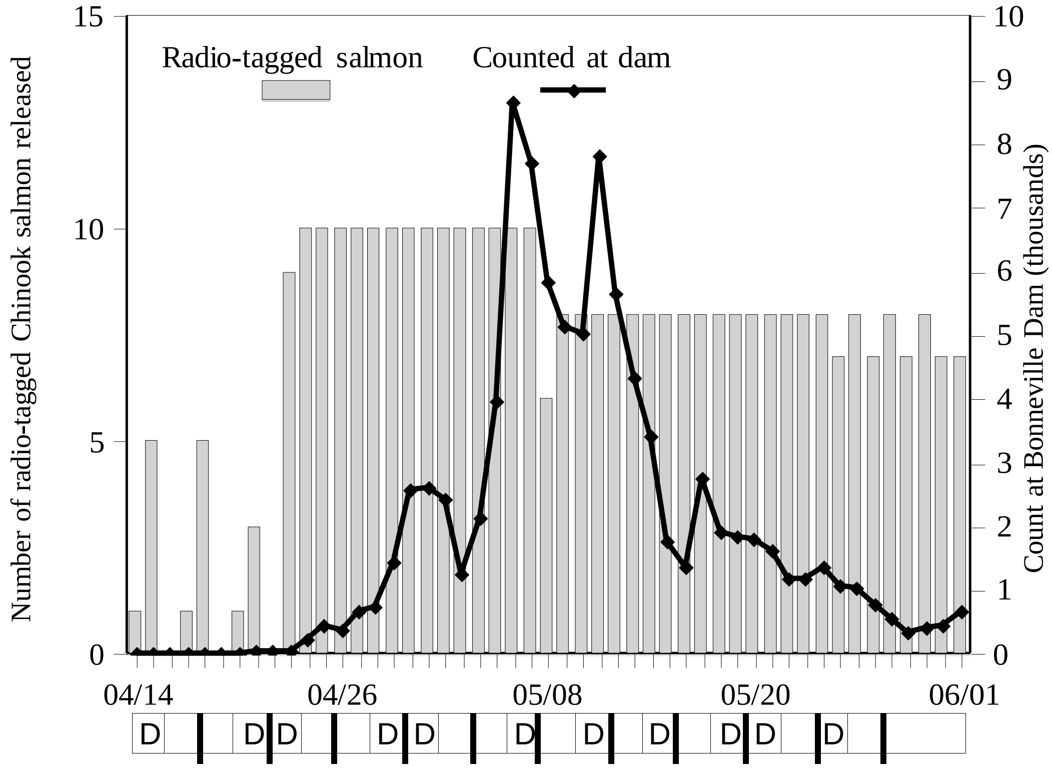

Figure 4. The number of spring–summer Chinook salmon radio tagged and released downstream from Bonneville Dam during 2006 and the count of adult Chinook salmon passing the dam. Sea lion deterrent treatments (D) are depicted in 2-day intervals (within 4-day blocks) below the X-axis.

In late March 2006, a sea lion was observed exiting Powerhouse 2 over the top of a floating orifice gate so bars were welded over the openings to exclude pinnipeds. Many floating gates subsequently sank because cracks at the welds adjoining the two pieces allowed water into the airspace. In response, all Powerhouse 2 floating orifice gates were closed to adult fish passage beginning on 4 May 2006. Another potentially confounding event included the removal of the SLEDs from the two downstream-most main fishway openings at Powerhouse 2 for approximately two days beginning on 24 April 2006.

Acoustic Deterrents and Hazing

Acoustic deterrent devices (ADDs) were deployed near all main fishway openings and transition pools (Figure 5). ADDs consisted of a transmitter box and an acoustic projector (db Plus II model by Airmar Technology Corporation, Milford, New Hampshire). ADDs operated using a 12 VDC deep-cycle battery which was constantly charged with a 12 VDC battery charger. Projectors cyclically emitted a 10 kHz pulse of sound for approximately 2.5 seconds followed by approximately 10 seconds of no sound emission.

Hazing and acoustic treatments were applied in a blocked design. Blocks were comprised of four days which consisted of two days each with or without hazing and ADD applications. The sequence of treatments within blocks was randomized. ADDs were turned on at 0500 hrs each morning active hazing was conducted and turned off at 2000 hrs on the last hazing day of each two-day ADD treatment (within four-day blocks).

Hazing occurred from 0500 hrs to 2000 hrs each day ADD treatments were applied but was discontinued between 2000 hrs of day one and 0500 hrs of day two. Pinnipeds were hazed from the tailrace deck only when observed on any ‘haul out’ sites at the dam (i.e., sites where pinnipeds go ashore to rest) or sighted within ~100' radius of any fishway opening. Hazing involved the use of sound and tactile stimuli; specifically, firecrackers and rubber bullets/buckshot.

Atlantic salmon can detect sounds at frequencies above 600 Hz (Hawkins and Johnstone 1978) and below 20 Hz (Knudsen et al. 1992, 1994). The amount of research on hearing in Pacific salmon is scant (Hastings and Popper 2005) but data on the anatomy of the ear of several salmonid species suggest that the auditory system is similar in all salmonids (Popper 1977). Based on cautious extrapolations from Atlantic salmon, we think the adult salmon radiotagged for this study probably could not directly detect/sense the 10 kHz sound emissions from the ADDs. We considered hazing and acoustic deterrent deployments to be components of one treatment for analytical purposes.

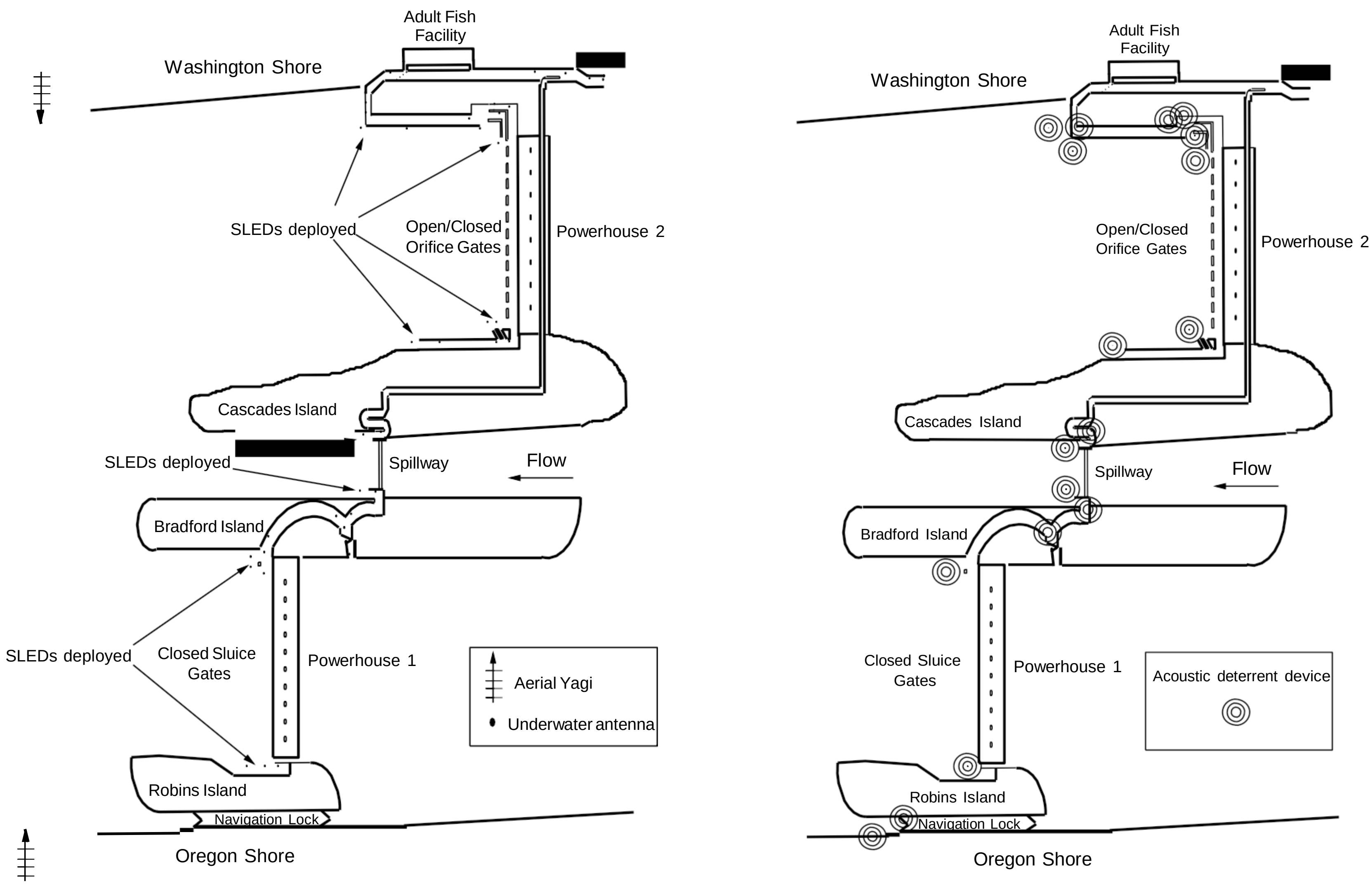

Figure 5. Aerial view of radio antennas, SLEDs (panel on left), and acoustic deterrent devices (panel on right) at Bonneville Dam during 2006.

