Passage and Survival of Hatchery Yearling Chinook Salmon at McNary Dam, 2003

Gordon A. Axel, Eric E. Hockersmith, M. Brad Eppard, and Benjamin P. Sandford

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Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

to

Walla Walla District
North Pacific Division
U.S. Army Corps of Engineers
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EXECUTIVE SUMMARY

In 2003, NOAA Fisheries continued the second year of a study to determine passage distribution and dam survival for radio-tagged, river-run, hatchery yearling chinook salmon passing McNary Dam on the Columbia River. Fish were collected, PIT tagged, and a radio transmitter was gastrically implanted. We released fish in the spillway and tailrace of Lower Monumental Dam, in the tailrace of Ice Harbor Dam, and into the Columbia River approximately 15 km upstream from its confluence with the Snake River to compare fish passage metrics for fish originating from each river. Releases occurred during the daytime on 26 days from 29 April to 6 June.

Approach path and subsequent passage route appeared to be related to delay time in the forebay. Further analysis demonstrated a statistical difference between spilled fish and bypassed fish in their associated forebay delay, with median delay times of 0.5 and 1.2 h, respectively (P <0.002). Overall passage distribution for Snake River fish through spillway, bypass, and turbine routes at McNary Dam was 46, 46, and 5%, respectively. Passage distribution for Columbia River fish through spillway, bypass, and turbine routes at McNary Dam was 48, 45, and 4%, respectively. Fish passage efficiency was similar between Snake and Columbia River fish at 95 and 96%, respectively. Overall fish guidance efficiency for Snake and Columbia River fish was 90 and 91%, respectively. Spill efficiency was 47% for Snake River fish and 49% for Columbia River fish. Mean spill effectiveness for Snake River migrants was 1.43:1 compared to 1.32:1 for Columbia River migrants.

Dam survival was estimated from detections of fish in the forebay of McNary Dam to Irrigon, 12 km downstream. Estimated survival through this reach was 0.893 (95% CI, 0.849-0.937). Spillway passed fish survival to Irrigon was 0.928 (95% CI, 0.874-0.892). The survival rate to Irrigon of those passing the juvenile bypass system was 0.865 (95% CI, 0.803-0.927). Not enough fish passed through turbine routes to estimate turbine survival.

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INTRODUCTION

The Columbia and Snake River Basins historically produced some of the largest runs of salmon *Oncorhynchus* spp. and steelhead *O. mykiss* in the world (Netboy 1980). More recently, however, some salmon stocks have decreased to levels warranting listing under the U.S. Endangered Species Act of 1973 (NMFS 1991, 1992, 1998, 1999). Human activities contributing to the decline and loss of these stocks include overfishing, hatchery practices, logging, mining, agricultural practices, and dam construction and operation (Nehlsen et al. 1991). A primary focus of recovery efforts for depressed stocks has been assessing and improving fish passage conditions at hydroelectric projects.

Pursuant to the National Marine Fisheries Service (NMFS/NOAA Fisheries) Biological Opinion (NMFS 2000), project operations at McNary Dam have relied on a combination of voluntary spill and turbine bypass to improve hydrosystem passage survival for migrating juvenile salmonids. The current voluntary spill program at McNary Dam calls for spill from 1800 to 0600 PDT up to the total allowable dissolved gas limit of 120%. In 2002, NOAA Fisheries determined passage distribution, dam survival, and route-specific survival for radio-tagged, river-run hatchery yearling chinook salmon passing McNary Dam. In 2003, to compare results and validate findings from 2002, we evaluated passage distribution, dam survival, and route-specific survival (bypass and spillway) for river-run hatchery yearling chinook salmon at McNary Dam using radiotelemetry.

Results of this study will be used to help inform management decisions meant to optimize survival for juvenile salmonids arriving at McNary Dam. The U.S. Army Corps of Engineers (USACE) is currently in the process of making evaluations to assess the need for improvements of the existing turbine units, intake screens, gatewell vertical barrier screens, and bypass facilities (including debris containment and removal systems, separation, sampling, loading, and outfall facilities) at McNary Dam. These evaluations will help determine where improvements are needed to increase fish survival, resolve holding and loading facility problems (including raceway jumping by juvenile salmon and steelhead and debris plugging of bypass lines), and reduce other debris problems, such as those experienced during the 1996 flood. This evaluation is also known as the McNary Modernization Project (www.nww.usace.army.mil/mcn-mod/default.html). Additionally, the USACE is evaluating whether the existing juvenile bypass system (JBS) outfall should be relocated. This study addressed research needs outlined in SPE-W-00-1 of the U.S. Army Corps of Engineers, Northwestern Division, Anadromous Fish Evaluation Program.

METHODS

Study Area

The study area included the 169-km reach of the Snake and Columbia Rivers from Lower Monumental Dam on the lower Snake River to Crow Butte on the lower Columbia River (Figure 1). McNary Dam, the fourth dam from the mouth of the Columbia River, is located at river kilometer 470.

Fish Collection, Tagging, and Release

River-run, hatchery yearling chinook salmon were collected at the Lower Monumental Dam smolt collection facility from 28 April to 5 June 2003. We chose fish that did not have any gross injury or deformity that were at least 125 mm in length and 25 g in weight. Only hatchery origin yearling chinook salmon not previously PIT tagged were used. Fish were anesthetized with tricaine methane sulfonate (MS-222) and sorted in a recirculating anesthetic system. Fish for tagging were transferred through a water-filled 10.2-cm hose to a 935-L holding tank.

Following collection and sorting, fish were held in a flow-through river water system for 24 h prior to radio tagging. In addition, we radio tagged previously PIT-tagged hatchery yearling chinook salmon collected at Wanapum Dam during gatewell dipping (associated with the dissolved gas and smolt monitoring program at the project) and treated them similarly to the fish collected at Lower Monumental Dam.

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had an expected battery life of 7 days, and were pulse-coded for unique identification of individual fish. Each radio tag measured 18 mm in length by 8 mm in diameter and weighed 1.8 g in air. Fish were gastrically implanted with radio transmitters using techniques described by Adams et al. (1998a).

All fish collected at Lower Monumental Dam were also PIT tagged by hand as described by Prentice et al. (1990a,b,c). Immediately following tagging, fish were placed into a 19-L recovery container (two fish per container) with aeration until recovery from

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1 Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

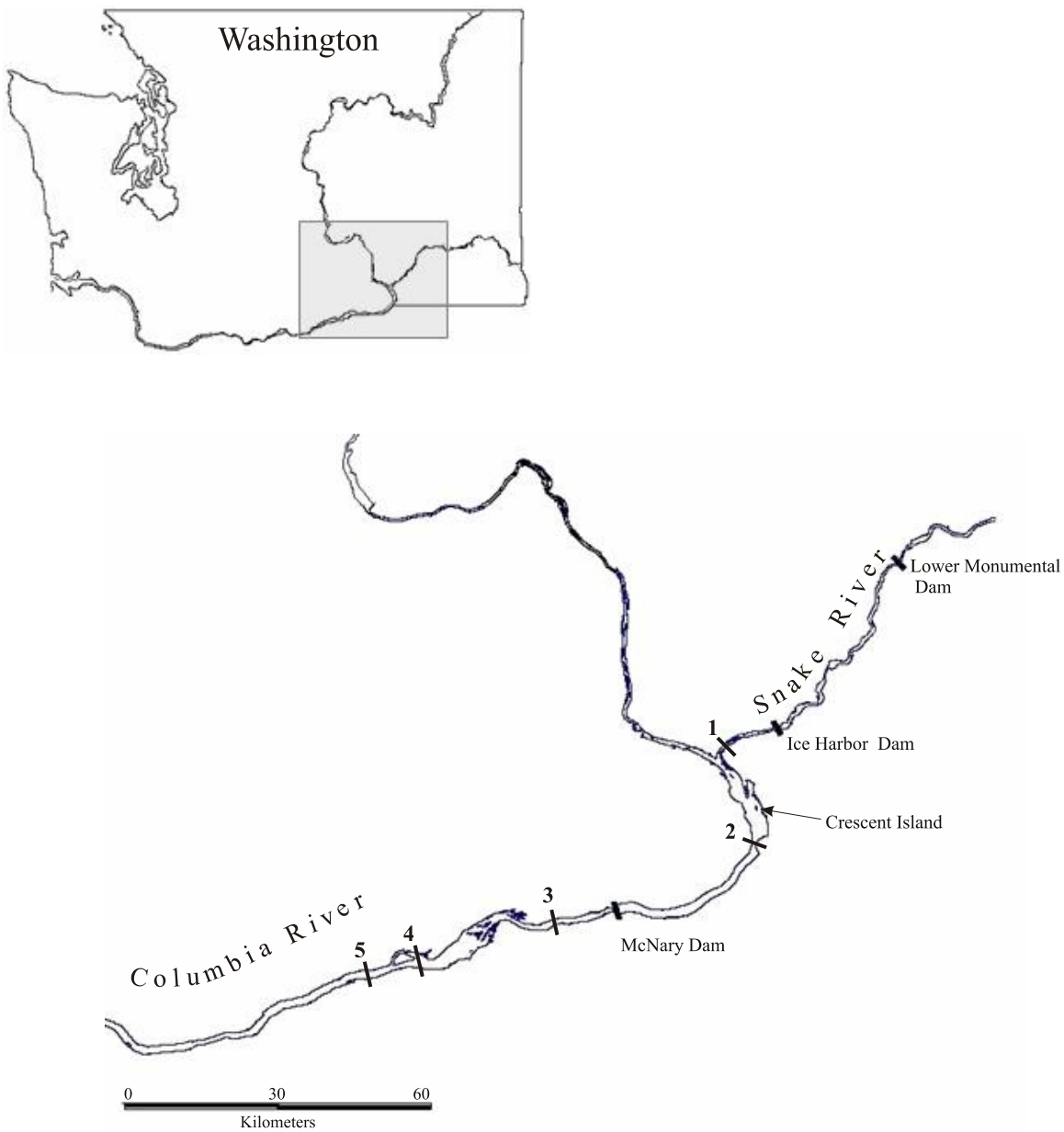

Figure 1. 2003 Study area showing location of radiotelemetry transects used for estimating spillway passage and overall dam survival at Ice Harbor Dam (Note: 1 = Mouth of the Snake River; 2 = Port Kelley; 3 = Irrigon, OR; 4 = Crow Butte East; and 5 = Crow Butte West. The forebay, tailrace, and all routes of passage at McNary Dam were also monitored.)

