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Summary of Juvenile Salmonid Passage and Survival at McNary Dam—Acoustic Telemetry Studies, 2006–09

Open-File Report 2011–1179

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of McNary Dam on the Columbia River, near Umatilla, Oregon.
(Photograph taken by Scott Brewer, U.S. Geological Survey, Cook, Washington.)

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

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Conversion Factors, Datums, and Abbreviations and Acronyms

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Volume	
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
	Flow rate	
meter per hour (m/h)	3.281	foot per hour (ft/h)
meter per day (m/d)	3.281	foot per day (ft/d)
kilometer per hour (km/h)	0.6214	mile per hour (mi/h)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32.$$

Datums

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS84).
Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Abbreviations and Acronyms

ATDL	acoustic tag data loggers
ATR	acoustic tag receiver
CJS	Cormack-Jolly-Seber models
CPUD	Chelan County public utility district
FGE	fish guidance efficiency
FPE	fish passage efficiency
GPUD	Grant County public utility district
PIT	passive integrated transponder
PUD	public utility district
rkm	river kilometer
RSSM	route-specific survival model
SI	modern metric system
TSW	temporary spillway weir
USGS	U.S. Geological Survey

Summary of Juvenile Salmonid Passage and Survival at McNary Dam—Acoustic Telemetry Studies, 2006–09

Edited by Noah S. Adams and Scott D. Evans

Abstract

Passage and survival data were collected at McNary Dam between 2006 and 2009. These data have provided critical information for resource managers to implement structural and operational changes designed to improve the survival of juvenile salmonids as they migrate past the dam. Given the importance of these annual studies, the primary objectives of this report were to summarize the findings of these annual studies to ensure that passage and survival metrics are consistently calculated and reported across all years and to consolidate this information in a single document, thereby making it easier to reference. It is worth noting that this report does not contain all the information from all the annual reports. The intent of this report was to summarize the key findings from multiple years of research. The reader is encouraged to reference the annual reports if more detailed information is needed. Chapter 1 summarizes existing behavior, passage, and survival results for fish released 10 rkm upstream of McNary Dam and from the McNary Dam tailrace during 2006–09. Chapter 2 summarizes existing behavior, passage, and survival results for fish released in the mid-Columbia River and detected at McNary Dam during 2006–09.

Results from 2006 indicated that higher spill discharge generally resulted in higher fish passage through spill, and in turn, higher fish survival through the entire dam. Within the spillway, passage effectiveness was highest for the south spill bays, adjacent to the powerhouse. Increased passage in this area, combined with detailed 3-dimensional approach paths, aided in the design and location of the temporary spillway weirs (TSWs) at McNary Dam prior to the 2007 migration of juvenile salmonids.

During the 2007 study, the TSWs were tested under two spill treatments during the spring and summer: a “2006 Modified spill,” and a “2007 test spill.” In the spring, slightly higher discharge through spill bays 14–17 was the primary difference between the spill treatments tested. During the summer, spill treatments were characterized by a high (60 percent) and low (40 percent) percent flow of the total discharge going through the spillway. Flow through the TSWs represented about 7–8 percent of total project discharge in spring and about 10–11 percent of total project discharge in summer. Overall, the TSWs passed 24 percent of yearling Chinook salmon and 27 percent of subyearling Chinook salmon, but passed about 65 percent of juvenile steelhead. In spring, there was little evidence for an effect of spill treatment on either fish passage or survival, however, this was not surprising given there was a relatively small difference between spill treatments. For subyearling Chinook salmon during the summer study, high spill discharge resulted in higher fish passage through the spillway and lower fish passage through the powerhouse. Season wide survival (paired-release) for yearling and subyearling Chinook salmon was 0.98 and 0.92 (SE<0.04) through TSW 20, and 0.96 and 0.97 (SE<0.04) through TSW 22, respectively. Season-wide survival (single-release) for juvenile steelhead was 0.98 (SE=0.024) through TSW 20, and 0.90 (SE=0.02) through TSW 22. The extent to which location and structural design contributed to the differences observed between the two TSWs was uncertain. Nonetheless, the

TSWs performed similarly to surface-oriented fish passage structures at other locations and appear to be a useful fish passage alternative at McNary Dam. The 2008 and 2009 studies confirmed previous results showing high survival for fish passing through the TSWs, especially juvenile steelhead. Although the number of all fish species passing through the TSWs was lower in 2008 and 2009 compared to 2007, fish passage efficiency for juvenile steelhead and subyearling Chinook salmon was higher in years with the TSWs, compared to 2006, before the TSWs were in place.

Chapter 1. Juvenile Salmonid Passage and Survival at McNary Dam, 2006–09

By Amy C. Braatz, Gabriel S. Hansen, Christopher E. Walker, Rachel E. Reagan, and John M. Plumb

Introduction

As juvenile salmon (*Oncorhynchus spp*.) and steelhead (*O. mykiss*) migrate from their natal streams to the ocean, they are subject to both natural and human-caused mortality. Avian and piscivorous predators contribute to total natural mortality, but hydroelectric projects on the Snake and Columbia Rivers also are sources of mortality for migrating juvenile fish. Studies conducted at McNary Dam between 2002 and 2005 provided baseline passage and survival information under typical dam operations (Axel and others, 2004a, 2004b; Perry and others, 2006, 2007a). These studies found that non-turbine passage routes, such as the spillway and juvenile bypass system, exhibited higher survival compared to the turbines. Additional studies at Lower Granite Dam showed that surface passage structures appear to be a safe alternative to passage through the turbines (Plumb and others, 2004; Perry and others, 2007b; Beeman and others, 2008; Puls and others, 2008). As a result of these studies, temporary spillway weirs (TSWs) were installed at McNary Dam and performance tests were conducted in 2007, 2008, and 2009.

This report synthesizes research conducted on fish passage at McNary Dam between 2006 and 2009. As a single document, it should serve as a useful reference for managers during the development of long-term management strategies at McNary Dam.

Environmental and Biological Setting

Project Description

McNary Dam is the fourth dam upstream of the mouth of the Columbia River, located 470 river kilometers (rkm) upstream of the Pacific Ocean and 52 rkm downstream of the confluence of the Columbia and Snake Rivers. The reservoir formed by McNary Dam (Lake Wallula) extends 98 rkm upstream to the Hanford Reach on the Columbia River, and impounds 16 rkm of the Snake River upstream to Ice Harbor Dam. The river downstream of McNary Dam (Lake Umatilla) is impounded by John Day Dam located 123 rkm downstream of McNary Dam. The study area encompassed 482 km, extending from the tailrace of Wells Dam (rkm 830), the upper most release point for tagged fish, to our most downstream detection array located at John Day Dam (rkm 348; fig. 1-1).

McNary Dam is oriented perpendicular to the river channel with a navigation lock, spillway, powerhouse, and earthen dam. The spillway is 399 m long with 22 vertical lift-type spill gates that regulate discharge through the dam. The spillway discharges water at the ogee crest approximately 14 m below the water surface. The powerhouse at McNary Dam is 433 m long with 14 turbine units. Each turbine unit has a generating capacity of 70 megawatts and a hydraulic capacity of 16.6 kcfs (kcfs =

1,000 ft³/s). The turbine intakes are about 19 m deep and are divided into three smaller, fully isolated slots. Each slot has a vertical barrier screen, trash rack (designed to prevent large debris from entering the turbines), and an extended-length submersible barrier screen that guides downstream migrating fish away from the turbine intakes and into the fish collection channel (orifice gallery). Guided fish are then routed through a series of pipes and channels to the juvenile fish bypass facility and held in concrete raceways where they await downstream transportation by barge or truck, or are routed back into the river to continue their migration. No study fish with PIT tags were barged during the four study years.

Two TSW designs were tested during 2007, 2008, and 2009 (fig. 1-2). TSW design 1 was installed in spill bay 22 during 2007, spill bay 19 during 2008, and spill bay 4 during spring of 2009 and spill bay 19 during summer of 2009 (fig. 1-3). TSW design 2 was installed in spill bay 20 during all three study years. Each TSW was comprised of a weir crest, set atop the spill leaf gate within the spill bay. The weir crest extended from the top of the ogee crest to about 2.4 m below the surface, thereby causing water to spill from the surface of the forebay rather than from 14 m below the surface like conventional spill bays. Discharge over the TSWs was a function of forebay elevation, and because TSW design 1 was about 0.2 m deeper than TSW design 2, discharge through TSW design 1 was, on average, slightly greater (about 600 ft^3/s) than discharge through TSW design 2. The difference in the elevation of the TSWs was the result of structural differences (fig. 1-2) to test the efficacy of varying entrance conditions for passing juvenile salmonids.

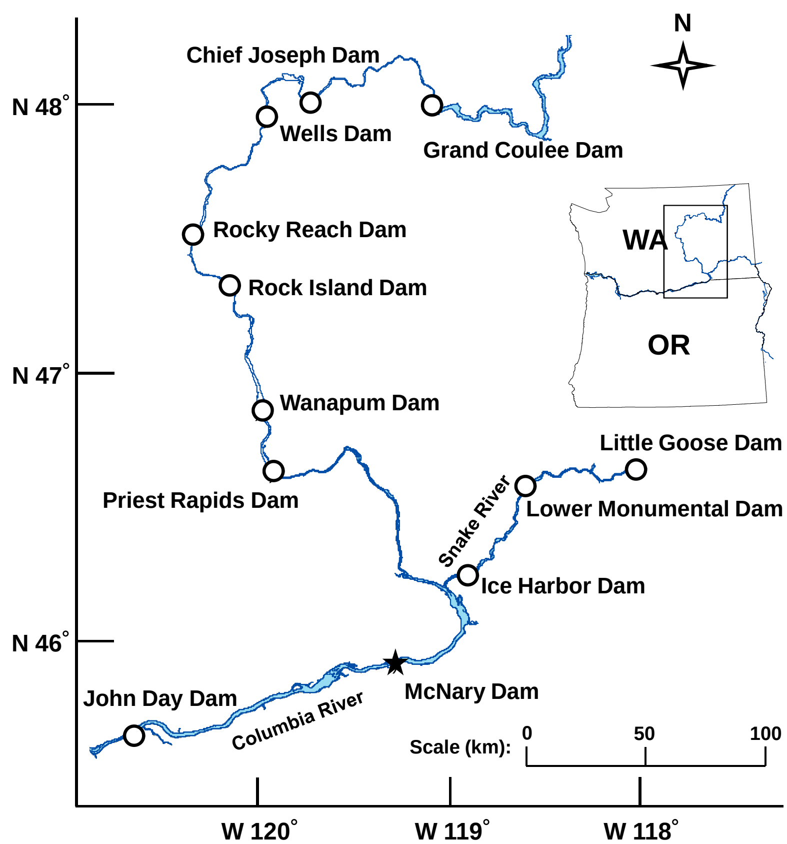

Figure 1-1. Map showing Columbia and Snake Rivers and location of McNary Dam relative to other major hydroelectric projects in the region.

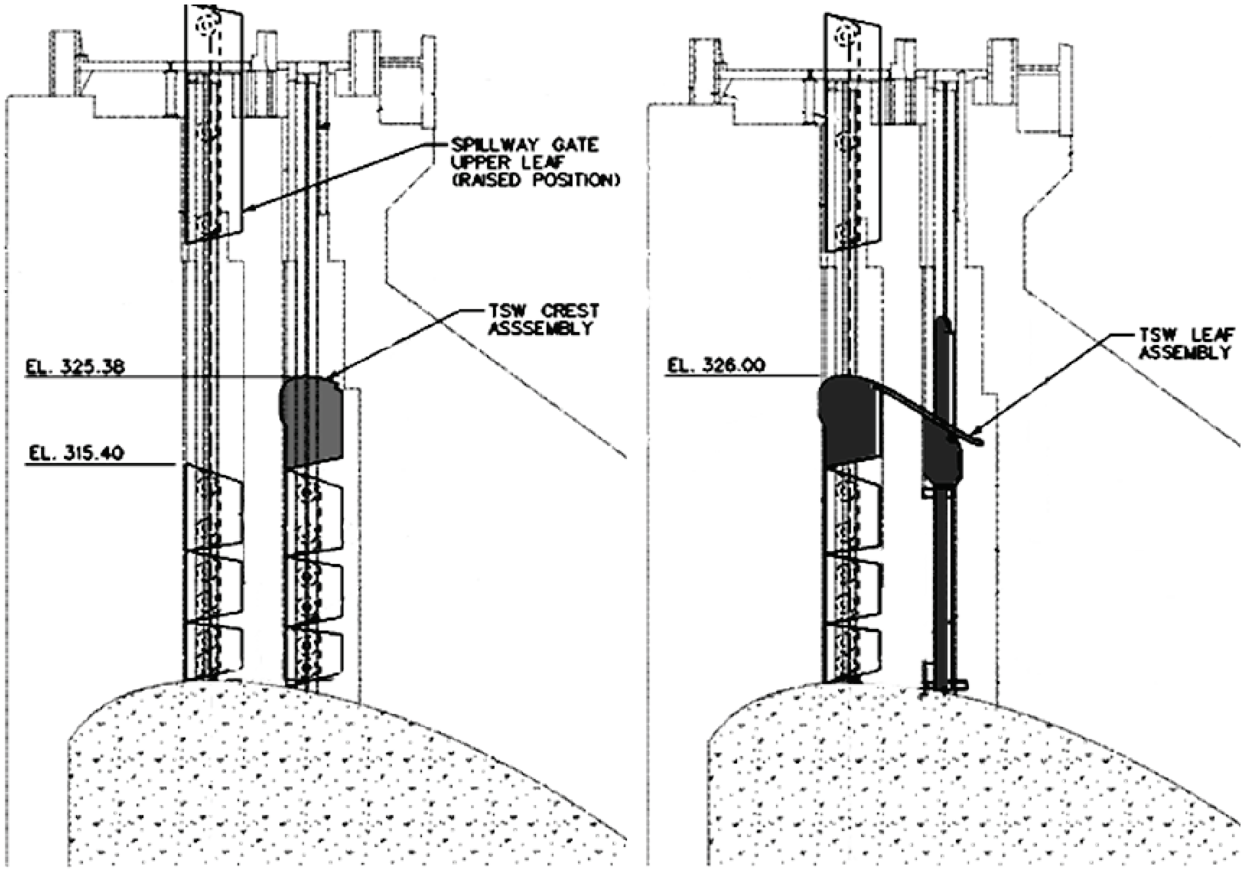

Figure 1-2. Cross-sectional view of the spillway at McNary Dam showing TSW (gray shaded area) design 1 (left side of page) and design 2 (right side of page). Water spilled over the TSW crest from the forebay (left side of page) to the tailrace (right side of page).

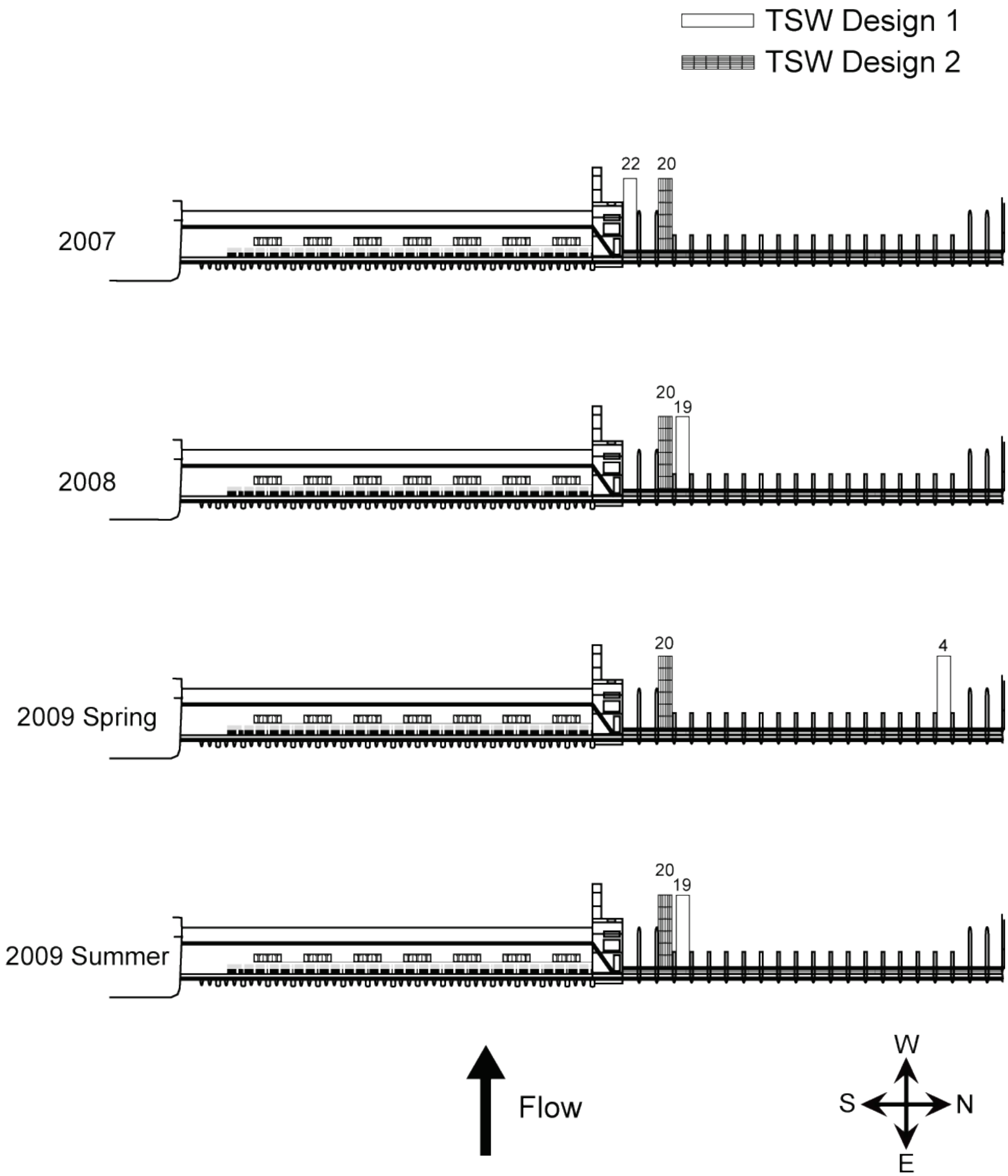

Figure 1-3. Plan view of McNary Dam showing locations of temporary spillway weirs (TSWs) in 2007, 2008, and 2009. There were no TSWs in 2006.

River Conditions

Mean daily discharge at McNary Dam throughout the season was variable, depending upon year (fig. 1-4). The 10-year average (2000–2009) discharge in mid-April was about 210 kcfs, increasing to greater than 250 kcfs by late May, then decreasing through June and July to less than 150 kcfs by August. Our study years followed a similar trend but were more pronounced, depending on the year. Of the years 2000–2009, the median daily project outflow for the spring study dates of 2006, 2009, and 2008 ranked as the highest 3 years with 2007 ranking fifth of the 10 years. During the summer study dates, 2008 and 2006 were second and third highest and 2007 and 2009 ranked fifth and sixth for median daily project outflow.

Mean daily spill at McNary Dam from 2000 to 2009 followed a similar trend to mean daily discharge (fig. 1-5). Mean daily spill in mid-April, at the start of the season, averaged 80 kcfs and peaked in late May or early June at 125 kcfs for the 10-year average. In 2008, the average daily maximum spill was 250 kcfs. Daily spill typically was lowest in July, near the end of the study period, at an average of 50 kcfs.

Water temperature steadily increased during the study period, rising from 9°C in April to a peak of about 21°C in late July or early August (fig. 1-6). Water temperatures were slightly lower (1–2°C) in 2008 than in the other three study years.

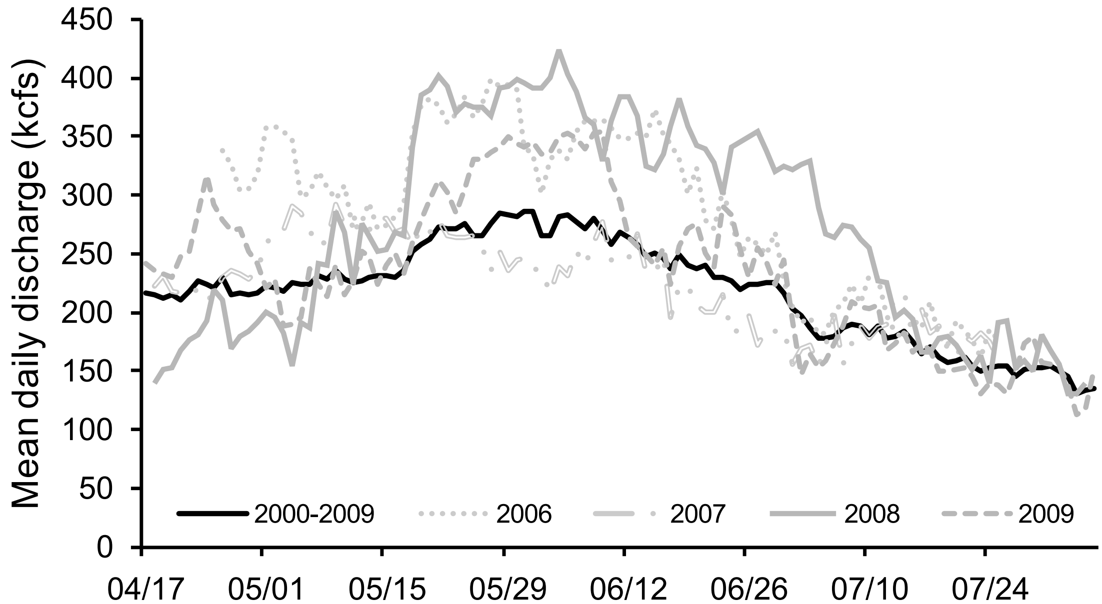

Figure 1-4. Hydrograph of mean daily project outflow during acoustic telemetry study dates at McNary Dam, 2006–09, and the 10-year average, 2000–2009. Data obtained from Columbia River DART website: *http://www.cbr.washington.edu/dart/river.html*.

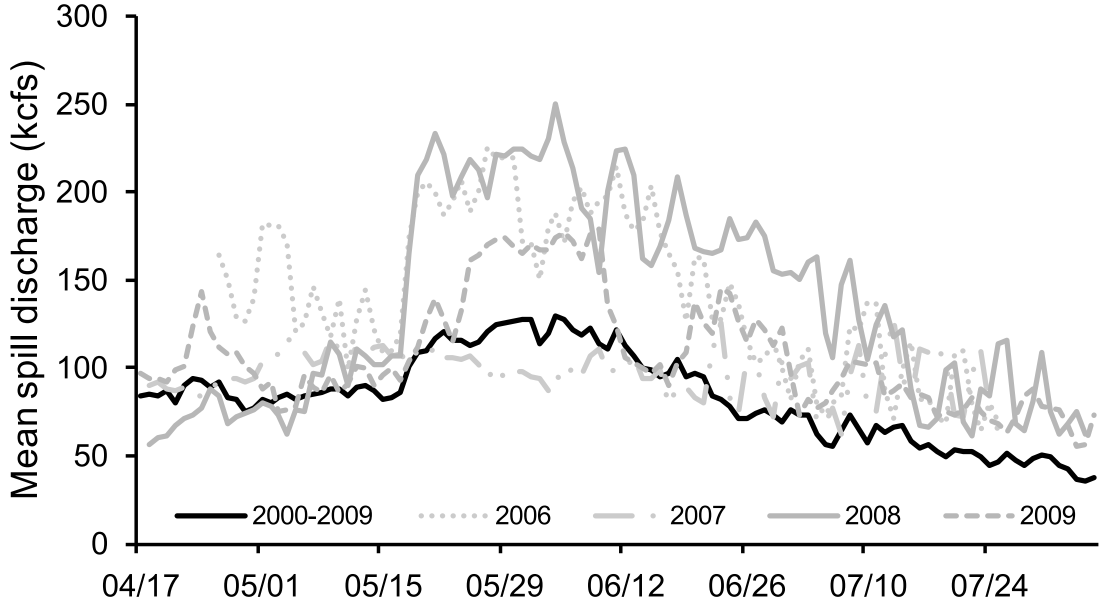

Figure 1-5. Hydrograph of mean daily project spill during acoustic telemetry study dates at McNary Dam, 2006–09, and the 10-year average, 2000–2009. Data obtained from Columbia River DART website: *http://www.cbr.washington.edu/dart/river.html*.

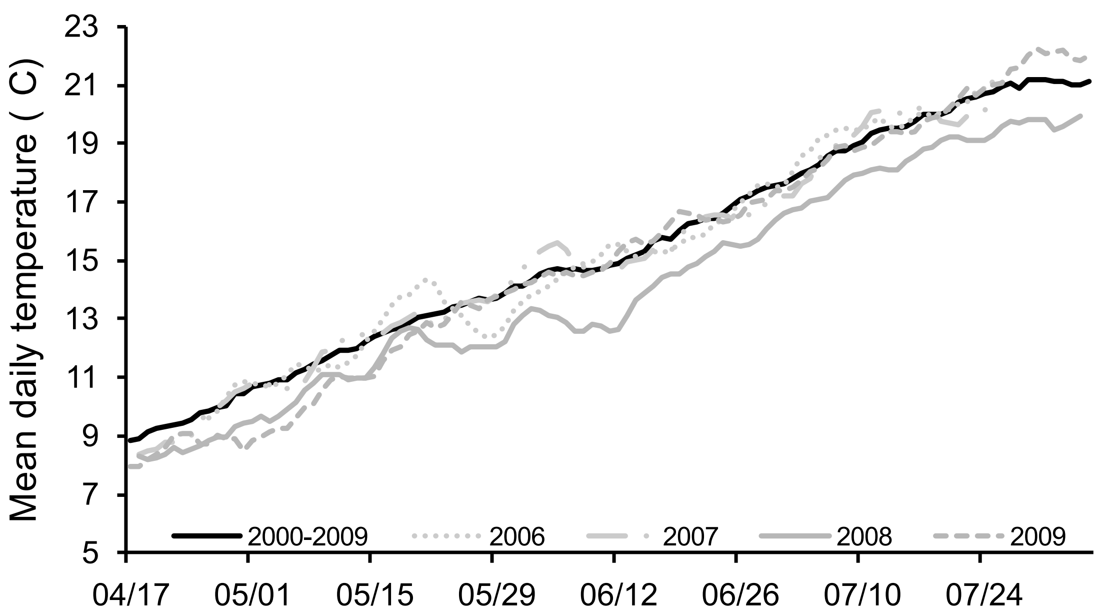

Figure 1-6. Hydrograph of mean daily water temperature of the Columbia River at McNary Dam during acoustic telemetry study dates, 2006–09, and the 10-year average, 2000–2009. Data obtained from Columbia River DART website: *http://www.cbr.washington.edu/dart/river.html*.

Project Operations and Study Treatments

Several treatments and operation schemes were implemented at McNary Dam between 2006 and 2009 (table 1-1 and figs. 1-7 and 1-8). Two treatments (Fish Passage Plan and 2006 Test Spill) were conducted during spring 2006. The Fish Passage Plan treatment consisted of higher discharge at the north end of the spillway. Conversely, the 2006 Test Spill pattern consisted of higher discharge at the southern end of the spillway. During spring 2007, the two treatments were a modification of the 2006 Test Spill (hereafter called Modified 2006 Test Spill) and a 2007 Test Spill pattern. Investigations into dam operations based on this schedule, however, revealed few differences between the spill treatments. Differences in spill bay- and turbine-specific discharge primarily were associated with spill bays 15, 16, and 17 (fig. 1-7). No treatments were planned in spring 2008 or 2009; however, we characterized two treatments in 2008. During the first one-half of the spring season (April 18 through May 17), discharge through the spillway was 40 percent, hereafter called Early Season. During the second one-half of the season (May 17 through June 9), spillway discharge was 50–60 percent, hereafter called Late Season. We were unable to characterize any spill patterns in 2009.

Only two planned treatment types occurred during the summer seasons between 2006 and 2009 (fig. 1-8). For the 2006 and 2007 treatments, two dam operations were evaluated: 24-h spill at 40 percent of total river discharge, and 24-h spill at 60 percent of total river discharge. Sixty percent spill and 40 percent spill also were planned and implemented in 2008 in randomized 4-dimensional blocks; however, the treatments began after July 3. Prior to July 3, high dissolved gas levels and involuntary spill prevented operation at the treatment level. The period of time before July 3 is hereafter called Early Season, which consisted of approximately 50 percent spill of total project discharge. No treatments were planned or characterized in summer 2009. For both spring and summer, diel periods were assigned as day (0600–1759 hours) and night (1800–0559 hours).

Table 1-1. Summary of study dates, seasonal treatment types, and seasonal mean daily project discharge for acoustic telemetry studies at McNary Dam, 2006–09.

[Discharge is measured in thousand ft^3/s. NA is not applicable]

	2006	2007	2008	2009
Spring study dates	**Apr 26–June 07**	**Apr 18–June 06**	**Apr 18–June 09**	**Apr 17–June 10**
Spring treatments[1]	Fish Passage Plan	Mod. 2006 test spill	Early season (40% spill)	NA
	2006 test spill	2007 test spill	Late season (50-60% spill)	NA
Mean project discharge	334.6	251.7	283.6	278.5
TSW Design 1 location	NA	Spill bay 22	Spill bay 19	Spill bay 4
TSW Design 2 location	NA	Spill bay 20	Spill bay 20	Spill bay 20
Summer study dates	**June 19–Jul 25**	**June 20–Jul 26**	**June 18–Aug 04**	**June 19–Aug 05**
Summer treatments[1]	60% spill	60% spill	Early season (~50% spill)	NA
	40% spill	40% spill	60% spill	NA
	NA	NA	40% spill	NA
Mean project discharge	219.2	184.0	241.0	184.9
TSW Design 1 location	NA	Spill bay 22	Spill bay 19	Spill bay 19[2]
TSW Design 2 location	NA	Spill bay 20	Spill bay 20	Spill bay 20

[1]Treatments represent proposed spill patterns or percent total project discharge. Although 2008 had no proposed treatments, treatments were characterized based on distinct flow patterns. 2009 had no proposed treatments and none were characterized.

[2]TSW Design 1 was moved to spill bay 19 for the 2009 summer study, but passage could only be calculated for spill bays 16–19 as a group.

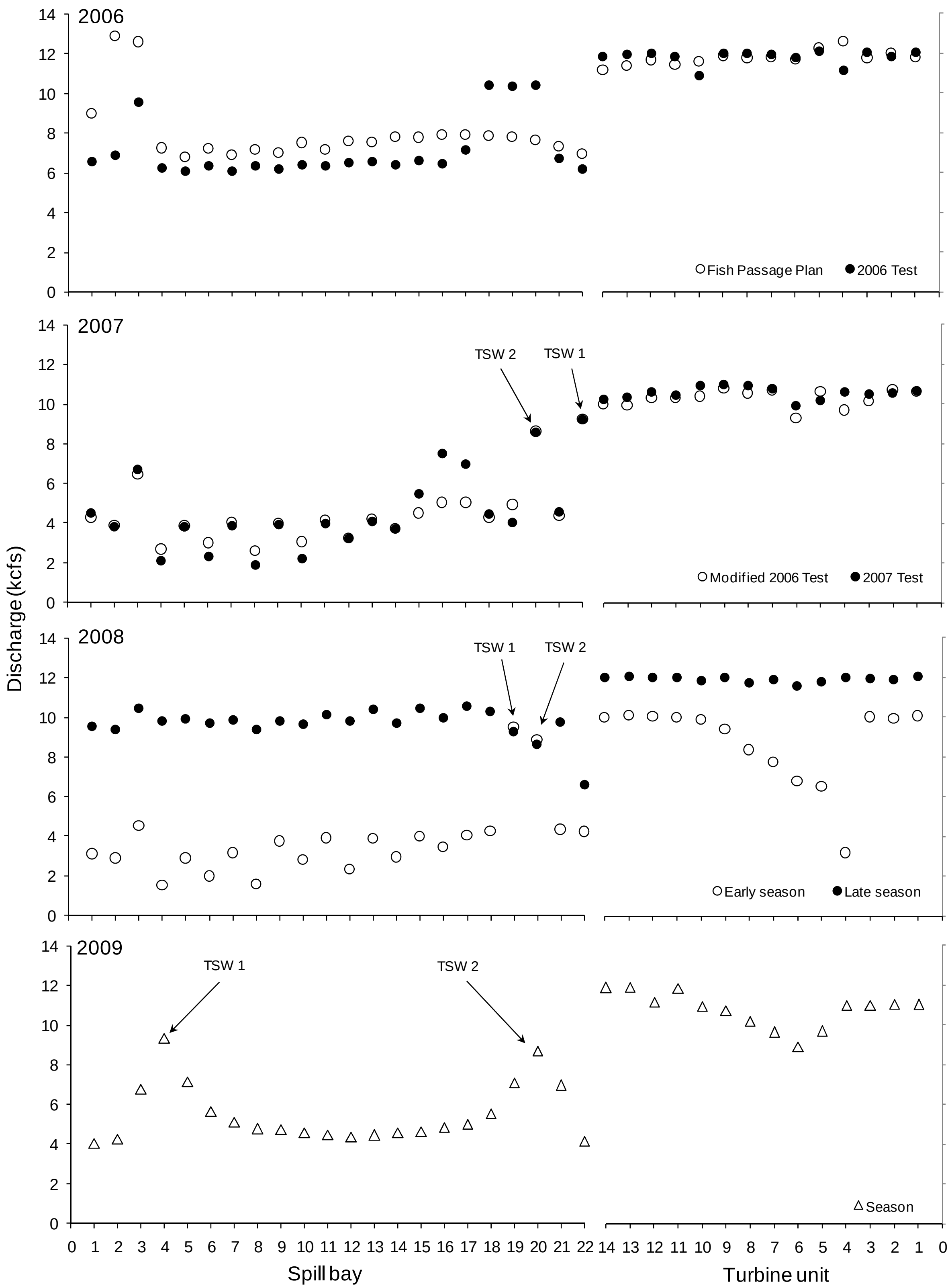

Figure 1-7. Hydrographs showing mean discharge of spill bays and turbine units by treatments or conditions during spring acoustic telemetry studies at McNary Dam, 2006–09.

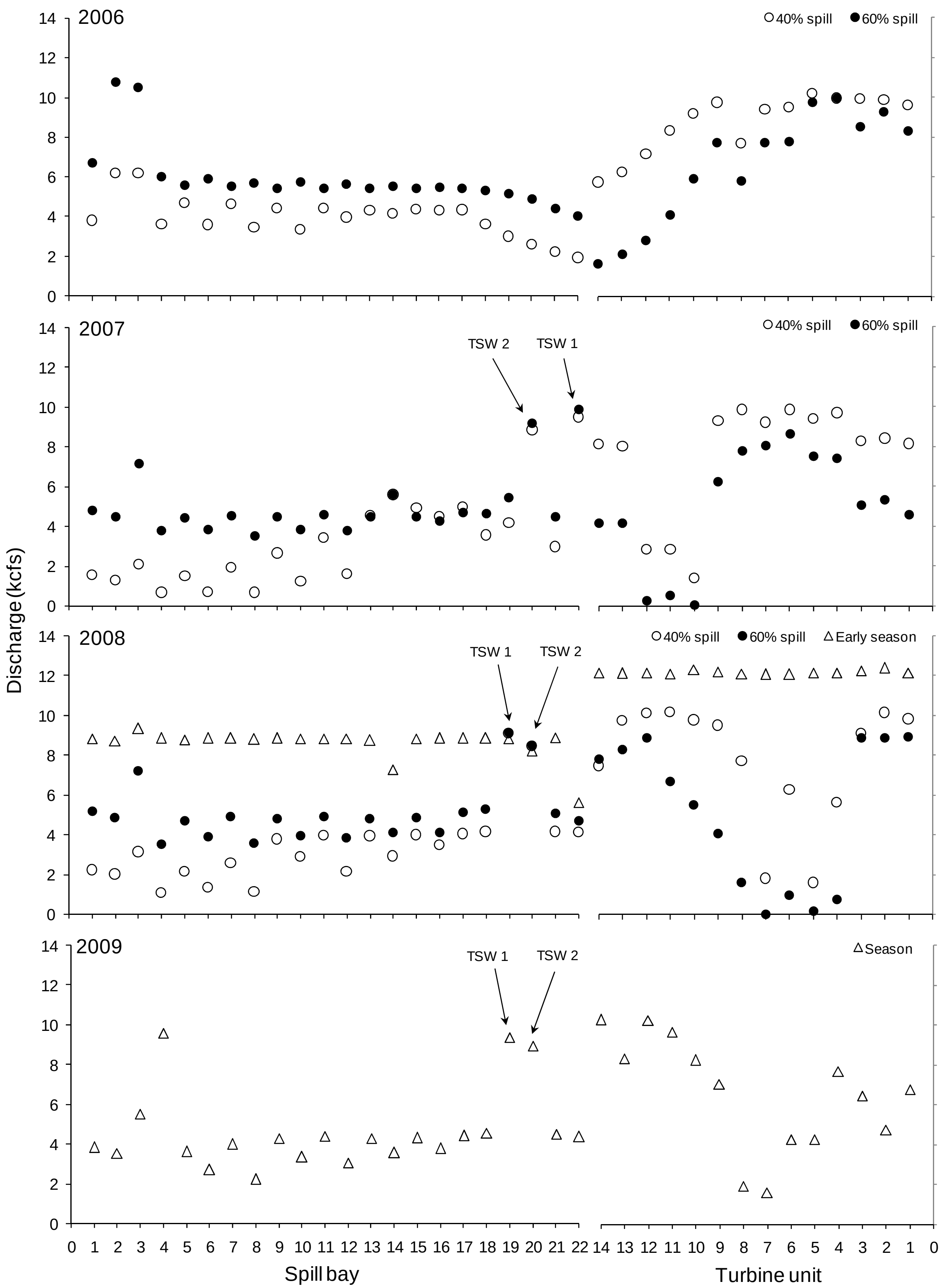

Figure 1-8. Hydrographs showing mean discharge of spill bays and turbine units by treatments or conditions during summer acoustic telemetry studies at McNary Dam, 2006–09.

Species Composition and Run Timing

Run timing from 2006 to 2009 at McNary Dam varied by species and year and generally followed the 10 year average in pattern but not in scale. During the spring, juvenile yearling Chinook salmon (*Oncorhynchus tshawytscha)*, Coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), and steelhead (*O. mykiss*) made up the majority of the fish run, but yearling Chinook salmon and juvenile steelhead were the most prevalent (fig. 1-9). Subyearling Chinook salmon made up the greatest proportion of the fish run during the summer study periods as well as over the entire 4 year study period (0.566; table 1-2). On a yearly basis, the number of sockeye and subyearling Chinook salmon passing McNary Dam was greatest in 2007, the number of yearling Chinook salmon and juvenile steelhead passing McNary Dam was greatest in 2009, and the largest number of Coho salmon passed McNary Dam in 2008. Most fish runs that passed McNary Dam in the spring from 2006 to 2009 had higher daily counts than the 10-year average. Only the subyearling Chinook salmon run in 2006–09 matched the 10-year average daily frequency, but the peak of the run during 2006–09 peaked several weeks later than the 10 year average.

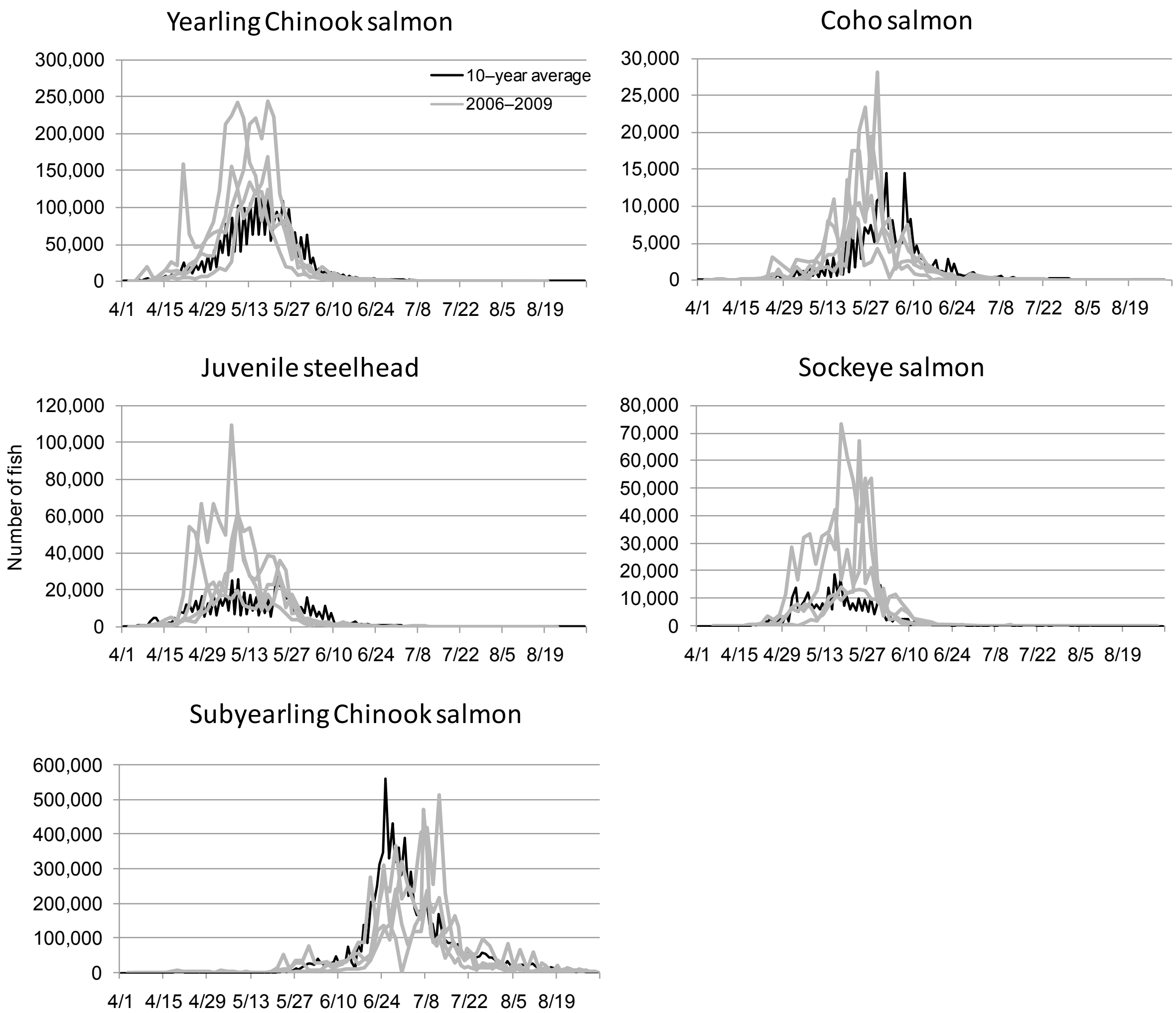

Figure 1-9. Run timing of yearling Chinook salmon, Coho salmon, juvenile steelhead, sockeye salmon, and subyearling Chinook salmon through McNary Dam for the 10-year average (black line) and 2006–09 (gray lines). Data obtained from the Fish Passage Center (*http://www.fpc.org.html*).

Table 1-2. Mean numbers of juvenile fish passing McNary Dam between April 1 and December 1 by year and species.

[Proportion is the total number of each species divided by all of the fish passing McNary Dam. Data obtained from the Fish Passage Center (*http://www.fpc.org.html*)]

Species	2006	2007	2008	2009	Total	Proportion
Yearling Chinook salmon	1,559,649	2,223,432	1,299,990	2,249,069	7,332,140	0.280
Coho	102,125	99,101	168,497	127,002	496,725	0.019
Sockeye	496,470	512,994	221,747	190,747	1,421,958	0.054
Steelhead	442,984	376,449	506,527	803,445	2,129,405	0.081
Subyearling Chinook salmon	4,064,681	4,721,057	2,408,207	3,652,430	14,846,375	0.566
Total	6,665,909	7,933,033	4,604,968	7,022,693	26,226,603	

Study Design

Acoustic Telemetry System

The acoustic telemetry system consisted of acoustic receivers, hydrophones, and transmitters. All hydrophones (model 590; Hydroacoustic Technology, Inc. ©, HTI; Seattle, WA) had a 290º beam width and were continuously monitored by either an acoustic telemetry receiver (ATR; model 290; HTI) or an acoustic tag data logger (ATDL; model 295-X; HTI). Depending on the year of study, 86–113 hydrophones were linked to 5–7 ATRs and 17–20 ATDLs. In the forebay, hydrophones were mounted about 2 m below the water's surface and near the bottom (greater than 18.3 m below the surface) of the river. Double hydrophone arrays were installed at all dam passage routes to permit the estimation of route-specific detection probabilities and use of the route-specific survival model (RSSM; Skalski and others, 2002). At remote detection arrays located upstream and downstream of the dam, hydrophones were deployed on floating barges or pre-existing structures (for example, bridge pilings, navigation markers, and navigation walls) at depths of 1.5–2.1 m, depending on the location. At locations where surface-mounting was not feasible, hydrophones were deployed about 1 m above the river bottom using steel towers. Satellite or cellular modems were deployed at each hydrophone array to establish a wireless network between each ATDL or ATR, and our data-processing servers at the Columbia River Research Laboratory. This network allowed automated transfer of data, as well as the ability to access and control each ATDL and ATR remotely. A detailed description of hydrophone arrays can be found in Adams and others (2008), Adams and Counihan (2009), and Adams and Liedtke (2009, 2010).

Although the same manufacturer and models of acoustic telemetry receiving equipment were used during all study years, and hydrophones were mounted to detect fish passing through any route, there were some differences in system deployment among years. Some of these differences were necessary due to changing locations of the TSWs, changing objectives, or to improve the detection performance of the hydrophones by locating them away from sources of noise. Appendix A portrays our acoustic telemetry system layout in each study year. However, some changes in deployment are not distinguishable on the plan views. One example includes the mounting of hydrophones 3 m lower on the spillway pier noses in 2007, 2008, and 2009 (compared to 2006) to decrease noise induced by flow at the spillway ogee. Another example, one that is distinguishable in appendix A, includes the different location of deep hydrophones at the powerhouse in 2009, compared to other years. In 2009, we deployed deep hydrophones on towers located 60 m in front of the powerhouse on the forebay floor, rather than using divers to mount the hydrophones directly to the powerhouse piernoses. This change was implemented at the request of the U.S. Army Corps of Engineers (USACE) to reduce installation costs. In additional to reducing the cost, this change in deployment also reduced the amount of noise detected by the monitoring system and improved the performance of the system.

Transmitters

We used acoustic transmitters that operated at a frequency of 307.5 kHz with a 1.0–2.0 ms pulse width. Each transmitter emitted a unique acoustic signal (encoded by pulse rate), allowing simultaneous monitoring of multiple transmitters by a single hydrophone. In addition to the acoustic transmitter, we also inserted a passive integrated transponder (PIT) tag (Destron-Fearing models TX1411ST and TXP148511B) into each fish. Only a subset of the juvenile steelhead released in the mid-Columbia River had a PIT tag, and rather than being inserted directly into the fish, the PIT tag was incorporated into the acoustic transmitter. Each PIT tag emitted a unique digitally encoded signal at 134.2 kHz when activated by an electromagnetic field from a PIT-tag detector. Each PIT tag weighed 0.07–0.1 g in air, depending on model. The additional weight and volume from the PIT tag added a negligible amount of weight and volume to the fish relative to the acoustic transmitter.

Tag life studies were conducted by USGS in 2006, 2007, 2008, and 2009; CPUD in 2006, 2007, and 2008; and both CPUD and GPUD in 2009 (Adams and others, 2008; Adams and Counihan, 2009; Adams and Liedtke, 2009, 2010; Steig and others, 2007, 2008, 2009, 2010; Timko and others, 2010). These studies indicated the average lifespan was between 18 and 28 days for tags implanted in juvenile steelhead and yearling Chinook salmon, between 14 and 22 days for tags implanted in sockeye salmon, and between 13 and 24 days for tags implanted in subyearling Chinook salmon, depending on tag model and year (table 1-3).

Table 1-3. Specifications of transmitters surgically implanted in juvenile salmonids, 2006–09.

Year	Site	Acoustic transmitter model	Average tag dimensions (millimeters)	Average tag weight in air (grams)	Average tag life (days)	PIT tag model
Yearling Chinook salmon and juvenile steelhead						
2006	Columbia	795-E	6.8 × 21.0	1.5	21	TX1411ST
2006	Mid-Columbia	795-E	6.8 × 21.0	1.5	22	NA
2007	Columbia	795-E	6.8 × 21.0	1.5	21	TX1411ST
2007	Mid-Columbia	795-E	6.8 × 21.0	1.5	22	NA
2008	Columbia	795-E	7.1 × 21.9	1.6	18	TX1411ST
2008	Mid-Columbia	795-E	6.8 × 21.0	1.5	19	NA
2009	Columbia	795-LE	6.7 × 21.1	1.4	28	TX1411ST
2009	Mid-Columbia	795-LE	6.8 × 18.0	1.5	23	NA
Juvenile steelhead with PIT						
2008	Mid-Columbia	795-E/ PIT	6.8 × 21.8	1.7	26	TXP148511B
2009	Mid-Columbia	795-E/ PIT	6.8 × 21.8	1.7	26	TXP148511B
Sockeye salmon						
2006	Mid-Columbia	795-M	6.8 × 16.5	0.8	14	NA
2007	Mid-Columbia	795-M	6.8 × 16.5	0.8	14	NA
2008	Mid-Columbia	795-M	6.8 × 16.5	0.8	17	NA
2009	Mid-Columbia	795-Lm	5.0 × 17.5	0.7	22	NA
Subyearling Chinook salmon						
2006	Columbia	795-M	6.8 × 16.5	0.8	17	TX1411ST
2007	Columbia	795-M	6.8 × 16.5	0.8	17	TX1411ST
2008	Columbia	795-S	6.5 × 22.2	0.7	13	TX1411ST
2009	Columbia	795-LM	6.5 × 16.3	0.7	24	TX1411ST

Fish Tagging and Release

All fish were tagged and released by personnel from USGS, excluding those released in the Mid-Columbia River (see chapter 2). The standard methodology and protocols used were based on studies conducted by Adams and others (2008). The source, collection, and release sites for each species and release group are briefly documented in this report. A detailed description of collection, transport, and tagging procedures can be found in Adams and others (2008), Adams and Counihan (2009), and Adams and Liedtke (2009, 2010). Juvenile salmonids were collected, tagged, and held at the McNary Dam Smolt Monitoring Facility operated by the Washington Department of Fish and Wildlife. For all experimental groups, handling protocols (that is, collection, transport, tagging, holding, and release) were standardized as much as possible among release groups to reduce the potential for bias. All acoustic transmitters were surgically implanted. Fish were held for 18–36 h before tagging, and for 18–36 h after tagging. The treatment release location was approximately 10 rkm upstream of McNary Dam at Hat Rock State Park, Oregon. Control groups were released in the tailrace of McNary Dam, directly out from the downstream tip of the navigation wall. Both treatment and control groups were released across the main channel in three locations (north, middle, and south of main river channel) to allow greater distribution in the river. In order to distribute fish arrival times at the dam, we released fish throughout the 24-h diel cycle. Species, release dates, release sites, passage dates, and percent spill are documented in tables 1-4 and 1-5.

Table 1-4. Summary statistics of fork length and weight for acoustic-tagged juvenile salmonids released in the Columbia River by release site, 2006–09.

[Species: Y. Chinook, yearling Chinook salmon; Steelhead, juvenile steelhead; S. Chinook, subyearling Chinook salmon. Release site: HAT, Near Hat Rock State Park, Oregon, approximately 10 km upstream of McNary Dam; TAIL, 0.5 km downstream of McNary Dam in the tailrace directly out from the downstream tip of the navigation wall; SAC, intentionally sacrificed fish released at the TAIL release site. *N*, number of fish; Min, minimum; Max, maximum]

Species	Release site	Release dates	*N*	Fork length, in millimeters			Weight, in grams		
				Mean	Min	Max	Mean	Min	Max
2006									
Y. Chinook	HAT	4/27–6/4/2006	1,797	149	125	179	31.7	23.0	59.5
Y. Chinook	TAIL	4/27–6/4/2006	1,213	148	133	175	31.3	22.6	49.8
Y. Chinook	SAC	4/30–6/1/2006	49	148	134	174	31.7	23.0	48.7
Steelhead	HAT	4/27–6/1/2006	1,005	209	122	290	78.6	31.0	236.5
Steelhead	SAC	5/4–5/31/2006	50	205	158	267	73.3	30.1	152.6
S. Chinook	HAT	6/20–7/19/2006	1,794	120	104	155	17.5	12.5	44.8
S. Chinook	TAIL	6/20–7/19/2006	1,191	120	108	158	17.4	13.5	44.9
S. Chinook	SAC	6/22–7/11/2006	50	118	112	133	16.7	13.6	25.1
2007									
Y. Chinook	HAT	4/19–6/7/2007	1,973	151	130	222	33.4	23.0	108.4
Y. Chinook	TAIL	4/19–6/7/2007	1,310	151	133	206	33.5	23.0	78.8
Y. Chinook	SAC	4/27–6/4/2007	53	151	135	179	33.2	23.7	49.9
Steelhead	HAT	4/21–6/6/2007	1,118	215	160	292	84.6	27.4	207.7
Steelhead	SAC	4/28–6/2/2007	50	223	178	279	93.4	43.7	166.8
S. Chinook	HAT	6/20–7/25/2007	1,771	118	105	166	17.8	13.2	55.2
S. Chinook	TAIL	6/20–7/25/2007	1,182	118	105	168	17.6	12.8	59.9
S. Chinook	SAC	6/24–7/24/2007	50	118	110	136	17.8	13.5	32.5
2008									
Y. Chinook	HAT	4/19–6/3/2008	1,424	154	131	206	36.0	23.0	147.6
Y. Chinook	TAIL	4/20–6/4/2008	949	153	130	200	35.5	23.0	76.7
Y. Chinook	SAC	4/22–5/31/2008	50	151	134	189	34.2	24.1	63.6
Steelhead	HAT	4/19–6/2/2008	1,186	211	136	289	82.8	27.5	224.0
Steelhead	TAIL	4/20–6/3/2008	785	210	135	294	81.7	25.0	232.7
Steelhead	SAC	4/22–5/31/2008	50	213	171	270	87.2	38.3	179.2
S. Chinook	HAT	6/19–7/28/2008	1,752	116	102	158	17.1	11.8	46.8
S. Chinook	TAIL	6/20–7/29/2008	1,176	117	103	155	17.1	11.8	40.7
S. Chinook	SAC	6/22–7/27/2008	50	117	107	142	17.4	12.4	33.3
2009									
Y. Chinook	HAT	4/18–6/4/2009	1,411	164	134	240	44.4	29.0	119.0
Y. Chinook	TAIL	4/18–6/4/2009	935	164	137	255	44.7	29.0	174.0
Y. Chinook	SAC	4/20–5/29/2009	51	161	143	195	41.9	30.4	75.2
Steelhead	HAT	4/18–6/4/2009	1,176	220	111	280	93.8	32.6	215.4
Steelhead	TAIL	4/18–6/4/2009	785	220	158	283	94.7	32.4	218.0
Steelhead	SAC	4/23–5/29/2009	51	216	156	254	87.4	31.5	130.0
S. Chinook	HAT	6/20–7/30/2009	1,784	121	105	158	20.2	13.5	47.0
S. Chinook	TAIL	6/20–7/30/2009	1,187	122	102	172	20.4	13.5	57.8
S. Chinook	SAC	6/25–7/28/2009	51	118	109	148	18.8	14.0	38.2

Table 1-5. Number of acoustic-tagged juvenile salmonids released in the Columbia River, number (and percent of those released) that passed McNary Dam, range of passage dates, and corresponding percent spill of total project discharge over dates of passage at McNary Dam, by species, 2006–09.

[Y. Chinook, yearling Chinook salmon; Steelhead, juvenile steelhead; S. Chinook, subyearling Chinook salmon]

Species	Number released	Number (%) passed	First passage date	Last passage date	Percent spill[1]
			2006		
Y. Chinook	1,797	1,717 (96)	4/27/2006	6/5/2006	50
Steelhead	1,005	944 (94)	4/27/2006	6/2/2006	48
S. Chinook	1,791	1,638 (91)	6/20/2006	7/30/2006	49
			2007		
Y. Chinook	1,974	1,911 (97)	4/20/2007	6/9/2007	43
Steelhead	1,118	1,086 (97)	4/22/2007	6/9/2007	41
S. Chinook	1,771	1,631 (92)	6/21/2007	8/7/2007	52
			2008		
Y. Chinook	1,424	1,396 (98)	4/19/2008	6/8/2008	46
Steelhead	1,186	1,186 (100)	4/19/2008	6/3/2008	47
S. Chinook	1,752	1,646 (94)	6/20/2008	8/8/2008	51
			2009		
Y. Chinook	1,403	1,351 (96)	4/18/2009	6/8/2009	44
Steelhead	1,170	1,107 (95)	4/19/2009	6/4/2009	43
S. Chinook	1,772	1,602 (90)	6/20/2009	8/7/2009	51

[1]The percentage of project discharge spilled includes the water discharged through the temporary spillway weirs.

