# Passage and Survival of Hatchery Yearling Chinook Salmon at McNary Dam, 2002

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## EXECUTIVE SUMMARY

In 2002, NOAA Fisheries determined passage distribution, dam survival, and route-specific survival for hatchery yearling chinook salmon passing McNary Dam on the lower Columbia River. River-run fish were collected, PIT tagged, and surgically implanted with a radio transmitter. We released 1,607 radio-tagged fish to the spillway and tailrace of Ice Harbor Dam on the lower Snake River. Releases were made during both daytime and nighttime operations over 31 d from 5 May to 5 June.

Overall passage distributions for radio-tagged Snake River hatchery yearling chinook salmon through spillway, bypass, and turbine routes at McNary Dam were 45, 46, and 4%, respectively, with approximately 5% of fish having undetermined passage routes. Fish passage efficiency (FPE) was 96%. Overall fish guidance efficiency (FGE) was 93% (95% CI 90-96%). Spill efficiency was 47% and mean spill effectiveness was 1.12:1.

Dam survival was estimated from the forebay of McNary Dam to the downstream telemetry transect at Irrigon, OR on the lower Columbia River. Estimated dam survival was 0.877 (95% CI, 0.849-0.905). Spillway passage survival was 0.976 (95% CI, 0.952-1.000). The bypass outfall survival estimate was 0.927 (95% CI, 0.889-0.965).

Analysis of tailrace egress identified a statistically significant difference between median egress times for spilled fish (5.5 min) and bypassed fish (10.2 min; $P < 0.001$). In diel comparisons there was also a statistically significant difference in tailrace egress times between fish that were bypassed during the day (9.4 min) vs. at night (11.4 min; $P < 0.001$).

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# INTRODUCTION

The Columbia and Snake River basins have historically produced some of the largest runs of salmon *Oncorhynchus* spp. and steelhead *O. mykiss* in the world (Netboy 1980). More recently, however, some 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 some salmonid 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.

Recent survival studies on juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that among the different passage routes, survival was highest through spillways, followed by bypass systems and then turbines (Iwamoto et al. 1994; Muir et al. 1995a,b, 1996, 1998, 2001; Smith et al. 1998). 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 collection with transportation to improve hydrosystem passage survival for migrating juvenile salmonids.

The current spill program at McNary Dam calls for spill to occur daily between 1800 and 0600, not to exceed the 120% limit for total dissolved gas (TDG). In 2002, we investigated passage distribution and project survival for river-run hatchery yearling chinook salmon using radiotelemetry. Results of this study will be used to help inform management decisions that will optimize survival for juvenile salmonids arriving at McNary Dam.

The U.S. Army Corps of Engineers (USACE) is evaluating existing facilities at McNary Dam to determine where improvements are necessary. The improvements are intended to reduce holding and loading problems such as raceway jumping by juvenile fish and debris obstruction in bypass lines and to increase fish survival. The evaluation is known as the McNary Powerhouse Modernization project, and will consider turbine units, intake screens, vertical-barrier screens, and bypass facilities, including debris containment and removal systems and fish separation, sampling, loading, and outfall facilities (USACE 2002). Additionally, the USACE will evaluate whether the existing juvenile bypass system outfall should be relocated. This study addresses research needs outlined in SPE-W-00-1 of the USACE North Pacific Division Anadromous Fish Evaluation Program.

# METHODS

## Study Area

The study area included the 158-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 on 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 3 May to 3 June. 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 treatment and reference release groups were transferred through a water-filled 10.2-cm hose to a 935-L holding tank. Following collection and sorting, fish were maintained via flow-through river water and held for 24 h prior to radio tagging.

Fish were surgically implanted with radio transmitters using techniques described by Adams et al. (1998). Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had an expected battery life of 7 d, and were pulse-coded for unique identification of individual fish. Each radio tag measured 18 mm in length by 7 mm in diameter and weighed 1.4 g in air.

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 (2 fish per container) with aeration until recovery from 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 for a

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

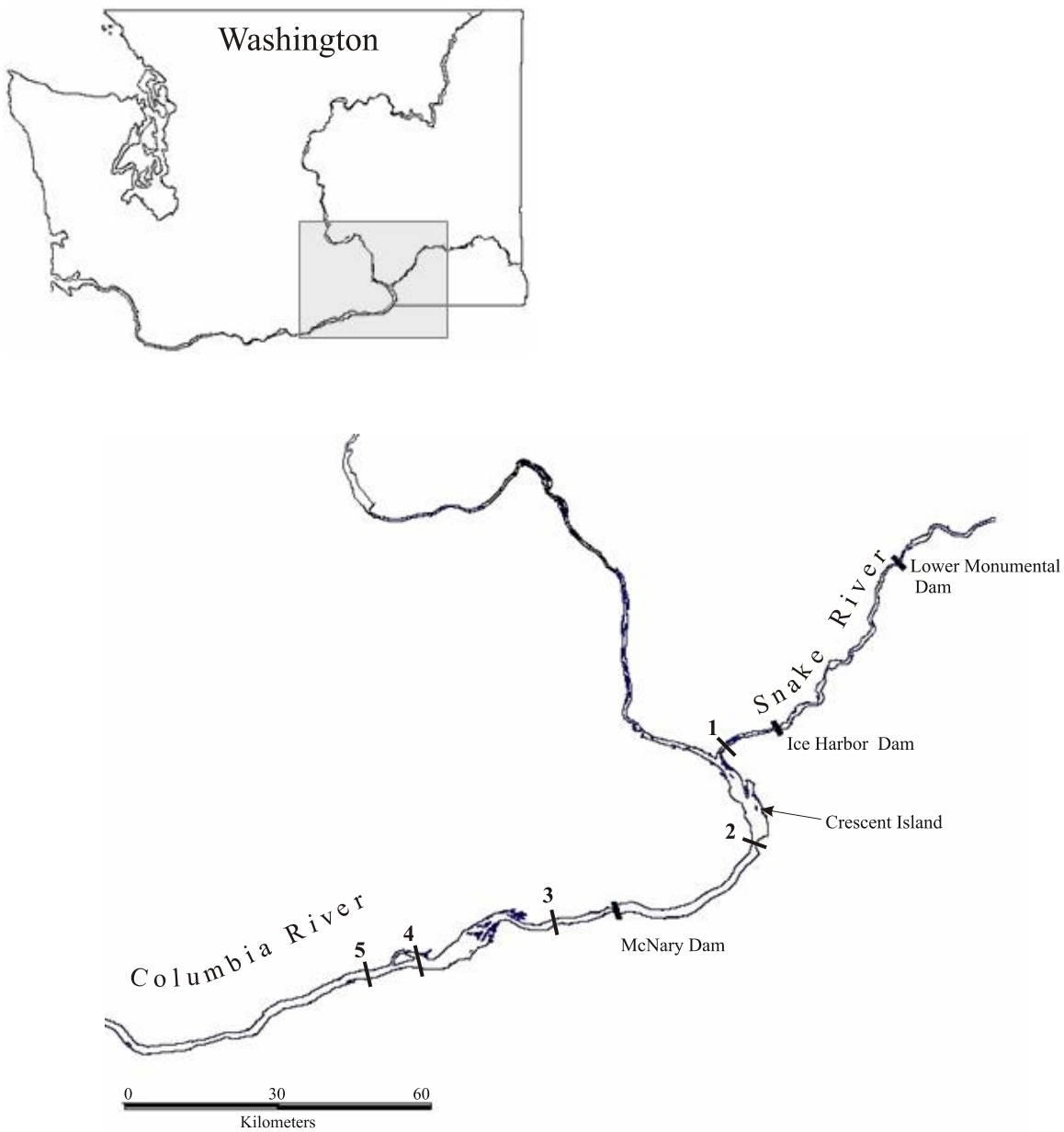


Figure 1. 2002 Study area showing location of radiotelemetry transects used for estimating spillway passage and overall project survival at Ice Harbor Dam Note: 1 = Mouth of the Snake River; 2 = Port Kelley; 3 = Irrigon, OR; 4 = Crow Butte East; and 5 = Crow Butte West. The forebay, tailrace, and all routes of passage at McNary Dam were also monitored.