the anesthesia. Recovery containers were then closed and transferred to a 1,152-L holding tank designed to accommodate up to 28 containers. Fish holding containers were perforated with 1.3-cm holes in the top 30.5 cm of the container to allow an exchange of water during holding. All holding tanks were supplied with flow-through water during tagging and holding and were aerated with oxygen during transportation to release locations. After tagging, fish were held a minimum of 20 h with flow-through water for recovery and determination of post-tagging mortality. Holding density did not exceed two fish per recovery container.

After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to release areas (Lower Monumental Dam spillway or tailrace, Ice Harbor Dam tailrace, and the Columbia River approximately 15 km above the Snake and Columbia River confluence). Treatment groups were transferred water-to-water from holding tanks to a release tank and released just upstream from either spillbay 4 or 7 via hose. Both the tailrace and Columbia River groups were transferred water-to-water from holding tanks to a release tank mounted on an 8.5 by 2.4-m barge, transported to the release location, and released mid-channel, water-to-water.

We released 5 groups of 18-41 (depending on availability at Wanapum Dam) Mid-Columbia fish during the day (1235-1615 PDT) into the mid-channel of the Columbia River approximately 15 km above the mouth of the Snake River. Twenty-six spillway release groups were released at Lower Monumental Dam consisting of 12-29 fish (usually 14-15 fish) which were released during the daytime (0925-1320). Twenty-six Lower Monumental Dam tailrace release groups consisting of 24-29 fish were released during the daytime (0925-1400).

We also released fish into two separate locations below Ice Harbor Dam: into the tailrace approximately 0.5 km downstream and in front of Goose Island approximately 2.5 km downstream from Ice Harbor. Thirty-two release groups consisting of 9-12 fish were made at each site during both day (0800-1500) and night (1800-2200). Mean length and weight for released fish was 150 mm (131-220 mm) and 31 g (25.0-111.3 g), respectively.

Survival Estimates

Survival to McNary Dam was estimated for groups of tagged fish based on detection histories using the single-release (SR) model (Cormack 1964; Jolly 1965; Seber 1965). Estimates were based on progressive downstream detections (both PIT and radio-tag detections) of single release groups. These estimates consider the probability that a tagged fish may pass the downstream boundary of the area in question without being detected. Thus, in order to separate the probability of detection from that of survival, the model requires detections of at least some fish downstream from the area of interest. For this purpose, we used data from detections at Irrigon for survival estimates through McNary Dam. Previous studies indicated that dead, radio-tagged fish released in the bypass system at McNary Dam are not detected at Irrigon (Axel et al. 2003); therefore, we could safely assume that fish detected at Irrigon were alive.

For estimates of survival through McNary Dam, we created "release groups" based on day of detection at the telemetry transect on the upstream edge of the McNary Boat Restricted Zone. Detections through all project passage routes were used for survival estimates. For bypass outfall survival estimates, we created "release groups" based on day of detection within the bypass system. For both dam and bypass outfall survival estimates, subsequent downstream detections from Irrigon and Crow Butte were used (Figure 1).

We were not able to measure mortality that may have occurred on or near the fish guidance screen itself. Since radio-tagged fish were also tagged with a PIT tag, detections from the juvenile collection facilities (Prentice 1990a,b) at McNary, John Day, and Bonneville Dams and from the PIT-trawl towed-array in the Columbia River estuary were also used for survival estimates.

Key assumptions underlying the SR model must be met in order to obtain unbiased estimates of survival through specific reaches or areas. One such assumption is that radiotelemetry detection at a given site does not affect subsequent detection probabilities downstream from that site. Tests of model assumptions are presented in Appendix A. For more detailed discussion of the SR model and its associated tests of assumption, see Iwamoto et al. (1994), Zabel et al. (2002), and Smith et al. (2003).

Passage Behavior and Timing

Forebay Residence Time

Forebay residence time was measured from the first detection on the forebay entrance line to either the last detection during spillway passage or the first detection in a gatewell or moving past a fish guidance screen into a turbine unit. Hypothesis testing to compare specific cohorts was evaluated using permutation methods (Efron and Tibshirani 1993), with the null hypothesis that the true medians of the particular pair of cohorts were equal. The data from the two cohorts were pooled and a permutation of two samples (using the original sample sizes) was randomly generated (without replacement). The medians of the two "permuted samples" were calculated as well as their difference. We repeated this process 1,000 times resulting in 1,000 permutation median difference estimates. We then calculated *P*-values as the proportion of times these differences were more extreme (usually larger) than the observed difference (doubled for a 2-tailed test).

Passage Route Distribution

To determine the route of passage individual fish used at the project, we monitored the spillway, extended-length submersible bar screens (fish guidance screens), and the bypass system. The spillway was monitored by four underwater dipole antennas in each spillbay. Two antennas were installed along each of the two pier noses of each spillbay at depths of 20 and 40 ft. Pre-season range testing showed that this configuration monitors the entire spillbay. We used armored coaxial cable, stripped at the end, to detect fish passage in the turbine and bypass system. These antennas were attached on both ends of the downstream side of the fish screen support frame located within each slot of the turbine intake.

We also placed an underwater antenna into the fish separator located upstream from the juvenile bypass system raceways. Fish that were detected on the fish screen antennas but were not subsequently detected on the PIT-detection system or the telemetry monitor located in the separator were designated turbine passed fish. Inputs from the spillway and fish screen antennas were monitored by a single Multiprotocol Integrated Telemetry Acquisition System (MITAS; Grant Systems Engineering, King City, Ontario, Canada). The MITAS system includes a single PC which monitors all inputs simultaneously and logs the data.

Fish Passage Metrics

The standard fish-passage metrics of spill efficiency, spill effectiveness, fish passage efficiency, and fish guidance efficiency were also evaluated using radiotelemetry detections in the locations used for passage route evaluation (described above). However, the method of calculating these metrics using radiotelemetry differs from those used in previous evaluations (e.g., fish guidance efficiency was formerly calculated based on the percentage of fish caught in fyke nets). Fish-passage metrics used for this evaluation were defined as follows:

- *Spill efficiency*: Total number of fish passing the spillway divided by total number passing the dam

- *Spill effectiveness*: Proportion of fish passing the spillway divided by proportion of water spilled

- *Fish passage efficiency*: Number of fish passing the dam via non-turbine routes divided by total number passing the dam

- *Fish guidance efficiency*: Number of fish guided into the bypass system divided by total number passing via the powerhouse

Tailrace Egress

Tailrace egress was measured from the last known detection through the project (spillway, turbine, or bypass system) to the last known detection at the telemetry transect located at the end of the navigation lock wing wall. Hypothesis testing to compare specific cohorts was conducted using the same methodology used for forebay delay time.

Avian Predation

Predation from the Caspian Tern colony on Crescent Island, located 12.9 km downstream from the Snake River mouth (Figure 1), was measured by monitoring with a telemetry receiver, physical recovery of tags deposited on the island, and PIT-tag detection. Radio tags and PIT tags were recovered on the tern colony at Crescent Island during fall 2003 after the birds left the island. PIT-tag detections at Crescent Island were provided by NMFS and Biomark (B. Ryan, NMFS, personal communication; see also Ryan et al. 2001). We physically recovered radio tags that were visible on the island and used radio-tag serial numbers to identify individual tagged fish.

RESULTS

Fish Collection, Tagging, and Release

River-run, hatchery yearling chinook salmon were collected, radio-tagged and PIT-tagged at Lower Monumental Dam on 26 days from 28 April to 5 June. Tagging began after 30% of the yearling chinook salmon had passed Lower Monumental Dam and was completed when 99% of these fish had passed. Handling and tagging mortality for yearling chinook salmon was 2.6% overall, and tag loss due to regurgitation was 0.3%. Overall mean fork length and weight was 150.0 mm and 30.8 g, respectively.

We released a total of 847 radio- and PIT-tagged fish into spillbay 4, spillbay 7, and the tailrace of Lower Monumental Dam. Releases occurred between 0925 and 1315 PDT. A total of 816 radio- and PIT-tagged fish were released into the tailrace of Ice Harbor Dam during daytime and nighttime project operations.

