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In-Reservoir Behavior, Dam Passage, and Downstream Migration of Juvenile Chinook Salmon and Juvenile Steelhead from Detroit Reservoir and Dam to Portland, Oregon, February 2013–February 2014

Open–File Report 2015–1090

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

Cover: Photograph showing Detroit Dam forebay from the shore of Detroit Lake, Oregon.
Photograph by Scott Evans, U.S. Geological Survey, July 4, 2011.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Contents

Figures

Chapter 1

Tables

Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter per second (m/s)	3.281	foot per second (ft/s)
liter (L)	0.2642	gallon (gal)
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound, avoirdupois (lb

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Datums

Vertical coordinate information is referenced to National Geodetic Vertical Datum of 1929 (NGVD 29).

Elevation, as used in this report, refers to distance above the vertical datum.

In-Reservoir Behavior, Dam Passage, and Downstream Migration of Juvenile Chinook Salmon and Juvenile Steelhead from Detroit Reservoir and Dam to Portland, Oregon, February 2013–February 2014

Edited by John W. Beeman and Noah S. Adams

Abstract

In the second year of 2 years of study, the movements of juvenile spring Chinook salmon (*Oncorhynchus tshawytscha*) and juvenile summer steelhead (*Oncorhynchus mykiss*) through Detroit Reservoir, passing Detroit Dam, and migrating downstream to Portland, Oregon, were studied during a 1-year-long period beginning in February 2013. The primary purpose of the study was to provide empirical data to inform decisions about future alternatives for improving downstream passage of salmonids at Detroit Dam. A secondary purpose was to design and assess the performance of a system to detect juvenile salmonids implanted with acoustic transmitters migrating in the Willamette River. Inferences about fish migration were made from detections of juvenile fish of hatchery origin at least 95 millimeters in fork length surgically implanted with an acoustic transmitter and released during the spring (March–May) and fall (September–November) of 2013. Detection sites were placed throughout the reservoir, near the dam, and at two sites in the North Santiam River and at three sites in the Willamette River culminating at Portland, Oregon. We based most inferences on an analysis period up to the 90th percentile of tag life (68–78 days after release, depending on species and season), although a small number of fish passed after that period as late as April 8, 2014. Chinook salmon migrated from the tributaries of release to the reservoir in greater proportion than steelhead, particularly in the fall. The in-reservoir migration behaviors and dam passage of the two species were similar during the spring study, but during the fall study, few steelhead reached the reservoir and none passed the dam within the analysis period. Migrations in the reservoir were directed and non-random, except in the forebay. Depths of fish within 25 meters of the dam were deeper in the day than at night for Chinook salmon and similar in the day and night for steelhead; steelhead generally were at shallower depths than Chinook salmon. The primary factors affecting dam passage rates were seasonal dam operating conditions and diel period. Fish passage rates were much greater during the spring and summer than in the fall and winter, and the difference was attributed to the availability and use of the spillway near the top of the dam during the spring and summer. The flood-control purpose of the reservoir prevented spillway use during much of the fall and winter because of the low forebay elevation. Passage rates at night were greater than in the day during spring and summer (4.2 times) and during the fall and winter (14.9 times).

Fish length, dam discharge, and forebay elevation also affected dam passage rates. Travel times from Detroit Dam passage to the downstream sites were shorter during the fall and winter than during the spring and summer, and were less than a median of 8.68 days to Portland. The estimated survival in the 11 kilometers (km) between Detroit Dam and the Minto Dam forebay was lower than in the remaining 241 km to the Portland site. Estimated survival per 100 km in the free-flowing reach from Minto Dam to Portland was 0.675–0.836, depending on species and season, and was similar to other free-flowing rivers in the Western United States. The high probability of fish in the reservoir reaching the dam, the chance for repeated presence near the dam, the fish depths, and the factors known to affect passage rates suggest that a properly designed surface passage route could be a viable downstream passage alternative for juvenile Chinook salmon and steelhead at Detroit Dam.

As part of the evaluations conducted at Detroit Dam, we continued to refine and improve methods for monitoring fish movements in the Willamette River. The goal was to develop stable, cost-effective, long-term monitoring arrays suitable for detection of any Juvenile Salmon Acoustic Telemetry System (JSATS)-tagged fish in the Willamette River. These data then could be used to estimate timing, migration rates, and survival of JSATS-tagged fish from various studies in the Willamette River Basin. The challenge, however, is that acoustic telemetry generally performs poorly in shallow, turbulent water, like that found in the Willamette River. We successfully designed, deployed, and maintained a series of monitoring sites near the Oregon cities of Salem, Wilsonville, and Portland. In the spring, detection probabilities at these sites ranged from 0.900 to 1.000. In the fall, the detection probabilities decreased and ranged from 0.526 to 1.000. The lower detection probabilities, particularly at the Salem site (0.526), were owing to loss of data caused by abnormally high flows as well as the 2013 Federal government shutdown, which prevented us from servicing the equipment. The monitoring sites that we installed seem to be robust and enable the efficient use of acoustic-tagged fish for studies of migration or survival in the Willamette River and similar environments.

Chapter 1. Behavior and Dam Passage of Juvenile Chinook Salmon and Juvenile Steelhead at Detroit Reservoir and Dam, Oregon, February 2013–February 2014

By John W. Beeman, Hal C. Hansel, Amy C. Hansen, Scott D. Evans, Philip V. Haner, Tyson W. Hatton, Eric E. Kofoot, Jamie M. Sprando, and Collin D. Smith

Introduction

The U.S. Army Corps of Engineers (USACE) operates the Willamette Project (Project) in western Oregon, including a series of dams, revetments, and hatcheries. The primary purpose of the Project is flood control, but it also is operated to provide hydroelectricity, irrigation water, navigation, instream flows for wildlife, and recreation. The Project includes 13 dams, about 68 km of revetments, and several fish hatcheries. Detroit Dam and several other dams are located on tributaries of the Willamette River (fig. 1-1). The National Oceanic and Atmospheric Administration (2008) determined that the Project was jeopardizing the sustainability of anadromous fish stocks in the Willamette River Basin.

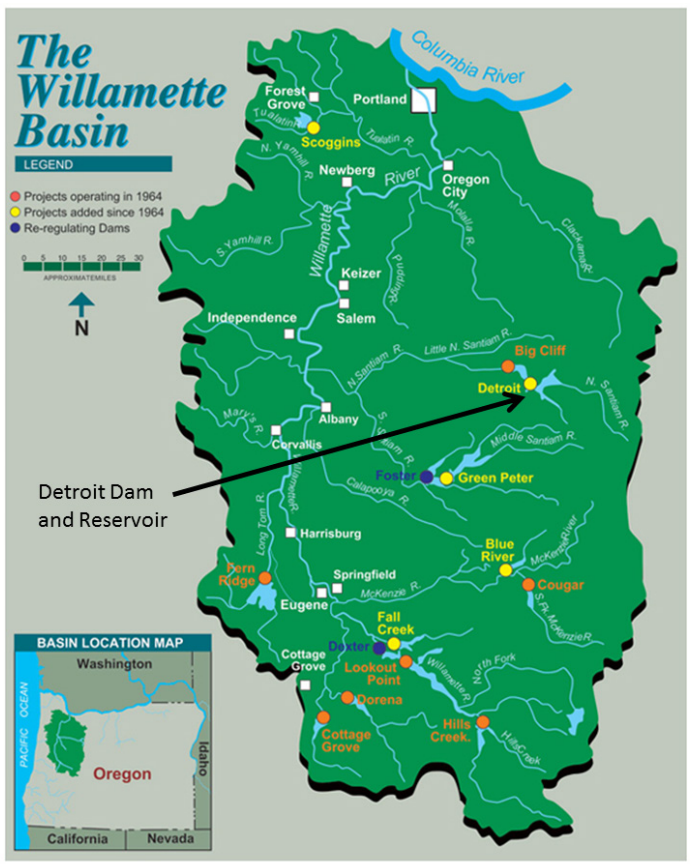

Figure 1-1. The Willamette River Basin showing dams and reservoirs of the Willamette Project, Oregon. Graphic from U.S. Army Corps of Engineers.

In 1953, the USACE constructed the Detroit Dam and Reservoir on the North Santiam River about 65 km east of Salem, Oregon. The primary purposes of the dam are flood control, power generation, navigation, and recreation. The dam has six spill bays, five regulating outlets, and two Francis turbines with a total hydraulic capacity of 5,340 ft^3/s and a generating capacity of 115 megawatts (fig. 1-2). The ceilings of the turbine intakes are at an elevation of 1,418.8 ft and the ceilings of the upper regulating outlet openings are at an elevation of 1,356.2 ft; 62.6 ft lower than the turbine intakes. The spillway ogee is at elevation 1,541.0 ft. Reservoir elevation normally ranges from 1,450.0 to 1,563.5 ft, with highest elevations in the summer and lowest elevations in the winter for flood control purposes. Fluctuations in discharge at Detroit Dam to meet power demand are re-regulated at Big Cliff Dam 4.2 km downstream.

Detroit Dam is operated in coordination with other dams in the Project. Flood control dams within the Project are filled during summer to benefit recreation and power generation and drawn down during the fall and winter to facilitate their flood-control purpose. Detroit Dam is scheduled as the first dam in the Project to fill during the spring and the last dam to be drawn down during the fall; refill normally begins on February 1. Site-specific rules also govern the use of the spillway and regulating outlets, depending on forebay elevation, such that the two routes rarely are used together. Additionally, to meet the demand for electricity and instream water temperatures and flows downstream, the powerhouse, spillway, and regulating outlets are operated singly, in various combinations, or not at all, resulting in a variety of dam operating conditions.

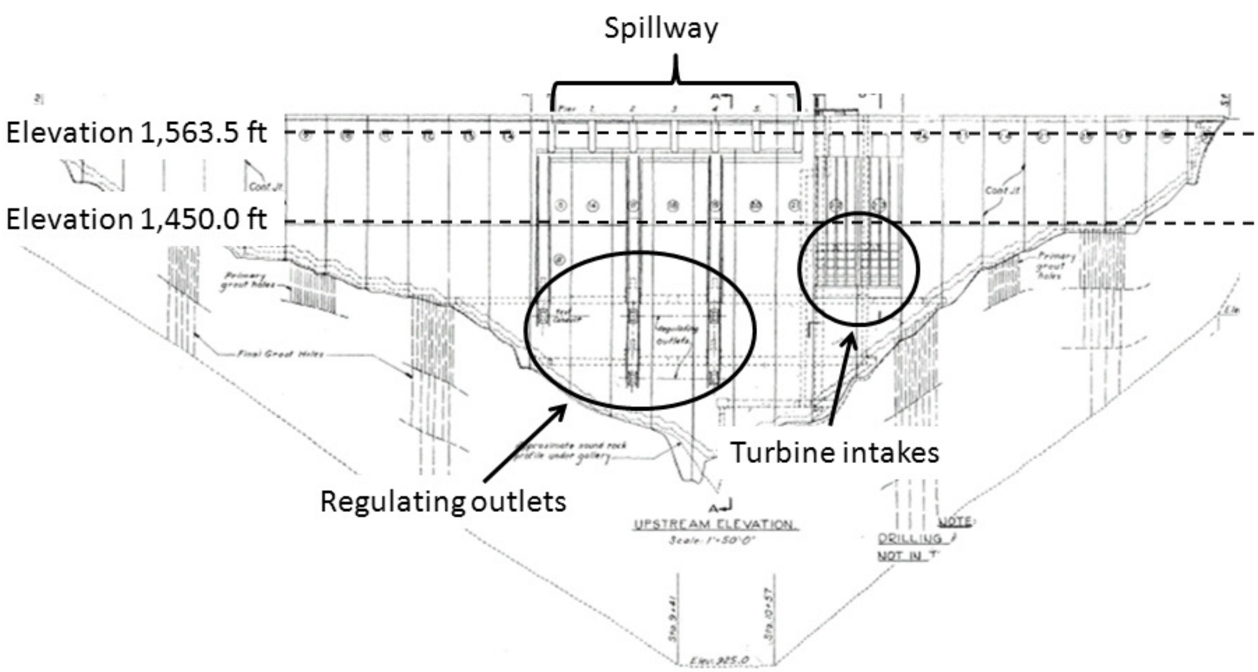

Figure 1-2. Elevation view of the upstream side of Detroit Dam showing outlet structures and elevations of full and minimum conservation pool. Modified from U.S. Army Corps of Engineers.

The 2008 Willamette Biological Opinion requires improvements to operations and structures to reduce impacts on Upper Willamette River (UWR) Chinook salmon (*Oncorhynchus tshawytscha*) and UWR steelhead (*Oncorhynchus mykiss*) (National Oceanic and Atmospheric Administration, 2008). The improvements include a requirement to mediate unseasonable water temperatures passed through the high-head dam by 2017 and to install fish passage facilities (or operational alternatives) at Detroit Dam by 2023. Among the alternatives designed to meet these mandates is a temperature control structure at the dam that also enables downstream fish passage. However, in the interim period, downstream passage of juvenile anadromous salmonids is to be achieved with the current configuration of the dam. Thus, there is a need for data about the locations and migration behaviors of juvenile anadromous salmonids to aid in the design of future passage facilities, as well as for data about factors that affect their dam passage rates using the existing configuration.

This report summarizes the second year of a 2-year study to quantify behavior of juvenile Chinook salmon and juvenile steelhead in the reservoir and near the dam (see Beeman and others, 2014a). The report also describes migration timing and survival of fish volitionally passing Detroit Dam using a series of sites terminating at the Willamette River in Portland, Oregon. The purpose of the study was to help understand the spatial and temporal movements of the fish and to quantify operational and biological factors affecting their dam passage rates with the current dam configuration. Fish implanted with acoustic transmitters with an expected life of about 2.5–6 months (depending on species, season, and release location) were the basis of inference. The study was designed to collect data from fish released in spring (March, April, and May) and fall (September, October, and November) 2013. This 2-year study is similar to a study conducted in Cougar Reservoir, another high-head dam in the Willamette River Basin (Beeman and others, 2013), and is part of a suite of research studies designed to collect information relative to the 2008 Willamette Biological Opinion.

Methods

Dam Operations and Environmental Conditions

Powerhouse discharge, regulating outlet discharge, spillway discharge, forebay elevation, and water temperature data were summarized for the 2013 study period to document the environmental conditions that juvenile salmonids experienced during the detection periods. Hourly powerhouse discharge, regulating outlet discharge, regulating outlet openings, spillway discharge, spill gate openings, and forebay elevation data were obtained from the USACE. Data were summarized using the hourly observations, but mean daily values were plotted to increase clarity in the plots. Water elevation data and fish depths are presented in feet and discharge is presented as cubic feet per second in accordance with the local convention. Hourly temperature data were obtained from the USACE Web site, http://www.nwd-wc.usace.army.mil/ftppub/water_quality/tempstrings. Diel periods were assigned using U.S. Naval civil twilight. Civil twilight for Detroit, Oregon, was obtained at http://www.usno.navy.mil/USNO/astronomical-applications.

Several variations of acoustic transmitters were used during the spring and fall tagging seasons. In the spring, we implanted 125 steelhead with transmitters left over from a study conducted by Pacific Northwest National Laboratory (PNNL) in 2011after changing the pulse rate interval (PRI) to 10 s (table 1-1). Another 104 steelhead were implanted with a transmitter with battery model 377 and a PRI of 6 s. We used tags with battery model 379 in steelhead in the fall and in all Chinook salmon. The expected battery life of the acoustic transmitters was 150 d, except for the tags used in Chinook salmon during the spring (90 d) and the tags used in the steelhead released into the reservoir in February (75 d). The acoustic tags were manufactured by Advanced Telemetry Systems (ATS, Isanti, Minnesota).

Table 1-1. Specifications of transmitters implanted into juvenile fish at Detroit Dam, spring and fall 2013.

[ATS, Advanced Telemetry Systems; d, days; mm, millimeters; PRI, pulse rate interval; s, seconds]

		Acoustic transmitter					
Season	Species implanted	Transmitter model	Battery model	Weight in air (grams)	Dimensions (length × width × height; mm)	PRI (s)	Expected life (d)
Spring	Steelhead	ATS SS3300	337	0.44	11.9 × 5.0 × 3.7	10	75
	Steelhead	ATS SS3300	377	0.58	12.8 × 7.3 × 4.0	6	150
	Chinook salmon	ATS SS3300	379	0.43	11.8 × 6.3 × 3.5	6	90
Fall	Both	ATS SS3300	379	0.43	11.8 × 6.3 × 3.6	10	150

Fish Capture, Handling, Tagging, and Release

All test fish were of hatchery origin. The fish were yearling (used in the spring) and subyearling (used in the fall) juvenile hatchery Chinook salmon and yearling juvenile summer hatchery steelhead, hereafter referred to as “Chinook salmon” and “steelhead,” respectively. The Chinook salmon were reared at the Fish Performance and Genetics Laboratory (FPGL) in Corvallis, Oregon, and the steelhead were reared at Willamette Hatchery in Oakridge, Oregon.

All fish were delivered and held at Marion Forks Hatchery (MFH) prior to tagging. Chinook salmon were delivered on a regular basis by FPGL staff. Deliveries of Chinook salmon to MFH included 622 during the spring (March–May) and 789 during the fall (September–November). Chinook salmon were sorted prior to transportation to MFH to meet a fork length requirement of 95–180 mm. The steelhead were transported from the Willamette Hatchery on February 13 and August 27, 2013, and held at MFH. A total of 360 and 743 steelhead were sorted to meet a fork length requirement of 95–180 mm in February and August, respectively, at the Willamette Fish Hatchery and transported in an insulated 1,556-L plastic tank. All fish at were held outdoors at MFH in circular ponds supplied with continuously flowing river water. The ponds were 7.3 m in diameter and 0.65 m deep, and held 27,750 L of river water. Chinook salmon were held 12–28 d and steelhead were held 13–97 d prior to tagging, depending on fish deliveries and use.

Water temperature and dissolved oxygen in the transport tank were monitored throughout the transport to MFH for both species. Chinook salmon were tempered by FPGL personnel during transport because the water was warmer at FPGL than at the MFH. Tempering consisted of placing blocks of ice made from well water into the transport tank if the difference between temperatures was more than 6 °C. Personnel stopped periodically to monitor water temperature and dissolved oxygen throughout the 3 h of transport time. Similar transport methods were followed by U.S. Geological Survey (USGS) staff for the steelhead transport. Additional tempering was performed at MFH if the temperatures differed by more than 2 °C at the time of arrival.

Fish were moved to 264-L pre-tag holding tanks on 1–3 d of every other week in the spring and fall periods and denied food in preparation for tagging. Pre-tag holding times were within the 18–30 h specification of the Surgical Protocols Steering Committee (2011) in all but two instances during the fall study period when fish were tagged prior to the minimum 18 h holding time.

Transmitters were surgically implanted using the protocol specified by the Surgical Protocols Steering Committee (2011). Fish were considered suitable for tagging if they were free of major injuries; had no external signs of gas bubble trauma, major fin damage, or fungus; were less than or equal to 20 percent descaled; had no visible signs of disease or deformities; and were not previously tagged other than with a coded-wire-tag. The fish were anesthetized using buffered tricane methanesulfonate (MS-222, Argent Chemical Laboratories, Redmond, Washington). The MS-222 concentration used varied with species and water temperature. The concentration range for Chinook salmon was 100–170 mg/L, whereas the concentration range for steelhead was 90–150 mg/L depending on the water temperature. Length and weight of each anesthetized fish were recorded immediately prior to the surgery. All weighing, measuring, and containment equipment were treated with a 0.25 mL/L concentration of Stress Coat® (Aquarium Pharmaceuticals, Inc., Chalfont, Pennsylvania) to reduce handling-related stress to the fish by electrolyte loss. Fish were placed in a 19-L perforated recovery bucket filled with 7 L of river water immediately after surgery. Dissolved oxygen concentrations were maintained between 80 and 110 percent of saturation during recovery. The mean density in a recovery bucket was 17.5 g/L (range 3.2–28.2 g/L) for Chinook salmon and 22.9 g/L (range 5.4–36.0 g/L) for steelhead, and we did not exceed four fish in a recovery bucket for either species. Water quality (temperature, dissolved oxygen, total dissolved gas) was monitored in holding buckets, transport tanks, the recovery pond, and at the release sites. Fish in the recovery buckets were observed periodically during the first 10 min after surgery to ensure that they recovered from anesthesia. Recovery buckets, fitted with bicycle inner tubes near their tops for flotation, were then fitted with lids and floated in an outdoor concrete pond with flowing river water where fish were held prior to release with access to air to adjust their buoyancy.

Tagged fish were released after an 18–36 h recovery period into either Detroit Reservoir or into the Breitenbush and North Santiam Rivers, the two primary tributaries feeding the reservoir. Post-tag holding times were within the 18–36 h specification of the Surgical Protocols Steering Committee (2011) in all but one instance during the spring study period where steelhead were released prior to the 18 h holding time. The 125 steelhead tagged and released in February were released into Detroit Reservoir downstream of Piety Island, hereafter referred to as “reservoir.” The remaining steelhead and all Chinook salmon were released into the North Santiam or Breitenbush Rivers, hereafter referred to as “tributaries.” For the release, all recovery buckets were removed from the recovery pond, inspected for mortalities, and transferred into an insulated 1,556-L plastic tank filled with river water. The fish were driven either 22.5 km to the North Santiam River release site or 29.9 km to the Breitenbush River release site. The distances of the release sites upstream of Detroit Reservoir were about 3.99 and 2.78 rkm, for the North Santiam River and Breitenbush River release sites, respectively. Fish were released near the center of the river at the North Santiam River site by lowering buckets from a bridge using a rope-pulley system. Fish released at the Breitenbush River site were carried down to the edge of the river and released from the shoreline. The reservoir-released steelhead were driven 30.3 km to the Mongold boat ramp, transferred in 5-gal buckets to a boat, motored to the downstream area of Piety Island, and then released in the center of the reservoir. Water-quality measurements were recorded to ensure that the water temperature difference between the recovery buckets and the release site was not greater than 2 °C, which would have required tempering; tempering was rarely required. All fish were released by partially submerging the buckets in the river and inverting them.

Acoustic Telemetry Detection Systems

Signals from acoustic transmitters were detected using autonomous and cabled types of Juvenile Salmon Acoustic Telemetry System (JSATS) hydrophone systems provided by the USACE. Acoustic signals from tagged fish in the reservoir from approximately the log boom in the upstream boundary of the dam forebay (array 6) to near the head of the reservoir at Piety Island (array 1) were detected using autonomous hydrophones spaced across the reservoir width at four locations (fig.1-3). Additionally, we deployed a single autonomous hydrophone each in the Kinney Creek and Blowout Creek arms of Detroit Reservoir. Two autonomous hydrophones were installed each at Big Cliff Dam and Minto Dam, 4.4 and 10.0 rkms downstream of Detroit Dam, respectively, to confirm fish passage at Detroit Dam. In 2011, we empirically determined in the east arm of Cougar Reservoir, Oregon, that 82 percent of the expected number of transmissions were detected at a range of 105 m, and 10 percent were detected at a range of 180 m (John Beeman, U.S. Geological Survey, unpub. data, 2011). Based on that data, the hydrophones were spaced about 100 m from shorelines and within 200 m of each other at a depth of about 33 m from the water surface along lines across the reservoir (hereafter referred to as “arrays”). Hydrophone depths were readjusted as necessary during bi-weekly visits to change batteries and download data. Hydrophones were deployed using methods similar to those described by Titzler and others (2010), except that burlap bags of sand were used as anchors. Twenty autonomous hydrophones, including one at Big Cliff Dam, were operational beginning on February 27, 2013. An additional autonomous hydrophone was added near the north shore at the array near Piety Island from April 23 to September 9, 2013, when reservoir water levels were sufficient to allow for installation. The two autonomous hydrophones at Minto Dam and a third hydrophone at Big Cliff Dam were installed on April 11, 2013. Data from autonomous hydrophones deployed in the Columbia River at rkm 126 were provided by PNNL on October 18, 2013. The Columbia River detection site was only in place during the migration of fish released in the spring (fig. 1-4). Sites in the Willamette River near Salem, Wilsonville, and Portland, Oregon, are described in chapter 2 of this report.

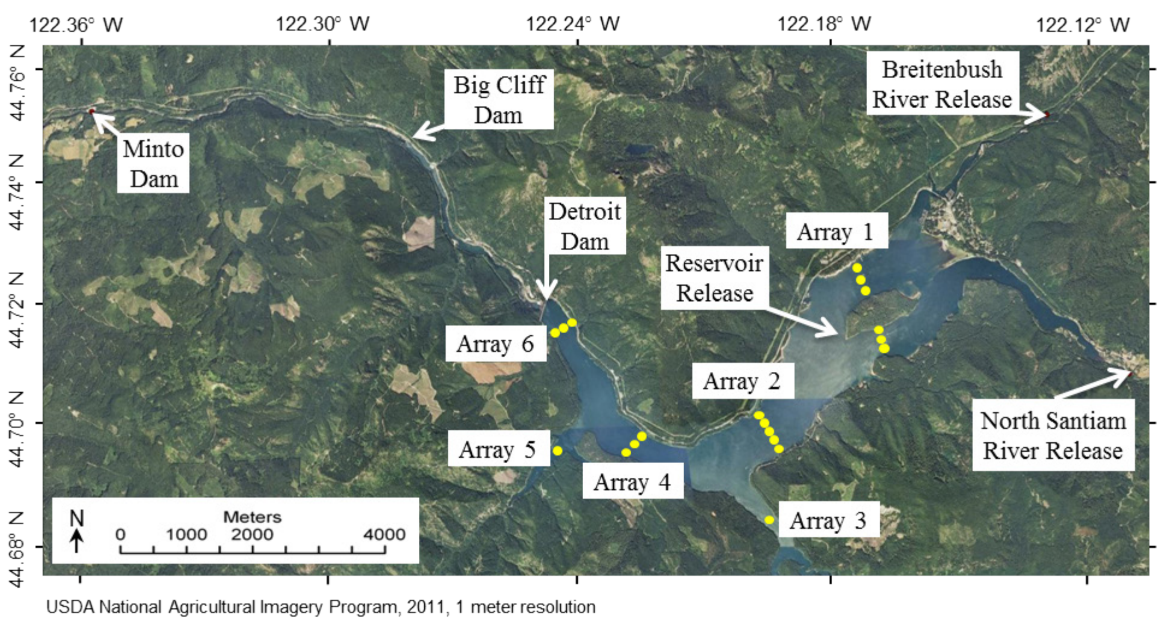

Figure 1-3. Locations of dams, juvenile fish release sites (arrows), and autonomous acoustic receivers (small circles) deployed in Detroit Reservoir and downstream on the North Santiam River, Oregon, 2013.

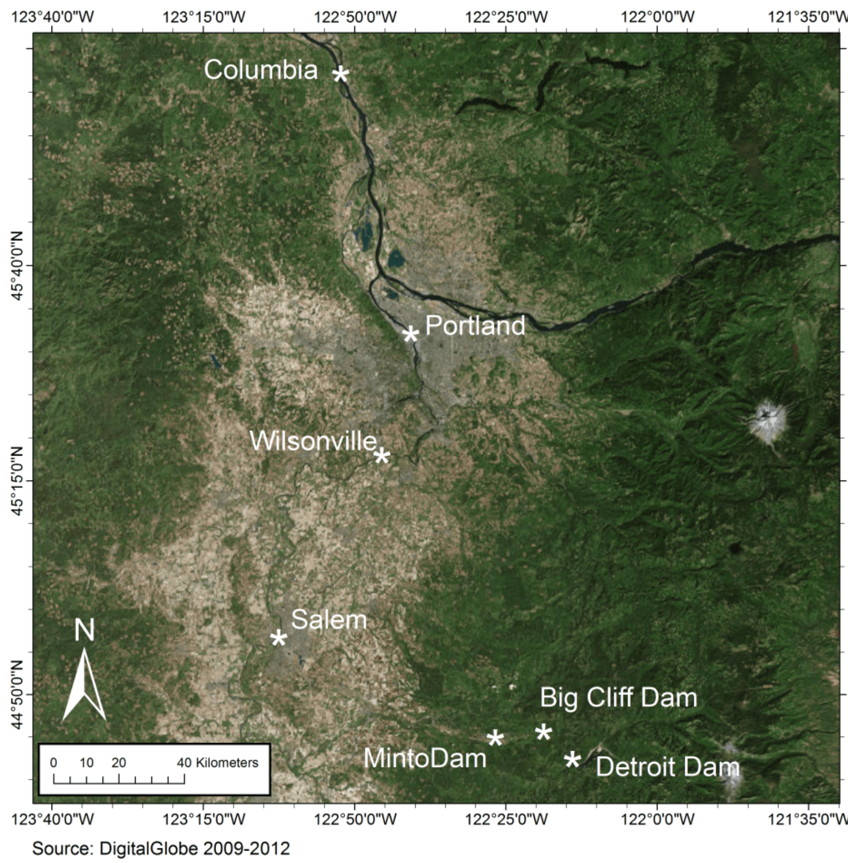

Figure 1-4. Locations of Detroit Dam, Oregon, and autonomous acoustic receiver sites used downstream for the 2013 study.

Acoustic signals from tagged fish near the dam were detected using five 4-hydrophone cabled systems linked to each other using a common clock. Each of these systems included four hydrophones connected with cables to a common computer. Each computer received its system time from a global positioning system (GPS) receiver (Meinberg GPS 170PCI, Meinberg Funkuhren GmbH & Co. KG, Bad Pymont, Germany). The use of a common time for all hydrophones allowed for the estimation of fish position based on time of signal arrival if hydrophone locations and the speed of sound in the study area are known. A GPS was used to determine locations of hydrophones deployed from floating platforms. Javad (San Jose, California) Global Navigation Satellite System (GNSS) Sigma receivers were used to collect positional data on hydrophones anchored in the forebay. The receivers were programmed to provide real-time kinematic positions every 5 s. Dorne-Margolin choke ring antennas with Southern California Integrated GPS Network radomes were used to minimize multipath signals from surrounding concrete and rock structures to increase the quality of position solutions. This combination of equipment used GPS, GLONASS (Russian satellites), and Galileo satellites to compute positions within ±1 cm. The cabled hydrophone system is described by Weiland and others (2009).

Cabled hydrophones were installed directly to the face of Detroit Dam at several elevations and from floating platforms before the first release of acoustic-tagged fish (figs. 1-5, 1-6, and 1-7). Array 7 was placed about 61 m upstream of the dam. The four hydrophones affixed to the dam face just below the spill bay crest were operational only when the forebay elevation was above 1,531.0 ft. The three floating hydrophones at the spillway pier noses were removed from April 8 to 18, 2013, and from August 8 to September 25, 2013, in order to avoid damage to the equipment when the forebay elevation was slightly greater than that of the spill ogee. Only the hydrophones mounted to Detroit Dam were used after January 29, 2014. The range of the cabled hydrophones was assumed to be similar to that of the autonomous hydrophones. This assumption seemed reasonable because each transmitter message was typically detected by hydrophones on arrays 7 and 8, which were spaced 61 m apart. Collectively the cabled hydrophone systems were capable of detecting fish within about 200 m upstream of the dam.

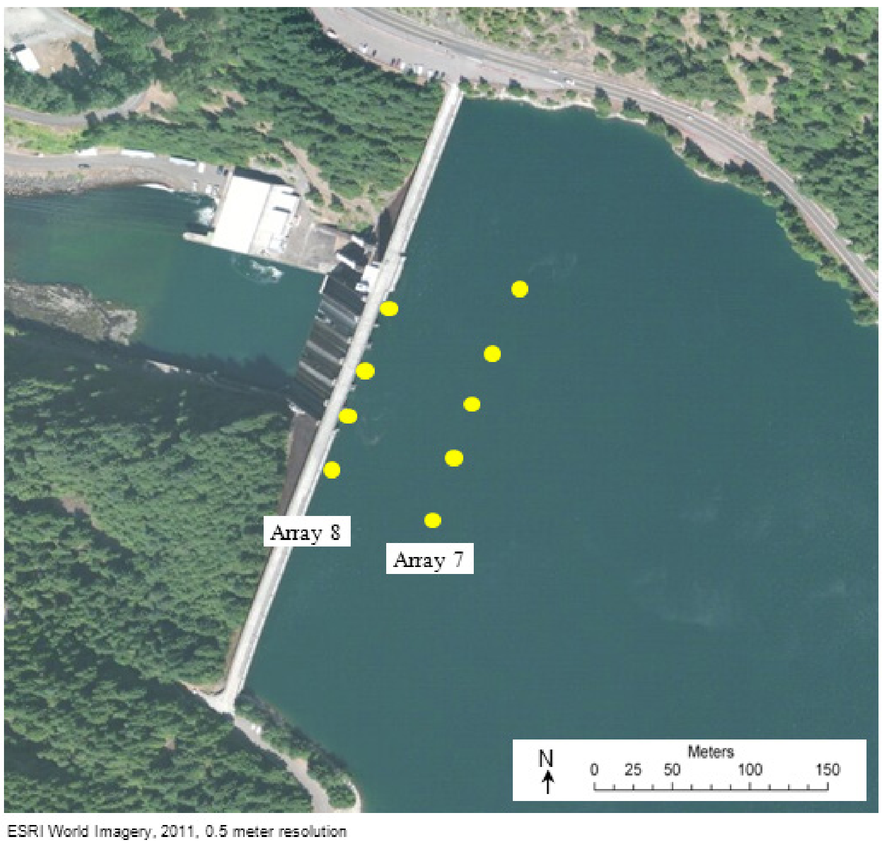

Figure 1-5. Locations of cabled hydrophones (small circles) on floating platforms deployed near Detroit Dam, Oregon, in 2013.