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.

Reference (tailrace release) and treatment (spillway release) groups for a study of survival through Ice Harbor Dam were also utilized for this evaluation. After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to release areas in the spillway and tailrace of Ice Harbor Dam. Treatment groups for the Ice Harbor study were transferred water-to-water from holding tanks to a release tank and released just upstream of the spill bay via hose. Tailrace 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.

Releases occurred between 1000 and 0100 PDT. A total of 1,607 radio-tagged fish were released into the spillway and tailrace of Ice Harbor Dam during daytime and nighttime project operations.

## Survival Estimates

Estimates of survival to McNary Dam were made for groups of tagged fish based on detection histories using the single-release (SR) model (Cormack 1964; Jolly 1965; Seber 1965). Survival estimates for the model use progressive downstream recapture records (in this case, 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 formed "release groups" according to day of detection at McNary Dam and used data from subsequent detections of these fish at Irrigon and for survival estimates through McNary Dam. Previous studies have shown that dead, radio-tagged fish released to 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 and below were alive.

For estimates of dam survival through McNary Dam, we created "release groups" based on day of detection at the telemetry transect on the upstream edge of the Boat Restricted Zone. Detections through all dam passage routes were used for survival estimates. Likewise, for bypass outfall survival estimates, we created "release groups" based on day of detection within the bypass system. Subsequent downstream detections

from Irrigon and Crow Butte were used for all survival evaluations (Figure 1). Since radio-tagged fish were also PIT-tagged, we also used detections from the juvenile fish facilities at McNary, John Day, and Bonneville Dams and from the pair-trawl detector in the Columbia River estuary 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 Timing, Diel Behavior, and Passage Distribution

### Passage Routes and Distribution

To determine route of passage, we monitored radiotelemetry detections at the spillway, turbine units, and juvenile bypass system. The spillway was monitored using four underwater dipole antennas in each spill bay, with two antennas installed along each of the two pier noses at depths of 20 and 40 ft. Pre-season range testing showed that this configuration provided detection coverage of the entire spill bay.

We used armored coaxial cable to detect fish passage through the turbine units and bypass system. The cable was stripped at the ends and attached on both ends of the downstream side of the fish guidance screen (extended-length bar screens) support frame located within each slot of the turbine intake. Turbine passed fish were those detected on these underwater antennas and subsequently in the immediate tailrace, but not within the juvenile bypass system at McNary Dam. We also placed an underwater antenna into the fish separator located upstream of the smolt monitoring system raceways.

Passage through the spillway was assigned by a last known detection on the underwater dipole antennas and subsequent detection in the immediate tailrace of McNary Dam. Tailrace detections were required to validate spillway passage since fish were frequently detected on spillway antennas while milling in the forebay. Detection histories were then completed for the treatment fish from telemetry records at the survival transects located downstream at Irrigon and Crow Butte, and from PIT-tag detections at John Day and Bonneville Dams and from the PIT trawl near Jones Beach.

### Tailrace Egress

Tailrace egress was measured from the last known detection at 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. Differences in egress time between specific cohorts were evaluated using permutation methods (Efron and Tibshirani 1993). We tested the null hypothesis that median tailrace egress time (forebay residence time) for a given pair of cohorts was equal. 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). Confidence intervals (95%) for the difference in median tailrace egress or forebay residence times were calculated using bootstrap methods (Efron and Tibshirani 1993).

We generated 1,000 bootstrap medians for each group and the difference between the medians, then estimated 95% confidence intervals as the 2.5 and 97.5 percentiles of the ordered distribution of 1,000 differences. When meaningful bias was detected, an adjustment was made to correct for it, and bias-corrected intervals were used as detailed in Efron and Tibshirani (1993).

## Fish Passage Metrics

Spill efficiency, spill effectiveness, fish passage efficiency, and fish guidance efficiency as used in this analysis are defined as follows:

| | |
|---|---|
| *Spill Efficiency*: | Number of fish passing the dam via the spillway divided by the total number of fish passing the dam |
| *Spill Effectiveness:* | The proportion of fish passing the dam via the spillway divided by the proportion of water spilled |
| *Fish Passage Efficiency:* | The number of fish passing the dam via non-turbine routes divided by total project passage |
| *Fish Guidance Efficiency:* | The number of fish guided into the bypass system divided by total powerhouse passage |

## 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 physical recovery of tags deposited on the island and by PIT-tag detection. Radio tags and PIT tags were recovered on the tern colony during fall, after nests had been abandoned. PIT-tag detections were collected during an ongoing effort by NMFS to monitor PIT tags on active tern colonies in the region (Ryan et al. 2001). PIT-tag data were provided by Biomark and NMFS (B. Ryan, NMFS, personal communication).

# RESULTS

## Fish Collection, Tagging, and Release

Yearling chinook salmon were collected, radio tagged, and PIT tagged at Lower Monumental Dam over 31 d from 5 May 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 4.9% overall. Overall mean fork length was 145.1 mm (SD = 10.4) for fish released to the spillway and 145.5 mm (SD = 9.4) for fish released to the tailrace of Ice Harbor Dam.

## Survival Estimates

Estimated dam survival was 0.877 (95% CI, 0.849B0.905). There was no statistically significant difference observed between pooled day (0.870) and pooled night (0.890) dam survival point estimates with respect to project operations ($P$ = 0.334; see project operations report in Appendix B). Spillway passage survival was 0.976 (95% CI, 0.952-1.000). The bypass outfall survival estimate was 0.927 (95% CI, 0.889-0.965). Insufficient numbers of fish passed through the turbines to enable us to estimate survival.

## Passage Timing, Diel Behavior, and Passage Distribution

### Travel and Arrival Times

We detected 1,008 radio-tagged Snake River yearling chinook salmon that approached the forebay of McNary Dam. Travel times and migration rates were calculated for each release site relative to the release time for fish from Ice Harbor Dam to the forebay of McNary Dam (Tables 1 and 2). The hour of arrival at McNary Dam was fairly consistent across all hours, ranging from 2.9 to 5.7% of the fish (Figure 2).

Table 1. Travel time (h) for river-run, radio-tagged hatchery yearling chinook salmon from Ice Harbor Dam release sites to first detection at McNary Dam, 2002.

| Release Site | Harmonic Mean | Median | STD | Min | Max |
|---|---|---|---|---|---|
| Spill Day | 40.6 | 42.5 | 16.0 | 16.3 | 120.1 |
| Spill Night | 43.2 | 45.3 | 14.1 | 20.1 | 89.8 |
| Tailrace Day | 37.8 | 38.8 | 16.1 | 23.1 | 134.8 |
| Tailrace Night | 37.6 | 40.1 | 15.4 | 12.5 | 130.1 |
| Overall | 39.4 | 41.3 | 15.6 | 12.5 | 134.8 |

Table 2. Migration rate (km/h) for river-run, radio-tagged hatchery yearling chinook salmon from Ice Harbor Dam release sites to first detection at McNary Dam, 2002.

| Release site | Harmonic Mean | Median | STD | Min | Max |
|---|---|---|---|---|---|
| Spill Day | 1.5 | 1.6 | 0.5 | 0.6 | 4.1 |
| Spill Night | 1.4 | 1.5 | 0.5 | 0.7 | 3.3 |
| Tailrace Day | 1.6 | 1.7 | 0.5 | 0.5 | 2.9 |
| Tailrace Night | 1.6 | 1.7 | 0.6 | 0.5 | 5.4 |
| Overall | 1.5 | 1.6 | 0.6 | 0.5 | 5.4 |