Percentages of tagged salmon that entered a fishway the same day as first approach

We used a Chi-square Test to compare the proportions of tagged salmon that entered a fishway on the same day they first approached one during days with ADDs/hazing and days with no ADDs/hazing. By doing so, we tried to isolate any effects of the treatment from any diel effects associated with longer passage times. Specifically, Chinook salmon typically become less active at dams during the night (Burke et al. 2005; Naughton et al. 2005; Keefer et al. *in review*) and salmon that do not first enter the fishway on the same day they approach it are likely to experience longer passage times.

Daily Dam and PIT-tag Counts

We ln-transformed total daily PIT- and visual count data to better meet the ANOVA assumption of normality and used a randomized, complete block design to evaluate any effects of the hazing/ADD treatments using the general linear model: Ln (daily PIT or visual count) = treatment + block + error. We specifically tested for any treatment effects using the treatment*block mean square as the error term.

We assessed how many salmon passing Bonneville Dam on a daily basis could reasonably be assigned a treatment level (presence or absence of ADDs/hazing) based on their date of passage and the treatment level being applied on that date. Specifically, we used the number of daily dam passage events by radio-tagged salmon and the individual passage histories of tagged fish to estimate the percentage of daily dam and PIT-tag counts that could be directly attributable to either the application or absence of sea lion deterrents during 2006. Of the total number of daily dam passage events recorded by radio-tagged salmon, we counted the number of tagged salmon that made their first approach or first entry during the same treatment level present on the date of their dam passage. We then evaluated what effect these percentages might have on any meaningful comparisons of the treatment levels using dam and PIT-counts as dependent variables.

Randomized Complete Block Design

We ln-transformed times for radio-tagged salmon to pass from a) tailrace to first approach, b) tailrace to first entry, c) first approach to first entry, and d) tailrace to a ladder top to meet the assumption of normality for the ANOVA. We used a randomized, complete block ANOVA to test for any differences between treatments and blocks (model: ln (passage time) = treatment + block + error) and specifically tested for any treatment effects using the treatment*block mean square as the error term. Passage times used for these analyses were restricted to tagged salmon that first approached and first entered a fishway operning during a single treatment application within a block (i.e., they saw no treatment skipping or switching – see Caudill et al. 2006). We evaluated the statistical power of this test using methods described in Kirk (1994).

Time-to-Event Analysis

We used Cox Proportional Hazard modeling (Castro-Santos and Haro 2003; Caudill et al. 2006) to test the effect of sea lion deterrents on times to first approach or first enter a fishway. We did not distinguish between entrance locations and therefore estimated the effect of sea lion deterrent treatments across the dam as a whole. We evaluated the statistical power of this test using methods described in Schoenfeld (1983).

Ad hoc SLED evaluation

We compared passage times from April-May 2006 during periods with no sea lion deterrents to passage times from April-May in 2003 and 2004, when no SLEDs were deployed. We used 2003 and 2004 for comparisons because the sluice gates at Powerhouse I were configured similarly (closed) as in 2006.

Results

Outages

There were five outages at receiver sites that made direct evaluations of salmon behavior near SLEDs challenging or calculations of total dam passage times impossible (Table 1). Four of the five outages occurred at receiver sites that monitored ladder exits which precluded calculating total dam passage times, one during 2005 and three during 2006. The outages at ladder exits combined for a total of 23.2 days without monitoring during both years. Inferred from detections at upstream sites or PIT detectors, dam passage times were not estimable for at least 16 summer Chinook salmon during 2005 (17% of all passage events) and 49 salmon during 2006 (15% of all passage events) as a result of these outages. Salmon behavior at/near the Washington-shore downstream opening at Powerhouse 2, an opening where SLEDS were intermittently deployed, was not monitored during 14 of 18 trial days during 2005 (Figure 3). During the 14-day outage, SLEDS were deployed during eight days and SLEDs were not deployed during six days. We considered tagged fish initially recorded on the antenna immediately upstream from the non-working antennas (Figure 3) to have entered via the opening affected by the outage but no passage times from the tailrace to their first approach or first entry were estimated for these fish.

Table 1. Sites, dates, durations, and causes of receiver outages while monitoring Bonneville Dam during 2005 and 2006.

Site	Outage Start	Outage End	Duration (d)	Cause
Washington shore downstream opening at PH2	09 June 2005	22 June 2005	13	No power to line amps
Bradford Island ladder top	15 June 2005	21 June 2005	6	Power turned off
Bradford Island ladder top	27 April 2006	01 May 2006	6.2	Receiver unplugged
Bradford Island ladder top	14 May 2006	22 May 2006	8	Defective power supply cord
Washington shore ladder top	16 June 2006	19 June 2006	~3	Defective power supplycord

2005 Studies

Distribution of First Approaches and First Entrances- 2005

Sixty (63%) of the 95 radio-tagged salmon released at the Hamilton Island boat ramp during 2005 made their first approach at Powerhouse 2, a relatively high percentage that presumably reflects the release site choice. Based on the site of initial detection within the fishway, we believe two of these 60 (3%) fish first approached (and first entered) the dam via a fishway opening with a SLED during an outage. Twelve tagged salmon made their first fishway approach at Powerhouse 1 and 23 made their first approach at one of the spillway openings.

Twenty-eight (47%) of the 60 tagged salmon that first approached Powerhouse 2 did so at a fishway opening where and when a SLED was deployed. The distribution of first approach sites used by radio-tagged salmon during SLED deployments (Figure 6) was not significantly different from the distribution of first approach sites used when no SLEDs were deployed (*P* = 0.97, χ^2 test).

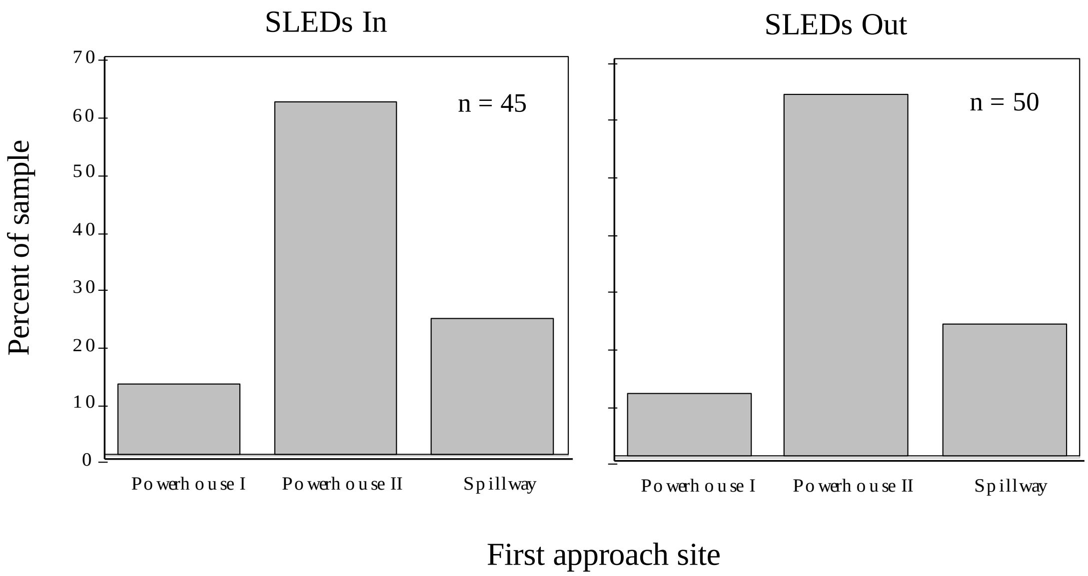

Figure 6. Distributions of first approach sites used by radio-tagged summer Chinook salmon when SLEDS were and were not deployed at Bonneville Dam during 2005.

Fifty-five (58%) of the 95 radio-tagged salmon released during 2005 made their first entrance at Powerhouse 2. Thirteen tagged salmon made their first fishway entrance at Powerhouse 1 and 27 made their first entrance at one of the spillway openings.