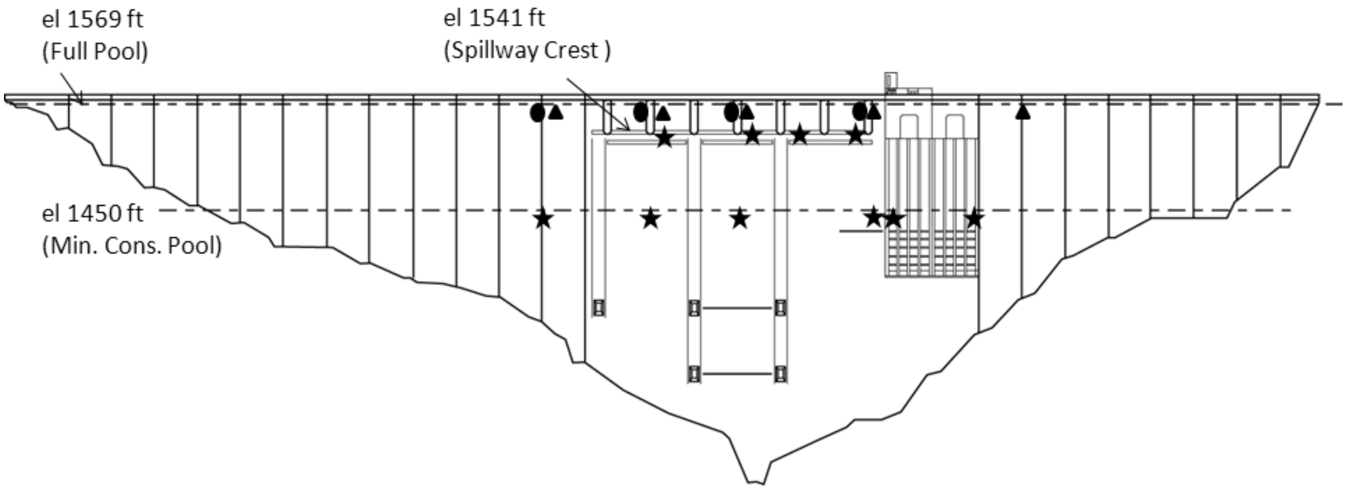

Figure 1-6. Schematic showing locations of cabled hydrophones at Detroit Dam, Oregon, 2013. Stars represent hydrophones affixed to the dam face, ovals indicate hydrophones deployed from floating platform attached to guide cables on the dam face, and triangles represent hydrophones deployed from floating platforms anchored 61 meters upstream of the dam face. Dotted lines represent approximate locations of full and minimum conservation pool elevations of 1,569 and 1,450 feet, respectively. Original drawing from U.S. Army Corps of Engineers.

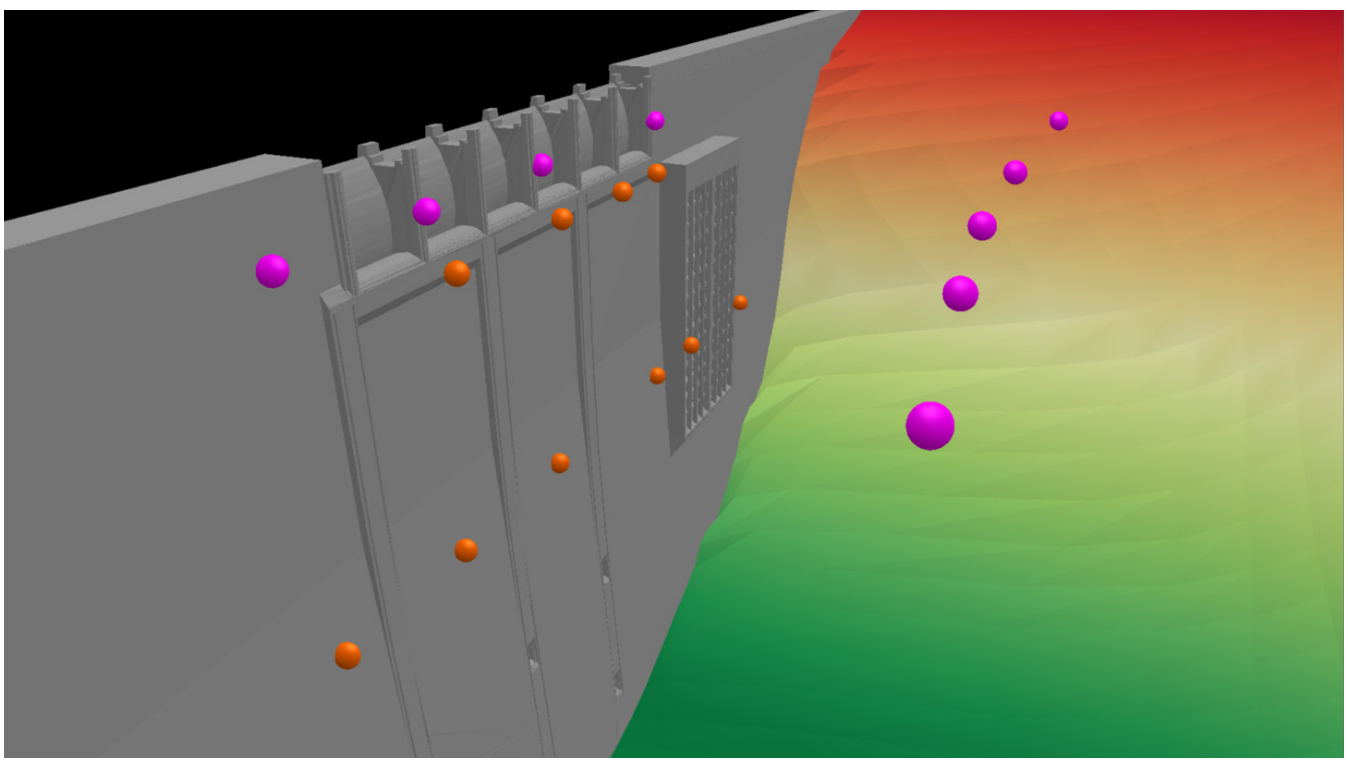

Figure 1-7. Schematic showing locations of underwater cabled hydrophones at Detroit Dam, Oregon, 2013. Gray surface is a three-dimensional representation of the dam face. Reservoir bed elevations are illustrated by the ramped colors, with greens showing low elevations and reds showing high elevations. Pink spheres are floating hydrophones and orange spheres are hydrophones attached to the dam.

Data Management and Analysis

Removing False-Positive Records

Data from the hydrophones were processed to remove false-positive records prior to analysis of presence data. False-positive records are those that indicate detection of a transmitter when the transmitter was not present, and are common in most active telemetry systems (Beeman and Perry, 2012). We used the procedure developed by PNNL (Mark Weiland, Pacific Northwest National Laboratory, written commun., June 17, 2010) to remove false-positive records. The procedure includes removing records from tag codes not released, records suspected of being from reflections of valid tag signals (multipath), and records that are not close to a multiple of the tag pulse interval (McMichael and others, 2010). Records from the cabled hydrophone system additionally were required to be present on more than one hydrophone to be retained.

Transmitter Life Tests

We selected 50 transmitters from the spring tags and 50 transmitters from the fall tags and empirically determined tag life. We activated the spring tags on March 25, April 19, and April 24, 2013, and the fall tags on September 6 and 17, 2013, and placed them in a 82.6 × 279.4 × 31.7 mm plastic box submerged in a 1.5-m diameter circular tank at the USGS Columbia River Research Laboratory in Cook, Washington. The water temperature in the tank was controlled to represent the average monthly water temperatures in the upper 20 ft of the Detroit Dam forebay. The tag signals were monitored with an Advanced Telemetry Systems model Trident SR5000 receiver. The data were run through the same filter as the fish detection data and summarized with the time-to-event Kaplan-Meier survivorship analysis.

Estimating Fish Positions

Fish positions within the area monitored by the cable hydrophone system near the dam were estimated using software under development through a USGS subcontract with the University of Washington in Seattle. The software estimates fish positions with an iterative technique using the Gauss-Newton method to find the location that minimizes the root-mean squared misfit to all available arrival time data by repeatedly solving a set of linearized equations relating adjustments in location to changes in the arrival time misfit (Klein, 1978; Lee and Stewart, 1981; Menke, 1989; Speisberger and Fristrup, 1990). The software uses all available hydrophones and can adjust the speed of sound in water for vertical changes in water temperature using the method of Moser (1991). Water temperatures from the temperature string located near the log boom in the Detroit Dam forebay were used for this purpose.

Fish position estimates were passed through a filter to identify spurious results. The filter limited swim speeds to a burst speed of as much as 3 m/s for 20 s or a sustained speed of as much as 1.0 m/s for longer than 20 s based on values from the literature (Bainbridge, 1960; Webb, 1978; Taylor and McPhail, 1985; Mesa and others, 2008). The first observation of each trip into the monitored area was omitted because of the lack of data to estimate swim speed. A new trip was assigned if the time elapsed between successive positions was greater than the 99th percentile of successive detections (Chinook salmon 858 s, steelhead 537 s). The filter identified 2.2 percent of Chinook salmon positions and 2.0 percent of steelhead positions, which were removed prior to analysis.

Fish position estimates were used to describe the densities, depths, and paths of fish near the dam. Fish densities were estimated by dividing the monitored area near the dam into cells and interpolating over the entire area using the kriging process. Percent presence in cells within the horizontal plane (x, y) was calculated as the percentage of tagged fish with position estimates within 105 m of the dam present at least once in each 10-m × 10-m cell in the x-y plane. Percent presence within cells in the vertical plane (x, z) was calculated as the percentage of tagged fish with position estimates within 105 m of the dam present at least once in each 20-m × 10-m cell in the x-z plane. The mean hourly depths of each species were calculated from the median hourly depths of each fish.

Movements within the Reservoir and Dam Passage

Descriptions of fish behavior and an analysis of factors affecting rates of movement in the reservoir and dam passage were based on detections of the tagged fish. General fish movements between arrays over time were plotted as an example of the raw data used in subsequent analyses. Analyses of fish presence (probability of presence at each array and across all arrays between release and the dam) and movement probabilities (Markov transition probabilities) were based on detections of fish at the arrays. Data from fish with position estimates within 25 m of the dam were used to assess selected factors that affected dam passage rates.

Dam passage was determined using presence data from the cabled hydrophones nearest Detroit Dam. The date and time of assigned dam passage events were assigned if the first detection of the last transmitted message was at any of the hydrophones located on Detroit Dam that were closest to the water outlets. This method was selected to limit passage assignments to fish last detected in the area generally in front of the spillway, powerhouse, or regulating outlet when operating, and was consistent with histories of tagged fish known to have passed the dam based on detections of acoustic tags downstream. Detections of tags within the 90th percentile of the empirically determined tag life were used to limit the effects of false negatives in the data. Several general measures of fish passage were estimated from these data (table 1-2).

Table 1-2. Definitions of passage efficiency and effectiveness metrics.

[RO, regulating outlet; Number, number of tagged fish; NA, not applicable]

Metric	Acronym	Definition
Stream passage efficiency	STRE	Number detected in the reservoir divided by number released.
Reservoir passage efficiency	RPE	Number detected at array 6 divided by number detected in the reservoir.
Dam passage efficiency	DPE	Number passing the dam divided by number detected at array 6.
Spill passage efficiency	SPE	Number passing the spillway divided by number passing the dam with known routes.
RO passage efficiency	ROE	Number passing the RO divided by number passing the dam with known routes.
Fish passage efficiency	FPE	Percent passing through non-turbine routes (ROE plus SPE).
Turbine passage efficiency	TPE	Number passing the turbines divided by number passing the dam with known routes.
RO effectiveness	NA	ROE divided by percentage of dam discharge passing through the regulating outlets.
Spill effectiveness	NA	SPE divided by percentage of dam discharge passing through the spillway.
Turbine effectiveness	NA	TPE divided by percentage of dam discharge passing through the turbines.

Analyses of the timing and rates of downstream movement in the reservoir and dam passage were conducted using time-to-event methods (Hosmer and Lemeshow, 1999). These methods are ideally suited to analysis of data based on the timing of events, such as travel times, and the rates of event occurrences, such as the guidance, attraction, and passage of fish (Castro-Santos and Haro, 2003, 2010; Castro-Santos and Perry, 2012).

The time elapsed from fish release to three event types was described using Kaplan-Meier survivorship functions. The events are (1) detection by any hydrophone in Detroit Reservoir after release in the tributaries, (2) detection by the autonomous hydrophones at the log boom, and (3) dam passage. The survivorship function of a variable *T* is defined as

$$S(t) = \Pr\{T > t\} \tag{1}$$

where

T is a random variable with a probability distribution, denoting an event time for an individual.

In our analysis, S(t) is an estimate of the probability of not passing the dam after time t. As such, the median time occurs when the survivorship function equals 0.5. In the absence of censoring, the survivorship function represents the proportion of the population that has not experienced an event (for example, passing the dam). Examining the survivorship function can be useful to describe the timing of events as well as the proportion of the population still at risk of the event at different points in time. Fish that had not experienced an event by the longest known transmitter life were right censored at that time.

Cox proportional-hazards regression was used to determine the potential effects of selected variables on the rates of dam passage. In Cox proportional-hazards regression, the rates of events are expressed as a hazard function defined as

$$h(t) = \lim_{\Delta t \to 0} \Pr\{t \le T < t + \Delta t \mid T \ge t\} / \Delta t \tag{2}$$

representing the instantaneous risk, or rate, of an event occurring at time t. Equation 2 describes a conditional rate: It is the probability of the event occurring in a limited time interval, conditional on the event having not occurred yet, divided by the length of the interval (which makes it a rate, not a probability) (Allison, 1995). Results are expressed in terms of a hazard ratio that describes the change in the rate of interest for each unit increase in an independent variable. For continuous variables, the hazard rate is interpreted by subtracting 1 from the hazard ratio and multiplying the remainder by 100 percent. For dichotomous variables, the hazard ratio is interpreted directly. For example, a hazard ratio of 1.15 from a continuous covariate indicates that the rate of the event increases 15 percent for each unit increase in the covariate, and a hazard rate of 0.75 indicates a decrease of 25 percent per unit increase in the covariate. A hazard ratio of 2.00 for a dichotomous covariate (for example, day = 1, night = 2) indicates that the rate of the event is twice the value at the higher value relative to the lower value (at night compared to during the day in this example). Hazards are independent of the size of the population. The measure of interest generally is the hazard ratio, which is the ratio of the rate of an event relative to the values of a covariate (for example, night versus day). Hazard ratios of variables that are not involved in an interaction with one or more other variables can be read directly from most statistical package outputs. However, hazard ratios of variables involved in interactions must be estimated from the parameter estimates (slopes) of each variable involved in the interaction plus their interaction term or terms, and, therefore, are typically included the text rather than in report tables.

The counting-process-style data input was used to divide the data into diel period (day or night) and to increment other time-varying covariates by hour (Hosmer and Lemeshow, 1999). We reset the time interval each time an individual entered a new zone or when it passed the dam. Censor values used to delineate between no event, downstream movement, upstream movement, route-specific dam passage, or passage through an undetermined route were used in a competing-risks analysis focusing on overall or route-specific dam passage. We used the 90th percentile of expected tag life based on the transmitter extinction tests to right censor the data (see section, "Transmitter Life Tests"). Cox regression is appropriate only for categorical variables that are proportional in the hazard and for numerical variables that are linear in the hazard, so these assumptions were evaluated prior to forming regression models. Models of factors supported as determinants of dam passage rates were formed by sequentially reducing full models by one variable at a time until only statistically significant variables remained at the $\alpha = 0.10$ level. Independent variables including total project discharge, route-specific discharge, forebay elevation, diel period, fork length, species, and selected two-way interactions were considered in the full models if the factors met selection criteria. The selection criteria included bivariate correlations of less than 0.8 and meeting assumptions of linearity and proportionality in the hazards (Hosmer and Lemeshow, 1999). In some cases, the Akaike Information Criterion (AIC) was used to assess support for competing models. Analyses were conducted for dam operating conditions (the various combinations of powerhouse, spillway, and regulating outlets being on or off) with a sufficient number of passage events.

Movement Probabilities within the Reservoir

The probabilities of upstream and downstream movements for fish detected at each array were estimated to determine if there were net upstream or downstream movements of fish and if the movements in the reservoir depended on past movements. Movement probabilities can be used to stochastically predict or simulate future fish movements (Johnson and others, 2004). A Markov-chain analysis was used to determine if movements between reservoir arrays followed a one-step process, by which movement from one array to an adjacent array is not dependent on its previous movement (a first-order Markov process; Bhat and Miller, 2002). We estimated the probability of a fish moving from one array to the next as either a first-order (one-step) process, or two-step process (dependent on previous location), and assessed support of the hypotheses by the data using the AIC (Burnham and Anderson, 2002).

Probability of Presence near Detroit Dam

We estimated the probability that a fish was present at least once after release at each array or at the Detroit Dam forebay. The purpose of this analysis was to determine if fish near the head of the reservoir would be available for capture by a juvenile fish collection facility at the dam if one were present. This analysis does not indicate whether fish that were not detected at an array or near the dam were alive or dead, only that they were never detected in the area of interest while a fish tag was still active. The data were based on presence of fish detected at the arrays throughout the reservoir or at the cabled hydrophone systems near the dam, which together detect fish within about 200 m of the dam.

The probability of fish being present near Detroit Dam at least once was estimated using Cormack-Jolly-Seber (CJS) mark-recapture methodology (Cormack, 1964; Jolly, 1965; Seber, 1965) using Program MARK (White and Burnham, 1999). This method primarily is used to estimate survival and recapture (detection) probabilities in mark-recapture studies, but in this case we used it to estimate fish presence and recapture probabilities. Detection of a tagged animal is the joint probability of presence and being detected when present, so these parameters must be estimated separately. We constructed models of presence and recapture probabilities based on various hypotheses about differences among arrays. In this analysis, the “recapture probability” at an array is the probability of being detected at that array at least once. Overdispersion in the data was estimated using the median ĉ procedure in Program MARK. Models describing different hypotheses about processes driving presence or detection probabilities were evaluated using the AIC with an adjustment for effects of sample size (AICc). Burnham and Anderson (2002) suggest that when AICc values differ by less than 2 units (delta AICc <2), the support for one hypothesis over another is not meaningfully different based on the data and models considered. They also suggest that delta AICc differences of 4–7 indicate considerably less support for the model with the greater AICc, and delta AICc differences greater than 10 indicate essentially no support for the model with the greater AICc. The probability of being present within 200 m of the dam at least once was estimated as the product of array-specific presence probabilities, with the standard error (SE) estimated using the delta method (Seber, 1982). When more than one probability of presence model was supported, leading to model-selection uncertainty, the probability of presence was estimated from model-averaged coefficients for all models with an AICc within 10 units of the model with the lowest AICc.

Estimating Detection and Survival Probabilities

CJS mark-recapture methods were used in Program MARK (White and Burnham, 1999) to estimate detection and reach-specific survival probabilities of Chinook salmon and steelhead downstream of Detroit Dam (Cormack, 1964; Jolly, 1965; Seber, 1965). Detection probabilities were estimated for each of the detection sites in the North Santiam River and for each individual bridge with detection equipment in the Willamette River (described in chapter 2 of this report). Reach-specific survivals of fish volitionally passing Detroit Dam were estimated using a single-release model (Burnham and others, 1987).

The survival estimated in this and other studies in which the fate of animals is not directly observable is referred to as “apparent survival” (Burnham and others, 1987). Apparent survival is the probability that an animal remains available for recapture or “detection,” as in the current context. In this study, apparent survival is the joint probability that a tagged fish is alive and migrates through the study area. This means that fish that stop migrating downstream during the life of their tags, or whose tags stop transmitting before they travel through the entire study area, are counted as mortalities. The cumulative probability of survival from Detroit Dam to each detection site downstream to as far as the Willamette River at Portland, Oregon, was calculated as the product of the reach-specific survival probabilities, with the SE estimated using the delta method (Seber 1982).

Two datasets differing in the numbers of occasions in the detection histories were used to estimate survival. A six-occasion history included one occasion for the virtual release comprised of fish that passed Detroit Dam and one occasion for each subsequent downstream monitoring site at Big Cliff Dam, Minto Dam, Salem, Wilsonville, and Portland, Oregon. The 12-occasion history included an occasion for the virtual release, Big Cliff Dam, and Minto Dam, and one occasion for each of the individual arrays equipped with hydrophones at each of the three Willamette River monitoring sites at Salem, Wilsonville, and Portland. Models constructed using the six-occasion detection histories were used to estimate detection probabilities at each monitoring site and reach-specific survivals between monitoring sites from the pooled detection data at each site, but the detection and reach-survival probability for the Portland site were not estimable because we had no monitoring sites downstream.

The 12-occasion histories were used to estimate the detection probability at each of the Willamette River bridges (except for the most downstream Portland Bridge) and the reach survival between Wilsonville and the most upstream Portland bridge. We chose to exclude fish detected at Detroit Dam or downstream after the 90th percentile of the empirically determined tag life to reduce the probability that a tag would stop transmitting within the study area.

Estimation of detection probabilities was based on the evaluation of a suite of models representing different assumptions. The suite included models that assumed detection probabilities varied independently among sites or, conversely, that detection probability was a constant for all sites. When individual bridge detection probabilities were estimated for the Willamette River sites, we also evaluated an additional model that assumed a constant detection probability for the individual arrays at each site, but different detection probabilities among sites. Individual detection probabilities often were not estimable because no tags passed undetected, in which case the probabilities were fixed to 1.0. Survival probabilities were allowed to vary among reaches in all models, but in the models developed to estimate bridge-specific detection probabilities, the survival probabilities between bridges within sites were fixed to 1.0. The probabilities of detection and survival were estimated from model-averaged coefficients for all models, with an AICc value within 10 units of the most supported model. Overdispersion in the data was estimated using the median ĉ procedure in Program MARK. In most instances, estimates of median ĉ were less than 1.0 or not calculable (most likely because the detection probabilities were near 1.0), and a median ĉ value of 1.0 was assigned. When the estimate of median ĉ was greater than 1.0, the quasi-likelihood modification to the AICc (QAICc) was computed and used for model selection. Detailed descriptions of these methods are available in White and Burnham (1999) and Burnham and Anderson (2002). Cumulative downstream survival probabilities from Detroit Dam to Portland were calculated as the joint probability of individual reach survival estimates, and standard errors of the estimates were calculated using the delta method.

Results

Definition of Spring and Fall Study Periods

The study periods ranged from the first release until the empirically estimated 90th percentile of tag life. The spring study period was from February 27 to August 6, 2013, for Chinook salmon, and from February 27 to July 19, 2013, for steelhead; the difference between species was owing to tag life. The fall study period was from September 11 to January 27, 2014. Few tagged fish with active tags likely were in the reservoir between August 6 and September 11, 2013 (fig. 1-8). The study area was last monitored on April 10, 2014.

Transmitter Life Tests

The acoustic transmitters tested had shorter than expected tag lives. The tags used in Chinook salmon during the spring had a median tag life of 93.4 d, and the 90th percentile of tag life was 77.7 d. The first transmitter stopped working at 9.8 d from activation and the longest tag lasted 128.5 d (fig. 1-9). The tags used in steelhead released into the tributaries in the spring had a median tag life of 128.3 d, and the 90th percentile of tag life was 73.4 d. The first of those tags expired at 49.2 d after activation and the last expired at 164.4 d. We did not conduct a tag life study on the battery model 337 tags that were used in steelhead released into the reservoir because of the small number of tags available. In the fall, the tag life ranged from 48.9 to 164.9 d, the median tag life was 128.6 d, and the 90th percentile of tag life was 68.0 d. To reduce the probability of false positive detections in the data, we truncated or censored each fish detection history at the 90th percentile of the empirically determined tag life. The tags used in steelhead released into the reservoir were truncated at the expected tag life of 75 d.

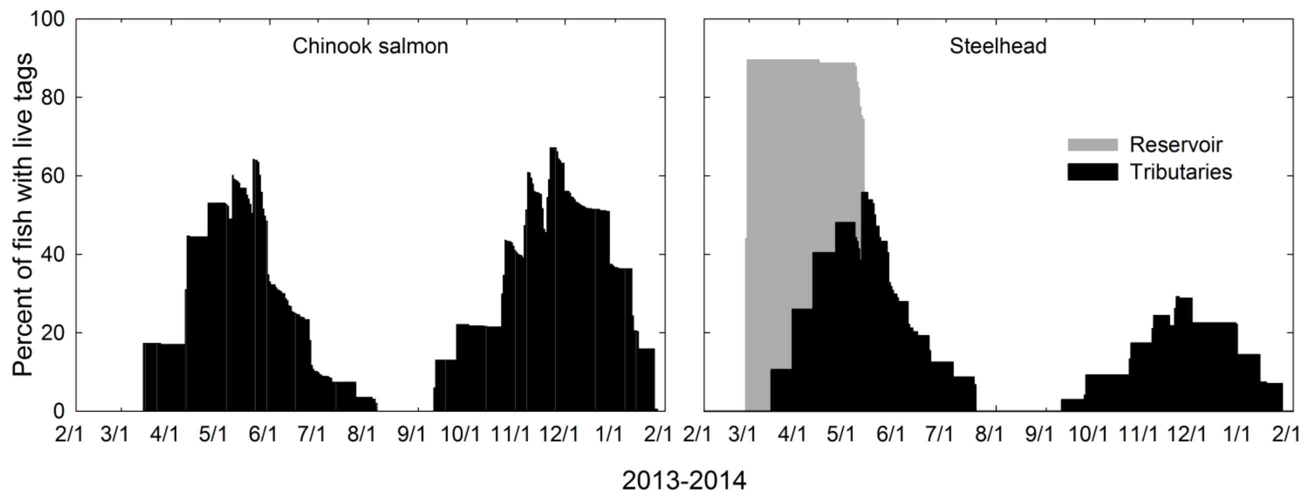

Figure 1-8. Graphs showing percentage of live tags available, by date, in Detroit Reservoir. Oregon, 2013–14.

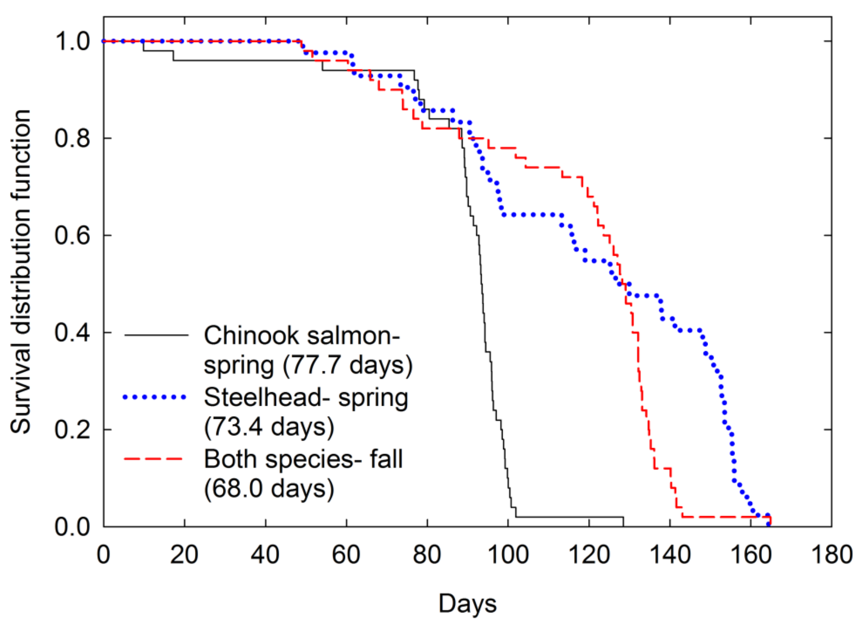

Figure 1-9. Graph of survival distribution function of tag life from activation to expiration for tags used at Detroit Reservoir, Oregon, and downstream, in the 2013 spring and fall study periods. Numbers in parentheses represent the 90th percentile of tag life for each group of tags.

Fish Handling, Tagging, and Release

During the spring study period, a total of 394 juvenile hatchery Chinook salmon and 229 juvenile hatchery steelhead were tagged and released between February 27 and May 22, 2013. Of the 394 Chinook salmon, 197 fish were released into each of the North Santiam River and Breitenbush River release sites between March 15 and May 22, 2013. The mean fork lengths of Chinook salmon were 152.4 mm (range 115–181 mm) for fish released into the North Santiam River and 152.7 mm (range 118–181 mm) for those released into the Breitenbush River (table 1-3). The mean fork lengths of steelhead released were 175.2 mm (*N*=53, range 140–183 mm) for those released into the North Santiam River and 175.8 mm (*N*=51, range 156–183 mm) for those released into the Breitenbush River. The fork lengths of the fish released at the two tributary release sites were similar within species (1-way analysis of variance, $P_{Chinook} = 0.97$, $P_{steelhead} = 0.09$). We also released 125 steelhead downstream of Piety Island in Detroit Reservoir on February 27 and 28, 2013. They had a mean fork length of 170.0 mm (range 143–180 mm; table 1-3). The tag-weight-to-body-weight percentages of the fish released in the spring averaged 1.3 percent (range 0.6–3.5 percent), 1.1 percent (range 0.9–1.7 percent), and 0.9 percent (range 0.7–1.5 percent), for the Chinook salmon, steelhead released into tributaries, and steelhead released into the reservoir, respectively.

During the fall study period, a total of 606 Chinook salmon and 271 steelhead were tagged and released upstream of Detroit Reservoir from September 11 to November 22, 2013. Of the 606 Chinook salmon, 303 fish were released into each of the North Santiam River and Breitenbush River release sites. The mean fork length for Chinook salmon was 149.1 mm (range 118–180 mm) for those released into the North Santiam River and 148.9 mm (range 115–179 mm) for those released into the Breitenbush River. The mean fork length for steelhead was 164.6 mm (range 135–180 mm) for those released into the North Santiam River and 166.2 mm (range 138–180 mm) for those released into the Breitenbush River (table 1-3). The tag-weight-to-body-weight percentages averaged 1.3 percent (range 0.7–2.7 percent) for Chinook salmon and 0.9 percent (range 0.6–1.6 percent) for steelhead.

Table 1-3. Summary statistics of fork length and weight of acoustic-tagged juvenile hatchery Chinook salmon and steelhead at Detroit Reservoir, Oregon, 2013.

[*N*, number of fish; SD, standard deviation. Release site indicates the location were fish were released: SAN, North Santiam River; BRE, Breitenbush River; RES, downstream of Piety Island in the Detroit Reservoir near the head of the reservoir]

Season	Species	Release site		Fork length (millimeters)			Weight (grams)		
			N	Mean	SD	Range	Mean	SD	Range
Spring	Chinook salmon	SAN	197	152.4	14.2	115–181	36.5	10.8	12.2–74.4
		BRE	197	152.7	14.0	118–181	36.3	10.4	15.6–63.9
	Steelhead	SAN	53	175.2	6.6	140–183	54.3	5.6	33.6–65.3
		BRE	51	175.8	5.9	156–183	53.4	5.5	35.7–62.8
		RES	125	170.0	5.9	143–180	50.5	5.3	29.2–66.3
Fall	Chinook salmon	SAN	303	149.1	12.0	118–180	35.5	9.0	15.8–60.8
		BRE	303	148.9	11.5	115–179	35.0	8.4	16.0–59.1
	Steelhead	SAN	135	164.6	10.3	135–180	49.4	9.6	27.3–68.5
		BRE	136	166.2	10.1	138–180	50.9	9.3	28.4–70.2

Pre-tag holding times were within the 18–30 h specification of the Surgical Protocols Steering Committee (2011) in all but two instances—a Breitenbush River release group of Chinook salmon tagged 42 min early and a North Santiam River release group of steelhead tagged 23 min early during the fall study period. Pre-tag holding times for the Chinook salmon during the spring ranged from 18.1 to 24.7 h for fish released into the North Santiam River and from 18.6 to 24.4 h for fish released into the Breitenbush River. Pre-tag holding times of steelhead ranged from 18.0 to 19.1 h for fish released into Detroit Reservoir, from 18.2 to 20.9 h for fish released into the North Santiam River, and from 18.1 to 25.9 h for fish released into the Breitenbush River. Pre-tag holding times for the Chinook salmon during the fall ranged from 18.2 to 24.4 h for fish released into the North Santiam River and from 17.3 to 23.8 h for fish released into the Breitenbush River. Steelhead pre-tag holding times ranged from 17.6 to 24.3 h for fish released into the North Santiam River and from 18.9 to 25.2 h for fish released into the Breitenbush River.

Post-tag holding times were within the 18–36 h specification of the Surgical Protocols Steering Committee (2011) in all but one instance where one Breitenbush River release group of steelhead was released 49 min early. Post-tag holding times for the Chinook salmon in the spring ranged from 18.1 to 28.2 h for fish released into the North Santiam River and from 18.2 to 26.6 h for fish released into the Breitenbush River. Steelhead released during the spring directly into Detroit Reservoir had a post-tag holding range between 18.6 and 22.1 h. Steelhead released at the North Santiam River release site had a range of 20.6 to 27.0 h and steelhead released at the Breitenbush River release site had a post-tag holding time range of 17.2 to 27.6 h. Post-tag holding times for the Chinook salmon during the fall ranged from 20.8 to 28.0 h for fish released into the North Santiam River and from 21.4 to 29.6 h for fish released into the Breitenbush River. Steelhead released into the North Santiam River had post-tag holding times ranging from 23.3 to 29.6 h and those released into the Breitenbush River had post-tag holding times ranging from 23.0 to 30.5 h.

There were few post-tagging mortalities prior to release. The post-tagging mortality rates of Chinook salmon during the spring season were 2.5 percent (5 of 197) and 7.6 percent (15 of 197) for those released at the North Santiam River and Breitenbush release sites, respectively. There were no post-tagging mortalities of steelhead during the spring study. In the fall, there were no post-tagging mortalities of Chinook salmon and one steelhead mortality at the North Santiam River release site (0.4 percent, 1 of 271).

During the spring, the rate of pre-tag mortalities for Chinook salmon was higher than normal. We provided an Oregon Department of Fish and Wildlife employee, who was taking samples at MFH, with five of our pre-tag mortalities for a pathology analysis. Analysis results indicated that the gills of the fish were pale but had normal structure, and no pathogens were present. There was inconsistent bacterial grown from the kidneys, and two of the five fish had signs of cold water disease (*Flavobacterium psychrophilum*). It also was noted that because these Chinook salmon are smolts, the increased mortality could be stress related. During April and May, there was a 16.0 percent holding mortality rate (100 of 622) for the Chinook salmon. There was a 5.7 percent holding mortality rate for steelhead (20 of 352) in the beginning of February and then a zero rate for the rest of the spring. During the fall, there were a total of 8 pre-tag mortalities (8 of 789), a 1.0 percent pre-tag mortality rate for Chinook salmon and no pre-tag mortalities for the steelhead.