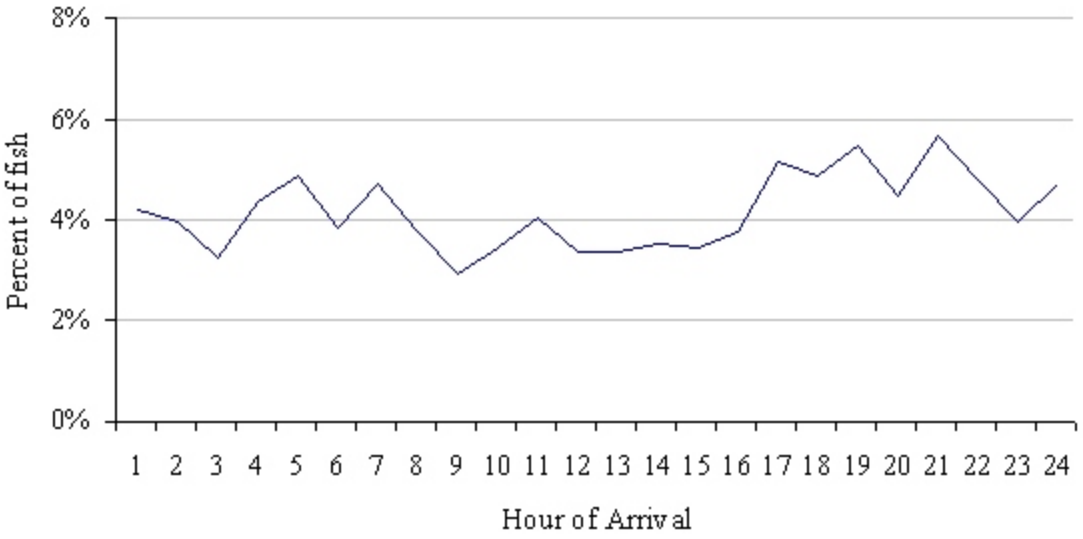


Figure 2. Hour of arrival for river-run, radio-tagged hatchery yearling chinook salmon at McNary Dam, 2002.

**Diel Passage Behavior**

The time of day that radio-tagged fish passed McNary during the spring was affected by project operations (Figure 3). Most passage through the bypass system occurred during the day: daytime passage averaged 5.1% of the total passage per hour vs. 3.3% per hour for nighttime passage (Table 3). Fish passing via the spillway during daytime operations averaged 1.6% per hour. During nighttime operations, fish passing the spillway increased to an average of 6.8% per hour.

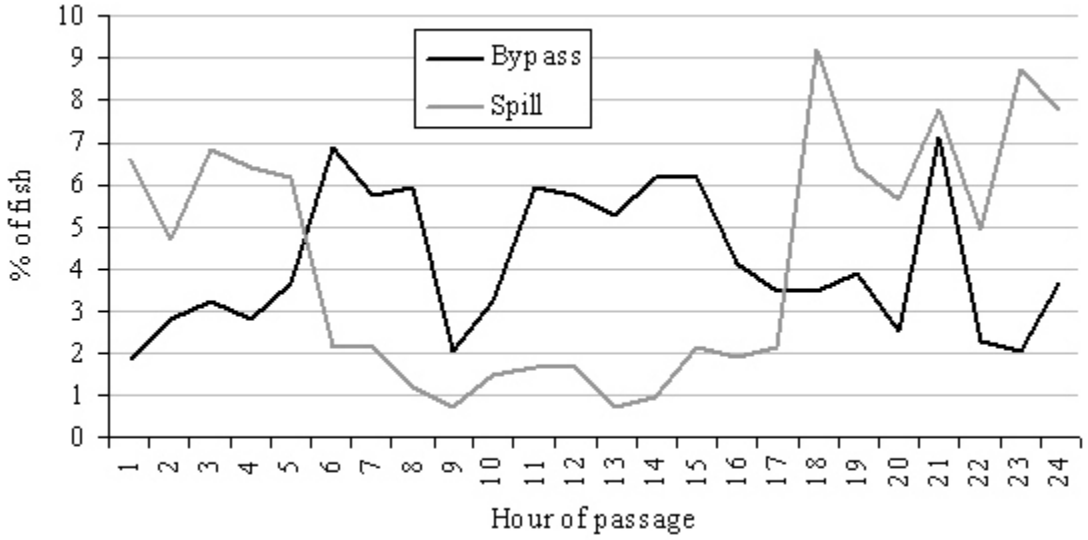


Figure 3. Percent of fish passage by hour through the bypass system and spillway at McNary Dam, 2002.

Table 3. Number and percent of fish passing through the bypass system, spillway, and turbines each hour during daytime (0600-1800) and nighttime (1800-0600; shaded rows) operations tests at McNary Dam, 2002.

| | All passage routes | | Bypass | | Spill | | Turbine | |
|---|---|---|---|---|---|---|---|---|
| Hour | Number | % | Number | % | Number | % | Number | % |
| 0100 | 39 | 4.4 | 8 | 1.8 | 28 | 6.6 | 3 | 8.8 |
| 0200 | 32 | 3.6 | 12 | 2.8 | 20 | 4.7 | 0 | 0.0 |
| 0300 | 44 | 4.9 | 14 | 3.2 | 29 | 6.9 | 1 | 2.9 |
| 0400 | 40 | 4.5 | 12 | 2.8 | 27 | 6.4 | 1 | 2.9 |
| 0500 | 44 | 4.9 | 16 | 3.7 | 26 | 6.1 | 2 | 5.9 |
| 0600 | 40 | 4.5 | 30 | 6.9 | 9 | 2.1 | 1 | 2.9 |
| 0700 | 35 | 3.9 | 25 | 5.7 | 9 | 2.1 | 1 | 2.9 |
| 0800 | 34 | 3.8 | 26 | 6.0 | 5 | 1.2 | 3 | 8.8 |
| 0900 | 12 | 1.3 | 9 | 2.1 | 3 | 0.7 | 0 | 0.0 |
| 1000 | 21 | 2.4 | 14 | 3.2 | 6 | 1.4 | 1 | 2.9 |
| 1100 | 35 | 3.9 | 26 | 6.0 | 7 | 1.7 | 2 | 5.9 |
| 1200 | 35 | 3.9 | 25 | 5.7 | 7 | 1.7 | 3 | 8.8 |
| 1300 | 26 | 2.9 | 23 | 5.3 | 3 | 0.7 | 0 | 0.0 |
| 1400 | 32 | 3.6 | 27 | 6.2 | 4 | 0.9 | 1 | 2.9 |
| 1500 | 38 | 4.3 | 27 | 6.2 | 9 | 2.1 | 2 | 5.9 |
| 1600 | 27 | 3.0 | 18 | 4.1 | 8 | 1.9 | 1 | 2.9 |
| 1700 | 25 | 2.8 | 15 | 3.4 | 9 | 2.1 | 1 | 2.9 |
| 1800 | 55 | 6.2 | 15 | 3.4 | 39 | 9.2 | 1 | 2.9 |
| 1900 | 46 | 5.2 | 17 | 3.9 | 27 | 6.4 | 2 | 5.9 |
| 2000 | 35 | 3.9 | 11 | 2.5 | 24 | 5.7 | 0 | 0.0 |
| 2100 | 68 | 7.6 | 31 | 7.1 | 33 | 7.8 | 4 | 11.8 |
| 2200 | 33 | 3.7 | 10 | 2.3 | 21 | 5.0 | 2 | 5.9 |
| 2300 | 47 | 5.3 | 9 | 2.1 | 37 | 8.7 | 1 | 2.9 |
| 2400 | 50 | 5.6 | 16 | 3.7 | 33 | 7.8 | 1 | 2.9 |
| Mean | 37 | 4.2 | 18 | 4.2 | 18 | 4.2 | 1 | 4.2 |

**Passage Route and Horizontal Distribution**

Overall passage distribution for radio-tagged Snake River hatchery yearling chinook salmon through spillway, bypass, and turbine routes was 45, 46, and 4%, respectively (Figure 4). Approximately 5% of the fish passed the project by an unknown route. Horizontal powerhouse distribution generally favored the central turbine units at McNary Dam with the majority of the fish being guided away from the turbines (Figure 5). Horizontal spillway distribution generally favored the middle to southern spill bays (Figure 6).