Signal Processing and Verification

Passage routes, approach distributions, and travel times were determined from acoustic transmitter signals collected by hydrophones at the dam and in the reservoir. Valid acoustic signals were separated from ambient noise using the HTI© software MarkTags. Files were then compiled and the auto-marking software identified individual tags to be verified by data technicians. Tracking parameters were set in the software to minimize the marking of false detections caused by noise or overlap of individual tags and to maximize detections of available fish (based on a tag list of all possible tags). Tag lists were generated for each batch based on a search duration determined by the estimated travel time information. Once fish records were verified by technicians, a second round of processing occurred with a wider parameter set and search duration and a smaller tag list to look for remaining undetected fish. All verified fish records were then compiled and detections of individual fish were identified and given to data technicians for manual marking of the individual tracks. After manual marking, the MarkTags software was used to assign a date and time for the beginning and end of each valid acoustic track. The detections were then used to estimate the proximity of an acoustic transmitter to hydrophones in the array and to estimate the 2-D and 3-D locations of the acoustic transmitters.

Travel Times and Rates

We evaluated travel times and rates of fish as they traveled to McNary Dam and in reaches downstream of McNary Dam. Travel times of juvenile salmonids are often non-normally distributed, have a skewed distribution, and are highly variable (Giorgi and others, 1997). Much of this variability arises from the dispersal of fish as they travel downstream after release (Zabel, 1994; Zabel and

Anderson, 1997). To account for this, we used the inverse Gaussian distribution to estimate mean travel times and rates and to express the variation about these estimates. For each reach, we estimated a mean travel time, travel rate, and rate of population spread using methods described by Zabel and Anderson (1997). The rate of population spread provides an indication of how fast fish disperse as they migrate. Error in the estimates were expressed by calculating 95 percent confidence intervals about the mean travel rate (Zabel, 1994 2002; Zabel and Anderson, 1997). We chose to compare mean travel rates among reaches as a way to standardize across release sites, because mean travel time is dependent on reach length and mean travel rate is not. The rate of population spread and 95 percent confidence intervals about the mean travel rate are shown in appendixes B and C.

Diel Depth Distribution

The depth distribution for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon was estimated over the 24-h diel cycle. For each species, mean hourly depth was calculated for each fish and then averaged among fish for each hour over the study period.

Passage Determinations

Fish were assigned to one of four passage routes at McNary Dam; turbine, bypass, spillway, or TSW (bay-specific passage was determined). The PIT-tag detectors in the bypass facility were used to determine if fish passed through the bypass system. Because some fish released in the mid-Columbia did not have PIT tags, we could not distinguish if they passed through the turbines or the bypass system. As a result, these fish were assigned to three passage routes: powerhouse (includes both turbine and bypass routes), spillway, or TSW passage. The TSW passage route only applies to the 2007, 2008, and 2009 study years because the TSWs were not installed in 2006. In 2009, there was an unplanned relocation of TSW1 from spill bay 4 in the spring to spill bay 19 in the summer. Monitoring equipment was not deployed to accommodate this change. As a result, we could not assign passage to bay 19 and instead assigned passage to the group of bays 16–19 during summer 2009. Passage routes were determined using the last two hydrophones an acoustic-tagged fish was nearest to that clearly defined a route. In some instances, passage route could not be determined due to excessive noise, data gaps (faint, intermittent track), and/or conflicting information (for example, between primary and secondary pulse, among systems). For these fish, it was necessary to determine passage manually. If insufficient or conflicting information still existed then passage was categorized as unknown. In addition to the manual determinations, a number of random fish records were manually interrogated as a quality-assurance procedure to verify that the passage route assignments made by the SAS program were correct. Once the final dataset was compiled, we conducted a series of data checks to verify detection records. All last detections were examined for any negative travel times from release to the dam or to downstream arrays; events that indicated the possibility of a false record. Records also were examined visually when passage was assigned by proximity if the last two hydrophone detections were more than 2 minutes apart.

Survival Model

In Chapter 1, we used the route-specific survival model (RSSM; Skalski and others, 2002) to estimate passage and survival probabilities for yearling and subyearling Chinook salmon and juvenile steelhead. In 2006 and 2007, juvenile steelhead passage and survival probabilities were estimated using the single release-recapture model because juvenile steelhead were only released at the treatment release location near Hat Rock State Park. Variation about the estimates also was estimated and reported as 95-

percent profile likelihood confidence intervals and the standard error. The foundation of the RSSM is based on the single release-recapture models of Cormack (1964), Jolly (1965), and Seber (1965; CJS model), and the paired release-recapture model of Burnham and others (1987). The RSSM partitions survival among reservoir and route-specific components and uses a branching process to estimate conditional route-specific passage probabilities (tables 1-6, 1-7, and 1-8; fig. 1-10). We employed an expanded version of the RSSM to incorporate diel periods or treatments into the analysis by adding an additional branching process. The additional branching process estimates the probability of passing the dam during a particular diel period or treatment. The model also expresses parameters below the dam as a function of each release group.

Because of the branching process employed by the RSSM to accommodate multiple variables (passage routes, treatments, and diel period), and the way the paired release-recapture model calculates concrete survival, it is possible for rounding error to be incorporated into the estimate. One way to examine the extent of rounding error is to divide the single release survival estimate (all routes survival) by the control survival estimate, and then compare the resulting value to the paired-release estimate of concrete survival. In cases where rounding error was not problematic, the new value will be equal to concrete survival as estimated by the model. If rounding error was problematic, then the new value will be different (usually about 1 percent) and can be considered the more accurate estimate. We conducted these calculations for all estimates of concrete survival and provided the alternative value as a footnote if the new estimate differed from the original by 0.5 percent or more.

We estimated season wide passage and survival with respect to diel periods (that is, day and night) and treatments under which the fish passed the dam. Day and night periods for analysis were dictated by when spill operations typically changed rather than by sunrise and sunset; day was considered 0600–1759 hours, and night was considered 1800–0559 hours. Fish were assigned to treatments and diel periods based on their time of passage at McNary Dam. For the turbines and the spillway passage routes (including the TSWs), time of passage was assigned to the last detection of fish within the route of passage. For fish passing through the juvenile bypass system, passage was assigned using the first detection on the PIT tag detection coils.

We assessed model fit by examining residuals of observed versus expected capture history counts (appendixes D and E).

Table 1-6. Definitions of fish detection parameters for fish released near Hat Rock State Park and McNary Dam tailrace estimated using the route-specific survival model, 2006–09.

[Parameter: Detect. Prob., detection probability; Source: MLE, maximum likelihood estimate]

Parameter	Source	Definition
Turbine Detect. Prob.	Derived	Overall detection probability of the turbines.
Bypass Detect. Prob.	Derived	Overall detection probability of the bypass.
Spillway Detect. Prob.	Derived	Overall detection probability of all conventional spill bays.
TSW1 Detect. Prob.[1]	Derived	Overall detection probability of TSW1.
TSW2 Detect. Prob. [1]	Derived	Overall detection probability of TSW2.
Detect. Prob. for Treatment Release Group	MLE	Probability of the treatment release group being detected at the first detection array downstream of McNary Dam.
Detect. Prob. for Control Release Group	MLE	Probability of the control release group being detected at the first detection array downstream of McNary Dam.
λ Treatment Fish	MLE	Joint probability of treatment fish surviving and being detected by all detection arrays downstream of first detection array downstream of McNary Dam.
λ Control Fish	MLE	Joint probability of control fish surviving and being detected by all detection arrays downstream of first detection array downstream of McNary Dam.

[1]Parameter was not estimable in 2006 because TSWs were not present.

Table 1-7. Definitions of fish passage probabilities and passage metrics for McNary Dam, 2006–09.

Parameter	Estimate	Definition
Overall	Definition	Estimate reported for each species for the entire study period.
Day	Definition	Estimate reported for each species for 0600–1759 hours during the entire study period.
Night	Definition	Estimate reported for each species for 1800–0559 hours during the entire study period.
Treatment 1	Definition	Estimate reported for each species for one treatment or condition during the entire study period. Treatments are listed on each table for each year.
Treatment 2	Definition	Estimate reported for each species for the second treatment or condition during the entire study period. Treatments are listed on each table for each year.
Treatment 3	Definition	Estimate reported for each species for the third treatment or condition during the entire study period. Treatments are listed on each table for each year. Treatment 3 operated only during summer of 2008.
TSW1	Definition	TSW Design 1 (See figure 3 for TSW spill bay location by year and season).
TSW2	Definition	TSW Design 2 (TSW2 was installed in spill bay 20 during the study periods from 2007 to 2009).
Turbine	Passage	Unconditional probability of passing through the turbines.
Bypass	Passage	Probability of bypass passage, conditional on the fish not passing through the turbines.
Spillway (also Spillway Passage Efficiency)	Passage	Probability of spillway passage, conditional on the fish not passing through the powerhouse. This is also called spillway passage efficiency (SPE).
TSW1[1]	Passage	Probability of TSW1 passage, conditional on the fish not passing through the powerhouse or spillway.
TSW2[1]	Passage	Probability of TSW2 passage, conditional on the fish not passing through the powerhouse, spillway, or TSW1.
Fish Passage Efficiency	Metric	FPE. Probability of passing through non-turbine routes.
Fish Guidance Efficiency	Metric	FGE. Probability of passing through the juvenile bypass system given fish passed the powerhouse.
Powerhouse Effectiveness	Metric	The ratio of the proportion of fish passing through the powerhouse (turbine+bypass) to the proportion of water being discharged through the powerhouse.
Spillway Effectiveness	Metric	SPS. The ratio of the proportion of fish passing through the spillway to the proportion of water being spilled through the spillway.
TSW1 Effectiveness [1]	Metric	SOS_1-Surface Outlet Effectiveness for TSW1. The ratio of the proportion of fish passing through TSW1 to the proportion of water being spilled through TSW1.
TSW2 Effectiveness [1]	Metric	SOS_2-Surface Outlet Effectiveness for TSW2. The ratio of the proportion of fish passing through TSW2 to the proportion of water being spilled through TSW2.
Both TSWs Effectiveness [1]	Metric	SOS_{Both}-Surface Outlet Effectiveness for TSW1 and TSW2. The ratio of the proportion of fish passing through TSW1+TSW2 to the proportion of water being spilled through TSW1+TSW2.
TSW and Spill Effectiveness [1]	Metric	SPS+SOS. The ratio of the proportion of fish passing through the entire spillway to the proportion of water being spilled through the entire spillway.

[1]Parameter was not estimable in 2006 because TSWs were not present.

Table 1-8. Definitions of fish survival parameters for fish released near Hat Rock State Park and McNary Dam tailrace, 2006–09.

[Single-Release, Single-release survival estimate; Paired-Release, Paired-release survival estimate. Estimates were obtained using paired- and single-release, route-specific survival model]

Parameter	Estimate	Definition
All Routes	Single-Release	Survival probability from the upstream boundary of McNary Dam (the dam face) to the first downstream detection array as a weighted average for all routes. Note: this is similar to the paired-release estimate of concrete survival with the exception that it includes the section of river from the tailrace to the first downstream detection array.
Control	Single-Release	Survival probability from control group release location, located at the downstream tailrace boundary, to the first downstream detection array.
Pool	Single-Release	The probability of survival from Hat Rock State Park (rkm 480, 10 rkm upstream of McNary Dam) to the upstream boundary of the forebay (rkm 472).
Forebay	Single-Release	The probability of survival from the upstream forebay boundary (rkm 472) to passage at McNary Dam (rkm 470).
Turbine	Single-Release	The probability of survival for fish passing through the turbine to the first downstream detection site.
Bypass	Single-Release	The probability of survival for fish passing through the bypass to the first downstream detection site.
Spillway	Single-Release	The probability of survival for fish passing through conventional spill bays to the first downstream detection site.
TSW1[1]	Single-Release	The probability of survival for fish passing through TSW1 to the first downstream detection site.
TSW2[1]	Single-Release	The probability of survival for fish passing through TSW2 to the first downstream detection site.
Concrete	Paired-Release	The probability of survival from the upstream boundary of McNary Dam (the dam face) to the downstream boundary of the tailrace where the reference group is released; it includes all routes of passage and the tailrace of McNary Dam. The probability of survival through each route of passage is weighted by the probability of passage through each route. *NOTE: The 2008 FCRPS Biological Opinion terms this parameter "dam survival".*
Project	Paired-Release	The probability of survival from Hat Rock State Park (rkm 480, 10 rkm upstream of McNary Dam) to the downstream boundary of the McNary tailrace. Includes survival through the reservoir from the treatment release location, forebay, dam, and tailrace.
Turbine	Paired-Release	The probability of survival for fish passing through the turbine to the release location of the tailrace reference group.
Bypass	Paired-Release	The probability of survival for fish passing through the bypass to the release location of the tailrace reference group.
Spillway	Paired-Release	The probability of survival for fish passing through conventional spill bays to the release location of the tailrace reference group.
TSW1[1]	Paired-Release	The probability of survival for fish passing through TSW1 to the release location of the tailrace reference group.
TSW2[1]	Paired-Release	The probability of survival for fish passing through TSW2 to the release location of the tailrace reference group.

[1]Parameter was not estimable in 2006 because TSWs were not present.

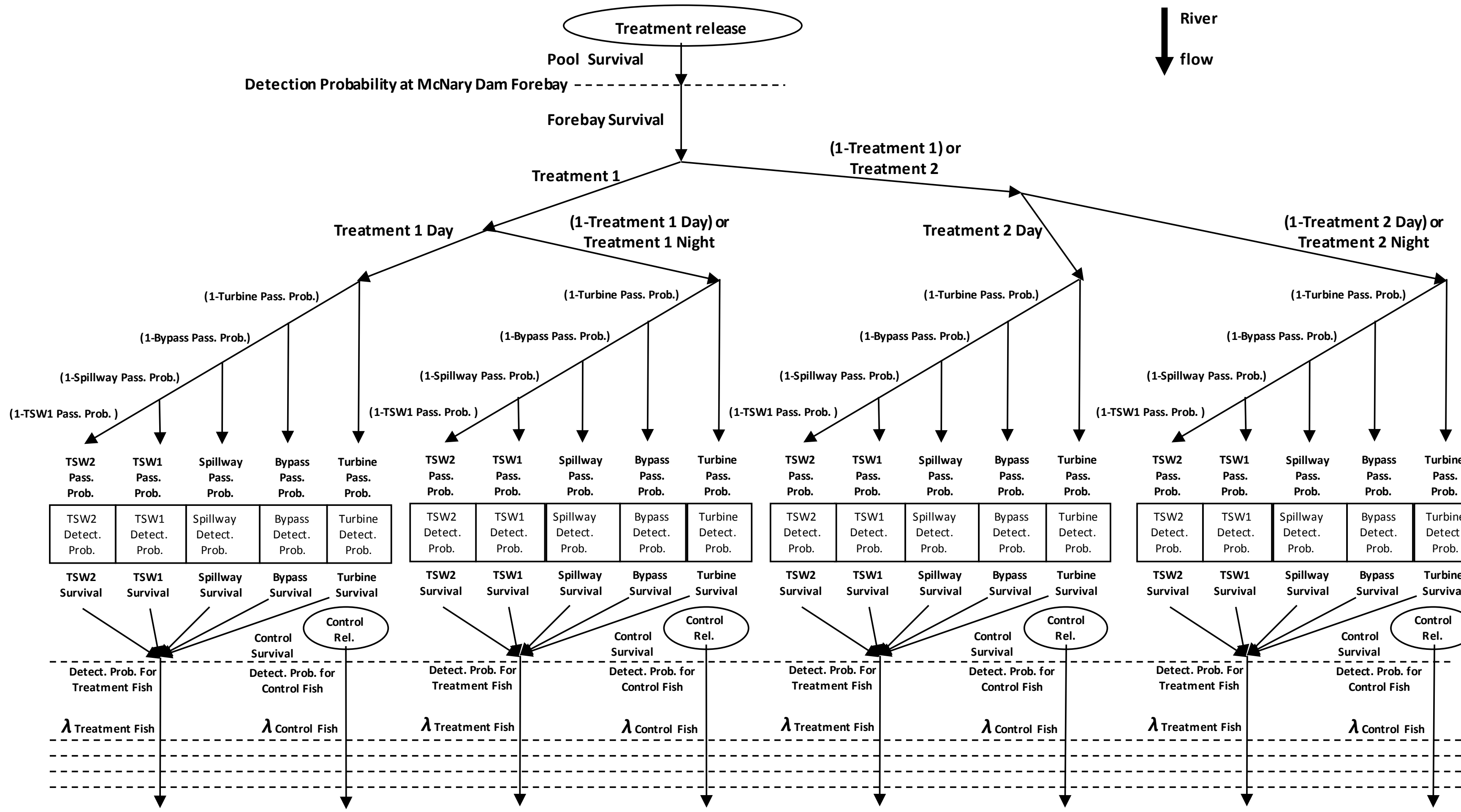

Figure 1-10. Schematic of "full" route-specific survival model whereby survival and detection probabilities are separated among river reaches upstream and downstream of McNary Dam, diel periods, treatment, passage routes, and the release group (Treatment release group, Control release group). A single-release version of this model would only include parameters associated with the treatment release group. A third set of branches was used for the 2008 summer model where three treatments were evaluated.

Fish Behavior

Travel Times and Rates

Fish traveled to the entrance gate located 2 km upstream of McNary Dam (rkm 472) relatively quickly following release at Hat Rock State Park (rkm 480), regardless of species or year of study. Yearling Chinook salmon had the shortest travel times after release (7–8 h), followed by juvenile steelhead (9–10 h), and subyearling Chinook salmon (9–14 h; table 1-9). These travel times translate to travel rates of 13.84–26.59 km/d, depending on year and species, in the 8 km reach from the release point to the entrance gate. Travel rates slowed considerably as fish approached the forebay of McNary Dam, ranging from 4.79–12.88 km/d for yearling Chinook salmon, 4.36–7.73 km/d for juvenile steelhead, and 7.65–9.55 km/d for subyearling Chinook salmon, depending on year (table 1-9). Travel rates increased after fish passed the dam, ranging from 29.06–45.24 km/d for yearling Chinook salmon, 46.48–74.43 km/d for juvenile steelhead, and 42.31–64.70 km/d for subyearling Chinook salmon, depending on year (table 1–9).

Although travel rates decreased as fish approached the forebay of McNary Dam, the time fish resided in the last 160 m (near dam area) before passing the dam was relatively short. Overall, fish resided in the forebay between 0.22 and 1.75 h, depending on species and year (table 1-10). Juvenile steelhead spent the greatest amount of time (0.53–1.75 h) in the forebay during all years except 2006. Yearling Chinook salmon had the second longest duration time in the forebay (0.22–0.69 h), and subyearling Chinook salmon spent the least amount of time in the forebay before passing (0.28–0.84 h). During 2006, both species had shorter forebay residence times during the 2006 Test treatment (higher discharge through south spill bays) than during the Fish Passage Plan treatment (higher discharge through north spill bays), especially juvenile steelhead (table 1-10). Subyearling Chinook salmon had shorter forebay residence times during 40 percent spill than during 60 percent spill. During 2007, although little difference in discharge was observed between the two treatments, both species had shorter forebay residence times during the 2007 Test treatment than during the Modified 2006 Test treatment (table 1-10). Subyearling Chinook salmon had shorter forebay residence times during 40 percent spill than during 60 percent spill, similar to 2006. During 2008, both yearling Chinook salmon and juvenile steelhead had much shorter forebay residence times during Late Season (50–60 percent spill) than during Early Season (40 percent spill; table 1-10). Subyearling Chinook salmon had longer residence times during 40 percent spill, unlike 2006 and 2007. Forebay residence times were longer during the day, compared to night, for juvenile steelhead during all years and treatments (table 1-11). Conversely, residence times were longer during the night, compared to day, for subyearling Chinook salmon during all years and treatments. Yearling Chinook salmon residence times in the forebay varied by year, treatment, and diel period (table 1-11). Regardless of species or year, fish that passed through the spillway had the shortest forebay residence times, followed closely by both TSWs. Fish that passed through the turbines or bypass had the longest forebay residence times (table 1-12).

Table 1-9. Mean and median travel time (d) and mean travel rate (km/d) for USGS active-tagged juvenile salmonids at McNary Dam, 2006–09.

Year	Release→entrance gate (8 km)			Entrance gate→dam (2 km)			Dam→downstream gate 1 (24 km)[1]		
	Mean travel time (d)	Median travel time (d)	Mean travel rate (km/d)	Mean travel time (d)	Median travel time (d)	Mean travel rate (km/d)	Mean travel time (d)	Median travel time (d)	Mean travel rate (km/d)
Yearling Chinook salmon									
2006	0.36	0.26	22.36	0.17	0.08	11.89	0.80	0.54	29.83
2007	0.30	0.26	26.59	0.16	0.08	12.88	0.83	0.56	29.06
2008	0.34	0.25	23.36	0.36	0.10	5.63	0.74	0.54	32.49
2009	0.35	0.28	23.06	0.42	0.13	4.79	0.49	0.38	45.24
Juvenile steelhead									
2006	0.41	0.30	19.46	0.26	0.11	7.73	0.51	0.30	47.51
2007	0.39	0.35	20.74	0.29	0.17	6.86	0.44	0.31	55.08
2008	0.43	0.35	18.53	0.42	0.22	4.77	0.52	0.33	46.48
2009	0.40	0.33	19.82	0.46	0.26	4.36	0.30	0.25	74.43
Subyearling Chinook salmon									
2006	0.58	0.37	13.84	0.23	0.12	8.84	0.53	0.41	45.14
2007	0.53	0.35	15.12	0.21	0.10	9.55	0.57	0.45	42.31
2008	0.39	0.30	20.33	0.26	0.08	7.76	0.42	0.38	57.27
2009	0.46	0.34	17.46	0.26	0.10	7.65	0.34	0.32	64.70

[1]Distance for 2009 Dam→downstream gate 1 (22 km), mean travel rate accounts for varying distances

Table 1-10. Median residence times (h) overall and by treatment for USGS acoustic-tagged juvenile salmonids in the near dam area (within 160 m) of McNary Dam, 2006–09.

Year	Treatment and Season		Yearling Chinook salmon	Juvenile steelhead	Subyearling Chinook salmon
	Spring	Summer			
2006	Overall	Overall	0.22	0.53	0.84
	Fish Passage Plan	60%	0.23	0.70	0.93
	2006 Test	40%	0.20	0.45	0.71
2007	Overall	Overall	0.41	1.75	0.34
	Modified 2006 Test	60%	0.41	1.87	0.38
	2007 Test	40%	0.38	1.61	0.26
2008	Overall	Overall	0.31	1.12	0.24
	Early Season	Early Season	0.55	2.42	0.13
	Late Season	60%	0.12	0.20	0.29
	NA	40%	NA	NA	0.37
2009	Overall	Overall	0.44	1.06	0.31

Table 1-11. Median residence times (h) overall and by treatment for each diel period for USGS acoustic-tagged juvenile salmonids in the near dam area (within 160 m) of McNary Dam, 2006–09.

[NA, not applicable]

Year	Treatment and Season		Yearling Chinook salmon		Juvenile steelhead		Subyearling Chinook salmon	
	Spring	Summer	Day	Night	Day	Night	Day	Night
2006	Overall	Overall	0.25	0.20	2.15	0.26	0.81	1.00
	Fish Passage Plan	60%	0.28	0.21	3.52	0.26	0.91	1.01
	2006 Test	40%	0.22	0.19	1.26	0.25	0.68	0.94
2007	Overall	Overall	0.34	0.58	1.97	1.13	0.26	0.46
	Modified 2006 Test	60%	0.36	0.55	2.69	0.98	0.34	0.58
	2007 Test	40%	0.34	0.62	1.66	1.34	0.22	0.41
2008	Overall	Overall	0.39	0.25	1.77	0.51	0.22	0.29
	Early Season	Early Season	0.57	0.52	3.84	1.17	0.11	0.18
	Late Season	60%	0.12	0.12	0.21	0.18	0.26	0.36
	NA	40%	NA	NA	NA	NA	0.35	0.44
2009	Overall	Overall	0.51	0.39	2.72	0.53	0.28	0.35

Table 1-12. Median residence times (h) overall and by passage route for USGS acoustic-tagged juvenile salmonids in the near dam area (within 160 m) of McNary Dam, 2006–09.

Species	Route	2006	2007	2008	2009
Yearling Chinook salmon	Overall	0.22	0.41	0.31	0.44
	Turbine	0.27	0.46	0.53	0.56
	Bypass	0.33	0.96	0.74	0.93
	TSW 1	NA	0.48	0.40	0.40
	TSW 2	NA	0.26	0.60	0.53
	Spillway	0.18	0.22	0.15	0.25
Juvenile steelhead	Overall	0.53	1.75	1.13	1.06
	Turbine	0.58	6.19	0.74	0.84
	Bypass	0.57	4.25	1.9	2.18
	TSW 1	NA	1.92	1.04	0.80
	TSW 2	NA	1.03	2.36	1.23
	Spillway	0.51	0.70	0.37	0.66
Subyearling Chinook salmon	Overall	0.84	0.34	0.24	0.31
	Turbine	1.07	0.55	0.45	0.47
	Bypass	1.05	0.55	0.32	0.48
	TSW 1	NA	0.29	0.23	NA
	TSW 2	NA	0.24	0.36	0.36
	Spillway	0.72	0.19	0.16	0.22
	Spill Bays 16-19	NA	NA	NA	0.24

Vertical Passage Distributions

The depth of acoustic-tagged fish within 60 m of the dam varied between species and year and changed over the 24-h diel period. The mean depth of yearling Chinook salmon was between 4 and 9 m during all years, and varied only 2–3 m in any given year (fig. 1-11). Diel distribution in 2007 and 2008 was shallower during the night than during the day. The mean depth of juvenile steelhead over the 24-h diel period was similar among all four study years. Juvenile steelhead generally were shallower (< 5 m) during the day and deeper (6–8 m) during the night. Subyearling Chinook salmon were slightly deeper during the day than during the night and were shallowest during the crepuscular periods. Differences in depths between the species were most apparent during the day and less apparent during the night, especially during the crepuscular periods. Because the TSWs are a surface-oriented passage route (the TSW crest was set about 2.4 m below the water surface), species and temporal differences in depth likely influence the passage performance of these structures.

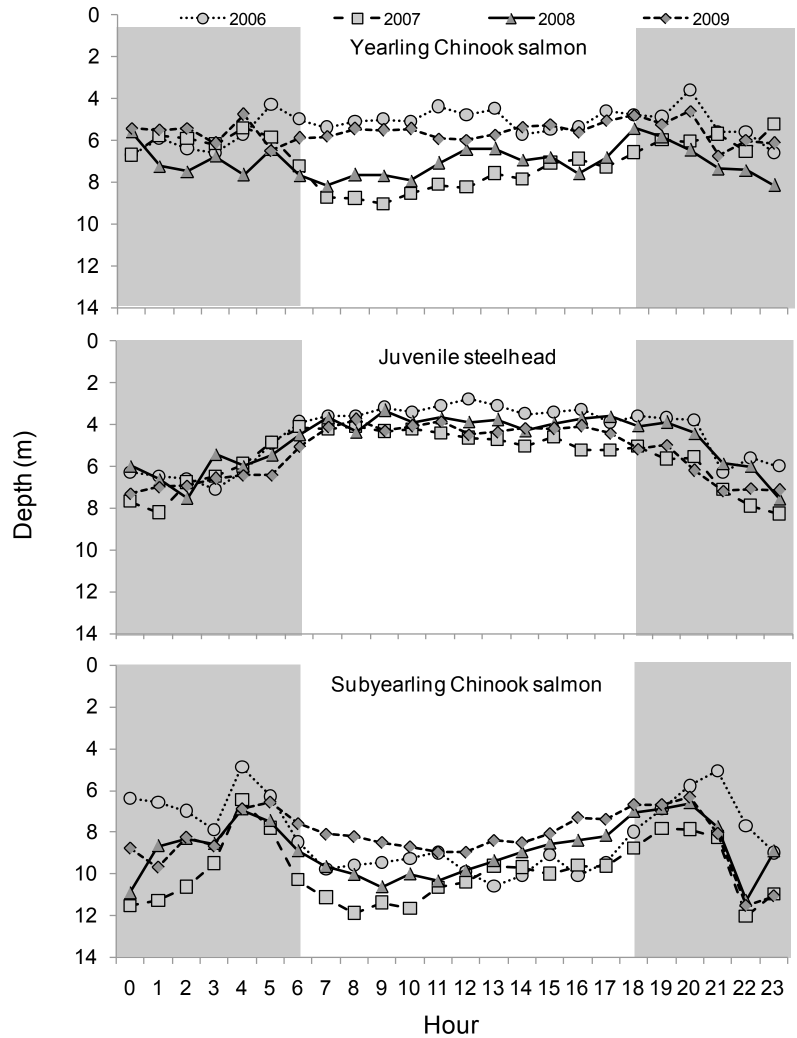

Figure 1-11. Mean depth of acoustic tagged salmonids for each hour of the day that fish were detected within 60 m of McNary Dam 2006–09. Light and dark areas designate diel periods of day and night, respectively.

Fish Passage and Survival

Route-Specific Passage Probabilities

Route-specific passage probabilities for yearling Chinook salmon varied by year, diel period, and treatment. In 2006, about 60 percent of fish passed through the spillway, regardless of diel period or treatment (table 1-13). Once the TSWs were installed in 2007, spillway passage declined to between 24.9 and 47.9 percent in 2007, 2008, and 2009 overall and by diel period, but was still the prominent passage route. TSW2, installed in spill bay 20, passed about 7.6 percent of fish overall in 2007 and 2008 with more passing during the day than night. In 2009, 9.1 percent of yearling Chinook salmon passed through TSW2 with more passing during the night than the day. TSW1 passed twice as many fish as TSW2 in 2007 while installed in spill bay 22 by diel period and overall. Passage through TSW1 in spill bay 19 was about 10 percent in 2008, but only about 4 percent in 2009 when it was installed in spill bay 4. Similar to the diel patterns of TSW2 passage, day passage through TSW1 was about 2 percent higher during the day in 2008, and 2 percent lower during the day in 2009. Overall, 21–32 percent of yearling Chinoook salmon passed though the bypass, and 13–14 percent passed through the turbines during all study years. More fish passed through either the bypass or turbines during the night than the day in 2006, 2007, and 2008. There was little difference in passage between the Fish Passage Plan treatment and the 2006 Test Spill treatment in 2006. More fish were bypassed during the 2007 Test Spill treatment than during the Modified 2006 Test Spill treatment and fish passing all other routes passed in greater numbers during the Modified 2006 Test Spill treatment in 2007. During 2008, powerhouse and TSW passage was greater during the Early Season, and spillway passage increased by 42 percent during the Late Season. Spillway passage was always greater during the day than the night when comparing treatments, except in the 2008 Late Season when 77.6 percent of fish passed during the night, compared to 69.6 percent during the day (table 1-14). When the TSWs were installed and treatments were operating, more fish passed through both TSWs during the day than during night except for TSW1 in both treatment periods in 2007. Regardless of diel period, treatment, or TSW availability, yearling Chinook salmon passed more readily through the spillway and bypass.

Route-specific passage probabilities for juvenile steelhead were similar to probabilities for yearling Chinook salmon. In 2006, about 65 percent of steelhead passed through the spillway (table 1-15). Spillway passage declined for steelhead to between 14 and 34 percent after the TSWs were installed but, unlike for yearling Chinook salmon, TSW passage (65 percent) exceeded spillway passage (14 percent) in 2007. Overall, between 4 and 10 percent of juvenile steelhead passed through the turbines, and between 17 and 25 percent passed through the bypass, during all years of study. Passage probabilities between each treatment in 2006 and 2007 were similar. During the Early Season in 2008, when flows were lower, 51.6 percent of juvenile steelhead passed through the TSWs while only 13.5 percent passed through the TSWs during the Late Season when a greater percent of water passed through the spillway. In 2007 and 2008, juvenile steelhead passed in greater numbers through the turbines, bypass, and spillway during the night, compared to day. Passage through the TSWs was higher during the day than during the night, during all years of study. During the day of Early Season in 2008, 65.8 percent of fish passed through both TSWs and 34.8 percent passed during the night of Early Season. Following a similar trend, four times as many fish passed during the day of Late Season compared to the night of Late Season. Juvenile steelhead used deeper passage routes (turbine and bypass) during the night, but overall passed through conventional and TSW spill bays in high numbers depending on flow.

Passage probabilities for subyearling Chinook varied by year, diel period, and treatment, similar to the other species. In 2006, more than one-half of subyearling Chinook salmon passed through the spillway, and more fish passed through the turbines than the bypass (table 1-17). In 2007 and 2009, 34–37 percent of fish passed through the spillway, and 27 percent passed through both TSWs. However, in 2008, when spill discharge was higher than other years, about one-half of subyearling Chinook salmon passed through the spillway, and only 17 percent passed through both TSWs. Over the diel cycle, passage through the TSWs was relatively unchanged, more fish consistently passed through the turbines at night, and through the spillway and bypass during the day. Subyearling Chinook salmon followed flow in 2006 and 2007, passing the spillway in greater numbers during 60 percent spill than during 40 percent spill. In 2007, TSW1 (located in spill bay 22) passed almost twice as many fish during 60 percent spill compared to 40 percent spill. In contrast, passage was higher through TSW2 than TSW1 (located in bay 19) during 2008. During the Early Season of 2008, 59.5 percent of fish passed through the spillway and 31.3 percent of fish passed through the powerhouse. During the 60 percent spill treatment in 2006, turbine passage increased during the night and spillway passage increased during the day (table 1-18). During the 60 percent treatment in 2007 and 2008, passage increased during the day through the spillway and TSW1. Bypass passage was higher during the day in 2007 and during the night in 2008. Passage trends during the 40 percent treatment diel periods were different between 2007 and 2008. In 2007, passage was higher during the night through the turbines and TSW1, while spillway and TSW2 passage was unchanged between the diel periods. In 2008, passage was higher during the night through the bypass, TSW1, and TSW2. The probability of passage through the spillway during the day was more than double than passage at night. During the Early Season of 2008, passage was higher during the day through the bypass and TSW1, but was unchanged between diel periods for fish passing through TSW2. The probability of subyearling Chinook salmon passing through the TSW was influenced by treatment, but was relatively constant when combined over treatment and diel period.

Table 1-13. Route-specific passage probabilities for yearling Chinook salmon overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error is shown in parentheses; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2
2006				Fish Passage Plan	2006 Test Spill
Turbine	0.125 (0.008)	0.089 (0.010)	0.164 (0.013)	0.137 (0.012)	0.113 (0.011)
Bypass	0.240 (0.010)	0.235 (0.014)	0.247 (0.015)	0.202 (0.014)	0.276 (0.015)
Spillway[1]	0.635 (0.012)	0.677 (0.016)	0.589 (0.017)	0.661 (0.016)	0.611 (0.016)
TSW1	NA	NA	NA	NA	NA
TSW2	NA	NA	NA	NA	NA
2007				Modified 2006 Test Spill	2007 Test Spill
Turbine	0.142 (0.008)	0.145 (0.010)	0.140 (0.015)	0.147 (0.011)	0.138 (0.011)
Bypass	0.288 (0.010)	0.255 (0.012)	0.368 (0.020)	0.255 (0.014)	0.320 (0.015)
Spillway[1]	0.327 (0.011)	0.358 (0.013)	0.249 (0.018)	0.341 (0.016)	0.313 (0.015)
TSW1	0.168 (0.009)	0.161 (0.010)	0.183 (0.016)	0.176 (0.012)	0.160 (0.012)
TSW2	0.076 (0.006)	0.081 (0.007)	0.061 (0.010)	0.082 (0.009)	0.070 (0.008)
2008				Early Season	Late Season
Turbine	0.131 (0.009)	0.119 (0.011)	0.151 (0.016)	0.179 (0.013)	0.055 (0.010)
Bypass	0.212 (0.011)	0.207 (0.014)	0.237 (0.019)	0.257 (0.015)	0.143 (0.015)
Spillway[1]	0.478 (0.013)	0.479 (0.017)	0.458 (0.020)	0.313 (0.016)	0.738 (0.019)
TSW1	0.102 (0.008)	0.112 (0.011)	0.088 (0.013)	0.146 (0.012)	0.031 (0.007)
TSW2	0.077 (0.007)	0.083 (0.009)	0.066 (0.011)	0.105 (0.010)	0.033 (0.008)
2009				NA	NA
Turbine	0.147 (0.010)	0.147 (0.013)	0.146 (0.015)	NA	NA
Bypass	0.316 (0.013)	0.329 (0.017)	0.299 (0.019)	NA	NA
Spillway[1]	0.402 (0.013)	0.405 (0.017)	0.398 (0.020)	NA	NA
TSW1	0.045 (0.006)	0.037 (0.007)	0.055 (0.010)	NA	NA
TSW2	0.091 (0.008)	0.082 (0.010)	0.102 (0.013)	NA	NA

[1]The probability of passing through the spillway also is termed spillway passage efficiency (SPE).

Table 1-14. Route-specific passage probabilities for yearling Chinook salmon by treatment and diel period at McNary Dam, 2006–09.

[Standard error is shown in parentheses; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1- Day	Treatment 1- Night	Treatment 2- Day	Treatment 2- Night
2006	Fish Passage Plan	Fish Passage Plan	2006 Test Spill	2006 Test Spill
Turbine	0.105 (0.016)	0.164 (0.017)	0.073 (0.012)	0.164 (0.019)
Bypass	0.206 (0.021)	0.198 (0.019)	0.262 (0.020)	0.293 (0.023)
Spillway[1]	0.689 (0.024)	0.638 (0.023)	0.665 (0.021)	0.543 (0.025)
TSW1	NA	NA	NA	NA
TSW2	NA	NA	NA	NA
2007	Modified 2006 Test Spill	Modified 2006 Test Spill	2007 Test Spill	2007 Test Spill
Turbine	0.138 (0.013)	0.168 (0.023)	0.151 (0.014)	0.112 (0.018)
Bypass	0.218 (0.016)	0.356 (0.030)	0.291 (0.018)	0.380 (0.028)
Spillway[1]	0.380 (0.019)	0.233 (0.027)	0.336 (0.019)	0.263 (0.026)
TSW1	0.171 (0.014)	0.188 (0.024)	0.151 (0.014)	0.179 (0.022)
TSW2	0.092 (0.011)	0.055 (0.014)	0.071 (0.010)	0.067 (0.014)
2008	Early Season	Early Season	Late Season	Late Season
Turbine	0.166 (0.016)	0.206 (0.024)	0.047 (0.013)	0.063 (0.014)
Bypass	0.228 (0.018)	0.315 (0.027)	0.173 (0.023)	0.115 (0.019)
Spillway[1]	0.342 (0.020)	0.255 (0.026)	0.696 (0.029)	0.776 (0.025)
TSW1	0.153 (0.015)	0.133 (0.020)	0.046 (0.013)	0.017 (0.008)
TSW2	0.111 (0.013)	0.091 (0.017)	0.038 (0.012)	0.028 (0.010)
2009[2]	NA	NA	NA	NA

[1]The probability of passing through the spillway also is termed spillway passage efficiency (SPE).

[2]There were no treatments in 2009.

Table 1-15. Route-specific passage probabilities for juvenile steelhead overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error is shown in parentheses; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2
2006				Fish Passage Plan	2006 Test Spill
Turbine	0.102 (0.010)	0.094 (0.017)	0.107 (0.013)	0.101 (0.015)	0.103 (0.015)
Bypass	0.250 (0.014)	0.164 (0.020)	0.302 (0.019)	0.213 (0.018)	0.289 (0.021)
Spillway[1]	0.648 (0.016)	0.742 (0.024)	0.590 (0.020)	0.686 (0.021)	0.608 (0.023)
TSW1	NA	NA	NA	NA	NA
TSW2	NA	NA	NA	NA	NA
2007				Modified 2006 Test Spill	2007 Test Spill
Turbine	0.043 (0.006)	0.023 (0.006)	0.078 (0.014)	0.043 (0.009)	0.044 (0.009)
Bypass	0.172 (0.011)	0.063 (0.009)	0.364 (0.025)	0.154 (0.015)	0.192 (0.017)
Spillway[1]	0.138 (0.011)	0.114 (0.012)	0.173 (0.020)	0.135 (0.015)	0.141 (0.016)
TSW1	0.468 (0.015)	0.583 (0.019)	0.277 (0.023)	0.470 (0.021)	0.466 (0.022)
TSW2	0.179 (0.012)	0.217 (0.016)	0.109 (0.016)	0.198 (0.017)	0.158 (0.016)
2008				Early Season	Late Season
Turbine	0.083 (0.011)	0.076 (0.018)	0.090 (0.013)	0.091 (0.015)	0.064 (0.013)
Bypass	0.172 (0.011)	0.091 (0.011)	0.275 (0.020)	0.158 (0.013)	0.206 (0.022)
Spillway[1]	0.342 (0.014)	0.310 (0.018)	0.378 (0.021)	0.235 (0.015)	0.595 (0.026)
TSW1	0.166 (0.011)	0.222 (0.017)	0.096 (0.013)	0.210 (0.014)	0.060 (0.013)
TSW2	0.237 (0.013)	0.300 (0.019)	0.160 (0.016)	0.306 (0.017)	0.075 (0.014)
2009				NA	NA
Turbine	0.070 (0.008)	0.087 (0.014)	0.057 (0.009)	NA	NA
Bypass	0.242 (0.013)	0.173 (0.017)	0.293 (0.018)	NA	NA
Spillway[1]	0.342 (0.014)	0.279 (0.020)	0.390 (0.019)	NA	NA
TSW1	0.103 (0.009)	0.109 (0.014)	0.098 (0.012)	NA	NA
TSW2	0.243 (0.013)	0.351 (0.022)	0.163 (0.015)	NA	NA

[1]The probability of passing through the spillway also is termed spillway passage efficiency (SPE).

Table 1-16. Route-specific passage probabilities for juvenile steelhead by treatment and diel period at McNary Dam, 2006–09.

[Standard error is shown in parentheses; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1- Day	Treatment 1- Night	Treatment 2- Day	Treatment 2- Night
2006	Fish Passage Plan	Fish Passage Plan	2006 Test Spill	2006 Test Spill
Turbine	0.105 (0.025)	0.100 (0.018)	0.083 (0.022)	0.116 (0.020)
Bypass	0.170 (0.028)	0.236 (0.024)	0.158 (0.027)	0.372 (0.029)
Spillway[1]	0.725 (0.035)	0.664 (0.027)	0.759 (0.033)	0.513 (0.030)
TSW1	NA	NA	NA	NA
TSW2	NA	NA	NA	NA
2007	Modified 2006 Test Spill	Modified 2006 Test Spill	2007 Test Spill	2007 Test Spill
Turbine	0.026 (0.008)	0.083 (0.021)	0.021 (0.008)	0.073 (0.017)
Bypass	0.051 (0.011)	0.389 (0.037)	0.075 (0.015)	0.338 (0.031)
Spillway[1]	0.129 (0.018)	0.151 (0.028)	0.097 (0.018)	0.196 (0.028)
TSW1	0.556 (0.025)	0.271 (0.034)	0.612 (0.029)	0.282 (0.030)
TSW2	0.238 (0.022)	0.106 (0.024)	0.195 (0.023)	0.111 (0.021)
2008	Early Season	Early Season	Late Season	Late Season
Turbine	0.083 (0.025)	0.099 (0.015)	0.061 (0.017)	0.069 (0.021)
Bypass	0.082 (0.013)	0.248 (0.022)	0.113 (0.022)	0.338 (0.039)
Spillway[1]	0.177 (0.019)	0.305 (0.024)	0.625 (0.034)	0.552 (0.041)
TSW1	0.281 (0.022)	0.126 (0.017)	0.083 (0.019)	0.028 (0.014)
TSW2	0.377 (0.024)	0.222 (0.021)	0.118 (0.023)	0.014 (0.010)
2009[2]	NA	NA	NA	NA

[1]The probability of passing through the spillway also is termed spillway passage efficiency (SPE).

[2]There were no treatments in 2009.

Table 1-17. Route-specific passage probabilities for subyearling Chinook salmon overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error is shown in parentheses; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2	Treatment 3
2006				60% Spill	40% Spill	NA
Turbine	0.265 (0.011)	0.237 (0.013)	0.329 (0.021)	0.220 (0.017)	0.290 (0.014)	NA
Bypass	0.195 (0.010)	0.210 (0.012)	0.161 (0.016)	0.110 (0.013)	0.244 (0.013)	NA
Spillway[1]	0.540 (0.012)	0.552 (0.015)	0.510 (0.023)	0.669 (0.020)	0.466 (0.015)	NA
TSW1	NA	NA	NA	NA	NA	NA
TSW2	NA	NA	NA	NA	NA	NA
2007				60% Spill	40% Spill	NA
Turbine	0.178 (0.009)	0.157 (0.011)	0.216 (0.017)	0.140 (0.012)	0.218 (0.015)	NA
Bypass	0.211 (0.010)	0.234 (0.013)	0.171 (0.015)	0.129 (0.011)	0.297 (0.016)	NA
Spillway[1]	0.341 (0.012)	0.344 (0.015)	0.334 (0.020)	0.425 (0.017)	0.250 (0.016)	NA
TSW1	0.174 (0.009)	0.176 (0.012)	0.171 (0.016)	0.219 (0.014)	0.127 (0.012)	NA
TSW2	0.096 (0.007)	0.090 (0.009)	0.109 (0.013)	0.086 (0.010)	0.107 (0.011)	NA
2008				Early Season	60% Spill	40% Spill
Turbine	0.190 (0.010)	0.189 (0.011)	0.194 (0.018)	0.141 (0.014)	0.125 (0.014)	0.303 (0.019)
Bypass	0.141 (0.008)	0.120 (0.009)	0.193 (0.017)	0.172 (0.016)	0.092 (0.012)	0.156 (0.015)
Spillway[1]	0.498 (0.012)	0.530 (0.014)	0.416 (0.021)	0.595 (0.020)	0.590 (0.021)	0.311 (0.019)
TSW1	0.093 (0.007)	0.091 (0.008)	0.098 (0.013)	0.048 (0.009)	0.110 (0.013)	0.123 (0.014)
TSW2	0.078 (0.007)	0.070 (0.007)	0.098 (0.013)	0.045 (0.009)	0.083 (0.012)	0.107 (0.013)
2009				NA	NA	NA
Turbine	0.188 (0.010)	0.168 (0.012)	0.216 (0.016)	NA	NA	NA
Bypass	0.167 (0.009)	0.168 (0.012)	0.165 (0.014)	NA	NA	NA
Spillway[1]	0.371 (0.012)	0.398 (0.016)	0.334 (0.018)	NA	NA	NA
Spill bays 16–19	0.143 (0.009)	0.127 (0.011)	0.165 (0.014)	NA	NA	NA
TSW2	0.131 (0.008)	0.139 (0.011)	0.120 (0.012)	NA	NA	NA

[1]The probability of passing through the spillway also is termed spillway passage efficiency (SPE).

Table 1-18. Route-specific passage probabilities for subyearling Chinook salmon by treatment and diel period at McNary Dam, 2006–09.

[Standard error is shown in parentheses; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1- Day	Treatment 1- Night	Treatment 2- Day	Treatment 2- Night	Treatment 3- Day	Treatment 3- Night
2006	60% Spill	60% Spill	40% Spill	40% Spill	NA	NA
Turbine	0.202 (0.020)	0.270 (0.035)	0.257 (0.016)	0.363 (0.027)	NA	NA
Bypass	0.108 (0.015)	0.115 (0.025)	0.269 (0.016)	0.188 (0.021)	NA	NA
Spillway[1]	0.689 (0.022)	0.616 (0.039)	0.474 (0.019)	0.450 (0.027)	NA	NA
TSW1	NA	NA	NA	NA	NA	NA
TSW2	NA	NA	NA	NA	NA	NA
2007	60% Spill	60% Spill	40% Spill	40% Spill	NA	NA
Turbine	0.128 (0.014)	0.165 (0.022)	0.188 (0.018)	0.269 (0.026)	NA	NA
Bypass	0.136 (0.014)	0.116 (0.019)	0.339 (0.021)	0.229 (0.024)	NA	NA
Spillway[1]	0.432 (0.021)	0.413 (0.031)	0.251 (0.021)	0.250 (0.026)	NA	NA
TSW1	0.225 (0.018)	0.207 (0.024)	0.123 (0.015)	0.133 (0.020)	NA	NA
TSW2	0.080 (0.011)	0.098 (0.018)	0.100 (0.013)	0.119 (0.019)	NA	NA
2008	Early Season	Early Season	60% Spill	60% Spill	40% Spill	40% Spill
Turbine	0.149 (0.018)	0.125 (0.024)	0.097 (0.015)	0.195 (0.031)	0.318 (0.023)	0.265 (0.035)
Bypass	0.180 (0.019)	0.156 (0.026)	0.057 (0.012)	0.176 (0.030)	0.120 (0.016)	0.247 (0.034)
Spillway[1]	0.574 (0.025)	0.637 (0.035)	0.652 (0.024)	0.441 (0.039)	0.368 (0.024)	0.167 (0.029)
TSW1	0.051 (0.011)	0.042 (0.014)	0.117 (0.016)	0.094 (0.023)	0.108 (0.015)	0.160 (0.029)
TSW2	0.046 (0.011)	0.042 (0.014)	0.078 (0.014)	0.094 (0.023)	0.086 (0.014)	0.160 (0.029)
2009[2]	NA	NA	NA	NA	NA	NA

[1]The probability of passing through the spillway also is termed spillway passage efficiency (SPE).

[2]There were no treatments in 2009.

Fish Passage Efficiency, Guidance Efficiency, and Passage Route Effectiveness

Passage metrics for yearling Chinook salmon varied by diel period, treatment, and year. Fish Passage Efficiency (FPE) and Fish Guidance Efficiency (FGE) were both higher during the day than during the night. Additionally, FGE was higher during the 2006 Test Spill treatment than during the Fish Passage Plan (FPP) treatment (table 1-19). In 2007, TSW1 (spill bay 22) was twice as effective at passing fish as TSW2 (spill bay 20), regardless of treatment or diel period, and TSW and spillway effectiveness combined was 0.405–0.480 higher than spillway effectiveness, depending on treatment and diel period. Due to the high probability of passing through the four non-turbine routes, FPE was more than 85 percent in all 3 years with the TSWs installed and FGE was around 66 percent (0.589–0.725). In 2008, when the TSWs were installed in adjacent spill bays, effectiveness of each TSW was similar, but higher through TSW1 (spill bay 19). TSW and spillway effectiveness combined in 2008 was similar to 2007 and was between 0.199 and 0.403 higher than spillway effectiveness; however, the TSWs did not increase combined effectiveness during the Late Season spill period of 2008 (table 1-19). During 2009, TSW2 (spill bay 20) was more than twice as effective as TSW1 (spill bay 4). The difference between TSW and spillway effectiveness combined and TSW effectiveness was only 0.113–0.195, depending on treatment and diel period. Overall spillway effectiveness of yearling Chinook salmon was 1.267 in 2006 (before the TSWs were installed) and increased by only 0–0.138 (based on TSW and spillway effectiveness combined) in the 3 years when the TSWs were operating, although over a range of operating condition.

Trends were evident in yearling Chinook salmon passage metrics by diel period and treatment combined (table 1-20). The highest fish passage efficiency was during the day when the 2006 Test Spill treatment was occurring. It also was high during the day and night when the 2008 Late Season treatment was occurring. Fish passage efficiency was lowest during the night when the 2008 Early Season treatment was tested. Fish guidance efficiency was higher during the night than day during both treatments in 2007 and the Early Season in 2008. However, FGE was higher during the day during the high flows of the 2008 Late Season. TSW and spillway effectiveness combined ranged from 1.171 to 1.571 in 2007 and 2008 and was higher during the day for all treatments except for the Late Season in 2008. TSW1 effectiveness during the 2008 Late Season at night was 0.838 less than spillway effectiveness but was greater during all other years and diel periods.

Passage metrics of juvenile steelhead were similar to those of yearling Chinook salmon. Fish passage efficiency was 0.898–0.977 depending on year, treatment, or diel period (table 1-21). Fish guidance efficiency was greater at night than during the day (0.093–0.208 higher). There was no difference in FGE between the 2006 or 2007 treatments, but FGE was greater during the 2008 Late Season than during the 2008 Early Season. For all years, TSW1 and TSW2 effectiveness during the day was more than double the effectiveness at night except when TSW1 was located in spill bay 4 during spring 2009. Durning this time, the effectiveness was only 1.15 times higher. The effect of the addition of the TSWs on overall spillway effectiveness was 0.872–1.895 in 2007, 0.141–1.127 in 2008, and 0.429–0.924 in 2009, depending on treatment and diel period.

Passage metrics by treatment and diel periods combined show differences for juvenile steelhead. Regardless of treatment, FGE was always higher at night (table 1-22). Fish passage efficiency was the same between diel periods and treatments in 2006 and 2008, but higher during the day during both treatments in 2007. TSW1 and TSW2 effectiveness during the day were more than double the effectiveness during the night. The effect of the addition of the TSWs on the overall TSW and spillway effectiveness combined was an increase of 0.88–1.920 in 2007 and 0–1.496. The two TSWs did not increase the combined TSW spillway effectiveness during the 2008 Late Season at night.

Passage metrics of subyearling Chinook salmon were fairly consistent within, and even across, years, treatments, and diel periods over the course of the four study years. Fish passage efficiency ranged from 0.671 to 0.843, depending on diel period, and was higher during the day than during the night (table 1-23). After installation of the TSWs, FPE increased from 0.735 overall in 2006 to approximately 0.815. Fish guidance efficiency was higher during the day and ranged from 0.411 to 0.527 overall from 2006 to 2009. Effectiveness of both the TSWs was around 2, but TSW and spillway effectiveness combined was 1.2–1.3; only 0.142–0.376 higher than spillway effectiveness alone. Spillway effectiveness and FPE were higher during 60 percent spill, but FGE and powerhouse effectiveness were higher during 40 percent spill. In spite of the vast difference in flow between treatments, there was no difference in combined TSW and spillway effectiveness between treatments.

Few differences were observed between diel periods for summer treatments. During 60 percent spill, powerhouse effectiveness was greater at night and spillway effectiveness was greater during the day (table 1-24). During 40 percent spill, FPE and FGE were higher during the day in 2006 and 2007, but higher at night during 2008. Combined TSW and spillway effectiveness was similar between diel periods in 2007, but was higher during the day during 60 percent spill in 2008.