We radio tagged 136 yearling chinook salmon collected at Wanapum Dam and released them in the Columbia River approximately 15 km upstream from the Snake and Columbia River confluence. Releases occurred between 1200 and 1615 PDT and were made once per week with approximately 35 fish from 2 May to 4 June, with the exception of the second week of releases which were made on two separate days due to low collection numbers at Wanapum Dam. Overall mean fork length was 150.3 mm.

McNary Dam Operations

Mean daily total discharge during the study was 248.2 kcfs, ranging from 180.2 to 352.5 kcfs (Appendix Figure B1). Throughout the first three weeks of the study, operations at McNary Dam were relatively consistent with BiOp spill operations occurring daily between 1800 and 0600 (Appendix Tables B1 and B2). Nighttime operations fluctuated very little throughout the entire study (Appendix Figure B2). On 27 May, the project began periods of involuntary spill to the total dissolved gas limit of 120% during the daytime to accommodate increased river flows (Appendix Figure B3).

Survival Estimates

Dam survival was estimated from detections of radio-tagged hatchery yearling chinook salmon in the forebay of McNary Dam and at a series of downstream telemetry transects between McNary Dam and John Day Dam on the lower Columbia River. Mean length and weight of fish used for survival estimates was 147 mm and 30.7 g, respectively. Estimated dam survival was 0.893 (95% CI, 0.849-0.937). Spillway passage survival was 0.928 (95% CI, 0.874-0.982). On 27 May flows increased at McNary Dam and the spill proportion increased from 12 to 38% and remained high for the remainder of the study (Appendix B). As a result, we looked at spill survival for the period of lower spill versus the increased spill period. During the lower spill levels, spill survival was 0.982 (95% CI, 0.872-1.092). When spill increased, spill survival decreased to 0.866 (95% CI, 0.790-0.941). The difference between the two estimates was statistically significant ($P = 0.048$). The bypass outfall survival estimate was 0.865 (95% CI, 0.803-0.927).

Passage Behavior and Timing

Travel and Arrival Times

We detected 1,216 radio-tagged Snake River fish and 110 Mid-Columbia River fish at McNary Dam. Travel times were calculated from the various release sites to the forebay entrance detection line (Table 1). Mean travel times to McNary Dam from Lower Monumental Dam, Ice Harbor Dam, and the Columbia River (15 km above the Snake River confluence) were 3.2, 1.6, and 1.9 days, respectively. Radio transmitter battery life exceeded approximately 99% of the maximum travel times observed for all release locations; therefore, all fish had relatively equal probabilities of detection at McNary Dam. Hour of arrival at McNary Dam was somewhat consistent across 24-h periods, ranging from 2.4 to 6.2% of the fish per hour (Figure 2).

Table 1. Travel time, in days, to McNary Dam for radio-tagged, hatchery yearling chinook salmon released at three locations, 2003.

	Travel time (d)			Mean		95% Confidence interval (d)		Migration rate
Release site	Min	Median	Max	(d)	SE	Low	High	(km/d)
Lower Monumental (sites combined)	1.4	3.1	8.2	3.2	0.1	3.0	3.4	37.1
Ice Harbor tailrace	0.5	1.5	8.6	1.6	0.1	1.4	1.8	42.5
Mid-Columbia	1	1.7	5.6	1.9	0.1	1.7	2.1	36.5

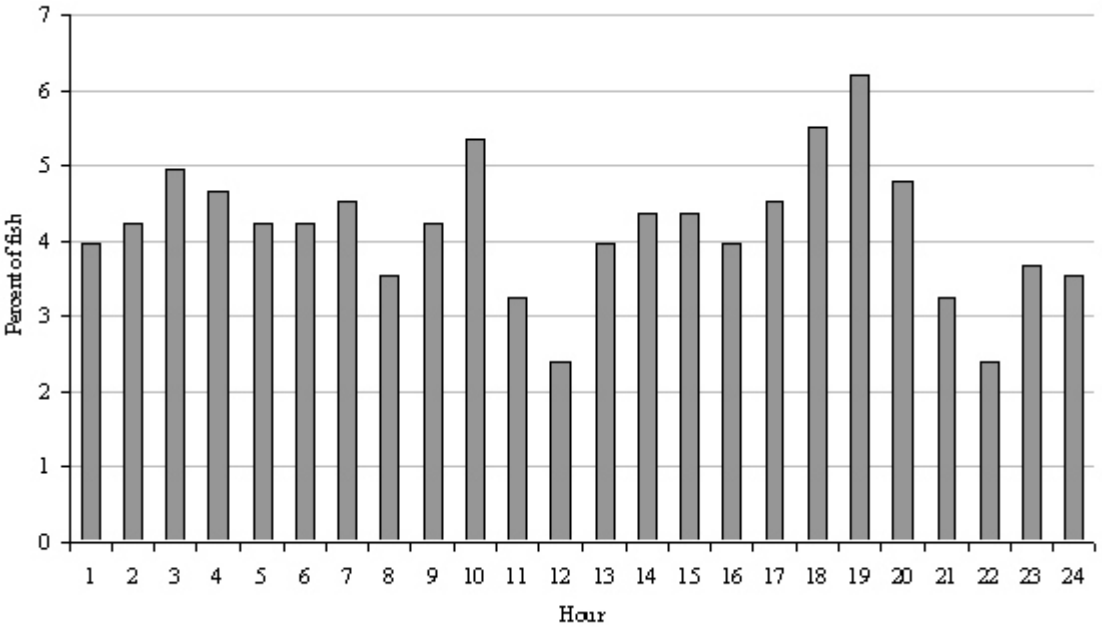

Figure 2. Percentage of yearling chinook arriving at McNary Dam by hour of day during spring 2003.

Forebay Residence Time

Overall median forebay residence time at McNary Dam was 0.7 h for radio-tagged, hatchery yearling chinook salmon. Median forebay delay was 2.6 h during periods of no spill vs. 0.6 h during periods of spill. Forebay delay was longest between 0500 and 1200, during which 31.7% of the fish passed the project. Approach path and subsequent passage route appeared to be related to delay time in the forebay. Further analysis demonstrated a statistical difference between spilled and bypassed fish and their associated median forebay delay times of 0.5 and 1.2 h, respectively ($P < 0.002$). Forebay delay was poorly correlated with fork length (Figure 3).

Passage Behavior and Project Operation

The route that radio-tagged fish used to pass McNary Dam during the spring was affected by project operations (Figure 4). The rate of fish passage through the bypass system was higher during the day, averaging 5.4%/h vs. 2.9%/h at night (Table 2). The rate of fish passing via the spillway during daytime operations averaged 2.0%/h. During nighttime operations (with generally much higher levels of spill), the rate of fish passing the spillway increased to an average of 6.3%/h.

On 27 May flows increased at McNary Dam and spill proportion increased from 12 to 38% for the remainder of the study period (Appendix B). During the higher flows, daytime spill levels increased dramatically causing the percent of fish spilled to increase from 8 to 47%.

Passage Route Distribution

Proportions of Snake River yearling chinook salmon that passed the spillway, bypass, and turbine routes at McNary Dam were 46, 46, and 5%, respectively, with 3% having unknown routes of passage (n = 1,155; Figure 5). Proportions of Columbia River yearling chinook that passed through spillway, bypass, and turbine routes were 48, 45, and 4%, respectively, with 3% of the fish having unknown routes of passage (n = 118; Figure 6).

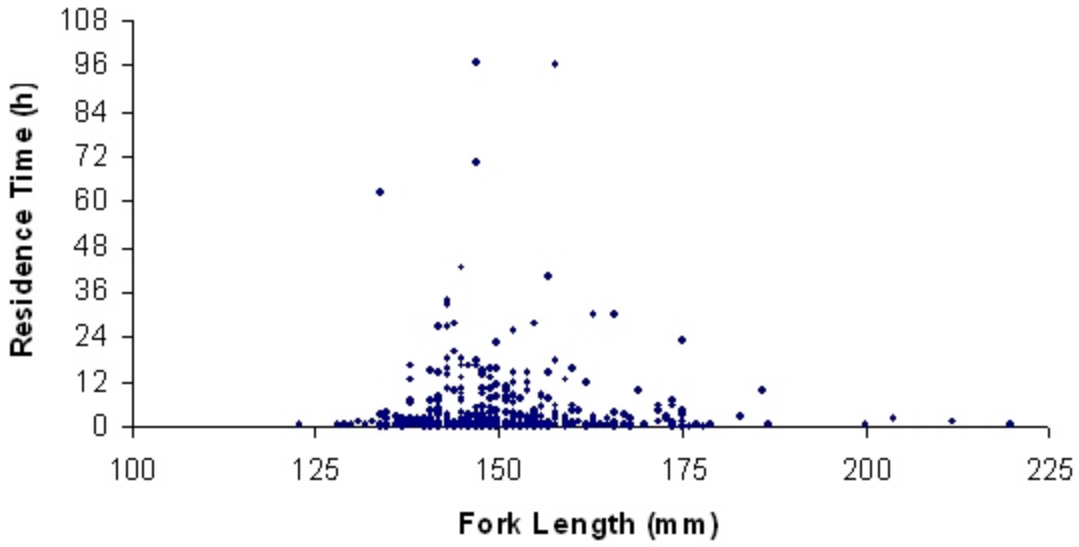

Figure 3. Forebay delay in relation to fork length for run-of-river, radio-tagged hatchery yearling chinook salmon passing McNary Dam, 2003.