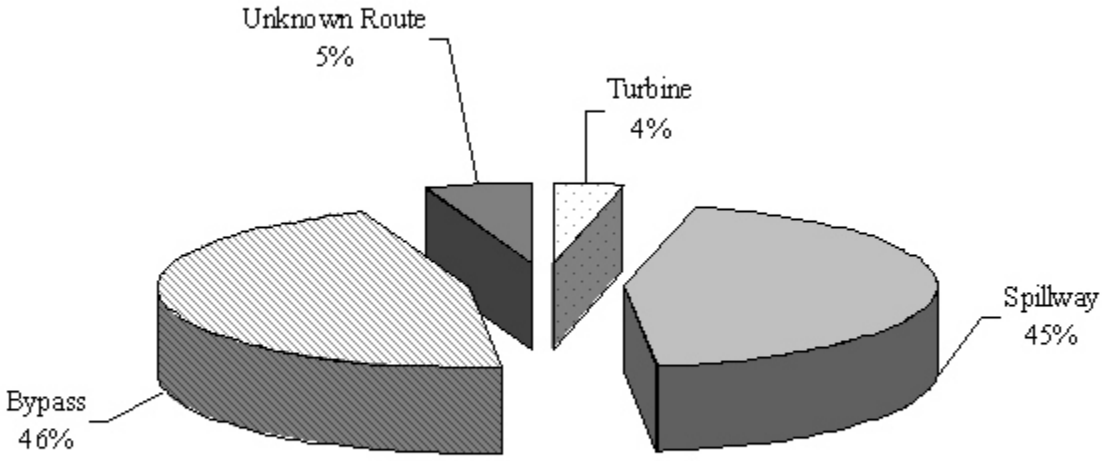


Figure 4. General passage route distribution for river-run radio-tagged hatchery yearling chinook salmon passing McNary Dam, 2002 (n = 947).

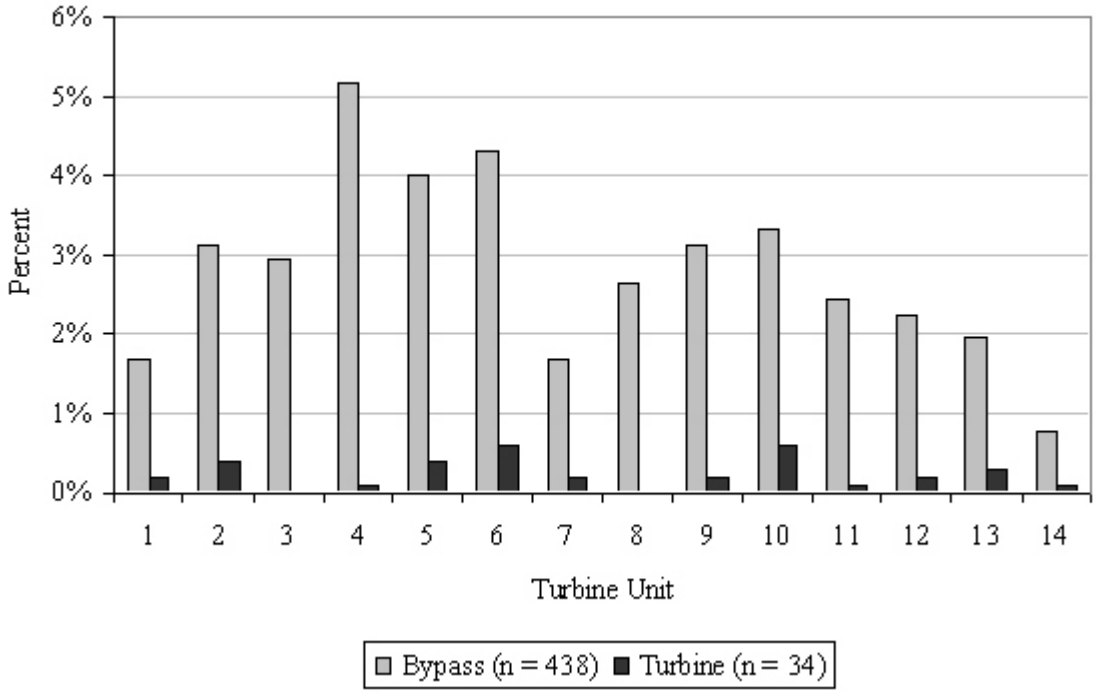


Figure 5. Proportional horizontal distribution of river-run, radio-tagged hatchery yearling chinook salmon passing the powerhouse at McNary Dam, 2002.

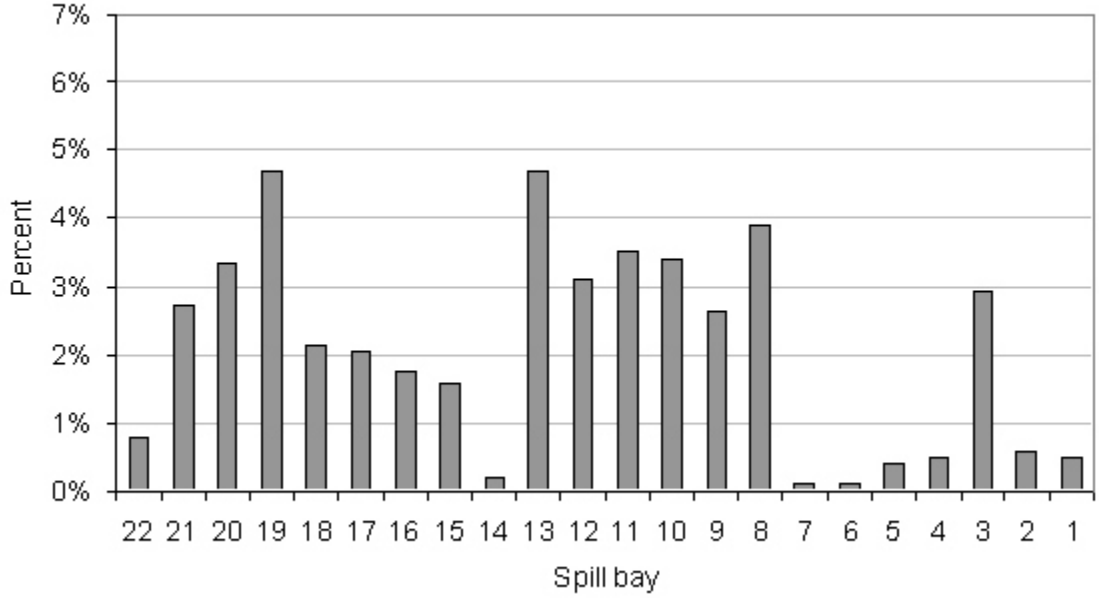


Figure 6. Proportional horizontal distribution of river-run, radio-tagged hatchery yearling chinook salmon passing the spillway at McNary Dam, 2002 (n = 423).

**Tailrace Egress**

Overall median tailrace egress time at McNary Dam was 6.8 min. Further analysis identified a statistically significant difference between median egress times for spilled fish (5.5 min) and bypassed fish (10.2 min). The two-tailed *P* value was less than 0.001. There were also differences revealed in diel comparisons as a result of changing project operations (Figure 7). Differences in egress time between fish bypassed during the day vs. at night were also determined to be statistically significant ($P < 0.001$).

