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Behavior of Radiotagged Adult Spring–Summer Chinook Salmon at Bonneville Dam in 2006
A Preliminary Summary from the University of Idaho and NOAA Fisheries – August, 2006

Methods

We radiotagged a total of 358 adult Chinook salmon (*mean FL* = 73.77 cm, *range* = 63.0-96.5 cm) at the Adult Fish Facility of Bonneville Dam and released them approximately nine kilometers downstream from the dam on either side of the river during spring 2006 (Figure 1). We deployed underwater antennas at all dam openings except the orifice gates at Powerhouse 2 which were initially opened and unmonitored. Sea lion exclusion devices (SLEDs) were deployed at all eight main fishway openings and there was a blocked, paired-treatment experimental design for evaluating any effects of hazing and acoustic deterrents on adult fish passage during 2006 (Figures 2).

Acoustic deterrent devices (ADDs) were deployed near all main fishway openings and transition pools (Figure 2). 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 V DC deep-cycle battery which was constantly charged with a 12 V DC 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 paired treatments 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).

In response to a sea lion being observed exiting Powerhouse 2 over the top of a floating orifice gate, bars were welded over the openings to exclude pinnipeds. Many floating gates sank because of cracks at the welds adjoining the two pieces which allowed water into the airspace. Powerhouse 2 floating orifice gates were eventually 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.

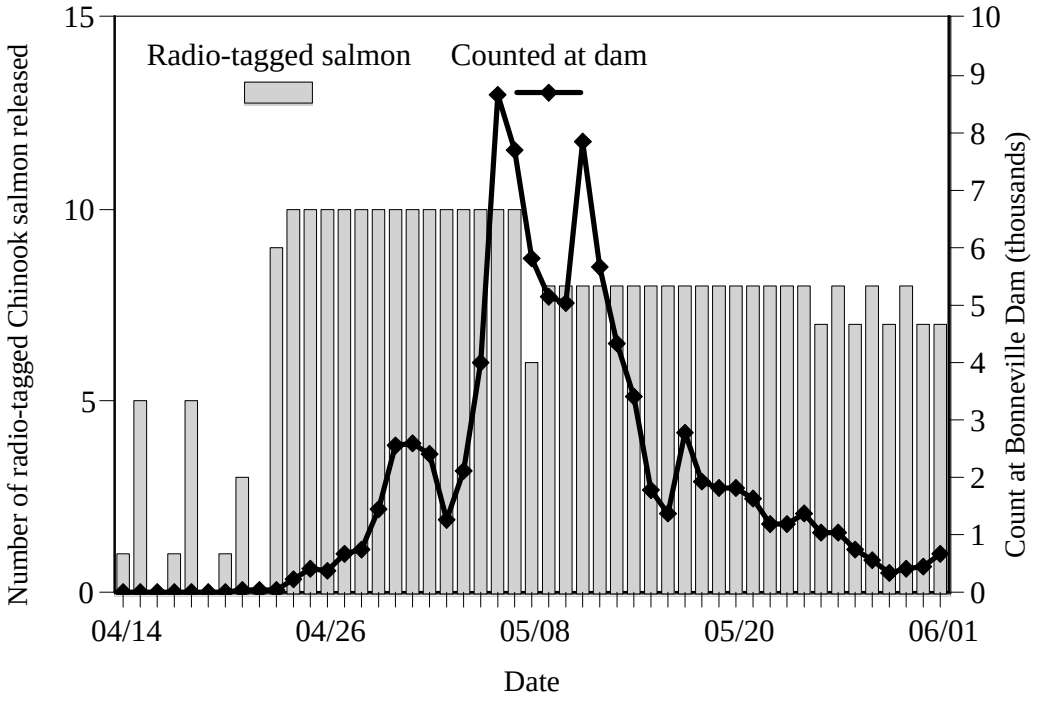

Figure 1. The number of Chinook salmon radiotagged and released downstream from Bonneville Dam during 2006 and the count of adult Chinook salmon passing the dam.

Results

We are currently evaluating analyses for assessing any effects of the hazing and ADDs on adult fish passage but present these summaries of overall behavior to examine whether passage metrics from 2006 were in the range of values estimated during other years.