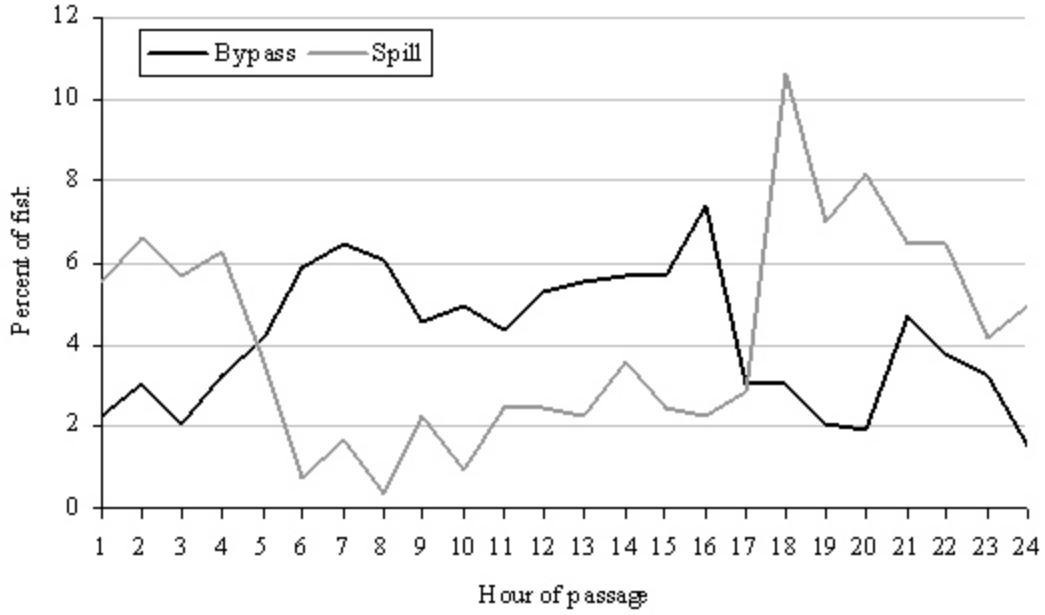

Figure 4. Percent of fish passage by hour through the bypass system and spillway at McNary Dam, 2003.

Table 2. The number and percentage of radio-tagged, hatchery yearling chinook salmon passing McNary Dam by hour of passage, 2003.

	All Routes		Bypass		Spill		Turbine	
Hour	No. of fish	%	No. of fish	%	No. of fish	%	No. of fish	%
1	43	3.9	12	2.3	29	5.5	2	3.3
2	52	4.7	16	3.0	35	6.6	1	1.6
3	43	3.9	11	2.1	30	5.7	2	3.3
4	51	4.6	17	3.2	33	6.3	1	1.6
5	42	3.8	22	4.2	19	3.6	1	1.6
6	43	3.9	31	5.9	4	0.8	8	13.1
7	44	3.9	34	6.5	9	1.7	1	1.6
8	39	3.5	32	6.1	2	0.4	5	8.2
9	41	3.7	24	4.6	12	2.3	5	8.2
10	32	2.9	26	4.9	5	0.9	1	1.6
11	43	3.9	23	4.4	13	2.5	7	11.5
12	44	3.9	28	5.3	13	2.5	3	4.9
13	42	3.8	29	5.5	12	2.3	1	1.6
14	53	4.8	30	5.7	19	3.6	4	6.6
15	45	4.0	30	5.7	13	2.5	2	3.3
16	55	4.9	39	7.4	12	2.3	4	6.6
17	34	3.0	16	3.0	15	2.8	3	4.9
18	74	6.6	16	3.0	56	10.6	2	3.3
19	49	4.4	11	2.1	37	7.0	1	1.6
20	54	4.8	10	1.9	43	8.2	1	1.6
21	62	5.6	25	4.7	34	6.5	3	4.9
22	56	5.0	20	3.8	34	6.5	2	3.3
23	39	3.5	17	3.2	22	4.2	0	0.0
24	35	3.1	8	1.5	26	4.9	1	1.6
Mean	*46*	*4.2*	*22*	*4.2*	*22*	*4.2*	*3*	*4.2*

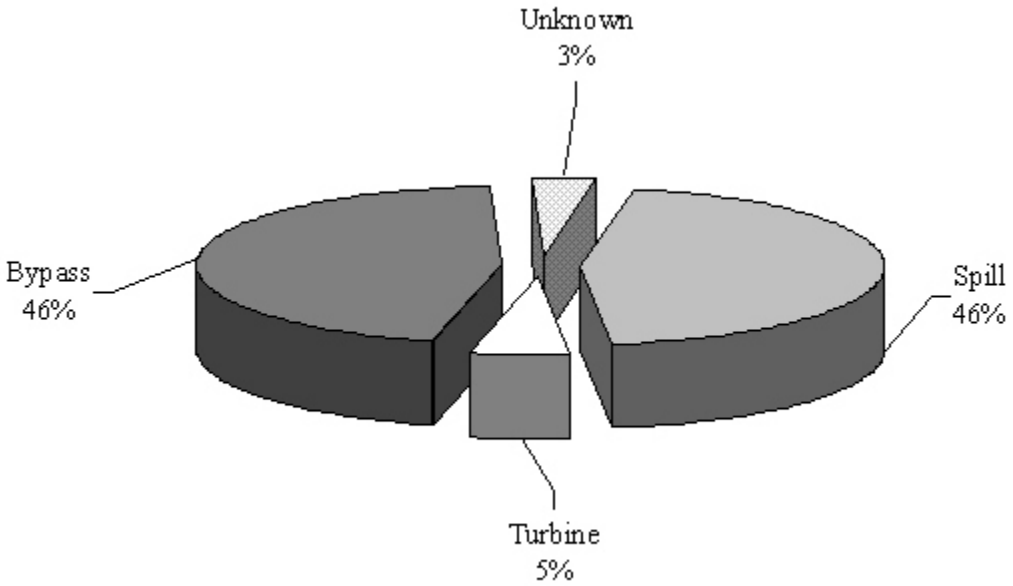

Figure 5. General passage route distribution for Snake River radio-tagged, hatchery yearling chinook salmon passing McNary Dam, 2003 (n = 1,155).

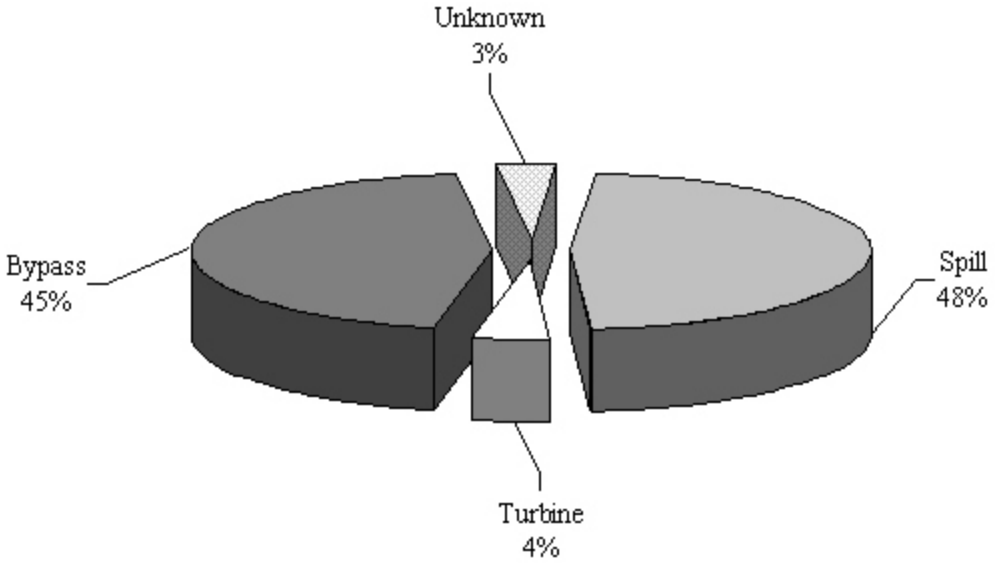

Figure 6. General passage route distribution for Columbia River radio-tagged, hatchery yearling chinook salmon passing McNary Dam, 2003 (n = 118).

Fish Passage Metrics

Mean fish passage efficiency at McNary Dam was 94% for Snake River fish and 96% for Columbia River fish (Tables 3 and 4). Fish guidance efficiency for Snake and Columbia River fish was 90 and 91%, respectively. Spill efficiency was 47% for Snake River fish and 49% for Columbia River fish. Mean spill effectiveness for Snake River migrants was 1.43:1 compared to 1.32:1 for Columbia River migrants. Horizontal distribution of fish passing via the powerhouse was similar for both groups of fish, with the highest percentages of fish generally passing through the middle units (Figures 7 and 8). The horizontal distribution of fish passing the spillway favored the middle to southern spillbays (spillbays 13-19) for both Snake and Columbia River fish (Figures 9 and 10).

Tailrace Egress

Overall median tailrace egress at McNary Dam was 6.9 min. Further analysis identified a significant difference between median egress times for spilled fish (5.8 min) and bypassed fish (7.7 min; $P < 0.002$). Differences also were seen in diel comparisons as a result of changing project operations. Diel comparisons between bypassed fish also revealed statistically significant differences (7.3 min during the day vs. 9.0 min at night; $P < 0.002$; Figure 11). Similar comparisons for spillway-passed fish showed no differences ($P < 0.612$). We also investigated tailrace egress time associated with horizontal distribution of spillway-passed fish and observed slightly longer tailrace egress times for fish passing through the end bays (Figure 12).