Similar comparisons were done for spill passed fish with no differences observed ($P < 0.358$). We also investigated the diel tailrace egress times associated with spillway passage, grouping spill bays together and referenced them with passage distribution (Figures 8 and 9), and observed slightly longer tailrace egress times for fish passing through the end bays. These differences were not statistically significant.

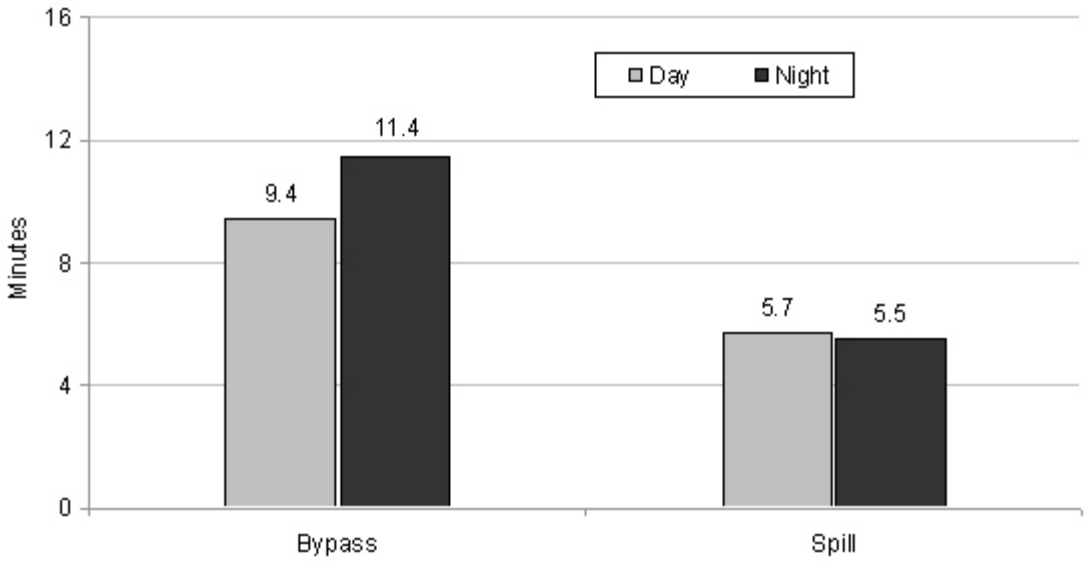


Figure 7. Diel tailrace egress for bypassed and spilled river-run, radio-tagged, hatchery yearling chinook salmon at McNary Dam, 2002.

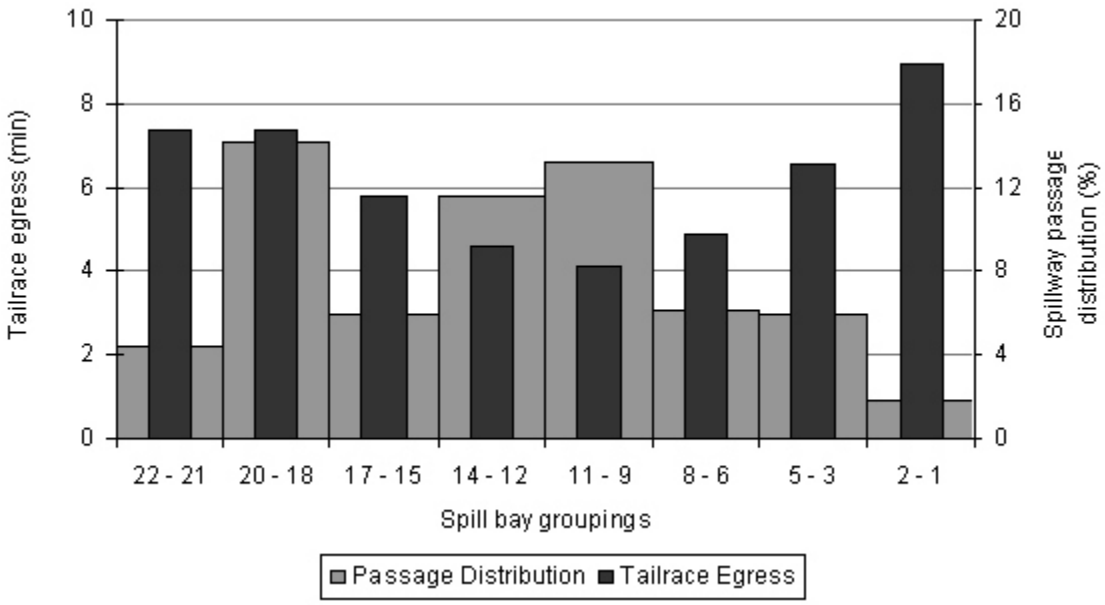


Figure 8. Nighttime spillway passage distribution and median tailrace egress for radio-tagged, hatchery yearling chinook salmon passing McNary Dam, 2002.

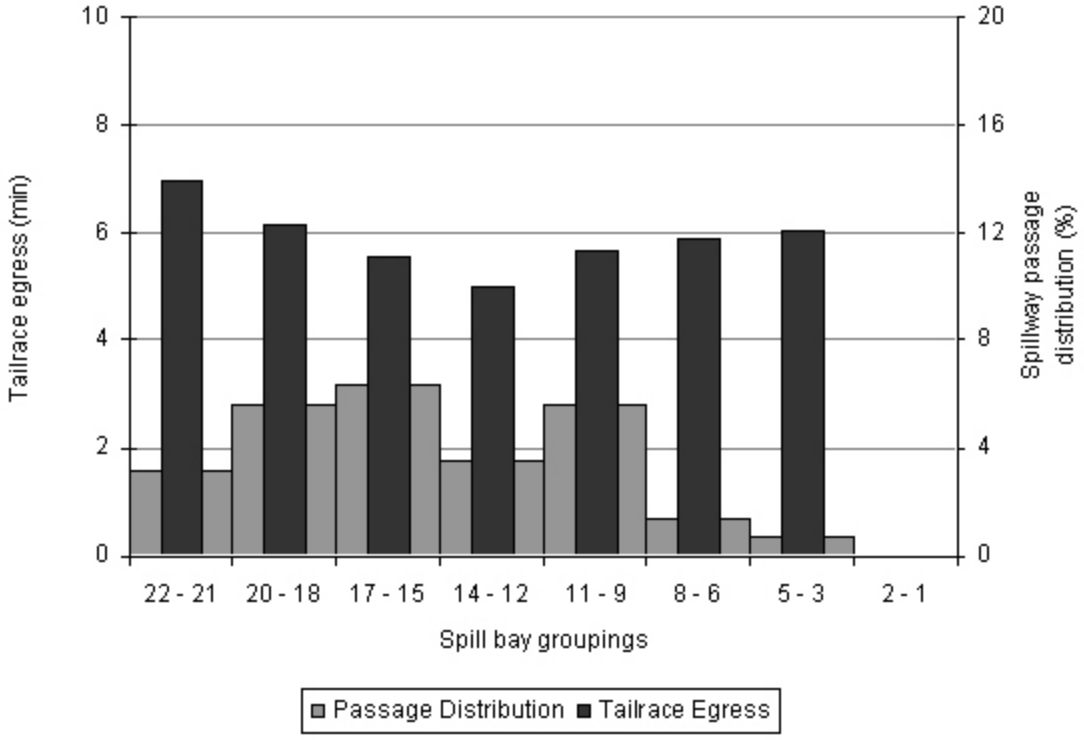


Figure 9. Daytime spillway passage distribution and median tailrace egress times for radio-tagged, hatchery yearling chinook salmon passing McNary Dam, 2002.

## Fish Passage Metrics

Fish passage metrics at McNary Dam are reported in Table 4. Fish passage efficiency (FPE) at McNary Dam was 96%. Overall FGE was 93% (95% CI 90-96%) with a minimum estimate of 85% by factoring in the fish with unknown passage routes as possible turbine passed fish. Spill efficiency was 47%. Mean spill effectiveness for Snake River migrants was 1.12:1.