Twenty-four (44%) of the 55 tagged salmon that first entered a fishway at Powerhouse 2 did so at an opening where and when a SLED was deployed. The distribution of first entrance sites used by radio-tagged salmon during SLED deployments (Figure 7) was not significantly different from the distribution of first entrance sites used when no SLEDs were deployed (*P* = 0.80, χ^2 test).

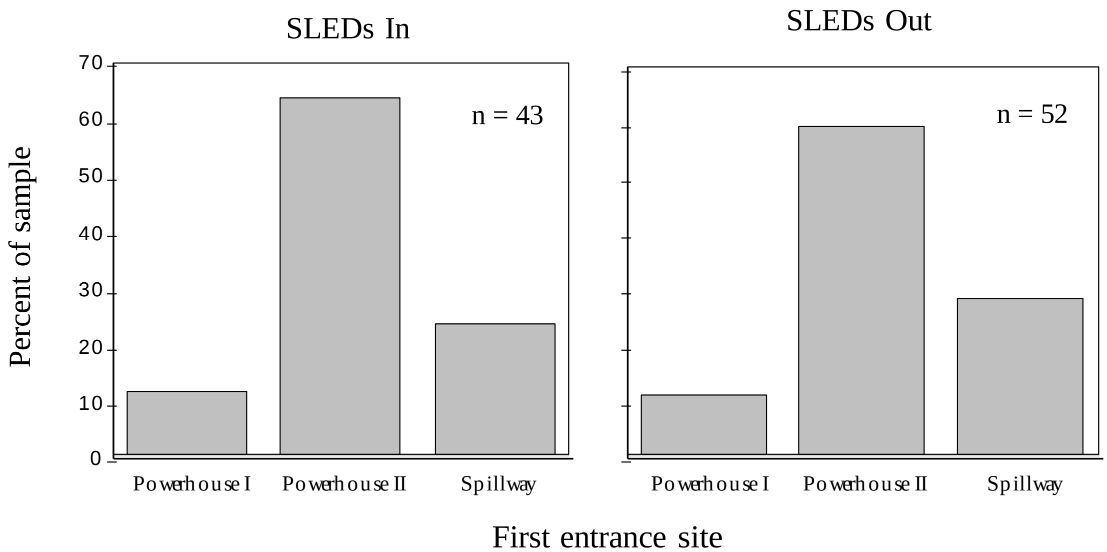

Figure 7. Distributions of first entry sites used by radio-tagged summer Chinook salmon when SLEDS were and were not deployed at Bonneville Dam during 2005.

Among radio-tagged salmon that first approached a fishway at a Powerhouse 1 or spillway opening, 67% (8/12) and 96% (22/23) ultimately made a first entry at those respective sites (Table 2). Of the radio-tagged salmon that first approached a fishway opening at Powerhouse 2 with a SLED, 68% (19/28) first entered at an opening with a SLED. Eighty-eight percent (28/32) of the tagged salmon that first approached at a Powerhouse 2 opening with no SLED made their first entry there.

Median times from first approach to first entry ranged from 0.3 to 1.3 h among first approach site groupings and the differences among these groups were significant (P = 0.02, df = 3, Kruskal-Wallis Test). Radio-tagged salmon that made their first approach at any fishway opening without a SLED had a median time from first approach to first entry of 0.5 h (n = 57). Radio-tagged salmon that first approached at a SLED had the highest median time from first approach to first entry (1.3 h), suggesting they may have been mildly impeded fishway entry. The higher passage times for the Powerhouse 1 and Powerhouse 2 with SLED groups were likely because approximately one-third of the fish swam away from their initial approach site before making their first entrance (Table 2).

Median times from first approach to first entry ranged from 0.3 to 1.0 h among groups of tagged salmon that first entered at the same sites where they first approached (Table 3). In contrast, radio-tagged salmon that first entered a fishway at sites different from their first approach sites had median times from first approach to first entry of 4.6 to 18.0 h; notably, sample sizes for this latter group were quite small.

Table 2. Distribution of first entry sites based on sites where radio-tagged summer Chinook salmon first approached Bonneville Dam fishways during 2005 and median time to make first entry after first approach. Sample sizes for passage times were smaller than some frequencies because some fish were first recorded on antennas inside fishways.

First Approach		First Entry					
Site	Freq.	PH1	Spillway	PH2 (no SLED)	PH2 (w/ SLED)	Median time from 1st approach to 1st entry (h)	*n*
PH 1	12	8	2	1	1	1.0	10
Spillway	23	0	22	1	0	0.3	22
PH2 (no SLED)	32	2	1	28	1	0.9	25
Non-SLED total	67	10	25	30	2	0.5	57
PH 2 (w/ SLED)	28	3	2	4	19	1.3	15
Total	95	13	27	34	21	0.6	72

Table 3. Distribution of first approach sites with a comparison of frequency, percentage, and median times from first approach to first entry for radio-tagged summer Chinook salmon that first entered Bonneville Dam at sites where they first approached versus those that did not, with sample sizes

First Approach Site	Freq.	First Entrance Site	Freq.	Percent	Med.time from 1st approach to first entry (h)	*n*
PH 1	12	PH 1	8	67	1.0	8
		Other	4	33	18.0	2
PH 2 (w/ SLED)	28	PH 2 (w/ SLED)	19	68	0.5	10
		Other	9	32	4.6	5
PH 2 (no SLED)	32	PH2 (no SLED)	28	88	0.4	21
		Other	4	12	7.7	4
Spillway	23	Spillway	22	96	0.3	22
		Other	1	4	-	0

Daily Dam and PIT-tag Counts – 2005

Both daily ladder-specific PIT and ladder-specific visual count data were not significantly different between treatments but the total daily PIT- and visual counts were (Table 4). On average, higher total PIT and total visual counts were recorded on days when SLEDs were deployed at Powerhouse 2.

Table 4. ANOVA results for tests of the effect of SLED deployments at Powerhouse 2 on ladder-specific and total PIT and visual count data at Bonneville Dam during 2005.

Fishway	Data type	*Probability* > F (*df* = 1)
Washington-shore	PIT-count	0.20
Bradford Island	PIT-count	0.27
Total	PIT-count	0.03
Washington-shore	Visual count	0.13
Bradford Island	Visual count	0.19
Total	Visual count	0.02

Using dam count and PIT data to make inferences about the behavior of salmon in the presence of SLEDs during 2005 was problematic, however. Two reasons include:

1) The counting station in the Washington-shore ladder is positioned such that one could not distinguish between fish entering the ladder via the north spillway opening versus any Powerhouse 2 opening based on count data alone.
2) Floating orifice gates at Powerhouse 2 were open for the duration of the 2005 evaluation. This meant we could not confidently estimate the proportion of salmon detected on the PIT detector downstream from the AFF (BO3) that may have entered Powerhouse 2 via an opening with a SLED versus one without, even when SLEDs were deployed.

On days when SLEDS were deployed, 15 to 17 of the 23 (65-74%) passage events by radio-tagged salmon via the Washington-shore ladder were by tagged fish that first approached, first entered, or last entered an opening with a SLED (Table 5). Conversely, approximately 5-10% of the passage events by radio-tagged salmon via the Washington-shore ladder on days when no SLEDs were deployed were by tagged fish that had first approached, first entered, or last entered an opening with a SLED.

Table 5. Date- and treatment-specific frequencies of Washington-shore passage events by radio-tagged summer Chinook salmon at Bonneville Dam during 2005 with frequencies of tagged salmon that first approached, first entered, or last entered the dam at an opening with a SLED.

Date	PH 2 SLEDs	WA-shore radio-tag pass. events	# 1st app. at SLED	# 1st entry at SLED	# Last entry at SLED
9 June	In	0	0	0	0
10 June	In	1	0	0	0
13 June	In	4	1	2	3
14 June	In	7	5	5	5
15 June	In	3	3	2	3
16 June	In	0	0	0	0
21 June	In	5	3	3	3
22 June	In	3	3	3	3
Total		23	15	15	17
6 June	Out	0	0	0	0
7 June	Out	0	0	0	0
8 June	Out	1	0	0	0
11 June	Out	0	0	0	0
12 June	Out	1	0	0	0
17 June	Out	3	2	1	1
18 June	Out	1	0	0	0
19 June	Out	2	0	0	0
20 June	Out	4	0	0	0
23 June	Out	0	0	0	0
24 June	Out	2	0	0	0
25 June	Out	4	0	0	0
2 July	Out	1	0	0	0
Total		19	2	1	1

On days when SLEDS were deployed (at Powerhouse 2), five to eleven of the 53 (9-21%) passage events by radio-tagged summer Chinook salmon via the Bradford Island ladder were by tagged fish that first approached or first entered a fishway opening with a SLED (Table 6). No tagged fish that passed the dam via the Bradford Island fishway made their last entry at a Powerhouse 2 opening, the only locations where SLEDs were deployed.