Avian Predation

During the study, we detected 42 radio tags on the Crescent Island Caspian Tern colony telemetry monitor. After the terns had left the island for the season, we initiated a physical recovery effort for radio tags that were left on the island. We recovered a total of 44 tags, 22 of which were never detected by our telemetry receiver. In addition, we obtained data from an ongoing monitoring effort by NOAA Fisheries to recover PIT tags from active Caspian Tern colonies in the region. The PIT-tag data from 2003 indicated an additional 10 fish were preyed upon and their subsequent PIT tags discarded on the island (28 more were detected but had been either previously detected by telemetry or physically recovered). In total, 74 mortalities were recorded within the tern colony, representing 3.7% of the fish we released into the Snake and Columbia Rivers.

Table 3. The number of radio-tagged, Snake River hatchery yearling chinook salmon detected passing McNary Dam and calculated fish passage metrics versus the percent of water spilled, 2003.

Spill proportion	No. of fish spilled	No. of fish bypassed	No. of fish through turbines	Total no. of fish detected	Spill efficiency	Spill effectiveness	Fish passage efficiency
0.30	21	27	4	52	0.40	1.35	0.92
0.31	26	37	1	64	0.41	1.31	0.98
0.32	21	47	5	73	0.29	0.90	0.93
0.33	37	59	4	100	0.37	1.12	0.96
0.34	107	102	19	228	0.47	1.38	0.92
0.35	46	26	6	78	0.59	1.68	0.92
0.36	85	85	12	182	0.47	1.30	0.93
0.37	11	12	1	24	0.46	1.24	0.96
0.38	30	12	4	46	0.65	1.72	0.91
0.39	38	9	0	47	0.81	2.07	1.00
0.40	99	61	3	163	0.61	1.52	0.98
0.41	4	8	2	14	0.29	0.70	0.86
0.42	3	7	0	10	0.30	0.71	1.00
0.43	4	11	1	16	0.25	0.58	0.94
0.45	1	5	0	6	0.17	0.37	1.00
0.50	0	4	0	4	0.00	0.00	1.00
Totals	*533*	*512*	*62*	*1107*	*0.48*		*0.94*

Table 4. The number of radio-tagged, Mid-Columbia hatchery yearling chinook salmon detected passing McNary Dam and calculated fish passage metrics versus the percent of water spilled, 2003.

Spill proportion	No. of fish spilled	No. of fish bypassed	No. of fish through turbines	Total no. of fish detected	Spill efficiency	Spill effectiveness	Fish passage efficiency
0.30	7	6	0	13	0.54	1.79	1.00
0.31	3	9	0	12	0.25	0.81	1.00
0.32	1	1	0	2	0.50	1.56	1.00
0.33	5	3	0	8	0.63	1.89	1.00
0.34	12	7	1	20	0.60	1.76	0.95
0.36	9	17	4	30	0.30	0.83	0.87
0.37	0	1	0	1	0.00	0.00	1.00
0.38	0	2	0	2	0.00	0.00	1.00
0.41	13	2	0	15	0.87	2.11	1.00
0.42	6	5	0	11	0.55	1.30	1.00
Totals	*56*	*53*	*5*	*114*	*0.49*		*0.96*

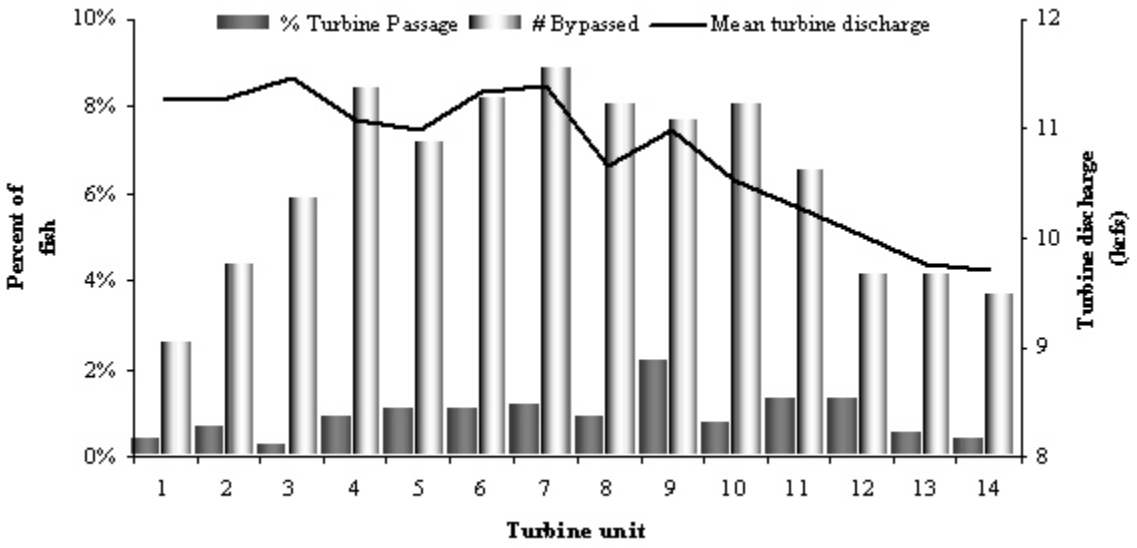

Figure 7. Horizontal passage distribution through McNary Dam powerhouse by Snake River radio-tagged hatchery yearling chinook salmon, 2003 (n = 784).

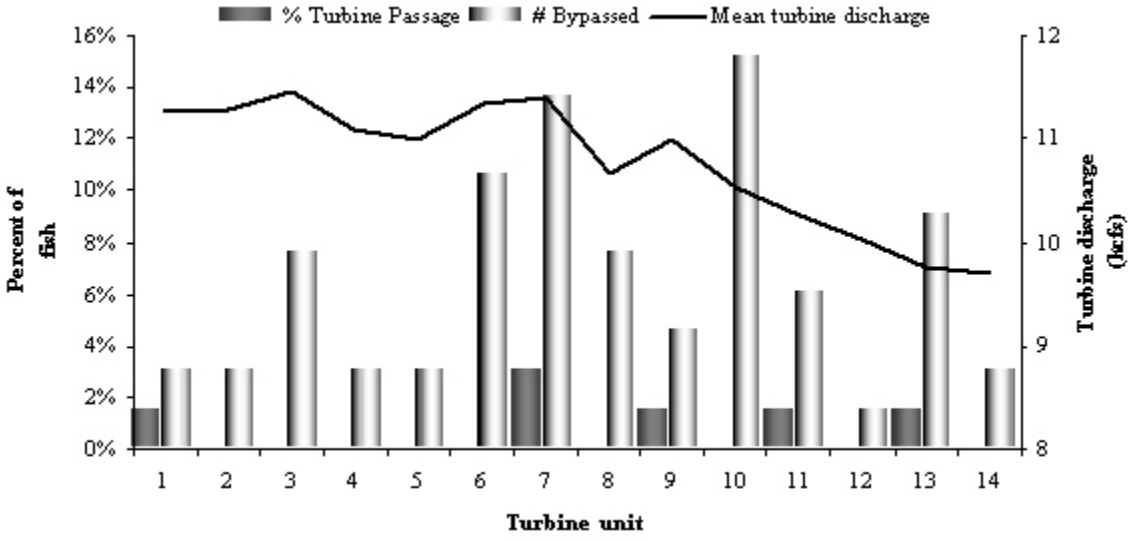

Figure 8. Horizontal passage distribution through McNary Dam powerhouse by Columbia River radio-tagged hatchery yearling chinook salmon, 2003 (n = 66).

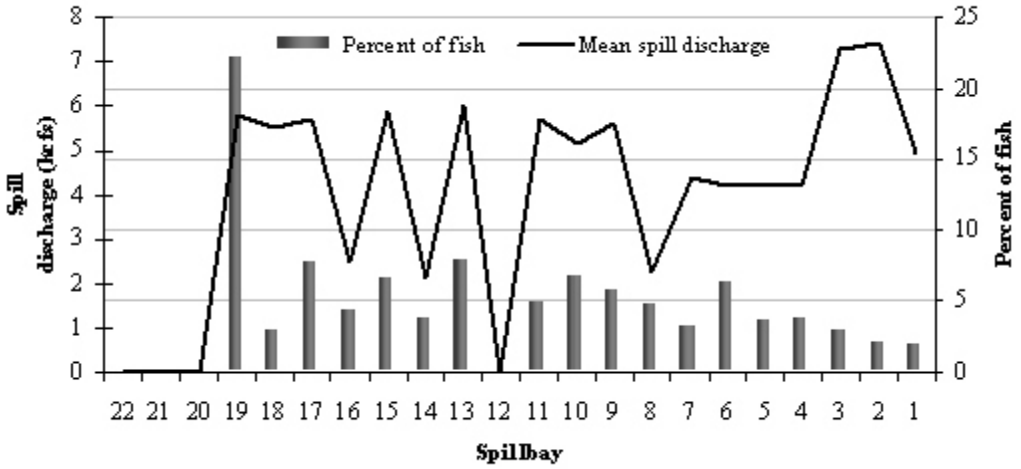

Figure 9. Horizontal passage distribution through spillbays at McNary Dam by Snake River radio-tagged hatchery yearling chinook salmon, 2003 (n = 527). Spillbays 12, 21, and 22 were not operated in 2003.