Environmental Conditions and Dam Operations

Daily operations varied seasonally, as dictated by a variety of factors including flood control, demand for electricity, water availability, and Biological Opinion mandates. Forebay elevation was high in the spring and summer, receded in the fall, and was low during the winter owing to the flood control purpose of the dam (fig. 1-10). Dam discharge during the spring study period was similar to the previous year, with a daily mean of 1,360.6 ft^3/s (fig. 1-11, appendix table A1). Water was passed over the spillway beginning on April 9 at 1:00 p.m. and continued during part of most dates until September 9, 2014, at 8:00 a.m.; the daily mean spillway discharge during the spring study period was 345.3 ft^3/s. The RO was not used during the spring study period. During the spring study period, the forebay elevation increased from 1,469.9 to 1,565.5 ft and was predominantly near the higher level. The mean spillway discharge was greater at night (552.5 ft^3/s) than in the day (199.3 ft^3/s) and the mean powerhouse discharge was greater during the day (1,291.3 ft^3/s) than during the night (606.4 ft^3/s). Operations during the fall study period included greater and more variable dam discharge than in the spring period (averaging 2,284 ft^3/s), the absence of spillway use owing to the forebay elevation being below the spillway crest of 1,541 ft, and intermittent use of the RO at a mean discharge of 13.5 ft^3/s (appendix table A2). The mean RO discharge differed by only 2.8 ft^3/s during the day and night, and the mean powerhouse discharge also was similar during the day (2,324.4 ft^3/s) and night (2,219.7 ft^3/s). The forebay elevation decreased from 1,543.2 to 1,444.9 ft during this period.

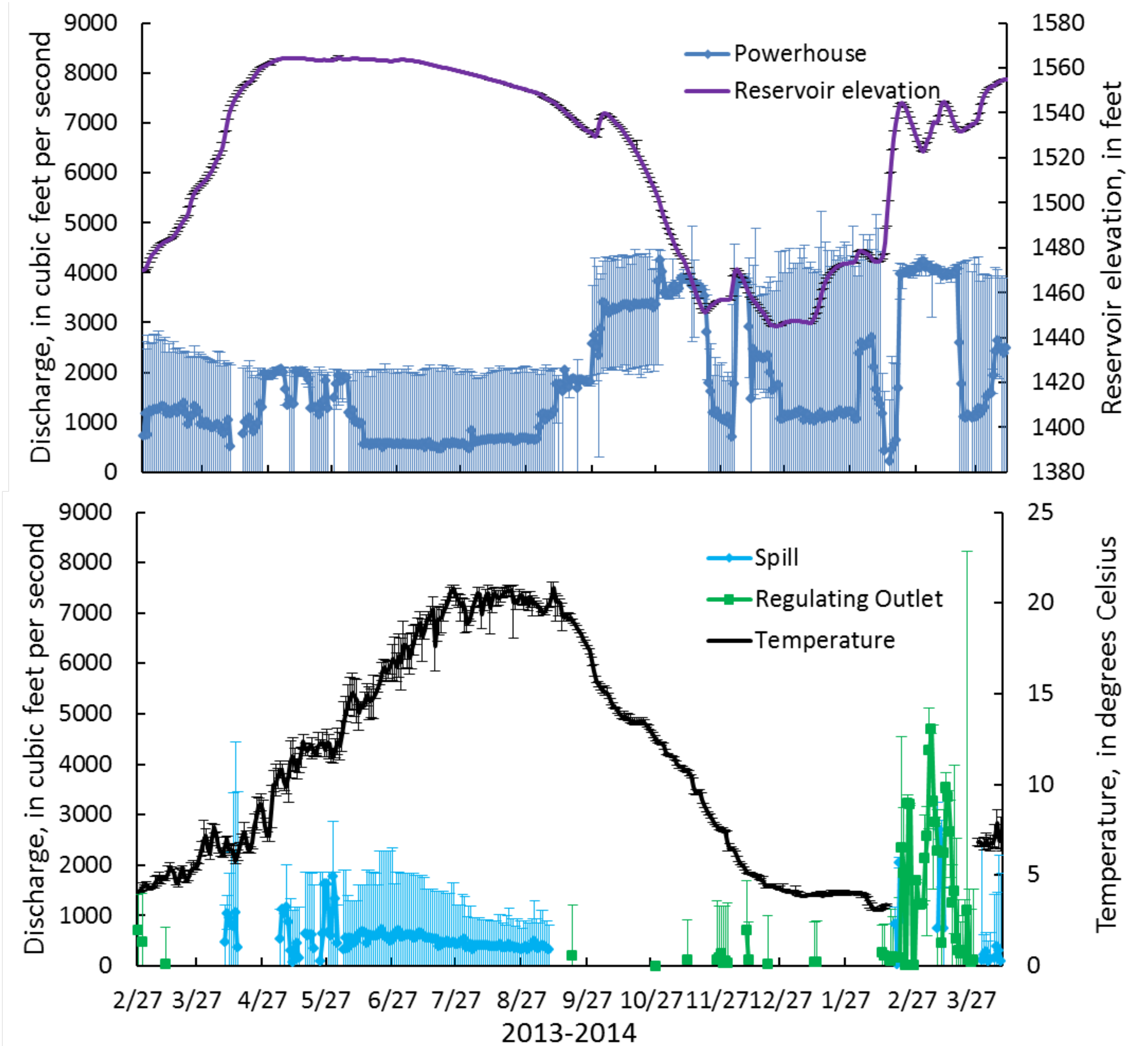

Figure 1-10. Graphs showing mean daily discharge (Powerhouse, Spill, Regulating Outlet), forebay elevation, and average water temperature of the upper 20 feet of the forebay at Detroit Dam, Oregon, during the 2013 spring and fall study periods. Whiskers indicate daily minimums and maximums.

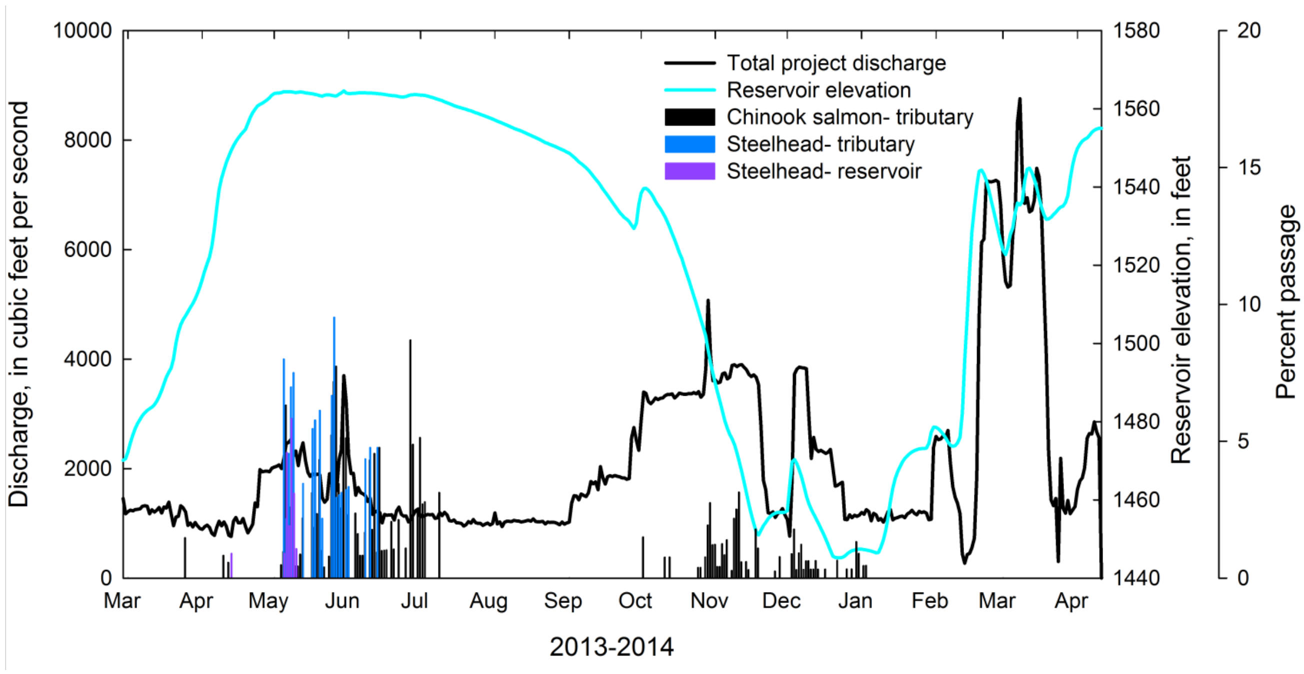

Figure 1-11. Graph showing daily mean dam operations and environmental conditions at Detroit Reservoir, Oregon, February 28, 2013–April 10, 2014, when fish were released and detected in the study area. Additionally, daily passage of juvenile Chinook salmon and steelhead were plotted as a percentage of fish in the reservoir available to pass (vertical bars).

The hourly dam operating conditions varied during most dates, with the powerhouse often operating during parts of the day but rarely at night and the spillway operating during parts of the day and night. A generalization of the varied conditions is shown by graphing the hourly operating conditions on the 15th day of each month (fig. 1-12). Note that the powerhouse and spillway often were operated intermittently. This resulted in relatively short periods of time with specific conditions used for analyses, such as powerhouse only, spillway only, or spillway plus powerhouse (see section, “Effects of Selected Variables on Dam Passage Rate”). For example, the powerhouse only operation was the most common condition during both the spring and fall study periods, yet based on the hourly discharge data, this condition only occurred continuously for a median of 6 h (range 1–153 h) in the spring period and a median of 4 h (range 1–920 h) in the fall period. Similarly, the spillway only condition occurred continuously for a median of 8 h during the spring period (range 1–56 h); the RO was used continuously for a median of 8 h (range 1–9 h) in the spring period and a median of 2 h (range 1–10 h) in the fall period; and the spillway plus powerhouse condition occurred continuously for a median of 4 h (range 1–51 h) in the spring period and never after the forebay elevation receded below the spillway ogee crest during the fall period.

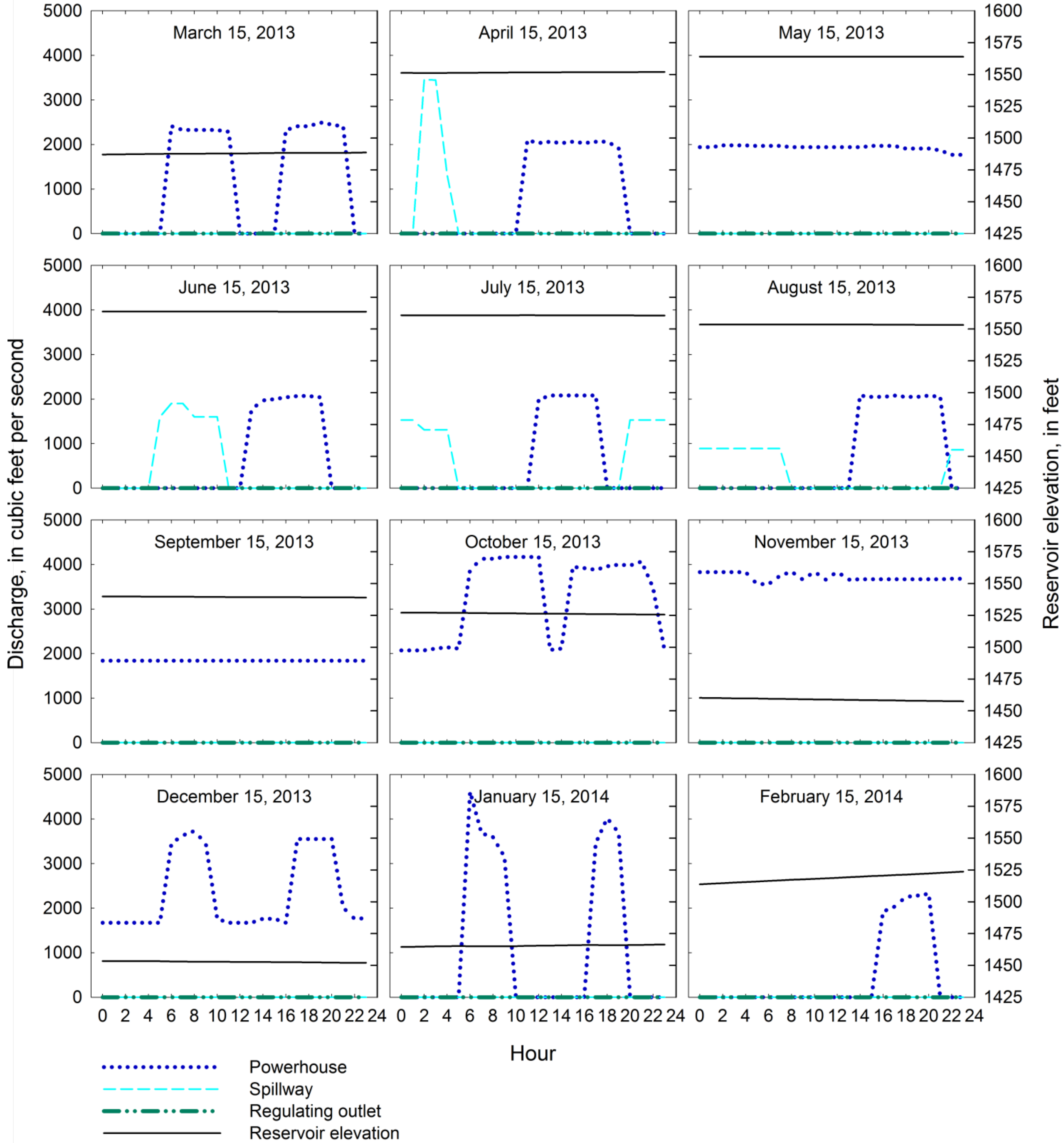

Figure 1-12. Graphs of hourly dam operations on the 15th day of each month at Detroit Dam, Oregon, March 2013–February 2014.

Movements within the Reservoir

General Fish Behavior

A higher proportion of Chinook salmon than steelhead were detected in the reservoir after release. During the spring study period, 19.5 percent (77 of 394) of the Chinook salmon and 31.7 percent (33 of 104) of the steelhead released into the tributaries were undetected within the 90th percentile of their tag life. Of the steelhead released into Detroit Reservoir in February, 10.4 percent (13 of 125) were not detected within the 90th percentile of their tag life. During the fall study period, 10.9 percent of the Chinook salmon (66 of 606) and 68.3 percent of steelhead (185 of 271) were undetected after release within the 90th percentile of their tag life. The undetected fish were from both release sites and all release groups (fig. 1-13). During the spring study period, Chinook salmon released at the Breitenbush River site constituted 48.1 percent of the undetected fish and steelhead constituted 30.3 percent. During the fall study period, Chinook salmon released at the Breitenbush River site constituted 42.4 percent of the undetected fish and steelhead constituted 57.8 percent.

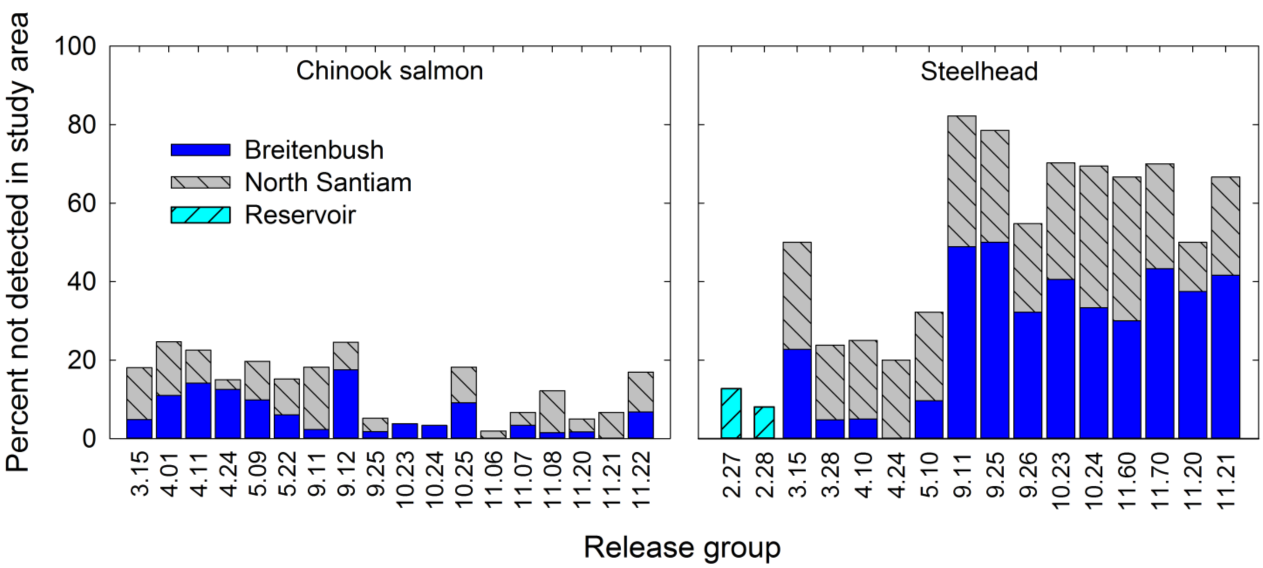

Figure 1-13. Graphs showing percentage of fish not detected at Detroit Dam and Reservoir, Oregon, during the 2013 spring and fall study periods. Bars represent percentage of each release site for each release group (month.day).

Fish detected in the reservoir were present at all monitored areas and often made repeated trips from the head of the reservoir to the dam and back. General movements of several randomly selected fish are shown in figures 1-14 and 1-15. During the spring study period, Chinook salmon made more trips throughout the reservoir than steelhead, but steelhead often took longer to travel from the release sites to the reservoir (release to array 1). During the spring study period, Chinook salmon made 1–37 trips from the reservoir upstream of the log boom to within 25 m of the dam. Steelhead released into the tributaries made 1–21 trips, and steelhead released into the reservoir made 1–11 trips to within 25 m of the dam. The average number of trips to within 25 m of the dam was 5.5 for Chinook salmon, 6.4 for steelhead released into the tributaries, and 4.2 for steelhead released into the reservoir. During the fall study period, Chinook salmon made 1–84 trips to within 25 m of the dam, with an average of 8.8 trips. Fewer steelhead were detected within 25 m of the dam in the fall, but the ones that were detected ranged from 1 to 24 trips with a mean of 6.3 trips.

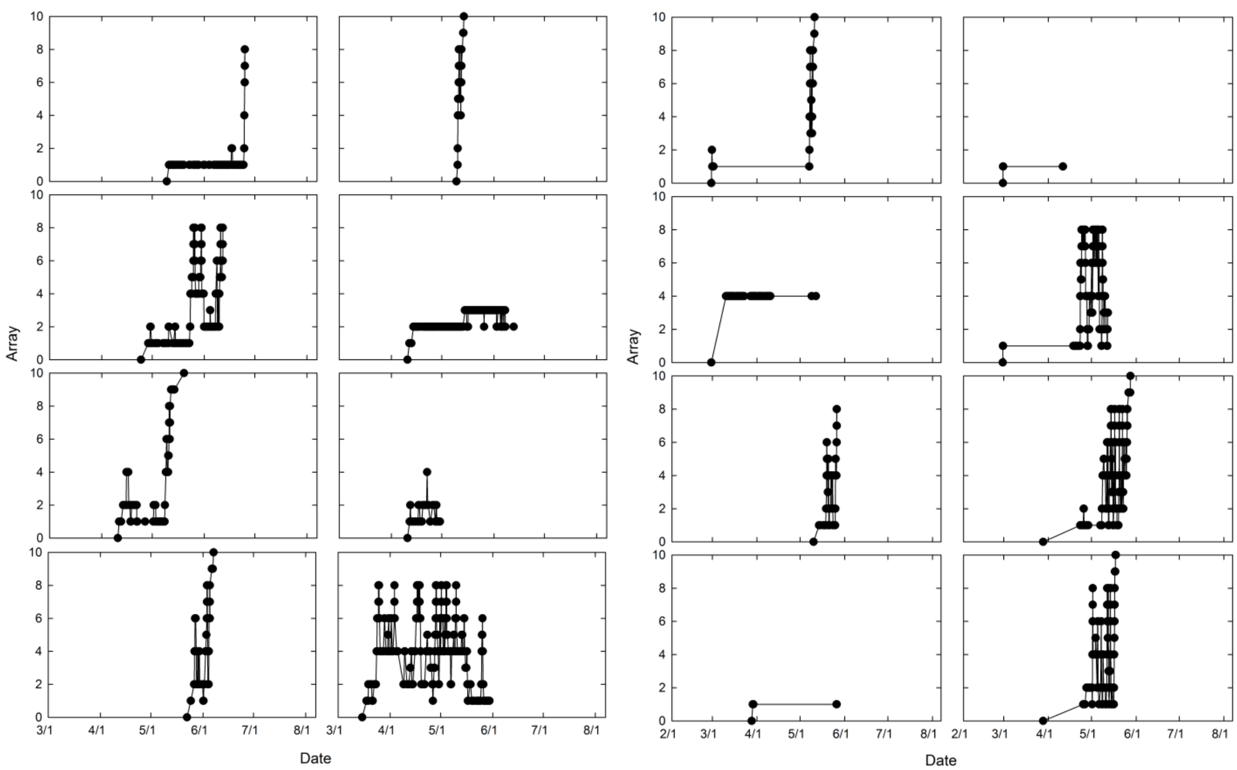

Figure 1-14. Graphs showing movements of eight randomly selected juvenile Chinook salmon (left 2 columns) and juvenile steelhead (right 2 columns) in Detroit Reservoir, Oregon, during the 2013 spring study period. The top four steelhead graphs are from fish released into the reservoir and the bottom four graphs are from steelhead released into the tributaries. Arrays represent hydrophone groups ranging from release (0) to Minto Dam (10). Arrays 1–6 were in Detroit Reservoir as described in figure 1-3, array 7 was 200 feet upstream of Detroit Dam, and array 8 was at Detroit Dam.

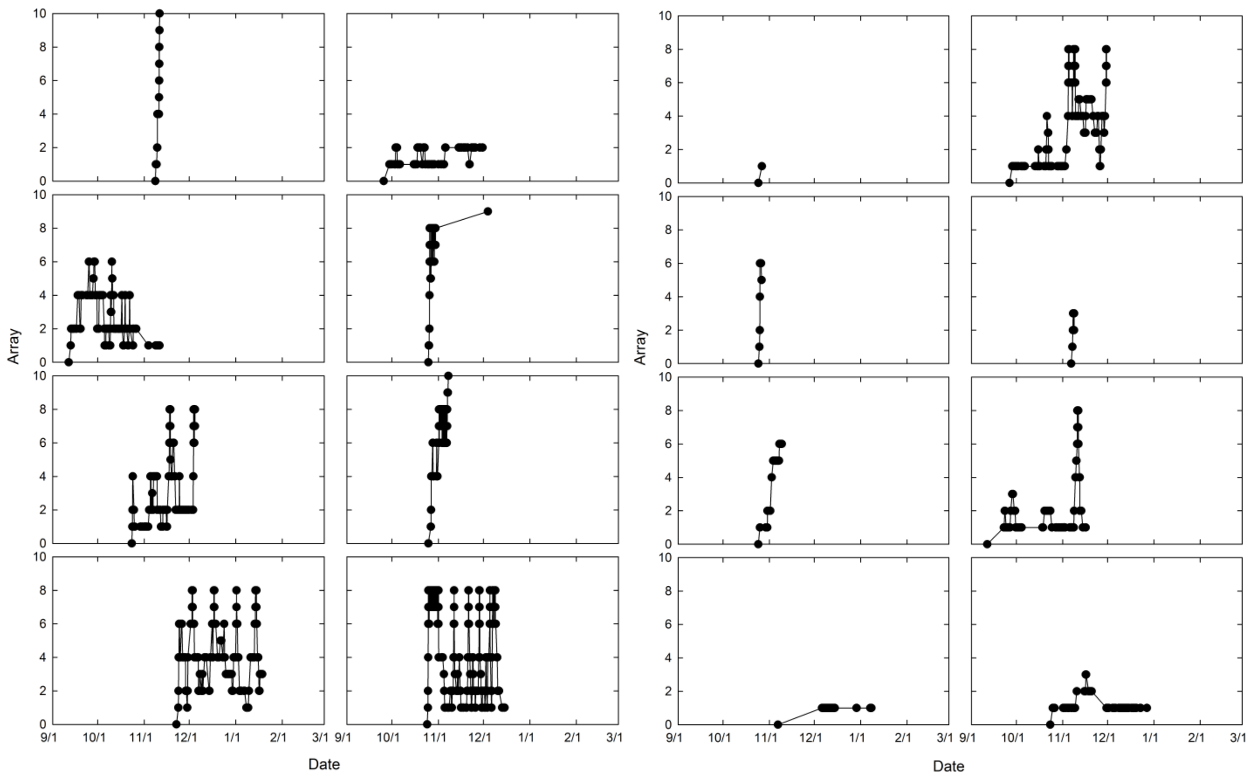

Figure 1-15. Graphs showing movements of eight randomly selected juvenile Chinook salmon (left 2 columns) and juvenile steelhead (right 2 columns) in Detroit Reservoir, Oregon, during the 2013 fall study period. Arrays represent hydrophone groups ranging from release (0) to Minto Dam (10). Arrays 1–6 were in Detroit Reservoir as described in figure 1-3, array 7 was 200 feet upstream of Detroit Dam, and array 8 was at Detroit Dam.

Timing of Detection

The distribution of arrival times of Chinook salmon and steelhead at detection arrays, an indicator of the timing of fish movements, differed slightly between species and between the two study periods (fig. 1-16). During the spring study period, the hour of detection at most arrays was similarly distributed between the day and night hours for both species. Small peaks in detections at array 6 (log boom) and at the dam occurred at about 5:00 p.m. for both Chinook salmon and steelhead. During the fall study period, Chinook salmon arrival times again were broadly distributed among the day and night hours at most arrays, but proportionately more fish arrived at the dam and forebay line at 6:00 a.m. than at any other time of the day. For steelhead in the fall study period, the distribution of arrival times at all arrays was highly variable because of the small number of steelhead that entered the reservoir after release.

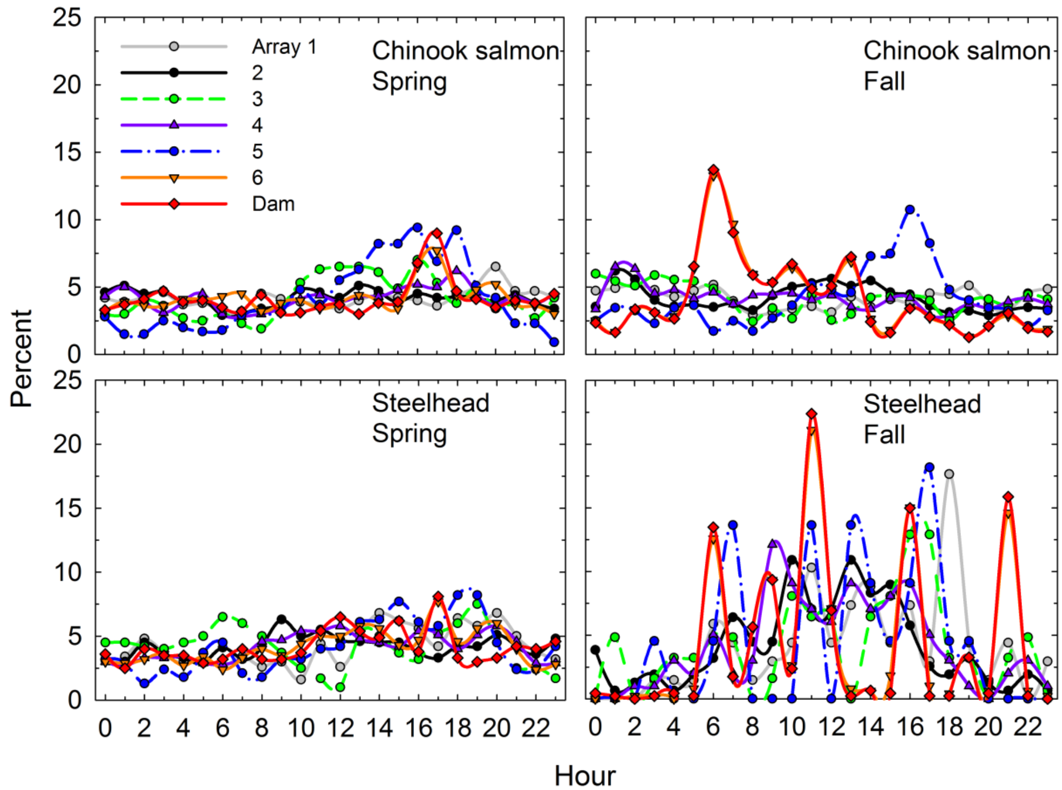

Figure 1-16. Graphs showing hourly arrival time percentages of individual Chinook salmon and steelhead at each detection array in Detroit Reservoir, Oregon, during the 2013 spring and fall study periods. Arrays 1–6 represent locations in Detroit Reservoir (from upstream to downstream, see fig. 1-3). Points are joined with smoothed lines.

Travel Time from Release to Detroit Dam and to Dam Passage

Travel times varied by species, season, and location in Detroit Reservoir. During the spring study period, Chinook salmon traveled faster than steelhead between the release sites in the tributaries to the reservoir; the median travel time was 1.7 d for Chinook salmon and 15.9 d for steelhead (fig. 1-17). The percentage of reservoir-released steelhead detected after release is represented in the minimum y-axis values in the “Release to first reservoir” graph in figure 1-17. During the spring study period, the median travel time from first detection in the reservoir to detection at the log boom (array 6) was slightly shorter for Chinook salmon than for steelhead released into the tributaries (median 7.1 d versus 9.1 d), but their distributions were similar. The time from the log boom to dam passage was shorter for steelhead than for Chinook salmon (median 16.9 d versus 26.8 d) and the distributions were distinct for about the first 70 percent of events. The median travel time of steelhead released into the reservoir from release to the log boom was 69.7 d; their median travel time from log boom to passage was not calculated because so few fish passed the dam. During the fall study period, the travel time distributions of Chinook salmon from release to first detection in the reservoir (median 1.0 d) and from first detection in the reservoir to detection at the log boom (median 3.6 d) were similar to those of Chinook salmon during the spring study period. However, during the fall study period, fewer Chinook salmon passed the dam than during the spring study period, and those that did took longer to do so. Few steelhead released in the fall were detected in the reservoir, and none passed within the 90th percentile of their tag life.

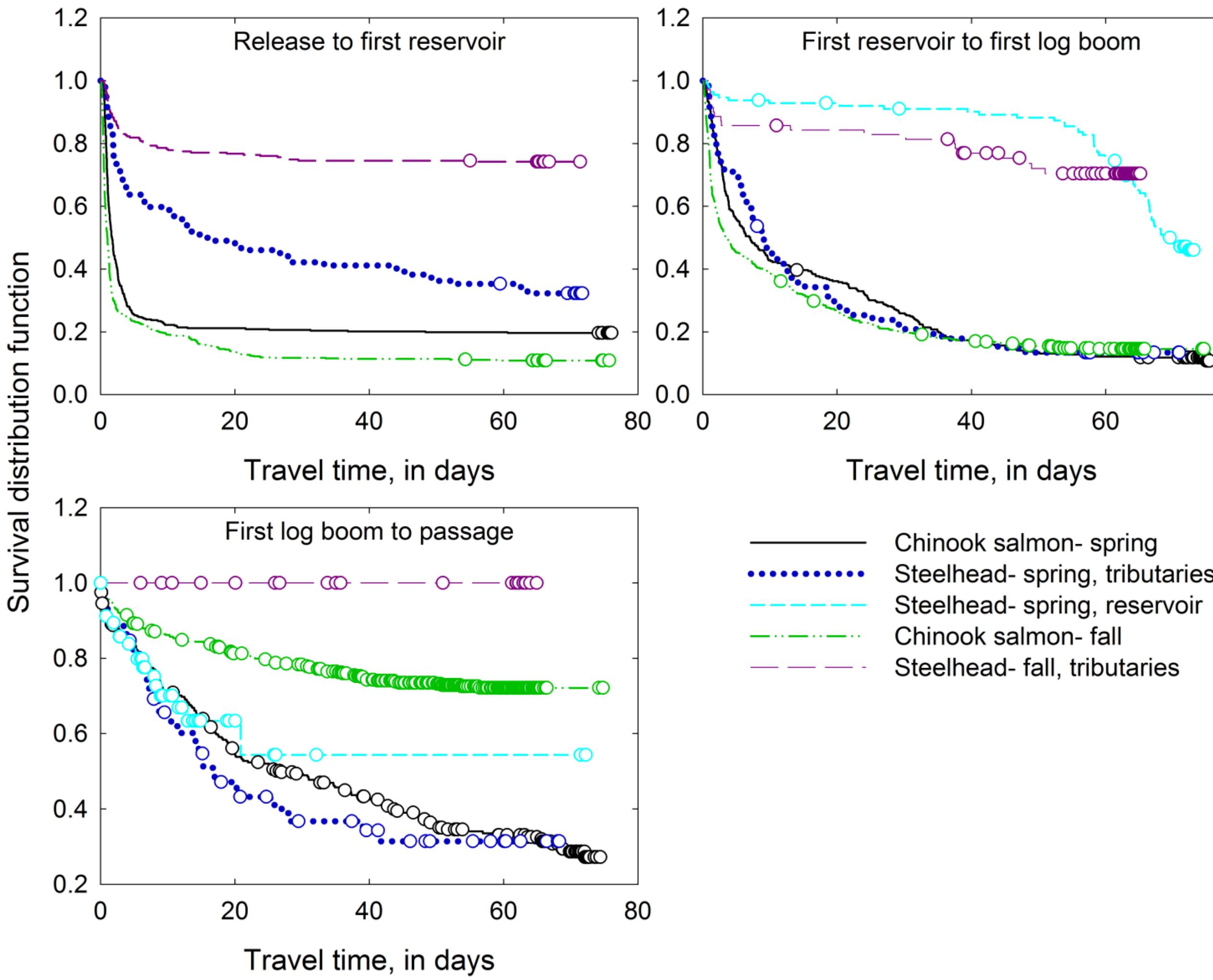

Figure 1-17. Survival distribution plots of travel times at Detroit Dam and Reservoir, Oregon, during the 2013 spring and fall study periods. Observations are right-censored (open circles) at the 90th percentile of tag life if no event occurred or at the last detection at the log boom if the passage route was unknown.

Probability of Presence near Detroit Dam

The probabilities of presence at each array and at Detroit Dam were based on the estimates from a single, highly supported model, or the model-averaged estimates of multiple models with considerable support from the data. Four models of presence probability were evaluated for the Chinook salmon released into the tributaries and the steelhead released into the reservoir during the spring study period, and two models were evaluated for the steelhead released into the tributaries in the spring and the fish released during the fall study period. These included models that assumed differences in recapture (detection) probabilities among reservoir arrays and models that assumed a common detection probability for all arrays that were supported by the data. The median $\hat{c}$ procedure did not converge for the models, likely owing to the detection probabilities being near 1.0, so a $\hat{c}$ value of 1.0 was applied to the data.