Table 1-19. Passage metrics of yearling Chinook salmon overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2
2006				Fish Passage Plan	2006 Test Spill
Fish Passage Efficiency	0.875 (0.008)	0.911 (0.010)	0.836 (0.013)	0.863 (0.012)	0.887 (0.011)
Fish Guidance Efficiency	0.654 (0.019)	0.726 (0.027)	0.602 (0.026)	0.596 (0.029)	0.709 (0.025)
Powerhouse Effectiveness	0.733 (0.023)	0.636 (0.031)	0.836 (0.035)	0.704 (0.034)	0.759 (0.032)
Spillway Effectiveness	1.267 (0.023)	1.375 (0.032)	1.153 (0.034)	1.283 (0.032)	1.253 (0.034)
TSW1 Effectiveness	NA	NA	NA	NA	NA
TSW2 Effectiveness	NA	NA	NA	NA	NA
Both TSWs Effectiveness	NA	NA	NA	NA	NA
TSW and Spill Effectiveness	NA	NA	NA	NA	NA
2007				Modified 2006 Test Spill	2007 Test Spill
Fish Passage Efficiency	0.858 (0.008)	0.855 (0.010)	0.860 (0.015)	0.853 (0.011)	0.862 (0.011)
Fish Guidance Efficiency	0.667 (0.016)	0.638 (0.021)	0.725 (0.026)	0.635 (0.025)	0.698 (0.022)
Powerhouse Effectiveness	0.729 (0.019)	0.677 (0.023)	0.860 (0.036)	0.680 (0.027)	0.776 (0.027)
Spillway Effectiveness	0.919 (0.042)	1.053 (0.039)	0.753 (0.056)	1.008 (0.046)	0.928 (0.045)
TSW1 Effectiveness	4.192 (0.213)	4.025 (0.249)	4.577 (0.408)	4.395 (0.309)	3.995 (0.294)
TSW2 Effectiveness	2.098 (0.169)	2.335 (0.216)	1.748 (0.294)	2.053 (0.223)	2.143 (0.253)
Both TSWs Effectiveness	3.478 (0.140)	3.463 (0.166)	3.486 (0.259)	3.684 (0.203)	3.278 (0.193)
TSW and Spill Effectiveness	1.399 (0.028)	1.465 (0.033)	1.231 (0.053)	1.468 (0.039)	1.333 (0.039)
2008				Early Season	Late Season
Fish Passage Efficiency	0.869 (0.009)	0.881 (0.011)	0.849 (0.016)	0.821 (0.013)	0.945 (0.010)
Fish Guidance Efficiency	0.640 (0.023)	0.634 (0.029)	0.612 (0.035)	0.589 (0.026)	0.721 (0.043)
Powerhouse Effectiveness	0.624 (0.023)	0.601 (0.031)	0.694 (0.037)	0.737 (0.029)	0.447 (0.038)
Spillway Effectiveness	1.177 (0.035)	1.176 (0.044)	1.094 (0.055)	0.979 (0.050)	1.451 (0.037)
TSW1 Effectiveness	2.456 (0.201)	2.845 (0.291)	1.930 (0.279)	3.225 (0.266)	1.244 (0.297)
TSW2 Effectiveness	2.068 (0.199)	2.312 (0.281)	1.681 (0.280)	2.472 (0.247)	1.432 (0.332)
Both TSWs Effectiveness	2.254 (0.134)	2.566 (0.192)	1.808 (0.188)	2.837 (0.167)	1.334 (0.218)
TSW and Spill Effectiveness	1.405 (0.028)	1.450 (0.036)	1.293 (0.047)	1.382 (0.042)	1.441 (0.031)
2009				NA	NA
Fish Passage Efficiency	0.853 (0.010)	0.853 (0.013)	0.854 (0.015)	NA	NA
Fish Guidance Efficiency	0.683 (0.019)	0.690 (0.024)	0.672 (0.029)	NA	NA
Powerhouse Effectiveness	0.835 (0.024)	0.861 (0.032)	0.800 (0.037)	NA	NA
Spillway Effectiveness	1.058 (0.035)	1.059 (0.046)	1.055 (0.054)	NA	NA
TSW1 Effectiveness	1.293 (0.162)	1.082 (0.197)	1.581 (0.272)	NA	NA
TSW2 Effectiveness	2.795 (0.239)	2.577 (0.306)	3.092 (0.381)	NA	NA
Both TSWs Effectiveness	2.038 (0.139)	1.835 (0.178)	2.314 (0.223)	NA	NA
TSW and Spill Effectiveness	1.205 (0.030)	1.172 (0.040)	1.250 (0.047)	NA	NA

Table 1-20. Passage metrics of yearling Chinook salmon by diel period and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1-Day	Treatment 1-Night	Treatment 2-Day	Treatment 2-Night
2006	Fish Passage Plan	Fish Passage Plan	2006 Test Spill	2006 Test Spill
Fish Passage Efficiency	0.895 (0.016)	0.836 (0.017)	0.927 (0.012)	0.836 (0.019)
Fish Guidance Efficiency	0.663 (0.043)	0.548 (0.039)	0.781 (0.032)	0.642 (0.036)
Powerhouse Effectiveness	0.617 (0.047)	0.777 (0.049)	0.654 (0.041)	0.890 (0.049)
Spillway Effectiveness	1.389 (0.048)	1.194 (0.042)	1.364 (0.043)	1.116 (0.052)
TSW1 Effectiveness	NA	NA	NA	NA
TSW2 Effectiveness	NA	NA	NA	NA
Both TSWs Effectiveness	NA	NA	NA	NA
TSW and Spill Effectiveness	NA	NA	NA	NA
2007	Modified 2006 Test Spill	Modified 2006 Test Spill	2007 Test Spill	2007 Test Spill
Fish Passage Efficiency	0.862 (0.013)	0.832 (0.023)	0.849 (0.014)	0.888 (0.018)
Fish Guidance Efficiency	0.611 (0.031)	0.679 (0.040)	0.659 (0.028)	0.773 (0.034)
Powerhouse Effectiveness	0.603 (0.031)	0.888 (0.053)	0.749 (0.033)	0.833 (0.048)
Spillway Effectiveness	1.119 (0.055)	0.707 (0.081)	0.989 (0.054)	0.797 (0.078)
TSW1 Effectiveness	4.285 (0.358)	4.690 (0.610)	3.772 (0.348)	4.466 (0.542)
TSW2 Effectiveness	2.305 (0.275)	1.368 (0.355)	2.364 (0.333)	1.675 (0.353)
Both TSWs Effectiveness	3.766 (0.240)	3.462 (0.383)	3.169 (0.231)	3.509 (0.349)
TSW and Spill Effectiveness	1.571 (0.045)	1.190 (0.078)	1.361 (0.047)	1.272 (0.071)
2008	Early Season	Early Season	Late Season	Late Season
Fish Passage Efficiency	0.834 (0.016)	0.794 (0.024)	0.953 (0.013)	0.937 (0.014)
Fish Guidance Efficiency	0.579 (0.033)	0.604 (0.040)	0.788 (0.054)	0.647 (0.067)
Powerhouse Effectiveness	0.665 (0.035)	0.882 (0.050)	0.500 (0.058)	0.399 (0.051)
Spillway Effectiveness	1.062 (0.062)	0.813 (0.082)	1.357 (0.056)	1.537 (0.049)
TSW1 Effectiveness	3.480 (0.342)	2.711 (0.410)	1.843 (0.520)	0.699 (0.310)
TSW2 Effectiveness	2.719 (0.321)	1.976 (0.370)	1.670 (0.518)	1.216 (0.424)
Both TSWs Effectiveness	3.077 (0.214)	2.355 (0.260)	1.760 (0.359)	0.947 (0.257)
TSW and Spill Effectiveness	1.486 (0.050)	1.171 (0.072)	1.392 (0.046)	1.486 (0.041)
2009[1]	NA	NA	NA	NA

[1]There were no treatments in 2009.

Table 1-21. Passage metrics of juvenile steelhead overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2
2006				Fish Passage Plan	2006 Test Spill
Fish Passage Efficiency	0.898 (0.010)	0.906 (0.017)	0.893 (0.013)	0.899 (0.015)	0.897 (0.015)
Fish Guidance Efficiency	0.707 (0.026)	0.636 (0.053)	0.738 (0.029)	0.677 (0.040)	0.738 (0.034)
Powerhouse Effectiveness	0.711 (0.032)	0.509 (0.047)	0.833 (0.041)	0.659 (0.045)	0.765 (0.045)
Spillway Effectiveness	1.284 (0.031)	1.507 (0.048)	1.149 (0.040)	1.320 (0.041)	1.247 (0.047)
TSW1 Effectiveness	NA	NA	NA	NA	NA
TSW2 Effectiveness	NA	NA	NA	NA	NA
Both TSWs Effectiveness	NA	NA	NA	NA	NA
TSW and Spill Effectiveness	NA	NA	NA	NA	NA
2007				Modified 2006 Test Spill	2007 Test Spill
Fish Passage Efficiency	0.957 (0.006)	0.977 (0.006)	0.922 (0.014)	0.957 (0.009)	0.956 (0.009)
Fish Guidance Efficiency	0.798 (0.026)	0.731 (0.058)	0.824 (0.029)	0.782 (0.039)	0.815 (0.035)
Powerhouse Effectiveness	0.365 (0.021)	0.146 (0.018)	0.749 (0.043)	0.333 (0.028)	0.399 (0.031)
Spillway Effectiveness	0.573 (0.052)	0.334 (0.037)	0.523 (0.060)	0.402 (0.044)	0.423 (0.048)
TSW1 Effectiveness	11.694 (0.379)	14.58 (0.476)	6.916 (0.568)	11.745 (0.529)	11.64 (0.548)
TSW2 Effectiveness	4.903 (0.323)	6.219 (0.467)	3.171 (0.477)	4.957 (0.422)	4.846 (0.493)
Both TSWs Effectiveness	9.234 (0.208)	11.435 (0.222)	5.503 (0.354)	9.544 (0.287)	8.904 (0.306)
TSW and Spill Effectiveness	1.926 (0.031)	2.229 (0.026)	1.395 (0.063)	1.970 (0.041)	1.880 (0.046)
2008				Early Season	Late Season
Fish Passage Efficiency	0.917 (0.011)	0.924 (0.018)	0.910 (0.013)	0.909 (0.015)	0.936 (0.013)
Fish Guidance Efficiency	0.674 (0.035)	0.545 (0.071)	0.753 (0.031)	0.636 (0.047)	0.763 (0.044)
Powerhouse Effectiveness	0.476 (0.026)	0.314 (0.036)	0.684 (0.040)	0.420 (0.030)	0.609 (0.054)
Spillway Effectiveness	0.916 (0.039)	0.748 (0.046)	1.007 (0.059)	0.741 (0.048)	1.166 (0.052)
TSW1 Effectiveness	3.979 (0.272)	5.476 (0.422)	2.128 (0.295)	4.646 (0.320)	2.407 (0.509)
TSW2 Effectiveness	6.026 (0.331)	7.982 (0.511)	3.564 (0.356)	7.204 (0.389)	3.247 (0.613)
Both TSWs Effectiveness	4.933 (0.188)	6.620 (0.281)	2.824 (0.212)	5.833 (0.210)	2.810 (0.381)
TSW and Spill Effectiveness	1.681 (0.033)	1.875 (0.047)	1.439 (0.048)	1.840 (0.044)	1.307 (0.043)
2009				NA	NA
Fish Passage Efficiency	0.930 (0.008)	0.913 (0.014)	0.943 (0.009)	NA	NA
Fish Guidance Efficiency	0.775 (0.023)	0.665 (0.044)	0.836 (0.025)	NA	NA
Powerhouse Effectiveness	0.562 (0.025)	0.471 (0.037)	0.629 (0.034)	NA	NA
Spillway Effectiveness	0.904 (0.037)	0.730 (0.053)	1.035 (0.051)	NA	NA
TSW1 Effectiveness	2.972 (0.261)	3.219 (0.418)	2.786 (0.333)	NA	NA
TSW2 Effectiveness	7.515 (0.395)	10.971 (0.680)	4.925 (0.440)	NA	NA
Both TSWs Effectiveness	5.221 (0.214)	7.085 (0.350)	3.824 (0.254)	NA	NA
TSW and Spill Effectiveness	1.545 (0.031)	1.654 (0.045)	1.464 (0.042)	NA	NA

Table 1-22. Passage metrics of juvenile steelhead by diel period and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1-Day	Treatment 1-Night	Treatment 2-Day	Treatment 2-Night
2006	Fish Passage Plan	Fish Passage Plan	2006 Test Spill	2006 Test Spill
Fish Passage Efficiency	0.895 (0.025)	0.900 (0.018)	0.917 (0.022)	0.884 (0.020)
Fish Guidance Efficiency	0.619 (0.074)	0.703 (0.047)	0.657 (0.077)	0.763 (0.038)
Powerhouse Effectiveness	0.546 (0.069)	0.721 (0.058)	0.470 (0.064)	0.949 (0.058)
Spillway Effectiveness	1.462 (0.070)	1.243 (0.051)	1.557 (0.067)	1.054 (0.061)
TSW1 Effectiveness	NA	NA	NA	NA
TSW2 Effectiveness	NA	NA	NA	NA
Both TSWs Effectiveness	NA	NA	NA	NA
TSW and Spill Effectiveness	NA	NA	NA	NA
2007	Modified 2006 Test Spill	Modified 2006 Test Spill	2007 Test Spill	2007 Test Spill
Fish Passage Efficiency	0.974 (0.008)	0.917 (0.021)	0.979 (0.008)	0.927 (0.017)
Fish Guidance Efficiency	0.667 (0.086)	0.825 (0.042)	0.786 (0.077)	0.823 (0.039)
Powerhouse Effectiveness	0.130 (0.023)	0.800 (0.065)	0.162 (0.029)	0.696 (0.055)
Spillway Effectiveness	0.378 (0.052)	0.457 (0.085)	0.286 (0.052)	0.593 (0.085)
TSW1 Effectiveness	13.903 (0.633)	6.781 (0.854)	15.30 (0.714)	7.059 (0.742)
TSW2 Effectiveness	5.958 (0.540)	2.653 (0.591)	6.496 (0.772)	2.781 (0.516)
Both TSWs Effectiveness	11.349 (0.298)	5.391 (0.532)	11.527 (0.331)	5.623 (0.463)
TSW and Spill Effectiveness	2.252 (0.033)	1.321 (0.096)	2.206 (0.042)	1.473 (0.082)
2008	Early Season	Early Season	Late Season	Late Season
Fish Passage Efficiency	0.917 (0.025)	0.901 (0.015)	0.939 (0.017)	0.931 (0.021)
Fish Guidance Efficiency	0.498 (0.091)	0.715 (0.040)	0.651 (0.081)	0.831 (0.049)
Powerhouse Effectiveness	0.280 (0.044)	0.588 (0.042)	0.395 (0.061)	0.910 (0.091)
Spillway Effectiveness	0.549 (0.057)	0.971 (0.076)	1.219 (0.066)	1.093 (0.082)
TSW1 Effectiveness	6.383 (0.504)	2.563 (0.350)	3.334 (0.774)	1.103 (0.544)
TSW2 Effectiveness	9.191 (0.597)	4.821 (0.467)	5.131 (0.984)	0.599 (0.421)
Both TSWs Effectiveness	7.648 (0.315)	3.656 (0.259)	4.195 (0.586)	0.862 (0.344)
TSW and Spill Effectiveness	2.045 (0.064)	1.595 (0.060)	1.474 (0.048)	1.073 (0.074)
2009[1]	NA	NA	NA	NA

[1]There were no treatments in 2009.

Table 1-23. Passage metrics of subyearling Chinook salmon overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2	Treatment 3
2006				60% Spill	40% Spill	NA
Fish Passage Efficiency	0.735 (0.011)	0.763 (0.013)	0.671 (0.021)	0.780 (0.017)	0.710 (0.014)	NA
Fish Guidance Efficiency	0.411 (0.018)	0.470 (0.022)	0.329 (0.030)	0.333 (0.033)	0.456 (0.021)	NA
Powerhouse Effectiveness	0.869 (0.024)	0.837 (0.028)	0.949 (0.046)	0.799 (0.047)	0.909 (0.026)	NA
Spillway Effectiveness	1.135 (0.027)	1.169 (0.032)	1.052 (0.048)	1.142 (0.033)	1.130 (0.037)	NA
TSW1 Effectiveness	NA	NA	NA	NA	NA	NA
TSW2 Effectiveness	NA	NA	NA	NA	NA	NA
Both TSWs Effectiveness	NA	NA	NA	NA	NA	NA
TSW and Spill Effectiveness	NA	NA	NA	NA	NA	NA
2007				60% Spill	40% Spill	NA
Fish Passage Efficiency	0.822 (0.009)	0.843 (0.011)	0.784 (0.017)	0.860 (0.012)	0.782 (0.015)	NA
Fish Guidance Efficiency	0.527 (0.021)	0.599 (0.024)	0.442 (0.033)	0.480 (0.033)	0.577 (0.024)	NA
Powerhouse Effectiveness	0.779 (0.025)	0.780 (0.031)	0.781 (0.043)	0.691 (0.039)	0.874 (0.031)	NA
Spillway Effectiveness	0.814 (0.039)	0.828 (0.039)	0.829 (0.053)	0.840 (0.034)	0.818 (0.053)	NA
TSW1 Effectiveness	3.290 (0.176)	3.514 (0.231)	2.855 (0.262)	4.149 (0.270)	2.373 (0.221)	NA
TSW2 Effectiveness	1.925 (0.145)	1.790 (0.175)	2.172 (0.258)	1.723 (0.192)	2.141 (0.219)	NA
Both TSWs Effectiveness	2.618 (0.106)	2.652 (0.135)	2.545 (0.171)	2.958 (0.154)	2.254 (0.145)	NA
TSW and Spill Effectiveness	1.190 (0.025)	1.182 (0.031)	1.200 (0.041)	1.198 (0.025)	1.181 (0.044)	NA
2008				Early Season	60% Spill	40% Spill
Fish Passage Efficiency	0.810 (0.010)	0.811 (0.011)	0.806 (0.018)	0.859 (0.014)	0.875 (0.014)	0.697 (0.019)
Fish Guidance Efficiency	0.438 (0.022)	0.389 (0.025)	0.498 (0.036)	0.549 (0.037)	0.423 (0.045)	0.340 (0.029)
Powerhouse Effectiveness	0.662 (0.023)	0.722 (0.034)	1.090 (0.068)	0.640 (0.039)	0.557 (0.045)	0.786 (0.036)
Spillway Effectiveness	1.130 (0.029)	1.208 (0.034)	0.926 (0.048)	1.308 (0.045)	1.135 (0.041)	0.942 (0.059)
TSW1 Effectiveness	2.276 (0.176)	2.281 (0.213)	2.291 (0.311)	1.642 (0.303)	2.462 (0.300)	2.746 (0.308)
TSW2 Effectiveness	2.052 (0.175)	1.898 (0.206)	2.450 (0.333)	1.635 (0.314)	1.968 (0.281)	2.558 (0.310)
Both TSWs Effectiveness	2.170 (0.119)	2.107 (0.144)	2.352 (0.212)	1.652 (0.214)	2.217 (0.195)	2.655 (0.204)
TSW and Spill Effectiveness	1.313 (0.023)	1.353 (0.027)	1.207 (0.044)	1.344 (0.038)	1.290 (0.029)	1.301 (0.050)
2009				NA	NA	NA
Fish Passage Efficiency	0.812 (0.010)	0.832 (0.012)	0.784 (0.016)	NA	NA	NA
Fish Guidance Efficiency	0.470 (0.021)	0.500 (0.028)	0.433 (0.031)	NA	NA	NA
Powerhouse Effectiveness	0.726 (0.024)	0.685 (0.032)	0.782 (0.038)	NA	NA	NA
Spillway Effectiveness	1.092 (0.035)	1.160 (0.047)	0.999 (0.054)	NA	NA	NA
Spill bays 16–19 Effectiveness	1.172 (0.071)	1.070 (0.092)	1.312 (0.113)	NA	NA	NA
TSW2 Effectiveness	2.665 (0.171)	2.898 (0.236)	2.344 (0.244)	NA	NA	NA
Both TSWs Effectiveness	NA	NA	NA	NA	NA	NA
TSW and Spill Effectiveness	1.263 (0.023)	1.302 (0.030)	1.208 (0.036)	NA	NA	NA

Table 1-24. Passage metrics of subyearling Chinook salmon by diel period and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1-Day	Treatment 1-Night	Treatment 2-Day	Treatment 2-Night	Treatment 3-Night	Treatment 3-Night
2006	60% Spill	60% Spill	40% Spill	40% Spill	NA	NA
Fish Passage Efficiency	0.798 (0.020)	0.730 (0.035)	0.743 (0.016)	0.637 (0.027)	NA	NA
Fish Guidance Efficiency	0.349 (0.041)	0.299 (0.058)	0.511 (0.026)	0.341 (0.035)	NA	NA
Powerhouse Effectiveness	0.749 (0.054)	0.935 (0.095)	0.888 (0.031)	0.957 (0.048)	NA	NA
Spillway Effectiveness	1.178 (0.038)	1.044 (0.066)	1.163 (0.046)	1.056 (0.064)	NA	NA
TSW1 Effectiveness	NA	NA	NA	NA	NA	NA
TSW2 Effectiveness	NA	NA	NA	NA	NA	NA
Both TSWs Effectiveness	NA	NA	NA	NA	NA	NA
TSW and Spill Effectiveness	NA	NA	NA	NA	NA	NA
2007	60% Spill	60% Spill	40% Spill	40% Spill	NA	NA
Fish Passage Efficiency	0.872 (0.014)	0.835 (0.022)	0.812 (0.018)	0.731 (0.026)	NA	NA
Fish Guidance Efficiency	0.515 (0.041)	0.412 (0.055)	0.644 (0.029)	0.460 (0.041)	NA	NA
Powerhouse Effectiveness	0.676 (0.048)	0.721 (0.069)	0.892 (0.039)	0.844 (0.050)	NA	NA
Spillway Effectiveness	0.847 (0.042)	0.826 (0.062)	0.809 (0.068)	0.832 (0.088)	NA	NA
TSW1 Effectiveness	4.491 (0.351)	3.458 (0.405)	2.470 (0.295)	2.211 (0.327)	NA	NA
TSW2 Effectiveness	1.601 (0.227)	1.969 (0.355)	1.992 (0.268)	2.388 (0.375)	NA	NA
Both TSWs Effectiveness	3.046 (0.194)	2.781 (0.253)	2.231 (0.188)	2.292 (0.229)	NA	NA
TSW and Spill Effectiveness	1.207 (0.030)	1.178 (0.044)	1.156 (0.056)	1.224 (0.072)	NA	NA
2008	Early Season	Early Season	60% Spill	60% Spill	40% Spill	40% Spill
Fish Passage Efficiency	0.851 (0.018)	0.875 (0.024)	0.903 (0.015)	0.805 (0.031)	0.682 (0.023)	0.735 (0.035)
Fish Guidance Efficiency	0.547 (0.044)	0.556 (0.068)	0.371 (0.063)	0.475 (0.065)	0.274 (0.033)	0.482 (0.055)
Powerhouse Effectiveness	0.673 (0.049)	0.573 (0.067)	0.388 (0.046)	0.966 (0.100)	0.751 (0.042)	0.874 (0.067)
Spillway Effectiveness	1.259 (0.055)	1.409 (0.078)	1.256 (0.047)	0.841 (0.075)	1.111 (0.072)	0.514 (0.090)
TSW1 Effectiveness	1.769 (0.385)	1.384 (0.480)	2.649 (0.371)	2.006 (0.493)	2.451 (0.349)	3.489 (0.627)
TSW2 Effectiveness	1.710 (0.394)	1.483 (0.514)	1.895 (0.332)	2.143 (0.527)	2.092 (0.338)	3.732 (0.671)
Both TSWs Effectiveness	1.773 (0.273)	1.408 (0.338)	2.286 (0.237)	2.050 (0.337)	2.278 (0.230)	3.607 (0.412)
TSW and Spill Effectiveness	1.311 (0.047)	1.408 (0.064)	1.401 (0.030)	1.021 (0.062)	1.350 (0.059)	1.178 (0.095)
2009[1]	NA	NA	NA	NA	NA	NA

[1]There were no treatments in 2009.

Route-Specific Survival Probabilities (Single-Release)

Single-release route-specific survival probabilities for yearling Chinook salmon varied by year and diel period. Overall survival through the pool and forebay was high (98–100 percent), and similar between years, but the control group had lower survival in 2006 and 2009 (table 1-25). Survival of yearling Chinook salmon through the turbines was 0.043–0.106 lower than survival through the bypass or spillway during all years. Survival through the TSWs varied by location, design, and water year. The highest survival through TSW1 was in 2009 when it was located in spill bay 4 (0.984), and the highest survival through TSW2 was in 2008 when it was located in spill bay 20 (0.965). Turbine survival was higher during the night and spillway survival was higher during the day for all years. Survival through all routes was highest during the 2006 Test Spill and 2008 Late Season and lowest during both treatments in 2007 (table 1-26). Turbine survival was less than 0.835 during the Fish Passage Plan treatment of 2006, Modified 2006 Test Spill, and during both 2008 study periods. Fish survival through the TSWs was less than or equal to 0.900 during 2007 Test Spill for TSW1 and 2008 Early Season for TSW2, but greater than 0.933 during the other treatments in 2007 and 2008.

When comparing single-release survival by diel period by treatment for yearling Chinook salmon, few trends were evident. Survival through all routes was higher at night for the 2006 Fish Passage Plan, Modified 2006 Test Spill, and the 2008 Early Season, but was higher during the day for the remaining treatments in each of the years (table 1-27). Survival of control fish was similar between diel periods and treatments except in 2006 when survival was higher at night. Similar to overall survival, survival through the turbines was higher during the night, and survival through the spillway and bypass was higher during the day during all treatments. There were few differences in survival through the TSWs by treatment and diel period for yearling Chinook salmon.

Single-release survival probabilities for juvenile steelhead at McNary Dam differed very little overall, by diel period, or by treatment. Overall survival through all routes was lower in 2007 than in the other three study years, and survival through the pool and forebay were similar between years (fig. 1-12; table 1-28). Survival through the TSWs was lowest through TSW1 in 2007, but similar between 2008 and 2009 and for TSW2 in all years. Although survival was low through the turbines for juvenile steelhead, passage probability through the turbines was less than 0.102. High passage through the spillway in 2006 resulted in high survival estimates and the highest survival through all routes among the 4 years. Similar to yearling Chinook salmon, turbine survival for juvenile steelhead was higher during the night and bypass and spillway survival were higher during the day. Survival through all routes differed between treatments in 2006, but was similar in 2007 and 2008 (table 1-29). Turbine, bypass, and spillway survival were lowest during the Modified 2006 Test Spill and 2007 Test Spill and turbine survival also was low during the 2008 Early Season.

Single-release survival probabilities for juvenile steelhead by treatment by diel period were similar during all four study years. Survival through all passage routes differed only between diel periods during the 2007 Test Spill (day was higher), and the 2008 Early Season (night was higher; table 1-30). Survival of juvenile steelhead after passing through the turbines was lowest during the day of Modified 2006 Test Spill (0.415) and 2008 Early Season (0.420), and during the night of 2007 Test Spill (0.609). Bypass survival was lowest during the day of 2007 Test Spill (0.754) and highest during the remaining 5-day treatments, night 2006 Test Spill, and night 2008 Late Season. Spill survival was greater than 0.931 for all diel treatments except during both 2007 night treatments when survival was less than 0.88. Survival through the TSWs was lowest for TSW1 during Modified 2006 Test Spill at night. Small sample sizes of juvenile steelhead lead to a wide variation in single-release survival estimates.

Single-release survival of subyearling Chinook salmon varied by year, diel period, and treatment. Survival through all routes of passage, pool, and control, were similar among years, but lowest during 2009, and at night during all years (table 1-31). Trends in survival among passage routes were similar during the four study years. Turbine survival in 2008 was higher during the night, but was similar between diel periods in all other years. Bypass survival was higher during the night in 2006, 2007, and 2008, but was higher during the day in 2009. Survival through TSW2 (spill bay 20) was highest during the day in all 3 years but survival through TSW1 was higher during the day, compared to night, only in 2007. Only survival through the spillway and TSW2 differed between treatments in 2007; both were higher during 60 percent spill than during 40 percent spill (table 1-32). During the Early Season in 2008, all survival estimates except TSW2 survival were substantially higher than during either 60 percent spill or 40 percent spill.

Subyearling Chinook salmon survival by diel period by treatment is shown in table 1-33. During the 60 percent spill treatment in 2006, 2007, and 2008, all survival probabilities were higher during the day than night, except in 2008 for the turbines (0.572 day; 0.911 night), and TSW1 (0.829 day; 0.874 night). Similarly, all 40 percent spill treatment survival probabilities were equal or higher during the day than during the night, except in 2008 for the turbines (0.670 day; 0.755 night), bypass (0.803 day; 0.837 night), and TSW1 (0.894 day; 0.936 night), however, sample sizes were small in each 2008 group.

Table 1-25. Route-specific (single-release) survival probabilities for yearling Chinook salmon overall and by diel period at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night
		2006	
All Routes	0.938 (0.007)	0.942 (0.009)	0.933 (0.010)
Pool	0.978 (0.004; 0.970, 0.984)	NA	NA
Forebay	0.990 (0.003; 0.984, 0.994)	NA	NA
Control	0.977 (0.006)	0.957 (0.009)	0.998 (0.007)
Turbine	0.839 (0.026)	0.735 (0.052)	0.892 (0.028)
Bypass	0.945 (0.012)	0.950 (0.017)	0.941 (0.018)
Spillway	0.954 (0.007)	0.966 (0.009)	0.941 (0.012)
TSW1	NA	NA	NA
TSW2	NA	NA	NA
		2007	
All Routes	0.921 (0.011)	0.919 (0.013)	0.926 (0.018)
Pool	0.987 (0.003; 0.981, 0.993)	NA	NA
Forebay	0.991 (0.003; 0.984, 0.995)	NA	NA
Control	0.991 (0.012)	1.002 (0.014)	0.980 (0.015)
Turbine	0.824 (0.029)	0.781 (0.036)	0.933 (0.044)
Bypass	0.916 (0.018)	0.917 (0.023)	0.916 (0.028)
Spillway	0.960 (0.016)	0.971 (0.017)	0.923 (0.034)
TSW1	0.935 (0.022)	0.933 (0.027)	0.941 (0.037)
TSW2	0.922 (0.033)	0.919 (0.038)	0.936 (0.063)
		2008	
All Routes	0.943 (0.007)	0.937 (0.009)	0.958 (0.010)
Pool	0.989 (0.003; 0.983, 0.994)	NA	NA
Forebay	0.999 (0.001; 0.996, 1.001)	NA	NA
Control	0.989 (0.005)	0.984 (0.008)	0.993 (0.007)
Turbine	0.903 (0.024)	0.861 (0.037)	0.960 (0.026)
Bypass	0.946 (0.015)	0.945 (0.019)	0.954 (0.022)
Spillway	0.956 (0.009)	0.964 (0.011)	0.950 (0.016)
TSW1	0.906 (0.026)	0.872 (0.035)	0.990 (0.024)
TSW2	0.965 (0.020)	0.954 (0.028)	0.980 (0.032)
		2009	
All Routes	0.946 (0.006)	0.946 (0.008)	0.944 (0.010)
Pool	0.978 (0.004; 0.970, 0.985)	NA	NA
Forebay	0.996 (0.002; 0.990, 0.999)	NA	NA
Control	0.972 (0.006)	0.962 (0.009; 0.942, 0.978)	0.984 (0.006; 0.969, 0.994)
Turbine	0.879 (0.023)	0.851 (0.034; 0.777, 0.909)	0.918 (0.030; 0.847, 0.965)
Bypass	0.955 (0.010)	0.959 (0.013; 0.930, 0.979)	0.950 (0.017; 0.910, 0.976)
Spillway	0.954 (0.009)	0.970 (0.010; 0.947, 0.986)	0.932 (0.017; 0.894, 0.960)
TSW1	0.984 (0.016)	0.967 (0.034; 0.858, 1.000)	[1]1.000
TSW2	0.961 (0.018)	0.940 (0.030; 0.864, 0.982)	0.985 (0.017; 0.929, 1.001)

[1]Survival probability and confidence limits were not estimable using maximum likelihood methods because we detected 100 percent of the fish passing this route at downstream detection arrays. Although the modeling software could not produce an estimate, our best estimate of survival is 100 percent. Variance from parameter not accounted for in other estimates derived from this parameter.

Table 1-26. Route-specific (single-release) survival probabilities for yearling Chinook salmon by treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable]

Passage route	Treatment 1	Treatment 2
2006	Fish Passage Plan	2006 Test Spill
All Routes	0.925 (0.010)	0.949 (0.008)
Control	0.983 (0.007)	0.972 (0.008)
Turbine	0.782 (0.040)	0.902 (0.032)
Bypass	0.947 (0.019)	0.943 (0.016)
Spillway	0.948 (0.011)	0.960 (0.010)
TSW1	NA	NA
TSW2	NA	NA
2007	Modified 2006 Test Spill	2007 Test Spill
All Routes	0.923 (0.014)	0.919 (0.015)
Control	0.994 (0.014)	0.987 (0.015)
Turbine	0.834 (0.039)	0.927 (0.024)
Bypass	0.917 (0.026)	0.944 (0.017)
Spillway	0.956 (0.021)	0.929 (0.017)
TSW1	0.933 (0.030)	0.900 (0.028)
TSW2	0.943 (0.042)	0.967 (0.022)
2008	Early Season	Late Season
All Routes	0.932 (0.010)	0.959 (0.010)
Control	0.982 (0.007)	0.998 (0.008)
Turbine	0.815 (0.041)	0.782 (0.079)
Bypass	0.915 (0.024)	0.953 (0.028)
Spillway	0.965 (0.022)	0.974 (0.011)
TSW1	0.937 (0.031)	0.950 (0.058)
TSW2	0.898 (0.051)	0.951 (0.054)
2009[1]	NA	NA

[1]There were no treatments in 2009.

Table 1-27. Route-specific (single-release) survival probabilities for yearling Chinook salmon by diel period and treatment at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours; No yearling Chinook salmon were released in 2009]

Passage route	Treatment 1-Day	Treatment 1-Night	Treatment 2-Day	Treatment 2-Night
2006	Fish Passage Plan	Fish Passage Plan	2006 Test Spill	2006 Test Spill
All Routes	0.927 (0.014)	0.924 (0.014)	0.955 (0.011)	0.942 (0.013)
Control	0.953 (0.014; 0.922, 0.976)	1.013 (0.005; 0.998, 1.022)	0.962 (0.012; 0.935, 0.982)	0.983 (0.011; 0.957, 1.001)
Turbine	0.633 (0.077; 0.477, 0.773)	0.863 (0.042; 0.769, 0.932)	0.872 (0.058; 0.734, 0.960)	0.919 (0.037; 0.831, 0.975)
Bypass	0.961 (0.025; 0.897, 0.996)	0.935 (0.029; 0.867, 0.979)	0.943 (0.022; 0.890, 0.978)	0.944 (0.024; 0.888, 0.981)
Spillway	0.962 (0.014)	0.936 (0.016)	0.969 (0.011)	0.947 (0.017)
TSW1	NA	NA	NA	NA
TSW2	NA	NA	NA	NA
2007	Modified 2006 Test Spill	Modified 2006 Test Spill	2007 Test Spill	2007 Test Spill
All Routes	0.917 (0.016)	0.939 (0.025)	0.922 (0.017)	0.913 (0.024)
Control	0.993 (0.019; 0.953, 1.029)	0.995 (0.019; 0.956, 1.029)	1.009 (0.018; 0.972, 1.042)	0.965 (0.022; 0.919, 1.006)
Turbine	0.788 (0.049; 0.685, 0.877)	0.936 (0.058; 0.802, 1.027)	0.775 (0.050; 0.671, 0.867)	0.929 (0.065; 0.777, 1.027)
Bypass	0.908 (0.033; 0.838, 0.967)	0.933 (0.041; 0.843, 1.002)	0.924 (0.030; 0.862, 0.978)	0.901 (0.038; 0.820, 0.968)
Spillway	0.963 (0.022; 0.916, 1.003)	0.923 (0.051; 0.808, 1.008)	0.980 (0.024; 0.929, 1.023)	0.922 (0.044; 0.826, 0.996)
TSW1	0.926 (0.035; 0.849, 0.987)	0.952 (0.053; 0.829, 1.034)	0.941 (0.039; 0.856, 1.008)	0.929 (0.051; 0.812, 1.012)
TSW2	0.928 (0.047; 0.821, 1.006)	1.010 (0.075; 0.785, 1.090)	0.908 (0.060; 0.772, 1.007)	0.877 (0.093; 0.662, 1.016)
2008	Early Season	Early Season	Late Season	Late Season
All Routes	0.918 (0.012)	0.962 (0.014)	0.967 (0.013)	0.952 (0.016)
Control	0.979 (0.010; 0.955, 0.996)	0.986 (0.009; 0.963, 1.000)	0.993 (0.014; 0.958, 1.015)	1.003 (0.009; 0.980, 1.016)
Turbine	0.893 (0.035; 0.814, 0.950)	0.981 (0.024; 0.912, 1.011)	0.676 (0.138; 0.392, 0.894)	0.854 (0.090; 0.638, 0.979)
Bypass	0.934 (0.023; 0.879, 0.972)	0.959 (0.025; 0.898, 0.996)	0.969 (0.031; 0.881, 1.006)	0.931 (0.051; 0.800, 1.001)
Spillway	0.928 (0.020; 0.884, 0.962)	0.932 (0.033; 0.854, 0.982)	0.991 (0.011; 0.962, 1.008)	0.960 (0.017; 0.921, 0.988)
TSW1	0.862 (0.038; 0.777, 0.926)	0.989 (0.026; 0.903, 1.016)	0.929 (0.081; 0.691, 1.009)	[1]1.000
TSW2	0.964 (0.027; 0.893, 0.999)	0.977 (0.038; 0.855, 1.014)	0.912 (0.096; 0.637, 1.008)	[1]1.000
2009[2]	NA	NA	NA	NA

[1]Survival probability and confidence limits were not estimable using maximum likelihood methods because we detected 100 percent of the fish passing this route at downstream detection arrays. Although the modeling software could not produce an estimate, our best estimate of survival is 100 percent. Variance from parameter is not accounted for in other estimates derived from this parameter.

[2]There were no treatments in 2009.

Table 1-28. Route-specific (single-release) survival probabilities for juvenile steelhead overall and by diel period at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night
		2006	
All Routes	0.973 (0.010)	0.979 (0.014)	0.970 (0.012)
Pool	0.967 (0.006; 0.955, 0.978)	NA	NA
Forebay	0.995 (0.003; 0.988, 1.000)	NA	NA
Control	NA	NA	NA
Turbine	0.887 (0.040)	0.833 (0.078)	0.912 (0.045)
Bypass	0.976 (0.016)	1.000	0.969 (0.020)
Spillway	0.986 (0.011)	0.993 (0.016)	0.981 (0.013)
TSW1	NA	NA	NA
TSW2	NA	NA	NA
		2007	
All Routes	0.897 (0.013)	0.918 (0.015)	0.866 (0.021)
Pool	0.980 (0.005; 0.970, 0.988)	NA	NA
Forebay	0.995 (0.003; 0.987, 1.000)	NA	NA
Control	NA	NA	NA
Turbine	0.684 (0.072)	0.607 (0.127)	0.762 (0.081)
Bypass	0.859 (0.029)	0.807 (0.068)	0.879 (0.032)
Spillway	0.891 (0.031)	0.959 (0.027)	0.828 (0.052)
TSW1	0.906 (0.017)	0.914 (0.019)	0.868 (0.038)
TSW2	0.967 (0.020)	0.973 (0.022)	0.948 (0.044)
		2008	
All Routes	0.954 (0.011)	0.940 (0.018)	0.972 (0.010)
Pool	0.981 (0.004; 0.972, 0.988)	NA	NA
Forebay	1.008 (0.008; 0.996, 1.040)	NA	NA
Control	0.964 (0.009)	0.973 (0.012)	0.955 (0.012)
Turbine	0.664 (0.085)	0.543 (0.132)	0.785 (0.063)
Bypass	0.992 (0.011)	1.000	0.990 (0.016)
Spillway	0.987 (0.010)	0.965 (0.017)	1.010 (0.010)
TSW1	0.972 (0.016)	0.983 (0.016)	0.941 (0.038)
TSW2	0.967 (0.014)	0.964 (0.017)	0.974 (0.024)
		2009	
All Routes	0.943 (0.007)	0.943 (0.012)	0.944 (0.009)
Pool	0.969 (0.005; 0.958, 0.978)	NA	NA
Forebay	0.997 (0.003; 0.990, 1.003)	NA	NA
Control	0.947 (0.008)	0.961 (0.010; 0.938, 0.977)	0.937 (0.012; 0.909, 0.958)
Turbine	0.808 (0.051)	0.780 (0.079; 0.607, 0.906)	0.839 (0.061; 0.699, 0.933)
Bypass	0.957 (0.012)	0.954 (0.023; 0.894, 0.986)	0.959 (0.015; 0.924, 0.982)
Spillway	0.942 (0.012)	0.942 (0.020; 0.894, 0.974)	0.942 (0.015; 0.908, 0.966)
TSW1	0.967 (0.017)	0.982 (0.019; 0.921, 1.000)	0.954 (0.027; 0.882, 0.989)
TSW2	0.961 (0.012)	0.966 (0.014; 0.931, 0.987)	0.954 (0.021; 0.902, 0.984)

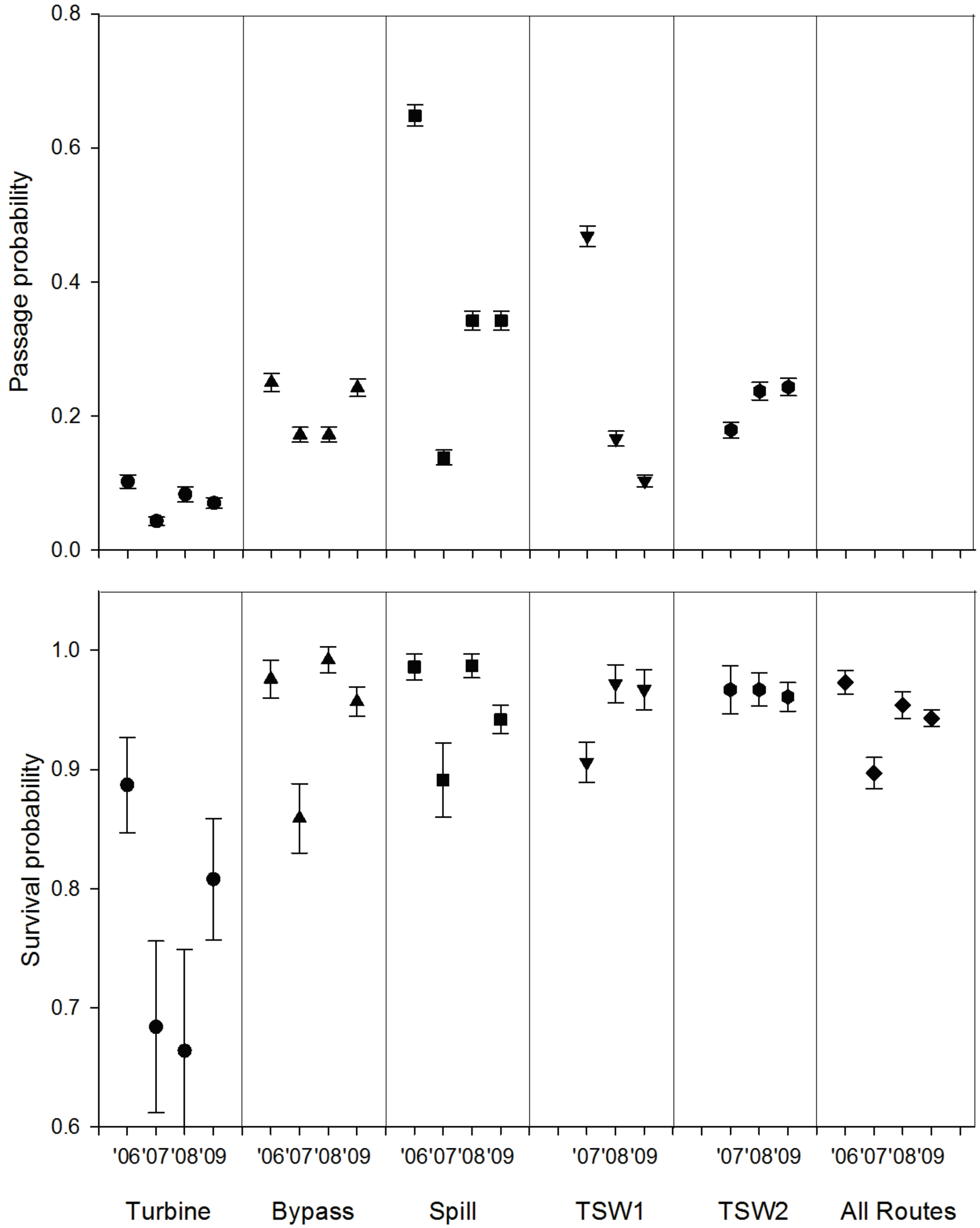

Figure 1-12. Passage (top plate) and single-release survival probabilities (bottom plate) of juvenile steelhead by passage route at McNary Dam, 2006–09. Whisker bars represent the standard error.

Table 1-29. Route-specific (single-release) survival probabilities for juvenile steelhead by treatment at McNary Dam, 2006–09.

[Standard error are shown in parenthesis; NA, not applicable]

Passage route	Treatment 1	Treatment 2
2006	Fish Passage Plan	2006 Test Spill
All Routes	0.953 (0.013)	0.995 (0.014)
Control	NA	NA
Turbine	0.888 (0.053)	0.886 (0.060)
Bypass	0.942 (0.027)	1.001 (0.018)
Spillway	0.966 (0.014)	1.011 (0.017)
TSW1	NA	NA
TSW2	NA	NA
2007	Modified 2006 Test Spill	2007 Test Spill
All Routes	0.907 (0.016)	0.887 (0.017)
Control	NA	NA
Turbine	0.691 (0.100)	0.676 (0.103)
Bypass	0.904 (0.038)	0.821 (0.042)
Spillway	0.911 (0.040)	0.871 (0.046)
TSW1	0.895 (0.023)	0.918 (0.022)
TSW2	0.980 (0.024)	0.949 (0.033)
2008	Early Season	Late Season
All Routes	0.938 (0.015)	0.992 (0.010)
Control	0.961 (0.010)	0.969 (0.015)
Turbine	0.597 (0.099)	0.889 (0.075)
Bypass	0.985 (0.016)	1.006 (0.014)
Spillway	0.975 (0.016)	0.999 (0.013)
TSW1	0.969 (0.017)	1.000 (0.000)
TSW2	0.965 (0.015)	0.986 (0.039)
2009[1]	NA	NA

[1]There were no treatments in 2009.

Table 1-30. Route-specific (single-release) survival probabilities for juvenile steelhead by diel period and treatment at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1-Day	Treatment 1-Night	Treatment 2-Day	Treatment 2-Night
2006	Fish Passage Plan	Fish Passage Plan	2006 Test Spill	2006 Test Spill
All Routes	0.951 (0.020)	0.954 (0.016)	1.009 (0.021)	0.986 (0.017)
Control	NA	NA	NA	NA
Turbine	0.771 (0.110; 0.525, 0.938)	0.956 (0.051; 0.817, 1.019)	0.915 (0.106; 0.646, 1.052)	0.873 (0.073; 0.704, 0.985)
Bypass	[1]1.000	0.919 (0.037; 0.834, 0.979)	[1]1.000	1.002 (0.023; 0.947, 1.040)
Spillway	0.966 (0.021)	0.966 (0.018)	1.021 (0.024)	1.001 (0.020)
TSW1	NA	NA	NA	NA
TSW2	NA	NA	NA	NA
2007	Modified 2006 Test Spill	Modified 2006 Test Spill	2007 Test Spill	2007 Test Spill
All Routes	0.917 (0.018)	0.884 (0.029)	0.919 (0.020)	0.846 (0.028)
Control	NA	NA	NA	NA
Turbine	0.415 (0.161; 0.151, 0.726)	0.889 (0.097; 0.643, 1.013)	0.864 (0.158; 0.463, 1.029)	0.609 (0.124; 0.367, 0.827)
Bypass	0.881 (0.083; 0.679, 0.997)	0.911 (0.042; 0.814, 0.980)	0.754 (0.099; 0.542, 0.914)	0.839 (0.046; 0.740, 0.920)
Spillway	0.930 (0.046; 0.821, 1.000)	0.873 (0.076; 0.693, 0.985)	[1]1.000	0.791 (0.071; 0.637, 0.911)
TSW1	0.912 (0.024; 0.861, 0.956)	0.812 (0.063; 0.674, 0.919)	0.915 (0.026; 0.859, 0.961)	0.926 (0.040; 0.833, 0.990)
TSW2	0.981 (0.026; 0.919, 1.022)	0.979 (0.057; 0.806, 1.042)	0.964 (0.036; 0.874, 1.018)	0.916 (0.065; 0.753, 1.008)
2008	Early Season	Early Season	Late Season	Late Season
All Routes	0.920 (0.025)	0.960 (0.013)	0.987 (0.013)	1.000 (0.015)
Control	0.978 (0.013; 0.948, 1.000)	0.943 (0.016; 0.908, 0.971)	0.959 (0.026; 0.898, 1.000)	0.977 (0.018; 0.934, 1.005)
Turbine	0.420 (0.139; 0.184, 0.695)	0.774 (0.072; 0.618, 0.895)	0.943 (0.081; 0.702, 1.024)	0.823 (0.130; 0.515, 0.992)
Bypass	[1]1.000	0.979 (0.022; 0.923, 1.010)	[1]1.000	1.008 (0.021; 0.940, 1.033)
Spillway	0.931 (0.033; 0.854, 0.982)	1.005 (0.013; 0.968, 1.022)	0.987 (0.018; 0.942, 1.015)	1.016 (0.014; 0.973, 1.034)
TSW1	0.981 (0.018; 0.936, 1.008)	0.936 (0.042; 0.832, 0.996)	1.000 (0.000)	[1]1.000
TSW2	0.961 (0.019; 0.918, 0.992)	0.974 (0.024; 0.912, 1.008)	0.985 (0.042; 0.852, 1.028)	[1]1.000
2009[2]	NA	NA	NA	NA

[1]Survival probability and confidence limits were not estimable using maximum likelihood methods because we detected 100 percent of the fish passing this route at downstream detection arrays. Although the modeling software could not produce an estimate, our best estimate of survival is 100 percent. Variances from parameter not accounted for in other estimates derived from this parameter.

[2]There were no treatments in 2009.

Table 1-31. Route-specific (single-release) survival probabilities for subyearling Chinook salmon overall and by diel period at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night
		2006	
All Routes	0.885 (0.009)	0.897 (0.010)	0.855 (0.017)
Pool	0.955 (0.005; 0.944, 0.964)	NA	NA
Forebay	0.991 (0.003; 0.984, 0.996)	NA	NA
Control	0.934 (0.008)	0.963 (0.011)	0.910 (0.013)
Turbine	0.739 (0.022)	0.745 (0.028)	0.728 (0.037)
Bypass	0.921 (0.017)	0.909 (0.036)	0.924 (0.019)
Spillway	0.943 (0.009)	0.952 (0.010)	0.920 (0.020)
TSW1	NA	NA	NA
TSW2	NA	NA	NA
		2007	
All Routes	0.863 (0.013)	0.906 (0.015)	0.782 (0.022)
Pool	0.968 (0.005; 0.959, 0.976)	NA	NA
Forebay	0.983 (0.004; 0.975, 0.991)	NA	NA
Control	0.926 (0.015)	0.935 (0.020)	0.918 (0.020)
Turbine	0.744 (0.031)	0.854 (0.037)	0.603 (0.049)
Bypass	0.869 (0.025)	0.806 (0.049)	0.893 (0.029)
Spillway	0.921 (0.020)	0.949 (0.023)	0.862 (0.035)
TSW1	0.881 (0.027)	0.913 (0.032)	0.821 (0.049)
TSW2	0.828 (0.038)	0.851 (0.048)	0.792 (0.062)
		2008	
All Routes	0.875 (0.009)	0.879 (0.010)	0.867 (0.016)
Pool	0.975 (0.004; 0.966, 0.981)	NA	NA
Forebay	0.994 (0.003; 0.989, 0.999)	NA	NA
Control	0.899 (0.013)	0.926 (0.012)	0.895 (0.013)
Turbine	0.763 (0.024)	0.725 (0.030)	0.853 (0.038)
Bypass	0.845 (0.025)	0.826 (0.040)	0.859 (0.031)
Spillway	0.918 (0.011)	0.928 (0.011)	0.888 (0.025)
TSW1	0.889 (0.026)	0.872 (0.033)	0.926 (0.040)
TSW2	0.912 (0.026)	0.962 (0.024)	0.825 (0.057)
		2009	
All Routes	0.823 (0.010)	0.871 (0.011)	0.758 (0.017)
Pool	0.934 (0.006; 0.922, 0.945)	NA	NA
Forebay	0.974 (0.004; 0.965, 0.981)	NA	NA
Control	0.920 (0.008)	0.955 (0.009; 0.935, 0.970)	0.873 (0.014; 0.844, 0.899)
Turbine	0.679 (0.027)	0.753 (0.035; 0.681, 0.817)	0.600 (0.041; 0.519, 0.677)
Bypass	0.855 (0.022)	0.879 (0.031; 0.809, 0.931)	0.838 (0.030; 0.774, 0.891)
Spillway	0.875 (0.014)	0.934 (0.013; 0.905, 0.957)	0.777 (0.028; 0.720, 0.829)
Spill bays 16–19	0.822 (0.025)	0.827 (0.035; 0.752, 0.888)	0.816 (0.037; 0.737, 0.881)
TSW2	0.847 (0.025)	0.911 (0.025; 0.853, 0.953)	0.744 (0.049; 0.641, 0.831)

Table 1-32. Route-specific (single-release) survival probabilities for subyearling Chinook salmon by treatment at McNary Dam, 2006–09.

[Standard error are shown in parenthesis; NA, not applicable]

Passage route	Treatment 1	Treatment 2	Treatment 3
2006	60% Spill	40% Spill	NA
All Routes	0.900 (0.014)	0.876 (0.011)	NA
Control	0.919 (0.015)	0.943 (0.010)	NA
Turbine	0.728 (0.040)	0.745 (0.026)	NA
Bypass	0.918 (0.038)	0.922 (0.019)	NA
Spillway	0.954 (0.013)	0.934 (0.013)	NA
TSW1	NA	NA	NA
TSW2	NA	NA	NA
2007	60% Spill	40% Spill	NA
All Routes	0.894 (0.017)	0.829 (0.018)	NA
Control	0.928 (0.020)	0.924 (0.020)	NA
Turbine	0.769 (0.047)	0.727 (0.040)	NA
Bypass	0.892 (0.043)	0.858 (0.030)	NA
Spillway	0.943 (0.023)	0.880 (0.033)	NA
TSW1	0.881 (0.034)	0.882 (0.044)	NA
TSW2	0.886 (0.053)	0.778 (0.054)	NA
2008	Early Season	60% Spill	40% Spill
All Routes	0.946 (0.012)	0.852 (0.016)	0.825 (0.017)
Control	0.959 (0.013)	0.876 (0.017)	0.864 (0.019)
Turbine	0.946 (0.029)	0.726 (0.055)	0.691 (0.036)
Bypass	0.898 (0.033)	0.787 (0.059)	0.818 (0.042)
Spillway	0.963 (0.015)	0.880 (0.019)	0.901 (0.024)
TSW1	0.943 (0.049)	0.840 (0.049)	0.910 (0.036)
TSW2	0.903 (0.064)	0.941 (0.038)	0.895 (0.041)
2009[1]	NA	NA	NA

[1]There were no treatments in 2009.

Table 1-33. Route-specific (single-release) survival probabilities for subyearling Chinook salmon by diel period and treatment at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model; NA, not applicable; Day is 0600-1759 hours; Night is 1800-0559 hours]

Passage route	Treatment 1-Day	Treatment 1-Night	Treatment 2-Day	Treatment 2-Night	Treatment 3-Day	Treatment 3-Night
2006	60% Spill	60% Spill	40% Spill	40% Spill	NA	NA
All Routes	0.918 (0.015)	0.850 (0.030)	0.885 (0.013)	0.858 (0.021)	NA	NA
Control	0.952 (0.019; 0.909, 0.984)	0.895 (0.021; 0.851, 0.932)	0.969 (0.012; 0.941, 0.990)	0.920 (0.016; 0.887, 0.948)	NA	NA
Turbine	0.757 (0.048; 0.657, 0.843)	0.668 (0.074; 0.516, 0.801)	0.739 (0.034; 0.670, 0.802)	0.753 (0.042; 0.667, 0.829)	NA	NA
Bypass	0.940 (0.040; 0.839, 0.997)	0.862 (0.086; 0.655, 0.980)	0.920 (0.022; 0.872, 0.958)	0.926 (0.038; 0.835, 0.983)	NA	NA
Spillway	0.963 (0.014)	0.928 (0.030)	0.943 (0.015)	0.913 (0.026)	NA	NA
2007	60% Spill	60% Spill	40% Spill	40% Spill	NA	NA
All Routes	0.938 (0.020)	0.804 (0.030)	0.872 (0.021)	0.759 (0.030)	NA	NA
Control	0.931 (0.025; 0.879, 0.979)	0.925 (0.027; 0.869, 0.976)	0.941 (0.029; 0.882, 0.994)	0.911 (0.026; 0.858, 0.959)	NA	NA
Turbine	0.842 (0.057; 0.722, 0.944)	0.654 (0.079; 0.498, 0.801)	0.863 (0.047; 0.763, 0.946)	0.570 (0.061; 0.451, 0.688)	NA	NA
Bypass	0.946 (0.047; 0.843, 1.025)	0.766 (0.088; 0.581, 0.919)	0.870 (0.035; 0.798, 0.934)	0.828 (0.058; 0.707, 0.930)	NA	NA
Spillway	0.981 (0.026; 0.927, 1.029)	0.862 (0.045; 0.768, 0.942)	0.891 (0.041; 0.804, 0.964)	0.863 (0.055; 0.746, 0.958)	NA	NA
TSW1	0.910 (0.039; 0.827, 0.980)	0.819 (0.063; 0.687, 0.930)	0.919 (0.052; 0.804, 1.005)	0.824 (0.076; 0.662, 0.953)	NA	NA
TSW2	0.923 (0.063; 0.782, 1.027)	0.824 (0.090; 0.628, 0.973)	0.789 (0.070; 0.642, 0.912)	0.763 (0.085; 0.587, 0.911)	NA	NA
2008	Early Season	Early Season	60% Spill	60% Spill	40% Spill	40% Spill
All Routes	0.951 (0.014)	0.935 (0.024)	0.856 (0.018)	0.844 (0.030)	0.827 (0.019)	0.820 (0.031)
Control	0.938 (0.022; 0.889, 0.976)	0.980 (0.014; 0.946, 1.002)	0.906 (0.020; 0.862, 0.942)	0.833 (0.029; 0.772, 0.884)	0.941 (0.020; 0.896, 0.973)	0.867 (0.023; 0.818, 0.909)
Turbine	0.934 (0.038; 0.842, 0.990)	0.975 (0.042; 0.844, 1.018)	0.572 (0.082; 0.411, 0.725)	0.911 (0.054; 0.774, 0.984)	0.670 (0.042; 0.585, 0.749)	0.755 (0.068; 0.610, 0.870)
Bypass	0.905 (0.039; 0.815, 0.967)	0.882 (0.063; 0.730, 0.974)	0.825 (0.083; 0.632, 0.947)	0.756 (0.083; 0.577, 0.892)	0.803 (0.058; 0.676, 0.900)	0.837 (0.061; 0.699, 0.934)
Spillway	0.976 (0.015; 0.942, 1.000)	0.938 (0.031; 0.863, 0.986)	0.892 (0.020; 0.848, 0.928)	0.836 (0.045; 0.735, 0.912)	0.915 (0.024; 0.861, 0.955)	0.826 (0.076; 0.652, 0.943)
TSW1	0.920 (0.069; 0.738, 1.005)	[1]1.000	0.829 (0.057; 0.700, 0.922)	0.874 (0.089; 0.648, 0.985)	0.894 (0.048; 0.778, 0.966)	0.936 (0.053; 0.792, 1.002)
TSW2	0.909 (0.076; 0.710, 1.003)	0.891 (0.119; 0.564, 1.011)	0.975 (0.033; 0.868, 1.007)	0.874 (0.089; 0.648, 0.985)	0.980 (0.028; 0.888, 1.008)	0.780 (0.084; 0.595, 0.914)
2009[2]	NA	NA	NA	NA	NA	NA

[1]Survival probability and confidence limits were not estimable using maximum likelihood methods because we detected 100 percent of the fish passing this route at downstream detection arrays. Although the modeling software could not produce an estimate, our best estimate of survival is 100 percent. Variances from parameter not accounted for in other estimates derived from this parameter.