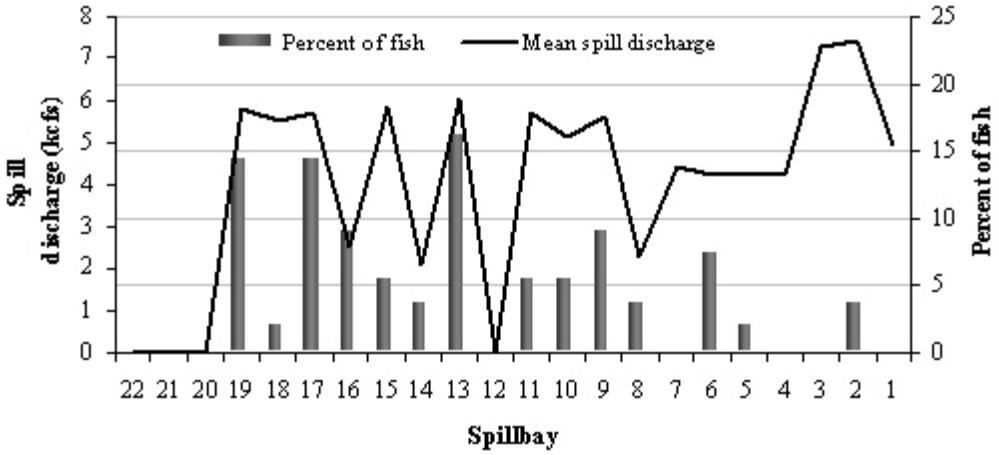

Figure 10. Horizontal passage distribution through spillbays at McNary Dam by Columbia River radio-tagged hatchery yearling chinook salmon, 2003 (n = 56). Spillbays 12, 21, and 22 were not operated in 2003.

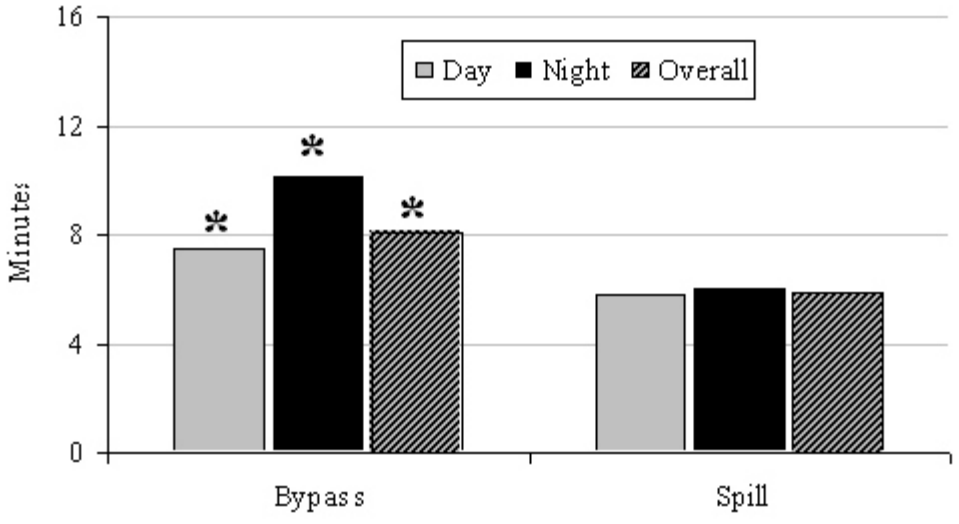

Figure 11. Diel and overall median tailrace egress for bypassed and spilled run-of-river, radio-tagged, hatchery yearling chinook salmon at McNary Dam, 2003. Asterisks denote statistically significant differences for bypass day vs. night and overall bypass vs. spill comparisons.

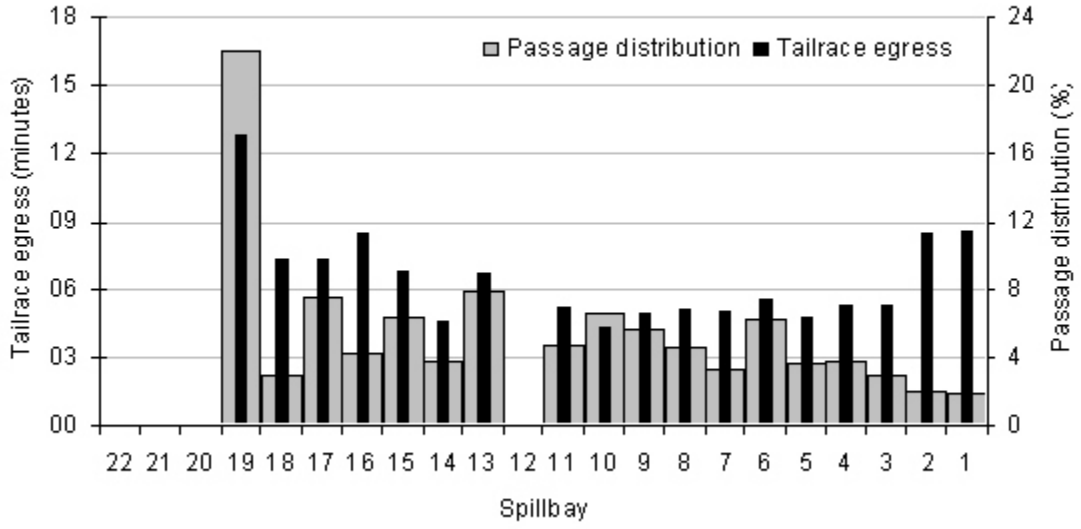

Figure 12. Spillway passage distribution and median tailrace egress for radio-tagged fish passing McNary Dam, 2003. Spillbays 12, 21, and 22 were not operated in 2003.

DISCUSSION AND RECOMMENDATIONS

This was the second year of a radiotelemetry evaluation of juvenile salmonid passage and survival at McNary Dam. In 2002, we monitored all routes of passage to examine fish passage behavior and survival (Axel et al. 2004). These 2 years of study are expected to provide baseline data for the ongoing McNary Modernization Project.

Project-wide fish passage metrics were obtained for the second consecutive year at McNary Dam. Previous work concluded that extended-length bar screens increased guidance to 80% for yearling chinook salmon (McComas et al. 1994). Our estimates for both 2002 and 2003 indicate that fish guidance efficiency at McNary Dam was closer to 90% for yearling chinook salmon. Spill efficiency, spill effectiveness, and fish passage efficiency for yearling chinook salmon in 2003 was similar to 2002 (Axel et al. 2004). Differences between years in the distribution of fish passing through individual spillbays were a result of several unused spillbays in 2003 on the southern end of the spillway. The large percentage of fish that passed through spillbay 19 most likely would have been spread out more evenly had the adjacent bays been used.

We observed longer forebay delay times and tailrace egress times at McNary Dam for hatchery yearling chinook salmon that were bypassed than for those that passed via spillways during spring operation. There was an apparent correlation between daily discharge and forebay delay time, where overall delay times were reduced during higher flows. We found no relationship between hour of arrival or hour of passage and delay time. A similar relationship between tailrace egress and passage route was observed in 2002 at McNary Dam (Axel et al. 2004); however, the difference in egress time between routes was small in both years and may not be large enough to indicate biologically significant consequences within the tailrace. Further study, including releases of fish from multiple sites within the tailrace, may be needed to substantiate this.

During project coordination meetings with regional managers it was suggested that Columbia River migrants might have a different passage distribution and different fish passage metrics in comparison with Snake River migrants. However, we found that passage distributions for the powerhouse and spillway were nearly identical for Snake and Columbia River fish and were similar to results obtained in 2002 (Axel et al. 2004). In addition, our results indicated that Columbia and Snake River migrants have nearly identical horizontal distributions and fish passage behavior, although our sample sizes for Columbia River migrants were relatively small. We recommend further study using larger sample sizes to corroborate the results obtained this year.

Survival at McNary Dam during 2003 of 0.893 (95% CI, 0.849–0.937) was similar to the estimate of 0.877 (95% CI, 0.849–0.905) reported for 2002 (Axel et al. 2004). The estimate for 2003 was slightly higher than for 2002 and had wider confidence intervals (0.088 in 2003 vs. 0.056 in 2002), but the point estimate still fit within the previously reported bounds.

The wider confidence intervals in 2003 may have resulted from a decrease in detection efficiency due to gastric rather than surgical implantation of the radio tags. Radio-tag antennas were crimped for gastric implantation, and the crimp affected detection efficiency according to post-study testing by our electronics technicians. Reduced detection efficiencies at downstream detection lines is of particular concern in survival estimates, particularly in the Columbia River, where width and depth may substantially exceed the detection range of the transect.

Spillway and bypass outfall survival estimates at McNary Dam were lower in 2003 than in 2002, at 0.928 (95% CI, 0.874-0.982) and 0.865 (95% CI, 0.803-0.927), respectively. In 2002 spillway survival was estimated at 0.976 (95% CI, 0.952-1.000) and bypass survival at 0.927 (95% CI, 0.889-0.965; Axel et al. 2004). The lower spillway survival during higher flows may involve several factors. One thought is that as daytime spill levels increase, predation may also increase within the tailrace following passage. We went back and analyzed spillway survival in 2002 to determine if the same differences existed when flows and daytime spill levels increased. Spillway survival did decline slightly; however, the difference was not statistically significant.