Table 4. Fish passage metrics at McNary Dam, 2002.

| | Passage route | | | | Spill | | Efficiency | |
|---|---|---|---|---|---|---|---|---|
| Spill (%) | Spill | Bypass | Turbine | Total | Efficiency | Effectiveness | Fish guidance | Fish passage |
| 0.0-0.09 | 10 | 144 | 9 | 163 | 0.06 | 1.23 | 0.94 | 0.94 |
| 0.1-0.19 | 8 | 28 | 2 | 38 | 0.21 | 1.4 | 0.93 | 0.95 |
| 0.2-0.29 | 5 | 22 | 1 | 28 | 0.18 | 0.71 | 0.96 | 0.96 |
| 0.3-0.39 | 25 | 28 | 3 | 56 | 0.45 | 1.28 | 0.90 | 0.95 |
| 0.4-0.49 | 155 | 89 | 5 | 249 | 0.62 | 1.38 | 0.95 | 0.98 |
| 0.5-0.59 | 138 | 91 | 11 | 240 | 0.58 | 1.05 | 0.89 | 0.95 |
| 0.6-0.69 | 72 | 30 | 3 | 105 | 0.69 | 1.05 | 0.91 | 0.97 |
| 0.7-0.79 | 10 | 6 | 0 | 16 | 0.63 | 0.83 | 1 | 1.00 |
| Overall | 423 | 438 | 34 | 895 | 0.47 | 1.12 | 0.93 | 0.96 |
| | | | | SE | 0.09 | 0.09 | 0.01 | 0.01 |
| | | | | lo CI | 0.27 | 0.91 | 0.90 | 0.95 |
| | | | | hi CI | 0.67 | 1.33 | 0.96 | 0.98 |

## Avian Predation

After the Crescent Island Caspian Tern colony had left the island for the season, we initiated the recovery effort for radio tags deposited on the island. In total we found 99 radio tags and detected 545 PIT-tags within the Crescent Island tern colony. This represented approximately 6.2% of the fish we released into the Snake River. However, the 6.2% was a minimum estimate of predation, since detection rates were not 100% (Ryan et al. 2001), and since it was almost certain that the tags of some consumed animals were dropped elsewhere. The rate of tern predation on radio-tagged hatchery yearling chinook salmon during 2002 was similar to that observed in 2001 for fish released from Ice Harbor Dam (Figure 10).

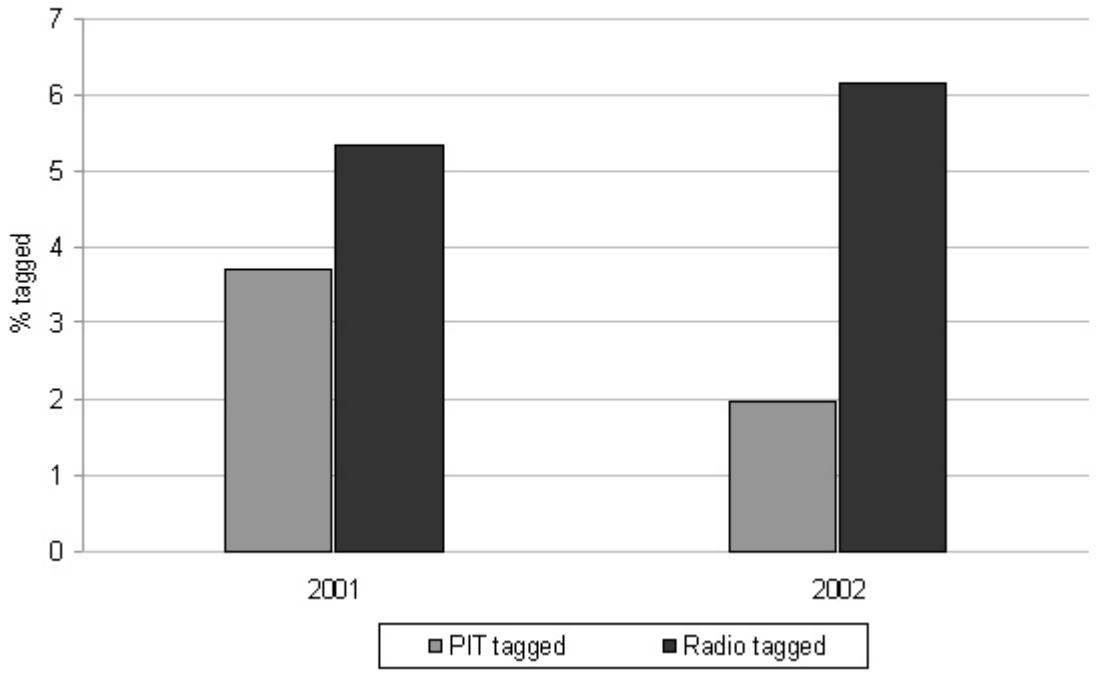


Figure 10. Percentage of Ice Harbor PIT and radio tags recovered from Crescent Island, 2001-2002.

## DISCUSSION AND RECOMMENDATIONS

Detection numbers at McNary Dam and the sites downstream were sufficient to estimate survival with reasonable precision in 2002. This year, McNary Dam was fitted with telemetry detectors to cover each passage route completely, allowing us to estimate survival through specific routes of dam passage.

There are some limitations to the route-specific survival model and detection systems, which may overestimate the number of fish passing a given route at McNary Dam, unless there are fish designated as "unknown passage." We have not been able to use records of last detection from air antennas in the forebay near the dam because of milling prior to passage combined with the depth of entry into a passage route. The forebay powerhouse aerial array would overestimate powerhouse passage and the two arrays would produce different estimates of passage distribution. We have only used the aerial arrays as an approach detection system and not for passage determination because of this issue.

Tailrace air antennas have a similar problem. Fish that pass via the turbines typically exit the draft tube and are entrained in the stilling basin prior to passing out of the tailrace. In contrast, fish that pass via the spillway are rarely detected in front of the powerhouse. Therefore, detections from the stilling basin aerial array would overestimate the numbers of fish passing spillways.

Close observation of the detection data reveals that a few of these fish passed downstream via the navigation lock and some via the adult fish ladder. To obtain more accurate information on passage distribution at each project, we designate some fish with "unknown passage route." However, the problem of unknown passage could be alleviated by attempting to detect fish within the draft tube, where detections of fish that may have been missed by antennas at the screens could be obtained.

In 1996, Swan et al. (1997) found that draft tube frames with underwater antennas could produce extremely high detection efficiencies. Although draft tube frames are fairly expensive, and it is time-consuming to construct and monitor every draft tube at a given project, the redundancy in telemetry detections would increase the precision of passage and survival estimates. We plan to investigate other alternatives to obtain detections through this route of passage.

Project-wide fish passage metrics were obtained for the first time at McNary Dam this year. These data will serve as a baseline for the McNary modernization project which is ongoing. Previous work concluded that extended-length screens increased guidance to 80% for yearling chinook salmon (McComas et al. 1993). Estimates this year indicate that FGE at McNary is closer to 90% for yearling chinook salmon. Spill efficiency, spill effectiveness, and fish passage efficiency for yearling chinook salmon were also reported for the first time at McNary Dam.

Tailrace egress was relatively short at McNary Dam. We did observe longer egress times for fish that passed via the bypass system and turbines as opposed to those that passed via spillways. This difference, however, was on the order of minutes and is probably not biologically significant. The presence of an eddy along the Washington shore adult fish ladder contributed to slightly longer egress times for fish passing through spill bays 1, 2, and 3. Also, an eddy seems to exist at the junction of the powerhouse and spillway, which may have generated slightly longer tailrace egress times for fish exiting spill bays 20, 21, and 22.