In the suite of models of detection probabilities that were examined for the Chinook salmon released into the tributaries and the steelhead released near the head of the reservoir during the spring study period, the models that assumed differences in detection probabilities among arrays received the greatest support from the data based on model weights (appendix table B1). However, for these same two groups, the models that assumed a constant detection probability for all arrays also were moderately supported and, for the steelhead released into the tributaries in the spring study, this type of model was the only model type supported (appendix table B1). During the fall study period, the model that assumed differences in detection probabilities among arrays was the only model supported for Chinook salmon, whereas, for steelhead, the model that assumed a constant detection probability was the only model supported (appendix table B1). The detection probabilities ranged from 0.997 (SE 0.004) to 1.000 (SE 0.000) for Chinook salmon and from 0.987 (SE 0.014) to 1.000 (SE 0.000) for steelhead during the spring study period. During the fall study period, detection probabilities for Chinook salmon ranged from 0.992 (SE 0.004) to 1.000 (SE 0.000), whereas the detection probability for steelhead was 1.000 for all arrays. Models of presence that assumed different presence probabilities among arrays and models that assumed a common presence probability for all arrays were paired with each of the detection models supported by the data for each species and study period (appendix tables B2-B6). Models of presence that assumed differences in presence probabilities among arrays were the only models supported by the data for Chinook salmon and steelhead during the spring and fall study periods (appendix tables B2–B6).

The cumulative probability of being present at an array decreased as the distance from the release site increased, and estimates were higher for Chinook salmon than for steelhead during each study period (fig. 1-18). The estimated cumulative probability of presence at Detroit Dam at least once during the spring study period was 0.685 (SE 0.023) for Chinook salmon and 0.567 (SE 0.049) for steelhead released into the tributaries (fig. 1-18). However, almost all of the difference in these cumulative probabilities can be accounted for by the lower proportion of steelhead entering the reservoir after release into the tributaries compared to Chinook salmon. The probability of presence at the first reservoir array for the fish released into the tributaries during the spring study period was 0.799 for Chinook salmon and 0.663 for steelhead (fig. 1-18). The cumulative probability of being present at the dam for the fish from the spring study period known to have reached the first reservoir array was 0.857 and 0.855 for Chinook salmon and steelhead, respectively. The cumulative probability of presence at Detroit Dam for steelhead released into the reservoir (spring study period) was 0.416 (SE 0.044) and, thus, substantially lower than the probabilities for fish released into the tributaries. In the fall study period, the estimated cumulative probability of presence at the dam at least once was 0.721 for Chinook salmon and 0.052 for steelhead (fig. 1-18). As during the spring study period, during the fall study period, the probability of the steelhead entering the reservoir after release (0.258) was lower than for Chinook salmon (0.891), which accounted for much of the lower probability that steelhead were detected at Detroit Dam. The probability of only the Chinook salmon detected in the reservoir being at the dam was 0.809, whereas for the steelhead that were detected in the reservoir, the probability of being at the dam was 0.700, indicating that once in the reservoir, similar proportions of each species were detected at the dam.

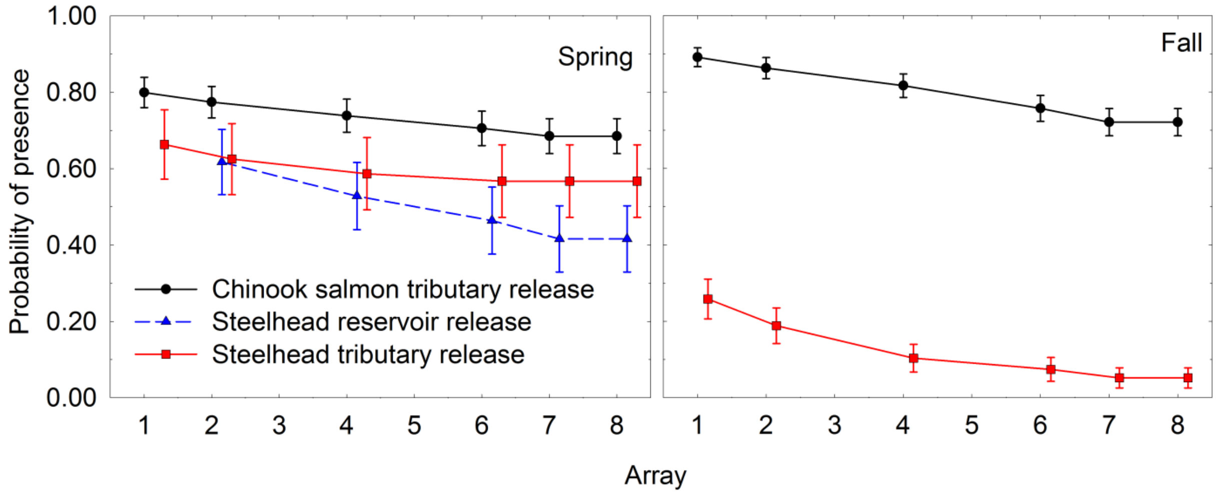

Figure 1-18. Graphs showing cumulative probabilities (±95-percent confidence interval) of being present at least once at reservoir arrays 1, 2, 4, 6 (forebay line), and arrays 7 and 8 at Detroit Dam for fish released into tributaries and near the head of Detroit Reservoir, Oregon, during the 2013 spring and fall study periods. Array 3 (Blowout Creek) and array 5 (Kinney Creek) were not included because fish can migrate to the dam without entering these areas.

Movement Probabilities within the Reservoir

Movement probabilities between reservoir arrays indicated that fish movements had a tendency to be directionally persistent, except in the forebay, where fish had a greater propensity to mill about (figs. 1-19 and 1-20; appendix tables C1 and C2). Directionally persistent reservoir movements indicate that fish moving downstream were likely to continue in that direction to the forebay and fish moving upstream tended to continue in that direction to the head of the reservoir. Milling movements occurred when fish moving upstream away from the dam tended to be more or equally likely to reverse their direction near the forebay line and move back downstream to the dam than they were to continue moving farther upstream.

Two-step Markov chain models were supported over one-step Markov models in 9 of the 12 possible cases for both Chinook salmon and steelhead during the spring study period. This indicates that the probability of a fish moving from one array to an adjacent array varied with its previous location or approach and is consistent with predominantly directional movements. For example, for Chinook salmon in the spring study period, the probability of moving downstream of array 4 was greater for a fish whose prior location had been upstream at array 2 and was continuing to move downstream (0.23 + 0.46) than it was for a fish that had been previously located at array 6 moving upstream and then reversed its direction at array 4 and moved back downstream to array 5 or 6 (0.12 + 0.21).

One-step Markov models generally received greater support than the two-step models of fish movements in the forebay. This milling-type movement is demonstrated by Chinook salmon in the spring study period that had been located near the dam (array 8), moved upstream to the forebay line (array 6), and then were more likely to return back to the dam (0.63) than they were to continue moving upstream to array 5 or 4 (0.07 + 0.30). One-step Markov models also tended to be supported for Chinook salmon and steelhead movement probabilities associated with moving into or out of the arms of Kinney and Blowout Creeks. Although the one-step models received greater support than the two-step models in these cases, the two-step models still received substantial support from the data, indicating a degree of model uncertainty.

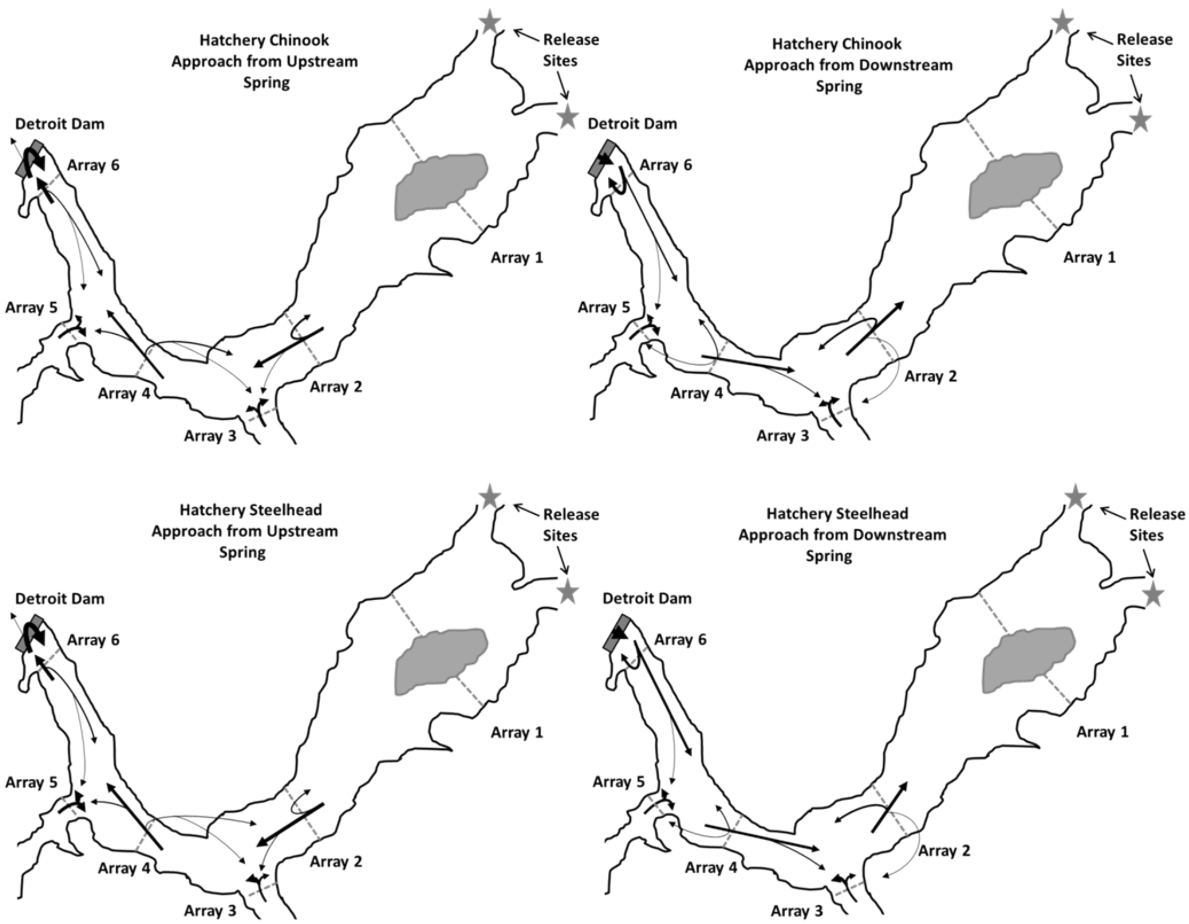

Figure 1-19. Movement probabilities of juvenile Chinook salmon and juvenile steelhead in Detroit Reservoir, Oregon, during the 2013 spring study period. Relative width of arrows indicates probabilities of moving from one array to an adjacent array based on the previous movement (wider is greater probability; see appendix table C1 for probabilities).

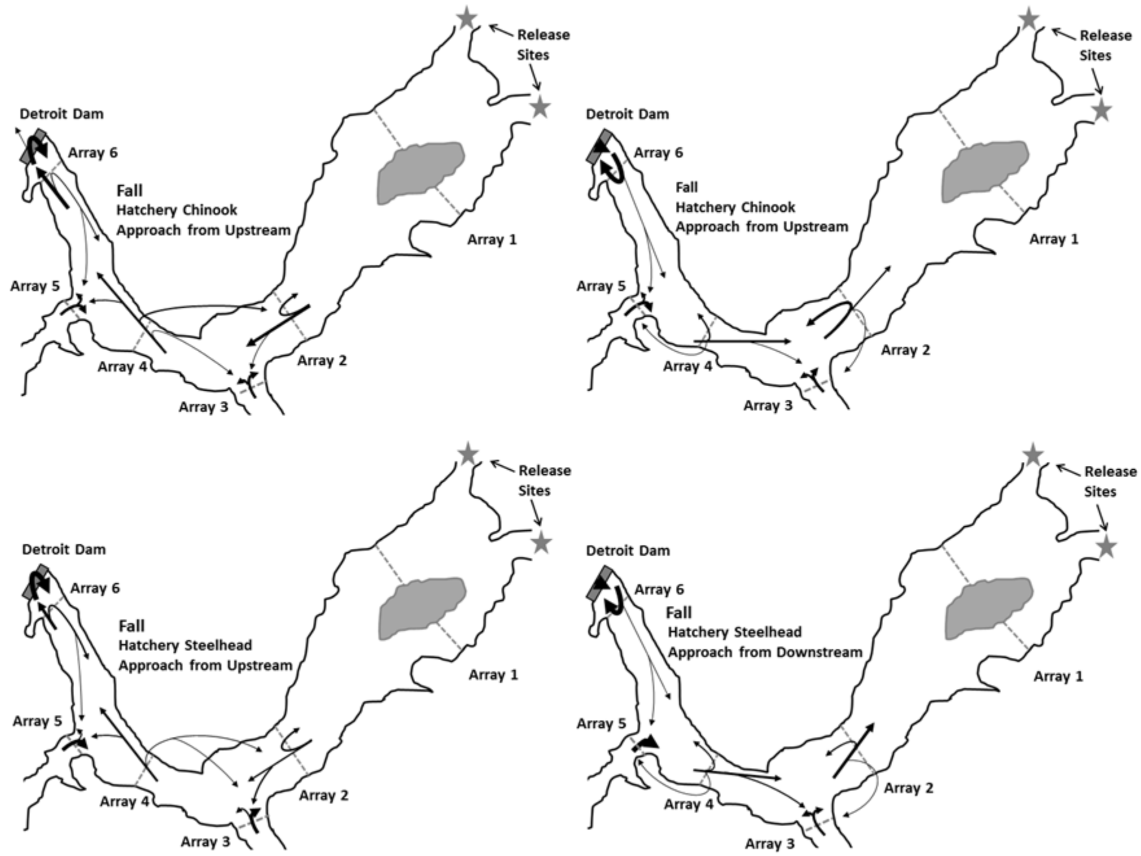

Figure 1-20. Movement probabilities of juvenile Chinook salmon and juvenile steelhead in Detroit Reservoir, Oregon, during the 2013 fall study period. Relative width of arrows indicates probabilities of moving from one array to an adjacent array based on the previous movement (wider is greater probability; see appendix table C3 for probabilities).

During the fall study period, the two-step Markov movement probability models were again supported over the one-step Markov models in 10 of the possible 12 cases for Chinook salmon, indicating that movement probabilities between adjacent reservoir arrays were dependent on the previous location of a fish and, therefore, were directional (appendix tables C3 and C4). However, Chinook salmon showed less directional persistence at array 4 as they approached from downstream and at array 2 as they approached from the upstream than in the spring study (fig. 1-20). For steelhead, two-step models were clearly supported over the one-step models in 4 of the possible 12 cases, but in 7 of the comparisons, neither of the two model types was clearly supported over the other (appendix table C4). This model ambiguity indicates that the data were inadequate to infer any strong difference between the one- and two-step models, most likely owing to the small number of steelhead that entered the reservoir after release in the fall study. Milling behavior near the dam was even more apparent for the two species during the fall than it was during spring. The probability that a fish moving upstream of the dam would reverse its direction after being detected near the forebay line was 0.93 for Chinook salmon and 0.96 for steelhead (appendix table C2).

The probability that a Chinook salmon or a steelhead approaching Detroit Dam from the forebay line would pass Detroit Dam on any given approach was low regardless of the study period. Out of about 1,909 such approaches to the dam in the spring study period and 15,043 approaches during the fall study period by Chinook salmon, the probability that a fish would pass the dam on any given approach was about 0.10 in the spring and 0.01 in the fall. Similarly for steelhead, out of 699 approaches to the dam in the spring study period and 458 approaches in the fall study period, the probabilities that a fish passed on any particular approach were about 0.08 and less than 0.01, respectively.

Behavior of Fish near the Dam

Qualitative examinations of tracks of fish within 105 m of the dam indicate that the dam operating conditions affected fish paths near the dam. During the spring study period, Chinook salmon paths generally were similar during the spillway only and spillway plus powerhouse operating conditions, but paths of steelhead were more dispersed during the latter condition (figs.1-21 and 1-22). During the fall study period, paths of Chinook salmon near the dam were more dispersed during the powerhouse only than during the RO plus powerhouse condition (fig. 1-23). There were too few steelhead detected near the dam during the fall study period to adequately examine their paths.

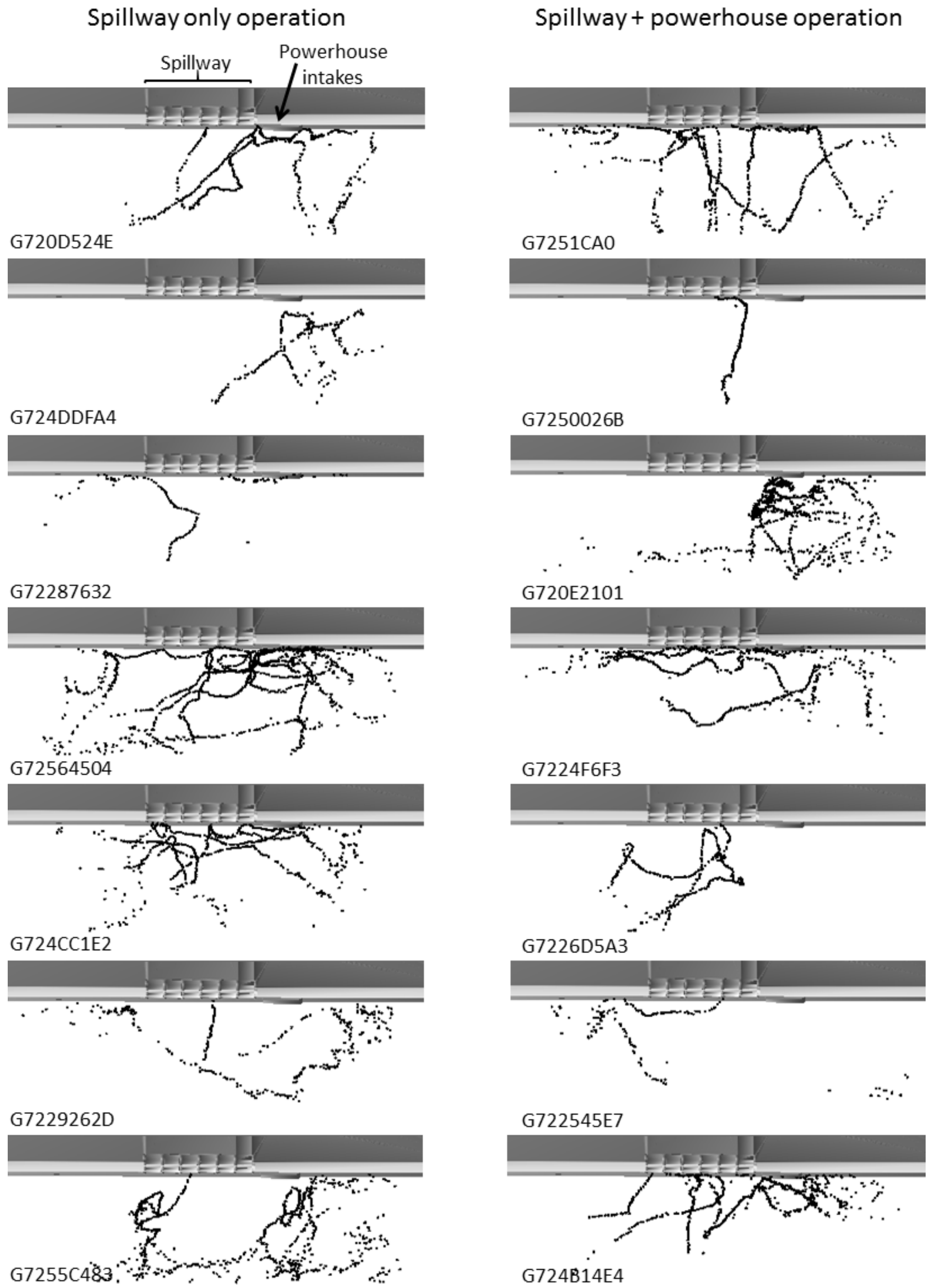

Figure 1-21. Position estimates of randomly selected juvenile Chinook salmon within 105 meters of Detroit Dam, Oregon, during the 2013 spring study period. Alphanumeric tag codes also are shown.

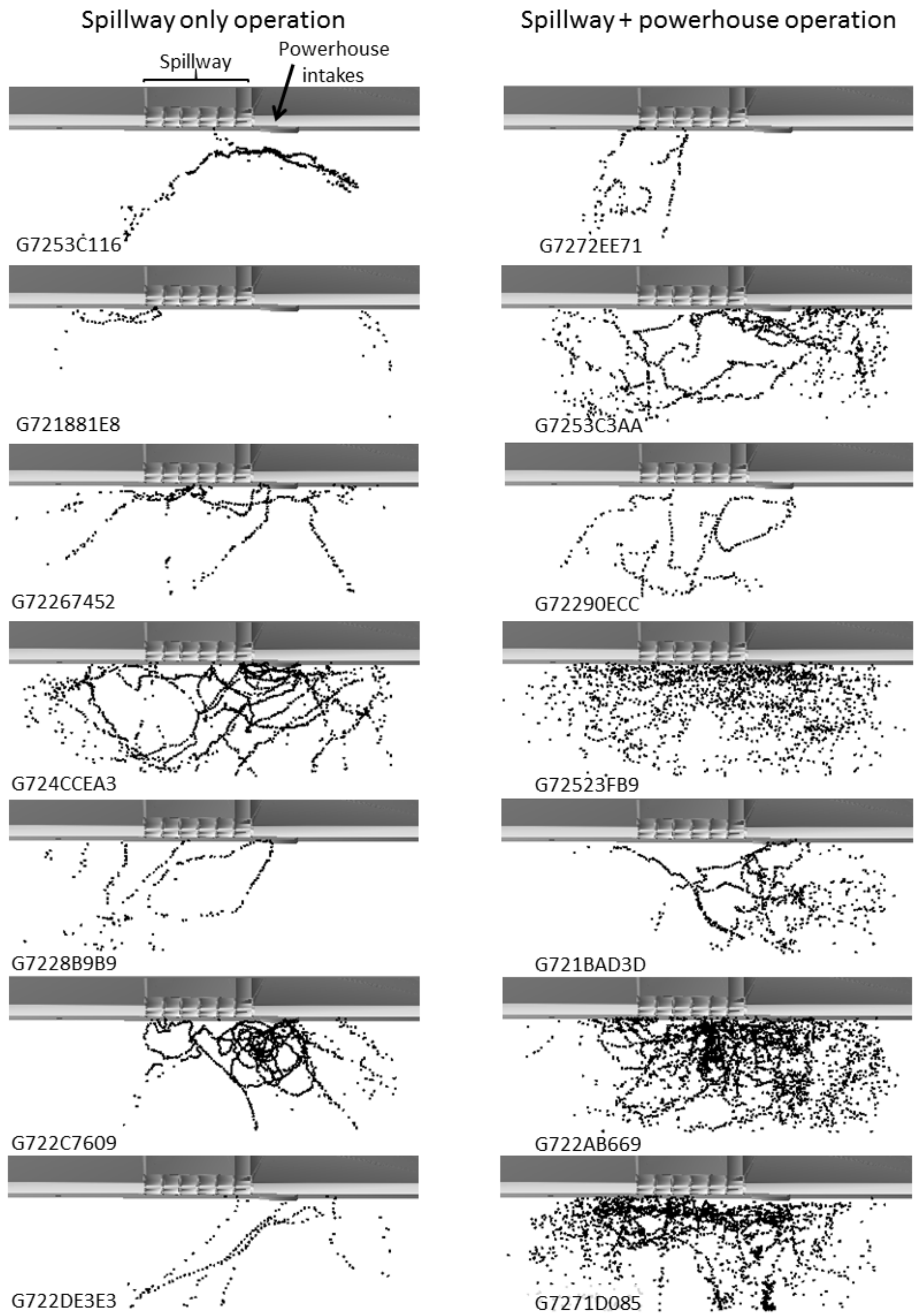

Figure 1-22. Position estimates of randomly selected juvenile steelhead within 105 meters of Detroit Dam, Oregon, during the 2013 spring study period. Alphanumeric tag codes also are shown.

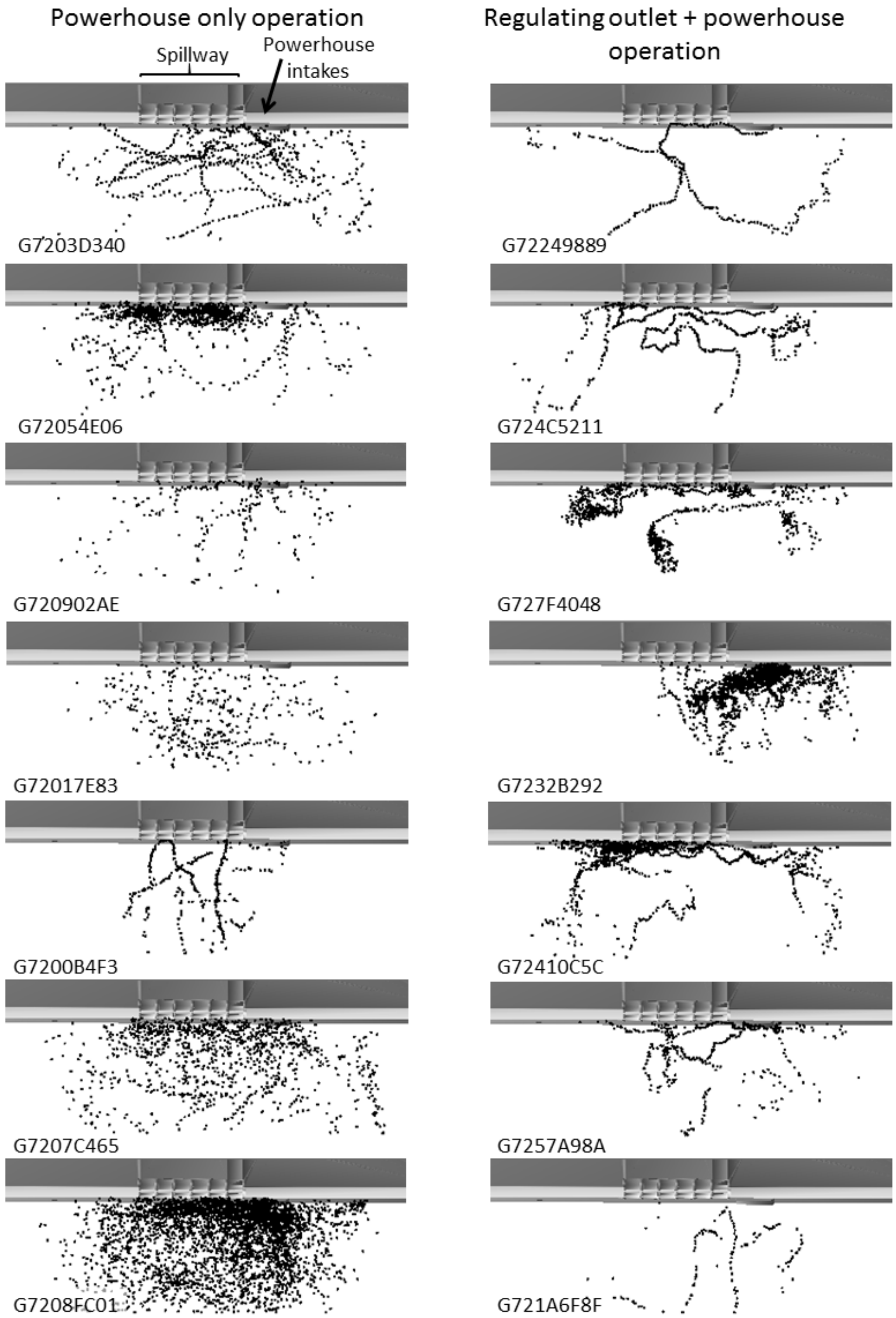

Figure 1-23. Position estimates of randomly-selected juvenile Chinook salmon within 105 meters of Detroit Dam, Oregon; during the 2013 fall study period. Alphanumeric tag codes also are shown.

The locations of Chinook salmon and steelhead in the forebay varied by dam operating condition, forebay elevation (which changed with time of year), and species. During the spring study period, when the reservoir was full or near full, fish of each species were present in similar areas, except that steelhead were shallower and more often present in a greater area of the forebay during the spillway plus powerhouse operation than the Chinook salmon (figs. 1-24 and 1-25).

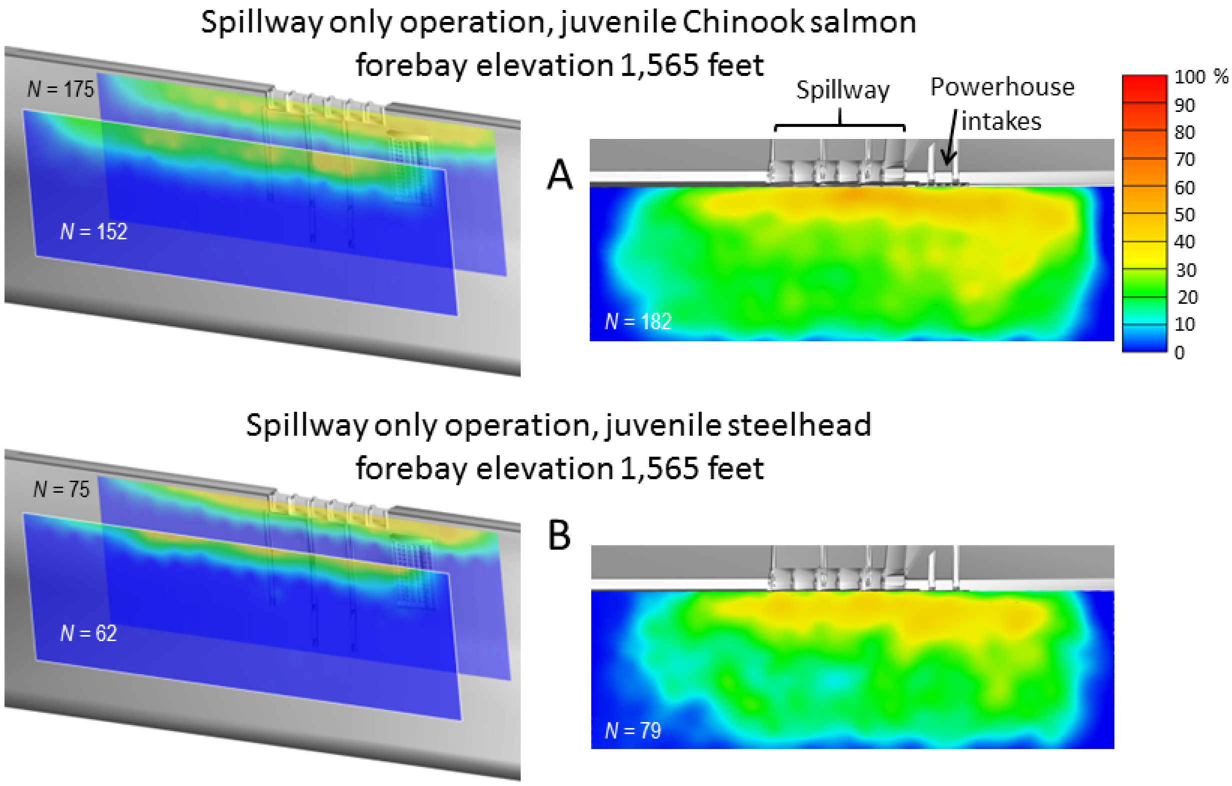

Figure 1-24. Distributions of the percent presence of juvenile Chinook salmon and juvenile steelhead during spillway only operation in the forebay of Detroit Dam, Oregon, during the 2013 spring study period. Vertical slices (left) represent distributions of fish in the 0–20 and 80–100 meter distance ranges from the dam based on 20 x 10 meter cells. Plan views (right) represent distributions along the x-y plane within 105 meters of the dam based on in 10 × 10 meter cells. Sample sizes (*N*) are numbers of fish represented.

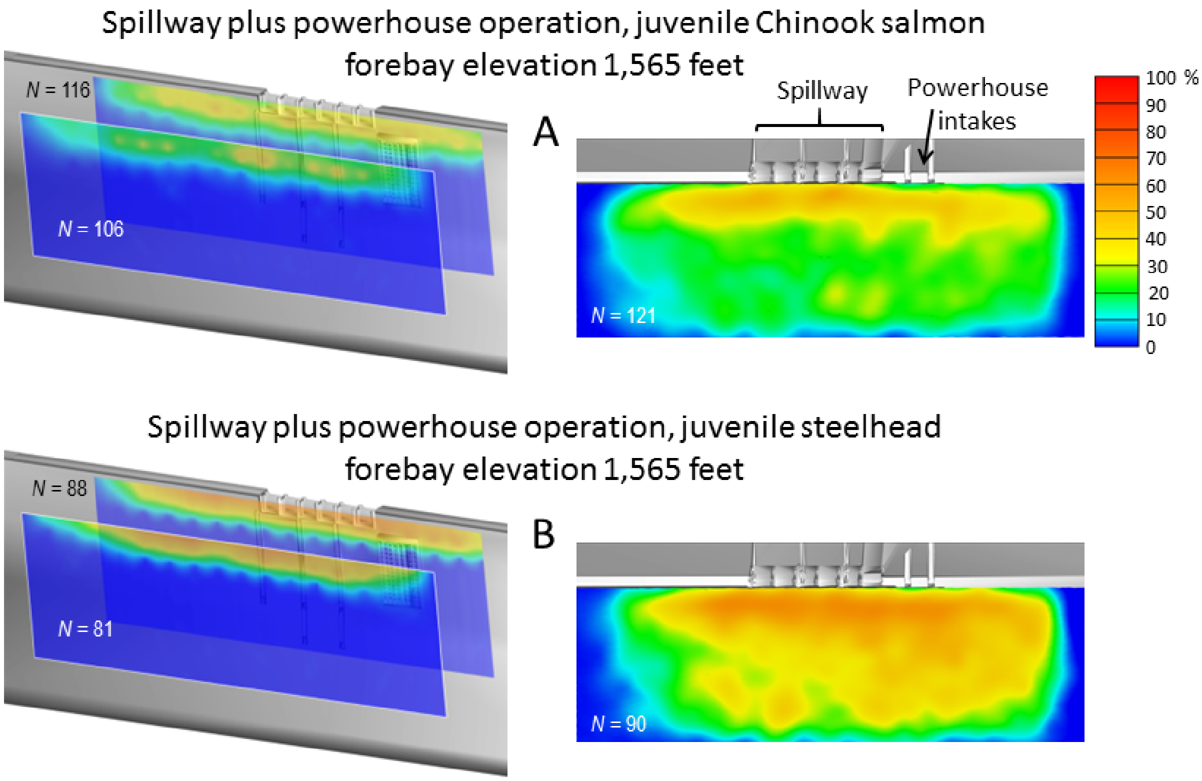

Figure 1-25. Distributions of the percent presence of juvenile Chinook salmon and juvenile steelhead during spillway plus powerhouse operation in the forebay of Detroit Dam, Oregon, during the 2013 spring study period. Vertical slices (left) represent distributions of fish in the 0–20 and 80–100 meter distance ranges from the dam based on 20 x 10 meter cells. Plan views (right) represent distributions along the x-y plane within 105 meters of the dam based on in 10 × 10 meter cells. Sample sizes (*N*) are numbers of fish represented.