Table 5. Date- and treatment-specific frequencies of Bradford Island passage events by radio-tagged salmon at Bonneville Dam during 2005 with frequencies of tagged salmon that first approached, first entered, or last entered a fishway with a SLED at Powerhouse 2 (PH2).

Date	PH2 SLEDs	Brad. Isl. Radio-tag Pass. Events	# 1st App. at SLED	# 1st Entry at SLED	# Last entry at SLED
6 June	Out	1	0	0	0
7 June	Out	3	0	0	0
8 June	Out	4	0	0	0
9 June	In	2	1	0	0
10 June	In	4	2	1	0
11 June	Out	3	1	0	0
12 June	Out	3	0	0	0
13 June	In	5	0	0	0
14 June	In	1	0	0	0
15 June	In	4	1	1	0
16 June	In	3	1	0	0
17 June	Out	2	0	0	0
18 June	Out	2	0	0	0
19 June	Out	2	0	0	0
20 June	Out	3	0	0	0
21 June	In	2	1	0	0
22 June	In	3	2	2	0
23 June	Out	2	2	1	0
24 June	Out	4	0	0	0
Total		53	11	5	0

If we assigned ladder-specific daily PIT or dam counts to SLED treatment groups based strictly on the dates SLEDs were deployed at Powerhouse 2, the likelihood of accurately attributing any treatment to the Bradford Island or Washington shore ladder count would be diminished considerably based on the use of these radio data as count data surrogates. For example, we estimate that approximately 80% of the Bradford Island counts recorded on days when SLEDs were deployed were comprised of fish that never experienced a SLED during their passage history (but would be assigned to a SLED treatment). To this extent, the uncertainty associated with this treatment assignment method likely makes any results from comparisons of the treatments on adult salmon passage using PIT detections or dam counts moot.

Time-to-event Analysis-2005

Fish were 21% more likely to approach Powerhouse 2 entrances at any given time when the SLEDs were ‘In’ than when they were ‘Out’ (Figure 8, left panel), but this difference was not statistically significant (P = 0.38; n = 60). Fish were 19% less likely to enter a Powerhouse 2 fishway at any given time when the SLEDs were ‘In’ than when they were ‘Out’ (Figure 8, right panel), but this difference was not statistically significant (P = 0.65; n = 52).

The median time from the tailrace to first fishway approach was 2.1 h (*uncensored events* = 26) when SLEDs were in compared to 2.7 h (*uncensored events* = 31) when SLEDs were out. The median time from the tailrace to first fishway entry was 3.6 h (*uncensored events* = 11) when SLEDs were in compared to 1.0 h (*uncensored events* = 22) when SLEDs were out. We estimated the true ratio of medians would have to be 2.0 and 2.9 for the times to first fishway approach and first fishway entry, respectively, to have a power of 0.8 given the sample sizes.

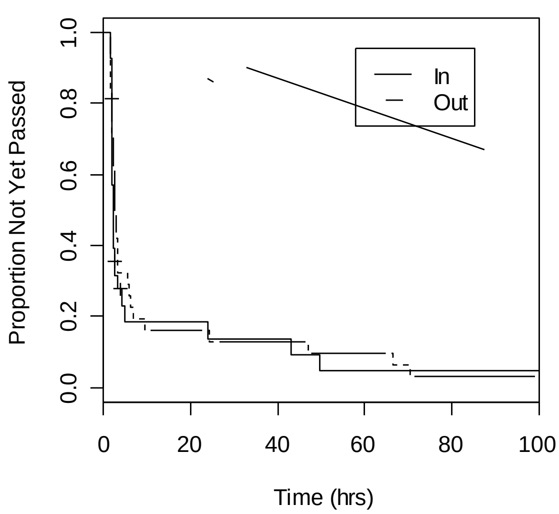

Figure 8. Cumulative passage time curves for first tailrace record to first approach (left panel) and first entrance (right panel) by summer Chinook salmon at Bonneville Dam during 2005 SLED evaluation.

2006 Studies

Percentage of tagged salmon first entering a fishway on same day as first approach - 2006

On average, 68% of tagged salmon first entered a fishway opening on the same day as they first approached it during the deterrent treatments (Figure 9). In contrast, 51% of tagged salmon first entered a fishway opening on the same as they first approached it during no deterrent treatments. Neither the Day 1 nor Day 2 comparison was statistically significant, however (Day 1 P = 0.36, Day 2 P = 0.25). Median times from first approach to first entry were consistently lower during deterrent treatments than during no deterrent treatments, suggesting there may have been a mild catalytic effect of the deterrents on adult salmon entering fishways. The mean time of day for tagged salmon to first approach a fishway opening during deterrent treatments was 1403 hrs (n = 164) and 1319 hrs (n = 127) during the no deterrent treatment.

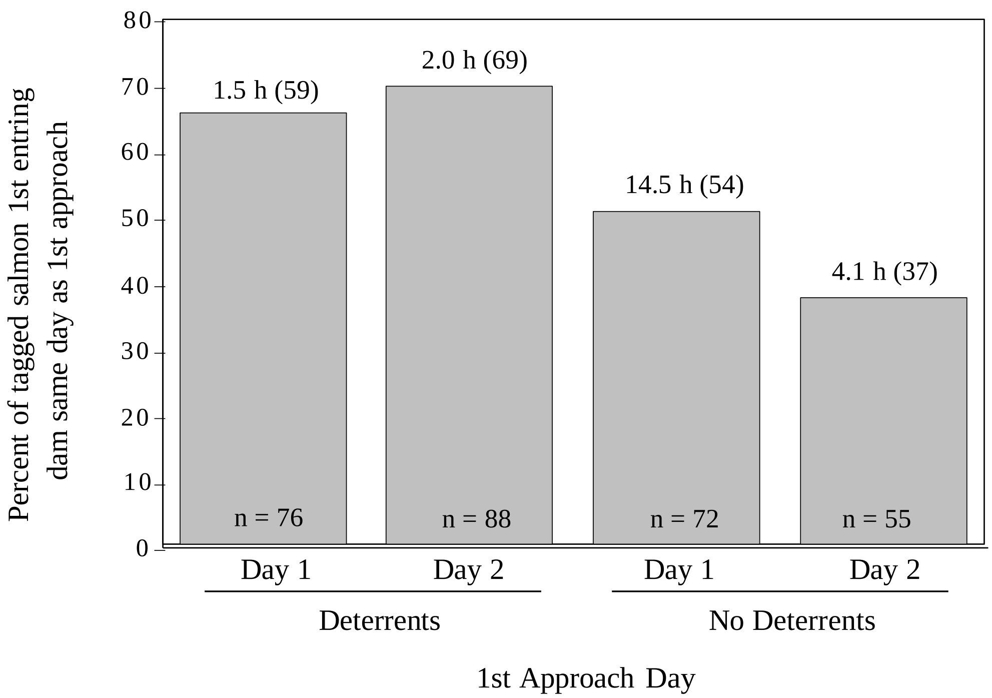

Figure 9. Percentages of radio-tagged salmon first entering a fishway opening on same day as first approach at Bonneville Dam during 2006. Denominators for percentage calculations are at the base of each bar. Median passage times from first approach to first entry are above each bar with sample sizes in parentheses. Day 1 is the first day of any two-day treatment application within a four-day block and Day 2 is the second.

Daily Dam and PIT-tag Counts - 2006

We found no significant effect of the hazing/ADDs treatments on total daily PIT and visual counts at Bonneville Dam during 2006 ((PIT) P =0.32; (Visual Count) $P = 0.38$, $df = 1$).

The number of daily dam passage events by radio-tagged salmon ranged from 0 to 24 between 20 April and 27 May 2006, with peak passage frequencies typically occurring on dates when sea lion deterrents were being applied (Figure 10). The daily percentage of tagged salmon that made their first approach during the same treatment level present on the date of their dam passage varied from 0 to 100% (n =3 8 days). Small numbers of tagged salmon passing on some dates likely accounted for some of the low percentages observed and as a consequence, the wide range. Overall, 199 of 269 (74%) radio-tagged salmon made their first approach during a treatment level that matched the one present on their date of dam passage. The mean daily percentage of tagged salmon that made their first approach during the same treatment level present on the date of their dam passage was 71.2% (n = 38).

The daily percentage of tagged salmon that made their first entrance during the same treatment level present on the date of their dam passage varied from 50 to 100%. Overall, 247 of 269 (92%) radio-tagged salmon made their first entrance during a treatment level that matched the one present on their date of dam passage. The mean daily percentage of tagged salmon that made their first entrance during the same treatment level present on the date of their dam passage was 93.3%.