The size of the Caspian Tern colony on Crescent Island was approximately 510 breeding pairs during 2003, a decline of about 12% compared to 2002 (Collis et al. 2003). Zabel et al. (2002) reported that the tags of 4.1% of the PIT-tagged spring/summer chinook salmon detected at Lower Monumental Dam during 2001 were subsequently detected on Crescent Island. We recovered tags from approximately 3.7% of our radio-tagged fish on Crescent Island in 2003. Detection histories of radio tags subsequently found on Crescent Island in 2003 indicated that, at a minimum, terns from this colony foraged from Ice Harbor Dam forebay to McNary Dam forebay, a distance of nearly 70 km. We also observed terns foraging in the forebay of Lower Monumental Dam during treatment group releases, and several radio tags from fish tagged at this site with no detection history at Ice Harbor ended up on Crescent Island.

Finally, we recommend extending the baseline data acquisition to steelhead and subyearling chinook salmon at McNary Dam in order to obtain vital passage and survival information on these species. Of particular importance is steelhead, which have been shown to have lower survival between the tailrace of Lower Monumental and that of

McNary Dam (Smith et al. 2003). Radiotelemetry techniques and new modifications which allow for further miniaturization of radio tags are creating an opportunity to evaluate the passage and survival of smaller fish, which make up a large portion of the run at McNary Dam.

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APPENDIX A: Tests of Model Assumptions

The single-release (SR) model was used to estimate survival of radio-tagged juvenile chinook salmon passing McNary Dam. Data for the model consists of individual downstream detection records of released fish. The model posits that each detection of an individual fish has an associated probability of occurrence, that these probabilities must be estimated in order to distinguish them from survival probabilities, and that certain assumptions be met for the model to produce unbiased estimates of these probabilities. For this evaluation, we considered each of the following assumptions. A discussion of these assumptions follows.

A1 All tagged fish have the same probability of being detected at a detection location.

A2 Individuals tagged for the study are a representative sample of the population of interest.

A3 The tag and/or tagging methods do not significantly affect the subsequent behavior or survival of the marked individual.

A4 Fish that die at either a project or passing through a passage route at a project are not subsequently detected downstream.

A5 Radio transmitters function properly and for the predetermined period of time.

The first assumption in the list above is perhaps the most critical assumption for the SR model:

A1 All tagged fish have the same probability of being detected at a detection location.

To evaluate detection probabilities, we evaluated the goodness-of-fit of the SR model to the observed data using the methods of Burnham et al. (1997, p. 71-77). First, we compiled a series of contingency tables from data on the various detection-history categories. We used chi-square tests to to identify differences between the observed and expected results that were greater than what would be likely due to chance variation. If systematic deviations were observed (indicating a violation of key assumptions), we examined the tables to determine the nature of the violation and to see if there was consistency in its pattern.

Two of the tests presented by Burnham et al. (1987) were applicable to the data: Test 2.C2 and Test 3.SR3. These tests used detection histories of McNary Dam "release groups" (i.e., fish grouped by day of detection at McNary Dam) with subsequent radiotelemetry detections at Irrigon and Crow Butte and subsequent PIT-detections at John Day and Bonneville Dam.

Test 2.C2 was based on the following contingency table:

Test 2.C2	First site detected below Irrigon	
df = 1	Crow Butte	JDA or BON
Not Detected at Irrigon	n_{11}	n_{12}
Detected at Irrigon	n_{21}	n_{22}

This table classifies fish detected below Irrigon according to history of detection at Irrigon and first detection below Irrigon. Fish in the n_{11} cell, for example, were not detected at Irrigon and were first detected downstream from Irrigon at Crow Butte. If the assumption that radio- or PIT-tag detection does not affect the probability of subsequent detection, then the counts for fish detected at Irrigon should be in constant proportion to those for fish not detected at Irrigon (i.e., n_{11}/n_{21} and n_{12}/n_{22} should be equal).

The second applicable test, 3.SR3, was based on the following contingency table:

Test 3.SR3	Detected again at JDA or BON?	
df = 1	YES	NO
Detected at Crow Butte; not detected at Irrigon	n_{11}	n_{12}
Detected at Crow Butte; detected at Irrigon	n_{21}	n_{22}

This test cross-classifies fish detected at Crow Butte according to their detection history at Irrigon (radiotelemetry detection) and at John Day or Bonneville Dams (PIT-tag detection). If radiotelemetry detection did not affect subsequent radiotelemetry or PIT-tag detection (i.e., SR model assumptions are met) then, as seen above in Test 2C2, the counts of fish detected at John Day or Bonneville Dam should be proportionate among fish detected and not detected at Irrigon (n_{11}/n_{21} and n_{12}/n_{22} should be equal).

Results of Test 2.C2 showed no evidence of assumption violation: only 2 of 20 tests (6 had insufficient data) produced *P*-values less than 0.10 (Appendix Table A1). Of these two, the evidence of violations trended in opposing directions. Results of Test 3.SR3 showed 6 of 23 tests (3 were not calculable) with *P*-values less than 0.10 (Appendix Table A2). Of these six, three indicated violations in a direction opposite from the other three, and a pooled test of all six groups had $P = 0.853$. Therefore, there was little evidence of violation for assumption A1.

A2 Individuals tagged for the study are a representative sample of the population of interest.

A3 The tag and/or tagging methods do not significantly affect the subsequent behavior or survival of the marked individual.

A4 Fish that die at either a project or passing through a passage route at a project are not subsequently detected at a downstream array which is used to estimate survival for the project or passage route.

Assumptions A2-A4 were not tested for validation in this study. However, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids have previously been evaluated by Adams et al. (1998a,b) and Hockersmith et al. (2003). The distance between McNary Dam and the first downstream detection array was used for survival estimation (Irrigon) was 11.2 km. Axel et al. (2003) reported that dead, radio-tagged fish released into the bypass systems at Ice Harbor and McNary Dams were not subsequently detected at downstream telemetry transects more than 3.2 km downstream.

A5 Radio transmitters function properly and for the predetermined period of time.

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish, and prior to release, to assure that transmitters were functioning properly. Tags which were not functioning properly were not used in the study. In addition, a portion of the radio transmitters from tagging mortalities throughout the study were allowed to run in river water and checked daily to test tag life function for the predetermined period of time. None of the tags tested for tag life failed prior to the preprogrammed shut-down after 7 days.

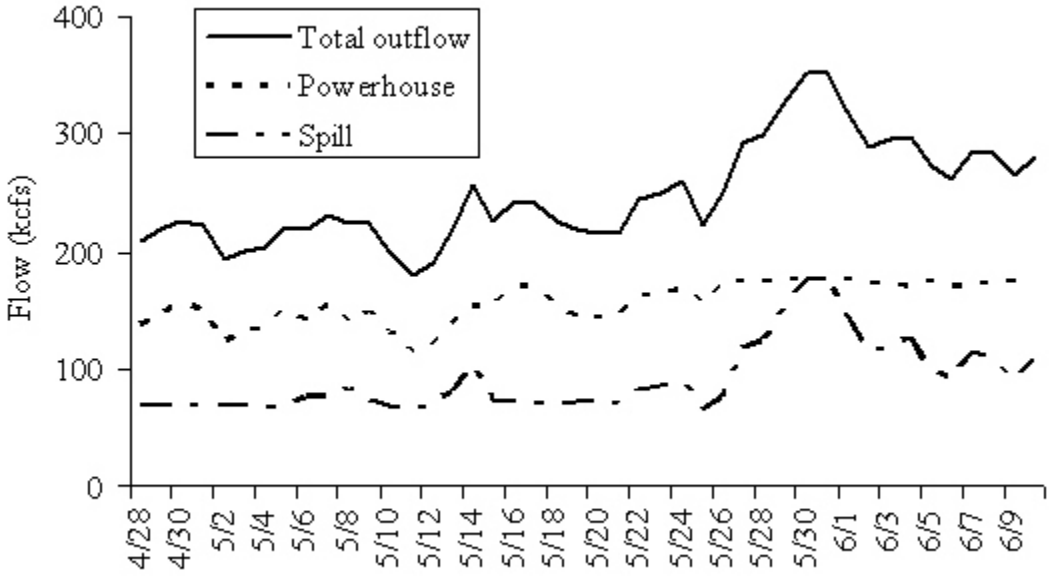
Appendix Table A1. Results of goodness-of-fit tests of the data used for McNary Dam survival estimates using the single-release model, 2003 (Burnham et al. 1997, Test 2.C2)

Temporal Group	^{2}	df	*P*
1	2.15	1	0.14
2	0.02	1	0.90
3	1.02	1	0.31
4		NA	
5		NA	
6	0.11	1	0.74
7	0.07	1	0.80
8		NA	
9	3.20	1	0.07
10	1.27	1	0.26
11	0.42	1	0.52
12	0.18	1	0.68
13	0.09	1	0.76
14		NA	
15	0.36	1	0.55
16		NA	
17	0.03	1	0.86
18	2.16	1	0.14
19	0.60	1	0.44
20	0.20	1	0.65
21	1.69	1	0.19
22	2.12	1	0.15
23	0.21	1	0.65
24	4.44	1	0.04
25	1.20	1	0.27
26		NA	
Pooled	0.95	1	0.33

Appendix Table A2. Results of goodness-of-fit tests of the data used for McNary Dam survival estimates using the single-release model, 2003 (Burnham et al. 1997, Test 3.SR3).