During the fall study period, the areas of greatest fish presence often were larger than those during the spring period. For example, during the powerhouse only operation, Chinook salmon presence was well dispersed over nearly the entire monitored area (fig. 1-26A and B). Note that too few tagged steelhead were present in the monitored area during the fall study period to make useful plots. During the fall study period, Chinook salmon were much deeper at both the 0–20 and 80–100 m distance ranges from the dam than they were during the spring study period. During the RO only operation, the fish were concentrated over a relatively small area and were more concentrated in the area from 0–20 m from the dam than from 80–100 m from the dam (fig 1-26C).

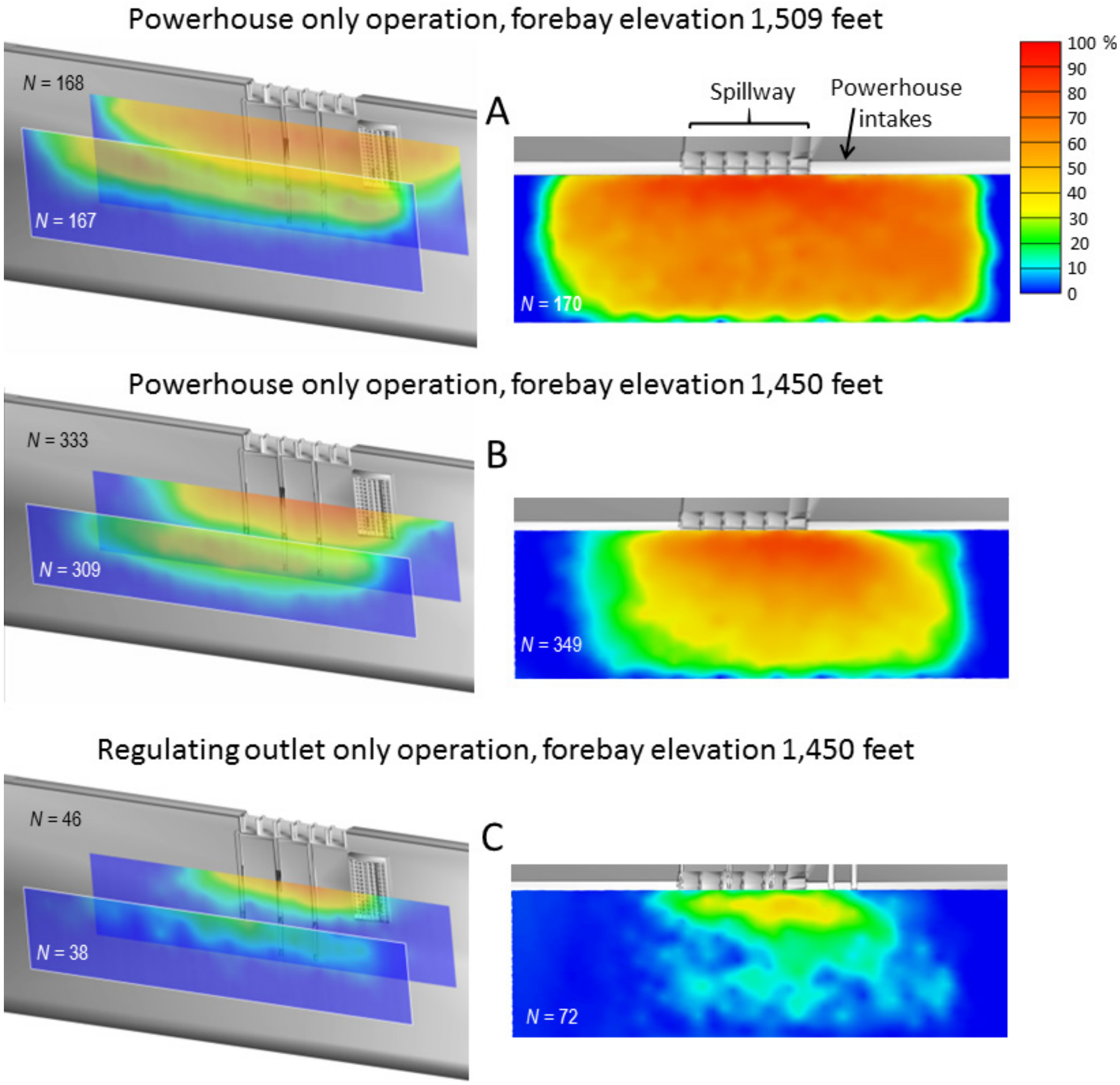

Figure 1-26. Distributions of the percent presence of juvenile Chinook salmon during powerhouse only and regulating outlet only operations in the forebay of Detroit Dam, Oregon, during the 2013 fall study period. Vertical slices (left) represent distributions of fish in the 0–20 and 80–100 meter distance ranges from the dam based on 20 x 10 meter cells. Plan views (right) represent distributions along the x-y plane within 105 meters of the dam based on in 10 × 10 meter cells. Sample sizes (*N*) are numbers of fish represented.

When the powerhouse and regulating outlet were operated together, Chinook salmon were most prevalent close to the dam and near the penstock opening, though there were relatively few fish present during this condition (fig. 1-27A and B). When all routes at the dam were closed, the fish were present over a larger area than when any routes were open, but the greatest concentration was still near the dam (fig. 1-27C).

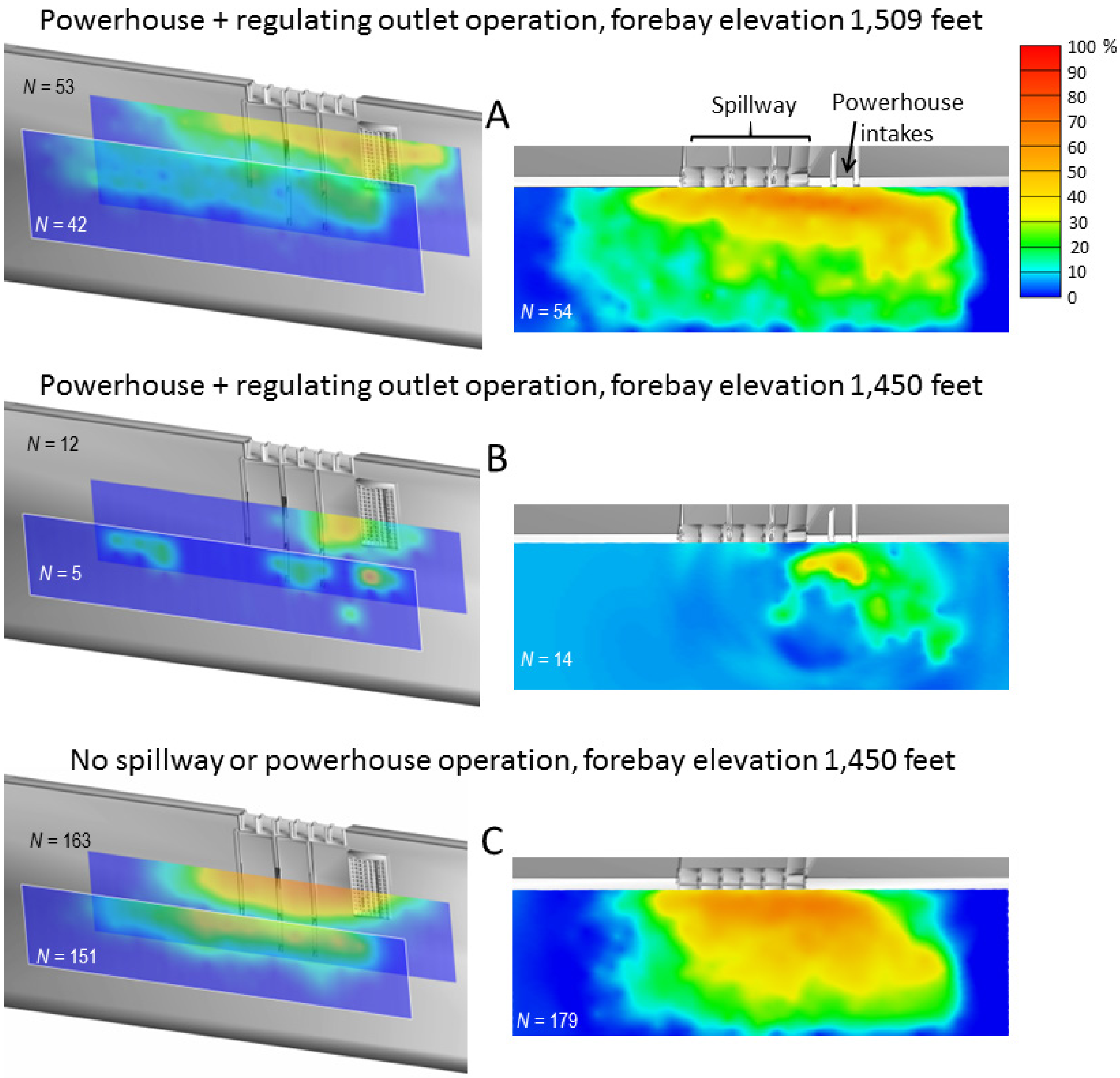

Figure 1-27. Distributions of the percent presence of juvenile Chinook salmon during powerhouse plus regulating operation and no spillway or powerhouse operation in the forebay of Detroit Dam, Oregon, during the 2013 fall study period. Vertical slices (left) represent distributions of fish in the 0–20 and 80–100 meter distance ranges from the dam based on 20 x 10 meter cells. Plan views (right) represent distributions along the x-y plane within 105 meters of the dam based on in 10 × 10 meter cells. Sample sizes (*N*) are numbers of fish represented.

Depths of tagged fish within 25 m of the dam varied between species, reservoir elevation and diel period (fig. 1-28). When the reservoir elevation was less than 1,525 ft during the spring study period, which occurred as the reservoir was filling in March and April, Chinook salmon showed a large diel difference in hourly depths. Their individual mean hourly depths ranged from 1.3 to 107.0 ft, with mean values around 60 ft during the day and 27 ft during the night (table 1-4). When the reservoir elevation was greater than the spillway ogee of 1,541 ft during the spring study period (spill was present during much of this period), the mean of the median hourly depths of Chinook salmon ranged from 5.2 to 43.9 ft, were deeper during the day than during the night, and were highly variable (recall the fish depths were summarized as the mean among the median depths of each fish in each hour).

Depths of steelhead were shallower and less variable than those of Chinook salmon during the spring study period (fig. 1-28). Steelhead were only present within 25 m of the dam when the reservoir elevation was greater than 1,541 ft, except for one fish present when the reservoir elevation was between 1,450 and 1,500 ft. Their mean of the median hourly estimated depths ranged from 1.6 to 10.1 ft and were similar during the day and night during both elevation bins available.

Position estimates of Chinook salmon and steelhead were present over a wide range of reservoir elevations during the fall study period, but most fish were present when the reservoir elevation was less than 1,525 ft. Chinook salmon often were deeper during the day than at night, but their depths were highly variable (fig. 1-29, table 1-4). The mean of their median hourly depths ranged from 9.5 to 70.5 ft when the reservoir elevation was at least 1,450 ft, and from 15.4 to 50.9 ft when the elevation was less than 1,450 ft. Few steelhead were present in the reservoir during the fall study period, but the mean of their median hourly depths ranged from 7.1 to 68.2 ft when the reservoir elevation was between 1,450 and 1,500 ft.

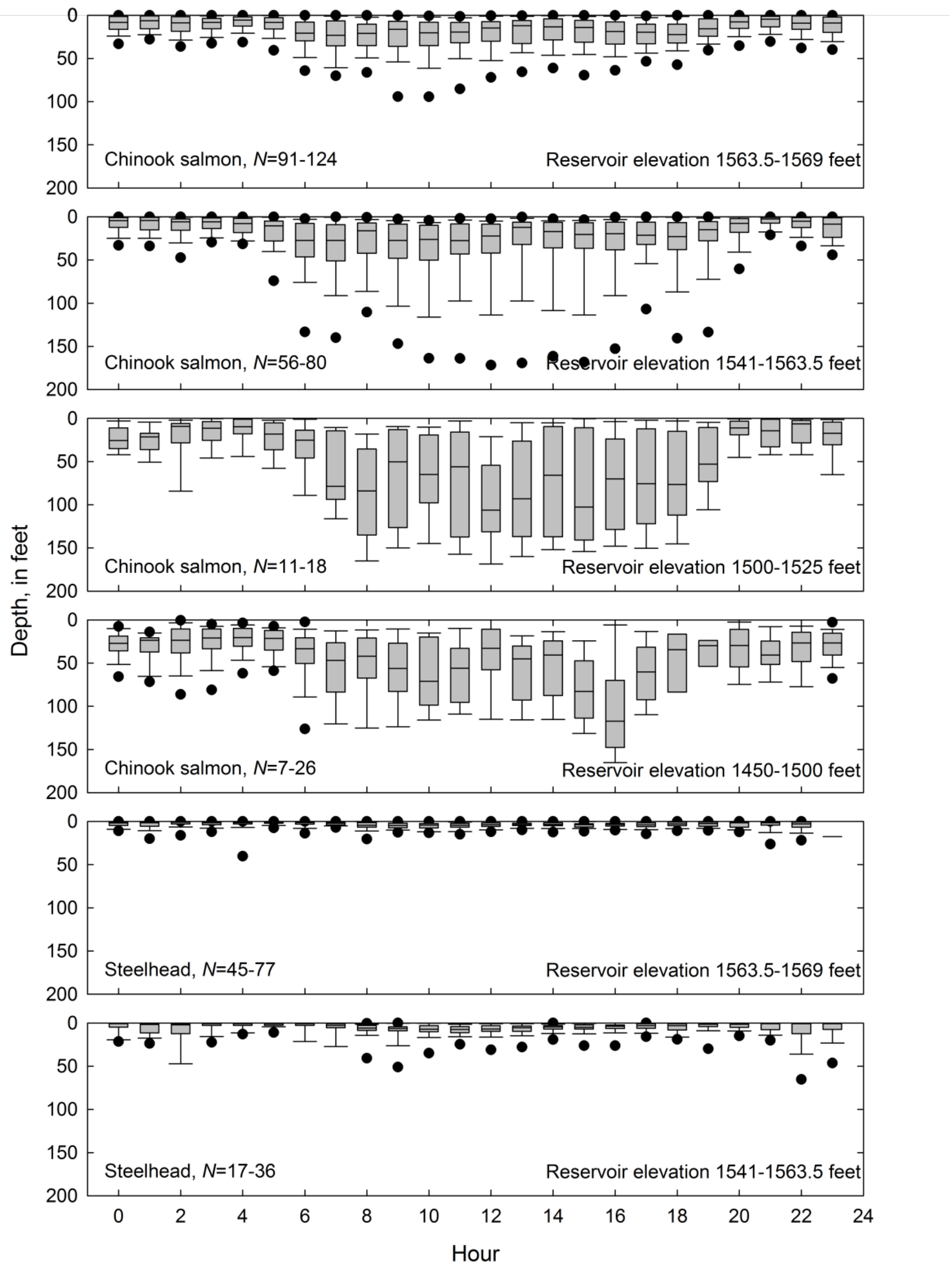

Figure 1-28. Boxplots of the hourly depths in feet of juvenile Chinook salmon and steelhead with position estimates within 25 meters of Detroit Dam, Oregon, during the 2013 spring study period. Data summarized are the median hourly depths of each fish present at the elevation ranges indicated. Boxes range from the 25th to the 75th percentiles with a line indicating the median, whiskers represent the 10th and 90th percentiles, and dots represent the 5th and 95th percentiles. Boxes without whiskers or dots contained insufficient data for them to be estimated. Sample sizes represent the number of fish (*N*) in the hourly boxes.

Table 1-4. Summary of the mean of the median hourly depths of each fish with position estimates within 25 meters of Detroit Dam, Oregon, during the 2013 spring and fall study periods.

[Reservoir elevations are expressed in feet. ≥, greater than or equal to; < less than; sample size, the number of fish from which the depths were estimated; SE, standard error; NA, not applicable. Elevation bins without data are not shown]

Season	Species	Reservoir elevation Bin	Diel period	Sample size	Mean (feet) Depth	Mean (feet) SE
Spring	Chinook salmon	≥1,563.5	Day	200	23.42	24.27
			Night	199	9.10	7.86
		1,541 to <1,563.5	Day	163	30.57	34.96
			Night	156	8.21	9.11
		1,525 to <1,541	Day	4	30.37	44.29
			Night	4	7.29	5.35
		1,500 to <1,525	Day	22	61.30	52.56
			Night	23	27.48	27.47
		1,450 to <1,500	Day	23	57.22	33.86
			Night	28	27.35	11.73
	Steelhead	≥1,563.5	Day	105	3.93	4.27
			Night	100	2.56	2.99
		1,541 to <1,563.5	Day	67	4.98	6.12
			Night	54	3.80	8.56
		1,450 to <1,500	Day	0	NA	NA
			Night	1	29.89	NA
Fall	Chinook salmon	1,541 to < 1,563.5	Day	1	35.50	NA
			Night	1	30.69	NA
		1,525 to <1,541	Day	53	54.57	15.01
			Night	56	24.09	16.93
		1,500 to <1,525	Day	84	59.59	20.05
			Night	98	15.75	12.43
		1,450 to <1,500	Day	344	54.27	24.45
			Night	395	22.24	13.48
		<1,450	Day	64	40.49	21.11
			Night	71	29.70	20.51
	Steelhead	1,525 to <1,541	Day	1	36.86	NA
			Night	0	NA	NA
		1,500 to <1,525	Day	4	14.65	9.57
			Night	2	15.58	7.93
		1,450 to <1,500	Day	7	39.09	42.85
			Night	10	29.02	27.47

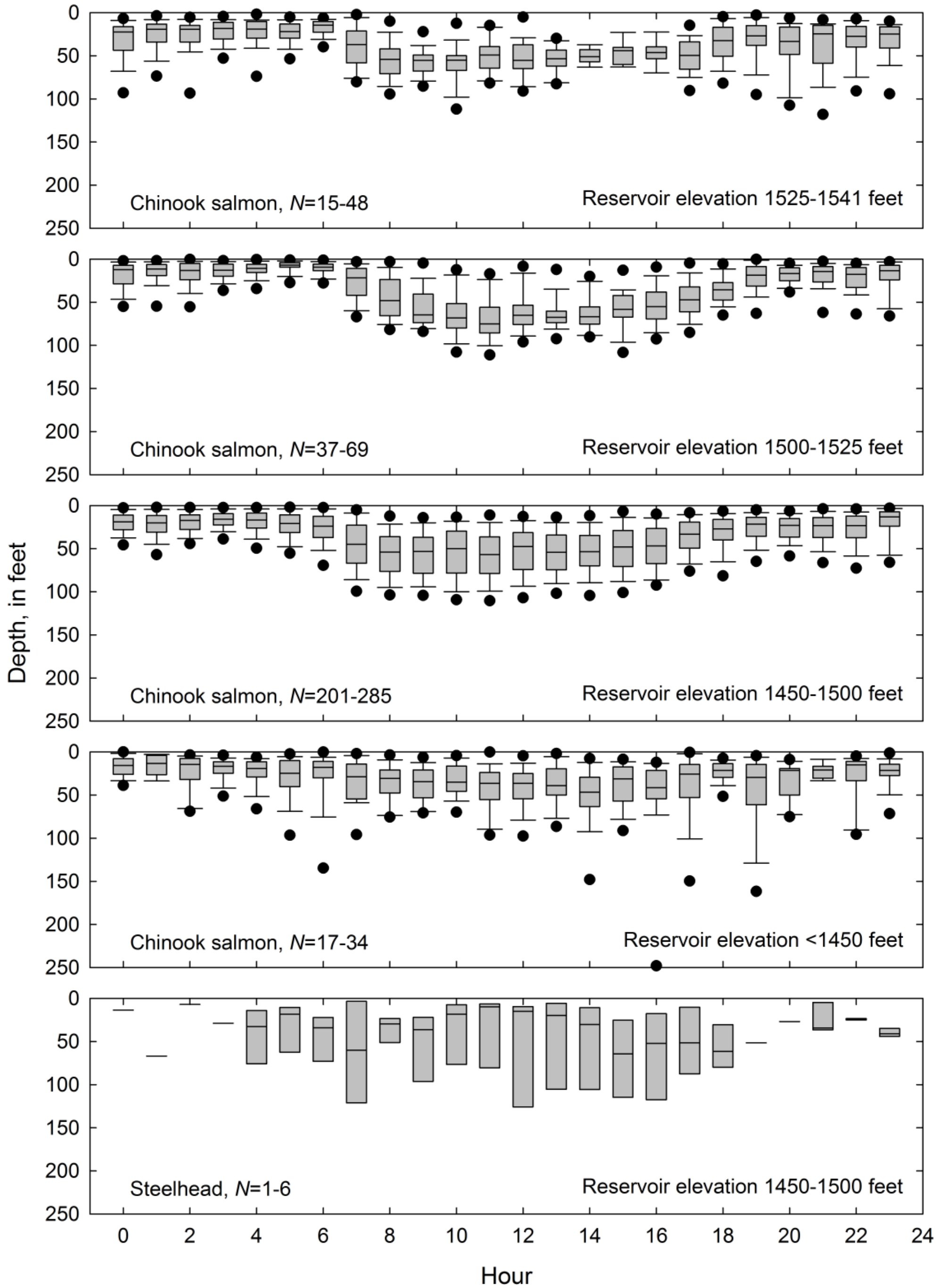

Figure 1-29. Boxplots of the hourly depths in feet of juvenile Chinook salmon and steelhead with position estimates within 25 meters of Detroit Dam, Oregon, during the 2013 fall study period. Data summarized are the median hourly depths of each fish present at the elevation ranges indicated. Boxes range from the 25th to the 75th percentiles with a line indicating the median, whiskers represent the 10th and 90th percentiles, and dots represent the 5th and 95th percentiles. Boxes without whiskers or dots contained insufficient data for them to be estimated. Sample sizes represent the number of fish (*N*) in the hourly boxes.

Dam Passage

The daily timing of passage events varied primarily by season. During the spring study period, 50.2 percent of the Chinook salmon (198 of 394 released), 38.5 percent of the steelhead released into the tributaries (40 of 104), and 15.2 percent of the steelhead released into the reservoir (19 of 125) passed the dam within the 90th percentile of their tag life. An additional 13 Chinook salmon and 15 steelhead were assigned passage after the tag life cutoff. Recall that only data within the 90th percentile of tag life were used in passage estimates to control for the effects of false negatives (passage of fish with non-functioning tags). The Chinook salmon passed between March 25, 2013, at 8:31:57 a.m., and July 9, 2013, at 12:39:33 a.m., and the steelhead passed between April 13, 2014, at 1:33:12 p.m., and June 13, 2013, at 4:27:15 a.m. Most dam passage of fish with known passage routes was at night during the spring study period: 77.2 percent of juvenile Chinook salmon, 89.2 percent of juvenile steelhead released into the tributaries, and 61.1 percent of the steelhead released into the reservoir passed at night (fig. 1-30). There also was a secondary peak of dam passage of Chinook salmon at mid-day. During the fall study period, 20.1 percent of the Chinook salmon (122 of 606 released) and none of the 271 steelhead released passed the dam within the 90th percentile of their tag life. A total of 11.4 percent of the Chinook salmon released and 0.7 percent of the steelhead released passed after the tag life cutoff. There was a greater predominance of night passage during the fall study period compared to the spring period, with 95.1 percent of the Chinook salmon and one of the two steelhead passing the dam at night during this period.

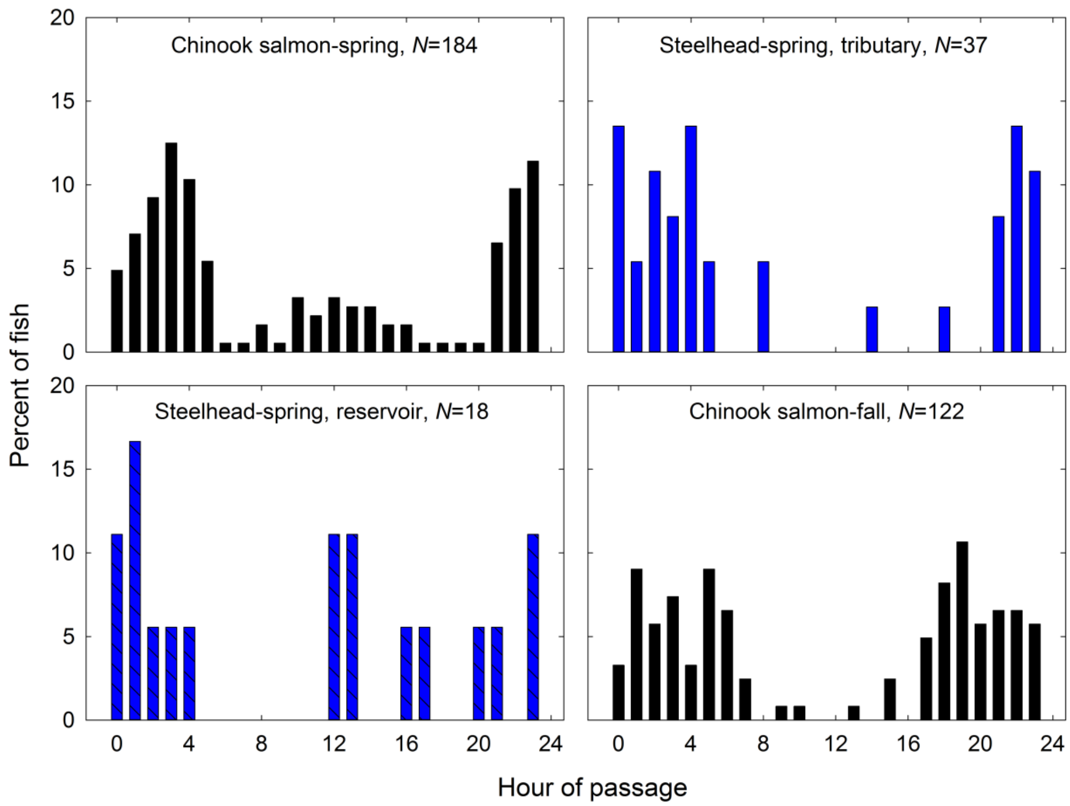

Figure 1-30. Graphs of the percentage of fish passing by hour at Detroit Dam, Oregon, during the 2013 spring and fall study periods.

Reservoir and Dam Passage Efficiencies

During the spring study period, the passage metrics were similar between Chinook salmon and steelhead released into the tributaries, but differed from those of steelhead released into the reservoir. A slightly lower proportion of steelhead released into the tributaries than Chinook salmon were detected in the reservoir (stream passage efficiency [STRE] 0.799 Chinook salmon, 0.663 steelhead), but once in the reservoir, the proportions detected at the head of the forebay (reservoir passage efficiency [RPE] 0.883 Chinook salmon, 0.855 steelhead) and passing the dam afterwards (dam passage efficiency [DPE] 0.712 Chinook salmon, 0.678 steelhead) were similar between groups (table 1-5). Most fish passing the dam were assigned a route—93 percent of Chinook salmon, 92.5 percent of steelhead released into the tributaries, and 94.5 percent of steelhead released into the reservoir. Nearly all Chinook salmon (181 of 184) and every steelhead (37) passing the dam with a known route during the spring study period did so by the spillway. There also were 3 Chinook salmon passing by the powerhouse and 14 passing by unknown routes. Slightly more than one-half of the steelhead released into the reservoir were detected at the head of the forebay (RPE 0.518) and about one-third of those passed the dam (DPE 0.328). The route effectiveness of the spillway was similar between the groups released into the tributaries (spillway passage efficiency [SPE] 3.05 for Chinook salmon, 2.92 for steelhead). The route effectiveness of the spillway for steelhead released into the reservoir was SPE 8.84, but there were few fish from which to make the estimate.

During the fall study period, the STRE and RPE of Chinook salmon were similar to the STRE and RPE in the spring study period, but passage metrics of steelhead differed from the spring and the Chinook salmon in the fall. The DPE and route of passage were the primary differences between passage metrics of Chinook salmon between the study periods. In the fall study period, the DPE of Chinook salmon was 0.266 and all but two of the fish passing the dam did so by the turbines with the other 2 by the RO (turbine passage efficiency [TPE] 0.984, 120 of 122; all fish were assigned a route). The route effectiveness of the turbines was 0.99, meaning that nearly 1 percent of fish passed for each percent of water passed by that route. Few steelhead from the fall study period were detected in the reservoir (STRE 0.258) or at the head of the forebay (RPE 0.286), and none of the 20 fish detected in the forebay passed the dam within the 90th percentile of their tag life.

The DPE also varied by forebay elevation. During the spring study period, the DPE of Chinook salmon when the forebay was at least 1,563.5 ft was higher than when it was between 1,541 and 1563.5 ft (0.515 versus 0.332; table 1-6). Similarly, the DPE of steelhead released into the tributaries and steelhead released into the reservoir were highest when the forebay elevation was at least 1,563.5 ft. The DPEs of the steelhead released into the tributaries were similar to the DPEs of the Chinook salmon and greater than those of the steelhead released into the reservoir. Few tagged fish were present at elevations lower than 1,541 ft during the spring study period.

During the fall study period, the greatest DPE for Chinook salmon was when the forebay elevation was between 1,450 and 1,500 ft (0.248). Eighty Chinook salmon were available for DPE estimates when the forebay was between 1,525 and 1,541 ft, and at least 116 tagged Chinook salmon were present during forebay elevations of less than 1,525 ft. Recall that there was no passage of tagged steelhead during the fall study period.

Table 1-5. Seasonal passage metric estimates, standard errors, and lower and upper 95-percent confidence intervals from the study of acoustic-tagged juvenile salmonids at Detroit Dam, Oregon, 2013.

[Sample size, number of tagged fish in the denominator of the estimate; SE, standard error; LCI, lower 95-percent confidence interval; UCI, upper 95-percent confidence interval; STRE, stream passage efficiency; RPE, reservoir passage efficiency; DPE, dam passage efficiency; FPE, fish passage efficiency; SPE, spillway passage efficiency; TPE, turbine passage efficiency; ROE, regulating outlet efficiency; NA, not applicable]

Study period	Species	Release site	Metric	Sample Size	Estimate	SE	LCI	UCI	Route effectiveness
Spring	Chinook salmon	Tributaries[1]	STRE	394	0.799	0.020	0.757	0.836	
			RPE	315	0.883	0.018	0.842	0.914	
			DPE	278	0.712	0.027	0.656	0.762	
			FPE	184	0.984	0.009	0.953	0.994	
			SPE	184	0.984	0.009	0.953	0.994	3.05
			TPE	184	0.016	0.009	0.006	0.047	0.02
	Steelhead	Tributaries[1]	STRE	104	0.663	0.046	0.568	0.747	
			RPE	69	0.855	0.042	0.753	0.919	
			DPE	59	0.678	0.061	0.551	0.783	
			FPE	37	1.000	0.000	0.906	1.000	
			SPE	37	1.000	0.000	0.906	1.000	2.92
			TPE	37	0.000	0.000	0.000	0.094	0.00
	Steelhead	Reservoir	STRE	125	NA	NA	NA	NA	
			RPE	112	0.518	0.047	0.426	0.608	
			DPE	58	0.328	0.062	0.221	0.456	
			FPE	18	1.000	0.000	0.824	1.000	
			SPE	18	1.000	0.000	0.824	1.000	8.84
			ROE	18	0.000	0.000	0.000	0.176	0.00
			TPE	18	0.000	0.000	0.000	0.176	0.00
Fall	Chinook salmon	Tributaries[2]	STRE	606	0.891	0.013	0.864	0.914	
			RPE	540	0.850	0.015	0.817	0.878	
			DPE	459	0.266	0.021	0.227	0.308	
			FPE	122	0.016	0.012	0.005	0.058	
			ROE	122	0.016	0.012	0.005	0.058	1.62
			TPE	122	0.984	0.012	0.942	0.996	0.99
	Steelhead	Tributaries[2]	STRE	271	0.258	0.027	0.210	0.314	
			RPE	70	0.286	0.054	0.193	0.401	
			DPE	20	0.000	0.000	0.000	0.166	
			FPE	0	NA	NA	NA	NA	
			ROE	0	NA	NA	NA	NA	0.00
			TPE	0	NA	NA	NA	NA	0.00

[1] The regulating outlets were not used during presence of this group.

[2] The spillway was not used during presence of this group.

Table 1-6. Dam passage efficiency estimates, standard errors, and lower and upper 95-percent confidence intervals, by pool elevation, from the study of acoustic-tagged juvenile salmonids at Detroit Dam, Oregon, 2013.