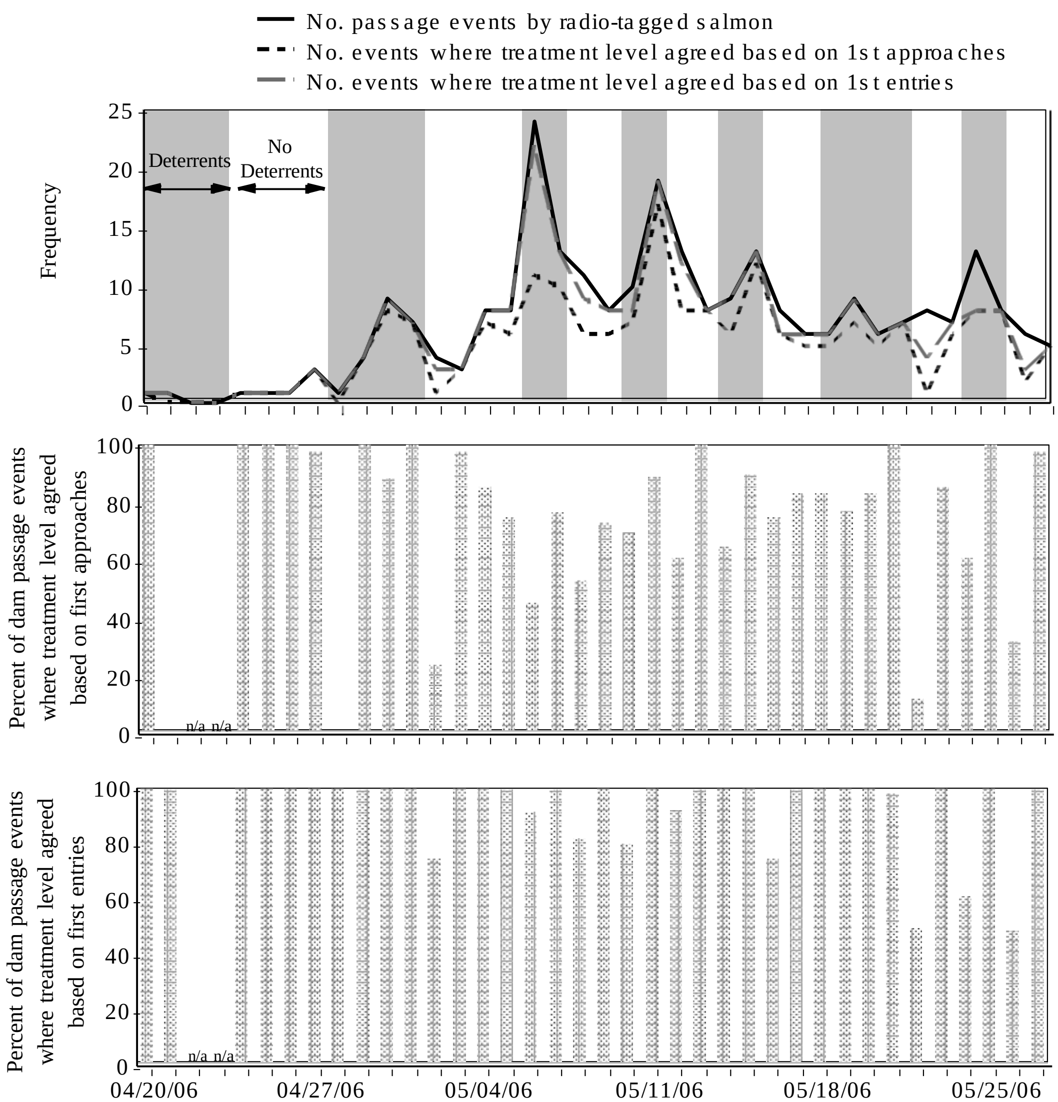

Figure 10. Number of daily dam passage events by radio-tagged salmon and numbers of those events where treatment level agreed based on first approaches or first entries (upper panel). Also included are the daily percentages of dam passage events by radio-tagged salmon where treatment level agreed based on first approaches (middle panel) or first entries (bottom panel).

If we assigned daily PIT-tag or dam counts to treatment groups based strictly on the dates when deterrent treatments were or were not applied, the likelihood of accurately attributing either treatment level to the dam or PIT-tag counts would be small based on the use of these radio data as count data surrogates. Similar to results from the 2005 SLED evaluation, we think the uncertainty associated with this treatment assignment method diminishes the validity of any results from comparisons of the treatment levels on adult salmon passage during 2006 using PIT-tag detections or dam counts as dependent variables.

Randomized Complete Block Design - 2006

Sea lion deterrent treatments and the arrival of radio-tagged salmon in the tailrace of Bonneville Dam resulted in eight complete 4-day blocks beginning on 26 April and ending on 27 May 2006. We found no significant treatment effects for any passage time metric but the block term was significant for all passage time metrics except the time from first approach to first entry (Table 7). Passage times were typically higher during late April and early May than during the latter part of May, likely a reflection of fish passing more quickly when water temperatures were higher (Figure 12).

Generally, the statistical power of these tests, or the probability of rejecting the null hypothesis when it was in fact false, was low. For example, with the number of blocks and the amount of variability we observed, we estimated there would need to be a true difference in means of 440 hrs (nine times the duration of a given block) for tailrace to first approach times for the power of this test to approximate 0.8.

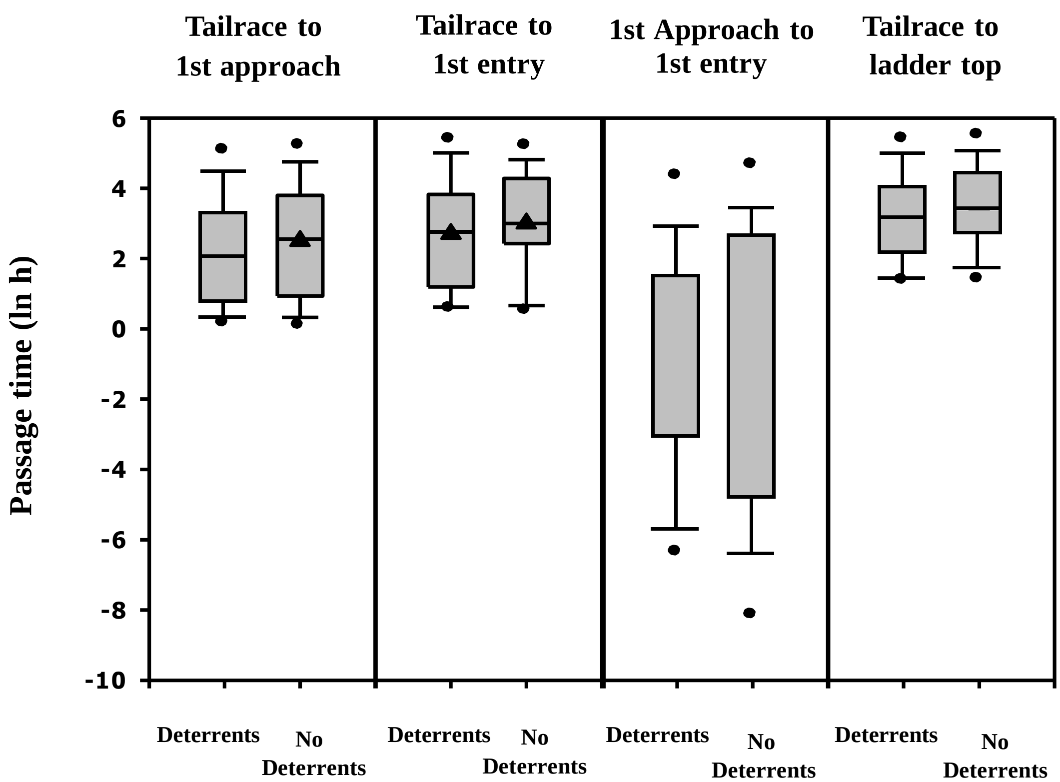

Figure 11. Median, mean (triangles), quartile, 5th, 10th, 90th and 95th percentile ln-transformed passage times from tailrace to first approach, tailrace to first entry, first approach to first entry, and first tailrace to last record at a ladder top for radio-tagged spring Chinook salmon at Bonneville Dam during 2006.