Temporal Group	^{2}	df	*P*
1	1.17	1	0.28
2	0.19	1	0.67
3	0.26	1	0.61
4	0.32	1	0.57
5	0.28	1	0.60
6	2.12	1	0.15
7	4.29	1	0.04
8	2.17	1	0.14
9		NA	
10	1.44	1	0.23
11	3.60	1	0.06
12	0.23	1	0.63
13	4.00	1	0.05
14		NA	
15	1.03	1	0.31
16	6.67	1	0.01
17	3.09	1	0.08
18	0.78	1	0.38
19	2.74	1	0.1
20	1.67	1	0.2
21	2.21	1	0.14
22		NA	
23	0.22	1	0.64
24	0.05	1	0.83
25	1.82	1	0.18
26	0.78	1	0.38
Pooled	0.68	1	0.41

APPENDIX B: McNary Dam Operations



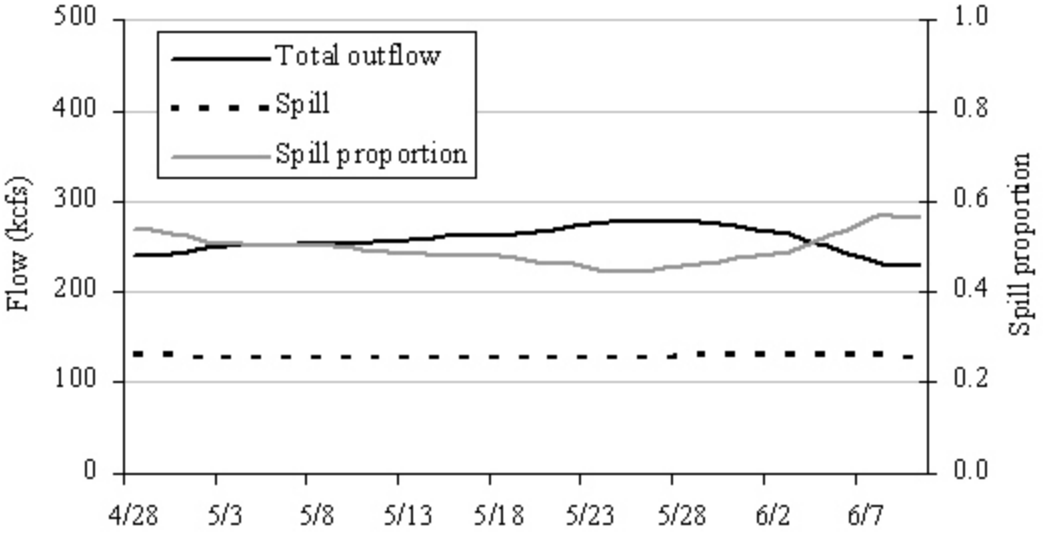
Appendix Figure B1. Total river, powerhouse, and spillway flow volumes (kcfs) at McNary Dam, 28 April to 10 June 2003.

Appendix Table B1. Mean daytime (0600-1800 hours) project operations at McNary Dam during passage and survival evaluations, 2003.

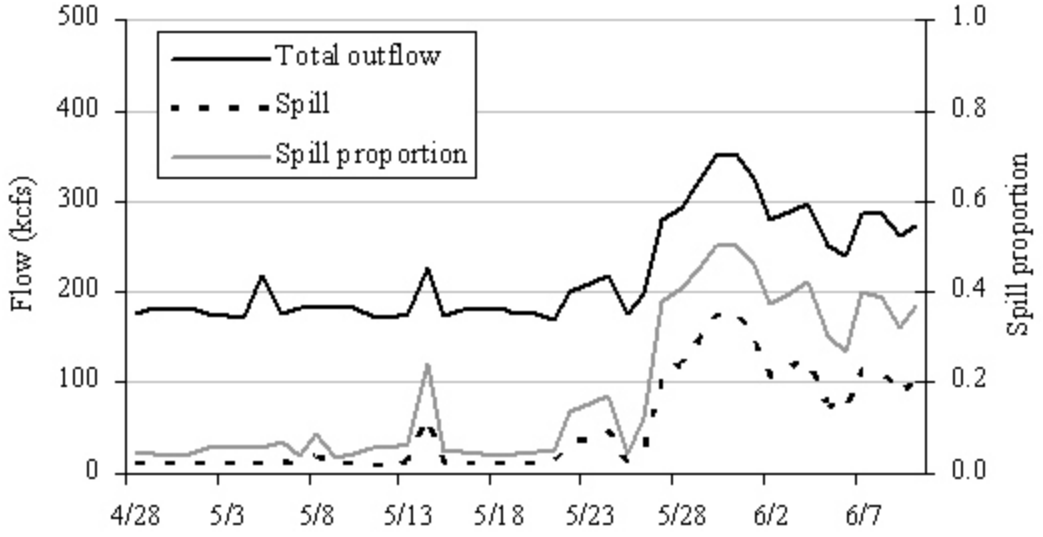
Date	Total outflow (kcfs)	Spill (kcfs)	Spill proportion
28-Apr	176.5	10.7	0.05
29-Apr	181.0	11.5	0.04
30-Apr	180.2	11.1	0.04
1-May	181.5	11.4	0.04
2-May	175.3	10.6	0.06
3-May	173.9	10.8	0.06
4-May	171.2	11.0	0.05
5-May	217.9	11.2	0.05
6-May	177.7	13.6	0.07
7-May	182.2	10.6	0.04
8-May	181.3	20.2	0.09
9-May	183.1	10.8	0.04
10-May	181.0	10.8	0.04
11-May	172.8	9.6	0.06
12-May	172.5	8.0	0.05
13-May	175.6	13.7	0.06
14-May	226.7	59.3	0.24
15-May	174.8	11.1	0.05
16-May	179.6	11.8	0.05
17-May	180.0	10.9	0.04
18-May	180.9	10.6	0.04
19-May	176.6	10.7	0.04
20-May	176.8	10.6	0.05
21-May	169.2	10.4	0.05
22-May	199.8	31.4	0.14
23-May	210.2	36.9	0.15
24-May	218.1	45.9	0.17
25-May	175.8	9.7	0.04
26-May	198.4	28.5	0.12
27-May	280.5	107.2	0.38
28-May	292.9	119.7	0.41
29-May	323.1	147.2	0.45
30-May	351.4	175.2	0.50
31-May	352.3	176.7	0.50
1-Jun	326.3	150.2	0.46
2-Jun	280.6	105.3	0.38
3-Jun	287.0	114.6	0.40
4-Jun	295.9	124.9	0.42
5-Jun	251.1	76.8	0.30
6-Jun	239.7	67.4	0.26
7-Jun	286.6	115.2	0.40
8-Jun	286.3	110.0	0.38
9-Jun	261.5	85.9	0.32
10-Jun	271.5	99.8	0.37
Mean	*221.3*	*51.1*	*0.18*

Appendix Table B2. Mean nighttime (1800-0600 hours) project operations at McNary Dam during passage and survival evaluations, 2003.

Date	Total outflow (kcfs)	Spill (kcfs)	Spill proportion
28-Apr	239.3	130.3	0.54
29-Apr	239.1	129.9	0.54
30-Apr	241.0	129.5	0.53
1-May	243.7	129.0	0.52
2-May	246.6	128.5	0.51
3-May	249.5	128.0	0.50
4-May	249.6	128.0	0.50
5-May	250.1	127.8	0.50
6-May	250.7	127.8	0.50
7-May	251.7	127.7	0.50
8-May	252.1	127.7	0.50
9-May	252.0	127.6	0.50
10-May	253.9	127.5	0.49
11-May	255.9	127.4	0.49
12-May	256.0	127.4	0.49
13-May	257.3	127.3	0.48
14-May	258.7	127.3	0.48
15-May	259.8	127.3	0.48
16-May	259.7	127.3	0.48
17-May	260.1	127.6	0.48
18-May	260.4	127.6	0.48
19-May	263.3	127.7	0.47
20-May	266.3	127.7	0.47
21-May	269.1	127.8	0.46
22-May	271.0	127.8	0.46
23-May	275.1	127.8	0.45
24-May	277.8	127.8	0.45
25-May	278.2	127.8	0.45
26-May	278.6	127.8	0.45
27-May	277.2	127.8	0.45
28-May	279.1	129.5	0.46
29-May	276.4	129.6	0.46
30-May	274.8	129.6	0.47
31-May	271.6	129.7	0.47
1-Jun	268.6	129.8	0.48
2-Jun	266.4	129.9	0.48
3-Jun	263.7	129.9	0.49
4-Jun	256.5	130.1	0.50
5-Jun	250.0	130.3	0.52
6-Jun	243.0	130.4	0.54
7-Jun	236.0	130.6	0.56
8-Jun	230.7	130.7	0.57
9-Jun	229.1	129.0	0.56
10-Jun	227.5	128.8	0.57
Mean	*257.2*	*128.6*	*0.49*



Appendix Figure B2. Mean nighttime operations at McNary Dam, 2003.



Appendix Figure B3. Mean daytime operations at McNary Dam, 2003.