[The dam passage efficiency metrics are not adjusted for the length of time each condition was present. Total time is limited to periods when tagged fish were present in the forebay. <, less than; sample size, number of tagged fish in the denominator of the estimate; SE, standard error; LCI, lower 95-percent confidence interval; UCI, upper 95-percent confidence interval; NA, not applicable]

Season	Species	Release site	Reservoir elevation bin (feet)	Sample size	Estimate	SE	LCI	UCI
Spring	Chinook salmon	Tributaries	1,563.5 or greater	239	0.515	0.032	0.452	0.577
			<1,563.5 to 1,541	223	0.332	0.032	0.273	0.396
			<1,541 to 1,525	9	0.000	0.000	0.000	0.300
			<1,525 to 1,500	31	0.032	0.032	0.006	0.162
			<1,500 to 1,450	32	0.000	0.000	0.000	0.107
	Steelhead	Tributaries	1,563.5 or greater	57	0.491	0.066	0.366	0.617
			<1,563.5 to 1,541	43	0.279	0.068	0.168	0.427
			<1,541 to 1,525	0	NA	NA	NA	NA
	Steelhead	Reservoir	1,563.5 or greater	51	0.353	0.067	0.236	0.490
			<1,563.5 to 1,541	23	0.043	0.043	0.008	0.210
			<1,541 to 1,525	0	NA	NA	NA	NA
			<1,525 to 1,500	0	NA	NA	NA	NA
			<1,500 to 1,450	3	0.000	0.000	0.000	0.562
Fall	Chinook salmon	Tributaries	<1,563.5 to 1,541	1	0.000	0.000	0.000	0.794
			<1,541 to 1,525	80	0.050	0.024	0.020	0.122
			<1,525 to 1,500	136	0.044	0.018	0.020	0.093
			<1,500 to 1,450	408	0.248	0.021	0.208	0.292
			<1,450	116	0.095	0.027	0.054	0.162
	Steelhead	Tributaries	<1,563.5 to 1,541	0	NA	NA	NA	NA
			<1,541 to 1,525	1	0.000	0.000	0.000	0.794
			<1,525 to 1,500	6	0.000	0.000	0.000	0.390
			<1500 to 1,450	17	0.000	0.000	0.000	0.184
			<1,450	2	0.000	0.000	0.000	0.658

Effects of Selected Variables on Dam Passage Rate

The effects of several variables on dam passage rates were evaluated for the dam operating conditions during which sufficient numbers of tagged fish passed the dam. The most common condition during the spring study period was powerhouse only (49.7 percent of the period), but there was insufficient passage of tagged fish for analysis during that condition (15 Chinook salmon and 6 steelhead; table 1-7). The two conditions with sufficient data for analysis were the spillway only and powerhouse plus spillway conditions, comprising 21.1 and 8.6 percent of the spring study period, respectively. The weir spill condition occurred intermittently on April 9, 10, and 12, 2013, for a total of 26 h during which only two tagged fish passed the dam. Fewer conditions occurred during the fall study

Table 1-7. Summary of the frequency of use of various operating conditions and the numbers of tagged fish positioned within 25 meters of the dam passing during each condition at Detroit Dam, Oregon, during the 2013 spring and fall study periods.

[Routes include powerhouse (PH), regulating outlet (RO), and spillway (SP) used together, singly, or not at all (All off). Chinook salmon were released into the tributaries and steelhead were released into the tributaries (Sthd_trib) and reservoir (Sthd_res)]

	Spring study period				Fall study period		
	Percent of total time	Passage events			Percent of total time	Passage events	
Route in use		Chinook	Sthd_trib	Sthd_res		Chinook	Sthd_trib
--------- Condition = Weir spill ---------							
PH,SP,RO	0.0	0	0	0	0.0	0	0
PH, SP	0.0	0	0	0	0.0	0	0
PH,RO	0.0	0	0	0	0.0	0	0
SP,RO	0.0	0	0	0	0.0	0	0
PH	0.0	0	0	0	0.0	0	0
SP	100.0	2	0	0	0.0	0	0
RO	0.0	0	0	0	0.0	0	0
All off	0.0	0	0	0	0.0	0	0
Total	100.0	2	0	0	0.0	0	0
--------- Condition = Not weir spill ---------							
PH,SP,RO	0.0	0	0	0	0.0	0	0
PH, SP	8.6	55	13	11	0.0	0	0
PH,RO	0.0	0	0	0	0.9	1	0
SP,RO	0.0	0	0	0	0.0	0	0
PH	49.7	15	5	1	83.8	104	0
SP	21.1	114	20	6	0.0	0	0
RO	0.0	0	0	0	1.1	1	0
All off	20.7	10	1	1	14.2	4	0
Total	100.0	194	39	19	100.0	110	0

period than during the spring study period, and the powerhouse only condition (83.8 percent of the fall study period) was the only condition with sufficient passage for analysis. There was no water passing the dam during 20.7 percent of the spring study period and 14.2 percent of the fall study period. Note that there were several fish assigned dam passage during the "all off" condition; this likely occurred when fish passed very near the time the discharge was turned on or off.

Spring Study Period

Most of the passage events of tagged fish occurred during the spill only condition, followed by the spillway plus powerhouse and powerhouse only conditions. The spillway only and powerhouse plus spillway conditions had a sufficient number of passage events for analysis. There were 268 Chinook salmon, 60 steelhead released into the tributaries, and 52 steelhead released into the reservoir that were detected within 25 m of the dam during the spring study period. No more than 11 steelhead released into the reservoir passed the dam during any one operating condition, so they were not used in analyses and are not described further.

Spillway Only Condition.—There were 180 Chinook salmon and 42 steelhead released into the tributaries that were detected within 25 m of the dam during the spillway only condition during the spring study period. Chinook salmon were present between April 9 and August 8, 2012, with a maximum of 27 present per date. Steelhead released into the tributaries were present from April 7 to July 19, 2012, with a maximum of 8 present per date. The number of tagged fish passing the dam during the spillway only condition included 114 Chinook salmon (108 through the spillway, 6 through an undetermined route) and 20 steelhead released into the tributaries (all through the spillway).

Diel period was the only variable supported by the data and models as a significant determinant of dam passage rate during this condition. The models indicated that the rate of dam passage of Chinook salmon at night was 2.295 times (95-percent confidence interval of 1.425–3.696 times, $P > \chi^2 = 0.0006$) greater than the rate during the day, but no significant effect was supported for juvenile steelhead released into the tributaries (table 1-8). Results of a model based on data from both groups controlling for species-specific differences and restricted to the time period when both species were present was similar to the Chinook salmon model. That result likely is an indication of the greater number of Chinook salmon than steelhead in the data.

Table 1-8. Regression coefficients from analyses of the effects of selected variables on the rate of dam passage of juvenile Chinook salmon and steelhead within 25 meters of the upstream face of Detroit Dam, Oregon, during the powerhouse off, spillway on condition without weir spill during the 2013 spring study period.

[Results are based on analysis of three-dimensional position estimates of tagged fish within 25 meters of the dam. DF, degrees of freedom; Parm., parameter; Pr > ChiSq, probability of a larger Chi-Square value under the hypotheses that the parameter estimate equals 0; <, less than. Results are based on a significance threshold of alpha = 0.10. Diel period (0=day, 1=night) was the only significant variable. Data are from fish released into the tributaries.]

Species	Variable	DF	Parm.	Standard error	Chi-square	Pr > ChiSq	Hazard ratio	95-percent hazard ratio confidence limits	
Chinook salmon	Diel period	1	0.830	0.243	11.660	0.0006	2.295	1.425	3.696
Steelhead	Diel period	1	0.820	0.628	1.708	0.1913	2.271	0.664	7.772
Both[1]	Diel period	1	0.829	0.227	13.366	0.0003	2.292	1.469	3.574

[1] Data restricted to the time period in which both species were present.

Powerhouse Plus Spillway Condition.—There were 126 Chinook salmon and 41 steelhead released into the tributaries that were detected within 25 m of the dam during the powerhouse plus spillway condition during the spring study period. Chinook salmon were present between April 9 and August 6, 2013, with a maximum of 43 fish per date. Steelhead were present between May 7 and July 18, 2012, with a maximum of 5 fish per date. The numbers of tagged fish detected passing the dam during this condition included 55 Chinook salmon (53 through the spillway, 2 through an undetermined route) and 13 steelhead released into the tributaries (all through the spillway).

The variables supported as factors affecting dam passage rate during this condition depended on the discharge variable used in the models. The results were similar when project discharge or spillway discharge were used, although the model based on spillway discharge was better supported by the data as indicated by an AIC value 6 units smaller than the project discharge model (table 1-9). Both models indicated that dam passage was greater at night relative to the day and increased with fish length and discharge. The best-supported model indicates that dam passage rate was inversely related to fish size, decreasing 20.5 percent ([0.795 – 1.00] × 100, 95-percent confidence interval of -36.0 to -1.1 percent) for each 10 mm increase in fork length. The model also indicates that dam passage rate at night is 4.65 times greater than during the day, and that the passage rate increases 15.0 percent (95-percent confidence interval of 8.6–21.8 percent) for each 100 ft^3/s increase in spillway discharge. The exercise with powerhouse discharge as the discharge variable resulted in a final model that received essentially no support from the data compared to the spillway discharge model, given the 12.4-unit difference in AIC.

Only diel period was supported as a contributing factor of dam passage of steelhead released into the tributaries. Regardless of which of the three discharge variables were used, the result was identical (discharge was not supported) and indicated that the rate of dam passage at night was about 39 times greater than the rate during the day. The 13 passage events in this dataset were comprised of 12 passage events at night and 1 in the day, and because of the low number of passage events, caution is advised when interpreting the results.

Fall Study Period

All but 6 of the 110 passage events during the fall study period occurred during the powerhouse only condition (table 1-7). There were 12 tagged steelhead positioned within 25 m of the dam during the fall study period and none were detected passing the dam. There were 413 tagged Chinook salmon positioned within 25 m of the dam during the fall study period, including 384 during the powerhouse only condition. The numbers of tagged Chinook detected per date increased gradually after their arrival on September 12, 2013, peaked at 58 on December 4, 2013, and decreased gradually until they were absent after January 25, 2014. Data beginning on October 1, 2013, were used for analysis to coincide with the onset of fish passage on the next day. There were at least 10 tagged Chinook salmon detected within 25 m of the dam on most dates between October 18 and December 18, 2013.

Table 1-9. Regression coefficients from analyses of the effects of selected variables on the rate of dam passage of juvenile Chinook salmon and steelhead within 25 meters of the upstream face of Detroit Dam, Oregon, when the powerhouse and spillway were operated together during the 2013 spring study period.

[Results are based on analysis of three-dimensional position estimates of tagged fish within 25 meters of the dam. AIC, Akaike Information Criterion; Parm., parameter; Pr > ChiSq, probability of a larger Chi-Square value under the hypotheses that the parameter estimate equals 0; <, less than; NA, not applicable. Results are based on a significance threshold of alpha = 0.10. Significant variables include project discharge in 100 cubic feet per second (ft^3/s) increments (Proj.100cfs), spill discharge in 100 ft^3/s increments (Spill.100cfs), fork length in 10-millimeter increments (Fl.10), water temperature in Celsius in the upper 20 feet of the forebay (Temp.top20), and diel period (0 = day, 1=night). All variables have one degree of freedom. Data are from fish released into the tributaries]

Discharge variable	AIC	Variable	Parm.	Standard error	Chi-square	Pr > ChiSq	Hazard ratio	95-percent hazard ratio confidence limits	
		Chinook salmon							
Project	549.8	Fl.10	-0.2618	0.110	5.636	0.0176	0.770	0.620	0.955
		Diel period	1.6123	0.298	29.259	< 0.0001	5.015	2.796	8.994
		Proj.100cfs	0.0843	0.024	12.552	0.0004	1.088	1.038	1.140
Spillway	543.8	Fl.10	-0.2288	0.111	4.260	0.0390	0.795	0.640	0.989
		Diel period	1.5368	0.299	26.421	< 0.0001	4.650	2.588	8.355
		Spill.100cfs	0.1401	0.029	22.852	< 0.0001	1.150	1.086	1.218
Powerhouse	556.2	Fl.10	-0.2243	0.105	4.551	0.0329	0.799	0.650	0.982
		Diel period	1.4550	0.292	24.755	< 0.0001	4.284	2.415	7.600
		Temp.top20	0.4269	0.209	4.178	0.0410	1.532	1.018	2.308
		Steelhead							
Any	NA	Diel period	3.679	1.041	12.490	0.0004	39.603	5.148	304.639

Powerhouse Only Condition.—During the powerhouse only condition, the passage rate of juvenile Chinook salmon was influenced by diel period, fish length, powerhouse discharge, and forebay elevation. Diel period was the most influential factor, with the rate of dam passage at night 19.846 times greater than the rate during the day (95-percent confidence interval of 6.289–62.624; table 1-10). The model indicates a 17.6 percent increase in passage rate for each additional 10 mm in fork length, a 6.8 percent increase in rate per 100 ft^3/s addition to powerhouse discharge, and a 12.1 percent increase in rate per 10-ft reduction in forebay elevation. The predicted passage rate at an elevation of 1,454 ft (the 10th percentile in the data) is 1.98 times (95-percent confidence interval of 1.07–3.67 times) greater than the rate at an elevation of 1,507 ft (the 90th percentile in the data).

Comparison of Study Periods

The dam passage rates over the season-wide dam operating conditions were compared between study periods. In this analysis, only the variables of study period, diel period, and their interaction term were considered. Significant effects of all three variables were supported by the data, indicating there were differences in dam passage rates seasonally and during the day and night, as well as unique effects of diel period within each study period (table 1-11). The passage rate was greater during the spring period than during the fall period, and the effect of diel period was greater in the fall period. Specifically, the model predicts that day dam passage rates during the spring study period were 18.1 times (95-percent confidence interval of 6.5–50.4 times, $P > \chi^2 < 0.0001$) greater than rates during the fall study period, and that night dam passage rates during the spring study period were 5.1 times (95-percent confidence interval of 4.0–6.6 times, $P > \chi^2 < 0.0001$) greater than rates during the fall study period. In the spring study period, the dam passage rate during the night was 4.2 times (95-percent confidence interval of 3.0–5.9 times, $P > \chi^2 < 0.0001$) greater than during the day. In the fall study period, the dam passage rate during the night was 14.9 times (95-percent confidence interval of 5.5–40.4 times, $P > \chi^2 < 0.0001$) greater than during the day.

Table 1-10. Regression coefficients from analyses of the effects of selected variables on the rate of dam passage of juvenile Chinook salmon within 25 meters of the upstream face of Detroit Dam, Oregon, during the powerhouse on, regulating outlet and spillway off condition during the 2013 fall study period.

[Results are based on analysis of three-dimensional position estimates of tagged fish within 25 meters of the dam. DF, degrees of freedom; Parm., parameter; Pr > ChiSq, probability of a larger Chi-Square value under the hypotheses that the parameter estimate equals 0; <, less than. Results are based on a significance threshold of alpha = 0.10. Significant variables include fork length in 10-millimeter increments (Fl.10), powerhouse discharge in 100 cubic feet per second (ft^3/s) increments (Ph.100cfs), forebay elevation in 100-ft increments (Fbelev.10), and diel period (0=day,12=night)]

Variable	DF	Parm.	Standard error	Chi-square	Pr > ChiSq	Hazard ratio	95-percent hazard ratio confidence limits	
Fl.10	1	0.1625	0.087	3.482	0.0620	1.176	0.992	1.395
Ph.100cfs	1	0.0655	0.018	13.977	0.0002	1.068	1.032	1.105
Fbelev.10	1	-0.1289	0.059	4.710	0.0300	0.879	0.782	0.988
Diel period	1	2.9880	0.586	25.973	< 0.0001	19.846	6.289	62.624

Table 1-11. Regression coefficients from analyses of the effects of study period (spring and fall) and diel period on rate of dam passage of juvenile Chinook salmon within 25 meters of the upstream face of Detroit Dam, Oregon, during the 2013 spring and fall study periods.

[Results are based on analysis of three-dimensional position estimates of tagged fish within 25 meters of the dam. DF, degrees of freedom; Parm., parameter; Pr > ChiSq, probability of a larger Chi-Square value under the hypotheses that the parameter estimate equals 0; <, less than. Results are based on a significance threshold of alpha = 0.10. Significant variables include study period (0 = spring, 1 = fall), diel period (0=day, 1=night), and their interaction term (study*diel)]

Variable	DF	Parm.	Standard error	Chi-square	Pr > ChiSq	Hazard ratio	95-percent hazard ratio confidence limits	
Study period	1	-2.8948	0.520	30.927	< 0.0001	0.055	0.020	0.153
Diel period	1	1.4441	0.166	75.399	< 0.0001	4.238	3.059	5.871
Study*diel	1	1.2570	0.536	5.505	0.0190	3.515	1.230	10.045

Detections Downstream of Detroit Dam

Travel Times

Travel time varied by species, season, and reach, and includes data collected after the 90th percentile of the tag life. The median travel time of Chinook salmon from passage at Detroit Dam to first detection at Minto Dam was about 1 day during the spring study period and about one-half day during the fall study period. Overall, travel times of Chinook salmon released in the fall were faster than travel times of Chinook salmon released in the spring (table 1-12, figs. 1-31 and 1-32). Median travel rates were greatest in the Minto Dam-to-Salem reach (2.71–4.67 km/h, depending on species and study period) followed by the Salem-to-Wilsonville reach (1.71–3.00 km/h depending on species and study period). Median travel rates were slowest in the 4.5 km-long reach between Detroit and Big Cliff Dams (0.20–0.39 km/h). The overall median travel time for Chinook salmon from Detroit Dam passage to first detection at the Portland site was 7.97 d in the spring and 6.25 d in the fall (table 1-12, fig. 1-33). The median travel time from passage to Portland for steelhead released in the spring study period was 7.54 d for those released into the tributaries and 8.68 d for those released into the reservoir.

Table 1-12. Travel times and median travel rates, by river reach, of Chinook salmon and steelhead released at Detroit Reservoir, spring and fall 2013.

[Only two steelhead released in the fall were detected downstream of Detroit Dam and were not presented. *N*, number of fish; rkm, river kilometer; km/h, kilometer per hour; NA, not applicable]

Species and season	River reach	Distance (rkm)	*N*	Travel time (days)			Median travel rate (km/h)
				Mean	Median	Range	
Chinook salmon- spring							
	Passage to Big Cliff Dam	4.5	153	1.11	0.64	0.14–45.49	0.29
	Big Cliff Dam to Minto Dam	6.5	111	1.52	0.39	0.01–33.28	0.69
	Minto Dam to Salem	127.1	75	2.13	1.55	0.81–16.97	3.41
	Salem to Wilsonville	73.5	60	1.77	1.35	0.73–9.01	2.26
	Wilsonville to Portland	40.3	41	2.49	2.27	1.14–5.66	0.74
	Portland to Columbia	37.0	17	1.81	1.70	1.15–3.90	0.91
	Passage to Portland	251.9	41	9.78	7.97	3.60–32.47	1.32
Steelhead- spring, tributaries							
	Passage to Big Cliff Dam	4.5	34	1.11	0.84	0.12–5.00	0.22
	Big Cliff Dam to Minto Dam	6.5	29	0.73	0.14	0.04–6.13	1.88
	Minto Dam to Salem	127.1	24	2.27	1.96	0.81–4.56	2.71
	Salem to Wilsonville	73.5	24	1.70	1.46	0.86–4.52	2.09
	Wilsonville to Portland	40.3	23	2.03	1.79	0.99–4.72	0.94
	Portland to Columbia	37.0	5	1.17	1.20	0.96–1.26	1.29
	Passage to Portland	251.9	23	8.42	7.54	4.16–14.73	1.39
Steelhead- spring, reservoir							
	Passage to Big Cliff Dam	4.5	27	1.39	0.96	0.15–6.40	0.20
	Big Cliff Dam to Minto Dam	6.5	17	0.41	0.12	0.04–4.16	2.30
	Minto Dam to Salem	127.1	9	2.57	1.85	1.00–8.50	2.86
	Salem to Wilsonville	73.5	8	2.07	1.79	1.31–4.09	1.71
	Wilsonville to Portland	40.3	7	2.39	2.09	1.36–4.06	0.80
	Portland to Columbia	37.0	5	1.17	1.07	1.00–1.66	1.44
	Passage to Portland	251.9	7	8.80	8.68	4.46–13.66	1.21
Chinook salmon- fall							
	Passage to Big Cliff Dam	4.5	132	5.92	0.48	0.10–133.34	0.39
	Big Cliff Dam to Minto Dam	6.5	67	0.57	0.09	0.03–15.12	2.91
	Minto Dam to Salem	127.1	44	1.48	1.13	0.76–4.27	4.67
	Salem to Wilsonville	73.5	51	1.23	1.02	0.58–3.47	3.00
	Wilsonville to Portland	40.3	51	2.83	1.57	0.32–23.15	1.07
	Portland to Columbia	37.0	NA	NA	NA	NA	NA
	Passage to Portland	251.9	54	19.53	6.25	2.58–116.81	1.68

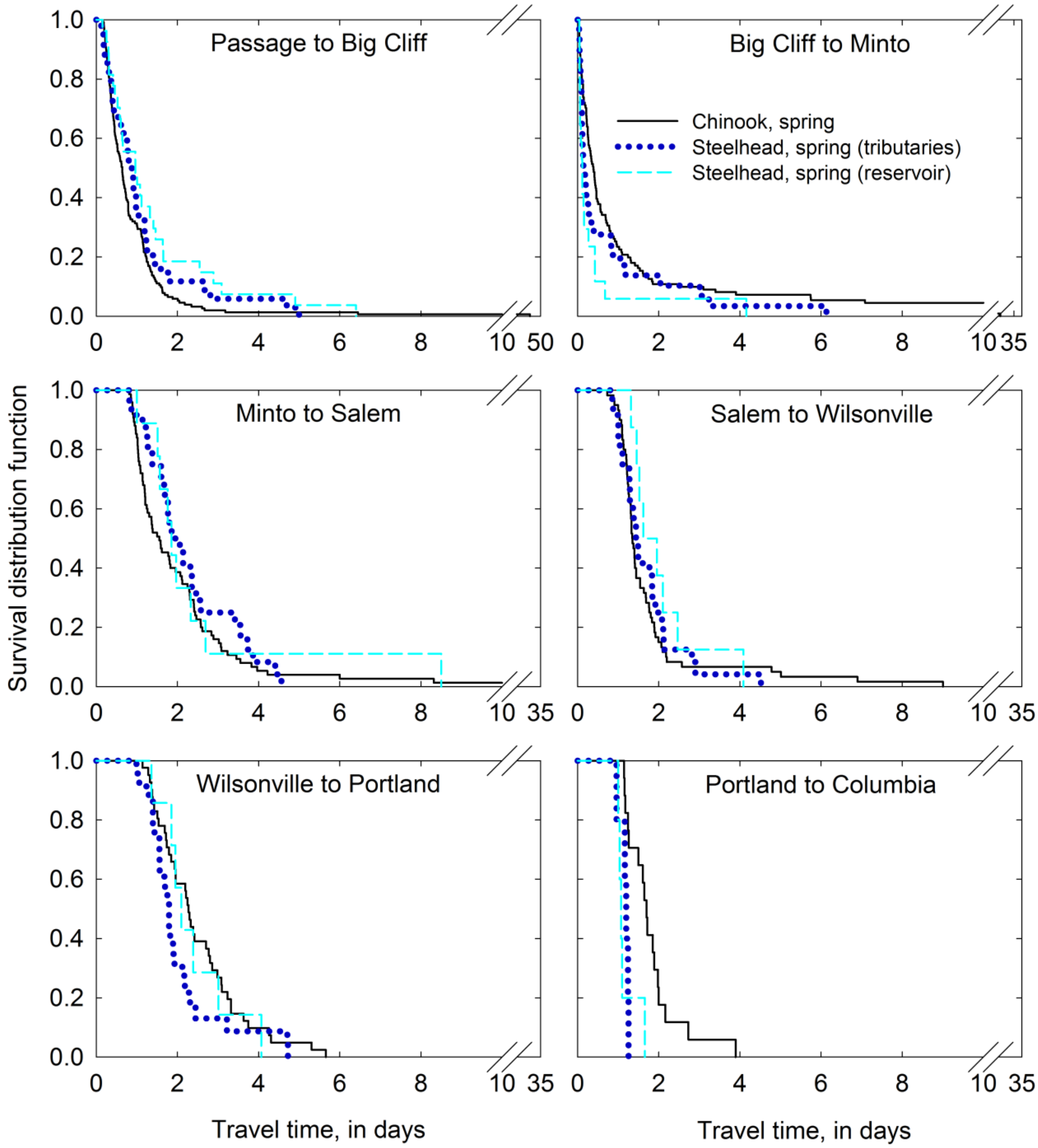

Figure 1-31. Graphs showing travel time from the last detection at an upstream site to the first detection at the next downstream site for fish released in the spring at Detroit Reservoir, 2013. Note the different x-axis on the Passage to Big Cliff plot.

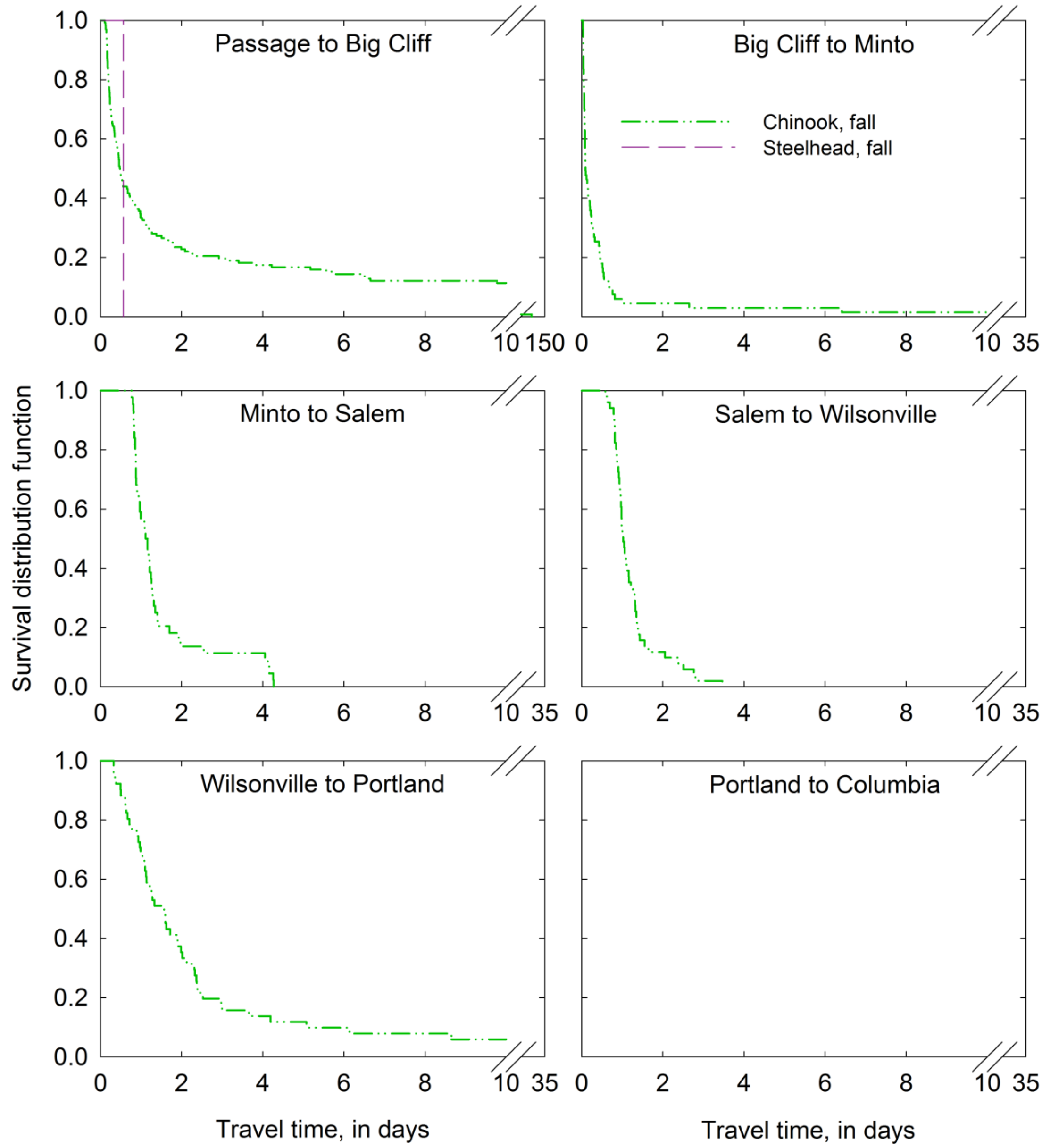

Figure 1-32. Graphs showing travel time from the last detection at an upstream site to the first detection at the next downstream site for fish released in the fall at Detroit Reservoir, 2013. Note the different x-axis on the Passage to Big Cliff plot.

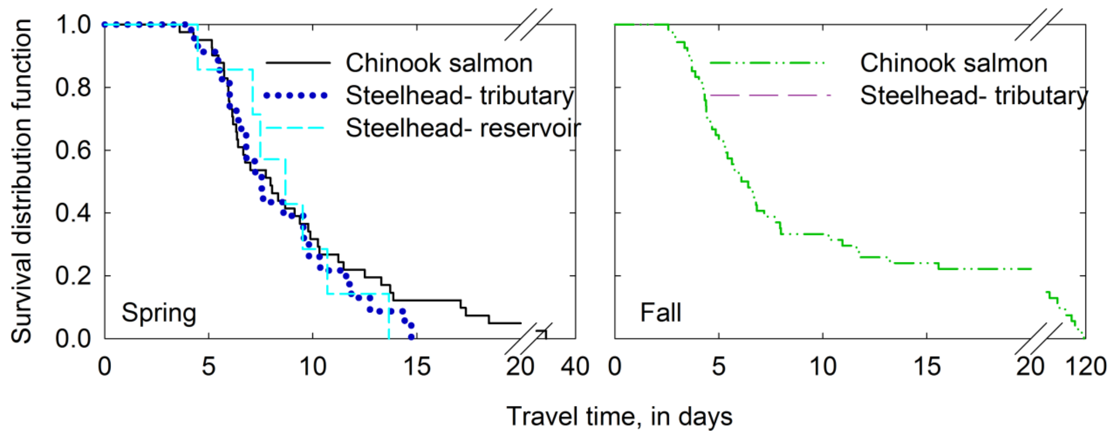

Figure 1-33. Graphs showing travel time from passage at Detroit Dam until first detection at the Portland site for fish released at Detroit Reservoir, 2013. Note the difference in x-axis scales.

Survival

The reach survival estimates of fish released during the spring study period were consistently higher for steelhead than for Chinook salmon, and the estimates for Chinook salmon differed slightly between seasons. Point estimates of reach survival during the spring study period ranged from 0.700 to 0.955 for juvenile steelhead and from 0.670 to 0.812 for Chinook salmon, but the reach-specific differences were within the error of the estimates (table 1-13). Point estimates of reach-specific survival of Chinook salmon in the fall study period ranged from 0.622 to 0.921 and, compared to estimates from the spring study period, were slightly lower in the upstream reaches and slightly higher in the downstream reaches.

The estimated cumulative survival from passage at Detroit Dam to detection at the Portland site 251.9 km downstream ranged from 0.207 to 0.392, depending on season and species. In the spring study period, the estimate for juvenile steelhead (0.392, 95-percent confidence interval of 0.255–0.529) was higher than that for Chinook salmon (0.206, 95-percent confidence interval of 0.149–0.263). The estimate for Chinook salmon in the fall study period was 0.270 (95-percent confidence interval of 0.104–0.436). The differences between cumulative survival estimates between species and seasons generally were within the error of the estimates. However, during the spring study period, the cumulative survivals of steelhead were consistently greater than survivals of Chinook salmon.

The cumulative survival decreased sharply in the first 11 km downstream of Detroit Dam, and decreased slowly thereafter (fig. 1-34). The first 11 km was between Detroit Dam and the forebay of Minto Dam, and included passage through Big Cliff Reservoir and Dam. In the spring study period, this reach accounted for 59.1 percent of cumulative Chinook salmon mortality between Detroit Dam and Portland and 63.1 percent of the cumulative steelhead mortality in that reach. In the fall study period, the first 11 km accounted for 80.0 percent of the cumulative mortality of Chinook salmon between Detroit Dam and Portland. The survivals per 100 km through the reaches of Detroit Dam to Minto Dam and Minto Dam to Portland were 0.003 and 0.675, respectively, for Chinook salmon released in the spring; 0.012 and 0.829, respectively, for steelhead released in the spring; and less than 0.001 and 0.836, respectively, for Chinook salmon released in the fall.

Table 1-13. Estimated survival probabilities, by river reach, ending at each detection array for juvenile Chinook salmon and steelhead released in the spring and fall of 2013 and detected between Detroit Dam and Portland, Oregon.

[Fish were released in tributaries upstream of Detroit Reservoir or near the head of the reservoir during the spring study period and detected from May 8 to July 19, 2013, or released during the fall study period and detected from October 3, 2013 to April 10, 2014. No steelhead released in the fall were detected downstream within the 90th percentile of the empirical tag life. Prob, probability; SE, standard error; LCI, lower 95-percent confidence interval; UCI, upper 95-percent confidence interval]

Season	River reach	Chinook salmon				Steelhead			
		Prob	SE	LCI	UCI	Prob	SE	LCI	UCI
Spring	Detroit Dam to Big Cliff Dam	0.716	0.032	0.649	0.775	0.784	0.058	0.651	0.876
	Big Cliff Dam to Minto Dam	0.741	0.037	0.662	0.807	0.786	0.068	0.625	0.890
	Minto Dam to Salem	0.670	0.046	0.574	0.754	0.700	0.084	0517	0.836
	Salem to Wilsonville	0.812	0.047	0.702	0.887	0.955	0.044	0.739	0.994
	Wilsonville to Portland	0.714	0.060	0.583	0.817	0.952	0.046	0.729	0.993
Fall	Detroit Dam to Big Cliff Dam	0.622	0.092	0.433	0.780				
	Big Cliff Dam to Minto Dam	0.670	0.114	0.424	0.848				
	Minto Dam to Salem	0.823	0.114	0.501	0.955				
	Salem to Wilsonville	0.921	0.088	0.523	0.992				
	Wilsonville to Portland	0.857	0.118	0.475	0.976				

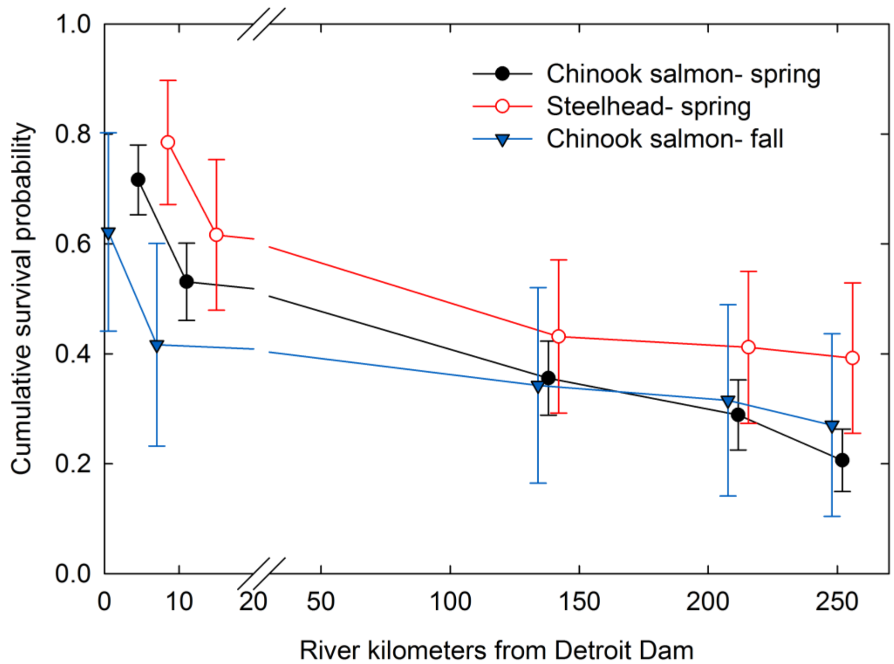

Figure 1-34. Graph showing cumulative survival probabilities by season and species of fish passing Detroit Dam, Oregon, 2013 spring and fall study periods. Chinook salmon released in the fall and steelhead were plotted at -4 river kilometers (rkm) and +4 rkm, respectively, for clarity. The x-axis scale is broken between 20 and 30 rkm. Whiskers represent 95-percent confidence intervals

Discussion

This study was the second year of a 2-year effort to provide information about fish movements in the reservoir, locations near the dam, and factors affecting dam passage rates to inform decisions about future downstream salmonid passage alternatives. The study was a continuation of work at Detroit Reservoir and Dam described by Beeman and others (2014a) and similar to earlier work completed at Cougar Reservoir and Dam (Beeman and others, 2013, 2014b).