[2]There were no treatments in 2009.

Route-Specific Survival Probabilities (Paired-Release)

Paired-release survival probabilities for yearling Chinook salmon generally followed similar trends to the single-release survival probabilities. Overall concrete and project survival probabilities were lowest in 2007 (concrete 0.926, project 0.918) and highest in 2009 (concrete 0.973, project 0.969; fig. 1-13 and table 1-34). For the three main passage routes, survival probabilities were lowest for the turbines during all years and equal for spillway and bypass except in 2007 when spill survival was higher than bypass. Although survival through the turbines was low, passage probabilities through the turbines also were low. When the TSWs were operating, survival probabilities ranged from 0.922 (TSW1 in 2008) to 1.011 (TSW1 in 2009), but passage probabilities were less than 0.17. Concrete survival was similar between day and night during 2007, 2008, and 2009, but was higher during the day than night, during 2006. During all years of study, survival through the turbines and TSWs were both higher during the night than the day, spillway survival was higher during the day than night, and bypass survival was similar between day and night. All survival estimates in 2006 were higher during 2006 Test Spill than during the Fish Passage Plan treatment. All survival estimates in 2007 and 2008 were nearly equal between treatments except for turbine survival in 2008, which was 0.944 during Early Season, and only 0.782 during Late Season. Paired-release survival probabilities generally were higher during the night for all treatments and years, except for spillway survival, which was higher during the day (table 1-35).

Paired-release survival probabilities for juvenile steelhead were only calculated for 2008 and 2009 when control releases occurred. In 2006 and 2007, no steelhead were released as control fish downstream of the dam. Overall concrete and project survival were equal between years, and survival through each individual passage route was about 1.000, except for the turbines which was 0.693 in 2008, and 0.851 in 2009 (table 1-36). In general, survival probabilities were similar during the day and night. The exceptions were for the turbines in both years, which had much higher survival during the night, and for the TSW1 in 2008, which had 8 percent higher survival during the day than night. Survival was high and similar by treatment in 2008 except turbine survival was 0.625 during the Early Season and 0.920 during the Late Season. Paired-release survival probabilities for juvenile steelhead were very similar between day and night for each treatment in 2008, with the following exceptions: (1) Concrete survival was 8 percent higher at night during Early Season, (2) turbine survival was 39 percent higher at night during Early Season and 14 percent lower at night during Late Season, and (3) spillway survival was 11 percent higher at night during Early Season (table 1-37).

Paired-release survival probabilities for subyearling Chinook salmon varied by year, diel period, and treatment. Concrete and project survival were similar and greater than 91 percent in 2006, 2007, and 2008 but both estimates were less than 90 percent in 2009 (fig. 1-14; table 1-38). Overall survival probabilities through individual routes of passage generally were lower in 2009 than in other years. Fish passing during the day had higher concrete survival in 2007 and 2009 whereas concrete survival was similar between diel periods during 2006 and 2008. Turbine survival was higher during the day in 2007 and 2009 but higher during the night in 2008. Spillway survival was higher during the day in 2007 and 2009 and bypass survival was higher during the night in 2008. TSW1 survival was higher during the night in 2008 and TSW2 survival was higher during the day in 2009. All other survival estimates were similar between diel periods. Nearly all paired-release estimates of survival were higher during 60 percent spill than during 40 percent spill during all years of study. Paired-release survival probabilities by treatment by diel period were often similar among years (table 1-39), but sample sizes were low. Survival probabilities were higher during the 2007 day treatment compared to the night treatment for concrete, turbines, and bypass during 60 percent spill and concrete and turbines during 40 percent spill. In 2008, concrete and spillway survival probabilities were higher during the day during the Early Season (about 50 percent spill) but higher at night during 60 percent spill. Turbine survival was highest at night during 60 percent spill, TSW1 survival was highest at night during 40 percent spill, and TSW2 survival was highest during the day during 60 percent spill.

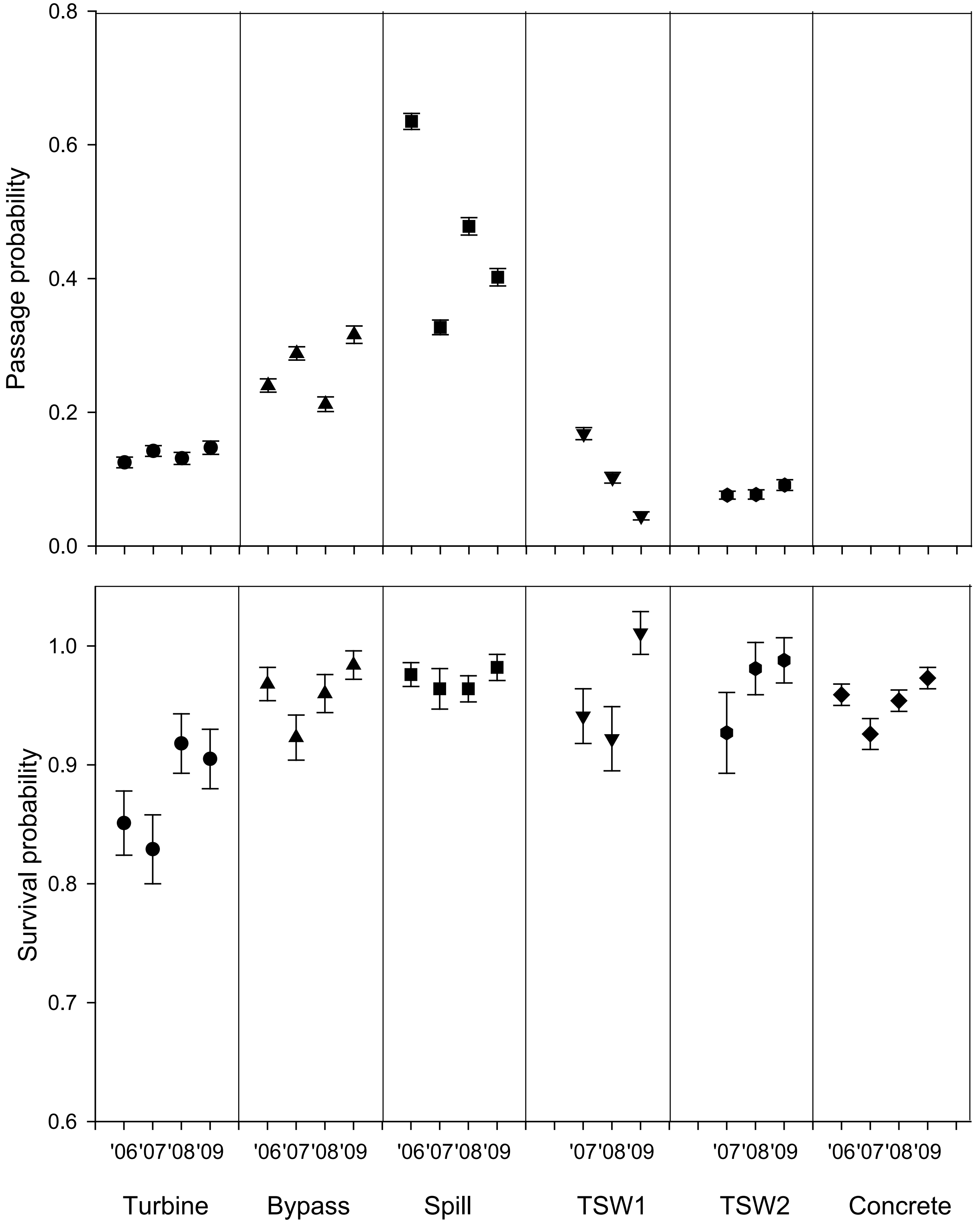

Figure 1-13. Passage (top plate) and paired-release survival probabilities (bottom plate) of yearling Chinook salmon by passage route including concrete survival at McNary Dam, 2006–09. Whisker bars represent the standard error.

Table 1-34. Route-specific (paired-release) survival probabilities for yearling Chinook salmon overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2
2006				Fish Passage Plan	2006 Test Spill
Concrete	0.959 (0.009; 0.943, 0.977)	0.983 (0.013)	0.935 (0.011)	0.940 (0.012)	0.978 (0.012)
Project	0.950 (0.009)	NA	NA	NA	NA
Turbine	0.851 (0.027)	0.768 (0.055)	0.894 (0.029)	0.786 (0.040)	0.925 (0.033)
Bypass	0.968 (0.014)	0.993 (0.020)	0.943 (0.019)	0.963 (0.021)	0.971 (0.019)
Spillway	0.976 (0.010)	1.008 (0.013)	0.943 (0.013)	0.965 (0.013)	0.990 (0.013)
2007				Modified 2006 Test Spill	2007 Test Spill
Concrete	0.926 (0.013; 0.902, 0.952)	0.918 (0.015)	0.945 (0.021)	0.929 (0.018)	[1]0.924 (0.017)
Project	0.918 (0.013)	NA	NA	NA	NA
Turbine	0.829 (0.029)	0.779 (0.036)	0.953 (0.046)	0.839 (0.040)	0.818 (0.042)
Bypass	0.923 (0.019)	0.916 (0.024)	0.935 (0.031)	0.923 (0.028)	0.923 (0.026)
Spillway	0.964 (0.017)	0.970 (0.019)	0.942 (0.036)	0.962 (0.024)	0.967 (0.024)
TSW1	0.941 (0.023)	0.931 (0.028)	0.960 (0.039)	0.939 (0.032)	0.943 (0.033)
TSW2	0.927 (0.034)	0.918 (0.039)	0.956 (0.065)	0.949 (0.044)	0.903 (0.052)
2008				Early Season	Late Season
Concrete	0.954 (0.009; 0.937, 0.972)	0.952 (0.012)	0.964 (0.012)	0.950 (0.012)	0.961 (0.013)
Project	0.953 (0.009)	NA	NA	NA	NA
Turbine	0.918 (0.025)	0.874 (0.038)	0.967 (0.026)	0.944 (0.025)	0.782 (0.079)
Bypass	0.960 (0.016)	0.960 (0.021)	0.960 (0.023)	0.962 (0.019)	0.956 (0.030)
Spillway	0.964 (0.011)	0.979 (0.014)	0.957 (0.017)	0.948 (0.019)	0.975 (0.013)
TSW1	0.922 (0.027)	0.886 (0.036)	0.996 (0.025)	0.917 (0.030)	0.954 (0.059)
TSW2	0.981 (0.022)	0.970 (0.030)	0.987 (0.033)	0.986 (0.024)	0.954 (0.055)
2009				NA	NA
Concrete	0.973 (0.009; 0.956, 0.991)	0.983 (0.013)	0.960 (0.011)	NA	NA
Project	0.969 (0.009)	NA	NA	NA	NA
Turbine	0.905 (0.025)	0.884 (0.036)	0.933 (0.031)	NA	NA
Bypass	0.984 (0.012)	0.997 (0.016)	0.965 (0.018)	NA	NA
Spillway	0.982 (0.011)	1.008 (0.014)	0.947 (0.018)	NA	NA
TSW1	1.011 (0.018)	1.005 (0.037)	1.016 (0.006)	NA	NA
TSW2	0.988 (0.019)	0.977 (0.032)	1.001 (0.018)	NA	NA

[1]Value is 0.931 after correcting for rounding error.

Table 1-35. Route-specific (paired-release) survival probabilities for yearling Chinook salmon by diel period and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1- Day	Treatment 1- Night	Treatment 2- Day	Treatment 2- Night
2006	Fish Passage Plan	Fish Passage Plan	2006 Test Spill	2006 Test Spill
Concrete	0.973 (0.021)	0.912 (0.014)	0.993 (0.016)	0.958 (0.017)
Turbine	0.664 (0.082)	0.852 (0.042)	0.907 (0.062)	0.935 (0.039)
Bypass	1.009 (0.030)	0.923 (0.029)	0.980 (0.026)	0.961 (0.027)
Spillway	1.010 (0.020)	0.924 (0.017)	1.008 (0.017)	0.964 (0.021)
2007	Modified 2006 Test Spill	Modified 2006 Test Spill	2007 Test Spill	2007 Test Spill
Concrete	0.923 (0.022)	0.944 (0.029)	0.913 (0.021)	0.947 (0.031)
Turbine	0.793 (0.051)	0.941 (0.060)	0.768 (0.051)	0.963 (0.070)
Bypass	0.914 (0.036)	0.937 (0.043)	0.915 (0.032)	0.935 (0.043)
Spillway	0.969 (0.027)	0.928 (0.054)	0.971 (0.027)	0.956 (0.049)
TSW1	0.932 (0.039)	0.957 (0.055)	0.932 (0.040)	0.963 (0.056)
TSW2	0.934 (0.050)	1.016 (0.077)	0.899 (0.061)	0.909 (0.098)
2008	Early Season	Early Season	Late Season	Late Season
Concrete	0.937 (0.016)	0.976 (0.017)	0.974 (0.019)	0.948 (0.017)
Turbine	0.912 (0.037)	0.995 (0.026)	0.681 (0.139)	0.851 (0.090)
Bypass	0.954 (0.026)	0.973 (0.027)	0.976 (0.034)	0.928 (0.052)
Spillway	0.948 (0.023)	0.946 (0.034)	0.999 (0.018)	0.957 (0.019)
TSW1	0.880 (0.040)	1.003 (0.028)	0.936 (0.083)	0.997 (0.009)
TSW2	0.984 (0.029)	0.991 (0.040)	0.919 (0.098)	0.997 (0.009)
2009[1]	NA	NA	NA	NA

[1]There were no treatments in 2009.

Table 1-36. Route-specific (paired-release) survival probabilities for juvenile steelhead overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2
2006				Fish Passage Plan	2006 Test Spill
Concrete	NA	NA	NA	NA	NA
Project	NA	NA	NA	NA	NA
Turbine	NA	NA	NA	NA	NA
Bypass	NA	NA	NA	NA	NA
Spill	NA	NA	NA	NA	NA
2007				Modified 2006 Test Spill	2007 Test Spill
Concrete	NA	NA	NA	NA	NA
Project	NA	NA	NA	NA	NA
Turbine	NA	NA	NA	NA	NA
Bypass	NA	NA	NA	NA	NA
Spill	NA	NA	NA	NA	NA
TSW1	NA	NA	NA	NA	NA
TSW2	NA	NA	NA	NA	NA
2008				Early Season	Late Season
Concrete	0.991 (0.015; 0.985, 1.018)	0.966 (0.022)	1.017 (0.010)	0.976 (0.019)	1.026 (0.020)
Project	0.998 (0.012)	NA	NA	NA	NA
Turbine	0.693 (0.089)	0.558 (0.136)	0.785 (0.063)	0.625 (0.104)	0.920 (0.079)
Bypass	1.034 (0.016)	1.028 (0.013)	0.990 (0.016)	1.033 (0.021)	1.035 (0.021)
Spill	1.027 (0.015)	0.992 (0.021)	1.010 (0.010)	1.019 (0.020)	1.034 (0.022)
TSW1	1.004 (0.019)	1.011 (0.020)	0.941 (0.038)	1.000 (0.021)	1.039 (0.023)
TSW2	1.002 (0.017)	0.991 (0.021)	0.974 (0.024)	0.999 (0.019)	1.027 (0.048)
2009				NA	NA
Concrete	0.996 (0.012; 0.974, 1.020)	0.981 (0.016)	1.008 (0.017)	NA	NA
Project	0.993 (0.012)	NA	NA	NA	NA
Turbine	0.851 (0.054)	0.812 (0.082)	0.896 (0.066)	NA	NA
Bypass	1.014 (0.017)	0.993 (0.026)	1.024 (0.021)	NA	NA
Spill	0.997 (0.016)	0.980 (0.023)	1.005 (0.021)	NA	NA
TSW1	1.020 (0.020)	1.023 (0.022)	1.018 (0.032)	NA	NA
TSW2	1.010 (0.015)	1.005 (0.018)	1.018 (0.026)	NA	NA

Table 1-37. Route-specific (paired-release) survival probabilities for juvenile steelhead by diel period and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1-Day	Treatment 1-Night	Treatment 2-Day	Treatment 2-Night
2006	Fish Passage Plan	Fish Passage Plan	2006 Test Spill	2006 Test Spill
Concrete	NA	NA	NA	NA
Turbine	NA	NA	NA	NA
Bypass	NA	NA	NA	NA
Spillway	NA	NA	NA	NA
2007	Modified 2006 Test Spill	Modified 2006 Test Spill	2007 Test Spill	2007 Test Spill
Concrete	NA	NA	NA	NA
Turbine	NA	NA	NA	NA
Bypass	NA	NA	NA	NA
Spillway	NA	NA	NA	NA
TSW1	NA	NA	NA	NA
TSW2	NA	NA	NA	NA
2008	Early Season	Early Season	Late Season	Late Season
Concrete	0.940 (0.029)	1.018 (0.022)	1.029 (0.031)	1.023 (0.024)
Turbine	0.429 (0.142)	0.821 (0.078)	0.983 (0.089)	0.843 (0.134)
Bypass	1.023 (0.014)	1.038 (0.029)	1.043 (0.028)	1.032 (0.028)
Spillway	0.952 (0.036)	1.065 (0.023)	1.029 (0.033)	1.040 (0.023)
TSW1	1.003 (0.023)	0.992 (0.047)	1.043 (0.028)	1.023 (0.019)
TSW2	0.983 (0.023)	1.032 (0.031)	1.027 (0.052)	1.023 (0.019)
2009[1]	NA	NA	NA	NA

[1]There were no treatments in 2009.

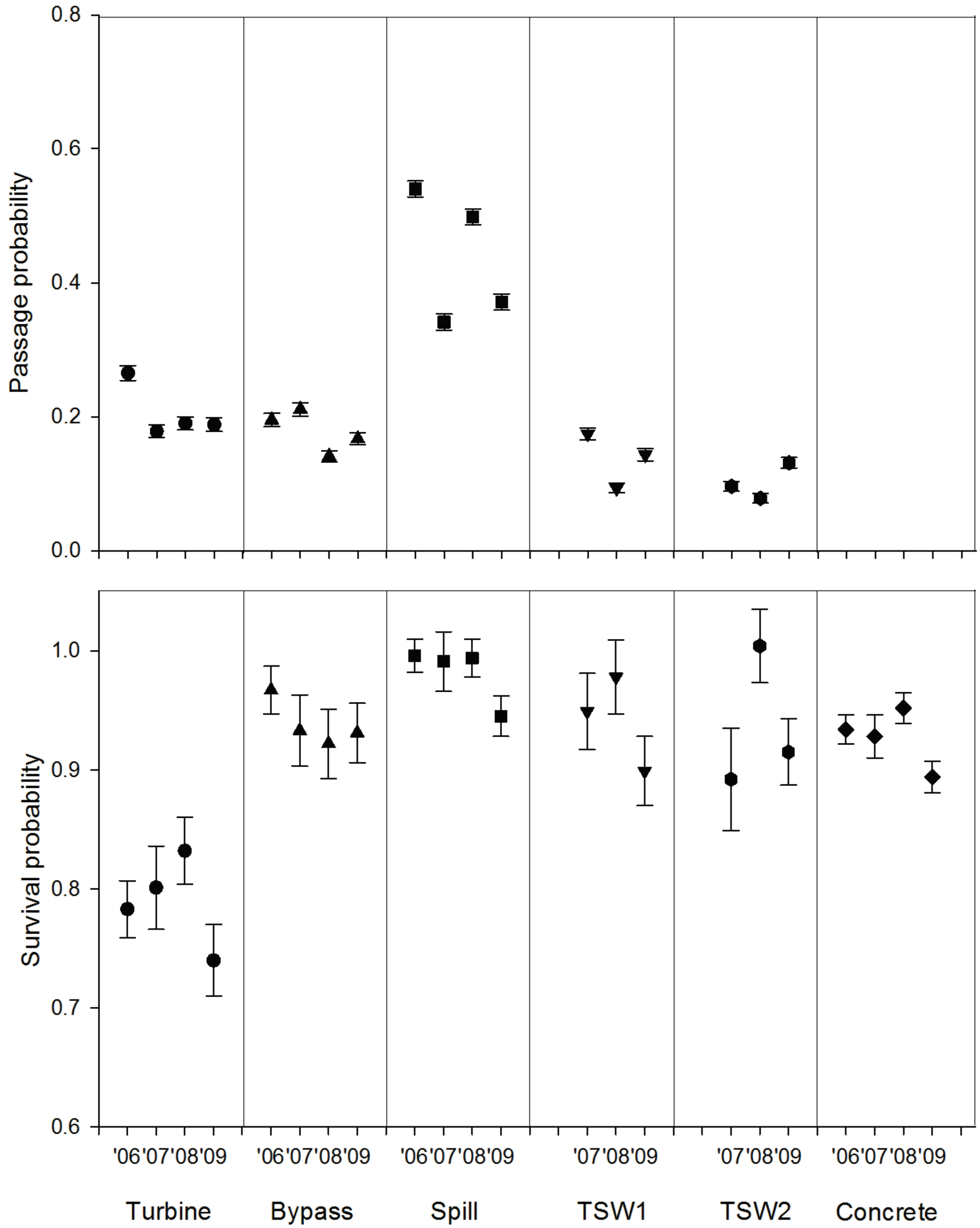

Figure 1-14. Passage (top plate) and paired-release survival probabilities (bottom plate) of subyearling Chinook salmon by passage route including concrete survival at McNary Dam, 2006–09. Whisker bars represent the standard error.

Table 1-38. Route-specific (paired-release) survival probabilities for subyearling Chinook salmon overall, by diel period, and treatment at McNary Dam, 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Overall	Day	Night	Treatment 1	Treatment 2	Treatment 3
2006				60% Spill	40% Spill	NA
Concrete	[1]0.934 (0.012; 0.910, 0.959)	0.931 (0.014)	0.939 (0.023)	[2]0.961 (0.021)	[3]0.919 (0.015)	NA
Project	0.926 (0.012)	NA	NA	NA	NA	NA
Turbine	0.783 (0.024)	0.773 (0.030)	0.799 (0.042)	0.779 (0.045)	0.784 (0.029)	NA
Bypass	0.967 (0.020)	0.959 (0.023)	0.999 (0.042)	0.980 (0.043)	0.963 (0.022)	NA
Spill	0.996 (0.014)	0.989 (0.015)	1.010 (0.026)	1.017 (0.022)	0.979 (0.017)	NA
2007				60% Spill	40% Spill	NA
Concrete	0.928 (0.018; 0.893, 0.965)	0.969 (0.024)	0.852 (0.028)	0.962 (0.025)	[4]0.892 (0.026)	NA
Project	0.913 (0.018)	NA	NA	NA	NA	NA
Turbine	0.801 (0.035)	0.914 (0.042)	0.657 (0.054)	0.828 (0.053)	0.782 (0.045)	NA
Bypass	0.933 (0.030)	0.955 (0.035)	0.878 (0.055)	0.960 (0.049)	0.920 (0.038)	NA
Spill	0.991 (0.025)	1.016 (0.030)	0.940 (0.042)	1.015 (0.031)	0.947 (0.040)	NA
TSW1	0.949 (0.032)	0.976 (0.038)	0.895 (0.055)	0.949 (0.040)	0.949 (0.051)	NA
TSW2	0.892 (0.043)	0.910 (0.054)	0.863 (0.069)	0.954 (0.059)	0.838 (0.060)	NA
2008				Early Season	60% Spill	40% Spill
Concrete	[5]0.952 (0.013; 0.926, 0.979)	0.949 (0.016)	0.969 (0.023)	[6]0.994 (0.021)	[7]0.965 (0.025)	[8]0.898 (0.023)
Project	0.947 (0.013)	NA	NA	NA	NA	NA
Turbine	0.832 (0.028)	0.783 (0.034)	0.954 (0.044)	0.996 (0.035)	0.841 (0.067)	0.751 (0.041)
Bypass	0.922 (0.029)	0.927 (0.035)	0.923 (0.047)	0.946 (0.039)	0.909 (0.071)	0.903 (0.049)
Spill	0.994 (0.016)	1.003 (0.018)	0.993 (0.031)	1.011 (0.023)	0.988 (0.028)	0.969 (0.031)
TSW1	0.978 (0.031)	0.942 (0.038)	1.035 (0.047)	0.992 (0.055)	0.948 (0.058)	0.998 (0.043)
TSW2	1.004 (0.031)	1.039 (0.029)	0.922 (0.065)	0.950 (0.069)	1.067 (0.047)	0.981 (0.048)
2009				NA	NA	NA
Concrete	0.894 (0.013; 0.868, 0.919)	0.912 (0.014)	0.868 (0.023)	NA	NA	NA
Project	0.870 (0.013)	NA	NA	NA	NA	NA
Turbine	0.740 (0.030)	0.789 (0.037)	0.687 (0.048)	NA	NA	NA
Bypass	0.931 (0.025)	0.878 (0.032)	1.006 (0.039)	NA	NA	NA
Spill	0.945 (0.017)	0.978 (0.017)	0.890 (0.035)	NA	NA	NA
Spill bays 16–19	0.899 (0.029)	0.866 (0.038)	0.934 (0.045)	NA	NA	NA
TSW2	0.915 (0.028)	0.955 (0.028)	0.852 (0.058)	NA	NA	NA

[1]Value is 0.948 after correcting for rounding error. [2]Value is 0.979 after correcting for rounding error. [3]Value is 0.929 after correcting for rounding error.

[4]Value is 0.897 after correcting for rounding error. [5]Value is 0.973 after correcting for rounding error. [6]Value is 0.986 after correcting for rounding error. [7]Value is 0.973 after correcting for rounding error. [8]Value is 0.955 after correcting for rounding error.

Table1-39. Route-specific (paired-release) survival probabilities for subyearling Chinook salmon by diel period and treatment at McNary Dam, 2006–09.

[Standard error is shown in parenthesis; NA, not applicable; Day is 0600–1759 hours; Night is 1800–0559 hours]

Passage route	Treatment 1- Day	Treatment 1- Night	Treatment 2- Day	Treatment 2- Night	Treatment 3- Day	Treatment 3- Night
2006	60% Spill	60% Spill	40% Spill	40% Spill	NA	NA
Concrete	0.965 (0.025)	0.949 (0.041)	0.913 (0.018)	0.932 (0.027)	NA	NA
Turbine	0.795 (0.053)	0.746 (0.085)	0.763 (0.036)	0.818 (0.047)	NA	NA
Bypass	0.987 (0.046)	0.962 (0.098)	0.949 (0.026)	1.006 (0.044)	NA	NA
Spillway	1.011 (0.025)	1.036 (0.042)	0.973 (0.020)	0.993 (0.033)	NA	NA
2007	60% Spill	60% Spill	40% Spill	40% Spill	NA	NA
Concrete	1.008 (0.032)	0.869 (0.040)	0.927 (0.035)	0.833 (0.040)	NA	NA
Turbine	0.905 (0.065)	0.707 (0.087)	0.917 (0.056)	0.626 (0.069)	NA	NA
Bypass	1.016 (0.056)	0.828 (0.098)	0.925 (0.045)	0.909 (0.068)	NA	NA
Spillway	1.055 (0.038)	0.931 (0.054)	0.947 (0.051)	0.948 (0.065)	NA	NA
TSW1	0.978 (0.048)	0.886 (0.072)	0.977 (0.062)	0.905 (0.086)	NA	NA
TSW2	0.992 (0.072)	0.891 (0.101)	0.839 (0.078)	0.838 (0.096)	NA	NA
2008	Early Season	Early Season	60% Spill	60% Spill	40% Spill	40% Spill
Concrete	1.014 (0.028)	0.954 (0.028)	0.945 (0.029)	1.013 (0.050)	0.879 (0.028)	0.945 (0.044)
Turbine	0.996 (0.047)	0.995 (0.045)	0.631 (0.092)	1.094 (0.075)	0.712 (0.047)	0.870 (0.081)
Bypass	0.965 (0.047)	0.900 (0.066)	0.910 (0.094)	0.908 (0.104)	0.853 (0.064)	0.964 (0.075)
Spillway	1.040 (0.029)	0.958 (0.035)	0.984 (0.031)	1.003 (0.065)	0.972 (0.033)	0.953 (0.091)
TSW1	0.981 (0.077)	1.020 (0.015)	0.915 (0.067)	1.049 (0.112)	0.950 (0.055)	1.079 (0.068)
TSW2	0.969 (0.084)	0.909 (0.122)	1.075 (0.044)	1.049 (0.112)	1.042 (0.037)	0.899 (0.100)
2009[1]	NA	NA	NA	NA	NA	NA

[1]There were no treatments in 2009.

Tailrace Egress

Tailrace egress rates for juvenile salmonids varied by year and passage route. We did not measure egress to the I-82 Bridge (located 2 km downstream of McNary Dam) in 2006. For yearling Chinook salmon, the egress rate was fastest for fish passing through either TSW (> 2.5 km/h; fig. 1-15). The rate of leaving the tailrace after passing though the spillway in 2007 or 2008, or through the powerhouse in any year, was about one-half the egress rate of fish that passed either TSW. There was greater variability in rates of egress, among year, for juvenile steelhead. Egress rates in 2007 were higher for fish passing through the spillway or either TSW than in 2008 or 2009. However, this trend did not apply to juvenile steelhead passing through the powerhouse, which had egress rates of less than 2 km/h in all years (fig. 1-16). Egress rates of subyearling Chinook salmon followed a similar trend to the yearling Chinook salmon. Powerhouse and spillway egress was less than 2.1 km/h but TSW passage was greater than 3 km/h except for TSW1 in 2008 (fig. 1-17). Overall, egress after passing through the powerhouse was highest in 2009 and egress after passing the spillway or TSWs varied by species and year but was usually greater than 2 km/h.

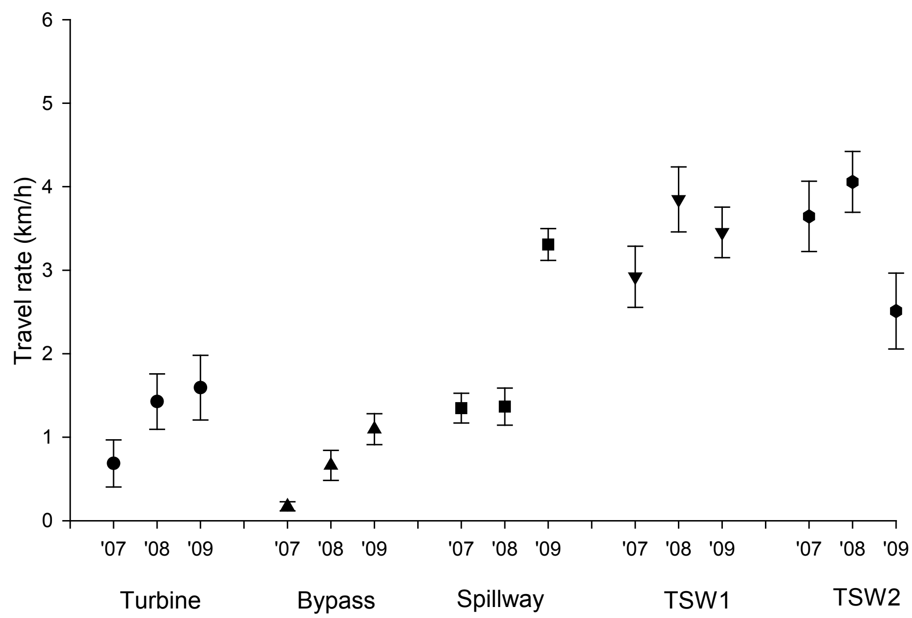

Figure 1-15. Graph showing mean travel rate (km/h) for yearling Chinook salmon released near Hat Rock State Park from time of passage at McNary Dam to first detection at the I-82 Bridge, by year and passage route, 2007–09.

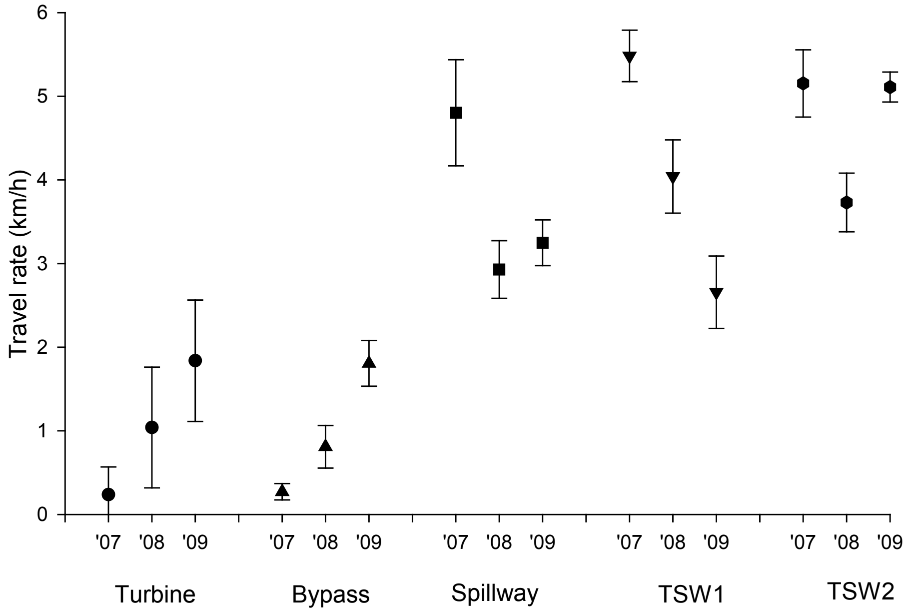

Figure 1-16. Graph showing mean travel rate (km/h) for juvenile steelhead released near Hat Rock State Park from time of passage at McNary Dam to first detection at the I-82 Bridge, by year and passage route, 2007–09.

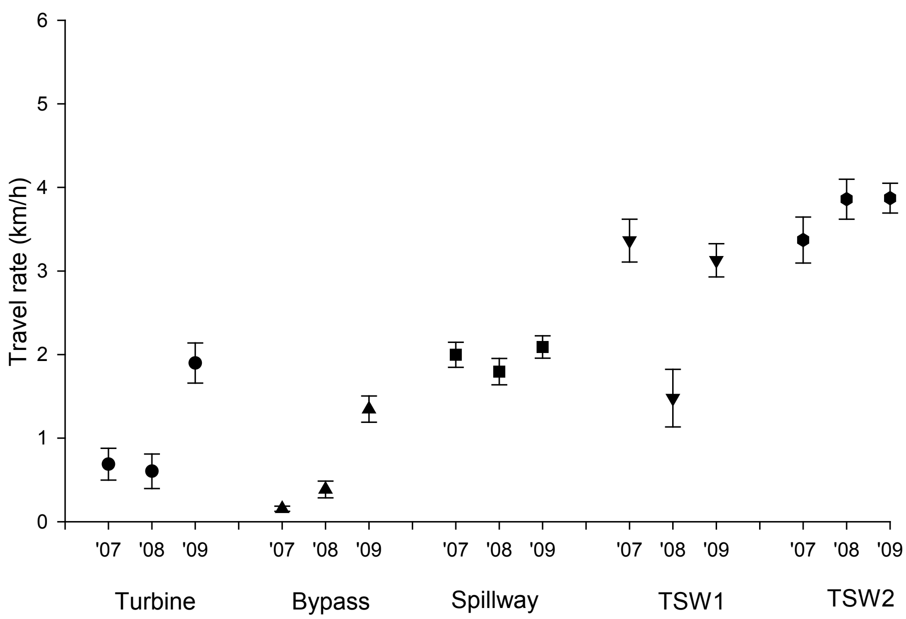

Figure 1-17. Graph showing mean travel rate (km/h) for subyearling Chinook salmon released near Hat Rock State Park from time of passage at McNary Dam to first detection at the I-82 Bridge, by year and passage route, 2007–09.

Summary

Forebay Behavior

McNary Dam and the reduced flow and altered hydraulics it creates, slows the migration of juvenile salmonids, reducing their rate of travel by between 36 and 94 percent compared to travel rates exhibited upstream and downstream of the dam. However, residence times within 160 m of the dam were relatively short; fractions of an hour for yearling and subyearling Chinook salmon and between 0.5 and 3.0 hours for juvenile steelhead. Forebay residence times were similar during day and night for all species, shorter during high spill (50–60 percent of project discharge) treatments for yearling Chinook salmon and juvenile steelhead, but longer during high spill treatments (60 percent of project discharge) for subyearling Chinook salmon. Forebay residence times typically were shortest for fish that passed through the spillway and TSWs and longest for fish that passed through the powerhouse.

The depth of fish in the forebay varied by species and diel period. Vertical distributions of fish within 60 m of the dam face were 4–9 m for yearling Chinook salmon, 2–8 m for juvenile steelhead, and 4–12 m for subyearling Chinook salmon. Juvenile steelhead were shallower during the day than night, and both yearling and subyearling Chinook salmon varied their depth little during day and night but were shallower during the crepuscular periods.

Passage Probabilities

Route-specific passage probabilities for juvenile salmonids at McNary Dam held the same pattern across all years of study. The majority of fish (33–65 percent), regardless of species, year, diel period, or treatment, passed through the spillway. One major exception to this occurred in 2007 when 64.7 percent passed through the TSWs (46.8 percent passed through TSW1 in bay 22 alone). The addition of the TSWs at McNary Dam benefited juvenile steelhead the greatest and resulted in a spillway and TSW combined passage probability of between 69 and 79 percent compared to the spillway probability of 64.8 percent observed in 2006 before installation of the TSWs. Although far fewer yearling and subyearling Chinook salmon used the TSWs than juvenile steelhead, spillway and TSW passage combined for salmon was similar to (for yearlings), or slightly higher (for subyearlings) than, spillway passage prior to installation of the TSWs. Further, the spillway and TSW combined passage rates were achieved using less water than was used with conventional spill alone. Probabilities of passage through the turbines and bypass were variable, but typically low during all study years ranging from 4 to 27 percent and 14 to 32 percent, respectively.

Passage Efficiency, Guidance Efficiency, and Passage Route Effectiveness

Fish passage efficiency showed similar trends over the four study years for each fish species. Fish passage efficiency was highest in 2007, followed by 2009, 2008, and was lowest in 2006, for both juvenile steelhead and subyearling Chinook salmon. Fish passage efficiency for yearling Chinook salmon differed little among the four study years, but was at least 6 percent higher in 2006, when there were no TSWs, than in any year with the TSWs. During all years, juvenile steelhead had the highest FPE (range 0.898–0.957), followed by yearling Chinook salmon (range 0.853–0.875), and subyearling Chinook salmon (range 0.735–0.822). Fish passage efficiency typically was highest for all species during the day, and during treatments that consisted of higher discharge through the south spill bays and 60 percent spill.

Fish guidance efficiency also followed similar trends over the four study years. Fish guidance efficiency was highest for all species during 2007 and 2009 (the two years with the lowest project discharge), and lowest during 2006 and 2008 (the two years with the highest project discharge). Fish guidance efficiency was highest for juvenile steelhead (range 0.674–0.798), followed by yearling Chinook salmon (range 0.640–0.667), and subyearling Chinook salmon (range 0.411–0.527). Both yearling and subyearling Chinook salmon had higher FGE during the day than night. Conversely, juvenile steelhead had much higher FGE during the night than day. Similar to FPE, estimates of FGE for yearling Chinook salmon and juvenile steelhead were highest during treatments with increased discharge through the south spill bays and 60 percent spill. Fish guidance efficiency for subyearling Chinook salmon, however, was higher during 40 percent spill than during 60 percent spill.

Effectiveness of the various passage routes followed similar trends among years for all species. Spillway effectiveness was highest for all species during 2006, followed by 2008, 2009, and 2007; project and spill discharge also was highest in 2006, followed by 2008, 2009, and 2007. Effectiveness of TSW1 for all species was highest in 2007 and 2008 and lowest in 2009. Effectiveness of TSW2 for all species was highest in 2009. Effectiveness varied by year between the two TSW designs but was substantially higher during 2007, for all species, compared to any other year. Effectiveness of both TSWs combined was also highest for all species in 2007, when project and spillway discharge were the lowest of all study years. The TSWs were most effective for juvenile steelhead (range 2.972–11.694), followed by yearling (range 1.293–4.192) and subyearling (range 1.925–3.290) Chinook salmon. Effectiveness of the TSWs varied by day and night for both yearling and subyearling Chinook salmon but was always much higher during the day, than night, for juvenile steelhead. Passage effectiveness of the TSWs on a diel basis was influenced by the vertical distribution of fish. Because juvenile steelhead were distributed shallow in the water column during the day and deeper at night, more juvenile steelhead passed through the shallow TSWs during the day. The TSWs were less effective for yearling and subyearling Chinook salmon, both overall and during day or night, likely because both salmon migrants were distributed deeper in the water column. Between spill treatments, TSW effectiveness was highest during 40 percent spill for yearling Chinook salmon and juvenile steelhead but highest during 60 percent spill for subyearling Chinook salmon.

Survival Probabilities

Estimates of concrete and project survival were similar among years but varied by species. Concrete and project survival were both typically greater than 90 percent and ranged from 97 to 100 percent for juvenile steelhead, from 92 to 97 percent for yearling Chinook salmon, and from 87 to 95 percent for subyearling Chinook salmon. Concrete survival was similar between diel periods for juvenile steelhead but variable between diel periods for both yearling and subyearling Chinook salmon. Concrete survival was higher for all species of fish during 60 percent spill than during 40 percent spill.

Route-specific survival estimates were highly variable among year and species but were typically greater than 90 percent. The spillway and TSWs generally provided the highest survival and the turbines the lowest, for all species. The spillway typically provided higher survival during the day than night for all species, and likewise for the TSWs for juvenile steelhead and subyearling Chinook salmon. However, for yearling Chinook salmon, survival through the TSWs was higher during the night than day.

References Cited

Adams, N.S., and Counihan, T.D., eds., 2009, Survival and migration behavior of juvenile salmonids at McNary Dam, 2007: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Contract W68SBV70178419, Walla Walla, Washington.

Adams, N.S., and Liedtke, T.L., eds., 2009, Juvenile salmonid survival, passage, and egress at McNary Dam during tests of temporary spillway weirs, 2008: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Report number 2008-W68SBV80448890.

Adams, N.S., and Liedtke, T.L., eds., 2010, Juvenile salmonid survival, passage, and egress at McNary Dam during tests of temporary spillway weirs, 2009: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Report number 2009-W68SBV90070150.

Adams, N.S., Plumb, J.M., Hatton, T.W., Jones, E.C., Swyers, N.M., Sholtis, M.D., Reagan, R.E., and Cash, K.M., 2008, Survival and migration behavior of juvenile salmonids at McNary Dam, 2006: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Report number 2006-W68SBV60478899.

Axel, A.G., Hockersmith, E.E., Eppard, M.B., and Sanford, B.P., 2004a, Passage and survival of hatchery yearling Chinook salmon at McNary Dam, 2002: Final report of research by National Marine Fisheries Service to U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866.

Axel, A.G., Hockersmith, E.E., Eppard, M.B., and Sanford, B.P., 2004b, Passage and survival of hatchery yearling Chinook salmon at McNary Dam, 2003: Final report of research by National Marine Fisheries Service to U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866.

Beeman, J.W., Fielding, S.D., Braatz, A.C., Wilkerson, T.S., Pope, A.C., Walker, C.E., Hardiman, J.M., Perry, R.W., and Counihan, T.D., 2008, Survival and migration behavior of juvenile salmonids at Lower Granite Dam, 2006: Final report of research by the U.S. Geological Survey to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV60378208.

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C., and Pollock, K.H., 1987, Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture: American Fisheries Society Monograph 5.

Cormack, R.M., 1964, Estimates of survival from the sighting of marked animals: Biometrika, v. 51, p. 429–438.

Fish Passage Center, 2010, Fish Passage Center website, accessed March 10, 2010, at http://www.fpc.org/smolt/historicsmpsubmitdata.html.

Giorgi, A.E., Hillman, T.W., and Stevenson, J.R., 1997, Factors that influence the downstream migration rates of juvenile salmon and juvenile steelhead through the hydroelectric system in the mid-Columbia River Basin: North American Journal of Fisheries Management, v. 17, p. 268–282.

Jolly, G.M., 1965, Explicit estimates from capture-recapture data with both death and immigration-stochastic model: Biometrika, v. 52, p. 225–247.

Perry, R.W., Braatz, A.C., Fielding, S.D., Lucchesi, J.N., Plumb, J.M., Adams, N.S., and Rondorf, D.W., 2006, Survival and migration behavior of juvenile salmonids at McNary Dam, 2004: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Contract W68SBV40271050.

Perry, R.W., Braatz, A.C., Novick, M.S., Lucchesi, J.L., Rutz, G.L., Koch, R.C., Schei, J.S., Adams, N.A., and Rondorf, D.W., 2007a, Survival and migration behavior of juvenile salmonids at McNary Dam, 2005: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Contract W68SBV50407617.

Perry, R.W., Kock, T.J., Novick, M.S., Braatz, A.C., Fielding, S.D., Hansen, G.S., Sprando, J.M., Wilkerson, T.S., George, G.T., Schei, J.L., Adams, N.S., and Rondorf, D.W., 2007b, Survival and migration behavior of juvenile salmonids at Lower Granite Dam, 2005: Final report of research by the U.S. Geological Survey to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV50498133.

Plumb, J.M., Braatz, A.C., Lucchesi, J.N., Fielding, S.D., Cochran, A.D., Nation, T.K., Sprando, J.M., Schei, J.L., Perry, R.W., Adams, N.S., and Rondorf, D.W., 2004, Behavior and survival of radio-tagged juvenile Chinook salmon and steelhead and performance of a removable spillway weir at Lower Granite Dam, Washington, 2003: Final report of research by the U.S. Geological Survey to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV00104592.

Puls, A.L., Counihan, T.D., Walker, C.E., Hardiman, J.M., and Duran, I.N., 2008: Survival and migration behavior of subyearling Chinook salmon at Lower Granite Dam, 2007: Final report of research by the U.S. Geological Survey to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV70198655.

Seber, G.A.F., 1965, A note on the multiple recapture census: Biometrika, v. 52, p. 249–259.

Skalski, J.R., Townsend, R., Lady, J., Giorgi, A.E., Stevenson, J.R., and McDonald, R.S., 2002, Estimating route-specific passage and survival probabilities at a hydroelectric project from smolt radio telemetry studies: Canadian Journal of Fisheries and Aquatic Sciences, v. 59, p. 1385–1393.

Steig, T.W., Nealson, P.A., Kumagai, K.K., Rowdon, B.J., Klein, L.S., and McFadden, B.D., 2007, Route-specific passage of juvenile steelhead and sockeye salmon using acoustic tag methodologies at Rocky Reach and Rock Island Dams in 2006. Final report for Chelan County Public Utility District No. 1 by Hydroacoustic Technology, Inc..

Steig, T.W., Nealson, P.A., Kumagai, K.K., Rowdon, B.J., Klein, L.S., and McFadden, B.D., 2008, Route-specific passage of juvenile Chinook and sockeye salmon using acoustic tag methodologies at Rocky Reach and Rock Island Dams in 2007: Final report for Chelan County Public Utility District No. 1 by Hydroacoustic Technology, Inc..

Steig, T.W., Nealson, P.A., Kumagai, K.K., Rowdon, B.J., Selleck, J.R., and McFadden, B.D., 2009, Route specific passage of juvenile Chinook, sockeye and juvenile steelhead salmon using acoustic tag methodologies at Rocky Reach and Rock Island Dams in 2008: Final report for Chelan County Public Utility District No. 1 by Hydroacoustic Technology, Inc..

Steig, T.W., Nealson, P.A., Kumagai, K.K., Rowdon, B.J., Selleck, J.R., and Tunnicliffe, C., 2010, Route specific passage of juvenile Chinook, sockeye and juvenile steelhead salmon using acoustic tag methodologies at Rocky Reach and Rock Island Dams in 2009: Final report for Chelan County Public Utility District No. 1 by Hydroacoustic Technology, Inc..

Timko, M.A., Sullivan, L.S., Wright, C.D., Rizor, S.E., O'Connor, R.R., Skalski, J.R., Townsend, R.L., Fitzgerald, C.A., Meagher, M.M., Kukes, T.J., and Stephenson, J.D., 2010, Behavior and survival analysis of juvenile steelhead and sockeye through the Priest Rapids Hydroelectric Project in 2009: Final report for Grant County Public Utility District No. 2 by Blue Leaf Environmental.

University of Washington, 2010, Columbia River DART website, accessed March 30, 2010, at http://www.cbr.washington.edu/dart/dart.html.

Zabel, R.W., 1994, Spatial and temporal models of migrating juvenile salmon with applications: Seattle, Wash., University of Washington, Ph.D. dissertation.

Zabel, R.W., 2002, Using "travel time" data to characterize the behavior of migrating animals: The American Naturalist, vol. 159, p. 372–387.

Zabel, R.W., and Anderson, J.J., 1997, A model of the travel time of migrating juvenile salmon, with an application to Snake River spring Chinook salmon: North American Journal of Fisheries Management, v. 17, p. 93–100.

Chapter 2. Juvenile Salmonid Passage and Survival at McNary Dam, 2006–09, for Fish Released in the Mid-Columbia River

By Christopher E. Walker, Scott J. Brewer, Jill M. Hardiman, and Tim D. Counihan

Introduction

Hydroelectric projects on the Snake and Columbia Rivers are major sources of mortality for migrating juvenile fish. Impoundments caused by dams may indirectly contribute to mortality by slowing the migration of juvenile salmonids (Raymond, 1968, 1979; Plumb and others, 2006), thus increasing exposure to predators and disease in reservoirs. Passage through dams is a direct source of mortality (Mesa, 1994; Whitney and others, 1997) and is cumulative for populations negotiating multiple dams. Few studies have been conducted using acoustic telemetry techniques encompassing long reaches and passage through multiple hydroelectric projects. The technology implemented in the Columbia and Snake Rivers made it possible to collect detailed information at dams as well as estimate survival in smaller reaches throughout the Columbia River.

In spring 2006, the U.S. Geological Survey (USGS) applied acoustic telemetry technology at McNary Dam to obtain approach, passage, and survival information of yearling Chinook salmon and juvenile steelhead (Adams and others, 2008). Results from that study indicated that higher spill discharge generally resulted in higher fish passage through the spillway, and in turn, higher fish survival through the entire dam. In addition, the combination of detailed 3-dimensional (3-D) approach paths of fish and high passage effectiveness estimated for the south spill bays, aided in the design and location of future surface bypass structures installed for the 2007 migration study period.

Using acoustic telemetry technology, the USGS conducted behavioral and survival studies during 2007, 2008, and 2009 at McNary Dam to assess the performance of the new temporary spillway weirs (TSWs) during various spill operations. In 2007, a “2006 Modified spill” and “2007 Test spill” were planned for evaluation of TSW performance. During the spring of 2007, however, the USGS observed few differences in spill operations between the two spill treatments. Consequently, no measurable differences in fish passage and survival were observed between the spill treatments. No spill treatments were planned in spring 2008 or 2009; however, in 2008, two distinct flow conditions were evident. The flow conditions were characterized by 40 percent of project discharge spilled during the first one-half of the spring season and 60 percent of project discharge spilled during the second one-half. Results indicated that more yearling Chinook salmon and juvenile steelhead passed through the TSWs during 40 percent spill compared to the 60 percent spill. However, spillway survival and survival through all routes were slightly higher for both species during 60 percent spill. Fish passage efficiency (FPE) for yearling Chinook salmon was higher during the higher spill treatment.

In addition to the acoustic-tagged fish released specifically for studies at McNary Dam, several thousand additional fish migrated past McNary Dam every year that were tagged and released from dams in the mid-Columbia River by Grant and Chelan County Public Utility Districts (PUDs). Because the tags implanted in mid-Columbia released fish were compatible with the acoustic receivers used by USGS at McNary Dam, it was possible to obtain movement information on mid-Columbia released fish at McNary Dam. We estimated travel time, passage, and survival for yearling Chinook salmon, juvenile sockeye salmon (hereafter referred to as sockeye salmon), and juvenile steelhead released in the mid-Columbia River and passing McNary Dam from 2006 to 2009. A subset of fish also was implanted with passive integrated transponder (PIT) tags, which allowed these fish to be monitored in the bypass system at McNary Dam and determine if they passed through the turbines or the juvenile bypass system. The information contained in this report was made possible by sharing data from the PUDs, allowing the USGS to process the detection data at and downstream of McNary Dam. The USGS was able to estimate passage and survival of these fish at McNary Dam during these years and compare passage and survival probabilities to the tagged salmonids that USGS released 8 km upstream of McNary Dam.

Environmental and Biological Setting

Project Description

Please refer to the *Project Description* section in Chapter 1

River Conditions

Please refer to the *River Conditions* section in Chapter 1.

Project Operations and Study Treatments

Please refer to the *Project Operations and Study Treatments* section in Chapter 1.

Species Composition and Run Timing

Please refer to the *Species Composition and Run Timing* section in Chapter 1.

Study Design

Acoustic Telemetry System

Please refer to the *Acoustic Telemetry System* section in Chapter 1.

Transmitters

Please refer to the *Transmitters* section in Chapter 1.

Fish Tagging and Release

The mid-Columbia River released fish were tagged and released by personnel from Hydroacoustic Technologies Incorporated, LGL Limited, Chelan County Public Utility District (CPUD), and Grant County Public Utility District (GPUD). The standard methodology and protocols used were based on studies conducted in 1999 and 2000 (Stevenson and others, 2000; Skalski and others, 2001). The source, collection, and release sites for each species and release group are briefly documented in this report. A detailed description of collection, transport, and tagging procedures can be found in Steig and others (2007, 2008, 2009, 2010), Sullivan and others (2009), and Timko and others (2007, 2008, 2010). Juvenile salmonids were collected from the Turtle Rock Hatchery in 2006, Rocky Reach juvenile surface collector and gate well dipping from Wanapum Dam in 2006, 2007, 2008, and 2009, and from Priest Rapids Dam in 2006, 2007, and 2009 (table 2-1). For all mid-Columbia experimental groups, handling protocols (including, collection, transport, tagging, holding, and release) were standardized as much as possible among release groups to reduce the potential for bias (Stevenson and others, 2000; Skalski and others, 2001). All acoustic transmitters were surgically implanted. Fish were typically held for 24–48 hours before tagging to ensure evacuation of stomach contents and for 24–48 hours after tagging to allow for recovery from the tagging procedures, to remove any post-tagging mortalities, and to identify any early acoustic tag failure. Species, collection sources, release dates, number of fish per release, and release sites are documented in table 2-1.

Tagging and release procedures were similar to those used in the lower Columbia and Snake Rivers by the USGS, although differences were observed. In addition to releasing fish from boats, fish released from the mid-Columbia River also were released from a helicopter. Another notable difference from USGS procedures was that fish released by CPUD were held for up to 48 hours post-tagging and fish released by GPUD were held 24 hours post-tagging. Fish released by USGS were held 18–34 hours post-tagging. Detailed tagging and release procedures for USGS released fish are described by Adams and others (2008), Adams and Counihan (2009), and Adams and Liedtke (2009, 2010).