Of the 358 radiotagged Chinook salmon released during 2006, 348 were recorded at the dam and 317 passed it (Table 1). One-hundred and forty-one passage events (44%) were via the Washington-shore ladder and 176 (56%) were via the Bradford Island ladder. We observed 51 fallback events by 44 unique salmon (fallback percentage = 44 salmon that fell back /317 unique salmon passed = 13.9%). Forty-five of the 51 fallback events (88%) were preceded by passage events via the Bradford Island ladder.

Table 1. Number and percent of adult radiotagged fish released downstream from Bonneville Dam, recorded at the dam, that passed the dam, that were recorded on their first passage of the tailrace, first approach at a fishway opening, first fishway entry, and exit from the top of a ladder.

2006	Freq.	Percent
Released downstream	*358*	*100*
Recorded at dam	*348*	*97*
Known to pass dam	*317*	*89*
Recorded first tailrace passage	*315*	*88*
Recorded first fishway approach	*333*	*93*
Recorded first fishway entrance	*318*	*89*
Recorded ladder exit	*268*	*75*

Hazing occurred from 0500 to 2000 hrs each day. ADD treatments were 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 (i.e, sites where pinnipeds go ashore) at the dam or sighted within an approximately 100' radius of any fishway opening. Hazing involved the use of audio and tactile stimuli; specifically, firecrackers and rubber bullets/buckshot. It was not known if fish were exposed to any acoustic or hazing treatments prior to their being radiotagged.

Release to Tailrace Times

The median times from release to first record in the tailrace were 47.8 h for salmon first detected there during April, 21.3 h for salmon detected in the tailrace during May, and 75.0 h for tagged salmon first detected there in June (Table 2). The median time for all radiotagged salmon to swim from the release site to the tailrace sites was 24.1 h during 2006, which was the highest median value estimated among all other study years.