The results were based on juvenile Chinook salmon and juvenile steelhead of hatchery origin intended as surrogates for wild fish in the reservoir. The Chinook salmon were about 50 mm shorter than yearling wild fish in the spring and similar in size to subyearling wild fish in the fall, based on Oregon Department of Fish and Wildlife net catches of wild fish in the reservoir in 2012 (Monzyk and others, 2013). The steelhead were intended to represent wild fish that may be released upstream of Detroit Dam in the future, as there were no adult outplants during the period studied. If steelhead are reintroduced upstream of Detroit Dam, they likely will be a winter run stock to represent the native life history type, but we used a summer run stock because there was no hatchery program for winter run steelhead in the Willamette River Basin at the time.

Fish movements through the reservoir generally were similar for Chinook salmon and steelhead released into the tributaries, but few steelhead released into the reservoir were detected near the dam. As in 2012, during the spring study period, the Chinook salmon migrated from the tributary release sites in greater proportion than the steelhead, but the behaviors of the two species were similar once detected in the reservoir (Beeman and others, 2014a). In the fall study period, the steelhead migrated to and through the reservoir in lower proportions than the Chinook salmon, perhaps because of the use of a summer stock of steelhead. Based on the data from 2012, we released some of the steelhead into the reservoir in late February 2013 to have tagged steelhead near the dam when the spillway was opened in early April. Few of the fish released into the reservoir were detected migrating downstream earlier than those released into the tributaries, so the action was not successful.

The movements of both species were directionally persistent in the reservoir and the high probability of migrating back downstream shortly after turning upstream at the dam resulted in a net accumulation of fish in the forebay. Most fish made more than one trip from one end of the reservoir to the other. This pattern is similar to previous results at Detroit and Cougar Reservoirs and likely reflects low dam passage rates of fish arriving near the dam (Beeman and others, 2013, 2014a, b). Juvenile Chinook salmon within 25 m of the dam were deeper in the day than at night, and were deeper during the fall study period than during the spring study period. Juvenile steelhead within 25 m of the dam were shallow during the day and night, and were considerably shallower than Chinook salmon. These diel and species differences are similar to differences described for these species elsewhere (Smith, 1974; Beeman and Maule, 2006). The depths we report generally are similar to depths from catches in gill nets reported by Monzyk and others (2013) for August through October, but are deeper than they report for later in the calendar year.

Fish locations near the dam were most prevalent near the routes of water passage, but during the powerhouse only condition, fish were widely dispersed in the area monitored within 105 m of the dam. During the spring study period, the spatial distribution of tagged fish in this area was nearer to the dam than during the fall study period, but even when all routes were closed during the fall study period, most fish in the area were near the dam. This observation may suggest that the dam operating conditions have limited effect on fish distributions near the dam; however, that may be an artifact of the varied hourly operating conditions at the dam and the relatively short duration of any one condition. That is, each dam operating condition may occur for too short a time for condition-specific hydraulic conditions to stabilize in the forebay. If so, the results collected during the existing structural and operational conditions may be of limited value in predicting fish distributions during an alternative scenario such as if a single water temperature control and fish passage alternative were in place. However, the data support the premise that fish near Detroit Dam are attracted to the water passing the dam and also could be attracted to a properly designed passage alternative.

Dam passage rates of fish within 25 m of the dam were affected by several measured factors, but the largest effects were seasonal conditions and diel period. Unlike the pattern at several other dams in the Willamette Valley Project, fish passage rates at Detroit Dam were greatest in the spring and summer and lowest in the fall and winter (Keefer and others, 2013). The high proportion of fish passage through the spillway, the high spill effectiveness relative to the other routes, and the support for models of passage rates based on spillway discharge over those of powerhouse discharge all provide clear evidence that the spring-dominated seasonal passage at Detroit Dam is largely owing to the operation of the seasonally available spillway during the spring and summer. The natural timing of the seaward migration of juvenile salmonids is during the spring and fall, but the observed passage timing at many Willamette River Basin dams primarily represents dam operating conditions (Keefer and others, 2011).

The passage rate was much greater in the spring study period than in the fall study period, but the fish passage at Detroit Dam occurred slowly. For example, the median travel time from detection at the head of the forebay to dam passage was 26.8 d for Chinook salmon during the 2013 spring study period at Detroit Dam, was 42.6 d from about 200 m upstream of the temperature control tower to dam passage at Cougar Dam during the fall and winter of 2012, and was less than 7 h from the entrance at the 2-km forebay to passage at Little Goose Dam on the Snake River in 2009 (Beeman and others, 2010, 2014b). This shows the difference between passage time at dams on two flood-control reservoirs on tributaries of the Willamette River and that of a run-of-river dam on the Snake River. The low overall rate of dam passage at Detroit Dam is further supported by the low estimated probabilities of dam passage after entering the forebay, which were about 1 in 10 during the spring study period and 1 in 100 during the fall study period. Apart from season and diel period, passage rates were directly related to discharge and inversely related to reservoir elevation, which is consistent with previous results at Detroit and Cougar Reservoirs (Beeman and others, 2013, 2014a, b). The near lack of passage of tagged steelhead during the fall study period may be related to the use of a summer-run stock, but results from tagged winter-run steelhead at Foster Dam were similar to those we report, suggesting it is a seasonal phenomenon (James Hughes, Pacific Northwest National Laboratory, written commun., February 24, 2015).

The hydrophones installed at sites downstream of Detroit Dam were useful for confirming dam passage and estimating travel rates and survival. The travel rates were slowest between Detroit and Big Cliff Dams, fastest from Big Cliff Dam to the Willamette River at Salem, and intermediate though the Willamette River from Salem to Portland. The varied travel rates through the different reaches show the importance of separately estimating travel rates through functionally distinct river reaches, such as the North Santiam and Santiam Rivers versus the Willamette River. The estimated survival was lower in the 11 km between Detroit Dam and Minto Dam (a reach including Big Cliff Reservoir and Dam) than in the remaining 241 km from Minto Dam to Portland. Estimating survival was not a primary objective of the study, so we used a single-release design rather than a multiple-release design commonly used to estimate survival over short distances such as passage at a dam. Our estimates of survival, therefore, incorporate mortality from factors including dam passage, predation, and effects of tagging and handling. The estimated survivals per 100 km in the Minto-Dam-to-Portland reach (0.675–0.836) were similar to survivals of juvenile salmon in the free-flowing sections of the Klamath (0.709), Trinity (0.639), and Snake (0.897) Rivers (Williams and others, 2004; Beeman and others, 2012; Chase and others, 2012).

The available data support the premise that a properly designed surface passage route could successfully collect juvenile Chinook salmon and steelhead at Detroit Dam. This is supported by the high probability of tagged fish in the reservoir reaching the dam, the chance for repeated encounters with a structure near the dam, and the frequent shallow depths of the fish. The existing spillway also could be an effective means to attract and pass juvenile salmonids, as indicated by the predominant use of that route when available, but even passage rates through this route can be low if used sparingly or with too low a discharge. Data from the 2012 study indicated that use of the RO during the fall study period resulted in increased passage through the powerhouse, so use of an RO does not seem to be a fruitful a means to divert fish from turbine passage when the powerhouse also is operating (Beeman and others, 2013). The survival of juvenile salmonids after passage at Detroit Dam was low until Minto Dam, although the available data do not enable separation of the effects of dam passage from other potential mortality pressures. Survival between the Minto Dam forebay and downtown Portland was similar to the rates described in other free-flowing river systems, indicating a normative migration corridor following dam passage.

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Chapter 2. Investigation of Methods for Successful Installation and Operation of JSATS Hydrophones in the Willamette River, Oregon, 2013

By Matthew D. Sholtis, Gary L. Rutz, Noah S. Adams, and John W. Beeman

Introduction

Mark-recapture methods commonly are used to estimate various population parameters including the timing and success of migration, dam passage probabilities, and in-river survival (Burnham and others, 1987; Williams and others, 2001; Perry and others, 2010). Marks identifying individual animals often are the most useful for such studies, and include passive integrate transponder (PIT) tags and active telemetry systems such as radio or acoustic telemetry. Under appropriate conditions, active telemetry systems have larger detection ranges and higher detection probabilities than passive systems such as PIT tags, and some offer transmitter positioning capabilities (Adams and others, 2012). For these reasons, active telemetry commonly is used for such studies within the Columbia River Basin to study juvenile salmonids and other fishes.

Recent studies funded by the U.S. Army Corps of Engineers (USACE) have relied almost exclusively on the Juvenile Salmon Acoustic Telemetry System (JSATS) as the active transmitter technology. The JSATS system (McMichael and others, 2010) is an acoustic telemetry system operating at a frequency of 416.7 kilohertz and is based on design specifications provided by USACE. The JSATS family of receiving equipment includes one system based on independent (autonomous) hydrophones and another based on hydrophones connected to a central computer by cables. The latter system uses a common time signature enabling positioning of transmitters based on hydrophone position and time-of-arrival of the transmitter pulses. The current transmitters are among the smallest active transmitters available, with a dry weight in air of about 0.3 g. There are ongoing studies using this system at several Columbia River and Snake River dams, Cougar and Detroit Reservoirs, and elsewhere.

Acoustic telemetry generally performs poorly in shallow, turbulent waters. Detection range primarily is dependent on spreading loss and distortion as the signal travels through the water and the noise levels at the receiver (Pincock and Johnston, 2012). Sources of noise at the receiver primarily are acoustic noise (that is, substrate movement, wave action, and water current), but also include entrained air, vegetation, suspended sediment, and reflections from surfaces such as the river bottom or the air-water interface, which further reduce effectiveness. Additionally, changes to the pattern of deployment within the same site can affect detection probabilities (Clements and others, 2005). Each of these conditions may be present to varying degrees in the Willamette River and its tributaries. Thus, careful selection of deployment sites and methods (type and arrangement of hydrophones) were considered to optimize the likelihood of detecting transmissions from the acoustic transmitters in this study.

Sources of noise can mimic the signal from valid transmitters and result in false-positive detections, which must be reduced or eliminated prior to making inferences from the data (Beeman and Perry, 2012). False-positive detections are present in all active telemetry systems and often are prevalent in acoustic systems. Common sources of false-positives are high water velocities, multipath detections from reflective surfaces, ambient noise, and interference or collisions of signals from more than one transmitter. The probability of false positives depends on many factors, including the physical environment, the numbers of transmitters simultaneously present at a telemetry receiver, how the data are transmitted, and how the transmission is assigned to an individual animal. The probability of accepting false-positive records may be reduced prior to or after the data are recorded. In the JSATS system, false positives recorded by the receivers are reduced through a series of software filters applied to the data (McMichael and others, 2010). One set of filters is applied to data from single autonomous receivers (recall that these have independent clocks and are not synchronized among units) and another is applied to the time-synchronized cabled-hydrophone system. This distinction is important to the use of hydrophones in the Willamette River because the potential for high water velocities and high migration rates of tagged fish reduces the probability of detecting a transmission within the detection range of a single hydrophone. One solution is to use multiple hydrophones to form a larger detection area. This seems obvious, but autonomous hydrophones typically have been used in isolation from one another (including the data filtering method) because of the variation in time keeping among hydrophones. Using multiple autonomous hydrophones as a single detection array entails using different data filter algorithms than those currently in use, synchronizing the clocks of multiple autonomous hydrophones and using one of the existing algorithms, or using the cabled-hydrophone system in the river. For this study, we chose to use autonomous receivers with single hydrophones.

The objective of this study was to investigate methods for the successful detection of acoustic-tagged fish in the Willamette River. The short-term goal was to locate sites, install and test equipment, and detect fish carrying JSATS tags from the study at Detroit Reservoir. The long-term goal was to develop stable, cost effective, long-term monitoring arrays suitable for detection of any JSATS-tagged fish in the Willamette River. These data could then be used to estimate timing, migration rates, and survival of JSATS-tagged fish from various studies within the Willamette River Basin.

Methods

Overall Deployment Methodology

Several deployment methods were considered prior to installing the equipment. Acoustic signals do not cross the air-water interface, so hydrophones used to 'hear' the tags were installed underwater (Pincock and Johnston, 2012). The primary concerns when installing in-water equipment are personal safety during installation, maintenance, removal, and equipment condition during the deployment period. We deployed equipment downstream of bridge pilings to provide protection for equipment during high-flow events. The bridge pilings also helped create an evenly distributed coverage area for maximum detection probability with overlapping receiver coverage. This type of deployment is a modified version of the methods used to mount fixed hydrophones on the pier noses of dams in the Columbia and Snake Rivers (Adams and Liedtke, 2009).

The development of a bridge mount design required special consideration because of the fluctuating water levels in the Willamette River throughout the study period. Traditional hydrophone mounts that are attached using concrete anchors were not suitable for this application because any maintenance of the equipment during the study would require divers. In-season maintenance issues have been addressed in previous studies at dams by installing trolley pipes to allow equipment to be moved up and down by the trollies inside the pipes. However, installation of trolley pipes at bridge sites was cost prohibitive for use in our study and would have required a much higher level of cooperation from the various entities responsible for maintaining the bridges. In most cases, it is unclear if the responsible parties would have allowed the necessary drilling and anchoring required to install trolley pipes to the concrete bridge pilings. Therefore, we developed a low-impact, inexpensive and flexible installation method for bridge piling for use on the Willamette River (fig. 2-1). The system was comprised of a length of 6.35-mm stainless steel wire rope secured to the top of a bridge piling using a concrete anchor or wrapped around a steel bridge member. The water end of this cable was attached to two 22.68-kg metal weights to act as anchors. These weights did not rest on the river bottom, so the suspended tension created by the weights insured that the wire rope was taut and stayed close to the bridge piling. Stainless steel clips spaced every 2 m were tied around the hydrophone cable and a section of 3.17-mm wire rope with an 11.34-kg metal weight on the water end. These clips were then attached to the 6.35-mm wire rope. This configuration allowed the hydrophone cable to slide on the anchor cable to set the desired hydrophone depth and allow for in-season maintenance checks. The 11.34-kg weight kept the hydrophone submerged while the float and metal guards protected the hydrophone. The float was sized to create a neutrally buoyant configuration where the hydrophone could move in the current 1.5 m downstream of the anchor cable connection. A beacon transmitter was attached to the hydrophone cable 1.5 m above the 11.34-kg weight (fig. 2-2). The extra length of hydrophone cable and 3.17-mm wire rope were secured on the top of the bridge piling after the depth of the hydrophone was established. The cable was then routed into a locked plastic or metal box affixed to the bridge that contained the receiver and battery.

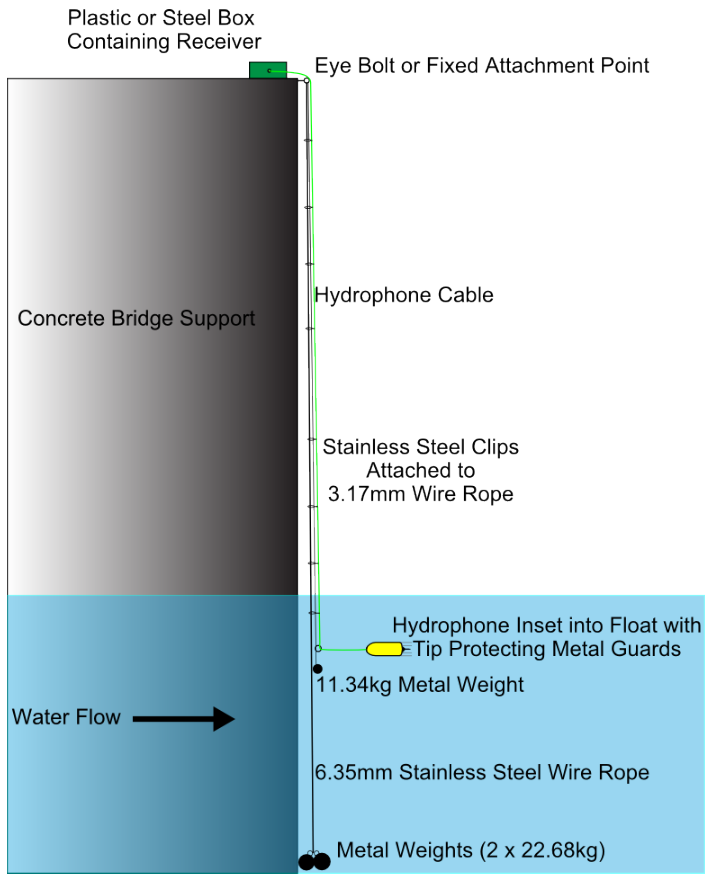

Figure 2-1. Diagram showing components used to deploy Juvenile Salmon Acoustic Telemetry System (JSATS) hydrophones from bridges in the Willamette River, Oregon.

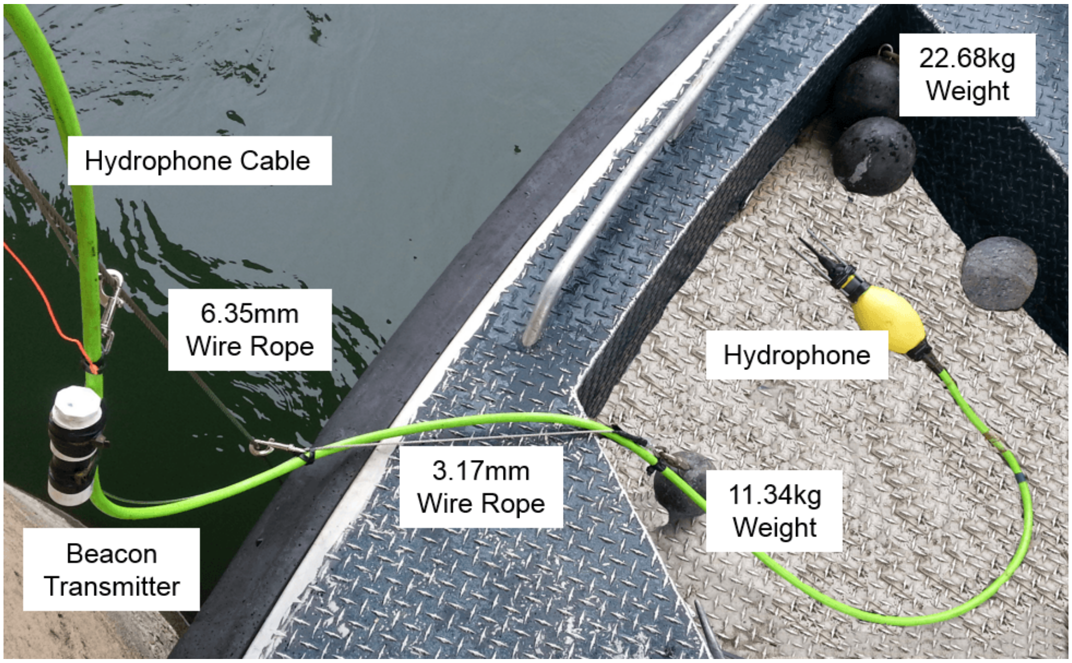

Figure 2-2. Photograph showing components used to deploy Juvenile Salmon Acoustic Telemetry System (JSATS) hydrophones in the Willamette River, Oregon. Photograph by Matthew Sholtis, U.S. Geological Survey.

Site Selection

Three monitoring sites were installed in the Willamette River in March, 2013 (fig. 2-3). Each site consisted of six receivers separated into three arrays. The receivers were spaced optimally to provide maximum coverage and to overlap depending on width, depth, and bathymetry of the river. Of the 18 total receivers deployed in the Willamette arrays, 12 were bridge piling mounts, 4 were in-river autonomous receivers on acoustic releases, and 2 were deployed from small pontoon barges at a marina. Beacon transmitters deployed on each mount were used to determine functionality of the receiving systems.

We selected three sites downstream of the confluence of the Santiam and Willamette Rivers to deploy receiver arrays: (1) downtown Salem (river kilometer [rkm] 136); (2) near the Interstate-5 bridge in Wilsonville (rkm 63), hereafter referred to as “Wilsonville”; and (3) in downtown Portland (rkm 23).These sites were selected because of geographic separation for survival analysis and the presence of multiple bridges to attach receivers. Arrays within each site were comprised of a pair of receivers deployed on or near the same bridge. Arrays were numbered “1” for upstream, “2” for the middle of a site , and “3” for the farthest downstream.

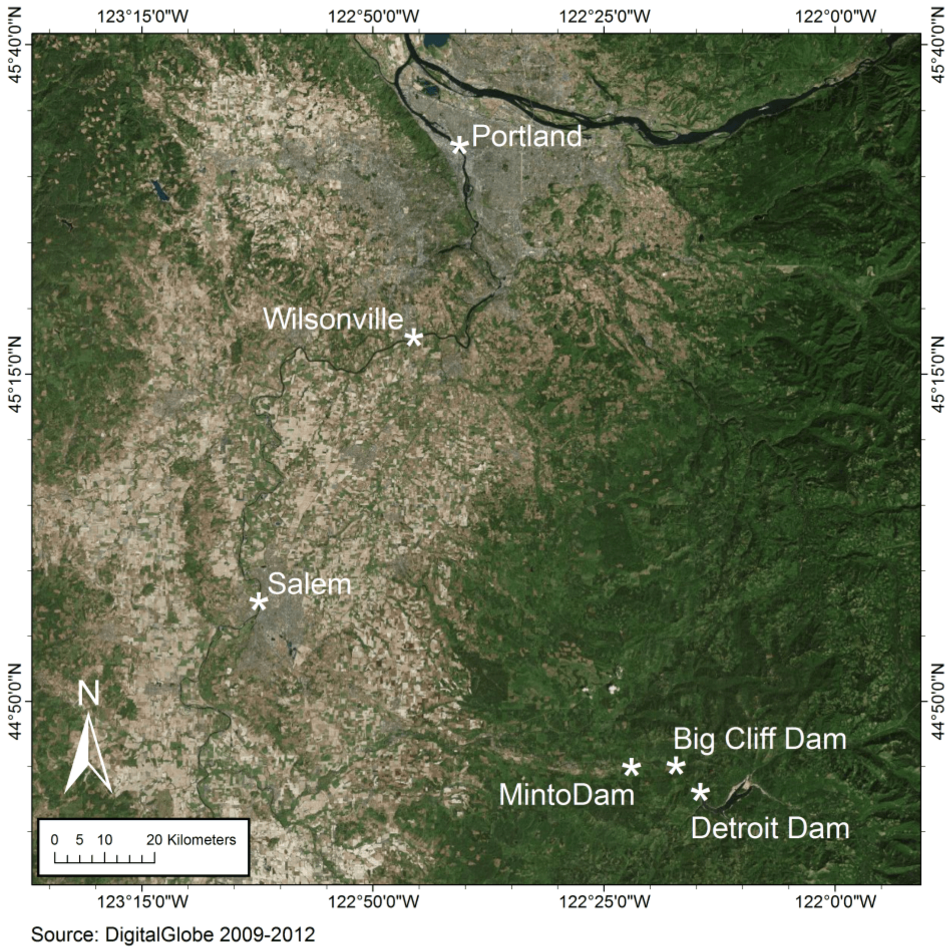

Figure 2-3. Map showing locations of Detroit, Big Cliff, and Minto Dams, and autonomous acoustic receiver sites deployed downstream in the Willamette River, Oregon, for the 2013 study.

Site-Specific Deployment

Salem

The site at Salem, Oregon (rkm 136), was installed in stages beginning in March 2013. Three separate bridges were used to deploy six total receivers, hydrophones, and beacon transmitters (fig 2-4). The farthest upstream bridge in Salem is State Route 22 eastbound, hereafter referred to as the “Center Street Bridge array.” The middle bridge is State Route 22 westbound, hereafter referred to as the “Marion Street Bridge array.” The farthest downstream bridge is the historic Union Pacific railroad bridge, now referred to as the “Union Street pedestrian bridge” (fig. 2-4). Center Street and Marion Street Bridges are administered and maintained by the Oregon Department of Transportation (ODOT). The Union Street pedestrian bridge is on the Nation Register of Historic Places and is maintained by the City of Salem. River depth at the hydrophone locations on the day of installation ranged from 4 to 10 m. All receiving equipment was secured to the top of the bridge pilings in access-controlled locations not open to the public.

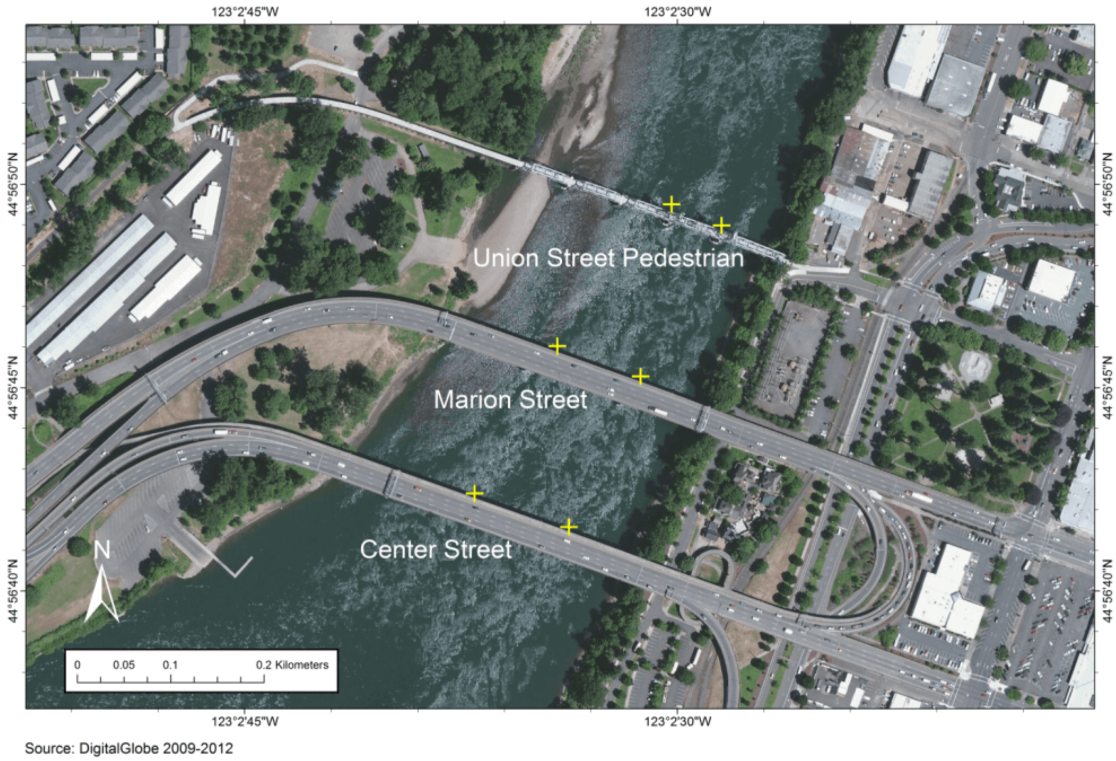

Figure 2-4. Map showing locations of hydrophones installed at river kilometer 136 on the Willamette River, Salem, Oregon. "Plus signs" indicate approximate locations of hydrophones.

Wilsonville

The site near the U.S. Route 5 bridge in Wilsonville (rkm 63) was installed in March 2013 (fig. 2-5). River depth at the hydrophone locations on the day of installation ranged from 4 to 9 m. We leased two boat slips at the Boones Ferry Marina and placed a 2.44-m-long aluminum pontoon barge in each slip. Each barge was outfitted with a steel box to hold the receiver, and this box was secured to the dock using 6.35-mm wire rope with swaged loops on each end. The hydrophone and cable were secured to a 3-m-long steel pole positioned at the center of the barge. This configuration placed the tip of the hydrophone 2 m below the water surface.

Four additional receivers were deployed using InterOcean systems Model 111 acoustic releases on the downstream side of bridge pilings near Boones Ferry Marina. Receivers were deployed using methods described by Titzler and others (2010) and allowed us to compare the new bridge piling deployment to the most commonly used acoustic release method.

Figure 2-5. Map showing locations of hydrophones installed at river kilometer 63 on the Willamette River, near Wilsonville, Oregon. "Plus signs" indicate approximate locations of hydrophones.

Portland

The site at Portland, Oregon (rkm 23) was installed in stages beginning in March 2013. Three separate bridges (Broadway, Steel, Burnside) were used to deploy six total receivers, hydrophones, and beacon transmitters (fig. 2-6). The Burnside and Broadway Bridges are administered and maintained by Multnomah County, and Union Pacific Railroad owns and operates the Steel Bridge. River depth at the hydrophone locations on the day of installation ranged from 8 to 14 m. Data from the beacon transmitters deployed on each mount were used to determine functionality of the receiving systems.

Figure 2-6. Map showing locations of hydrophones installed at river kilometer 20 on the Willamette River, Portland, Oregon. “Plus signs” indicate approximate locations of hydrophones.

Results

Detection Probabilities by Array and Site

Estimates of the detection probability at each array of hydrophones and at each site pooling arrays were based on a single, highly supported model, or the model-averaged estimates of multiple models supported by the data (see chapter 1 section, "Estimating Detection and Survival Probabilities"). For the Chinook salmon in the spring study period, only the model that assumed constant detection probability among downstream sites was supported, but for the steelhead in the spring and Chinook salmon in the fall, the models that assumed differences in detection probability among arrays and the models that assumed a constant detection efficiency for all arrays received considerable support (tables D1 and D2). In the suite of models used to estimate detection probabilities at each of the sites, only models that assumed differences in detection probabilities among sites were supported. The median $\hat{c}$ procedure often did not converge, likely because the detection probabilities were near 1.0, so a $\hat{c}$ value of 1.0 typically was applied to the data. However, in one case for Chinook salmon in the fall study, a $\hat{c}$ of 4.0 was applied because of the low detection probabilities at two arrays owing to intermittent system outages.

Detection probabilities were high at each of the arrays in the spring, but were lower and more variable in the fall (fig. 2-7). In the spring study period, Chinook salmon and steelhead detection probabilities at the Salem arrays ranged from 0.955 to 1.000; were 1.000 for all Wilsonville arrays; and ranged from 0.900 to 1.000 for the two most upstream Portland arrays (table 2-1). In the fall study period, detection probabilities ranged from 0.526 to 0.921 at the Salem arrays, from 0.743 to 1.000 at the Wilsonville arrays, and from 0.900 to 1.000 at the two most upstream Portland arrays (table 2-1). The lower detection probabilities during the fall study, particularly those at the Salem 3 (0.526) and Wilsonville 3 (0.743) arrays, were in part attributable to loss of data owing to higher flows and the 2013 Federal government shutdown.

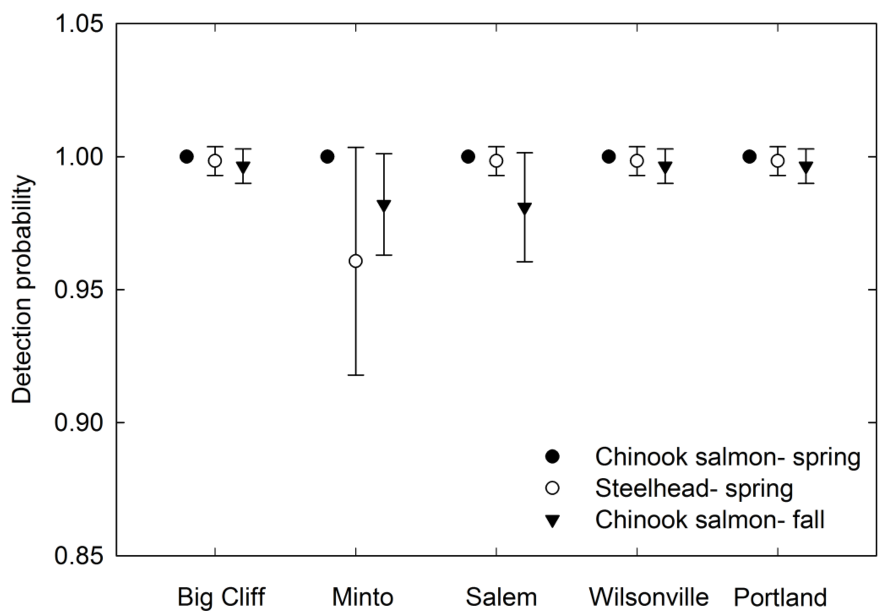

Figure 2-7. Graph showing estimated detection probability by species at each detection site downstream of Detroit Dam, Oregon, during the 2013 study period. Portland arrays 1 and 2 were pooled, whereas the other sites represent pooling of all three arrays. Whiskers show 95% confidence intervals.

Table 2-1. Estimated detection probabilities at each array based on tagged juvenile Chinook salmon and steelhead passing Detroit Dam, Oregon.