Juvenile salmonids were tagged and released from the mid-Columbia River release sites from April 20–June 3, 2006, April 20–May 31, 2007, April 24–June 6, 2008, and April 25–June 8, 2009 (tables 2-1 and 2-2). These release dates overlapped the releases made by the USGS at Hat Rock State Park, 10 rkm upstream of McNary Dam, from April 26–June 3, 2006, April 19–June 7, 2007, April 18–June 4, 2008, and April 17–June 2, 2009. Passage dates for mid-Columbia released fish at McNary Dam coincided with the majority of the population run timing for each species (68–94 percent) at McNary Dam according to the Fish Passage Center Smolt Indices (*http://www.fpc.org/smolt/historicsmpsubmitdata.html*). Passage date range, the percent spill observed during passage period, and, consequently, the time period and percent spill associated with passage and survival estimates, are presented for each species in table 2-3. Survival analyses for mid-Columbia River released fish were conducted on the following numbers of fish detected passing McNary Dam: 293 yearling Chinook salmon, 1,493 juvenile steelhead, and 1,339 sockeye salmon in 2006; 1,097 yearling Chinook salmon, 650 juvenile steelhead, and 1,224 sockeye salmon in 2007; 539 yearling Chinook salmon, 1,888 juvenile steelhead, and 1,084 sockeye salmon in 2008; 1,860 juvenile steelhead and 3,578 sockeye salmon in 2009.

Table 2-1. Summary of species, collection sources, release dates, release numbers per day, and release sites for acoustic-tagged juvenile salmonids released in the mid-Columbia River by Chelan and Grant County PUDs.

[Species: Y., yearling. Collection source: PG, Priest Rapids Dam Gatewells; RC, Rocky Reach Collector; WG, Wanapum Dam Gatewells. Release site: PR, Priest Rapids Dam; RC, Rocky Reach Collector; RI, Rock Island Dam; RR, Rocky Reach Dam; WA, Wanapum Dam; WE, Wells Dam; VB, Vantage Bridge]

Species	Collection source	Release dates	Fish per release	Release site
Y. Chinook	Turtle Rock Hatchery	May 2–June 3, 2006	19–24	WA
Steelhead	RC,WG, PG	April 20–June 2, 2006	19–34	WE, RR, RI, WA, PR
Sockeye	RC	May 5–May 29, 2006	19–23	WE, RR, RI
Y. Chinook	RC	April 20– May 31, 2007	21–39	RR, RI, WA
Steelhead	RC, WG	April 27–May 27, 2007	12–42	RI
Sockeye	RC	May 7–May 31, 2007	20–22	WE, RR
Y. Chinook	WG	May 8–June 5, 2008	30–80	VB
Y. Chinook	RC	April 24–May 30, 2008	21–27	RR
Steelhead	WG	May 8–June 3, 2008	8–26	RI, WA, PR
Steelhead	RC	April 24–June 1, 2008	23–27	RR
Sockeye	RC	May13–June 6, 2008	6–24	WE, RR, RI
Y. Chinook	RC	April 25–May 11, 2009	19–29	RR
Steelhead	WG, PG	May 2–May 25, 2009	20–53	RI, WA, PR
Steelhead	RC	April 27–May 11, 2009	19–32	RR
Sockeye	WG, PG	May 14–June 1, 2009	30–52	RI, WA, PR
Sockeye	RC	May15–June 8, 2009	29–41	WE, RC, RR

Table 2-2. Summary statistics of fork length and weight for acoustic-tagged juvenile salmonids released in the mid-Columbia River, 2006–09.

[Species: Y., yearling. CPUD, Chelan County Public Utility District; GPUD, Grant County Public Utility District. Release site: PR, Priest Rapids Dam; RC, Rocky Reach Collector; RR, Rocky Reach Dam; RH, Rock Island Hydro Park; RI, Rock Island Dam; WA, Wanapum Dam; WE, Wells Dam. mm, millimeter; g, grams; Min, minimum; Max, maximum]

Species	Release group	Release site	Number of fish	Fork length (mm) Mean	Min	Max	Weight (g) Mean	Min	Max
2006									
Y. Chinook	GPUD	WA	652	189	150	237	76	36	181
Steelhead	GPUD	RI, WA, PR	2,520	199	150	250	73	30	155
Steelhead	CPUD	WE, RI, RR	1,501	183	104	235	56	17	144
Sockeye	CPUD	WE, RR, RI	3,493	116	100	148	15	8	28
2007									
Y. Chinook	GPUD	WA	1,001	171	149	215	52	32	104
Steelhead	GPUD	RI	1,402	188	146	230	52	29	118
Y. Chinook	CPUD	RR, RI	1,000	167	132	260	47	20	114
Sockeye	CPUD	WE, RR	2,500	114	100	153	15	8	37
2008									
Y. Chinook	CPUD	RR, RI	949	161	114	224	43	24	119
Steelhead	CPUD	RR	498	187	149	230	58	29	104
Sockeye	CPUD	WE,RC,RR,RH	2,002	117	100	147	16	10	29
Steelhead	GPUD	RI,WA,PR	2,201	186	143	220	59	30	98
2009									
Steelhead	CPUD	RR	175	193	145	228	67	32	121
Sockeye	CPUD	WE,RC,RR	2,031	123	100	158	19	10	49
Steelhead	GPUD	RI,WA,PR	2,096	192	144	220	66	31	90
Sockeye	GPUD	RI,WA,PR	1,943	127	104	210	20	13	86

Table 2-3. Number of acoustic-tagged juvenile salmonids released in the mid-Columbia River, number (and percent of those released) that passed McNary Dam, range of passage dates, and corresponding percent spill of total project discharge over dates of passage at McNary Dam, by species, 2006–09.

[Percent spill is the percentage of project discharge spilled and includes the water discharged through the temporary spillway weirs. **Abbreviations**: NA, not applicable; Y., yearling]

Species	Period	Number released	Number passed (percent)	First passage date	Last passage date	Percent Spill
2006						
Y. Chinook	Overall	652	293 (45)	May 06	June 07	51
Steelhead	Overall	4,021	1,493 (37)	April 26	June 08	50
Sockeye	Overall	3,493	1,339 (38)	May 10	June 11	52
2007						
Y. Chinook	Overall	2,001	1,097 (55)	April 25	June 12	41
Steelhead	Overall	1,402	650 (46)	May 01	June 09	41
Sockeye	Overall	2,500	1,224 (49)	May 11	June 14	41
2008						
Y. Chinook	Overall	949	539 (57)	April 30	June 12	54
	Early	NA	182 (19)	April 30	May 17	45
	Late	NA	357 (38)	May 17	June 12	58
Steelhead	Overall	2,699	1,888 (70)	April 30	June 17	54
	Early	NA	412 (15)	April 30	May 17	45
	Late	NA	1,476 (55)	May 17	June 17	57
Sockeye	Overall	2,002	1,084 (54)	May 18	June 21	57
	Early	NA	0 (0)	NA	NA	NA
	Late	NA	1,084 (54)	May 18	June 21	57
2009						
Steelhead	Overall	2,271	1,860 (82)	May 02	June 12	49
Sockeye	Overall	3,974	3,578 (90)	May 18	June 20	50

Signal Processing and Verification

Please refer to the *Signal Processing and Verification* section in Chapter 1.

Travel Times and Rates

Please refer to the *Travel Times and Rates* section in Chapter 1.

Passage Determinations

Please refer to the *Passage Determinations* section in Chapter 1. The only difference in determining passage for mid-Columbia River released fish, compared to Hat Rock released fish, is that passage through the turbines and bypass could not be distinguished for fish that were not implanted with a PIT tag. Therefore, mid-Columbia released fish without an implanted PIT tag, were assigned powerhouse passage, not turbine or bypass passage.

Survival Model

We used a single-release, route-specific survival model (RSSM) to estimate passage and survival probabilities (Skalski and others, 2002). The foundation of this model is based on the single release-recapture models of Cormack (1964), Jolly (1965), and Seber (1965; CJS model). The RSSM partitions survival among reservoir, forebay, and route-specific components and uses a branching process to estimate route-specific passage probabilities (table 2-4; figs. 2-1 and 2-2). The route-specific model used in 2006 included two routes—the spillway and powerhouse (fig. 2-1), and the model used in 2007, 2008, and 2009 included four routes—the spillway, powerhouse, and two TSWs (fig. 2-2). For subsets of juvenile steelhead that were implanted with PIT tags in 2008 and 2009, a route-specific survival model that incorporated five routes was used where the powerhouse was split into bypass and turbine passage routes.

We estimated season-wide passage and survival with respect to diel periods (in other words, day and night) in 2009, and spill treatments in 2008, under which the fish passed the dam. Day and night periods for analysis were dictated by when spill operations typically changed rather than by sunrise and sunset; day was considered 0600–1759 hours and night was considered 1800–0559 hours. Fish were assigned to treatments and diel periods based on their time of passage at McNary Dam. For the turbines and the spillway, including the TSWs, time of passage was assigned to the last detection of fish within the route of passage. For fish passing through the juvenile bypass system, passage was assigned using the first detection on the PIT-tag detection coils.

We assessed model fit by examining residuals of observed versus expected capture history counts (appendix E).

Table 2-4. Definitions of fish detection, passage, and survival parameters for McNary Dam, 2006–09.

[Estimates were obtained using a single release, route-specific survival model and represent the survival probability from detection in front of the route to the first detection array downstream of McNary Dam. Parameter: PH, powerhouse; SP, spillway; TSW temporary spillway weir; PR, unconditional probability; P, detection probability; S, survival probability. Source: MLE, maximum likelihood estimate]

Parameter	Source	Definition
PH	MLE	Unconditional probability of powerhouse passage (turbines and bypass combined).
SP	MLE	Probability of spillway passage, conditional on the fish not passing the powerhouse. This is also spillway passage efficiency.
TSW1 [1]	MLE	Probability of TSW design 1 passage, conditional on the fish not passing the powerhouse or spillway.
TSW2 [1]	MLE	Probability of TSW design 2 passage, conditional on the fish not passing the powerhouse or spillway.
PR_{Ph}	Derived	Unconditional probability of powerhouse passage (same as PH above).
PR_{Sp}	Derived	Unconditional probability of spillway passage.
PR_{TSW1} [1]	Derived	Unconditional probability of TSW design 1 passage.
PR_{TSW2} [1]	Derived	Unconditional probability of TSW design 2 passage.
P_{Fb}	MLE	Detection probability of the forebay entrance site.
P_{Ph1}	MLE	Detection probability of first powerhouse array.
P_{Ph2}	MLE	Detection probability of second powerhouse array.
P_{Ph}	Derived	Overall detection probability of the powerhouse.
P_{Sp1}	MLE	Detection probability of first spillway array.
P_{Sp2}	MLE	Detection probability of second spillway array.
P_{Sp}	Derived	Overall detection probability of the spillway.
P_{TSW11} [1]	MLE	Detection probability of first TSW design 1 array.
P_{TSW12} [1]	MLE	Detection probability of second TSW design 1 array.
P_{TSW1} [1]	Derived	Overall detection probability of TSW design 1.
P_{TSW21} [1]	MLE	Detection probability of first TSW design 2 array.
P_{TSW22} [1]	MLE	Detection probability of second TSW design 2 array.
P_{TSW2} [1]	Derived	Overall detection probability of TSW design 2.
P_{TSW} [12]	MLE	Overall detection probability of TSW design 1 and TSW design 2 (estimated from downstream detection arrays under the CJS model).
P_{R}	MLE	Detection probability of the first detection array downstream of McNary Dam.
λ	MLE	Lambda. Joint probability of surviving and being detected by all detection arrays downstream of the first detection array downstream of McNary Dam.
S_{Pool}	MLE	Pool survival probability. Survival probability from upstream boundary of reservoir to detection at the forebay entrance.
S_{Fb}	MLE	Forebay survival probability. Survival probability from point of detection at forebay entrance to point of detection within a passage route.
$S_{\mathrm{All\_routes}}$	Derived	Survival probability through all passage routes. The probability of survival from the upstream boundary of the dam (dam face) to detection at the first downstream detection array; it includes all routes of passage, the tailrace, and section of river to the first downstream detection array. The probability of survival through each route of passage is weighted by the probability of passage through each route (that is, $(S_{\mathrm{Spill}} \times P_{\mathrm{Spill}}) + (S_{\mathrm{Bypass}} \times P_{\mathrm{Bypass}}) + (S_{\mathrm{Turbine}} \times P_{\mathrm{Turbine}})$) where “S” is the probability of survival and “P” is the probability of passage. Similar to concrete survival but uses single-release model.
S_{Sp}	MLE	Spillway survival probability.
S_{Ph}	MLE	Powerhouse survival probability.
S_{TSW1} [1]	MLE	TSW design 1 survival probability.
S_{TSW2} [1]	MLE	TSW design 2 survival probability.

[1]Parameter was not estimable in 2006 because TSWs were not present.

[2]Parameter was estimated in 2007 only due to absence of double array at TSWs in 2007.

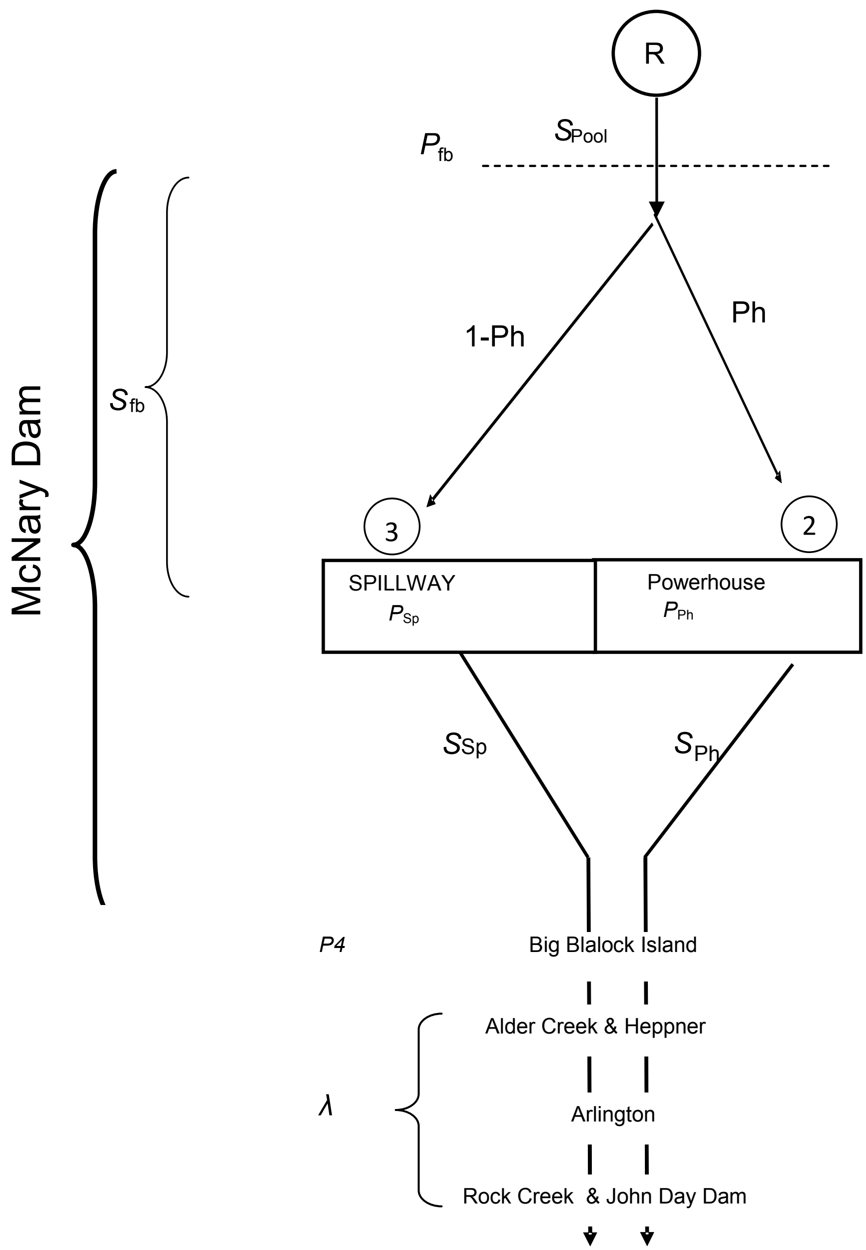

Figure 2-1. Schematic of a single release, route-specific survival model whereby survival and detection probabilities are separated among available routes and river reaches upstream and downstream of McNary Dam, 2006. Release sites in the mid-Columbia River are represented by R. Circled numbers indicate passage route codes used in detection histories for each fish. Lambda (λ) is the joint probability of surviving and being detected by telemetry arrays downstream of the first detection array downstream of McNary Dam.

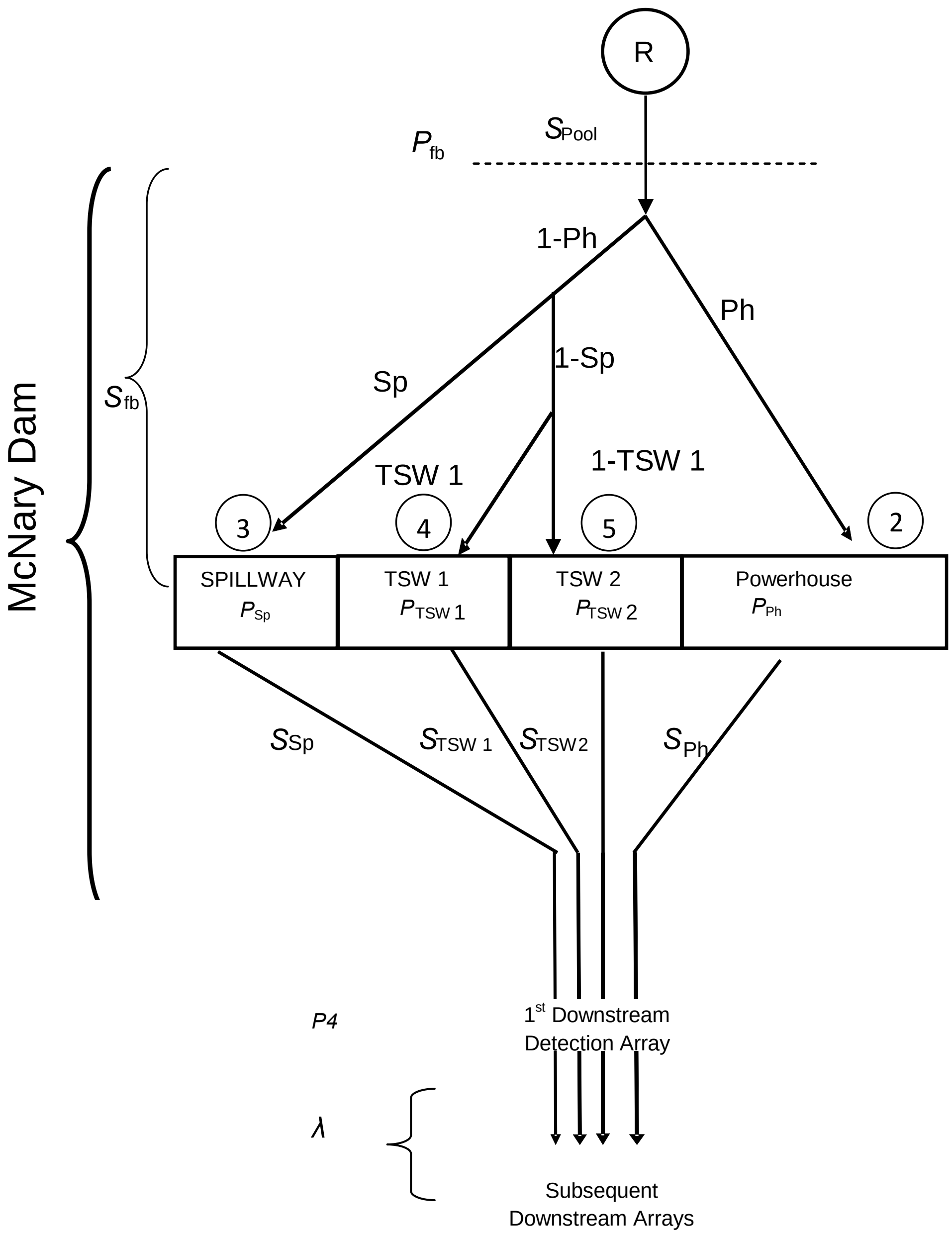

Figure 2-2. Schematic of a single release, route-specific survival model whereby survival and detection probabilities are separated among available routes and river reaches upstream and downstream of McNary Dam, 2007–09. Release sites in the mid-Columbia River are represented by R. Circled numbers indicate passage route codes used in detection histories for each fish. Lambda (λ) is the joint probability of surviving and being detected by telemetry arrays downstream of the first detection array downstream of McNary Dam. For subsets of juvenile steelhead that were implanted with PIT tags in 2008 and 2009, a route-specific survival model that incorporated five routes was used where the powerhouse was split into bypass and turbine passage routes.

Fish Behavior

Travel Times and Rates

Average travel times from release to McNary Dam were 2–3 days from Priest Rapids Dam, 3–4 days from Wanapum Dam, 4–8 days from Rock Island Dam, 5–9 days from Rocky Reach Dam, and 6–8 days from Wells Dam (table 2-5). The mean travel rates from release to McNary Dam ranged from 37.0 to 64.1 km/d in 2006, 30.3 to 54.1 km/d in 2007, 37.5 to 69.5 km/d in 2008, and 33.1 to 92.4 km/d in 2009 for all species. Travel rates were greatest in 2008 for all species and release locations. Within each year, sockeye salmon had the highest rates of travel, followed by juvenile steelhead, and then yearling Chinook salmon. As fish traveled downstream, mean travel rates decreased in the near dam area of McNary Dam with average rates ranging from 10.50 to 19.03 km/d in 2006, 5.47 to 14.94 km/d in 2007, 4.24 to 18.57 km/d in 2008 and 4.19 to 21.46 km/d in 2009 (table 2-6). However, these travel rates in the last 160 m of river before passing the dam represent relatively short average forebay residence times of 2.9 to 4.8 h for yearling Chinook salmon, 2.9 to 11.5 h for juvenile steelhead, and 2.2 to 11.3 h for sockeye salmon, depending on year. Travel rates increased in reaches downstream of the dam and were similar to observed travel rates in the reach (in other words, pool) upstream of the dam (table 2-7 and appendix C). Little difference was observed in travel rates of fish through the near dam area (within 160 m of the dam face) when analyzed by route of passage, with the exception of sockeye salmon which had much higher (2-3 times) rates of travel through the forebay in 2009 for fish that passed through the spillway or either TSW, compared to the powerhouse (figs. C1–C3). Tailrace egress rates generally were higher for all species passing through the spillway or either TSW, than for fish passing through the powerhouse (figs. C4–C6). Similarly, travel rates of all species from passage at McNary Dam to the detection array located 24 km downstream in 2006–08, and 22 km downstream in 2009, generally were higher for fish passing through the spillway or TSWs, compared to fish passing though the powerhouse (figs. C7–C9).

Passage Distribution by Diel Period

Mid-Columbia River released fish passed McNary Dam during all hours of the day and nearly equal proportions of all species passed during the day and night (figs. 2-3, 2-4, 2-5, and 2-6). Based on the last detection in the forebay of McNary Dam, 45–54 percent of yearling Chinook salmon, 46–54 percent of juvenile steelhead, and 51–55 percent of sockeye salmon passed McNary Dam during the day (0600–1759 hours) and the remainder passed during the night (1800–0559 hours). Passage of all species during all years gradually increased over the 24-hour period and generally peaked between 1700 and 2300 hours.

Table 2-5. Mean and median travel times and mean travel rates from release to first detection in the McNary Dam forebay for juvenile salmonids released in the Mid-Columbia River, 2006–09.

[d, days; km, kilometers; km/d, kilometers per day; Rock Is., Rock Island]

Species	Distance	Mean travel time (d)				Median travel time (d)				Mean travel rate (km/d)			
Release location	(km)	2006	2007	2008	2009	2006	2007	2008	2009	2006	2007	2008	2009
Yearling Chinook salmon													
Rocky Reach Dam	290.0	—	8.55	7.73	—	—	7.91	7.03	—	—	33.92	37.53	—
Rock Island Dam	254.0	—	8.38	—	—	—	7.88	—	—	—	30.30	—	—
Wanapum Dam	197.5	3.68	4.13	—	—	3.49	3.91	—	—	53.72	47.82	—	—
Juvenile steelhead													
Wells Dam	358.0	7.79	—	—	—	7.30	—	—	—	45.93	—	—	—
Rocky Reach Dam	290.0	6.46	—	6.03	8.76	5.79	—	5.55	7.93	44.87	—	48.10	33.10
Rock Island Dam	254.0	6.86	6.40	5.38	7.53	5.97	5.88	4.95	6.97	37.04	39.67	47.23	33.75
Wanapum Dam	197.5	4.05	—	3.34	4.31	3.44	—	3.02	3.98	48.76	—	59.05	45.82
Priest Rapids Dam	167.0	2.61	—	2.40	3.24	2.37	—	1.99	2.67	64.09	—	69.53	51.53
Sockeye salmon													
Wells Dam	358.0	6.10	6.62	5.60	5.97	5.95	6.22	5.28	5.73	58.71	54.09	63.92	59.95
Rocky Reach Dam	290.0	5.11	5.70	4.48	4.88	4.85	5.31	4.12	4.68	56.74	50.90	64.75	59.43
Rock Is. Hydro Park	280.0	—	—	4.25	—	—	—	4.04	—	—	—	65.90	—
Rock Island Dam	254.0	4.82	—	3.91	4.75	4.38	—	3.57	4.46	52.72	—	65.01	53.44
Wanapum Dam	197.5	—	—	—	2.83	—	—	—	2.70	—	—	—	69.68
Priest Rapids Dam	167.0	—	—	—	1.81	—	—	—	1.81	—	—	—	92.35

Table 2-6. Mean and median travel times and mean travel rates from first detection in McNary Dam forebay until passage, by release location, for juvenile salmonids released in the Mid-Columbia River, 2006–09.

[d, days; km/d, kilometers per day]

Species Release location	Mean travel time (d) 2006	2007	2008	2009	Median travel time (d) 2006	2007	2008	2009	Mean travel rate (km/d) 2006	2007	2008	2009
Yearling Chinook salmon												
Rocky Reach Dam	—	0.13	0.20	—	—	0.09	0.09	—	—	14.94	10.01	—
Rock Island Dam	—	0.15	—	—	—	0.10	—	—	—	13.01	—	—
Wanapum Dam	0.12	0.18	—	—	0.08	0.08	—	—	16.83	11.27	—	—
Juvenile steelhead												
Wells Dam	0.17	—	—	—	0.07	—	—	—	11.96	—	—	—
Rocky Reach Dam	0.12	—	0.14	0.33	0.07	—	0.08	0.21	16.25	—	13.82	6.03
Rock Island Dam	0.19	0.37	0.36	0.41	0.08	0.14	0.07	0.19	10.50	5.47	5.53	4.83
Wanapum Dam	0.19	—	0.13	0.48	0.08	—	0.06	0.25	10.63	—	15.46	4.19
Priest Rapids Dam	0.13	—	0.19	0.44	0.07	—	0.07	0.21	15.87	—	10.78	4.59
Sockeye salmon												
Wells Dam	0.11	0.19	0.38	0.10	0.06	0.09	0.06	0.07	18.05	10.59	5.30	19.80
Rocky Reach Dam	0.11	0.26	0.40	0.10	0.06	0.09	0.05	0.06	18.09	7.60	5.02	19.88
Rock Island Hydro Park	—	—	0.47	—	—	—	0.06	—	—	—	4.24	—
Rock Island Dam	0.11	—	0.29	0.09	0.06	—	0.06	0.06	19.03	—	6.79	21.46
Wanapum Dam	—	—	—	0.13	—	—	—	0.06	—	—	—	14.86
Priest Rapids Dam	—	—	—	0.12	—	—	—	0.06	—	—	—	16.05

Table 2-7. Mean and median travel times and mean travel rates from passage at McNary Dam until detection at first detection array downstream of McNary Dam, by release location, for juvenile salmonids released in the mid-Columbia River, 2006–09.

[d, days; km/d, kilometers per day]

Species Release location	Mean travel time (d) 2006	2007	2008	2009	Median travel time (d) 2006	2007	2008	2009	Mean travel rate (km/d) 2006	2007	2008	2009
Yearling Chinook salmon												
Rocky Reach Dam	—	0.64	0.75	—	—	0.36	0.41	—	—	37.34	31.80	—
Rock Island Dam	—	0.74	—	—	—	0.47	—	—	—	32.35	—	—
Wanapum Dam	0.34	0.48	—	—	0.26	0.37	—	—	71.25	50.24	—	—
Juvenile steelhead												
Wells Dam	0.46	—	—	—	0.28	—	—	—	52.49	—	—	—
Rocky Reach Dam	0.66	—	0.41	0.56	0.24	—	0.26	0.26	36.25	—	58.23	39.63
Rock Island Dam	0.48	0.55	0.47	0.28	0.25	0.30	0.26	0.23	49.70	43.35	51.33	78.83
Wanapum Dam	0.43	—	0.41	0.32	0.25	—	0.27	0.24	55.40	—	59.06	69.78
Priest Rapids Dam	0.44	—	0.40	0.27	0.25	—	0.26	0.24	54.50	—	60.41	82.39
Sockeye salmon												
Wells Dam	0.50	0.51	0.54	0.26	0.25	0.36	0.53	0.18	47.92	46.76	44.25	84.65
Rocky Reach Dam	0.38	0.58	0.64	0.30	0.26	0.34	0.55	0.19	63.51	41.03	37.41	74.42
Rock Island Hydro Park	—	—	0.85	—	—	—	0.54	—	—	—	28.33	—
Rock Island Dam	0.43	—	0.57	0.30	0.26	—	0.53	0.19	55.69	—	41.79	72.64
Wanapum Dam	—	—	—	0.29	—	—	—	0.20	—	—	—	75.03
Priest Rapids Dam	—	—	—	0.31	—	—	—	0.20	—	—	—	71.65

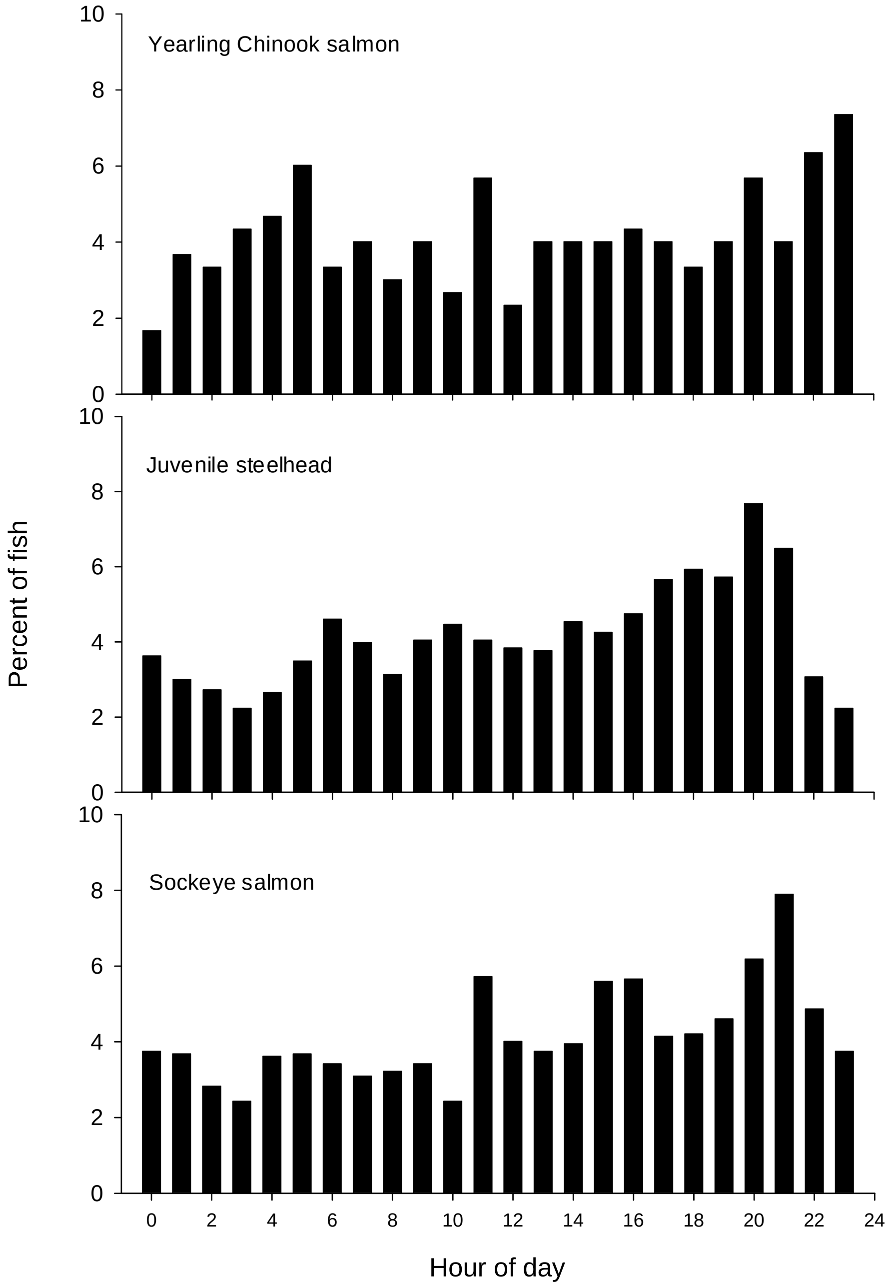

Figure 2-3. Graphs showing frequency distribution of the last detection hour at McNary Dam for mid-Columbia River released juvenile salmonids in 2006.

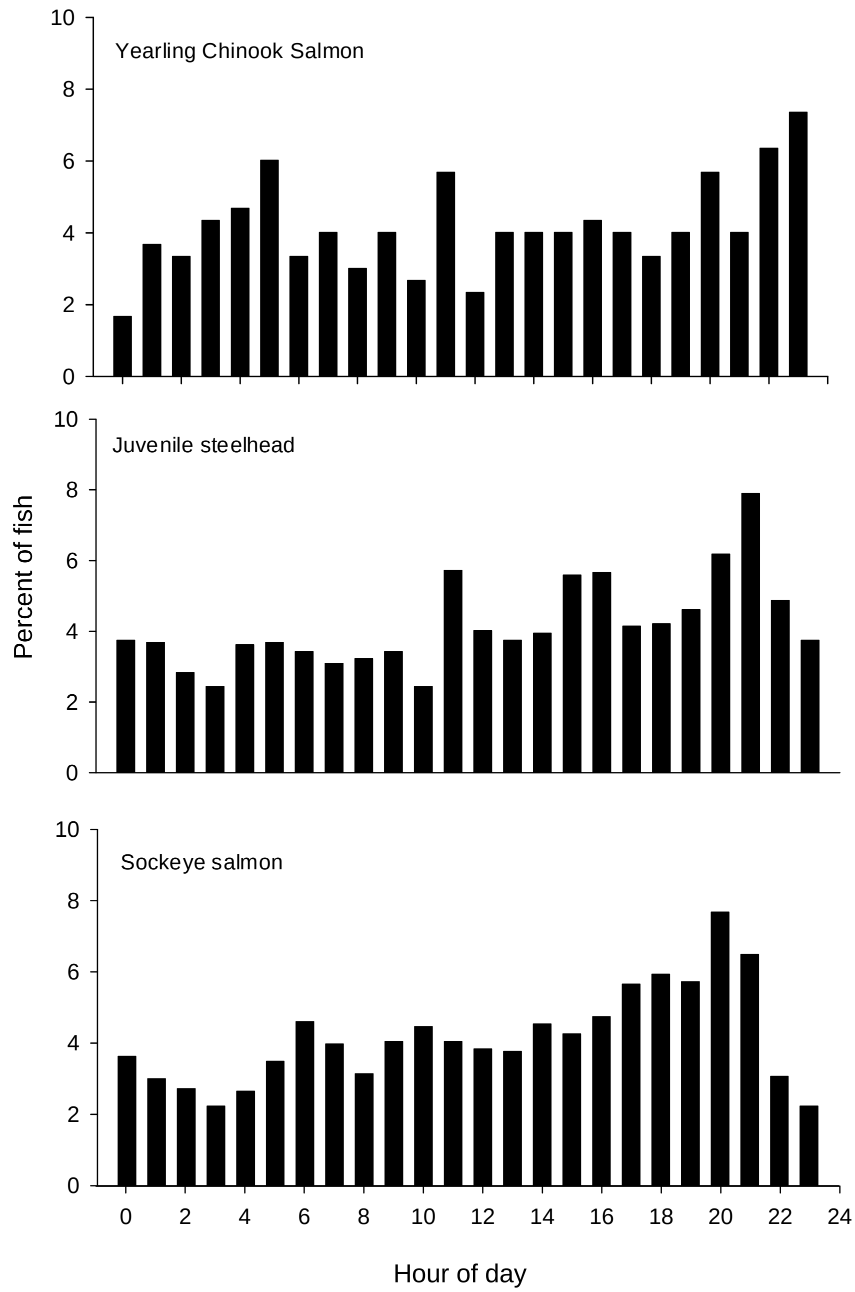

Figure 2-4. Graphs showing frequency distribution of the last detection hour at McNary Dam for mid-Columbia River released juvenile salmonids in 2007.

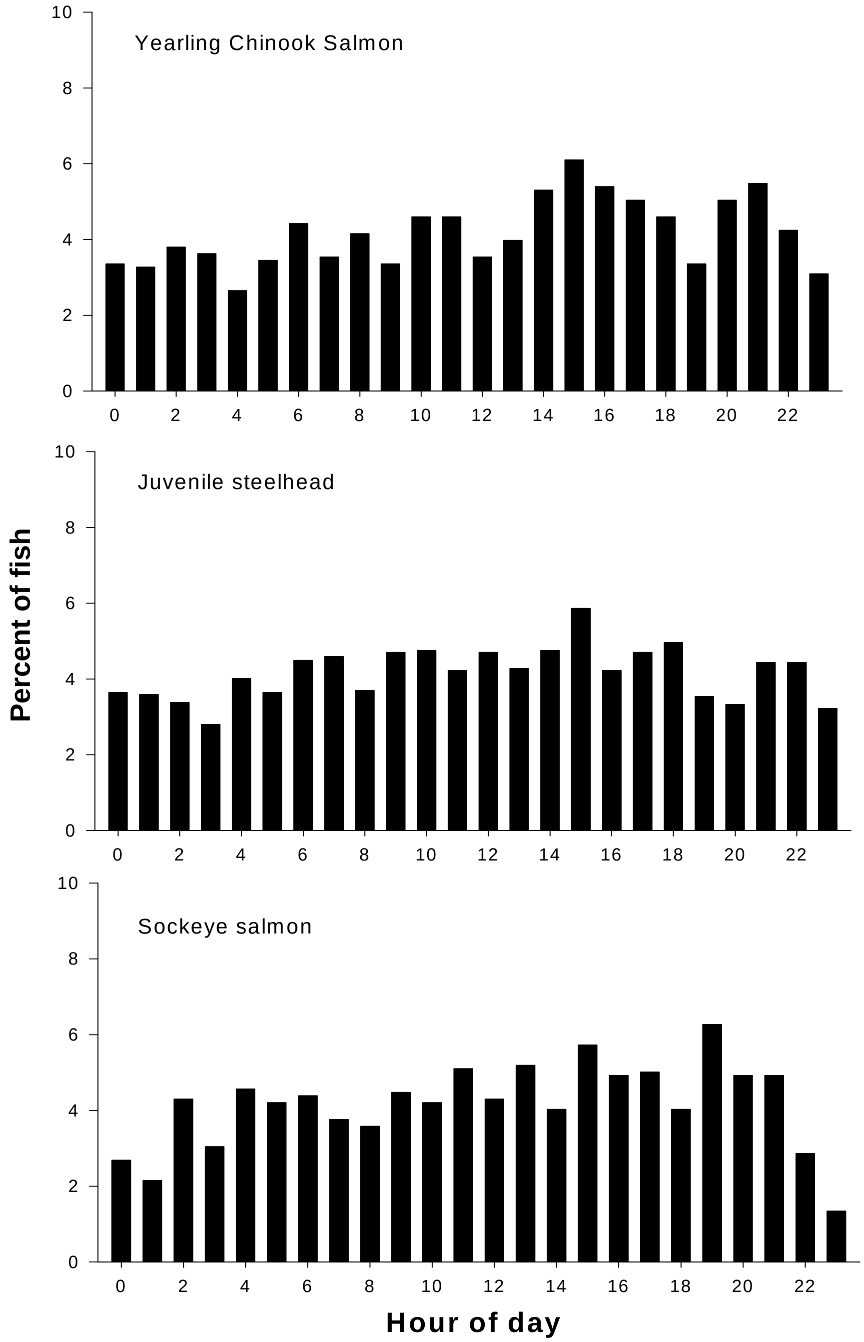

Figure 2-5. Graphs showing frequency distribution of the last detection hour at McNary Dam for mid-Columbia River released juvenile salmonids in 2008.

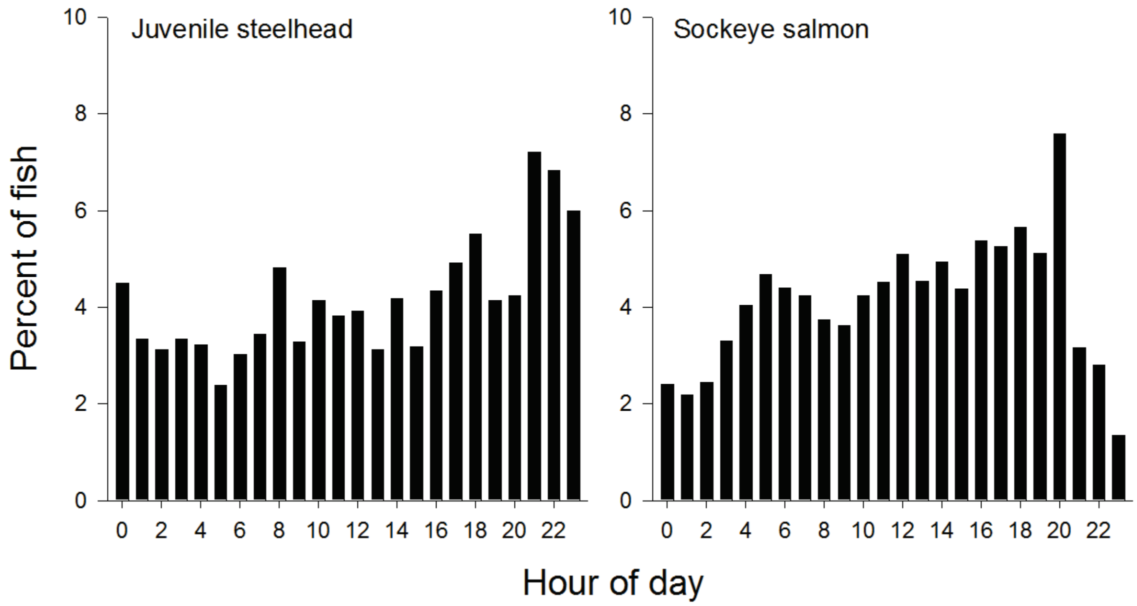

Figure 2-6. Graphs showing frequency distribution of the last detection hour at McNary Dam for mid-Columbia River released juvenile salmonids in 2009.

Fish Passage and Survival

Route-Specific Passage Probabilities

Passage Probabilities 2006

During 2006, passage probability was higher for all species passing through the spillway compared to the powerhouse (table 2-8). Passage probabilities for the spillway were 0.528, 0.659, and 0.672 for yearling Chinook salmon, juvenile steelhead, and sockeye salmon, respectively. Passage probabilities for the powerhouse were 0.472, 0.341, and 0.328 for yearling Chinook salmon, juvenile steelhead, and sockeye salmon, respectively.

Passage Probabilities 2007

During 2007, the first year that the TSWs were tested, passage probabilities varied among the three fish species (table 2-8). Passage probability was highest through the powerhouse for yearling Chinook salmon (0.360) and sockeye salmon (0.398) but, for juvenile steelhead, passage probability was highest through TSW1 (0.498). The probability of passing through TSW1 was 0.274 for yearling Chinook salmon and 0.312 for sockeye salmon. Spillway passage probabilities were 0.302 for yearling Chinook salmon, 0.207 for juvenile steelhead, and 0.244 for sockeye salmon. Passage probabilities were lowest for TSW2, ranging from 0.046 to 0.069, depending on species.

Passage Probabilities 2008

For yearling Chinook salmon in 2008, the spillway was the passage route with the highest passage probability overall (0.651), as well as during the late period when a higher proportion of discharge was spilled (0.765; tables 2-8 and 2-9). In comparison, during the lower spill levels of the early period, the probability of passing through the spillway (0.406) was much lower and most fish passed through the powerhouse (0.441). Although the probability of passage through each TSW during the early period was only 0.076, this was 2–3 times their efficiency during the higher spill levels of the late period (0.025 and 0.036 for TSW1 and TSW2, respectively; table 2-9).

Juvenile steelhead had a similar overall passage pattern to yearling Chinook salmon, with the highest passage probability being the spillway (0.617), followed by the powerhouse (0.184), TSW2 (0.110), and TSW1 (0.089; table 2-8). However, unlike Chinook salmon, which shifted their passage to the powerhouse during the low spill of the early period, juvenile steelhead passage increased through the TSWs during lower spill levels. The route with the second highest probability of passage during the early period for juvenile steelhead was TSW2 (0.239; table 2-9). Similar to yearling Chinook salmon, spillway passage probability for juvenile steelhead nearly doubled during the late period, when percent spill increased from 40 percent of total project discharge to 60 percent.

A subset of juvenile steelhead implanted with both a PIT tag and an acoustic tag enabled estimation of passage and survival probabilities for fish that passed through turbines, as well as for fish that passed through the juvenile bypass system. Passage probabilities for juvenile steelhead implanted with an acoustic and a PIT tag were similar to passage probabilities for juvenile steelhead implanted with only an acoustic tag (tables 2-8 and 2-10). The passage route with the highest probability of passage was the spillway (0.699) followed by the juvenile bypass (0.122), the turbines (0.067), TSW2 (0.064), and TSW1 (0.048). Fish guidance efficiency (FGE) for juvenile steelhead implanted with a PIT tag and acoustic tag was 0.647 and fish passage efficiency (FPE) was 0.933.

Passage probabilities for sockeye salmon were similar to the other species (table 2-8). The spillway had the highest probability of passage (0.744), followed by the powerhouse (0.189), TSW1 (0.045), and TSW2 (0.021).

Passage Probabilities 2009

Juvenile steelhead released from the mid-Columbia River in 2009 had the highest probability of passage at McNary Dam through the powerhouse, both overall (0.367) and during the day (0.378; tables 2-8 and 2-11). The spillway had the second highest probability of passage overall, but during the day, TSW2 provided the second highest passage probability. At night, the spillway had the highest passage probability (0.402), followed by the powerhouse (0.354), TSW2 (0.164), and TSW1 (0.080).

A subset of juvenile steelhead implanted with both a PIT tag and an acoustic tag enabled estimation of passage probabilities for fish that passed through turbines, as well as for fish that passed through the juvenile bypass system. Passage probabilities for juvenile steelhead implanted with an acoustic/PIT tag were nearly identical to passage probabilities for juvenile steelhead implanted with only an acoustic tag (tables 2-8 and 2-10). The passage route with the highest probability of passage was the spillway (0.341) followed by the juvenile bypass (0.326), TSW2 (0.238), TSW1 (0.055), and the turbines (0.040). Fish guidance efficiency (FGE) for juvenile steelhead implanted with a PIT/acoustic tag was 0.889 and fish passage efficiency (FPE) was 0.960.

Passage probabilities for sockeye salmon were highest at the spillway (0.475), followed by the powerhouse (0.366), TSW2 (0.123), and TSW1 (0.036; table 2-8). The same pattern existed for passage probabilities during day and night periods (table 2-11).

Table 2-8. Route-specific passage probabilities for mid-Columbia released juvenile salmonids in 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model; NA, not applicable]

Passage route	Yearling Chinook salmon	Juvenile steelhead	Sockeye salmon
		2006	
Powerhouse	0.472 (0.029)	0.341 (0.011)	0.328 (0.011)
Spillway[1]	0.528 (0.029)	0.659 (0.011)	0.672 (0.011)
TSW1	NA	NA	NA
TSW2	NA	NA	NA
		2007	
Powerhouse	0.360 (0.014)	0.226 (0.015)	0.398 (0.013)
Spillway[1]	0.302 (0.013)	0.207 (0.014)	0.244 (0.012)
TSW1	0.274 (0.014)	0.498 (0.019)	0.312 (0.014)
TSW2	0.064 (0.008)	0.069 (0.011)	0.046 (0.008)
		2008	
Powerhouse	0.259 (0.018)	0.184 (0.008)	0.189 (0.010)
Spillway[1]	0.651 (0.020)	0.617 (0.011)	0.744 (0.012)
TSW1	0.042 (0.008)	0.089 (0.006)	0.045 (0.005)
TSW2	0.049 (0.009)	0.110 (0.007)	0.021 (0.004)
		2009	
Powerhouse	NA	0.367 (0.011)	0.366 (0.008)
Spillway[1]	NA	0.338 (0.011)	0.475 (0.008)
TSW1	NA	0.055 (0.005)	0.036 (0.003)
TSW2	NA	0.240 (0.009)	0.123 (0.005)

[1]The probability of passing through the spillway is also termed spillway passage efficiency (SPE).

Table 2-9. Route-specific passage and survival (single-release) probabilities for mid-Columbia released juvenile salmonids during early (40 percent spill) and late (60 percent spill) spring, 2008.

[%, percent; Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model]

	Yearling Chinook salmon		Juvenile steelhead	
Passage route	**40% spill**	**60% spill**	**40% spill**	**60% spill**
		Passage probabilities		
Powerhouse	0.441 (0.037)	0.174 (0.019)	0.214 (0.020)	0.177 (0.009)
Spillway[1]	0.406 (0.036)	0.765 (0.021)	0.369 (0.024)	0.677 (0.011)
TSW1	0.076 (0.020)	0.025 (0.008)	0.178 (0.019)	0.067 (0.006)
TSW2	0.076 (0.020)	0.036 (0.009)	0.239 (0.021)	0.079 (0.007)
		Single-release survival probabilities		
Powerhouse	0.868 (0.053; 0.758, 0.968)	0.828 (0.061; 0.701, 0.942)	0.892 (0.067; 0.768, 1.051)	0.847 (0.036; 0.780, 0.926)
Spillway	0.894 (0.053; 0.783, 0.994)	1.004 (0.031; 0.946, 1.072)	0.939 (0.040; 0.863, 1.026)	0.971 (0.019; 0.935, 1.011)
TSW1	[2]1.000	0.883 (0.141; 0.551, 1.078)	0.970 (0.065; 0.849, 1.125)	0.889 (0.054; 0.790, 1.019)
TSW2	0.775 (0.132; 0.493, 0.986)	0.788 (0.135; 0.502, 1.003)	0.907 (0.052; 0.807, 1.026)	0.909 (0.044; 0.828, 1.010)
All routes	0.881 (0.037)	0.962 (0.030)	0.927 (0.027)	0.939 (0.015)

[1]The probability of passing through the spillway also is termed spillway passage efficiency (SPE).

[2]Survival probability and confidence limits were not estimable using maximum likelihood methods because we detected 100 percent (14/14) of the fish passing this route at downstream detection arrays. Although the modeling software could not produce an estimate, our best estimate of survival is 100 percent. Variance from parameter not accounted for in other estimates derived from this parameter.

Table 2-10. Route-specific passage and survival (single-release) probabilities for mid-Columbia released juvenile steelhead implanted with an acoustic tag and a PIT tag during spring, 2008 and 2009.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model]

Passage route	2008	2009
	Passage probabilities	
Turbine	0.067 (0.011)	0.040 (0.005)
Bypass	0.122 (0.014)	0.326 (0.011)
Spillway[1]	0.699 (0.020)	0.341 (0.011)
TSW1	0.048 (0.009)	0.055 (0.005)
TSW2	0.064 (0.010)	0.238 (0.010)
Fish guidance efficiency	0.647 (0.047)	0.889 (0.012)
Fish passage efficiency	0.933 (0.011)	0.960 (0.005)
	Single-release survival probabilities	
Forebay	1.007 (0.010; 0.985, 1.025)	0.999 (0.003; 0.992, 1.003)
Turbine	0.780 (0.086; 0.603, 0.934)	0.819 (0.045; 0.722, 0.896)
Bypass	0.898 (0.058; 0.777, 1.005)	0.940 (0.012; 0.914, 0.961)
Spillway	0.936 (0.033; 0.873, 1.007)	0.968 (0.007; 0.952, 0.981)
TSW1	0.822 (0.096; 0.618, 0.987)	0.917 (0.028; 0.852, 0.961)
TSW2	0.956 (0.068; 0.801, 1.073)	0.977 (0.008; 0.960, 0.990)
All routes	0.917 (0.030)	0.952 (0.006)

[1]The probability of passing through the spillway is also termed spillway passage efficiency (SPE).

Table 2-11. Route-specific passage and survival (single-release) probabilities) for mid-Columbia released juvenile salmonids during the day and night, spring 2009.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model]

	Juvenile steelhead		Sockeye salmon	
Passage route	**Day**	**Night**	**Day**	**Night**
		Passage probabilities		
Powerhouse	0.378 (0.015)	0.354 (0.015)	0.387 (0.011)	0.338 (0.012)
Spillway[1]	0.276 (0.014)	0.402 (0.016)	0.465 (0.011)	0.488 (0.012)
TSW1	0.032 (0.005)	0.080 (0.009)	0.026 (0.003)	0.051 (0.005)
TSW2	0.314 (0.014)	0.164 (0.012)	0.122 (0.007)	0.124 (0.008)
		Single-release survival probabilities		
Powerhouse	0.947 (0.016; 0.910, 0.974)	0.905 (0.016; 0.871, 0.933)	0.921 (0.012; 0.896, 0.942)	0.944 (0.010; 0.923, 0.961)
Spillway	0.990 (0.008; 0.970, 1.002)	0.952 (0.011; 0.928, 0.970)	0.961 (0.006; 0.948, 0.972)	0.956 (0.007; 0.940, 0.969)
TSW1	[2]1.000	0.889 (0.035; 0.808, 0.946)	0.967 (0.024; 0.897, 0.996)	0.930 (0.028; 0.862, 0.972)
TSW2	0.980 (0.009; 0.958, 0.995)	0.983 (0.010; 0.955, 0.997)	0.939 (0.015; 0.906, 0.964)	0.943 (0.016; 0.905, 0.970)
All routes	0.971 (0.007)	0.936 (0.008)	0.943 (0.006)	0.949 (0.005)

[1]The probability of passing through the spillway also is termed spillway passage efficiency (SPE).

[2]Survival probability and confidence limits were not estimable using maximum likelihood methods because we detected 100 percent (33/33) of the fish passing this route at downstream detection arrays. Although the modeling software could not produce an estimate, our best estimate of survival is 100 percent. Variance from parameter not accounted for in other estimates derived from this parameter.

Route-Specific Survival Probabilities

Survival Probabilities 2006

Forebay survival was estimated to be between 0.957 and 0.990, depending on species (table 2-12). The passage route with the highest survival for both yearling Chinook salmon (0.927) and juvenile steelhead (0.930) was the spillway (table 2-12). For sockeye salmon, the powerhouse had the highest survival probability (0.926). Survival through all routes was highest for juvenile steelhead (0.911), followed by yearling Chinook (0.867) and sockeye salmon (0.866).

Survival Probabilities 2007

During the first year of testing of TSWs, forebay survival was 1.010 for yearling Chinook salmon, 1.015 for juvenile steelhead, and 0.967 for sockeye salmon; 1–3 percent higher than in 2006, depending on species (table 2-12). Similarly, survival through all routes and route-specific survival estimates were higher in 2007 than in 2006, especially for yearling Chinook salmon passing the powerhouse and sockeye salmon passing the spillway. Survival in 2007 was highest through the spillway for all species, lowest through TSW2 for yearling Chinook and sockeye salmon, and lowest through the powerhouse for juvenile steelhead.

Survival Probabilities 2008

Forebay survival for mid-Columbia released yearling Chinook salmon was 0.984. Survival probabilities for yearling Chinook salmon were highest at the spillway (0.982), followed by TSW1 (0.951), the powerhouse (0.849), and TSW2 (0.781; table 2-12). Similar patterns in survival probabilities among passage routes were exhibited during early and late periods and wide confidence intervals indicated there may have been little difference in survival between the two periods. However, differences in point estimates of TSW1 and spillway survival were greater than 10 percent between the two periods (table 2-9).