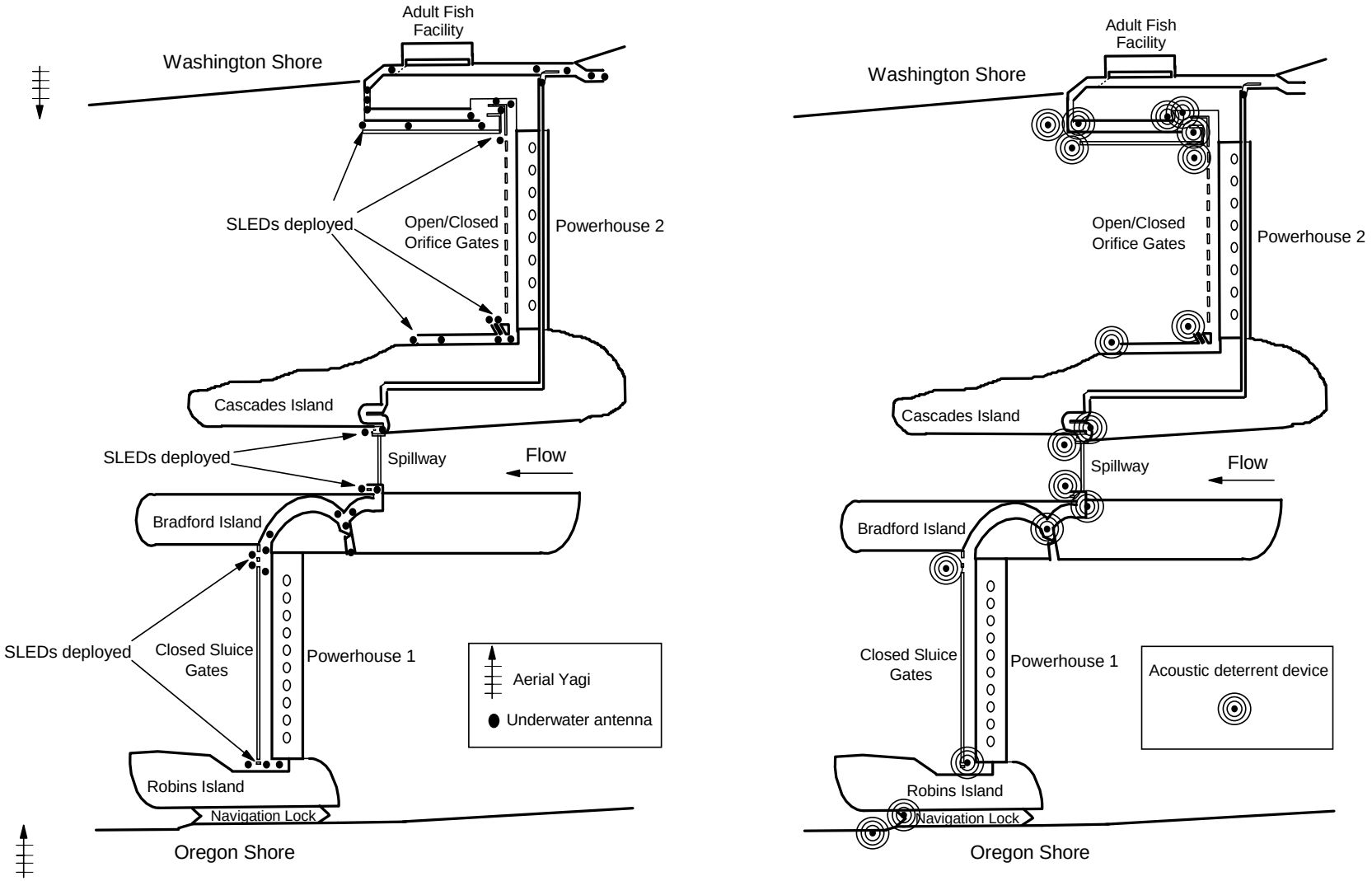

Figure 2. Aerial view of radio antenna, SLED (panel on left), and acoustic deterrent devices (panel on right) at Bonneville Dam during 2006. Powerhouse 2 orifice gates were closed to fish passage beginning on 4 May 2004.

Table 2. Number of adult radio-tagged spring-summer Chinook salmon and median times to pass (h) from release to first tailrace record, and from first tailrace record to first fishway approach, to first fishway entrance, and to pass Bonneville Dam based on month fish were first detected in the tailrace.

	1997		1998		2000		2001		2002		2003		2004		2006	
Release to tailrace	n	Med.	n	Med.	n	Med.	n	Med.	n	Med	n	Med.	n	Med.	n	Med.
April	314	**22.6**	341	**7.0**	461	**15.2**	253	**17.1**	255	**39.5**	434	**25.9**	124	**23.6**	46	**47.8**
May	311	**23.9**	275	**7.0**	222	**6.7**	258	**13.0**	272	**16.1**	225	**20.1**	173	**17.2**	252	**21.3**
June	146	**16.1**	155	**7.2**	120	**7.2**	115	**5.2**	161	**12.6**	188	**14.8**	110	**6.9**	17	**75.0**
All	771	**22.0**	771	**7.0**	803	**10.8**	626	**13.5**	688	**17.9**	847	**20.6**	407	**17.7**	315	**24.1**
Tailrace to 1st approach																
April	296	**3.4**	337	**3.9**	454	**6.9**	247	**20.3**	241	**17.5**	366	**23.5**	117	**46.7**	39	**15.7**
May	300	**2.6**	271	**2.0**	218	**2.5**	251	**9.0**	268	**12.1**	213	**9.2**	163	**29.7**	230	**5.2**
June	135	**2.6**	147	**1.8**	115	**1.7**	112	**3.7**	157	**2.4**	182	**2.3**	107	**18.7**	16	**3.5**
All	731	**2.9**	755	**2.4**	787	**3.4**	610	**10.6**	666	**10.5**	761	**9.4**	387	**29.9**	285	**6.4**
Tailrace to 1st entry																
April	226	**17.0**	294	**14.3**	373	**25.3**	228	**37.6**	214	**34.6**	313	**47.0**	101	**78.6**	27	**68.3**
May	249	**9.7**	250	**10.2**	185	**13.2**	231	**11.5**	228	**23.8**	195	**23.2**	148	**37.2**	182	**21.8**
June	115	**7.8**	130	**3.6**	101	**7.1**	100	**8.1**	142	**8.8**	170	**7.9**	101	**30.4**	14	**10.7**
All	590	**11.8**	674	**10.4**	659	**17.9**	559	**15.9**	584	**19.8**	678	**23.2**	350	**36.8**	223	**22.6**
Tailrace to pass dam																
April	306	**47.4**	330	**23.8**	449	**44.8**	237	**58.7**	248	**52.4**	400	**53.4**	110	**87.2**	33	**98.9**
May	304	**22.7**	267	**19.6**	219	**22.7**	254	**22.2**	267	**50.6**	206	**33.7**	158	**54.1**	193	**25.7**
June	141	**18.0**	152	**15.8**	119	**18.7**	115	**18.7**	158	**24.5**	158	**24.4**	107	**39.5**	16	**22.4**
All	751	**28.4**	749	**20.1**	787	**28.0**	606	**26.2**	673	**44.5**	787	**38.2**	375	**54.2**	242	**29.1**
First approach to first entry																
April	237	**4.8**	312	**4.2**	390	**16.2**	266	**3.0**	290	**4.3**	351	**1.6**	123	**1.5**	31	**8.0**
May	266	**2.3**	273	**2.9**	193	**4.6**	267	**1.2**	250	**4.8**	225	**1.4**	158	**1.8**	208	**3.2**
June	116	**1.5**	140	**0.7**	102	**0.8**	135	**0.7**	148	**1.3**	188	**0.7**	107	**1.6**	14	**1.3**
All	619	**2.5**	725	**2.5**	685	**6.4**	668	**1.6**	688	**2.9**	764	**1.2**	388	**1.8**	253	**3.2**