About 580 breeding pairs attempted to nest at the Crescent Island tern colony in 2002, about 12% fewer pairs than in 2001. An estimated 375 young were fledged from that colony in 2001, or 0.65 young raised per breeding pair, representing a lower nesting success than in 2000 (Collis et al. 2002). Zabel et al. (2002) reported that 4.1% of the PIT-tagged spring/summer chinook salmon detected at Lower Monumental Dam during 2001 were subsequently detected on Crescent Island. Based on 2 years of data, radio-tagged spring/summer chinook salmon appear to have been preyed upon at a slightly higher rate than their PIT-tagged cohorts; however, this discrepancy may be an artifact of the smaller sample sizes of radio-tagged fish. The last detection of radio-tagged fish subsequently found on Crescent Island indicated that, at a minimum, terns foraged from Ice Harbor Dam forebay to McNary Dam forebay, a distance of nearly 70 km.

We recommend continuing this study to further examine fish passage and survival at McNary Dam in order to provide sufficient baseline data for the McNary Modernization project. Additional data is required to validate 2002 findings. We also recommend comparing fish passage data for Columbia River migrants with those of Snake River migrants 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 for 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 at a downstream array which is used to estimate survival for the project or passage route.

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:

### Assumption A1

#### Methods

All fish that were seen below McNary had been detected somewhere above the project, either on approach or passage receivers. Thus, to test Assumption A1, we evaluated whether radiotelemetry detection at McNary Dam affected the probability of subsequent downstream PIT- or radio-tag detection.

We evaluated the goodness-of-fit of the SR model to the observed data using the methods of Burnham et al. (1987, 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 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 specific tests presented by Burnham et al. (1987) were applicable to the data: Test 2.C2 and Test 3.SR3 (considering pseudo-release at McNary Dam, radiotelemetry detection at Irrigon or Crow Butte, and PIT-detection at John Day and Bonneville Dams).

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, Burnham et al.'s (1997) 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 ($n_{11}/n_{21}$ should be equal).

**Results**

**Project survival--**None of the individual tests of assumption for Test 2.C2, and only 5 of the 22 individual tests of assumption for Test 3.SR3 was calculable. Because of the high detection rates at Irrigon and Crow Butte, few, if any, fish fell into the "not detected category." Therefore, testing the assumptions with these contingency table tests was not adequate due to insufficient data, particularly for individual temporal groups. The tests on the pooled data were:

| Project survival | | | |
|---|---|---|---|
| Test 2.C2 | | Test 3.SR3 | |
| 72 | 5 | 13 | 59 |
| 431 | 5 | 90 | 341 |

with $\chi^2$ values of 9.79 (P = 0.009) and 0.30 (P = 0.639), respectively. As with the bypass data shown below, the significant result for Test 2.C2 was most likely an indication that a few radio tags had weak or nonexistent signals, and not evidence of model assumption violation.

**Spillway survival--**None of the Test 2.C2 and only one of the Test 3.SR3 individual tests was calculable, for the reasons described above. The tests on the pooled data were:

| Spillway survival | | | |
|---|---|---|---|
| Test 2.C2 | | Test 3.SR3 | |
| 27 | 1 | 6 | 21 |
| 226 | 2 | 45 | 181 |

with $\chi^2$ values of 1.56 (P = 0.295) and 0.08 (P = 0.800), respectively.

**Bypass survival--**None of the Test 2.C2 and only one of the Test 3.SR3 individual tests was calculable, for the reasons described above. The tests on the pooled data were:

| Spillway survival | | | |
|---|---|---|---|
| Test 2.C2 | | Test 3.SR3 | |
| 33 | 4 | 6 | 27 |
| 190 | 2 | 36 | 154 |

with $\chi^2$ values of 11.60 ($P$ = 0.007) and 0.02 ($P$ = 0.568), respectively. The significant result from Test 2.C2 implies far too many of the fish not detected with radiotelemetry at Irrigon were next detected by PIT-detection at John Day or Bonneville Dams. This is probably an indication that a few of the radio tags had weak or nonexistent signals, and not evidence of model assumption violation.

## Assumptions A2-A4

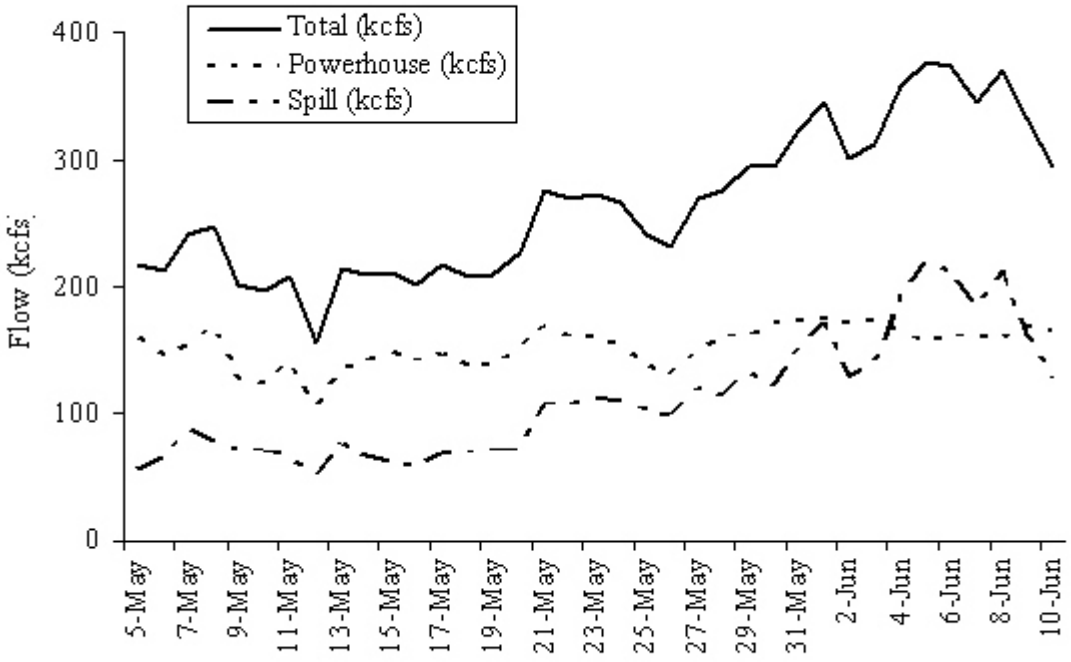
Assumptions A2-A4 were not tested for validation in this study. However, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids have previously been evaluated by Adams et al. (1998a,b) and Hockersmith et al. (2003). The distance between McNary Dam 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.

## Assumption A5

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish and prior to release, to assure that the transmitter was 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 check 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 B: McNary Dam Operations