Survival in the forebay for the mid-Columbia River released juvenile steelhead was 0.996. The passage route with the highest survival was the spillway (0.968), followed by TSW1 (0.921), TSW2 (0.909), and the powerhouse (0.857; table 2-12). A similar pattern was seen for both early and late periods, but due to high variance associated with survival estimates, we could not distinguish any difference in survival among routes between periods. Furthermore, differences in point estimates of survival between early and late periods were small (less than 0.040) except for the difference in survival through TSW1, which was 0.081 (table 2-9).

Survival probabilities for sockeye salmon were similar to the other species (table 2-12). The spillway had the highest probability of survival (0.925). Survival through other routes ranged between 0.819 and 0.866. Forebay survival was 0.997 and survival through all routes was 0.907 for sockeye salmon.

Survival Probabilities 2009

Forebay survival of juvenile steelhead was estimated at 0.998 and survival through all routes was 0.954. Survival overall was highest at TSW2 (0.981), followed by the spillway (0.968), the powerhouse (0.927) and TSW1 (0.921; table 2-12). During the day, survival of juvenile steelhead was highest through TSW1 (1.000), followed by the spillway (0.990), TSW2 (0.980), and the powerhouse (0.947; table 2-11). Survival at night followed the same pattern as the overall estimates. Survival at night was highest at TSW2 (0.983), followed by the spillway (0.952), the powerhouse (0.905), and TSW1 (0.889). Differences in survival between day and night were generally small (less than 0.040) with the exception of TSW1 where survival during the day was 0.111 higher than during night.

A subset of juvenile steelhead implanted with both a PIT tag and an acoustic tag, enabled estimation of survival probabilities for fish that passed through turbines, as well as for fish that passed through the juvenile bypass system. Survival was highest through TSW2 (0.977) and the spillway (0.968), followed by the juvenile bypass (0.940), TSW1 (0.917), and turbines (0.819; table 2-10). Forebay survival was 0.999 and survival through all routes was 0.952.

Forebay survival for sockeye salmon was estimated at 1.00 and survival through all routes was 0.945. Over the entire season, the spillway provided the highest survival (0.959) of all available routes, followed by TSW1 (0.945), TSW2 (0.941), and the powerhouse (0.930; table 2-12). During the day, survival was highest through TSW1 (0.967), followed closely by the spillway (0.961), then TSW2 (0.939) and the powerhouse (0.921; table 2-11). At night, the spillway had the highest survival (0.956), followed by the powerhouse (0.944), TSW2 (0.943), and TSW1 (0.930).

Passage Route Effectiveness

A useful criterion for judging the performance of passage routes at dams is passage route effectiveness. Passage route effectiveness is the proportion of fish passed through a particular route relative to the proportion of water that is passing through that route. Effectiveness of the powerhouse was lowest among all passage routes and ranged between 0.564 and 0.963 for yearling Chinook salmon, 0.381 and 0.720 for juvenile steelhead, and 0.444 and 0.726 for sockeye salmon, depending on the year of study (table 2-13). The spillway provided the next highest effectiveness at between 0.889 and 1.337 for yearling Chinook salmon, 0.612 and 1.315 for juvenile steelhead, and 0.722 and 1.412 for sockeye salmon. The TSWs provided the highest effectiveness of all available routes of passage. Combined, the two TSWs had an effectiveness of between 1.655 and 4.761 for yearling Chinook salmon, 3.685 and 8.217 for juvenile steelhead, and 1.404 and 5.114 for sockeye salmon. Of the two TSWs, TSW1 provided the highest effectiveness for all species in 2007 and TSW2 provided the highest effectiveness for all species in 2009. In 2008, TSW2 provided the highest effectiveness for yearling Chinook salmon and juvenile steelhead, whereas TSW1 provided the highest effectiveness for sockeye salmon. Regardless of TSW design or location, TSW effectiveness was higher for juvenile steelhead than for the other species during all years of study.

Table 2-12. Route-specific survival probabilities (single-release) for mid-Columbia released juvenile salmonids in 2006–09.

[Standard error and 95-percent profile likelihood confidence intervals are shown in parenthesis if estimable by the survival model; NA, not applicable]

Passage route	Yearling Chinook salmon	Juvenile steelhead	Sockeye salmon
		2006	
Forebay	0.990 (0.007; 0.972, 0.998)	0.986 (0.006; 0.972, 0.998)	0.957 (0.019; 0.921, 0.996)
Powerhouse	0.799 (0.036; 0.724, 0.865)	0.874 (0.020; 0.834, 0.912)	0.926 (0.026; 0.877, 0.978)
Spillway	0.927 (0.025; 0.872, 0.970)	0.930 (0.016; 0.899, 0.961)	0.836 (0.030; 0.778, 0.896)
TSW1	NA	NA	NA
TSW2	NA	NA	NA
All routes	0.867 (0.022)	0.911 (0.013)	0.866 (0.025)
		2007	
Forebay	1.010 (0.004; 1.000, 1.018)	1.015 (0.012; 0.987, 1.037)	0.967 (0.014; 0.939, 0.994)
Powerhouse	0.944 (0.037; 0.877, 1.023)	0.900 (0.046; 0.813, 0.998)	0.986 (0.064; 0.877, 1.134)
Spillway	1.002 (0.038; 0.933, 1.084)	0.958 (0.046; 0.872, 1.057)	1.043 (0.070; 0.923, 1.202)
TSW1	0.948 (0.041; 0.871, 1.035)	0.914 (0.042; 0.836, 1.007)	1.028 (0.073; 0.900, 1.193)
TSW2	0.893 (0.071; 0.748, 1.025)	0.906 (0.080; 0.737, 1.053)	0.834 (0.125; 0.595, 1.084
All routes	0.959 (0.033)	0.919 (0.036)	1.006 (0.063)
		2008	
Forebay	0.984 (0.008; 0.964, 0.997)	0.996 (0.004; 0.987, 1.004)	0.997 (0.010; 0.977, 1.015)
Powerhouse	0.849 (0.040)	0.857 (0.032)	0.858 (0.032; 0.795, 0.922)
Spillway	0.982 (0.027)	0.968 (0.018)	0.925 (0.023; 0.882, 0.973)
TSW1	0.951 (0.060)	0.921 (0.042)	0.819 (0.062; 0.689, 0.932)
TSW2	0.781 (0.094)	0.909 (0.033)	0.866 (0.085; 0.680, 1.009)
All routes	0.937 (0.024)	0.937 (0.013)	0.907 (0.021)
		2009	
Forebay	NA	0.998 (0.003; 0.992, 1.003)	1.000 (0.002; 0.997, 1.004)
Powerhouse	NA	0.927 (0.011)	0.930 (0.008)
Spillway	NA	0.968 (0.007)	0.959 (0.005)
TSW1	NA	0.921 (0.026)	0.945 (0.020)
TSW2	NA	0.981 (0.007)	0.941 (0.011)
All routes	NA	0.954 (0.005)	0.945 (0.004)

Table 2-13. Passage route effectiveness for mid-Columbia released juvenile salmonids in 2006–09.

[NA, not applicable]

Passage route	Yearling Chinook salmon	Juvenile steelhead	Sockeye salmon
		2006	
Powerhouse	0.963	0.683	0.689
Spillway	1.035	1.315	1.282
		2007	
Powerhouse	0.607	0.381	0.672
Spillway	0.899	0.612	0.722
TSW1	7.405	13.833	8.667
TSW2	1.882	2.091	1.353
Both TSWs	4.761	8.217	5.114
TSW and Spillway	1.572	1.902	1.475
		2008	
Powerhouse	0.564	0.404	0.444
Spillway	1.337	1.262	1.412
TSW1	1.500	3.179	1.875
TSW2	1.885	4.231	0.955
Both TSWs	1.655	3.685	1.404
TSW and Spillway	1.372	1.500	1.411
		2009	
Powerhouse	NA	0.720	0.726
Spillway	NA	0.788	1.075
TSW1	NA	1.774	1.333
TSW2	NA	8.276	4.556
Both TSWs	NA	4.917	2.944
TSW and Spillway	NA	1.292	1.278

Tailrace Egress

Tailrace egress rates of juvenile salmonids varied by year and passage route. We did not measure egress to the I-82 Bridge (located 2 km downstream of McNary Dam) in 2006. For yearling Chinook salmon, the egress rate was fastest for fish passing through either TSW in any year. Egress also was high in 2008 for fish passing through the spillway in 2008 (> 3.8 km/h; fig. 2-7). The rate of fish leaving the tailrace after passing though the spillway in 2007 or 2009, or through the powerhouse in any year, was about one-quarter, or less, the rate that fish exited the tailrace after passing through either TSW or the spillway in 2008. There was greater variability in rates of egress for both juvenile steelhead and sockeye salmon (figs. 2-8 and 2-9). However, the pattern was similar to egress rates for yearling Chinook salmon in that egress was lowest for fish that passed through the powerhouse and highest for fish that passed through the TSWs. Egress rates were low for all species after passing through TSW1 in 2007 and egress rates for fish passing the spillway were highest in 2007 and 2009 for juvenile steelhead and sockeye salmon; years that egress rates were low for yearling Chinook salmon that passed through the spillway.

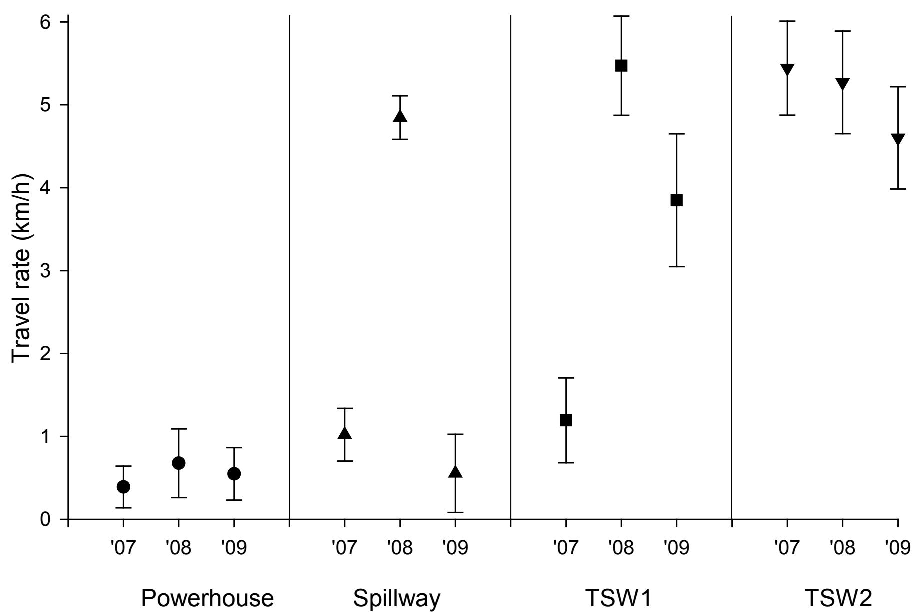

Figure 2-7. Graph showing mean travel rate (km/h) from passage at McNary Dam to first detection at the I82 Bridge located 2.4 km downstream of McNary Dam, by passage route, for yearling Chinook salmon released in the mid-Columbia River, 2006–09.

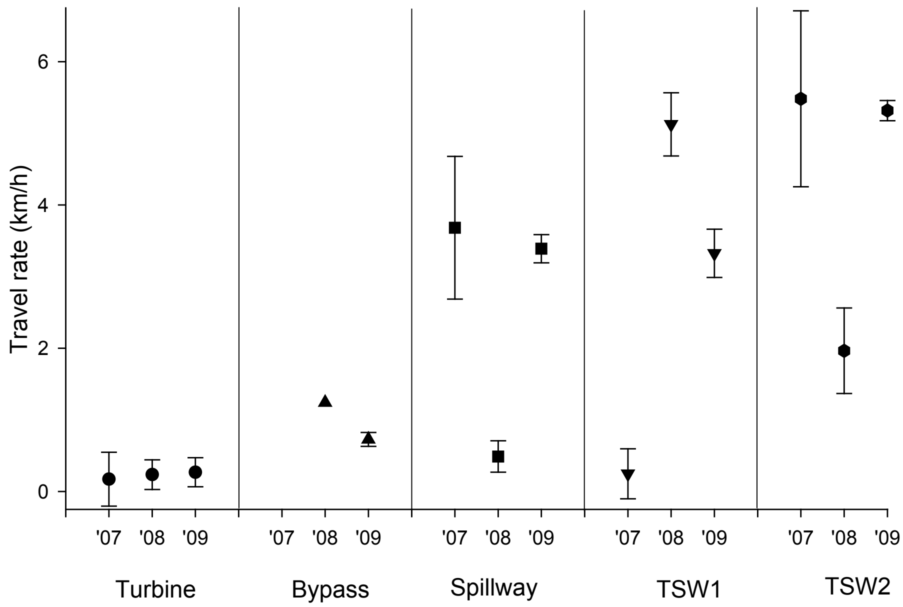

Figure 2-8. Graph showing mean travel rate (km/h) from passage at McNary Dam to first detection at the I82 Bridge located 2.4 km downstream of McNary Dam, by passage route, for juvenile steelhead released in the mid-Columbia River, 2006–09.

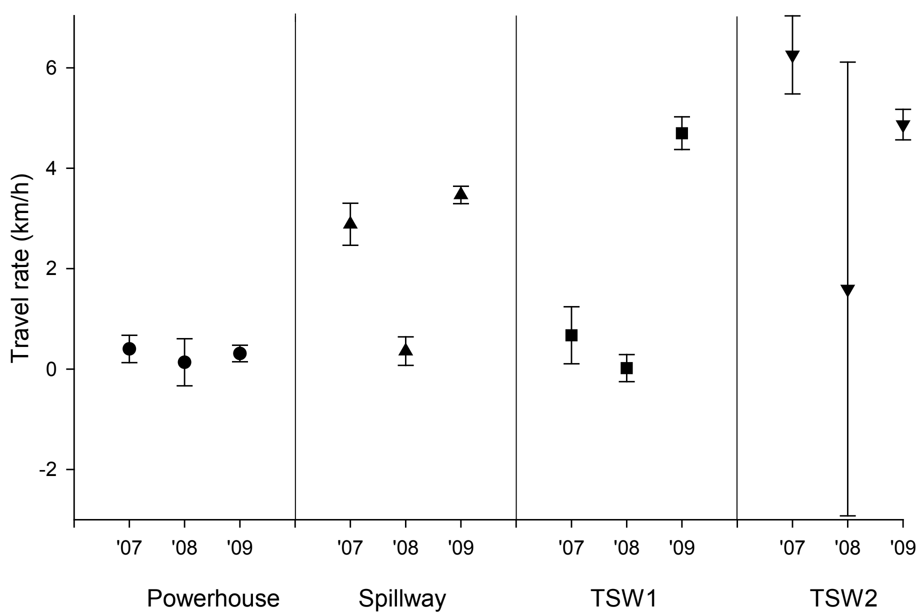

Figure 2-9. Graph showing mean travel rate (km/h) from passage at McNary Dam to first detection at the I-82 Bridge located 2.4 km downstream of McNary Dam, by passage route, for Sockeye salmon released in the mid-Columbia River, 2006–09.

Discussion

During all 4 years of study, we were able to assess passage and survival of acoustic-tagged juvenile salmonids at McNary Dam that were released by Grant and Chelan County PUDs in the Mid-Columbia River. These post-hoc analyses conducted on fish released from between 167 and 358 km upstream of McNary Dam provide data that can be compared with passage and survival data for fish released only 10 km upstream of McNary Dam. Additionally, this study provides 4 years of passage and survival data for juvenile sockeye salmon at McNary Dam, a species for which there is less information.

Comparisons of Mid-Columbia and Hat-Rock Released Fish

Below we discuss differences and similarities between the results from mid-Columbia River released fish and fish released near Hat Rock State Park, located 10 rkm upstream of McNary Dam (Adams and others, 2008; Adams and Counihan, 2009; Adams and Liedtke, 2009, 2010; Chapter 1 of this report). These comparisons were not part of either study plan and differences between the studies may confound direct comparisons made between the mid-Columbia and McNary release groups. Potential confounding factors include: differences in the source of the test fish, differences in tagging and release protocols, annual differences in dam operations and configurations, differences in how the survival models were constructed (that is, number of routes that could be estimated given the number of fish detected), and the number and length of reaches included in the analysis. These caveats aside, we believe it is still worthwhile to examine and discuss general trends among the various release groups to provide insight into the passage and survival of a group of fish that would otherwise be unattainable.

Passage and Survival 2006

During 2006, for yearling Chinook salmon, spillway passage probability was lower and powerhouse passage probability was higher, for fish released at Wanapum Dam than for fish released near Hat Rock State Park (fig. 2-10). All other passage probabilities were similar between Mid-Columbia released fish and Hat Rock released fish (figs. 2-10 and 2-11). Forebay survival was lower for Mid-Columbia released juvenile steelhead and sockeye salmon, but similar for yearling Chinook salmon, compared to Hat Rock released fish. Little difference was observed between release groups for powerhouse or spillway survival, largely due to high variance associated with the point estimates (figs. 2-12 and 2-13). Survival through all routes for both yearling Chinook salmon (0.867, SE=0.022) and juvenile steelhead (0.866, SE=0.025) released from the Mid-Columbia River were lower than the estimated single release survival probabilities for yearling Chinook salmon (0.938, SE=0.007) and juvenile steelhead (0.973, SE=0.010) released at Hat Rock State Park (figs. 2-12 and 2-13). Because survival is typically lower for powerhouse passage compared to spillway passage, and since we observed higher passage through the powerhouse for Mid-Columbia River released yearling Chinook salmon than for Hat Rock released yearling Chinook salmon, this could result in lower survival overall through McNary Dam. However, this would not be the case for juvenile steelhead, which passed equally through the powerhouse between release groups.

Passage and Survival 2007

In general, route-specific passage probabilities were very similar between the mid-Columbia River released fish and the Hat Rock released fish in 2007. For both yearling Chinook salmon release groups, the highest proportion of fish passed via the powerhouse followed by the spillway, TSW1, and TSW2 (fig. 2-14). For sockeye salmon, the route with the highest probability of passage also was the powerhouse, followed by TSW1, the spillway, and TSW2 (fig. 2-14). Hat Rock released yearling Chinook salmon had a higher probability of passage through the powerhouse (turbine and bypass routes combined; Adams and Counihan, 2009) than mid-Columbia released fish, which could be a result of higher detections of Hat Rock fish due to PIT tag detections within the bypass system. However, it was infrequent that fish were detected only in the bypass system and were not detected at the face of the powerhouse. None of the mid-Columbia River released fish had PIT tags and therefore we were not able to discern turbine passage from bypass passage. The most notable difference in passage between Hat Rock and mid-Columbia released fish was the relatively low passage probability through TSW1 for Hat Rock released Chinook salmon compared to mid-Columbia River release groups (fig. 2-14). This may be the result of fish approaching the dam in the transition area between the TSWs and the powerhouse and getting entrained into the powerhouse, where we observed relatively higher passage for Hat Rock released fish versus the other two groups. Higher passage was observed at TSW1, compared to TSW2, for all groups and relatively few fish passed through TSW2. The probability of passage through TSW1 was much higher for juvenile steelhead than for other species and was the highest probability of all routes for both release groups. Passage probabilities for juvenile steelhead through other routes were similar for both release groups through the powerhouse, higher for mid-Columbia juvenile steelhead at the spillway, and higher for Hat Rock juvenile steelhead at TSW2 (fig. 2-15).

All species of mid-Columbia River released fish had higher survival through the powerhouse, spillway, TSW1, and all routes combined compared to Hat Rock released fish (figs. 2-16 and 2-17). This could lead one to question whether the Hat Rock released fish were displaying an immediate negative tagging effect, which the mid-Columbia River released fish would have experienced earlier. However, the variance about these estimates makes it difficult to discern any true differences between these point estimates. Point estimates of forebay survival and survival through TSW2 were about equal among species and release groups. Overall, the mid-Columbia River fish followed the same passage and survival trends as the Hat Rock released fish. It also appears that sockeye salmon had very similar results to yearling Chinook salmon in passage and survival probabilities.

Passage and Survival 2008

During 2008, the passage probability of fish passing through the spillway was higher for all species released from the mid-Columbia River than for fish released near Hat Rock State Park (figs. 2-18 and 2-19). For all other routes, fish released from Hat Rock State Park had higher probabilities of passage than mid-Columbia River released fish. These differences could be explained by the timing of passage of each group. The majority (81–100 percent) of mid-Columbia fish passed McNary Dam during 60 percent spill and the majority (61–69 percent) of Hat Rock released fish passed during 40 percent spill. Because a higher proportion of the mid-Columbia fish passed during higher spillway discharge, fish were more likely to pass through the spillway. Conversely, since a higher proportion of Hat Rock fish passed during lower spillway discharge, these fish had a higher probability of passing through non-spill routes. Point estimates of survival probabilities were lower for mid-Columbia released fish and highly variable, compared to Hat Rock released fish, for all species and for all routes, with two exceptions: Yearling Chinook salmon that passed through the spillway and TSW1 (fig. 2-20). However, low detection probabilities (30–50 percent) and small sample size of mid-Columbia released fish resulted in relatively high variance about the point estimates. The high variance resulted in overlap of the confidence intervals for all survival estimates, indicating there may have been little difference in survival between release groups. In addition to the relatively small number of sockeye salmon detected, the transmitter for these fish also had a relatively high tag failure rate (about 8 percent, appendix C), which could bias the results. Nonetheless, the high variance observed would likely mask any tag bias effects.

Passage and Survival 2009

During 2009, passage probabilities within routes generally were very similar for the mid-Columbia River released fish and the Hat Rock released fish. Among routes, for both yearling Chinook salmon and juvenile steelhead release groups, the majority of fish passed through the powerhouse and spillway (probabilities were similar between powerhouse and spillway) followed by TSW2 and TSW1 (figs. 2-22 and 2-23). Although the TSWs individually had lower probabilities of passage (0.036–0.243) compared to the powerhouse (0.315–0.464) or spillway (0.338–0.475), when combined the two TSWs accounted for 14–35 percent of fish passage. Survival estimates by route and all routes combined were nearly identical among release groups and species (figs. 2-24 and 2-25). Although slight differences in point estimates existed for some routes, confidence intervals overlapped, indicating there was likely no difference in the estimates of survival between release groups.

Summary

Over the course of the four study years, 3,602 yearling Chinook salmon, 10,393 juvenile steelhead, and 11,969 sockeye salmon were released from the mid-Columbia River with acoustic tags that were compatible with monitoring equipment deployed at McNary Dam. Of these fish, 1,929 (54 percent) yearling Chinook salmon, 5,891 (57 percent) juvenile steelhead, and 7,225 (60 percent) sockeye salmon were detected passing McNary Dam. Travel times to McNary Dam were relatively short, ranging from 3 to 9 days, depending on the release site, which translated to travel rates ranging from 30.3 to 92.4 km/d, depending on year. Travel rates slowed considerably when fish reached the forebay of McNary Dam and ranged from 4.19 to 21.46, depending on year. However, these slower rates in the last 160 m before passing the dam represent relatively short mean forebay residence times of 2.2–11.5 h, depending on species and year. Travel rates increased in reaches downstream of the dam and were similar to travel rates observed for fish traveling from the release sites to the forebay. Travel rates of mid-Columbia released fish in the forebay and downstream of McNary Dam were similar to travel rates of Hat Rock released fish.

All species of mid-Columbia released fish passed McNary Dam throughout all hours of the diel cycle and were about equally distributed between the day and night. These results were similar to those for Hat Rock released fish. The majority of all species of fish passed through the spillway in 2006 and 2008, when total river discharge and spillway discharge were high. In 2007, when both total river discharge and spillway discharge were the lowest of all four study years, the majority of both salmon species passed through the powerhouse, but over half of the steelhead passed through the TSWs. Passage of fish through the powerhouse and spillway was similar during 2009, when total river discharge and spillway discharge were moderate. TSW passage was highest during 2007 (a low water year relative to the 10-year average) for all species. TSW1 (located in spill bay 22 in 2007) passed substantially more fish than any other TSW configuration during the four study years: 27–50 percent of all fish, depending on species, compared to 2–12 percent for other TSW configurations.

Forebay survival was high for all species and years, ranging between 96 and 100 percent. The spillway provided the highest survival (93–100 percent) of all routes for all species and years except for sockeye salmon in 2006 when survival was 93 percent through the powerhouse and 84 percent through the spillway. TSW1 generally provided the second highest survival for all species and years, followed by TSW2, and the powerhouse. Survival through all routes combined was lowest (87–91 percent) for all species in 2006, before installation of the TSWs. Survival through all routes was highest in 2007 for yearling Chinook (96 percent) and sockeye salmon (100 percent). For juvenile steelhead, survival through all routes combined was highest (95 percent) in 2009.

Comparison of passage and survival of mid-Columbia released fish with fish released from Hat Rock State Park, located 10 km upstream of McNary Dam, revealed few differences. Differences that were observed include:

1. In 2006, mid-Columbia released yearling Chinook salmon had a 10 percent higher probability of passing through the powerhouse and an 11 percent lower probability of passing through the spillway compared to Hat Rock released yearling Chinook salmon;
2. In 2006, mid-Columbia released sockeye salmon also had 3 percent lower forebay survival than yearling Chinook salmon released from either Hat Rock or the mid-Columbia River;
3. In 2007, Hat Rock released yearling Chinook salmon had a 10–14 percent lower probability of passing through TSW1 than yearling Chinook and sockeye salmon released from the mid-Columbia River;
4. In 2007, Hat Rock released yearling Chinook salmon also had 13–21 percent lower survival through the powerhouse, spillway, TSW1, and all routes combined, compared to salmon released from the mid-Columbia River;
5. In 2008, mid-Columbia released juvenile steelhead had a 27 percent higher probability of passing through the spillway, 8 percent lower probability of passing through TSW1, and 13 percent lower probability of passing through TSW2, compared to Hat Rock released juvenile steelhead; and
6. During both 2008 and 2009, Hat Rock released yearling Chinook salmon had a 9–16 percent higher probability of passing through the powerhouse and an 8–26 percent lower probability of passing through the spillway, compared to mid-Columbia released salmon.

All other point estimates of passage and survival for mid-Columbia River and Hat Rock released fish were very similar or confidence intervals overlapped making differences between the point estimates indistinguishable. It should be noted that we can not discern whether any differences in survival estimates are due to direct mortality at the dam or potential indirect effects such as a prolonged period from the time of tagging to the time of detection at the dam, varying tag life, or other potential differences in fish handling or source of test fish between release groups. Despite this, we note that the similarity of estimates between release groups provides valuable information and indicates that, for fish that make it to McNary Dam, increased migration time or migration distance likely are not causing any differences in survival.

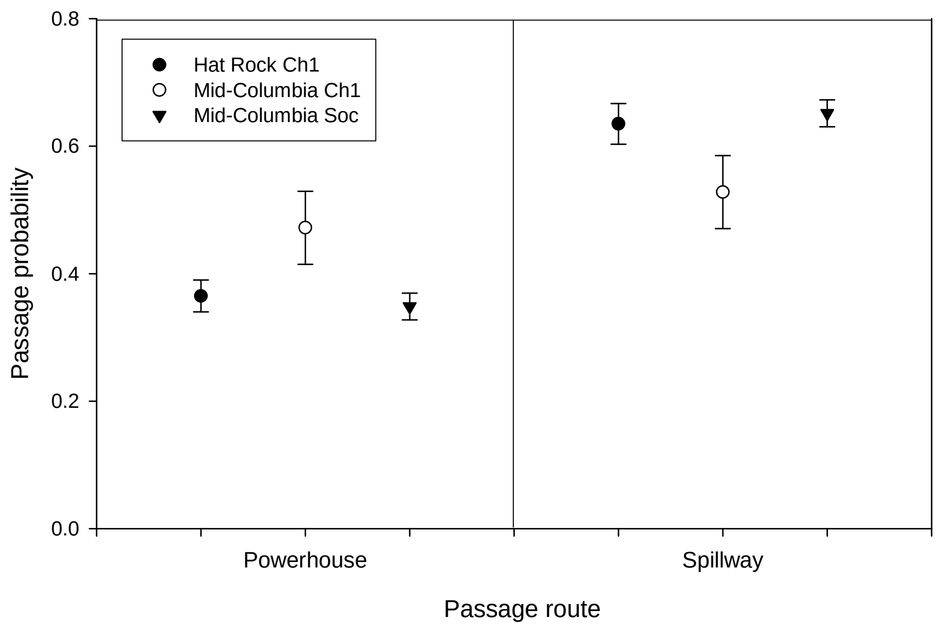

Figure 2-9. Graph showing passage probabilities for Hat Rock released yearling Chinook salmon (Ch1, black circles) and mid-Columbia River released yearling Chinook salmon (open circles), and sockeye salmon (Soc, black triangles) through individual passage routes at McNary Dam during 2006. Error bars represent the 95-percent profile likelihood confidence intervals.

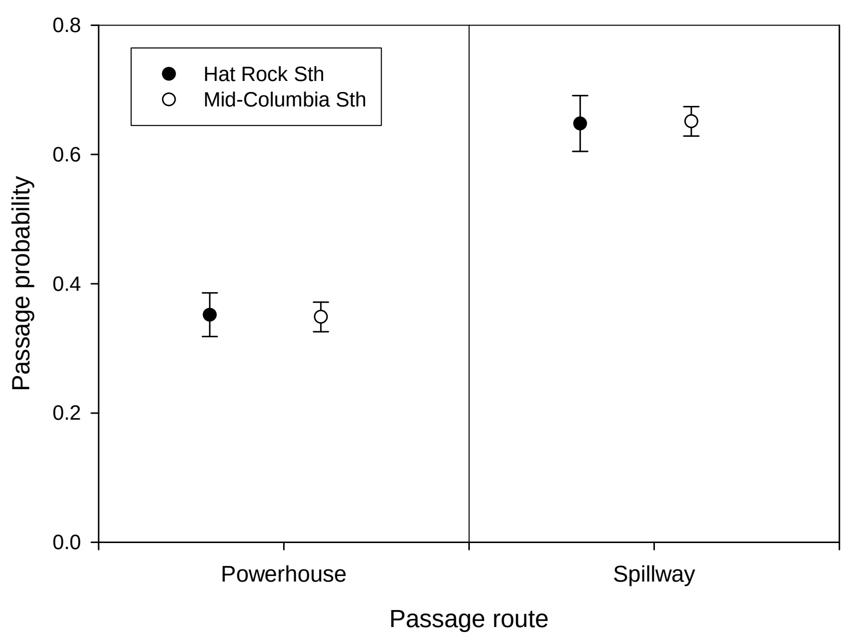

Figure 2-10. Graph showing passage probabilities for juvenile steelhead (Sth) released at Hat Rock State Park (black circles), and the mid-Columbia River (open circles) through individual passage routes at McNary Dam during 2006. Error bars represent the 95-percent profile likelihood confidence intervals.

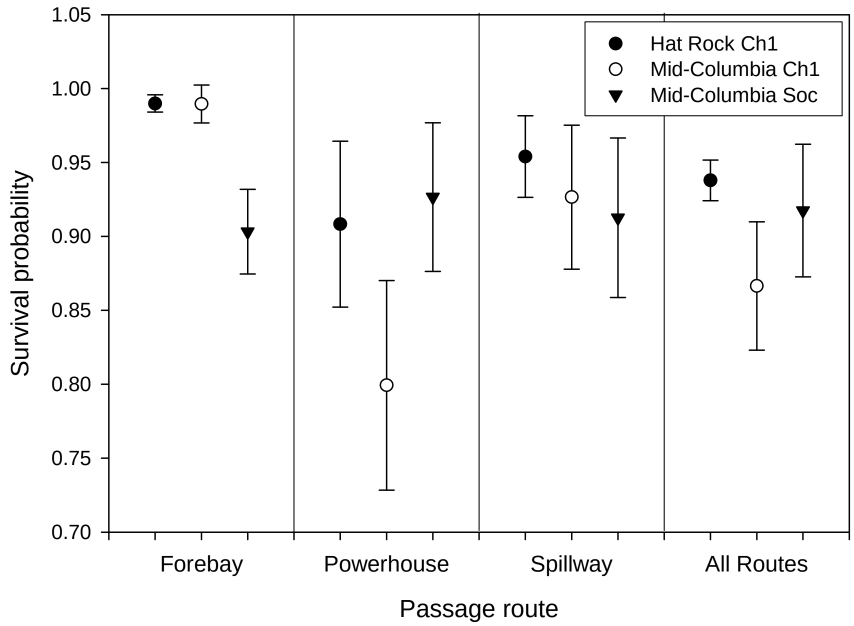

Figure 2-11. Graph showing survival probabilities for Hat Rock released yearling Chinook salmon (Ch1, black circles) and mid-Columbia River released yearling Chinook salmon (open circles), and sockeye salmon (Soc, black triangles) through individual passage routes at McNary Dam during 2006. Error bars represent the 95-percent profile likelihood confidence intervals.

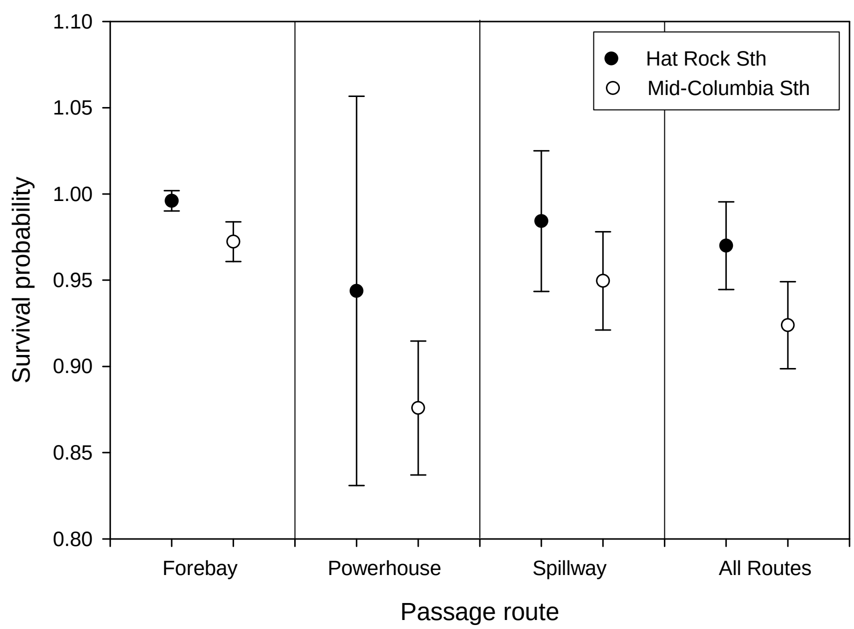

Figure 2-12. Graph showing survival probabilities for juvenile steelhead (Sth) released at Hat Rock State Park (black circles), and the mid-Columbia River (open circles) through individual passage routes at McNary Dam during 2006. Error bars represent the 95-percent profile likelihood confidence intervals.

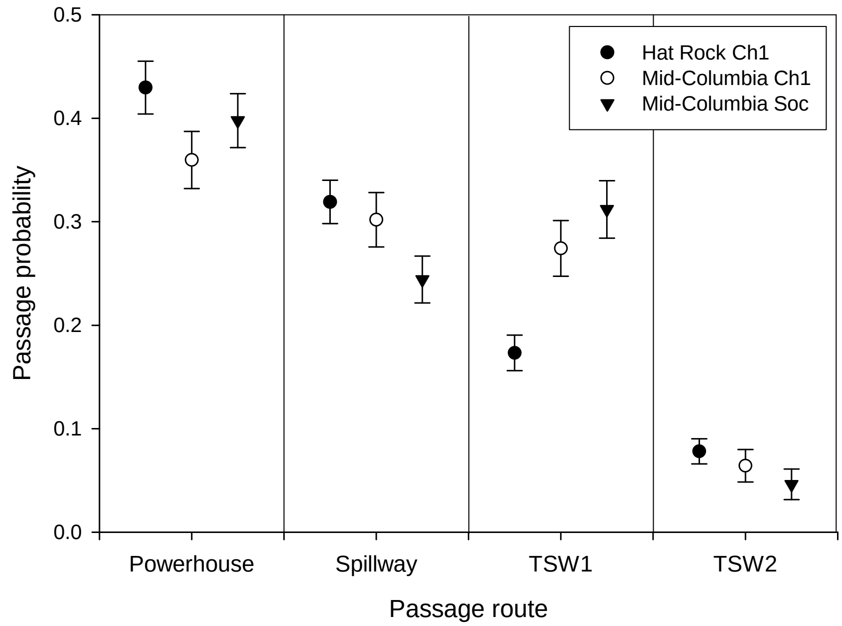

Figure 2-13. Graph showing passage probabilities for Hat Rock released yearling Chinook salmon (Ch1, black circles) and mid-Columbia River released yearling Chinook salmon (open circles) and sockeye salmon (Soc, black triangles) through individual passage routes at McNary Dam during 2007. Error bars represent the 95-percent profile likelihood confidence intervals.

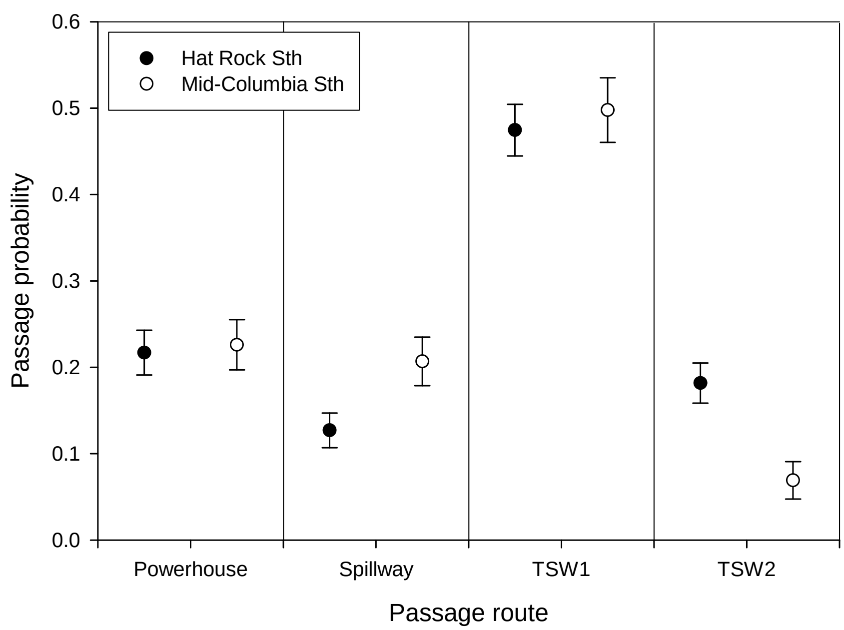

Figure 2-14. Graph showing passage probabilities for juvenile steelhead (Sth) released at Hat Rock State Park (black circles), and the mid-Columbia River (open circles) through individual passage routes at McNary Dam during 2007. Error bars represent the 95-percent profile likelihood confidence intervals.

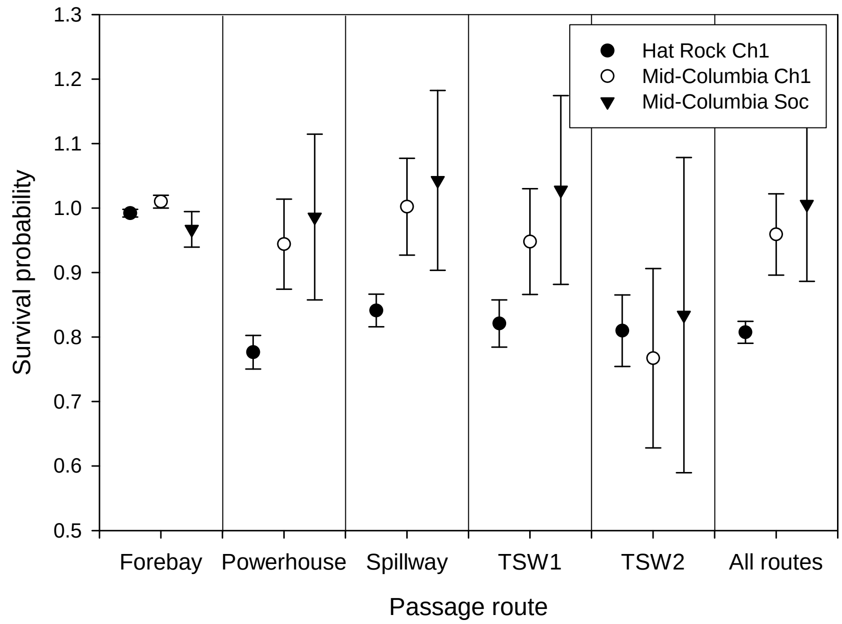

Figure 2-15. Graph showing survival probabilities for Hat Rock released yearling Chinook salmon (Ch1, black circles) and mid-Columbia River released yearling Chinook salmon (open circles) and sockeye salmon (Soc, black triangles) through individual passage routes at McNary Dam during 2007. Error bars represent the 95-percent profile likelihood confidence intervals.

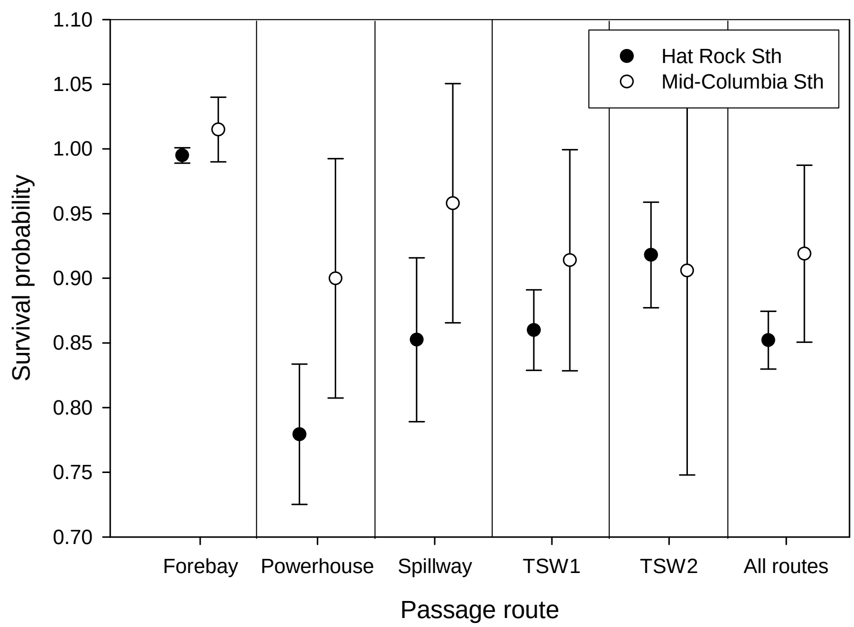

Figure 2-16. Graph showing survival probabilities for juvenile steelhead (Sth) released at Hat Rock State Park (black circles), and the mid-Columbia River (open circles) through individual passage routes at McNary Dam during 2007. Error bars represent the 95-percent profile likelihood confidence intervals.

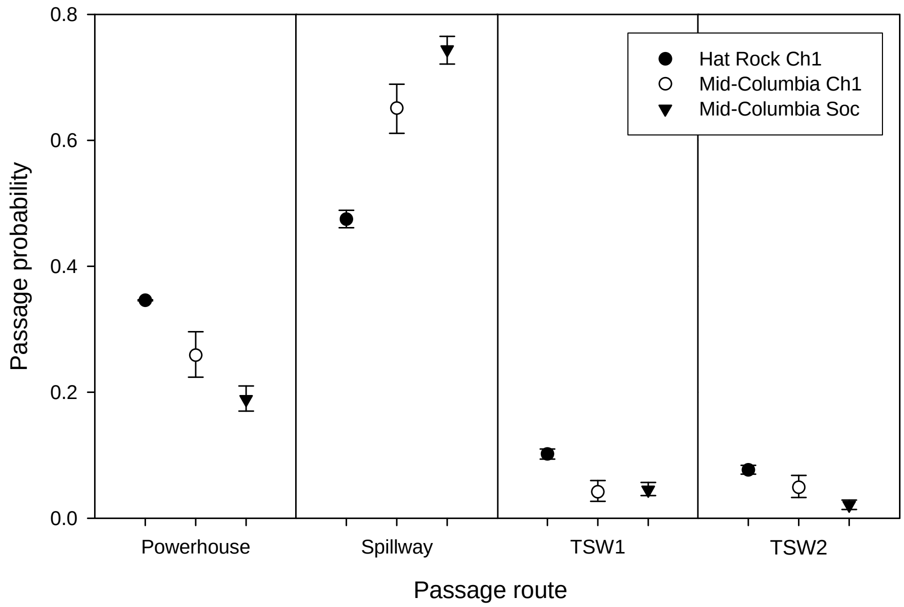

Figure 2-18. Graph showing passage probabilities for Hat Rock released yearling Chinook salmon (Ch1, black circles) and mid-Columbia River released yearling Chinook salmon (open circles) and sockeye salmon (Soc, black triangles) through individual passage routes at McNary Dam during 2008. Error bars represent the 95-percent profile likelihood confidence intervals.

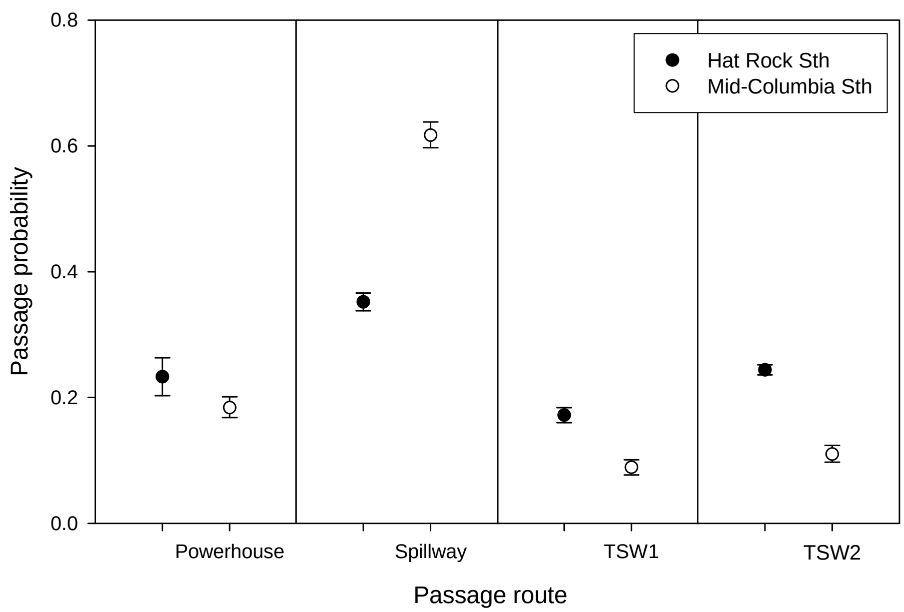

Figure 2-19. Graph showing passage probabilities for juvenile steelhead (Sth) released at Hat Rock State Park (black circles), and the mid-Columbia River (open circles) through individual passage routes at McNary Dam during 2008. Error bars represent the 95-percent profile likelihood confidence intervals.

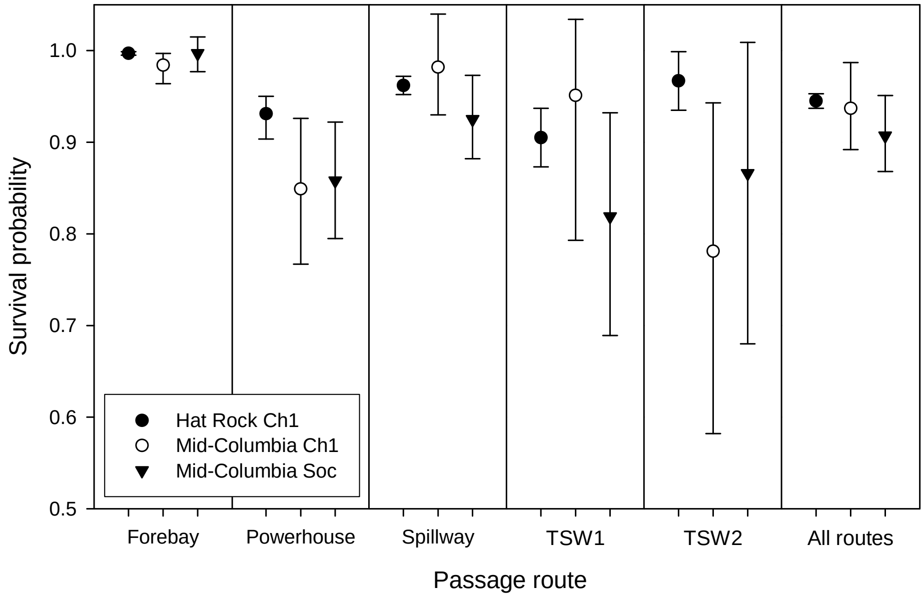

Figure 2-20. Graph showing survival probabilities for Hat Rock released yearling Chinook salmon (Ch1, black circles) and mid-Columbia River released yearling Chinook salmon (open circles) and sockeye salmon (Soc, black triangles) through individual passage routes at McNary Dam during 2008. Error bars represent the 95-percent profile likelihood confidence intervals.

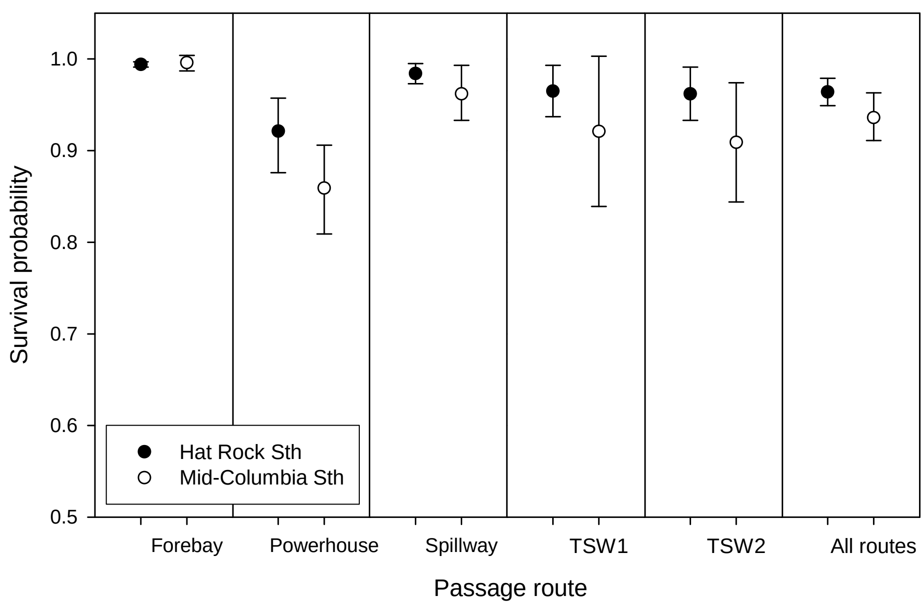

Figure 2-21. Graph showing survival probabilities for juvenile steelhead (Sth) released at Hat Rock State Park (black circles), and the mid-Columbia River (open circles) through individual passage routes at McNary Dam during 2008. Error bars represent the 95-percent profile likelihood confidence intervals.

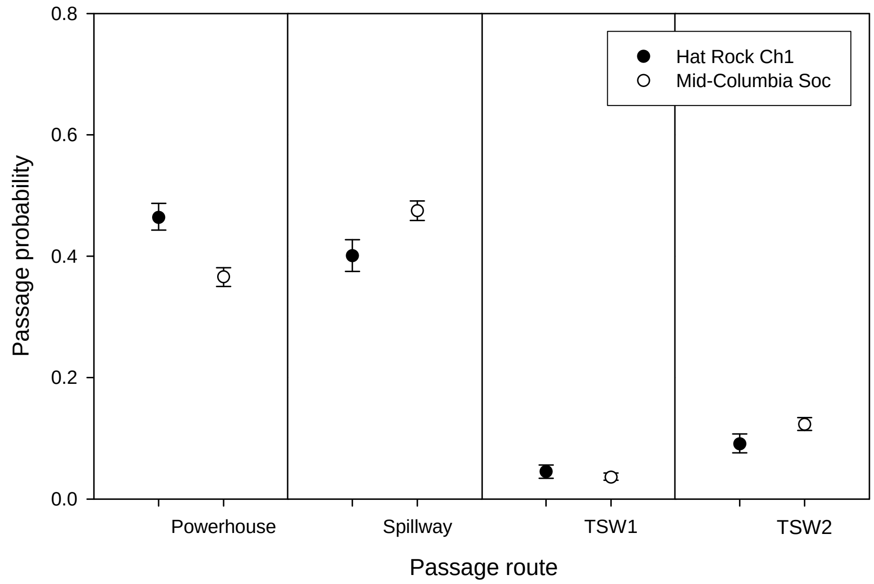

Figure 2-22. Graph showing passage probabilities for Hat Rock released yearling Chinook salmon (Ch1, black circles) and mid-Columbia River released sockeye salmon (Soc, open circles) through individual passage routes at McNary Dam during 2009. Error bars represent the 95-percent profile likelihood confidence intervals.

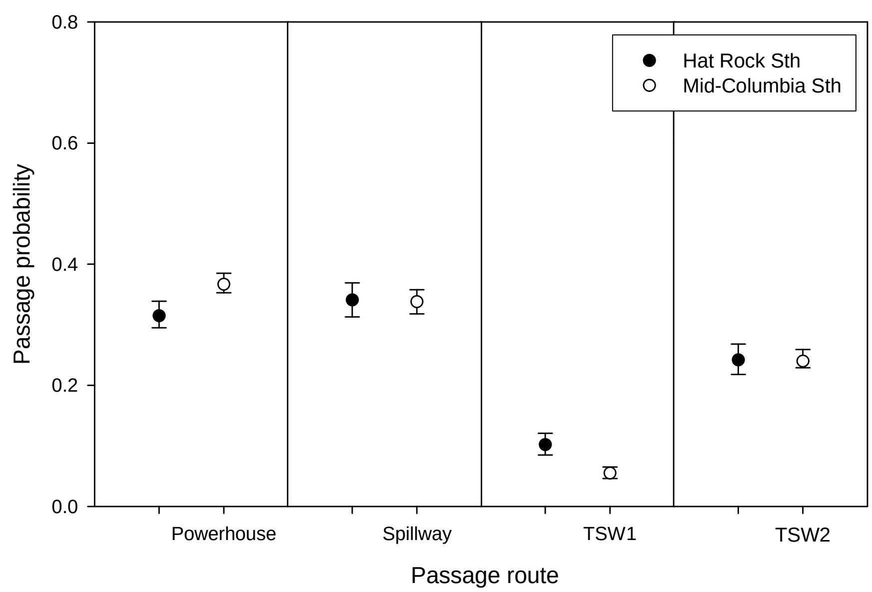

Figure 2-23. Graph showing passage probabilities for juvenile steelhead (Sth) released at Hat Rock State Park (black circles), and the mid-Columbia River (open circles) through individual passage routes at McNary Dam during 2009. Error bars represent the 95-percent profile likelihood confidence intervals.

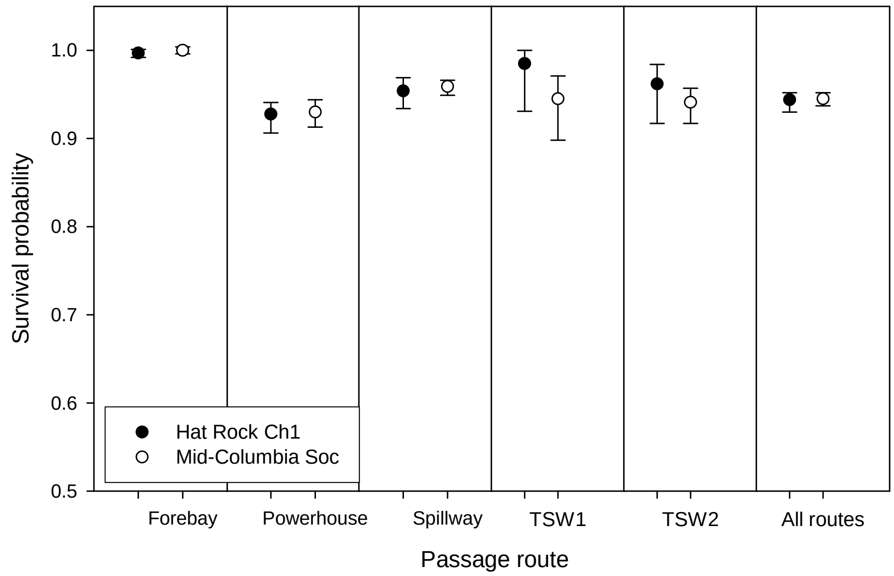

Figure 2-24. Graph showing survival probabilities for Hat Rock released yearling Chinook salmon (Ch1, black circles) and mid-Columbia River released sockeye salmon (Soc, open circles) through individual passage routes at McNary Dam during 2009. Error bars represent the 95-percent profile likelihood confidence intervals.