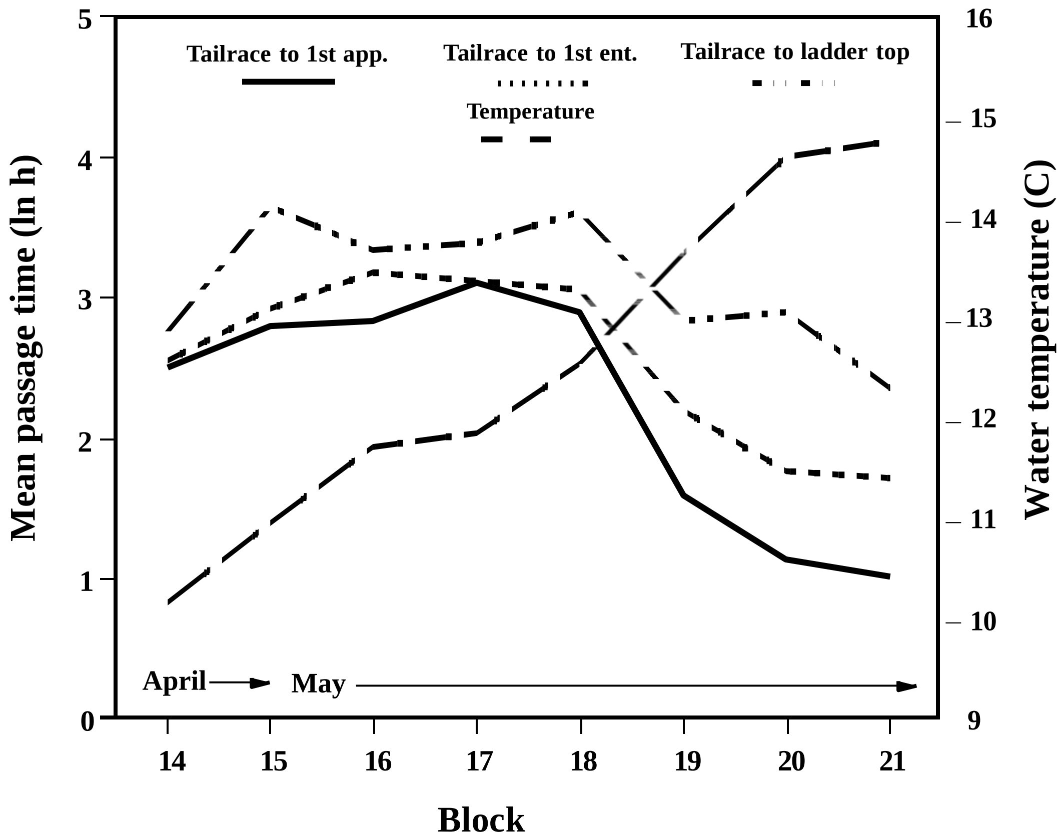

Figure 12. Block-specific mean ln-transformed passage times for radio-tagged spring Chinook salmon and river temperature at Bonneville Dam during 2006. Ln (24 hrs) = 3.2 and Ln (7 hrs) = 2.

Table 7. Results of ANOVA tests of the effect of sea lion deterrent on ln-transformed passage times at Bonneville Dam during 2006.

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a) Time from tailrace to first approach

Source	DF	Sum of Squares	MeanSquare	FValue	Pr>F
Model	8	116.84	14.61	7.40	<0.0001
Error	155	305.78	1.97		
Corrected Total	163	422.62			

Source	DF	TypeIIISS	MeanSquare	FValue	Pr>F
Treatment	1	1.96	1.96	0.61	0.4620
Block	7	112.25	16.04	8.13	<0.0001

---

b) Time from first approach to first entrance

Source	DF	Sum of Squares	MeanSquare	FValue	Pr>F
Model	8	92.61	11.57	1.07	0.3884
Error	137	1483.39	10.83		
Corrected Total	145	1576.00			

Source	DF	TypeIIISS	MeanSquare	FValue	Pr>F
Treatment	1	0.23	0.23	0.05	0.8259
Block	7	91.24	13.03	1.20	0.3048

---

c) Time from tailrace to first entrance

Source	DF	Sum of Squares	MeanSquare	FValue	Pr>F
Model	8	54.72	6.84	3.79	0.0005
Error	120	216.75	1.81		
Corrected Total	128	271.47			

Source	DF	TypeIIISS	MeanSquare	FValue	Pr>F
Treatment	1	7.39	7.39	3.31	0.1116
Block	7	49.45	7.06	3.91	0.0007

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d) Time from tailrace to ladder top

Source	DF	Sum of Squares	MeanSquare	FValue	Pr>F
Model	8	28.15	3.52	3.06	0.0034
Error	133	152.81	1.15		
Corrected Total	141	180.96			

Source	DF	TypeIIISS	MeanSquare	FValue	Pr>F
Treatment	1	1.35	1.35	0.79	0.4042
Block	7	24.59	3.51	3.06	0.0051

Time-to-event Analysis- 2006

Fish were 10% more likely to approach fishways during any given hour during the sea lion deterrents treatment than during no treatment (Figure 13, left panel), but this difference was not statistically significant (P = 0.40; n = 259). Fish were 17% more likely to enter fishways during any given hour during the sea lion deterrent treatment than during the no deterrent treatment (Figure 13, right panel), but this difference was not statistically significant (p=0.20; n=269).

The median time from the tailrace to first fishway approach was 8.9 h (*uncensored events* = 139) when hazing/ADDs occurred compared to 10.8 h (*uncensored events* = 107) when hazing/ADDs did not occur. The median time from the tailrace to first fishway entry was 3.4 h (*uncensored events* = 133) when SLEDs were in compared to 14.0 h (*uncensored events* = 79) when SLEDs were out. We estimated the true ratio of medians would have to be 1.4 and 1.5 for the times to first fishway approach and first fishway entry, respectively, to have a power of 0.8 given the samples sizes.

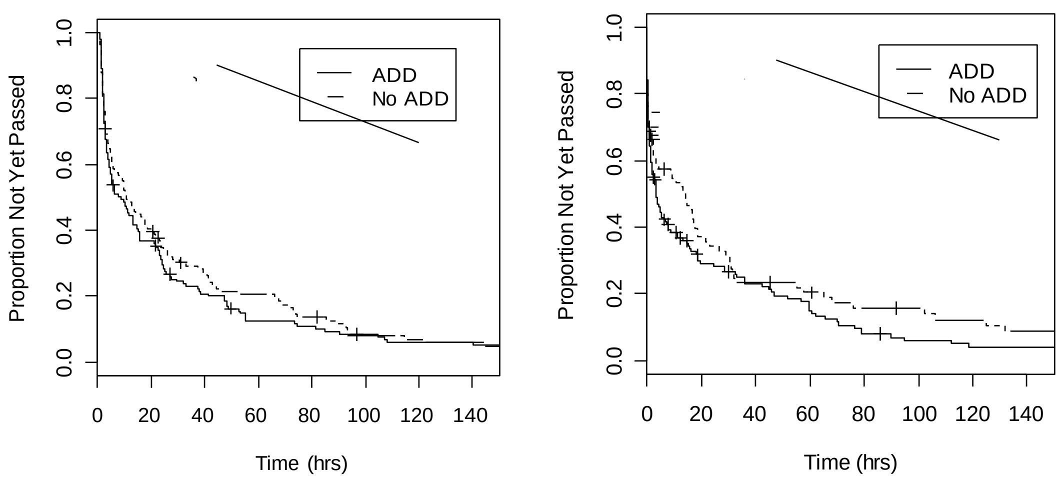

Figure13. Cumulative passage time curves for first tailrace record to first approach (left panel) and first enter (right panel) by radio-tagged spring Chinook salmon at Bonneville Dam during 2006.

Exit Percentages- 2006

Only 24 of the 294 radio-tagged spring Chinook salmon that entered a fishway before 1 June 2006 (8.2%) exited a fishway at least once. In contrast, exit percentages (unique fish exited/unique fish entered) for radio-tagged spring Chinook salmon in April-May of 1997-

1998 and 2000-2004 ranged from 25 to 61% for fishway entrants (Table 8). The median time to pass the dam for radio-tagged salmon that made at least one exit before 1 June 2006 was 41.0 h (n = 24) whereas it was 29.1 h (n = 196) for radio-tagged salmon that made no exit. It is unclear to what extent the SLED deployments in 2006 contributed to the low exit percentages.

Table 8. Number of radio-tagged Chinook salmon that entered a Bonneville Dam fishway prior to 1 June and frequency and percentage of those salmon that exited a fishway at least once.

Year	No. tagged salmon that entered dam	No. tagged salmon that exited dam	Percent
1997	654	398	60.8
1998	651	256	39.3
2000	700	273	39.0
2001	594	166	27.9
2002	630	198	31.4
2003	700	176	25.1
2004	298	99	33.2
2006	294	24	8.2

Ad-hoc Evaluation of SLEDs- 2006

All four median passage time metrics we examined from 2006 (during periods when there was no active hazing or ADD applications) were consistently lower than corresponding values from years with no SLEDs (Figure 14). This circumstantially suggested that the SLEDs alone did not impede the passage of radio-tagged salmon during 2006.