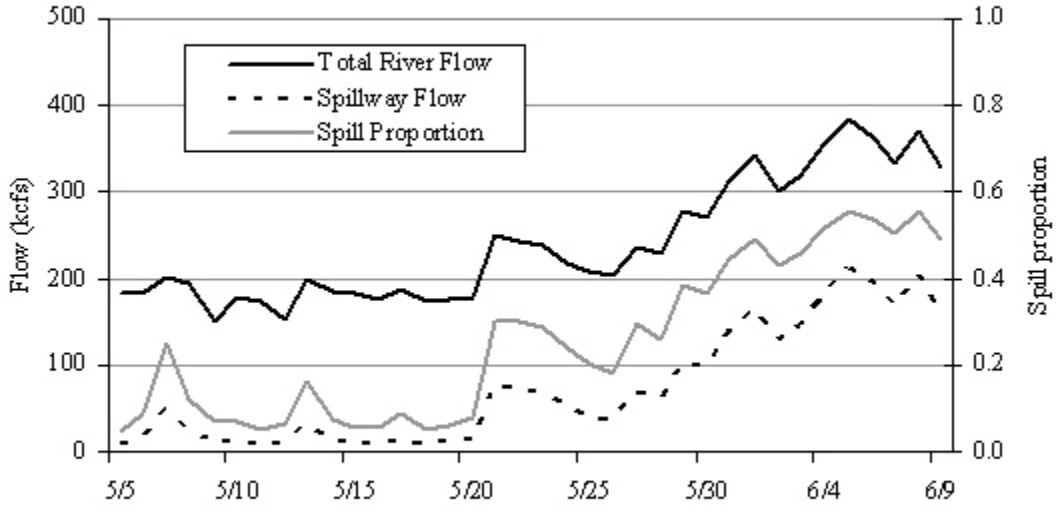
Mean daily total discharge during the study was 265.0 thousand cubic feet per second (kcfs), ranging from 156.3 to 376.9 kcfs (Appendix Table B1). Throughout the first three weeks of the study period, operations at McNary Dam were relatively consistent, with daily spill between 1800 and 0600 in accordance with NMFS Biological Opinion. On 21 May, the project began spilling water for longer periods (but within the total dissolved gase limit of 120%) to accommodate increased river flows (Appendix Figure B1). As a result, daytime operations tended to fluctuate daily with increased flows (Appendix Figure B2). Nighttime operations remained relatively consistent as the project spilled to the 120% dissolved gas limit (Appendix Figure B3).



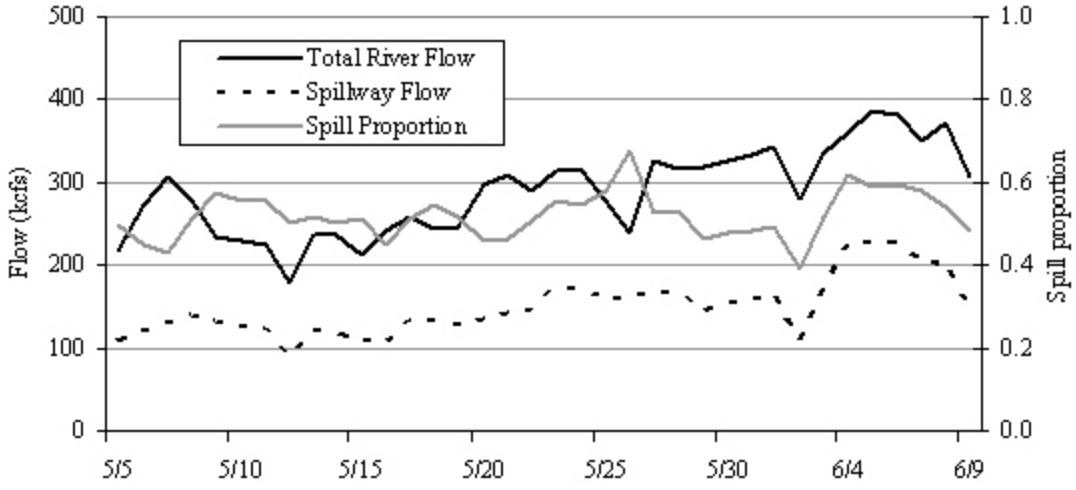

Appendix Figure B1. Total, powerhouse, and spillway flow volumes (kcfs) at McNary Dam, 5 May to 10 June 2002.

Appendix Table B1. Mean daily project operations and river conditions at McNary Dam, 2002.

| Date | Total (kcfs) | Powerhouse (kcfs) | Spill (kcfs) | Spill (%) | Temp (°C) | Dissolved gas (%) |
|---|---|---|---|---|---|---|
| 5-May | 217.5 | 160.6 | 56.9 | 0.261 | 10.1 | 113.3 |
| 6-May | 212.4 | 147.5 | 65.0 | 0.306 | 10.1 | 113.2 |
| 7-May | 241.4 | 153.5 | 88.0 | 0.364 | 10.0 | 114.4 |
| 8-May | 247.3 | 168.9 | 78.4 | 0.317 | 10.1 | 113.8 |
| 9-May | 201.8 | 128.6 | 73.2 | 0.363 | 10.1 | 115.8 |
| 10-May | 196.3 | 124.4 | 72.0 | 0.367 | 10.3 | 116.7 |
| 11-May | 208.0 | 140.8 | 67.2 | 0.323 | 10.8 | 117.1 |
| 12-May | 156.3 | 105.5 | 50.8 | 0.325 | 11.1 | 115.4 |
| 13-May | 213.6 | 135.9 | 77.7 | 0.364 | 11.2 | 116.5 |
| 14-May | 210.0 | 142.6 | 67.4 | 0.321 | 11.4 | 116.0 |
| 15-May | 211.6 | 149.5 | 62.1 | 0.293 | 11.5 | 115.5 |
| 16-May | 202.3 | 142.3 | 60.0 | 0.297 | 11.5 | 114.8 |
| 17-May | 216.8 | 148.3 | 68.5 | 0.316 | 11.9 | 115.7 |
| 18-May | 208.4 | 138.6 | 69.8 | 0.335 | 12.1 | 115.6 |
| 19-May | 209.0 | 138.1 | 70.9 | 0.339 | 12.2 | 116.2 |
| 20-May | 226.4 | 153.3 | 73.2 | 0.323 | 12.5 | 116.2 |
| 21-May | 276.5 | 168.5 | 108.0 | 0.391 | 12.4 | 117.2 |
| 22-May | 269.1 | 161.8 | 107.3 | 0.399 | 12.2 | 116.4 |
| 23-May | 273.2 | 159.8 | 113.4 | 0.415 | 12.4 | 116.6 |
| 24-May | 266.0 | 154.9 | 111.2 | 0.418 | 12.7 | 117.1 |
| 25-May | 241.8 | 138.7 | 103.1 | 0.426 | 12.9 | 117.6 |
| 26-May | 230.7 | 131.4 | 99.3 | 0.431 | 13.0 | 117.1 |
| 27-May | 268.4 | 148.7 | 119.7 | 0.446 | 13.2 | 117.2 |
| 28-May | 276.3 | 161.4 | 114.9 | 0.416 | 13.4 | 118.9 |
| 29-May | 295.1 | 161.8 | 133.3 | 0.452 | 13.6 | 118.5 |
| 30-May | 294.8 | 172.0 | 122.8 | 0.416 | 13.6 | 117.6 |
| 31-May | 322.2 | 172.8 | 149.4 | 0.464 | 13.4 | 119.6 |
| 1-Jun | 345.2 | 174.2 | 171.0 | 0.495 | 13.2 | 121.1 |
| 2-Jun | 300.4 | 171.0 | 129.4 | 0.431 | 13.3 | 118.5 |
| 3-Jun | 313.1 | 173.5 | 139.6 | 0.446 | 13.7 | 119.3 |
| 4-Jun | 358.3 | 165.2 | 193.2 | 0.539 | 14.2 | 122.3 |
| 5-Jun | 376.9 | 155.4 | 221.5 | 0.588 | 14.3 | 123.7 |
| 6-Jun | 374.0 | 162.4 | 211.6 | 0.566 | 14.2 | 123.3 |
| 7-Jun | 344.8 | 160.7 | 184.1 | 0.534 | 13.9 | 121.6 |
| 8-Jun | 370.8 | 158.0 | 212.8 | 0.574 | 13.4 | 123.1 |
| 9-Jun | 332.6 | 169.1 | 163.5 | 0.492 | 13.1 | 120.5 |
| 10-Jun | 294.7 | 166.2 | 128.4 | 0.436 | 13.1 | 118.1 |
| *Average* | *265.0* | *153.1* | *111.8* | *0.405* | *12.3* | *117.6* |




Appendix Figure B2. Average daytime operations at McNary Dam, 2002.




Appendix Figure B3. Average nighttime operations at McNary Dam, 2002.