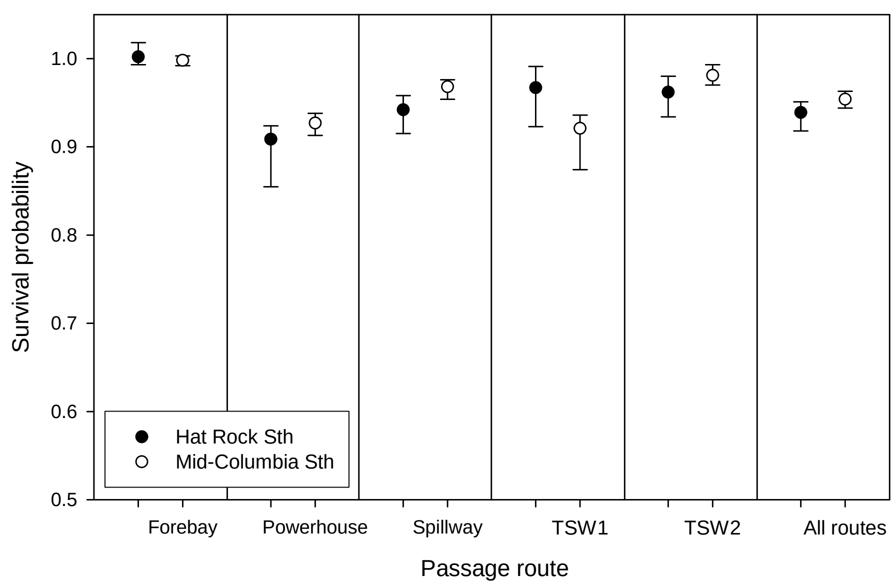

Figure 2-25. Graph showing survival probabilities for juvenile steelhead (Sth) released at Hat Rock State Park (black circles), and the mid-Columbia River (open circles) through individual passage routes at McNary Dam during 2009. Error bars represent the 95-percent profile likelihood confidence intervals.

References Cited

Adams, N.S., and Counihan, T.D., eds., 2009, Survival and migration behavior of juvenile salmonids at McNary Dam, 2007: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Contract W68SBV70178419, Walla Walla, Washington.

Adams, N.S., and Liedtke, T.L., eds., 2009, Juvenile salmonid survival, passage, and egress at McNary Dam during tests of temporary spillway weirs, 2008: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Report number 2008-W68SBV80448890.

Adams, N.S., and Liedtke, T.L., eds., 2010, Juvenile salmonid survival, passage, and egress at McNary Dam during tests of temporary spillway weirs, 2009: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Report number 2009-W68SBV90070150.

Adams, N.S., Plumb, J.M., Hatton, T.W., Jones, E.C., Swyers, N.M., Sholtis, M.D., Reagan, R.E., and Cash, K.M., 2008, Survival and migration behavior of juvenile salmonids at McNary Dam, 2006: Final report of research prepared by U.S. Geological Survey, Cook, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Washington, Report number 2006-W68SBV60478899.

Cormack, R.M., 1964, Estimates of survival from the sighting of marked animals: Biometrika, v. 51, p. 429–438.

Cowen, L., and Schwarz, C.J., 2005, Capture-recapture studies using radio telemetry with premature radio-tag failure: Biometrics, v. 61, p. 657–664.

Elandt-Johnson, R.C. and Johnson, N.L., 1980, Survival models and data analysis: Wiley, New York, 457 p.

Jolly, G.M., 1965, Explicit estimates from capture-recapture data with both death and immigration-stochastic model: Biometrika, v. 52, p. 225–247.

Mesa, M.G., 1994, Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile Chinook salmon: Transactions of the American Fisheries Society, v. 123, p. 786–793.

Plumb, J.M., Perry, R.W., Adams, N.S., and Rondorf, D.W., 2006, The effects of river impoundment and hatchery rearing on the migration behavior of juvenile steelhead in the Lower Snake River, Washington: North American Journal of Fisheries Management, v. 26, p. 438–452.

Raymond, H.L., 1968, Migration rates of hatchery Chinook salmon in relation to flows and impoundments in the Columbia and Snake Rivers: Transactions of the American Fisheries Society, v. 97, 356–359.

Raymond, H.L., 1979, Effects of dams and impoundments on migrations of juvenile Chinook salmon and juvenile steelhead from the Snake River, 1966 to 1975: Transactions of the American Fisheries Society, v. 108, p. 505–529.

Seber, G.A.F., 1965, A note on the multiple recapture census: Biometrika, v. 52, p. 249–259.

Seber, G.A.F., 1982, The estimation of animal abundance and related parameters: New York, New York, Macmillan, 654 p.

Skalski, J.R., Stevenson, J.R., Lady, J., Townsend, R., Giorgi, A.E., Miller, M., and English, K.E., 2001, An assessment of project, pool, and dam survival for Chinook and juvenile steelhead smolts at Rocky Reach and Rock Island dams using radio telemetry and PIT-tag techniques, 2000: Columbia Basin Research to Chelan County Public Utility District Report.

Skalski, J.R., Townsend, R., Lady, J., Giorgi, A.E., Stevenson, J.R., and McDonald, R.S., 2002, Estimating route-specific passage and survival probabilities at a hydroelectric project from smolt radio telemetry studies: Canadian Journal of Fisheries and Aquatic Sciences, v. 59, p. 1385–1393.

Steig, T.W., Nealson, P.A., Kumagai, K.K., Rowdon, B.J., Klein, L.S., and McFadden, B.D., 2007, Route-specific passage of juvenile steelhead and sockeye salmon using acoustic tag methodologies at Rocky Reach and Rock Island Dams in 2006. Final report for Chelan County Public Utility District No. 1 by Hydroacoustic Technology, Inc..

Steig, T.W., Nealson, P.A., Kumagai, K.K., Rowdon, B.J., Klein, L.S., and McFadden, B.D., 2008, Route-specific passage of juvenile Chinook and sockeye salmon using acoustic tag methodologies at Rocky Reach and Rock Island Dams in 2007: Final report for Chelan County Public Utility District No. 1 by Hydroacoustic Technology, Inc..

Steig, T.W., Nealson, P.A., Kumagai, K.K., Rowdon, B.J., Selleck, J.R., and McFadden, B.D., 2009, Route specific passage of juvenile Chinook, sockeye and juvenile steelhead salmon using acoustic tag methodologies at Rocky Reach and Rock Island Dams in 2008: Final report for Chelan County Public Utility District No. 1 by Hydroacoustic Technology, Inc..

Steig, T.W., Nealson, P.A., Kumagai, K.K., Rowdon, B.J., Selleck, J.R., and Tunnicliffe, C., 2010, Route specific passage of juvenile Chinook, sockeye and juvenile steelhead salmon using acoustic tag methodologies at Rocky Reach and Rock Island Dams in 2009: Final report for Chelan County Public Utility District No. 1 by Hydroacoustic Technology, Inc..

Stevenson, J.R., Skalski, J.R., Lady, J., Townsend, R., Giorgi, A.E., and McDonald, R., 2000, A pilot study assessing the feasibility of using radio telemetry and PIT-tag techniques to estimate project, pool, and dam survival of juvenile steelhead smolts at Rocky Reach and Rock Island dams, 1999: Report to Chelan County Public Utility District No. 1 by BioAnalysts.

Sullivan, L.S., Wright, C.D., Rizor, S.E., Timko, M.A., Fitzgerald, C.A., Meagher, M.L., Skalski, J.R., and Townsend, R.L., 2009: Analysis of juvenile Chinook, steelhead and sockeye salmon behavior using acoustic tags at Wanapum and Priest Rapids dams, 2008: Final report for Grant County Public Utility District No. 2 by Hydroacoustic Technology, Inc..

Timko, M.A., Brown, L.S., Wright, C.D., O'Connor, R.R., Fitzgerald, C.A., Meager, M.L., Rizor, S.E., Nealson, P.A., and Johnston, S.V., 2007, Analysis of juvenile Chinook, steelhead, and sockeye salmon behavior using acoustic tags at Wanapum and Priest Rapids Dams, 2006: Final report for Grant County Public Utility District No. 2 by Hydroacoustic Technology, Inc..

Timko, M.A., Brown, L.S., Wright, C.D., Rizor, S.E., Fitzgerald, C.A., O'Connor, R.R., and Meager, M.L., 2008, Analysis of juvenile Chinook, steelhead and sockeye salmon behavior using acoustic tags at Wanapum and Priest Rapids dams, 2007: Draft report for Grant County Public Utility District No. 2 by Hydroacoustic Technology, Inc..

Timko, M.A., Sullivan, L.S., Wright, C.D., Rizor, S.E., O'Connor, R.R., Skalski, J.R., Townsend, R.L., Fitzgerald, C.A., Meagher, M.M., Kukes, T.J., and Stephenson, J.D., 2010, Behavior and survival analysis of juvenile steelhead and sockeye through the Priest Rapids Hydroelectric Project in 2009: Final report for Grant County Public Utility District No. 2 by Blue Leaf Environmental.

Townsend, R.L., Skalski, J.R., Dillingham, P., and Steig, T.W., 2006, Correcting bias in survival estimation resulting from tag failure in acoustic and radio telemetry studies: Journal of Agricultural, Biological, and Environmental Statistics, v. 11, p. 183–196.

Whitney, R.R., Calvin, L.D., Erho, M.W., Jr., and Coutant, C.C., 1997, Downstream passage for salmon at hydroelectric projects in the Columbia River Basin—Development, installation, and evaluation: Northwest Power Planning Council Report No. 97–15.

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Glossary

CH1	Yearling Chinook salmon (*Oncorhynchus tshawytscha*).
CH0	Subyearling Chinook salmon (*Oncorhynchus tshawytscha*).
Forebay	Area of Columbia River extending from McNary Dam to 2 km upstream.
Near Dam	Area of Columbia River extending from McNary Dam to approximately 160 m upstream; the area monitored by hydrophones placed from the upstream face of McNary Dam to 60 m upstream, including an average detection range of 100 m.
PIT	Passive integrated transponder.
Powerhouse	Turbine and Bypass (units 1–14).
RKM	River kilometer.
Spillway	Conventional spill bays (bays 1–22 excluding bays 20 and 22 in 2007, 19 and 20 in 2008, 4 and 20 in spring 2009, and 19 and 20 in summer 2009).
STH	Steelhead (*Oncorhynchus mykiss*).
NOAA Fisheries	National Oceanic and Atmospheric Administration National Marine Fisheries Service.
SOC	Sockeye (*Oncorhynchus nerka*).
Tailrace	Area of Columbia River extending from McNary Dam to 2.4 km downstream.
TSW	Temporary Spillway Weir.
USACE	United States Army Corps of Engineers.
USGS	United States Geological Survey.

Appendix A. Locations of Hydrophones in the McNary Dam Forebay, 2006–09.

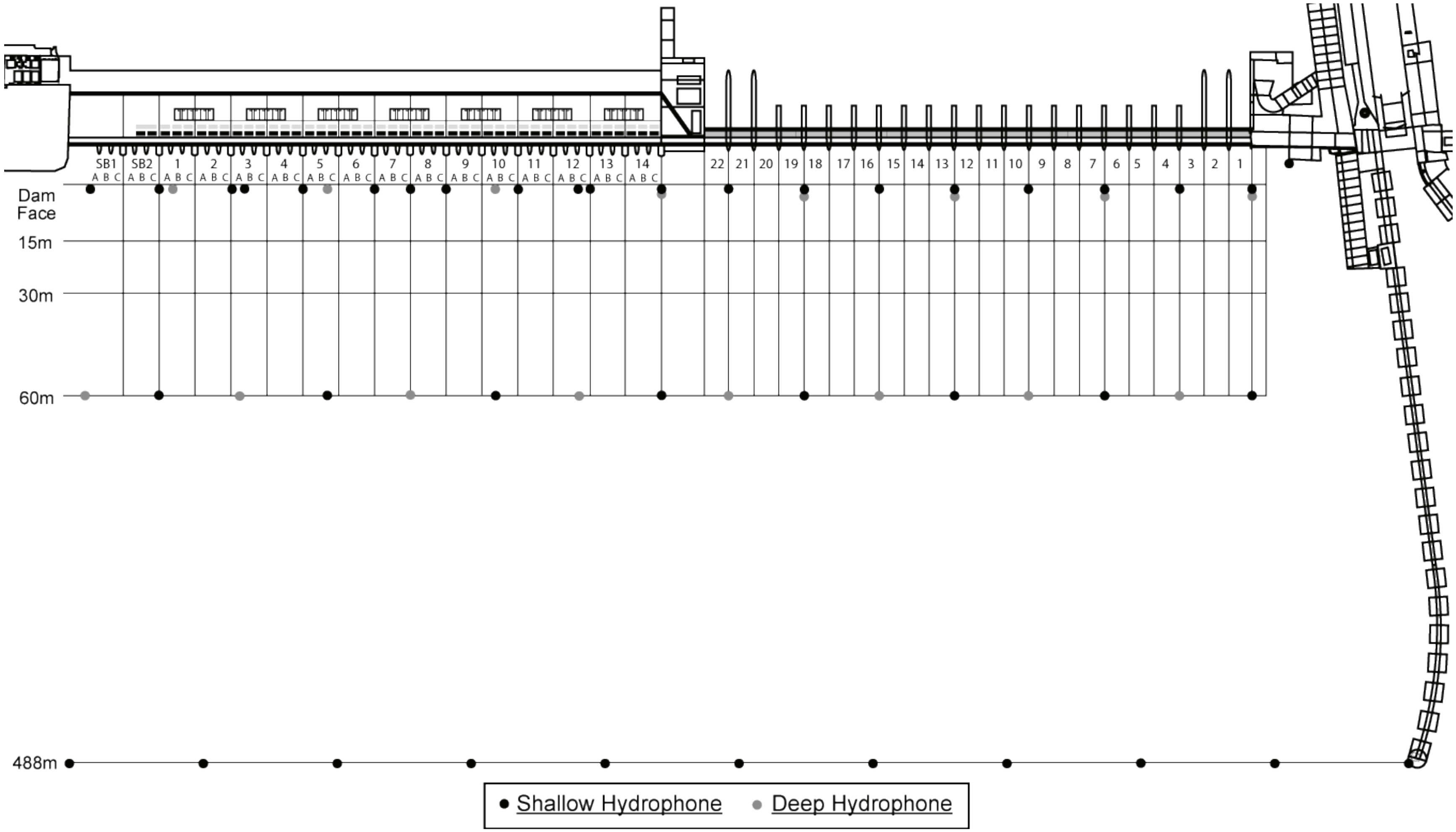

Figure A1. Schematic of hydrophones in the McNary Dam forebay during 2006.

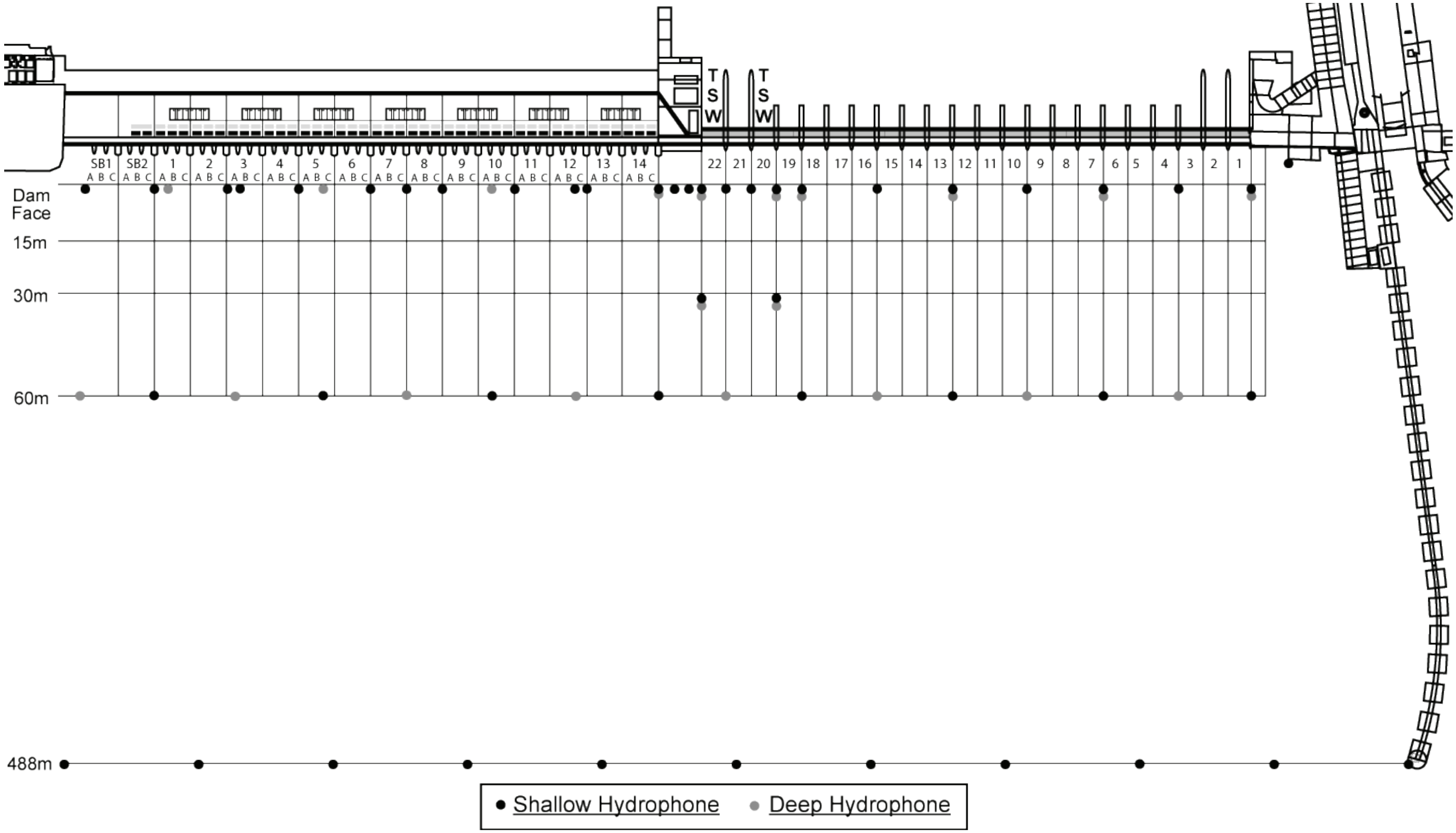

Figure A2. Schematic of hydrophones in the McNary Dam forebay during 2007.

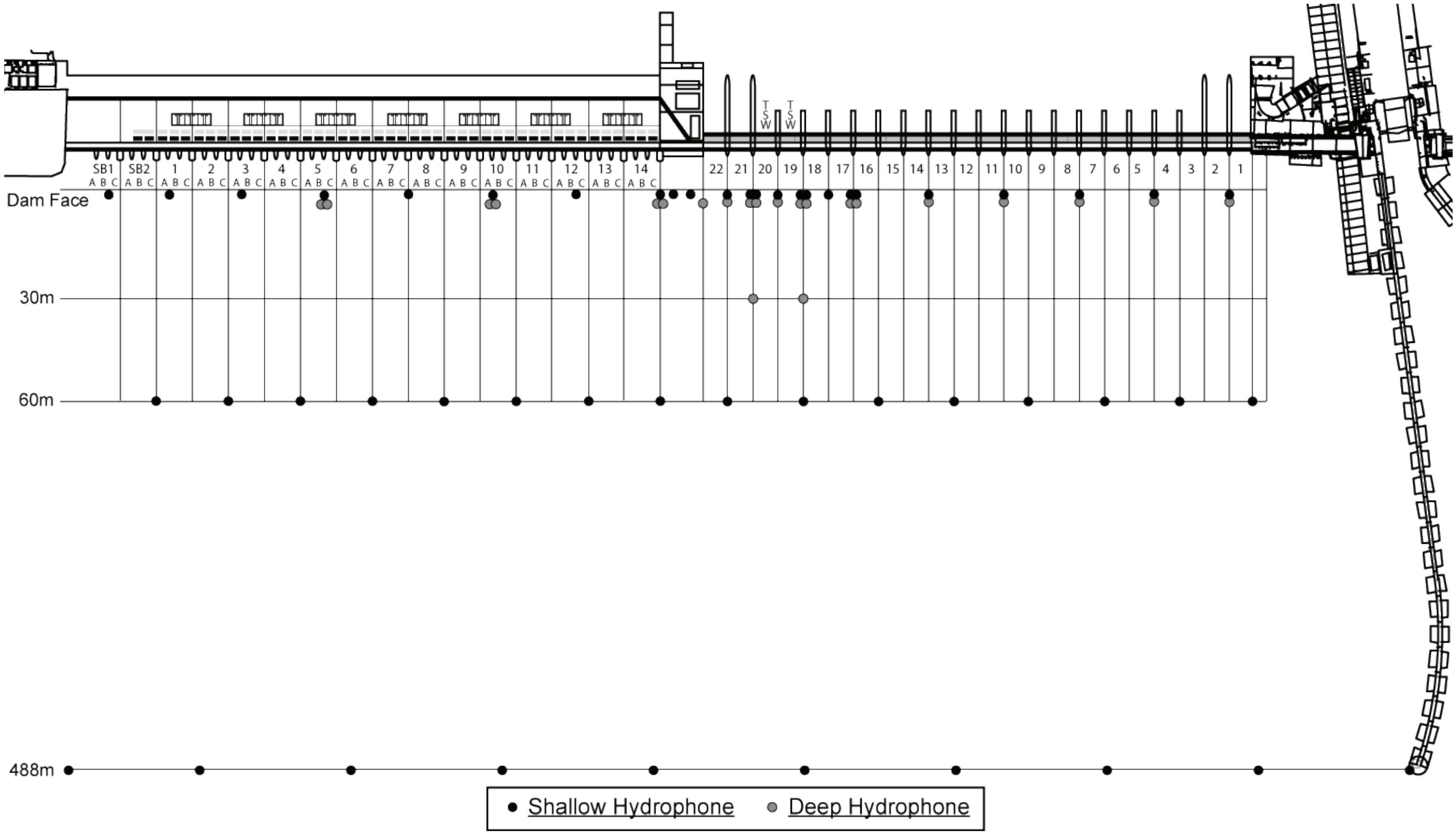

Figure A3. Schematic of hydrophones in the McNary Dam forebay during 2008.

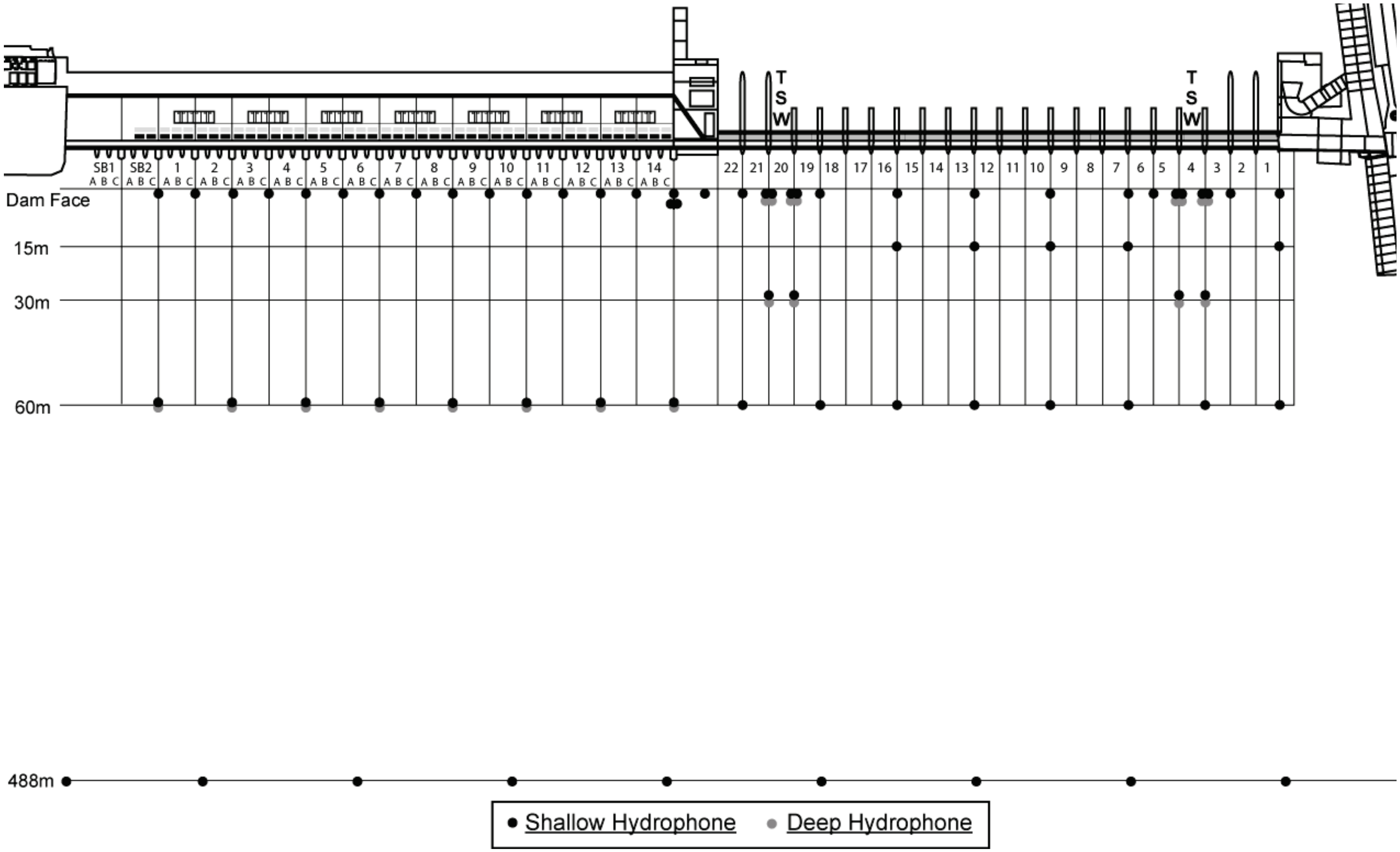

Figure A4. Schematic of hydrophones in the McNary Dam forebay during spring 2009.

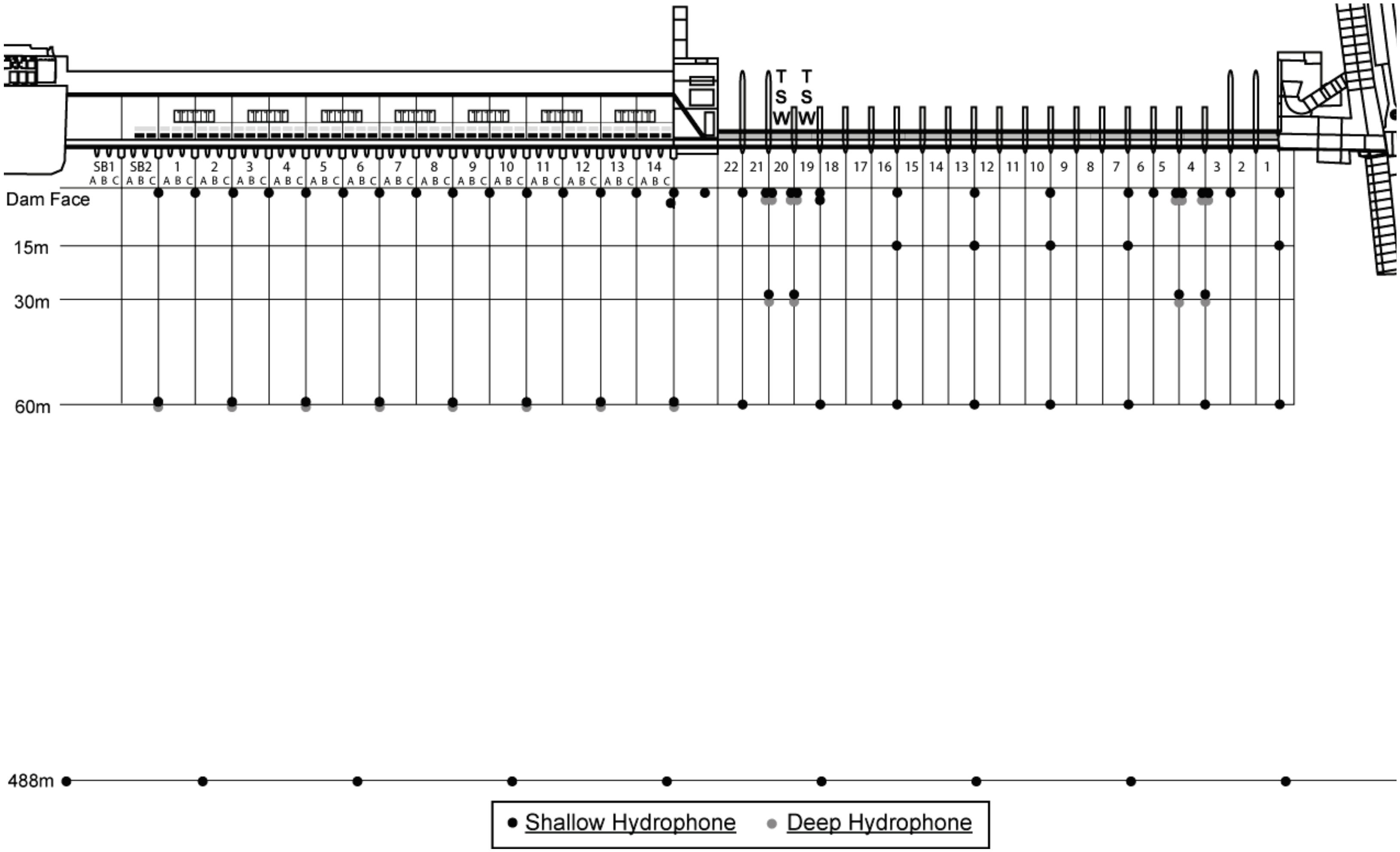

Figure A5. Schematic of hydrophones in the McNary Dam forebay during summer 2009.

Appendix B. Travel Rates for Hat Rock Released Fish, 2006–09.

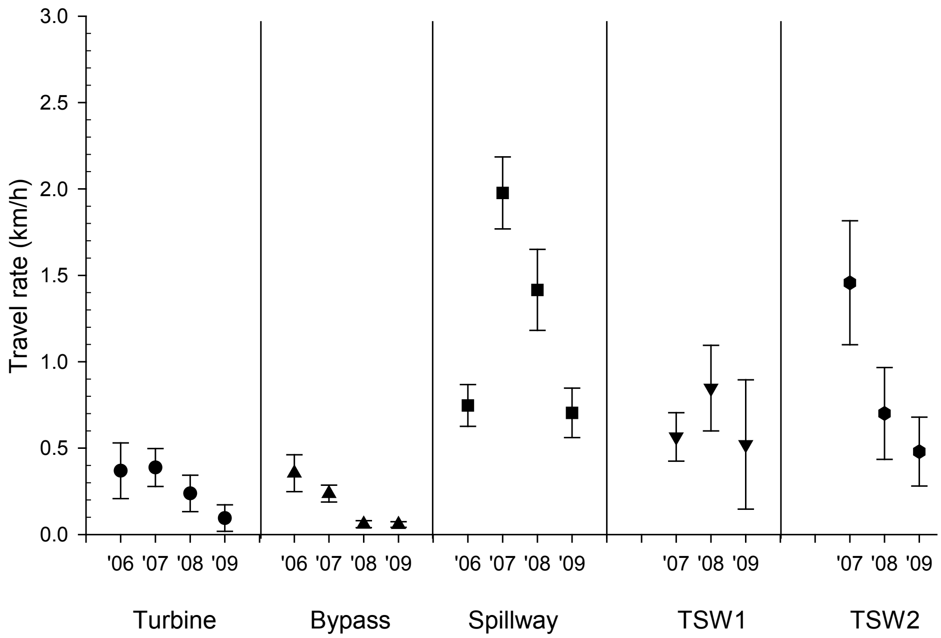

Figure B1. Graph showing mean travel rate (km/h) for yearling Chinook salmon released near Hat Rock State Park from first detection in the forebay to time of passage at McNary Dam, by passage route, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

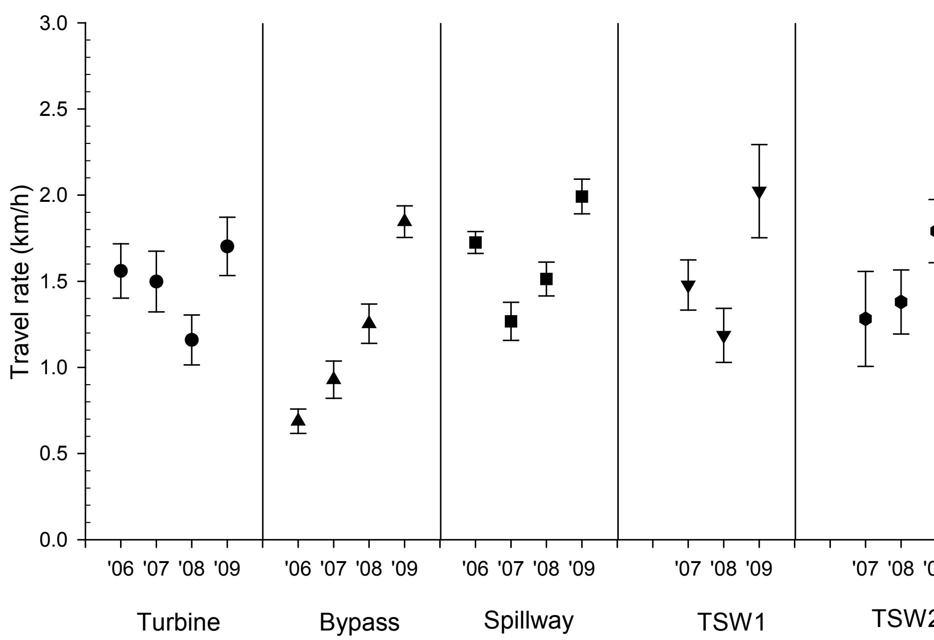

Figure B2. Graph showing mean travel rate (km/h) for yearling Chinook salmon released near Hat Rock State Park from time of passage at McNary Dam to first detection at the first downstream site, by passage route, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

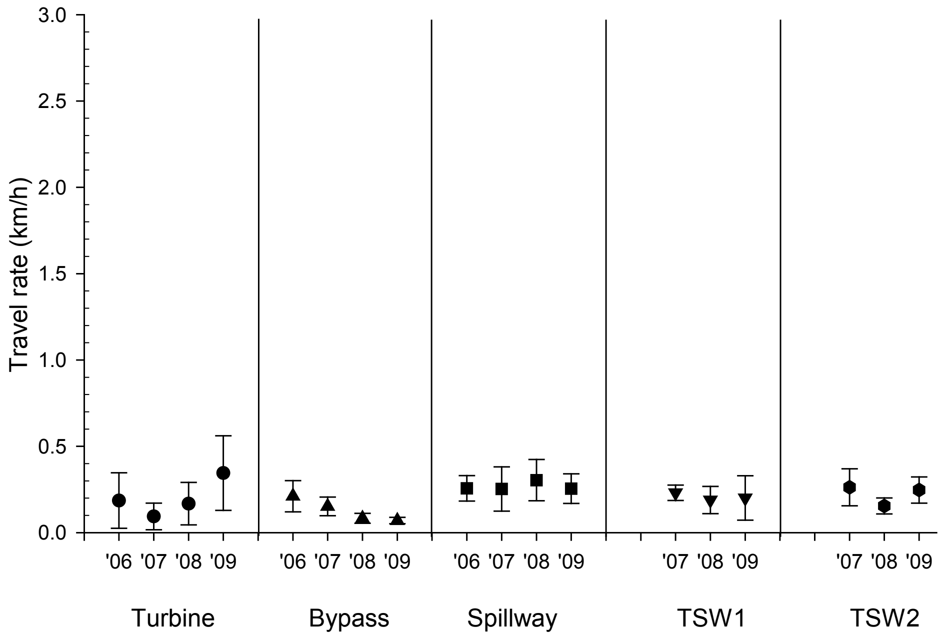

Figure B3. Graph showing mean travel rate (km/h) for juvenile steelhead released near Hat Rock State Park from first detection in the forebay to time of passage at McNary Dam, by passage route, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

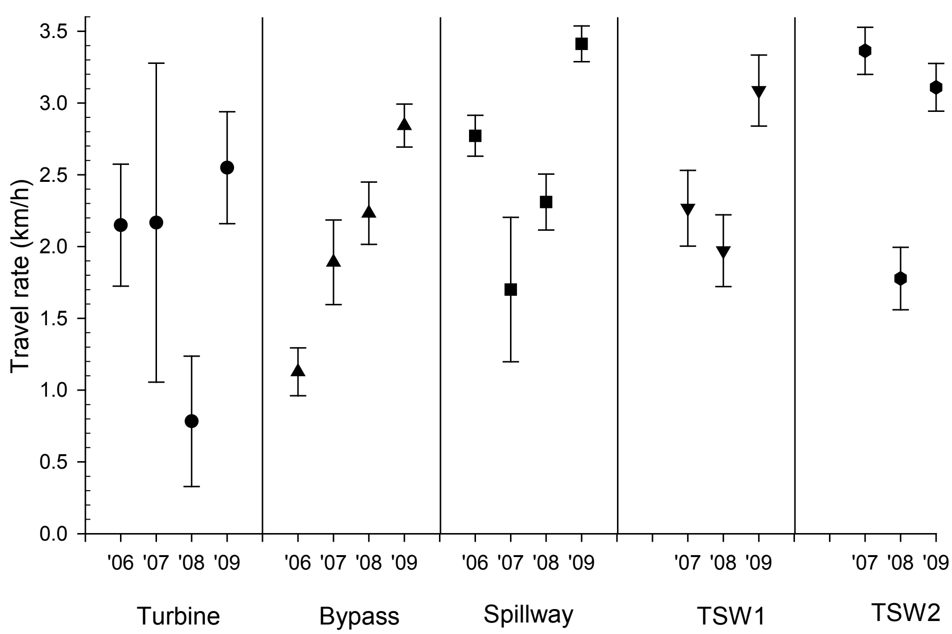

Figure B4. Graph showing mean travel rate (km/h) for juvenile steelhead released near Hat Rock State Park from time of passage at McNary Dam to first detection at the first downstream site, by passage route, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

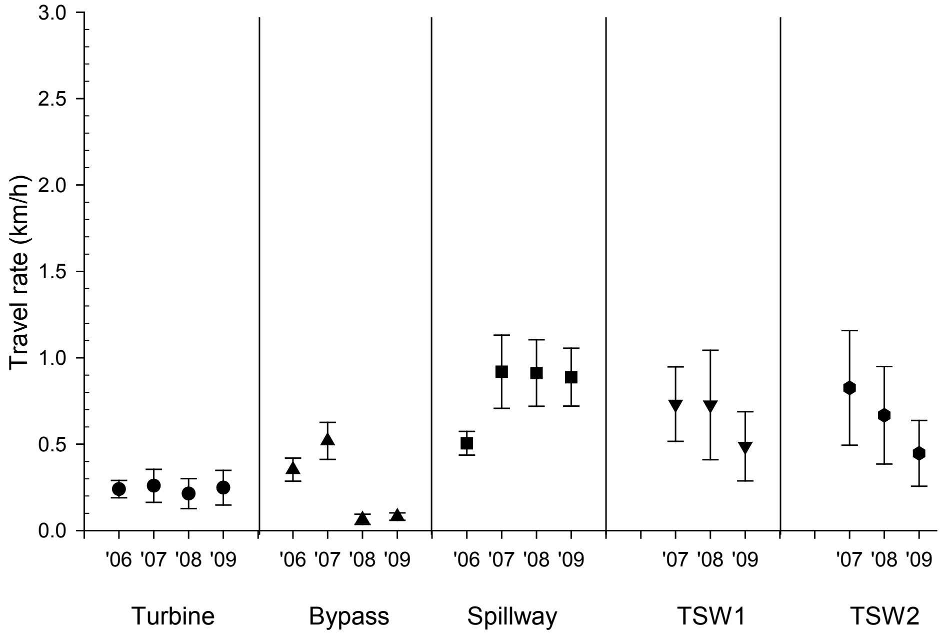

Figure B5. Graph showing mean travel rate (km/h) for subyearling Chinook salmon released near Hat Rock State Park from first detection in the forebay to time of passage at McNary Dam, by passage route, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

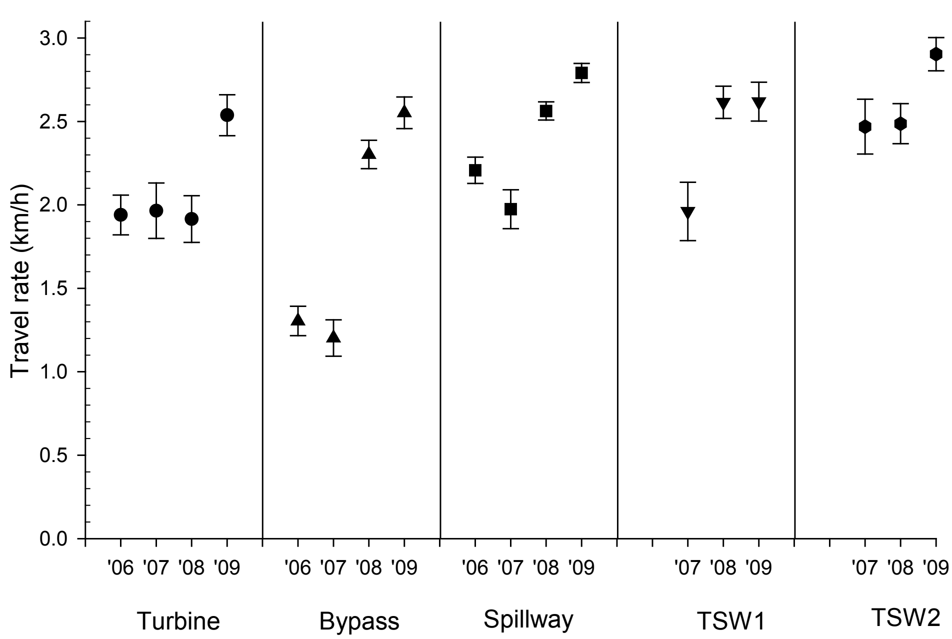

Figure B6. Graph showing mean travel rate (km/h) for subyearling Chinook salmon released near Hat Rock State Park from time of passage at McNary Dam to first detection at the first downstream site, by passage route, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

Appendix C. Travel Times and Rates for Mid-Columbia River Released Fish, 2006–09.

Table C1. Mean and median travel times (d), mean travel rates (km/d), and the mean rate of population spread (km^2/d) by river reach of yearling Chinook salmon (CH1), juvenile steelhead (STH), and sockeye salmon (SOC) released in the Mid-Columbia river during 2006.

[Species: CH1, yearling Chinook salmon; STH, juvenile steelhead; SOC, sockeye salmon. Release site: WE, Wells Dam; RR, Rocky Reach Dam; RI , Rock Island Dam; WA, Wanapum Dam; PR, Priest Rapids Dam; *N*, number of fish; CI, confidence interval; pop., population. Reach length is in kilometers. Reach 1 is defined from release to McNary Dam forebay; Reach 2 is defined from McNary Dam forebay to McNary Dam passage; Reach 3 is defined from McNary Dam passage to 1st detection array downstream of McNary Dam; Reach 4 is defined from 1st detection array downstream of McNary Dam to 2nd detection array downstream of McNary Dam]

Species	Release site	Reach	Reach length	*N*	Mean travel time	Median travel time	Mean travel rate (±95% CI)	Mean rate of pop. spread (±95% CI)
CH1	WA	1	198	264	3.68	3.49	53.72 (1.87)	29.52 (2.27)
		2	2	259	0.12	0.08	16.83 (1.63)	4.58 (0.35)
		3	24	200	0.34	0.26	71.25 (4.49)	18.65 (1.62)
		4	22	147	0.44	0.39	49.90 (3.12)	12.61 (1.26)
STH	WE	1	358	130	7.79	7.30	45.93 (2.40)	38.51 (4.05)
		2	2	118	0.17	0.07	11.96 (2.50)	5.59 (0.61)
		3	24	81	0.46	0.28	52.49 (8.89)	27.03 (3.47)
		4	22	42	0.35	0.33	63.18 (4.97)	9.29 (1.55)
STH	RR	1	290	142	6.46	5.79	44.87 (2.56)	39.07 (3.95)
		2	2	120	0.12	0.07	16.25 (2.52)	4.88 (0.53)
		3	24	90	0.66	0.24	36.25 (9.40)	36.33 (4.46)
		4	22	59	0.50	0.35	44.12 (7.61)	20.46 (2.99)
STH	RI	1	254	270	6.86	5.97	37.04 (1.83)	39.84 (3.03)
		2	2	225	0.19	0.08	10.50 (1.78)	5.91 (0.49)
		3	24	177	0.48	0.25	49.70 (6.49)	30.30 (2.78)
		4	22	102	0.50	0.37	44.02 (5.26)	18.85 (2.20)
STH	WA	1	198	108	4.05	3.44	48.76 (4.06)	42.60 (4.85)
		2	2	89	0.19	0.08	10.63 (2.71)	5.55 (0.69)
		3	24	82	0.43	0.25	55.40 (8.94)	26.62 (3.40)
		4	22	47	0.37	0.34	58.71 (4.66)	9.61 (1.54)
STH	PR	1	167	446	2.61	2.37	64.09 (1.97)	34.18 (2.07)
		2	2	386	0.13	0.07	15.87 (1.35)	4.81 (0.31)
		3	24	311	0.44	0.25	54.50 (4.80)	28.53 (2.04)
		4	22	198	0.36	0.35	60.44 (2.25)	9.65 (0.84)
SOC	WE	1	358	383	6.10	5.95	58.71 (1.29)	31.75 (2.06)
		2	2	185	0.11	0.06	18.05 (2.57)	5.89 (0.53)
		3	24	99	0.50	0.25	47.92 (8.91)	31.47 (3.72)
		4	22	36	0.45	0.36	49.14 (7.77)	15.15 (2.69)
SOC	RR	1	290	822	5.11	4.85	56.74 (0.97)	32.06 (1.46)
		2	2	406	0.11	0.06	18.09 (1.68)	5.72 (0.36)
		3	24	245	0.38	0.26	63.51 (5.13)	25.01 (1.99)
		4	22	83	0.51	0.38	43.19 (5.43)	17.66 (2.24)
SOC	RI	1	254	219	4.82	4.38	52.75 (1.98)	32.50 (2.72)
		2	2	114	0.11	0.06	19.03 (3.27)	5.69 (0.63)
		3	24	78	0.43	0.26	55.69 (10.20)	29.50 (3.85)
		4	22	17	0.40	0.39	54.78 (7.29)	8.71 (2.02)

Table C2. Mean and median travel times (d), mean travel rates (km/d), and the mean rate of population spread (km^2/d) by river reach of yearling Chinook salmon, juvenile steelhead, and sockeye salmon released in the Mid-Columbia river during 2007.

[Species: CH1, yearling Chinook salmon; STH, juvenile steelhead; SOC, sockeye salmon. Release site: WE, Wells Dam; RR, Rocky Reach Dam; RI , Rock Island Dam; WA, Wanapum Dam; *N*, number of fish; CI, confidence interval; pop., population. Reach length is in kilometers. Reach 1 is defined from release to McNary Dam forebay; Reach 2 is defined from McNary Dam forebay to McNary Dam passage; Reach 3 is defined from McNary Dam passage to 1st detection array downstream of McNary Dam; Reach 4 is defined from 1st detection array downstream of McNary Dam to 2nd detection array downstream of McNary Dam]

Species	Release site	Reach	Reach length	*N*	Mean travel time	Median travel time	Mean travel rate (±95% CI)	Mean rate of pop. spread (±95% CI)
CH1	RR	1	290	97	8.55	7.91	33.92 (1.89)	27.30 (3.25)
		2	2	94	0.13	0.09	14.94 (2.62)	4.65 (0.56)
		3	24	29	0.64	0.36	37.34 (10.99)	22.75 (4.38)
		4	31	13	1.23	0.57	25.22 (16.15)	28.47 (7.22)
CH1	RI	1	254	97	8.38	7.88	30.30 (1.79)	25.55 (3.04)
		2	2	96	0.15	0.10	13.01 (2.36)	4.55 (0.54)
		3	24	32	0.74	0.47	32.35 (9.34)	21.95 (4.07)
		4	31	19	0.55	0.52	56.64 (6.24)	9.32 (2.09)
CH1	WA	1	198	332	4.13	3.91	47.82 (1.40)	26.36 (1.83)
		2	2	331	0.18	0.08	11.27 (1.43)	5.56 (0.39)
		3	24	91	0.48	0.37	50.24 (5.10)	16.82 (2.06)
		4	31	52	0.57	0.51	54.05 (5.24)	14.11 (2.17)
STH	RI	1	254	266	6.40	5.88	39.67 (1.58)	33.07 (2.53)
		2	2	254	0.37	0.14	5.47 (1.03)	5.02 (0.39)
		3	24	97	0.55	0.30	43.35 (30.02)	110.24 (13.13)
		4	31	51	0.69	0.51	44.79 (7.34)	21.51 (3.33)
SOC	WE	1	358	121	6.62	6.22	54.09 (2.43)	34.55 (3.74)
		2	2	108	0.19	0.09	10.59 (2.31)	5.23 (0.60)
		3	24	25	0.51	0.36	46.76 (12.21)	20.77 (4.22)
		4	31	4	0.74	0.73	42.06 (26.86)	12.55 (4.34)
SOC	RR	1	290	495	5.70	5.31	50.90 (1.27)	34.21 (1.97)
		2	2	453	0.26	0.09	7.60 (1.03)	5.70 (0.34)
		3	24	67	0.58	0.34	41.03 (7.76)	24.15 (0.35)
		4	31	19	0.61	0.52	51.22 (9.88)	15.50 (3.47)

Table C3. Mean and median travel times (d), mean travel rates (km/d), and the mean rate of population spread (km^2/d) by river reach for yearling Chinook salmon, juvenile steelhead, and sockeye salmon released in the Mid-Columbia river during 2008.

[Species: CH1, yearling Chinook salmon; STH, juvenile steelhead; SOC, sockeye salmon. Release site: WE, Wells Dam; RR, Rocky Reach Dam; RH, Rock Island Hydro Park; RI , Rock Island Dam; WA, Wanapum Dam; PR, Priest Rapids Dam; *N*, number of fish; CI, confidence interval; pop., population. Reach length is in kilometers. Reach 1 is defined from release to McNary Dam forebay; Reach 2 is defined from McNary Dam forebay to McNary Dam passage; Reach 3 is defined from McNary Dam passage to 1st detection array downstream of McNary Dam; Reach 4 is defined from 1st detection array downstream of McNary Dam to 2nd detection array downstream of McNary Dam]

Species	Release site	Reach	Reach length	*N*	Mean travel time	Median travel time	Mean travel rate (±95% CI)	Mean rate of pop. spread (±95% CI)
CH1	RR	1	290	142	7.73	7.03	37.53 (1.96)	32.77 (3.32)
		2	2	134	0.20	0.09	10.01 (2.04)	5.33 (0.55)
		3	24	108	0.75	0.41	31.80 (5.90)	26.75 (3.04)
		4	31	57	0.52	0.54	59.47 (21.01)	56.65 (8.40)
STH	RR	1	290	159	6.03	5.55	48.10 (2.31)	36.09 (3.48)
		2	2	155	0.14	0.08	13.82 (2.12)	5.08 (0.49)
		3	24	116	0.41	0.26	58.23 (7.29)	25.34 (2.80)
		4	31	65	0.47	0.47	66.15 (15.47)	42.40 (5.96)
STH	RI	1	254	353	5.38	4.95	47.23 (1.51)	33.42 (2.25)
		2	2	308	0.36	0.07	5.53 (1.24)	6.64 (0.48)
		3	24	219	0.47	0.26	51.33 (5.36)	27.44 (2.29)
		4	31	133	0.48	0.47	64.96 (11.83)	47.48 (4.94)
STH	WA	1	197.5	233	3.34	3.02	59.05 (2.68)	37.86 (3.08)
		2	2	195	0.13	0.06	15.46 (2.31)	5.86 (0.52)
		3	24	142	0.41	0.27	59.06 (6.12)	23.44 (2.37)
		4	31	85	0.44	0.47	69.95 (16.14)	49.53 (6.24)
STH	PR	1	167	393	2.40	1.99	69.53 (2.59)	40.44 (2.59)
		2	2	344	0.19	0.07	10.78 (1.48)	6.01 (0.41)
		3	24	240	0.40	0.26	60.41 (4.90)	24.22 (1.94)
		4	31	137	0.42	0.45	74.54 (12.67)	48.18 (4.95)
SOC	WE	1	358	134	5.60	5.28	63.92 (3.05)	42.07 (4.36)
		2	2	111	0.38	0.06	5.30 (2.49)	8.09 (0.91)
		3	24	70	0.54	0.53	44.25 (6.90)	21.15 (2.88)
		4	31	59	0.82	0.10	37.89 (25.14)	86.51 (12.65)
SOC	RR	1	290	314	4.48	4.12	64.75 (1.96)	37.33 (2.65)
		2	2	234	0.40	0.05	5.02 (1.64)	8.04 (0.65)
		3	24	177	0.64	0.55	37.41 (4.65)	25.02 (2.30)
		4	31	164	0.24	0.09	129.07 (22.30)	70.65 (6.71)
SOC	RH	1	280	95	4.25	4.04	65.90 (3.36)	33.87 (4.07)
		2	2	78	0.47	0.06	4.24 (2.65)	8.01 (1.05)
		3	24	62	0.85	0.54	28.33 (8.41)	30.23 (4.33)
		4	31	48	0.26	0.09	121.53 (40.84)	70.30 (11.16)
SOC	RI	1	254	187	3.91	3.57	65.01 (2.69)	36.82 (3.30)
		2	2	143	0.29	0.06	6.79 (2.36)	7.73 (0.78)
		3	24	120	0.57	0.53	41.79 (5.91)	24.67 (2.68)
		4	31	100	0.25	0.10	125.53 (27.57)	68.71 (8.08)

Table C4. Mean and median travel times (d), mean travel rates (km/d), and the mean rate of population spread (km2/d) by river reach for juvenile steelhead and sockeye salmon released in the Mid-Columbia river during 2009.