First Approaches and First Entries

Radiotagged salmon used Powerhouse 1 openings most frequently as sites for first approaches, accounting for slightly over half of all first approaches recorded (Table 3). Thirty-six percent of all first approaches were recorded at Powerhouse 2 and 13% were recorded at spillway openings. Radiotagged salmon that made their first approach at a spillway or Powerhouse 2 opening had median first approach times over two to six times higher than those of radiotagged salmon that made their first approach at Powerhouse 1. The median time to first approach the dam for all radiotagged salmon during 2006 was 6.4 h.

While Powerhouse 1 was the site used most by radiotagged salmon for first approaches, Powerhouse 2 was the site used most for making their first entrance (Table 3). Radiotagged salmon that made their first entry at Powerhouse 2 did not have the lowest median time to first entry, however. Thirty-six percent of all radiotagged salmon made their first entry at Powerhouse 1 and their median time to first entry was 15.0 h. Radiotagged salmon that made their first entry at a spillway opening had the highest median time to first entry (43.5 h). The median time to first enter the dam for all radiotagged salmon during 2006 was 22.6 h.

Table 3. Location, frequency, percentage, median time from tailrace(h), and sample size for first fishway approaches and first fishway entries at Bonneville Dam during 2006.

	First Approach				First Entry			
Site	Freq.	(%)	Median	n	Freq.	(%)	Median	n
Powerhouse 1	169	51	4.1	154	113	36	15.0	92
Powerhouse 2	121	36	11.3	97	119	37	24.1	66
Spillway	43	13	25.0	34	80	25	43.5	65
Unknown	-	-			6	2	-	0
Total	333	100	6.4	285	318	100	22.6	223

Distribution of First Entries based on First Approach Sites

Among radiotagged salmon that made a first approach at Powerhouse 1, 61% (104/169) ultimately made a first entry there (Table 4). In comparison, 78% and 74% (94/121 and 32/43) of radiotagged salmon that made a first approach at either a Powerhouse 2 or spillway opening, made their first entry at those respective sites. The median times to first enter the dam after first approaching it ranged from 0.4 to 3.8 h among first approach site groupings and these differences were significant ($P = 0.04$, df=2, Kruskal-Wallis Test). Radiotagged salmon that first approached the dam at Powerhouse 1 had the highest median time from first approach to first entry. The overall median for 2006 was in the range of values recorded during previous years (see Table 2).

Table 4. Distribution of first entry sites based on sites where radiotagged salmon first approached Bonneville Dam during 2006, median time to make first entry after first approach, and sample sizes.

First Approach		First Entry						
Site	Freq.	PH 1	PH 2	Spillway	Unknown	No Entry	Median time from first approach to first entry (h)	n
PH 1	169	104	21	29	6	9	3.8	135
PH 2	121	6	94	19	0	2	3.4	81
Spillway	43	3	4	32	0	4	0.4	37
Total	333	113	119	80	6	15	3.2	253

Dam Passage Times and Exit Percentages

The median time for all radiotagged salmon to pass Bonneville Dam during 2006 was 29.1 h (*n*=242). Radiotagged fish that passed the dam via the Washington-shore ladder had a median dam passage time of 34.8 h (*n*=121) as compared to 24.8 h (*n*=121) for radiotagged salmon that passed via the Bradford Island ladder.