River conditions at Bonneville Dam during April and May 2006 were characterized by high flows compared to those during the same months of 2003 and 2004 (Figure 15). Spill levels during 2006 were most similar to those during 2003 whereas the year with the lowest mean daily spill was 2004, also the lowest-flow year. River temperatures during April and May were consistently cooler in 2003 compared to 2004. In contrast, temperatures during 2006 were cooler than those recorded during both 2003 and 2004 but were followed by a relatively rapid rise during May.

Because the high volumes of cool water at Bonneville Dam in April 2006 likely contributed to the late run-timing of the spring Chinook salmon run, the bulk of our radio-tagging effort during 2006 did not begin until 23 April. Moreover, we excluded approximately half of the tagged salmon in 2006 from this comparison because they experienced treatment conditions (i.e., ADDs and hazing) dissimilar to those experienced by tagged salmon during 2003 and 2004. As a result of these events, most of the relatively few passage time data we obtained during 2006 were derived from tagged fish passing Bonneville Dam in May, the warmer of the two months used in our comparisons. Because spring–summer Chinook salmon tend to migrate more rapidly as water temperature and date of migration increases (Keefer et al. 2004), any apparent differences in passage times among years may have been explained in part by the larger proportionate sample of tagged salmon that migrated during the cooler conditions of April 2003 and 2004 compared to relatively few tagged salmon that migrated during April 2006.

We therefore narrowed our comparisons to the use of 2003 and 2004 passage times from radio-tagged salmon that first entered the tailrace after 23 April of those years. As expected, median passage times from 2003 and 2004 were lower (up to ~25%) than corresponding values calculated using data from the entire month of April. However, median passage times for 2006 were still lower than corresponding values from 2003 and 2004, lending support to the conclusion that the SLEDs alone did not impede the passage of radio-tagged salmon during periods when there was no active hazing or ADD applications in 2006.

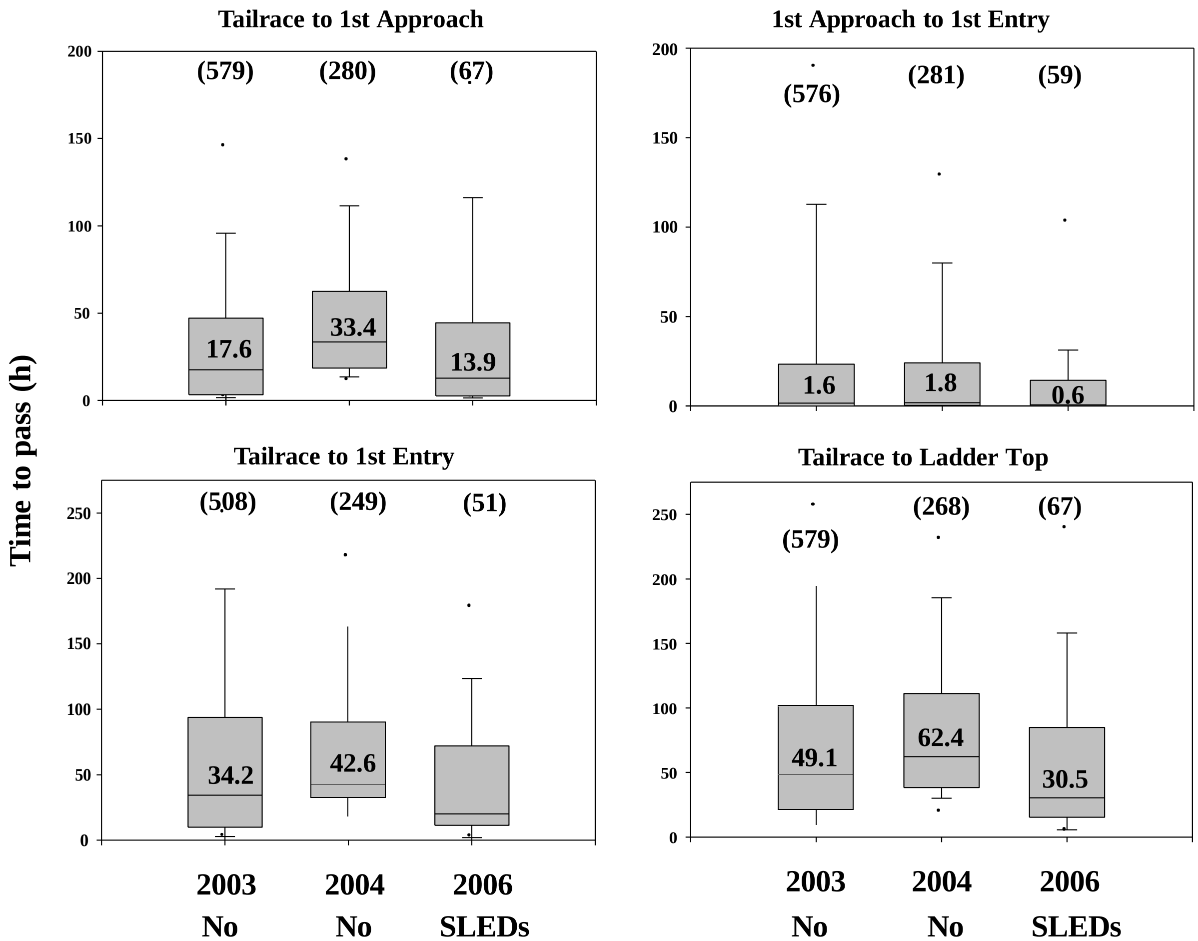

Figure 14. Median (value inside box), quartile, 5th, 10th, 90th and 95th percentile passage times from tailrace to first approach, tailrace to first entry, first approach to first entry, and first tailrace to last record at a ladder top for radio-tagged spring Chinook salmon at Bonneville Dam during April-May 2003 and 2004, and during periods when no sea lion hazing or acoustic deterrents were applied in 2006. Sample sizes are presented in parentheses above the box-and-whisker plots.

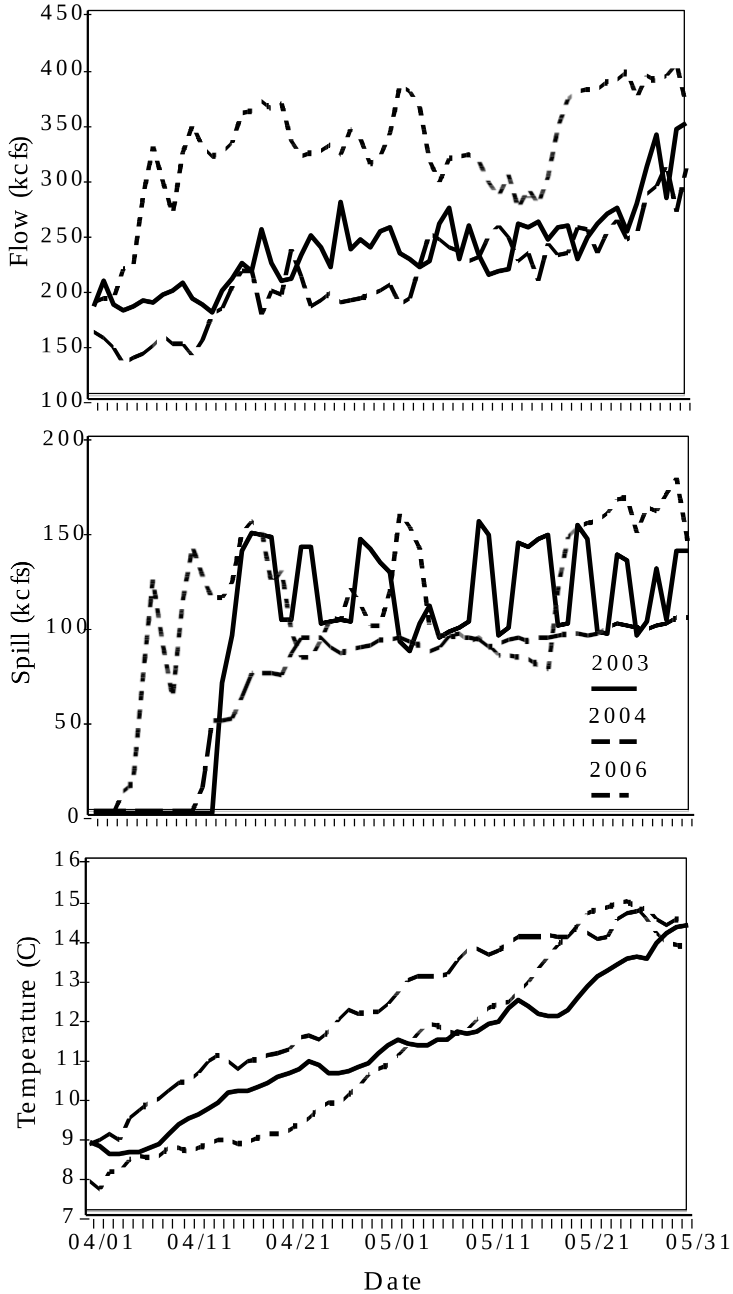

Figure 15. Mean daily flow, spill, and river temperature at Bonneville Dam during April-May 2003, 2004, and 2006.