[Species: STH, juvenile steelhead; SOC, sockeye salmon. Release site: WE, Wells Dam; RR, Rocky Reach Dam; RI , Rock Island Dam; WA, Wanapum Dam; PR, Priest Rapids Dam; *N*, number of fish; CI, confidence interval; pop., population. Reach length is in kilometers. Reach 1 is defined from release to McNary Dam forebay; Reach 2 is defined from McNary Dam forebay to McNary Dam passage; Reach 3 is defined from McNary Dam passage to 1st detection array downstream of McNary Dam; Reach 4 is defined from 1st detection array downstream of McNary Dam to 2nd detection array downstream of McNary Dam]

Species	Release site	Reach	Reach length	*N*	Mean travel time	Median travel time	Mean travel rate (±95% CI)	Mean rate of pop. spread (±95% CI)
STH	RR	1	290	64	8.76	7.93	33.10 (2.23)	26.24 (3.71)
		2	2	64	0.33	0.21	6.03 (1.59)	3.63 (0.51)
		3	22	71	0.56	0.26	39.63 (9.33)	29.16 (3.95)
		4	27	65	0.55	0.55	49.16 (2.88)	8.55 (1.20)
STH	RI	1	254	367	7.53	6.97	33.75 (0.96)	25.51 (1.69)
		2	2	352	0.41	0.19	4.83 (0.76)	4.66 (0.31)
		3	22	488	0.28	0.23	78.83 (3.17)	18.80 (1.09)
		4	27	463	0.53	0.47	51.15 (1.63)	12.98 (0.77)
STH	WA	1	197.5	266	4.31	3.98	45.82 (1.57)	26.89 (2.06)
		2	2	256	0.48	0.25	4.19 (0.75)	4.22 (0.33)
		3	22	337	0.32	0.24	69.78 (4.24)	22.16 (1.53)
		4	27	323	0.50	0.47	54.19 (1.49)	9.59 (0.67)
STH	PR	1	167	645	3.24	2.67	51.53 (1.57)	36.56 (1.87)
		2	2	620	0.44	0.21	4.59 (0.54)	4.55 (0.24)
		3	22	786	0.27	0.24	82.39 (2.13)	15.69 (0.73)
		4	27	765	0.51	0.47	52.98 (1.13)	11.32 (0.53)
SOC	WE	1	358	304	5.97	5.73	59.95 (1.33)	28.81 (2.08)
		2	2	270	0.10	0.07	19.80 (1.99)	5.27 (0.40)
		3	22	321	0.26	0.18	84.65 (5.54)	25.70 (1.81)
		4	27	325	0.43	0.41	62.71 (1.72)	10.31 (0.72)
SOC	RR	1	290	585	4.88	4.68	59.43 (1.17)	31.80 (1.70)
		2	2	517	0.10	0.06	19.88 (1.59)	5.82 (0.33)
		3	22	629	0.30	0.19	74.42 (4.06)	28.20 (1.46)
		4	27	618	0.45	0.43	59.84 (1.28)	10.84 (0.56)
SOC	RI	1	254	609	4.75	4.46	53.44 (1.12)	30.58 (1.60)
		2	2	565	0.09	0.06	21.46 (1.49)	5.50 (0.30)
		3	22	718	0.30	0.19	72.64 (3.58)	26.86 (1.30)
		4	27	702	0.44	0.42	61.77 (1.14)	10.19 (0.50)
SOC	WA	1	197.5	433	2.83	2.70	69.68 (1.64)	29.16 (1.79)
		2	2	423	0.13	0.06	14.86 (1.71)	6.56 (0.41)
		3	22	520	0.29	0.20	75.03 (4.11)	25.78 (1.45)
		4	27	516	0.45	0.42	60.41 (1.44)	11.15 (0.63)
SOC	PR	1	167	945	1.81	1.81	92.35 (0.97)	20.35 (0.87)
		2	2	915	0.12	0.06	16.05 (1.09)	5.95 (0.26)
		3	22	1,105	0.31	0.20	71.65 (2.78)	26.12 (1.03)
		4	27	1,090	0.45	0.41	60.45 (1.01)	11.40 (0.45)

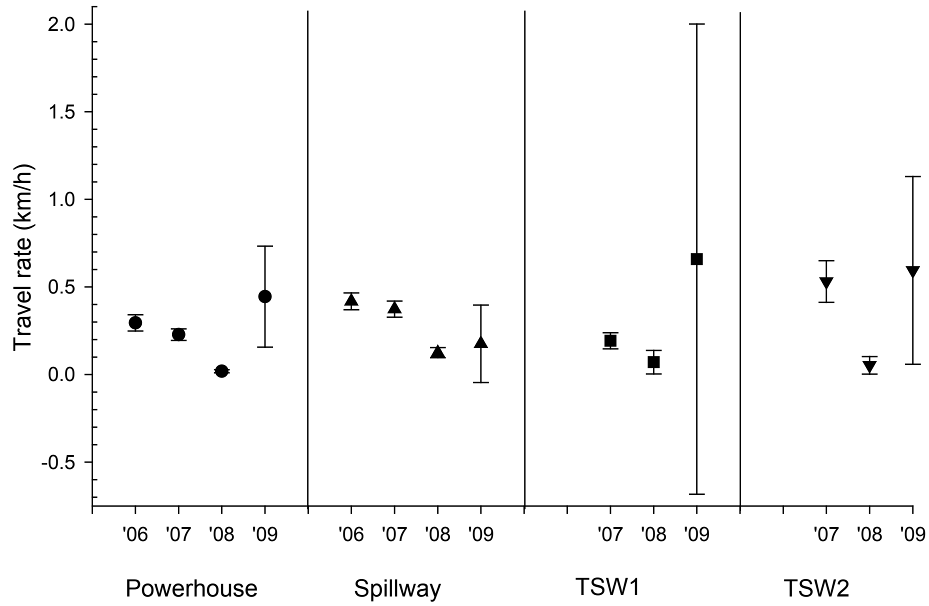

Figure C1. Graph showing mean travel rate (km/h) from first detection in the forebay to time of passage at McNary Dam, by passage route, for yearling Chinook salmon released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

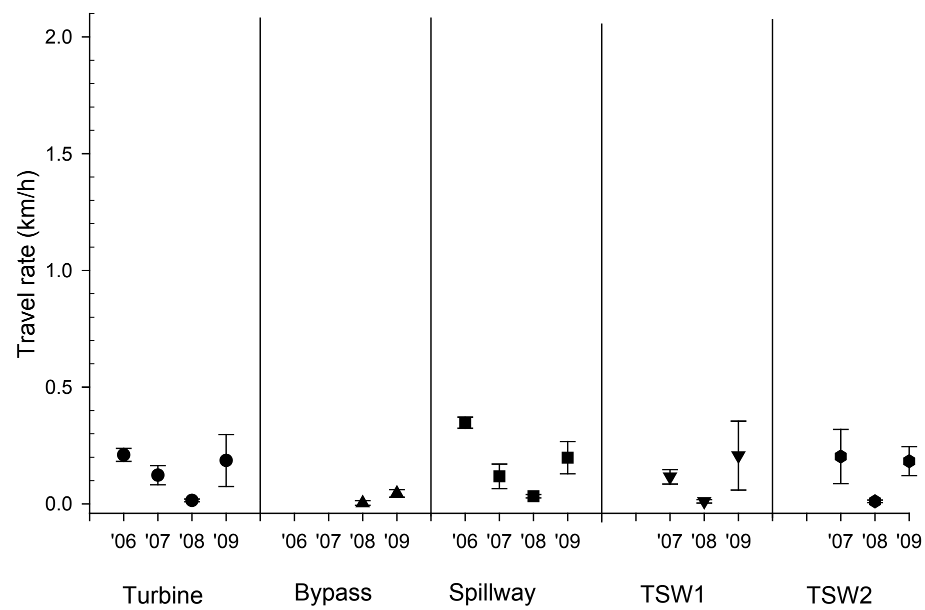

Figure C2. Graph showing mean travel rate (km/h) from first detection in the forebay to time of passage at McNary Dam, by passage route, for juvenile steelhead released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

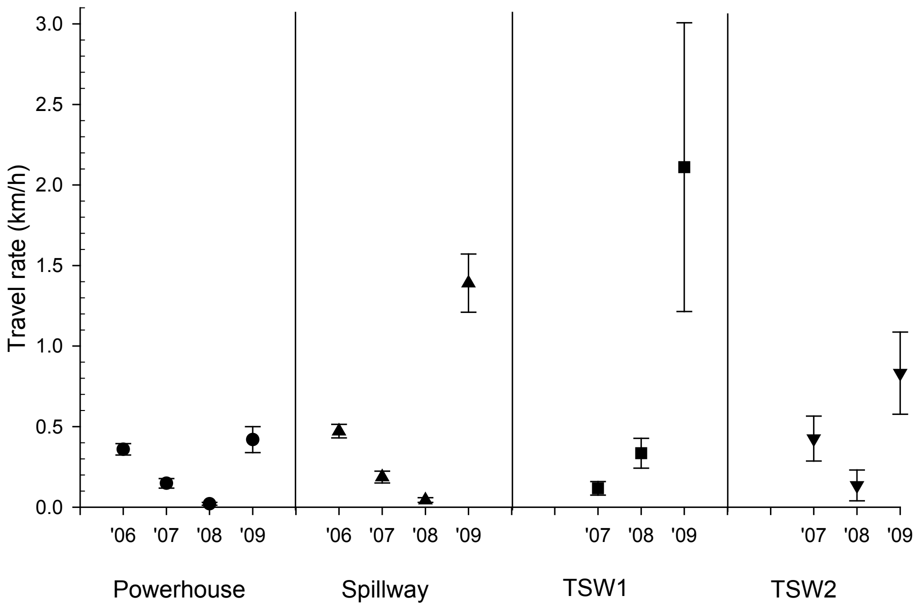

Figure C3. Graph showing mean travel rate (km/h) from first detection in the forebay to time of passage at McNary Dam, by passage route, for sockeye salmon released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

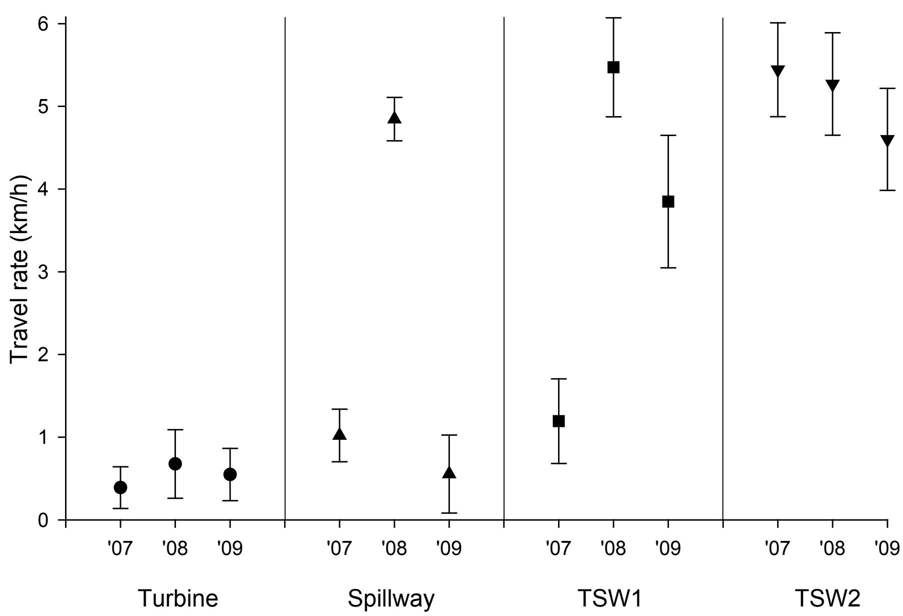

Figure C4. Graph showing mean travel rate (km/h) from passage at McNary Dam to first detection at I82 Bridge located 2.4 kilometers downstream of McNary Dam, by passage route, for yearling Chinook salmon released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

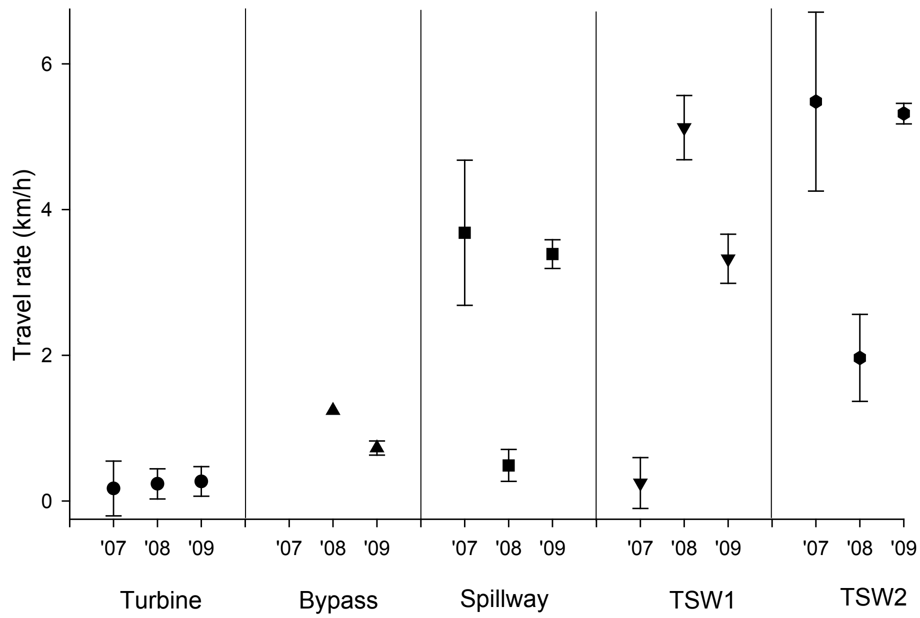

Figure C5. Graph showing mean travel rate (km/h) from passage at McNary Dam to first detection at I82 Bridge located 2.4 kilometers downstream of McNary Dam, by passage route, for juvenile steelhead released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

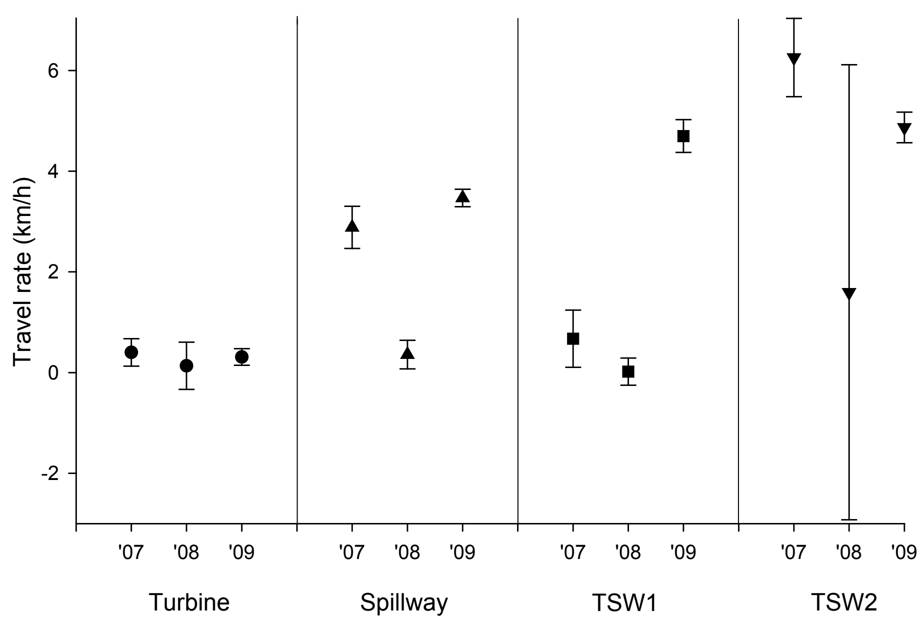

Figure C6. Graph showing mean travel rate (km/h) from passage at McNary Dam to first detection at I82 Bridge located 2.4 kilometers downstream of McNary Dam, by passage route, for Sockeye salmon released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

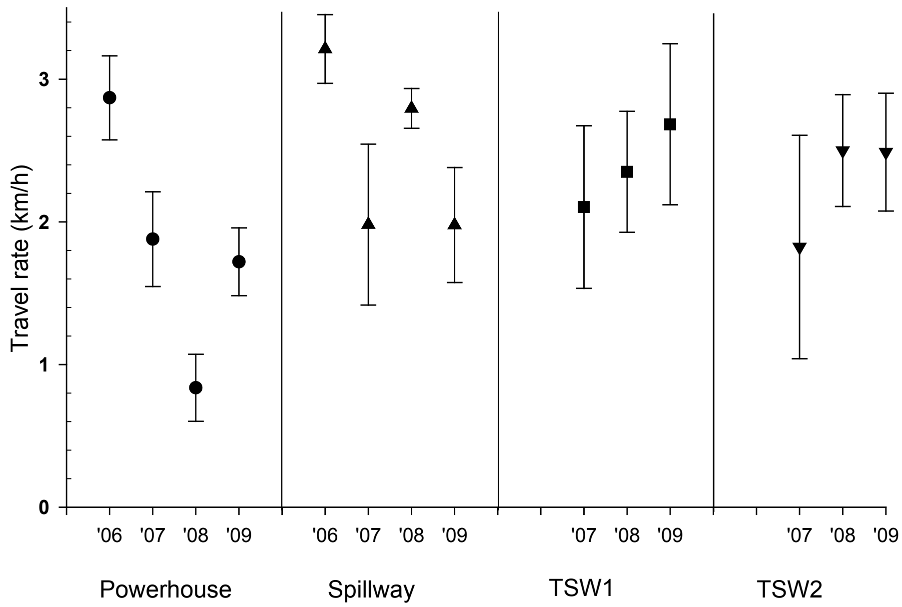

Figure C7. Graph showing mean travel rate (km/h) from passage at McNary Dam to detection array located 24 km downstream of McNary Dam, by passage route, for yearling Chinook salmon released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

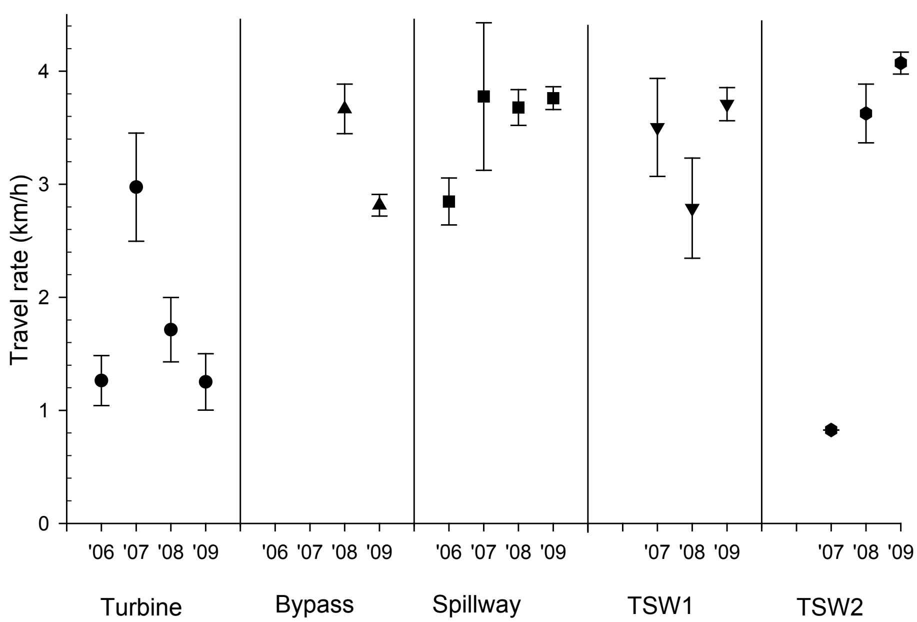

Figure C8. Graph showing mean travel rate (km/h) from passage at McNary Dam to first detection at array located 24 kilometers downstream of McNary Dam, by passage route, for juvenile steelhead released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

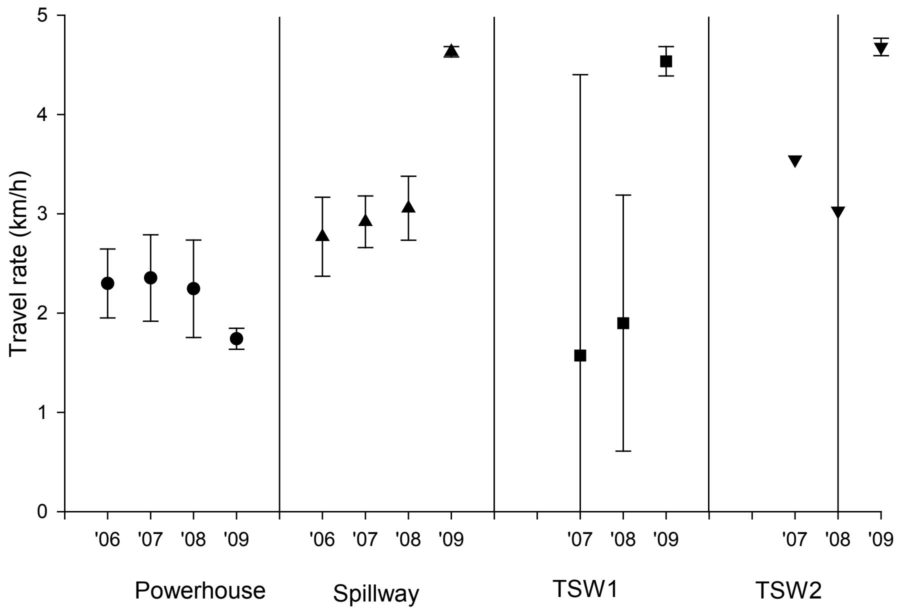

Figure C9. Graph showing mean travel rate (km/h) from passage at McNary Dam to detection array located 24 km downstream of McNary Dam, by passage route, for sockeye salmon released in the Mid-Columbia River, 2006–09. Error bars represent the 95-percent profile likelihood confidence intervals.

Appendix D. Goodness-of-Fit Model Results for the Route-Specific Survival Model Used for Hat Rock Released Fish Passing McNary Dam, 2006, 2008–09.

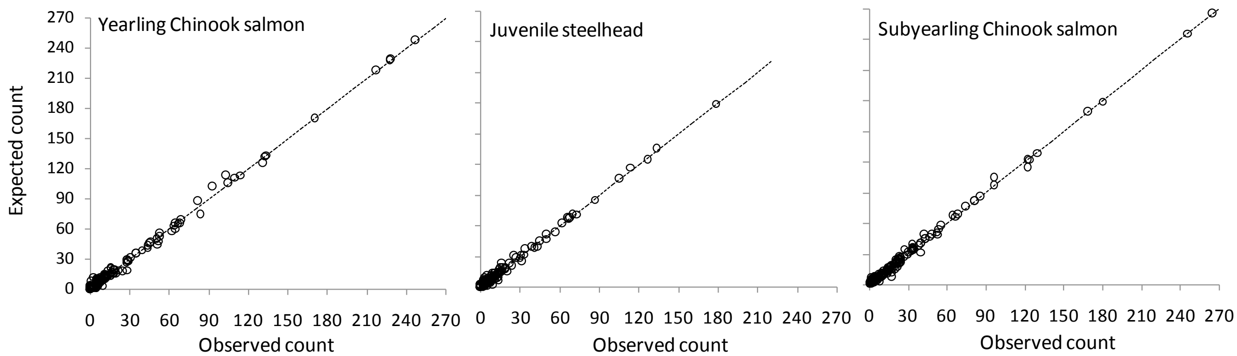

Figure D1. Plots showing observed versus expected counts for the route-specific survival model of passage and survival of yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon at McNary Dam during spring 2006. The dashed lines in plots are the 1:1 line.

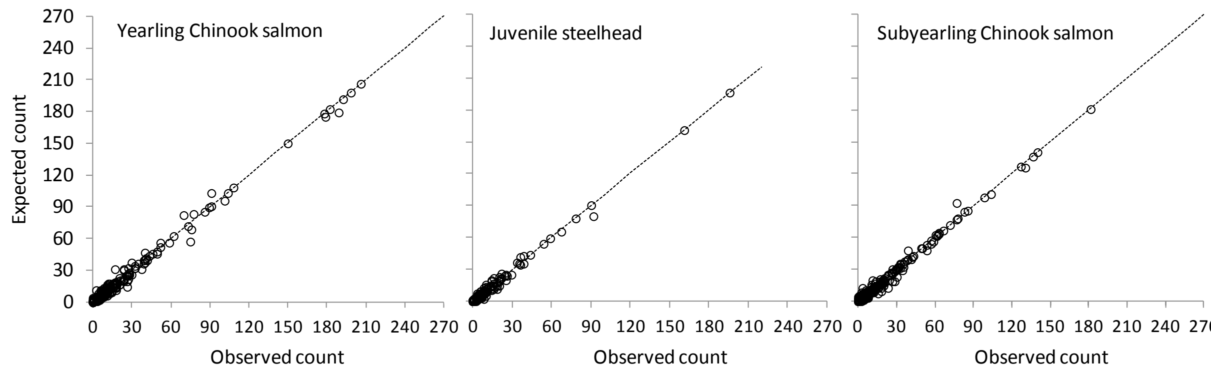

Figure D2. Plots showing observed versus expected counts for the route-specific survival model of passage and survival of yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon at McNary Dam during 2007. The dashed lines in plots are the 1:1 line.

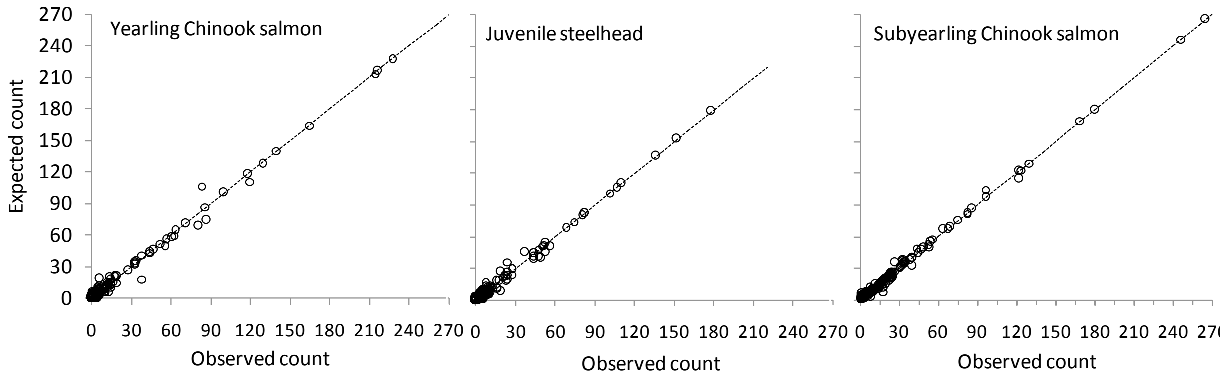

Figure D3. Plots showing observed versus expected counts for the route-specific survival model of passage and survival of yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon at McNary Dam during 2008. The dashed lines in plots are the 1:1 line.

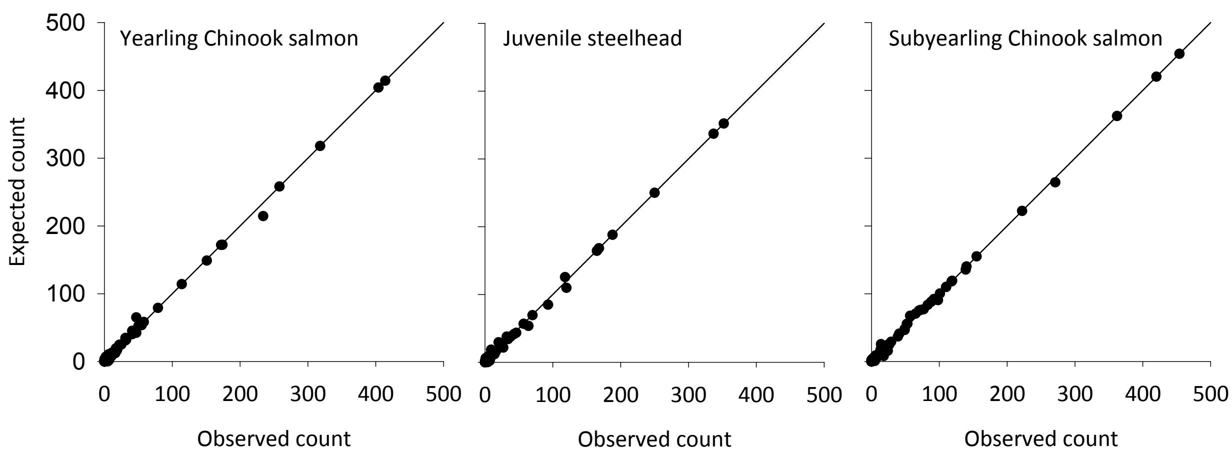

Figure D4. Plots showing observed versus expected counts for the route-specific survival model of passage and survival of yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon at McNary Dam during 2009. The dashed lines in plots are the 1:1 line.

Appendix E. Goodness-of-Fit Model Results for the Route-Specific Survival Model Used for Mid-Columbia River Released Fish Passing McNary Dam, 2006–09.

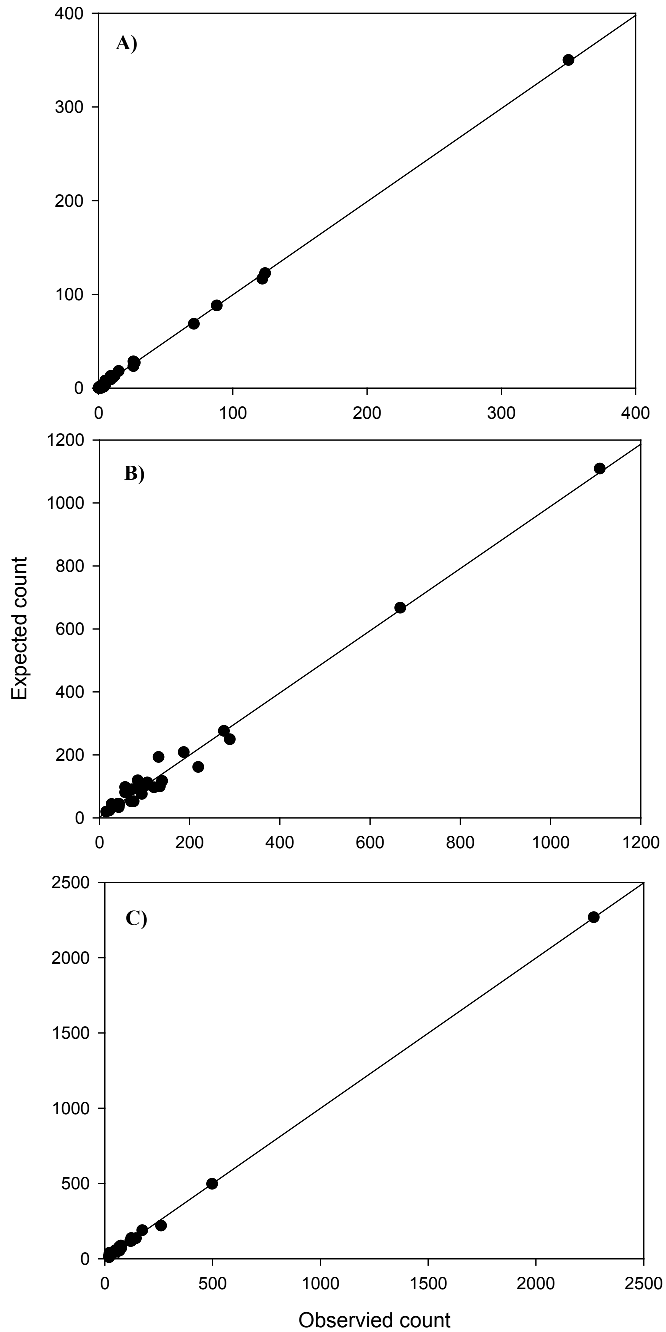

Figure E1. Graphs of observed versus expected counts for the route-specific survival model of passage and survival of yearling Chinook salmon (A), sockeye salmon (B), and juvenile steelhead (C), at McNary Dam for fish released in the Mid-Columbia River during spring 2006. The lines in plots are the 1:1 line.

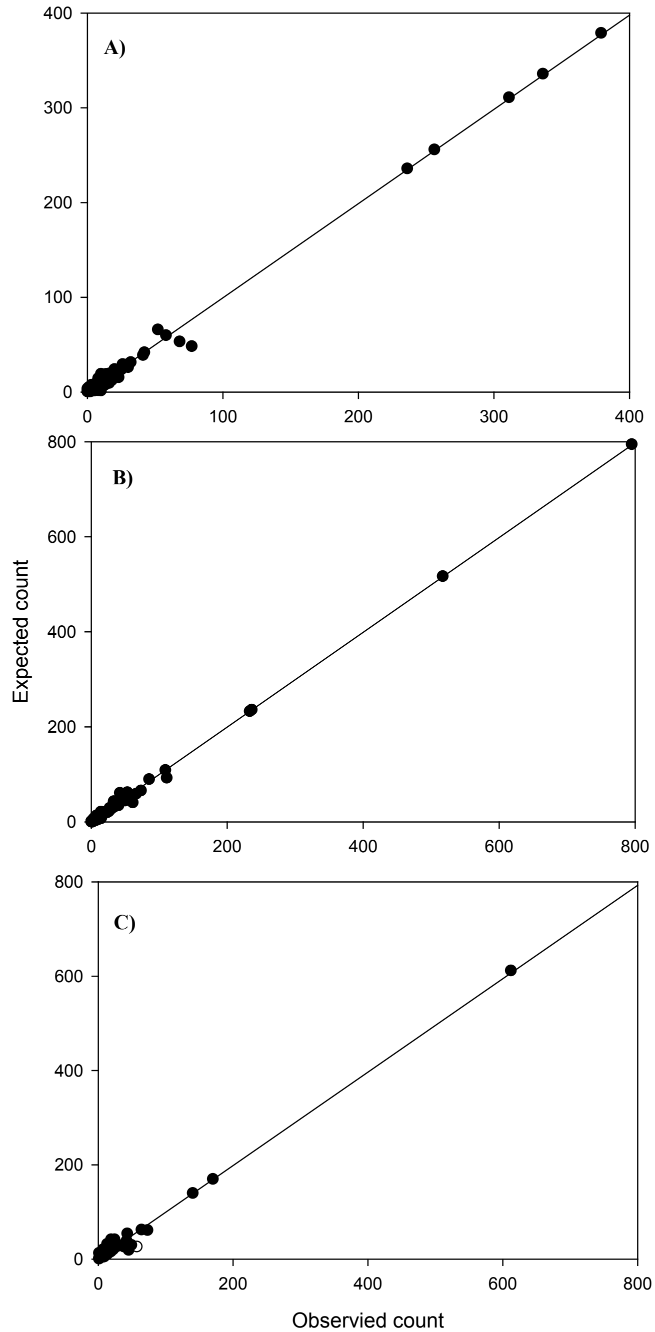

Figure E2. Graphs of observed versus expected counts for the route-specific survival model of passage and survival of yearling Chinook salmon (A), sockeye salmon (B), and juvenile steelhead (C), at McNary Dam for fish released in the Mid-Columbia River during spring 2007. The lines in plots are the 1:1 line.

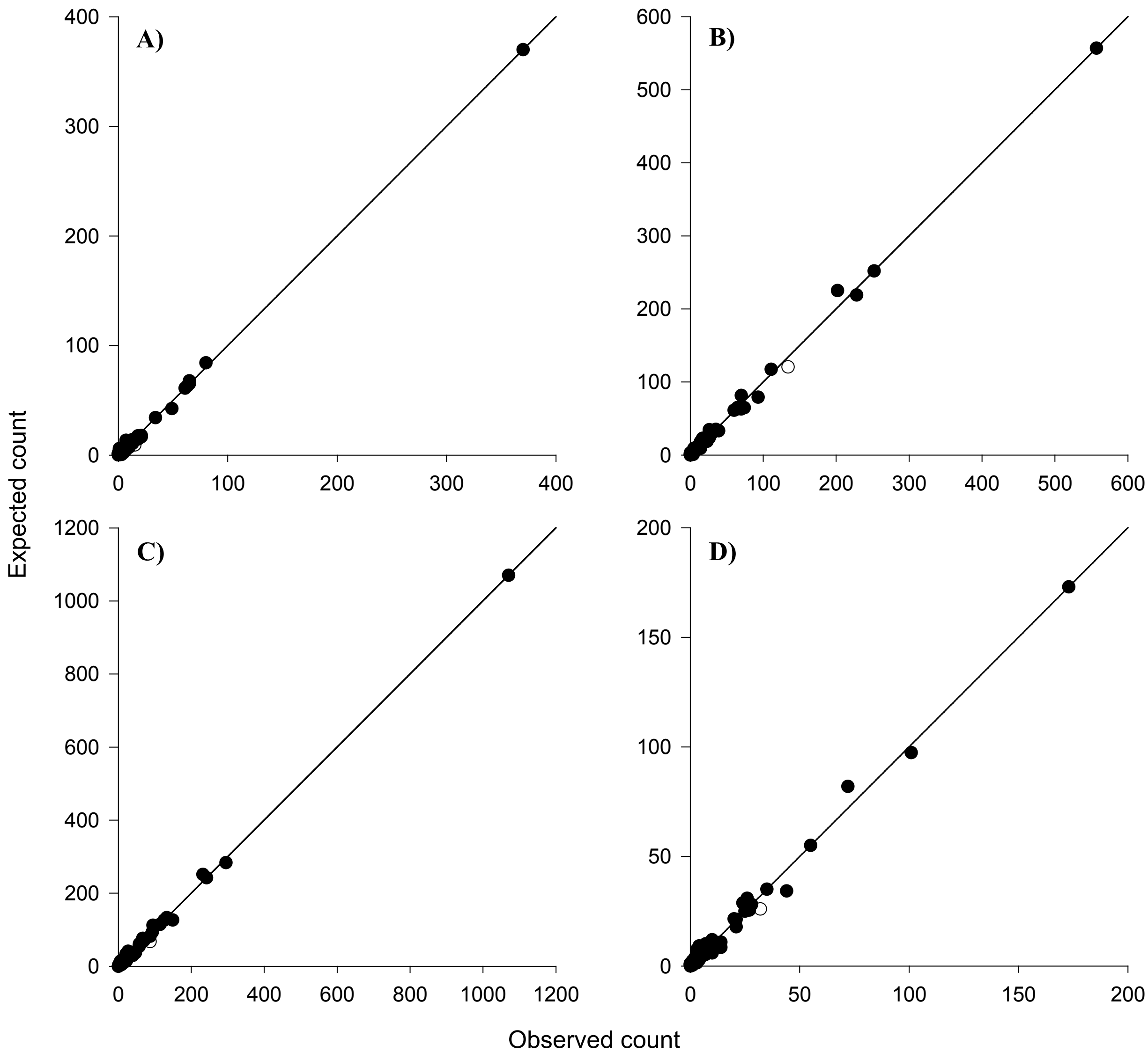

Figure E3. Graphs of observed versus expected counts for the route-specific survival model of passage and survival of yearling Chinook salmon (A), sockeye salmon (B), juvenile steelhead (C), and juvenile steelhead also implanted with a PIT-tag allowing use of a route-specific model with 5 routes (D), at McNary Dam for fish released in the Mid-Columbia River during spring 2008. The lines in plots are the 1:1 line.

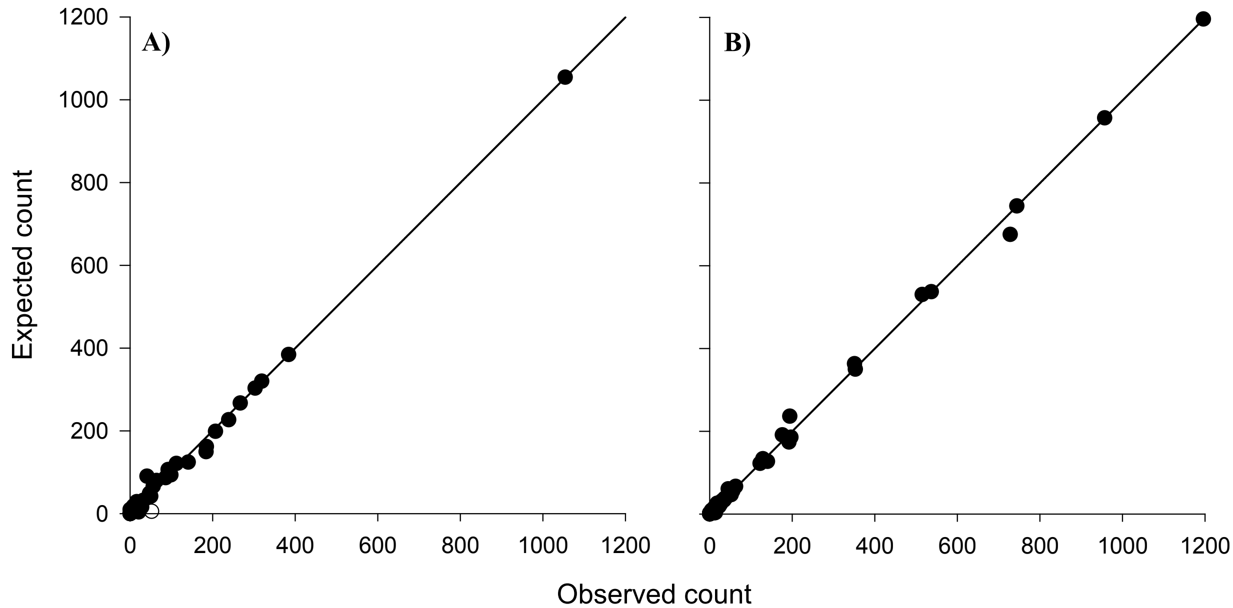

Figure E4. Graphs of observed versus expected counts for the route-specific survival model of passage and survival of juvenile steelhead (A) and sockeye salmon (B), at McNary Dam for fish released in the Mid-Columbia River during spring 2009. The lines in plots are the 1:1 line.

Appendix F. Tag Life Studies for Columbia River and Mid-Columbia River Released Fish, 2006–09.

Introduction

Tag life studies were conducted to test the assumption of the survival model that all tags are correctly identified and detections are not lost during the study due to tag failure. In the case of acoustic telemetry, when a transmitter fails the detections is lost. Significant premature failure of transmitters can negatively bias survival estimates, since survival models will interpret tag failure as mortality. However, if the rate of tag failure is known, survival estimates can be adjusted to correct for tag failure (Townsend and others, 2006; Cowen and Schwartz, 2005). Therefore, it is important to conduct a tag life study to assess the potential of introducing bias into the survival model due to tag failure. If a tag life study is not conducted, there is little recourse for accurately adjusting survival estimates after conducting a study and finding that tags failed prematurely. Premature tag failure may occur through a number of mechanisms including batch-specific manufacturer defects or long travel times of fish due to low flows. Thus, it is important to conduct a tag life study using a random sub-sample of transmitters that will be implanted in fish and test their performance under ambient field conditions during the study period. We used the methods of Townsend and others (2006) to achieve the following goals of the tag life study 1) to estimate the probability that a tag was alive at any point in time after it was turned on, 2) to estimate the probability of tags being in the study area at any given point in time after release, and 3) to estimate the average probability of a tag being alive when passing telemetry arrays used for survival analysis. Given this information, we then determined whether the tag failure rate was high enough to warrant correction of survival estimates.

Methods

The tag life studies in 2006–09 were conducted to estimate the tag life of transmitters implanted in yearling Chinook salmon, juvenile steelhead, sockeye salmon, and subyearling Chinook salmon during passage and survival studies in the Mid-Columbia River and at McNary Dam on the Columbia River. Studies in the Mid-Columbia River were conducted by Grant and Chelan County Public Utility Districts (PUDs) and studies at McNary Dam were conducted by USGS. A random sample of about 50–100 tags per tag type were evaluated for life expectancy during each study season. We received the tag life data and then estimated the probability of a tag being alive at any given point in time. The lifetime of each tag was calculated as the elapsed time between the time a tag was turned on and the time that the last detection was recorded by the data logging receiver. We then fit a survival distribution function to the tag life data to estimate the probability of a tag operating for a given amount of time. Although many forms of survival distribution functions can be fit to this data, we chose to use the Gompertz distribution (Elandt-Johnson and Johnson, 1980; Townsend and others, 2006) for Mid-Columbia and Hat Rock released fish in 2006 and 2007 and for Hat Rock release fish in 2008 and 2009. For 2008 and 2009 Mid-Columbia released fish, the Kaplan-Meier distribution was used because it better fit the data. The Gompertz survival distribution function takes the form:

$$S(t) = e^{\frac{\beta}{\alpha}\left(1-e^{\alpha t}\right)} \qquad \text{(F1)}$$

where $S(t)$ is the probability of a tag surviving to time t, and α and β are parameters to be estimated by fitting the model to the tag life data. We used nonlinear least squares methods to fit the Gompertz survival distribution function to the empirical tag survival data. The empirical survival distribution function is simply the proportion of tags surviving to time *t*.

The Kaplan-Meier survival distribution function takes the form:

$$S(t) = \Pr\{T > t\} \tag{F2}$$

where *S(t)* is the probability of a tag surviving to time *t*. We used maximum likelihood methods to fit the Kaplan-Meier survival distribution function to the empirical survival distribution function. The empirical survival distribution function is simply the proportion of tags surviving to time *t*.

The probability that a tag is alive when it arrives at a detection array is dependent on the travel time of the tag to each detection array used in the survival analysis. For the route-specific survival model, the travel times of interest are from time of release to the time of detection at McNary Dam, from time of release to the time of detection at first downstream gate, and from the time of release to the time of first detection at any one of the remaining downstream arrays used for survival analysis. In addition to fish travel time, the travel time of the tag must include all elapsed time that the transmitter was operating prior to fish release. Therefore the duration of time from activation to release was calculated and added to the travel time of fish to each detection array. We then plotted the empirical cumulative travel time distribution, which is simply the proportion of fish arriving at a given detection array at time *t*, against the survival distribution function to understand whether most fish passed the detection arrays prior to tag failure.

To quantify the rate of tag failure we calculated the average probability that the tag was operational for the ith release group to the jth detection array (Townsend and others, 2006):

$$\hat{P}(L_{ij}) = \frac{1}{k_{ij}} \sum_{x=1}^{k_{ij}} \hat{S}(t_{ijx}) \tag{F3}$$

where $\hat{P}(L_{ij})$ = average probability that a tag is alive at the *j*th detection array from the *i*th release group.

$\hat{S}(h_{ijx})$ = the estimated probability that a tag is alive at time t_{ijx} for the x^{th} fish arriving at the *j*th detection array for the *i*th release group. $\hat{S}(h_{ijx})$ is calculated simply by plugging into the survival distribution function the travel time of each tag to each detection array.

k_{ij} = the total number of fish detected at the *j*th detection array for the *i*th release group.

Results and Discussion—Columbia River Fish

Tag life for each model of tag varied by year and species of interest at McNary Dam. The tag life data for model 795-E transmitters used in spring fish ranged between 8.1–34.5 days in 2006, 6.6–40.6 in 2007, 9.8–26.7 days in 2008, and for model 795-LE from 1.0 to 54.8 days in 2009 (table F1). The life-expectancy for transmitters used in subyearling Chinook salmon ranged 6.7–16.6 days in 2006 (model 795-M), 8.4–16.1 days in 2007 (model 795-M), 2.2–16.7 days in 2008 (model 795-Ss), 5.0–16.8 days in 2008 (model 795-Se) and 2.1 to 31.7 days in 2009 (model 795-LM). The mean operational life of model 795-E transmitters was 11.7–20.2 days depending on year, while the mean for model 795-LE was 28.2 days. The mean operational life for summer transmitters was 12.9–23.6 days, depending on year and model.

Table F1. Descriptive statistics of life expectancy in days for transmitters released in the Columbia River used in yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon during 2006–09 at McNary Dam.

Year	Tag type	Number of tags	Mean tag life	Standard deviation	Minimum tag life	Maximum tag life
Yearling Chinook salmon						
2006	795-E	50	12.5	2.15	8.1	18.3
2007	795-E	49	20.2	6.21	6.6	40.6
2008	795-E	100	18.3	2.95	9.8	26.7
2009	795-LE	100	28.2	13.10	1.0	54.8
Juvenile steelhead						
2006	795-E	50	16.3	4.17	12.4	34.5
2007	795-E	49	11.7	2.02	7.3	16.8
2008	795-E	100	18.3	2.95	9.8	26.7
2009	795-LE	100	28.2	13.10	1.0	54.8
Subyearling Chinook salmon						
2006	795-M	50	11.9	1.85	6.7	16.6
2007	795-M	50	13.7	1.32	8.4	16.1
2008	795-Ss	47	13.1	3.49	2.2	16.7
2008	795-Se	25	12.9	3.24	5.0	16.8
2009	795-LM	50	23.6	5.34	2.1	31.7

By comparing the survival distribution function to the cumulative travel time distributions of the transmitters, we found that nearly all transmitters passed the detection arrays at the dam before tag failure became substantial and that most tagged fish arrived at downstream survival arrays before there was substantial tag failure. Tag failure was less than one percent for all species released detected at McNary Dam from Hat Rock State Park release site (<0.45 percent, table F2). Across all years, tag failure was highest for yearling Chinook salmon and juvenile steelhead (1.69 percent) at the downstream arrays regardless of release site in 2009. For subyearling Chinook salmon, tag failure was highest in 2009 and in 2008 with the transmitter model 795-Se, although less than 0.26 percent.

Townsend and others (2006) found that adjusted survival estimates changed very little from the unadjusted estimate when the probability of a tag being operational at downstream detection arrays was high (>98). Cowen and Schwarz (2005) found that survival estimates that do not account for tag failure have potential to be biased, especially when failure rates exceed 10 percent. Our tag failure rates were between 1–2 percent for all fish so we feel that correcting the estimates using the tag life data would be inconsequential.

Table F2. Mean probability of transmitters released in the Columbia River being operational [$\hat{P}(L_{ij})$] when passing telemetry detection sites used in the survival study conducted at McNary Dam, 2006–09.

Year	Detection site	Mean	SD
	Yearling Chinook salmon		
2006	Hat Rock State Park release to McNary Dam	0.9981	0.0046
	Hat Rock State Park release to downstream arrays	0.9942	0.0258
	Control release site to downstream arrays	0.9978	0.0031
2007	Hat Rock State Park release to McNary Dam	0.9955	0.0029
	Hat Rock State Park release to downstream arrays	0.9902	0.0083
	Control release site to downstream arrays	0.9927	0.0059
2008	Hat Rock State Park release to McNary Dam	0.9985	0.0284
	Hat Rock State Park release to downstream arrays	0.9987	0.0036
	Control release site to downstream arrays	0.9993	0.0025
2009	Hat Rock State Park release to McNary Dam	0.9986	0.0133
	Hat Rock State Park release to downstream arrays	0.9831	0.0071
	Control release site to downstream arrays	0.9881	0.0045
	Juvenile steelhead		
2006	Hat Rock State Park release to McNary Dam	0.9991	0.0080
	Hat Rock State Park release to downstream arrays	0.9995	0.0006
	Control release site to downstream arrays	NA	
2007	Hat Rock State Park release to McNary Dam	0.9989	0.0013
	Hat Rock State Park release to downstream arrays	0.9960	0.0139
	Control release site to downstream arrays	NA	
2008	Hat Rock State Park release to McNary Dam	0.9985	0.0284
	Hat Rock State Park release to downstream arrays	0.9987	0.0036
	Control release site to downstream arrays	0.9993	0.0025
2009	Hat Rock State Park release to McNary Dam	0.9986	0.0133
	Hat Rock State Park release to downstream arrays	0.9831	0.0071
	Control release site to downstream arrays	0.9881	0.0045
	Subyearling Chinook salmon		
2006	Hat Rock State Park release to McNary Dam	0.9994	0.0042
	Hat Rock State Park release to downstream arrays	0.9989	0.0072
	Control release site to downstream arrays	0.9997	0.0004
2007	Hat Rock State Park release to McNary Dam	1.0000	0.0001
	Hat Rock State Park release to downstream arrays	0.9999	0.0010
	Control release site to downstream arrays	1.0000	0.0000
2008 model 795-Ss	Hat Rock State Park release to McNary Dam	0.9989	0.0140
	Hat Rock State Park release to downstream arrays	0.9990	0.0122
	Control release site to downstream arrays	0.9998	0.0001
2008 model 795-Se	Hat Rock State Park release to McNary Dam	0.9985	0.0039
	Hat Rock State Park release to downstream arrays	0.9975	0.0074
	Control release site to downstream arrays	0.9986	0.0034
2009	Hat Rock State Park release to McNary Dam	0.9987	0.0083
	Hat Rock State Park release to downstream arrays	0.9974	0.0015
	Control release site to downstream arrays	0.9981	0.0013

The tag life data for model 795-E transmitters ranged between 2.3–48.6 days in 2006, 10.1–33.5 in 2007, 4.3–42.6 days in 2008, and from 6.0 to 49.0 days in 2009 (table F3). The life-expectancy for model 795-M transmitters ranged between 9.2–18.5 days in 2006, 9.5–18.0 days in 2007, 3.5–19.5 days in 2008, and 4.9 to 30.5 days in 2009. The mean operational life of model 795-E transmitters was 20.9–26.4 days, depending on year, excluding the 795-E tag with the faster pulse rate (mean life=10.9 days) used in 2006 for yearling Chinook salmon (table F3). The higher ping rate (1000–1500 ms) for the yearling Chinook salmon transmitter in 2006 decreased the average tag life considerably compared to the juvenile steelhead tag with a ping rate range of 5000–8000 ms. The mean operational life for model 795-M transmitters was 15.0–19.5 days, depending on year.

Table F3. Descriptive statistics of life expectancy in days for model 795-E transmitters, used in yearling Chinook salmon and juvenile steelhead, and model 795-M transmitters, used in sockeye salmon during 2006–09 for fish released in the Mid-Columbia River.

Year	Tag type	Number of tags	Mean tag life	Standard deviation	Minimum tag life	Maximum tag life
2006	795-E[1]	49	10.9	3.1	2.3	23.4
2006	795-E[2]	99	24.9	7.7	3.1	48.6
2006	795-M	50	15.0	2.1	9.2	18.5
2007	795-E	44	21.2	3.7	10.1	33.5
2007	795-M	42	15.4	1.8	9.5	18.0
2008	795-E	100	20.9	5.2	4.3	42.6
2008	795-M	51	15.7	3.7	3.5	19.5
2009	795-E	50	26.4	7.2	6.0	49.0
2009	795-M	107	19.5	4.9	4.9	30.5

[1]Pulse rate of tag was 1000–1500 ms.
[2]Pulse rate of tag was 5000–8000 ms.

By comparing the survival distribution function to the cumulative travel time distributions of the transmitters, we found that nearly all transmitters passed the dam detection arrays before tag failure became substantial and that most tagged fish arrived at downstream survival arrays before there was substantial tag failure (table F4). During 2006, yearling Chinook salmon had the highest tag failure rate at the dam (9.7 percent) and at the downstream gates (11.5 percent) while juvenile steelhead and sockeye salmon had a tag failure rate of 3.9 percent or less at the dam and less than 5.4 percent at the downstream gates for all release groups. Tag failure rates during 2007, for model 795-E tags ranged from 0.2–4.4 percent at the downstream gates and from 1.5–4.9 percent for tag model 795-M. Tag failure rates in 2008 were highest for model 795-M tags (7.3–7.6 percent) but only 1.1–3.0 percent for 795-E tags. Tag failure rates for 795-M tags improved substantially in 2009, to only 2.2–2.9 percent, similar to the failure rate of 795-E tags (2.2–2.7 percent).

Townsend and others (2006) found that adjusted survival estimates (0.9387) changed very little from the unadjusted estimate (0.9339) when the probability of a tag being operational at downstream detection arrays was high (>98). Cowen and Schwarz (2005) found that survival estimates that do not account for tag failure have potential to be biased, especially when failure rates exceed 10 percent. Our tag failure rates were between 1–5 percent for all fish except sockeye salmon in 2008 (which still had a tag failure rate well below 10 percent). We feel that the variance was high enough for uncorrected survival estimates that correcting the variance using the tag life data would be inconsequential. We feel that this is likely true even for the high probability of tag failure occurring for the 2008 sockeye salmon since this was a relatively smaller data set and the variance about these estimates is relatively high.

Table F4. Mean probability of transmitters released in the Mid-Columbia River being operational [$\hat{P}(L_{ij})$] when passing telemetry detection sites used in the survival study conducted at McNary Dam, 2006–09.

[Release site: PR, Priest Rapids Dam; RC, Rocky Reach Collector; RI, Rock Island Dam; WA, Wanapum Dam; WE, Wells Dam; Release sites were combined for analysis in 2008 and 2009. SD, standard deviation]

Year	Release site	Detection site	Mean	SD
		Yearling Chinook salmon		
2006	WA	McNary Dam	0.903	0.087
	WA	All detection sites downstream of McNary Dam	0.885	0.103
2007	RC	McNary Dam	0.975	0.045
	RC	All detection sites downstream of McNary Dam	0.956	0.073
	RI	McNary Dam	0.981	0.036
	RI	All detection sites downstream of McNary Dam	0.960	0.078
	WA	McNary Dam	0.998	0.002
	WA	All detection sites downstream of McNary Dam	0.996	0.007
2008	Combined	McNary Dam	0.977	0.053
	Combined	First detection site downstream of McNary Dam	0.977	0.040
	Combined	Second, 3rd, and 4th detection sites downstream of McNary Dam	0.970	0.050
		Juvenile steelhead		
2006	WE	McNary Dam	0.961	0.032
	WE	All detection sites downstream of McNary Dam	0.949	0.051
	RC	McNary Dam	0.973	0.023
	RC	All detection sites downstream of McNary Dam	0.961	0.050
	RI	McNary Dam	0.968	0.035
	RI	All detection sites downstream of McNary Dam	0.957	0.049
	WA	McNary Dam	0.984	0.010
	WA	All detection sites downstream of McNary Dam	0.977	0.023
	PR	McNary Dam	0.991	0.004
	PR	All detection sites downstream of McNary Dam	0.988	0.009
2007	RI	McNary Dam	0.989	0.028
	RI	All detection sites downstream of McNary Dam	0.977	0.083
2008	Combined	McNary Dam	0.989	0.019
	Combined	First detection site downstream of McNary Dam	0.989	0.017
	Combined	Second, 3rd, and 4th detection sites downstream of McNary Dam	0.984	0.037
2009	Combined	McNary Dam	0.978	0.029
	Combined	First detection site downstream of McNary Dam	0.978	0.018
	Combined	Second, 3rd, and 4th detection sites downstream of McNary Dam	0.973	0.042
		Sockeye salmon		
2006	WE	McNary Dam	0.991	0.004
	WE	All detection sites downstream of McNary Dam	0.988	0.009
	RC	McNary Dam	0.962	0.047
	RC	All detection sites downstream of McNary Dam	0.946	0.084
	RI	McNary Dam	0.975	0.059
	RI	All detection sites downstream of McNary Dam	0.967	0.060
2007	WE	McNary Dam	0.964	0.125
	WE	All detection sites downstream of McNary Dam	0.951	0.126
	RC	McNary Dam	0.985	0.066
	RC	All detection sites downstream of McNary Dam	0.973	0.078
2008	Combined	McNary Dam	0.927	0.101
	Combined	First detection site downstream of McNary Dam	0.924	0.101
	Combined	Second, 3rd, and 4th detection sites downstream of McNary Dam	0.926	0.049
2009	Combined	McNary Dam	0.978	0.021
	Combined	First detection site downstream of McNary Dam	0.975	0.025
	Combined	Second, 3rd, and 4th detection sites downstream of McNary Dam	0.971	0.033

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