Only 29 of the 318 (9%) radiotagged salmon that entered the dam exited it at least once. In contrast, annual exit percentages (unique fish exited/unique fish entered) for radiotagged spring–summer salmon at Bonneville Dam in 1997-1998 and 2000-2002 ranged from 36 to 63% for dam entrants (Keefer et al *in review*). The median time to pass the dam for radiotagged salmon that made at least one exit during 2006 was 45.2 h (*n* =27) whereas it was 26.6 h (*n*=215) for radiotagged salmon that did not exit. Comparisons of April to early June 2006 exit percentages with whole-season (April through July) spring–summer Chinook salmon may be misleading however, since the likelihood of exiting the dam steadily increases with water temperature (Keefer et al. *in review*), and this may exaggerate any apparent differences in exit percentages among years.

Reascension Rates of Fish that Fell Back

Fish that fall back at dams may be disorientated or injured which may make them more vulnerable to predation from sea lions. While the current or previous studies were not specifically designed to address this question, we used available data to see if there was an association between reascension rates for fish that fell back at Bonneville Dam and the numbers of pinnipeds counted in the tailrace. Since 2002, annual estimates of pinnipeds at Bonneville Dam have ranged between 31 and 111 animals (Table 5; R. Stansell, personal communication). The latest date sea lions have been observed in the tailrace of Bonneville Dam since 2002 was 10 June so we used that as a cutoff date when we examined the percentages of fallback events followed by reascension events and percentages of unique salmon that fell back and reascended the dam during 1996-1998 and 2000-2006.

We used linear correlation techniques (Zar, 1999) to evaluate the degree of association between pinniped counts and reascension rates of radiotagged salmon. Specifically, we applied an arcsine-square root transformation to reascension rates (i.e., percentages based on both events and unique salmon) and correlated them with the annual estimated count of individual pinnipeds in the tailrace of Bonneville Dam since 2002. The linear correlation models (p=0.77 and r= -0.18 for reascension rates based on events, p=0.94 and r= -0.05 for rates based on unique radiotagged salmon) did not indicate an association between estimated counts of pinnipeds and reascension rates of radiotagged spring-summer Chinook salmon during 2002-2006. Using annual input values for sea lion counts and reascension rates could mask finer-scaled patterns if they exist. It is also likely that a portion of the fall back events at Bonneville Dam were related to overshoot behavior (Boggs et al. 2004). We will continue to investigate this question.

Table 5. Estimated number of pinnipeds in tailrace of Bonneville Dam and frequency of fallback and reascension events by unique adult radiotagged Chinook salmon released downstream from the dam during April 01 through June 10 of 1996-1998 and 2000-2006 with reascension percentages based on number of events and number of unique adult radiotagged Chinook salmon.

Year	Estimated no. of pinnipeds at Bonneville Dam	Fallback events	Reascension events	Percent reascended (events)	Unique salmon that fell back	Unique salmon that reascended	Percent reascended (unique salmon)
1996	-	122	111	91.0	103	93	90.3
1997	-	151	147	97.4	114	111	97.4
1998	-	112	101	90.2	83	75	90.4
2000	-	159	148	93.1	126	117	92.9
2001	-	84	73	86.9	64	56	87.5
2002	31	50	45	90.0	45	40	88.9
2003	111	56	49	87.5	41	39	95.1
2004	105	11	8	72.7	10	7	70.0
2005	87+	2	2	100.0	2	2	100.0
2006	85+	50	33	66.0	43	29	67.4

Conclusions

During 2006, radiotagged spring–summer Chinook salmon spent the highest median time to swim from their release sites at Dodson or Skamania to the tailrace of Bonneville Dam than they spent during all previous study years. We believe this was likely due to lower than average river temperatures during the spring of this year. Once radiotagged salmon arrived in the tailrace, they had median passage times that were within the range of all corresponding passage time medians from previous study years. To this extent, any summed effects of the SLEDs, hazing, ADDs, and orifice gates closures on adult salmon passage appear to have been negligible. It is unclear to what degree these combined or individual treatments may have been associated with the low dam exit rates we observed during 2006, a behavioral response correlated with lower dam passage times.

Literature Cited

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