Discussion

The results of monitoring adult radio-tagged summer Chinook salmon at Bonneville Dam during 2005 generally supported the hypothesis that SLEDs did not significantly impede adult salmon passage. Radio-tagged salmon that first approached at a SLED had the highest median time from first approach to first entry (1.3 h), suggesting they may have been mildly impeded fishway entry. Results from 2006 were consistent with there being no detrimental effects of combined active sea lion hazing and ADD treatments on the passage of radio-tagged salmon.

Many studies have described the nature of pinniped/salmon interactions. Some research indicates pinniped abundance in rivers corresponds with the abundance of salmonids but studies by Jameson and Kenyon (1977) and Roffe and Mate (1984) in the Rogue River, Oregon, suggest that most pinniped predation is on the slower moving Pacific lamprey, *Lampetra tridentatus*. In contrast, Scordino and Pfeifer (1993) estimated steelhead predation by California sea lions at the Ballard Locks to be as high as 65% of an entire year's run. California sea lions have also been observed preying on adult salmonids near Willamette Falls (NMFS 1997b). Data from the Puntledge River estuary in British Columbia indicated that where salmonid populations are depressed, and particularly where fish passage is restricted by man-made structures (e.g., dams), narrow channels, or shallow water, pinniped predation can have a detrimental effect on salmonid populations (Bigg et al. 1990). It is unlikely that pinniped predation is the major cause of the decline in Columbia River salmonids but many agree that it has the potential to affect the recovery of many threatened and endangered stocks (NMFS 1999). London et al. (2002) suggest that any negative affect pinniped predation may have on particular salmonids stocks should be considered within the context of the myriad of other factors affecting them such as habitat degradation, harvest, climate change, and pollution.

Successful efforts at deterring pinniped predation on migratory fish in the long-term have been few. The deployment of acoustic devices near Atlantic salmon net-pens in Maine was considered to be ineffective at deterring seal predation because the seals eventually became habituated to them (Nelson et al. 2006). In southern Chile, acoustic harassment devices worked moderately well at deterring South American sea lion preying on salmon in the short-term but became ineffective after a period of months (Sepulveda and Oliva 2005). Deploying fiberglass models of killer whales near net-pens was also considered ineffective at deterring sea lion predation on salmon in the short-term (Sepulveda and Oliva 2005). A reason other than habituation suggested for the gradual ineffectiveness of acoustic harassment devices was potential hearing loss in seals (Johnston and Woodley 1998). Concerns about hearing loss in both target and non-target species resulted in the prohibition of such devices at marine finfish farms in British Columbia (Jamieson and Olesiuk 2001).

Tactile harassments have successfully produced avoidance reactions in some wildlife species (e.g., grizzly bears and polar bears) in some situations. Blunt-tipped arrows were tested by WDFW on California sea lions at the Ballard Locks with no significant change in predation rates and rubber projectiles discharged from a shotgun were tested by ODFW on California sea lions at Willamette Falls with limited success (Lecky 2003).

While many studies have described the impacts of sea lion predation on migratory fish, few have evaluated salmonid passage times in relation to pinniped deterrent structures or activities. Adult salmon passage at Bonneville Dam was evaluated in response to hazing activities conducted during four days in May 2005 (Norberg et al. 2005). Hourly fish passage rates (visual counts) appeared to be positively correlated with hazing activity but small sample sizes made interpreting passage trends difficult given the high variability in daily passage rates within a season. Similarly, we concluded using daily count data to make inferences about any effects of the SLEDs, ADDs, or hazing was not robust when we used passage histories of radio-tagged salmon as surrogates.

The 13-day outage at the most-downstream fishway opening on the Washington-shore of Powerhouse 2 during the 18-day trial of 2005 probably diminished the frequency of observed first approaches there. It is unclear to what extent the distribution of first approaches at Powerhouse 2 during 2005 may have been affected as a result. First approaches at this opening could only be inferred when a tagged salmon both first approached and first entered there during the outage. Times to first approach a fishway opening during 2005 were overestimated for any tagged fish that first approached there undetected during the outage. Similarly, the time to first enter a fishway opening after first approaching one was underestimated for any tagged salmon that may have first approached this opening undetected during the outage.

The frequency of first approaches at Powerhouse 2 orifice gates by radio-tagged spring–summer Chinook salmon during 1997 and 1998, when all fishway openings were monitored, averaged approximately 5% (Keefer et al. *in review*). This suggests that 2005 and 2006 results were affected negligibly by not monitoring Powerhouse 2 orifice gates. During 1997 and 1998 however, powerhouse priority, the allocation of discharge through turbines at either

Powerhouse 1 or 2, was through Powerhouse 1. Priority differences can result in substantial changes in the distribution of attraction flows and can affect the proportionate use of fishway openings by spring–summer Chinook salmon as first approach sites. For example, the proportionate use of Powerhouse 1 sluice gates as sites for first fishway approaches during 1997 and 1998 was 46% and 23%, respectively (Keefer et al. *in review*). Powerhouse priority during 2005 and 2006 was through Powerhouse 2. To this extent, not monitoring the Powerhouse 2 orifice gates during 2005 and 2006 may have resulted in a considerable lack of precision when evaluating the distributions of first approach sites, the times from first tailrace record to first fishway approach, and the times from first fishway approach to first fishway entry.

If the ADD/hazing treatment in 2006 was effective at keeping pinnipeds away from fishway openings, we might expect salmon passage times to be lower when these treatments were applied. Total pinniped activity within 100 feet of a fishway opening during treatment days was marginally lower during days with hazing and ADDs (R. Stansell, personal communication). This could explain in part the higher percentage of tagged salmon first entering a fishway opening on the same day as their first approach during days with hazing and ADDs.

Overall, the statistical power of the randomized complete block design was low. If similar evaluations are conducted at Bonneville Dam or elsewhere in the future, increasing the number of tagged fish released on the first days of each treatment level within a 4-day block (Days 1 and 3) and reducing or eliminating the number of tagged fish released on the last days of each treatment level within a 4-day block (Days 2 and 4) would likely reduce the number of tagged fish experiencing treatment switches. Increasing the number of tagged salmon within blocks would help to increase the statistical power of the test but not as much as increasing the total number of blocks. The time-to-event analysis, which accounted for fish that experienced treatment switching or skipping, was probably the more appropriate test. Both tests provided qualitatively similar results, however.

The relatively few tagged salmon that exited Bonneville Dam fishways during 2006 likely contributed to relatively low total dam passage times. It is not clear to what extent the SLEDs, hazing, ADDs, or the presence of predators in the tailrace were responsible for the low percentages of salmon exiting the fishways during 2006. It is possible that some salmon that may have otherwise exited the fishway remained inside as a predator avoidance strategy.

A concern with all radio-tagging studies involves whether behavioral responses exhibited by tagged fish reflect behaviors exhibited by untagged fish (Bridger and Booth 2003). Our sampling strategy during both years was not intended to be representative of the overall population. However, we have no evidence to suggest the range of behaviors exhibited by the salmon we tagged were atypical of the population at large, and comparisons between radio- and PIT- and PIT-only tagged fish have shown passage times are similar (Matter and Sandford 2003)

In summary, we did not detect any gross avoidance responses to the sea lion deterrent structures (SLEDs) or activities (hazing) by radio-tagged salmon during either study year. Results from 2005 showed no significant effect of the SLED deployments on the distribution of first approaches or first entrances by radio-tagged summer Chinook salmon. Moreover, we found no significant difference in the probability of tagged salmon either first approaching or first entering a Powerhouse 2 opening at any given time when the SLEDs were deployed versus when they were not. Based on passage times alone, we concluded that any effects the SLEDs may have had on adult salmon passage during 2005 were small. Our *ad hoc* evaluation of the 2006 data also suggested that SLEDs alone did not impede adult salmon passage. During 2006, both parametric and non-parametric analyses suggested that the combined effect of hazing and ADDs did not impede the passage of radio-tagged adult spring Chinook salmon.

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