[Fish were released into tributaries upstream of Detroit Reservoir or near the head of the reservoir during the spring study period and detected from May 8 to July 19, 2013, or released during the fall study period and detected from October 3, 2013, to April 10, 2014. No steelhead released in the fall were detected downstream within the 90th percentile of the empirical tag life. Prob, probability; SE, standard error; LCI, lower 95-percent confidence interval; UCI, upper 95-percent confidence interval; NA, not applicable]

Season	Detection array	Chinook salmon				Steelhead			
		Prob	SE	LCI	UCI	Prob	SE	LCI	UCI
Spring	Big Cliff	1.000	0.000	1.000	1.000	1.000	0.000	1.000	1.000
	Minto	1.000	0.000	1.000	1.000	0.955	0.044	0.739	0.994
	Salem 1	0.986	0.014	0.904	0.998	1.000	0.000	1.000	1.000
	Salem 2	0.986	0.014	0.904	0.998	0.955	0.044	0.739	0.994
	Salem 3	1.000	0.000	1.000	1.000	1.000	0.000	1.000	1.000
	Wilsonville 1	1.000	0.000	1.000	1.000	1.000	0.000	1.000	1.000
	Wilsonville 2	1.000	0.000	1.000	1.000	1.000	0.000	1.000	1.000
	Wilsonville 3	1.000	0.000	1.000	1.000	1.000	0.000	1.000	1.000
	Portland 1	0.950	0.034	0.821	0.987	0.900	0.067	0.676	0.975
	Portland 2	1.000	0.000	1.000	1.000	1.000	0.000	1.000	1.000
	Portland 3	NA	NA	NA	NA	NA	NA	NA	NA
Fall	Big Cliff	1.000	0.000	1.000	1.000				
	Minto	0.974	0.052	0.411	0.999				
	Salem 1	0.868	0.110	0.501	0.977				
	Salem 2	0.921	0.088	0.523	0.992				
	Salem 3	0.526	0.162	0.237	0.799				
	Wilsonville 1	1.000	0.000	1.000	1.000				
	Wilsonville 2	1.000	0.000	1.000	1.000				
	Wilsonville 3	0.743	0.148	0.388	0.929				
	Portland 1	0.900	0.110	0.453	0.990				
	Portland 2	1.000	0.000	1.000	1.000				
	Portland 3	NA	NA	NA	NA				

Environmental Conditions

Graphs of the daily mean discharges for the study period near each site are shown in figures 2-8–2-10. River discharge data were obtained from the USGS water monitoring Web site, http://waterdata.usgs.gov/nwis/inventory. The mean daily discharge at Salem during the period of deployment was 22,218 ft^3/s (range 6,910 ft^3/s [July 27, 2013] to 107,000 ft^3/s [February 17, 2014]). The mean daily discharge at the gauge nearest Wilsonville (Newberg) was 24,248 ft^3/s (range 6,590 ft^3/s [July 28, 2013] to 118,000 ft^3/s [February 18, 2014]). Mean daily discharge at the Portland site was 31,184 ft^3/s (range 7,770 ft^3/s [August 31, 2013] to 150,000 ft^3/s [February 19, 2014]).

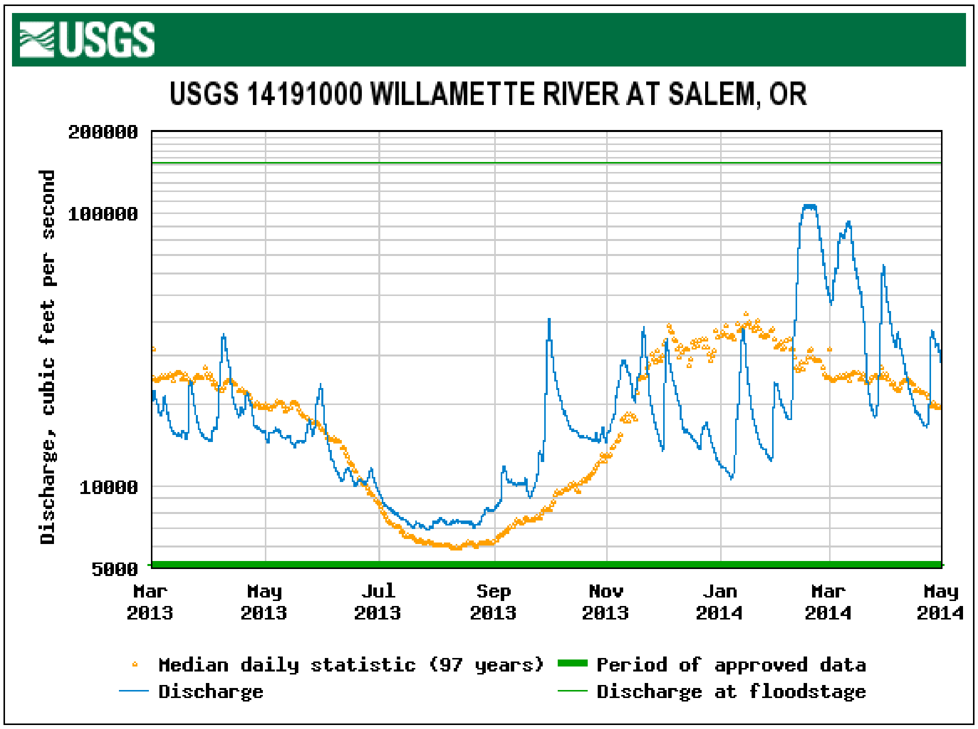

Figure 2-8. Hydrograph showing Willamette River discharge near the Salem, Oregon, site from March 1, 2013 through May 31, 2014. Data are from Salem stream gage, located at river kilometer 136 (U.S. Geological Survey, 2014).

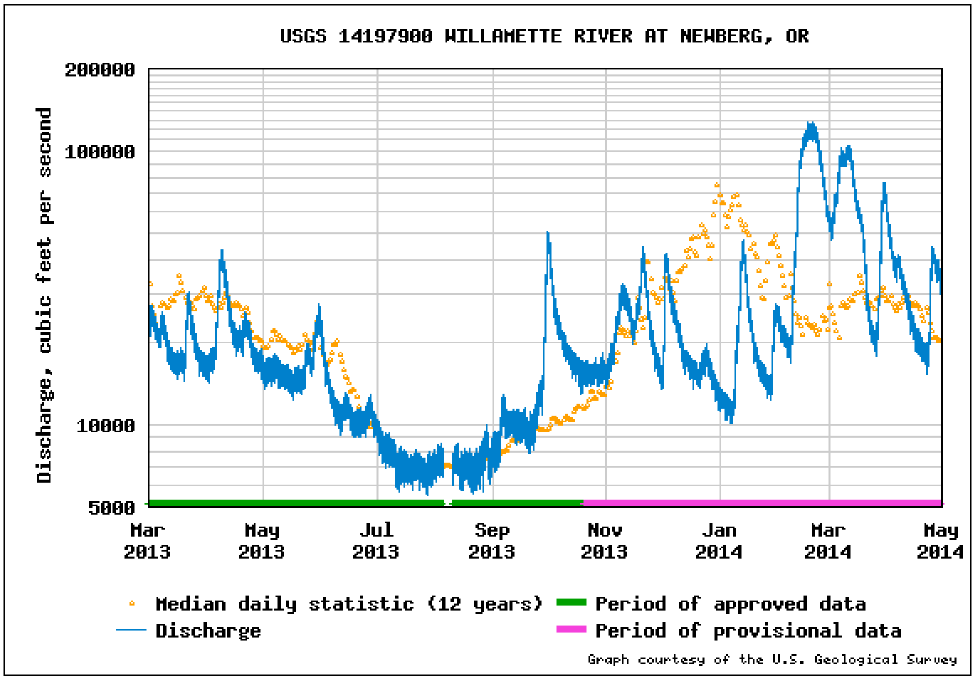

Figure 2-9. Hydrograph showing Willamette River discharge near the Wilsonville, Oregon site from March 1, 2013 through May 31, 2014. Data are from Newberg stream gage, located at river kilometer 81.5 (U.S. Geological Survey, 2014).

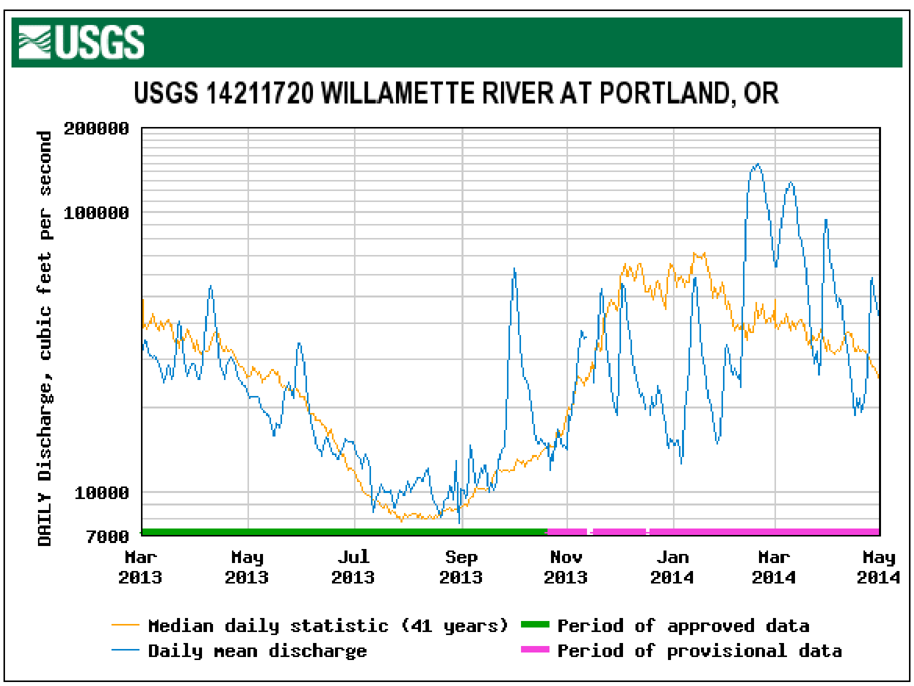

Figure 2-10. Hydrograph showing Willamette River discharge near the downtown Portland, Oregon site from March 1, 2013 through May 31, 2014. Data are from the Morrison Bridge stream gage, located at river kilometer 21 (U.S. Geological Survey, 2014).

Range Testing

Range testing was conducted throughout the study period to ensure data collection quality (Melnychuk, 2012). A GPS unit mounted on a boat was used to log positions of test transmitters deployed at multiple depths in the water. The data collected on the receivers were processed and matched to the recorded GPS transects. These data allowed us to measure the effective range of the hydrophone arrays under multiple flow conditions. An example of range testing is plotted in figure 2-11 (Site = Salem, flow 13,100 ft^3/s). All three bridge arrays detected transmitters in both the upstream and downstream directions with array overlap (fig. 2-11).

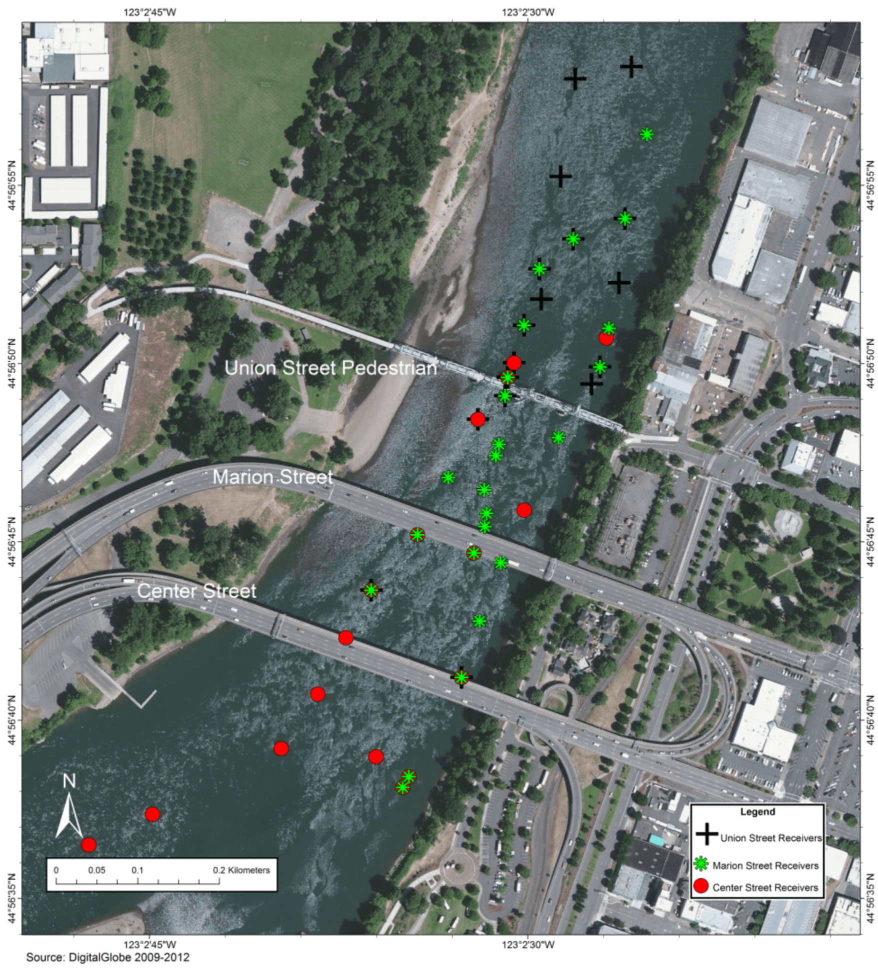

Figure 2-11. Example of range testing performed in Salem, Oregon, illustrating the overlapping coverage of the detection arrays. Symbols show positions of test tags and the receiver(s) that detected them.

Impacts of High River Flow on Monitoring Equipment

Traditional deployment methods were proven inadequate during previous studies because of the dynamic nature of the hydrology in the Willamette River (Rutz and others, 2014). However, the methods developed and tested in this study were successful. High detection probabilities were achieved and maintained for periods when the tagged fish were moving downstream through the system. Bridge piling mounts experienced no equipment loss during high-flow events. An increase in the amount of background noise was detected at the monitoring sites during high-flow events. The arrays in Salem were most prone to excessive noise and false detections during peak flows, likely caused by the higher water velocities interacting with the local river morphology. No tagged fish were present in the river during high flows to quantify system performance.

The hydrophones deployed using acoustic releases were more challenging to maintain for this study than other receiver mounting strategies. The primary difficulty was getting the acoustic release to work consistently so we could retrieve the monitoring equipment and download the data. The batteries in the acoustic releases are believed to be a source of release failure. These batteries needed to be replaced periodically and the replacement cycle we chose was conservative, but one of the cycles happened to occur during the 2013 Federal government shut down. As a result, failure to replace the batteries at the optimum time likely caused the releases not to function and prevented us from retrieving two receivers. Another receiver was lost for unknown reasons during the season in a period when the acoustic release batteries should have been fully functional. In all cases, the river currents made it very challenging to recover unresponsive acoustic release-deployed receivers using methods that are otherwise successful in a reservoir environment.

Discussion

This study was designed to develop functional and cost-effective methodologies for the deployment of telemetry equipment with the ability to detect JSATS transmitters in the Willamette River system. The bridge piling method proved highly successful at providing reliable spatial coverage of the river within a site. Equipment maintenance was minimal after the initial installation because bridge pilings provided protection from debris. Hydrophones could be pulled up and inspected from the top of the pilings, further reducing the burden on boat and staff time. The chosen locations proved to be secure, as we did not experience any theft or vandalism. The use of acoustic release deployment methods was more unreliable in a riverine system and led to data loss on occasions where we were unable to retrieve the receivers.

System performance across the entire range of the hydrograph was not fully tested. We were unable to evaluate the detection range of equipment during peak flows because of safety concerns. Our intention was to perform transects using test transmitters pulled behind a boat during periods of high flows to gain empirical data on the effects of hydrological noise on the detection range of the transmitters. The weather did not cooperate, and only provided us with a two day spike of flows around October 1, 2013. The hydrograph then trended downward, below the historical mean flows for the next 4 months until a major rain on high elevation snow event caused the flows to reach the highest levels of the study period. The daily river discharge increased greatly between February 10 and 19, 2014, and peaked on February 17, 2014. During this period, flows reached 107,000 ft^3/s in Salem, which is much greater than the 97-year average of around 30,000 ft^3/s for this time period. The water levels in the Willamette River became too dangerous to perform range tests using a boat. The boat ramps in Salem, Wilsonville, and Portland were closed by authorities because of public safety concerns. The weather patterns did not provide us with a gentle increase of flows over time to compare with low-flow results.

The detection range in low-flow conditions proved suitable for ongoing research objectives. Detection probabilities are high enough to meet the paired release survival objectives for future studies. The methods developed in this study could serve as a template for a long-term monitoring deployment implemented to provide data to multiple groups performing research in the Willamette River Basin.

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Appendix A. Daily Operating Conditions Calculated from Hourly Data, at Detroit Dam, Oregon, 2013

Table A1. Summary statistics of hourly dam operations and environmental conditions at Detroit Reservoir, Oregon, March 25–July 9, 2013, when spring-released fish were detected in the study area.

[SD, standard deviation; RO, regulating outlet; ft^3/s, cubic foot per second]

	Period	Mean	Median	Range	SD
Total project (ft^3/s)	Overall	1,360.6	1,830.0	0.0–4,840.0	992.3
	Day	1,497.1	1,940.0	0.0–4,840.0	988.4
	Night	1,166.9	1,370.0	0.0–3,946.0	965.4
Powerhouse (ft^3/s)	Overall	1,008.3	1,270.0	0.0–2,827.7	1,020.6
	Day	1,291.3	1,915.1	0.0–2,3759.3	980.1
	Night	606.4	0.0	0.0–2,827.7	939.1
Spillway (ft^3/s)	Overall	345.3	0.0	0.0–4,442.7	654.7
	Day	199.3	0.0	0.0–4,442.7	539.0
	Night	552.5	0.0	0.0–3,458.5	742.9
Regulating outlet (ft^3/s)	Overall	7.6	0.0	0.0–1,436.5	102.6
	Day	7.2	0.0	0.0–1,429.7	99.3
	Night	8.1	0.0	0.0–1,436.5	107.1
Forebay elevation (ft)	Overall	1,544.9	1,561.1	1,469.9–1,565.5	29.4
	Day	1,547.4	1,561.8	1,470.1–1,564.6	27.6
	Night	1,541.4	1,559.9	1,469.9–1,565.5	31.3
Water temperature (degrees Celsius)	Overall	11.6	11.7	4.0–21.0	5.3
	Day	12.1	12.0	4.1–21.0	5.3
	Night	11.0	10.7	4.0–20.8	5.3
Percent spill of total	Overall	30.1	0.0	0.0–100.0	44.0
	Day	14.3	0.0	0.0–100.0	32.4
	Night	55.4	100.0	0.0–100.0	48.2
Percent RO of total	Overall	0.7	0.0	0.0–0.0	8.3
	Day	0.7	0.0	0.0–0.0	8.2
	Night	0.8	0.0	0.0–0.0	8.4

Table A2. Summary statistics of hourly dam operations and environmental conditions at Detroit Dam and Reservoir, Oregon, September 11, 2013—January 28, 2014, when fall-released fish were detected in the study area.

[SD, standard deviation; RO, regulating outlet; ft3/s, cubic foot per second]

	Period	Mean	Median	Range	SD
Total project (ft^3/s)	Overall	2,284.4	1,910.0	0.0–6,470.0	1,401.5
	Day	2,346.4	1,880.0	0.0–6,470.0	1,406.6
	Night	2,234.4	1,940.0	0.0–5,360.0	1,395.7
Powerhouse (ft^3/s)	Overall	2,266.4	1,910.0	0.0–5,220.0	1,401.4
	Day	2,324.4	1,880.0	0.0–4,920.0	1,397.0
	Night	2,219.7	1,940.0	0.0–5,220.0	1,403.5
Spillway (ft^3/s)	Overall	0.0	0.0	0.0–0.0	0.0
	Day	0.0	0.0	0.0–0.0	0.0
	Night	0.0	0.0	0.0–0.0	0.0
Regulating outlet (ft^3/s)	Overall	13.5	0.0	0.0–1,702.4	126.7
	Day	15.0	0.0	0.0–1,702.4	133.5
	Night	12.2	0.0	0.0–1,701.3	120.8
Forebay elevation (ft)	Overall	1,495.9	1,494.6	1,444.9–1,543.2	37.4
	Day	1,500.5	1,517.9	1,444.9–1,542.9	37.2
	Night	1,492.2	1,476.5	1,445.0–1,543.2	37.2
Water temperature (degrees Celsius)	Overall	11.8	12.4	3.8–21.1	6.0
	Day	12.5	13.5	3.8–21.1	6.0
	Night	11.2	11.5	3.8–21.0	5.9
Percent spill of total	Overall	0.0	0.0	0.0–0.0	0.0
	Day	0.0	0.0	0.0–0.0	0.0
	Night	0.0	0.0	0.0–0.0	0.0
Percent RO of total	Overall	1.0	0.0	0.0–100.0	9.3
	Day	0.8	0.0	0.0–100.0	7.3
	Night	1.2	0.0	0.0–100.0	10.7

Appendix B. Models Used to Estimate Probability of Detection and Presence of Fish in Detroit Reservoir, Oregon, 2013

Table B1. Suite of models of detection probabilities for the analysis of presence probabilities of juvenile Chinook salmon and steelhead released into tributaries or within Detroit Reservoir, Oregon, during the 2013 spring and fall study periods.

[Models of detection probability (P) include array or a common value fitted to all arrays (.). All models shared a common presence probability with an array effect. AICc is Akaike Information Criterion with an adjustment for effects of sample size. Num par is number of parameters. A ĉ value of 1.000 was applied to all models]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
Chinook salmon – spring tributary						
1 P(array)	801.178	0.000	0.862	1.000	6	0.000
2 P(.)	804.841	3.664	0.138	0.160	6	3.664
Steelhead - spring reservoir						
3 P(.)	337.514	0.000	0.810	1.000	5	4.336
4 P(array)	340.414	2.901	0.190	0.235	5	7.236
Steelhead - spring tributary						
5 P(array)	219.153	0.000	1.000	1.000	4	0.000
Chinook salmon - fall tributary						
6 P(array)	1307.821	0.000	0.998	1.000	7	1.480
7 P(.)	1319.862	12.041	0.002	0.002	7	13.521
Steelhead - fall tributary						
8 P(array)	529.767	0.000	1.000	1.000	5	0.000
9 P(.)	599.474	69.707	0.000	0.000	1	77.832

Table B2. Suite of models used in estimation of presence probabilities of juvenile Chinook salmon released into tributaries upstream of Detroit Reservoir, Oregon, during the 2013 spring study period.

[Models of presence probability (M) include array or a common value fitted to all arrays (.). AICc is Akaike Information Criterion with an adjustment for effects of sample size. Num par is number of parameters. A ĉ value of 1.000 was applied to the data]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
1 M(array), P(array)	801.178	0.000	0.862	1.000	6	0.000
2 M(array), P(.)	804.841	3.664	0.138	0.160	6	3.664
3 M(.), P(array)	927.316	126.138	0.000	0.000	2	134.177
4 M(.), P(.)	930.950	129.772	0.000	0.000	2	137.811

Table B3. Suite of models used in estimation of presence probabilities of juvenile steelhead released within Detroit Reservoir, Oregon, during the 2013 spring study period.

[Models of presence probability (M) include array or a common value fitted to all arrays (.). AICc is Akaike Information Criterion with an adjustment for effects of sample size. Num par is number of parameters. A ĉ value of 1.000 was applied to the data]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
1 M(array), P(array)	337.514	0.000	0.810	1.000	5	4.336
2 M(array), P(.)	340.414	2.901	0.190	0.235	5	7.236
3 M(.), P(array)	384.323	46.809	0.000	0.000	2	57.275
4 M(.), P(.)	388.022	50.508	0.000	0.000	2	60.974

Table B4. Suite of models used in estimation of presence probabilities of juvenile steelhead released into tributaries upstream of Detroit Reservoir, Oregon, during the 2013 spring study period.

[Models of presence probability (M) include array or a common value fitted to all arrays (.). AICc is Akaike Information Criterion with an adjustment for effects of sample size. Num par is number of parameters. A ĉ value of 1.000 was applied to the data]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
1 M(array), P(array)	219.153	0.000	1.000	1.000	4	0.000
2 M(.), P(array)	287.347	68.194	0.000	0.000	1	74.281

Table B5. Suite of models used in estimation of presence probabilities of juvenile Chinook salmon released into the tributaries upstream of Detroit Reservoir, Oregon, during the 2013 fall study period.

[Models of presence probability (M) include array or a common value fitted to all arrays (.). AICc is Akaike Information Criterion with an adjustment for effects of sample size. Num par is number of parameters. A ĉ value of 1.000 was applied to the data]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
1 M(array), P(array)	1307.821	0.000	0.998	1.000	7	1.480
2 M(.), P(array)	1319.862	12.041	0.002	0.002	7	13.521

Table B6. Suite of models used in estimation of presence probabilities of juvenile steelhead released into the tributaries upstream of Detroit Reservoir, Oregon, during the 2013 fall study period.

[Models of presence probability (M) include array or a common value fitted to all arrays (.). AICc is Akaike Information Criterion with an adjustment for effects of sample size. Num par is number of parameters. A ĉ value of 1.000 was applied to the data]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
1 M(array), P(array)	529.767	0.000	1.000	1.000	5	0.000
2 M(.), P(array)	599.474	69.707	0.000	0.000	1	77.832

Appendix C. Results of Analyses of Movement Probabilities from Fish in Detroit Reservoir, Oregon, 2013

Table C1. Movement probabilities of juvenile Chinook salmon and steelhead moving from one detection array to an adjacent detection array, given the previous array location within Detroit Reservoir, Oregon, during the 2013 spring study period.

		Juvenile Chinook salmon probability of moving from current array to adjacent array															
Previous array		2 to 3	2 to 4	2 to 1	3 to 4	3 to 2	4 to 5	4 to 6	4 to 3	4 to 2	5 to 6	5 to 4	6 to 8	6 to 5	6 to 4	8 to 6	8 to Pass
	1	0.08	0.55	0.38													
	2				0.45	0.55	0.23	0.46	0.05	0.26							
	3	0.18	0.31	0.50			0.28	0.50	0.03	0.19							
	4	0.07	0.36	0.57	0.47	0.53					0.44	0.56	0.74	0.06	0.21		
	5						0.11	0.22	0.17	0.50			0.76	0.04	0.20		
	6						0.12	0.21	0.16	0.52	0.46	0.54				0.90	0.10
	8												0.63	0.07	0.30		

		Juvenile steelhead probability of moving from current array to adjacent array															
Previous array		2 to 3	2 to 4	2 to 1	3 to 4	3 to 2	4 to 5	4 to 6	4 to 3	4 to 2	5 to 6	5 to 4	6 to 8	6 to 5	6 to 4	8 to 6	8 to Pass
	1	0.14	0.64	0.22													
	2				0.61	0.39	0.22	0.54	0.10	0.14							
	3	0.13	0.32	0.55			0.16	0.61	0.10	0.13							
	4	0.09	0.35	0.57	0.60	0.40					0.39	0.61	0.70	0.05	0.25		
	5						0.09	0.22	0.26	0.43			0.74	0.06	0.19		
	6						0.12	0.19	0.21	0.48	0.52	0.48				0.92	0.08
	8												0.47	0.09	0.44		

Table C2. Movement probabilities of juvenile Chinook salmon and steelhead moving from one detection array to an adjacent detection array, given the previous array location within Detroit Reservoir, Oregon, during the 2013 fall study period.

	Juvenile Chinook salmon probability of moving from current array to adjacent array															
Previous array	2 to 3	2 to 4	2 to 1	3 to 4	3 to 2	4 to 5	4 to 6	4 to 3	4 to 2	5 to 6	5 to 4	6 to 8	6 to 5	6 to 4	8 to 6	8 to Pass
1	0.10	0.53	0.36													
2				0.41	0.59	0.08	0.44	0.07	0.41							
3	0.19	0.39	0.42			0.16	0.47	0.09	0.29							
4	0.10	0.54	0.36	0.45	0.55					0.37	0.63	0.63	0.03	0.34		
5						0.14	0.23	0.16	0.47			0.66	0.04	0.30		
6						0.06	0.31	0.13	0.49	0.37	0.63				0.99	0.01
8												0.93	0.01	0.06		

	Juvenile steelhead probability of moving from current array to adjacent array															
Previous array	2 to 3	2 to 4	2 to 1	3 to 4	3 to 2	4 to 5	4 to 6	4 to 3	4 to 2	5 to 6	5 to 4	6 to 8	6 to 5	6 to 4	8 to 6	8 to Pass
1	0.31	0.32	0.37													
2				0.31	0.69	0.25	0.43	0.15	0.18							
3	0.23	0.12	0.65			0.24	0.18	0.35	0.24							
4	0.12	0.28	0.60	0.50	0.50					0.25	0.75	0.60	0.07	0.33		
5						0.13	0.31	0.31	0.25			1.00	0.00	0.00		
6						0.04	0.26	0.26	0.43	0.00	1.00				1.00	0.00
8												0.96	0.01	0.03		

Table C3. Markov model comparisons for juvenile Chinook salmon and steelhead in Detroit Reservoir, Oregon, during the 2013 spring study period.

[Models assuming a one-step Markov chain movement from one array to an adjacent array were compared to a full model that assumed a two-step Markov chain. NS indicates no support for the model relative to the model with the lowest AIC, CS indicates considerably less support for the model relative to the model with the lowest AIC, and SS indicates substantial support for the model. When both the two- and one-step models had substantial support from the data, one model was not clearly supported over the other]

Model	Chinook salmon				Steelhead			
	AIC	Delta AIC	Model Weight	Model Support	AIC	Delta AIC	Model Weight	Model Support
Full model	234.1	0.0	1.00	SS	213.5	0.0	0.66	SS
M123=M323=M423	257.0	22.8	0.00	NS	214.7	1.3	0.34	SS
Full model	234.1	0.0	1.00	SS	213.5	0.0	1.00	SS
M124=M324=M424	335.5	101.4	0.00	NS	293.1	80.0	0.00	NS
Full model	234.1	0.0	1.00	SS	213.5	0.0	1.00	SS
M121=M321=M421	316.1	82.0	0.00	NS	323.4	109.9	0.00	NS
Full model	234.1	1.8	0.29	SS	213.5	1.9	0.28	SS
M234=M434, M232=M432	232.3	0.0	0.71	SS	211.5	0.0	0.72	SS
Full model	234.1	0.0	1.00	SS	213.5	0.0	1.00	SS
M245=M345=M545=M645	295.4	61.3	0.00	NS	231.0	17.5	0.00	NS
Full model	234.1	0.0	1.00	SS	213.5	0.0	1.00	SS
M246=M346=M546=M646	408.7	174.5	0.00	NS	376.4	162.9	0.00	NS
Full model	234.1	0.0	1.00	SS	213.5	0.0	1.00	SS
M243=M343=M543=M643	321.6	87.4	0.00	NS	242.9	29.4	0.00	NS
Full model	234.1	0.0	1.00	SS	213.5	0.0	1.00	SS
M242=M342=M542=M642	418.6	184.4	0.00	NS	369.2	155.7	0.00	NS
Full model	234.1	1.8	0.29	SS	213.5	0.0	0.76	SS
M456=M656, M454=M654	232.3	0.0	0.71	SS	215.8	2.3	0.24	CS
Full model	234.1	1.3	0.34	SS	213.5	1.2	0.35	SS
M468=M568=M868	232.8	0.0	0.66	SS	212.2	0.0	0.65	SS
Full model	234.1	0.0	0.82	SS	213.5	0.0	0.90	SS
M465=M565=M865	237.1	3.0	0.18	CS	217.8	4.3	0.10	CS
Full model	234.1	0.0	1.00	SS	213.5	0.0	1.00	SS
M464=M564=M864	263.0	28.8	0.00	NS	264.5	51.0	0.00	NS

Table C4. Markov model comparisons for juvenile Chinook salmon and steelhead in Detroit Reservoir, Oregon, during the 2013 fall study period.

[Models assuming a one-step Markov chain movement from one array to an adjacent array were compared to a full model that assumed a two-step Markov chain. NS indicates no support for the model relative to the model with the lowest AIC, CS indicates considerably less support for the model relative to the model with the lowest AIC, and SS indicates substantial support for the model. When both the two- and one-step models had substantial support from the data, one model was not clearly supported over the other]

	Chinook salmon				Steelhead			
Model	AIC	Delta AIC	Model Weight	Model Support	AIC	Delta AIC	Model Weight	Model Support
Full model	245.5	0.0	1.00	SS	131.8	0.0	0.54	SS
M123=M323=M423	274.8	29.3	0.00	NS	132.1	0.3	0.46	SS
Full model	245.5	0.0	1.00	SS	131.8	0.0	0.61	SS
M124=M324=M424	281.5	36.0	0.00	NS	132.7	0.9	0.39	SS
Full model	245.5	0.0	0.75	SS	131.8	0.0	0.93	SS
M121=M321=M421	247.7	2.2	0.25	CS	136.8	5.1	0.07	CS
Full model	245.5	0.8	0.40	SS	131.8	0.3	0.46	SS
M234=M434, M232=M432	244.7	0.0	0.60	SS	131.5	0.0	0.54	SS
Full model	245.5	0.0	1.00	SS	131.8	0.2	0.48	SS
M245=M345=M545=M645	279.1	33.6	0.00	NS	131.6	0.0	0.52	SS
Full model	245.5	0.0	1.00	SS	131.8	1.9	0.28	SS
M246=M346=M546=M646	345.2	99.7	0.00	NS	129.9	0.0	0.72	SS
Full model	245.5	0.0	1.00	SS	131.8	2.5	0.22	CS
M243=M343=M543=M643	294.1	48.6	0.00	NS	129.3	0.0	0.78	SS
Full model	245.5	0.0	1.00	SS	131.8	1.0	0.38	SS
M242=M342=M542=M642	301.6	56.1	0.00	NS	130.8	0.0	0.62	SS
Full model	245.5	2.0	0.27	SS	131.8	0.0	0.73	SS
M456=M656, M454=M654	243.5	0.0	0.73	SS	133.8	2.0	0.27	SS
Full model	245.5	0.0	1.00	SS	131.8	0.0	1.00	SS
M468=M568=M868	1396.5	1151.0	0.00	NS	162.3	30.5	0.00	NS
Full model	245.5	0.0	1.00	SS	131.8	0.0	0.82	SS
M465=M565=M865	322.9	77.3	0.00	NS	134.7	3.0	0.18	CS
Full model	245.5	0.0	1.00	SS	131.8	0.0	1.00	SS
M464=M564=M864	1285.0	1039.5	0.00	NS	158.0	26.2	0.00	NS

Appendix D. Models Used to Estimate Detection Probabilities of Fish from Detroit Dam to Portland, Oregon, 2013

Table D1. Suite of 6-occasion models for the analysis of detection probabilities of juvenile Chinook salmon and steelhead (all site data pooled) from Detroit Dam to Portland, Oregon, during the 2013 spring and fall study periods.

[Models of detection probability (P) include site or a common value fitted to all sites (.). All models shared a common survival probability model with a reach effect. AICc is Akaike Information Criterion with an adjustment for effects of sample size. Num par is number of parameters. A ĉ value of 1.000 was applied to all models]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
Chinook salmon – spring						
1 P(site)	664.903	0.000	1.000	1.000	5	0.000
Steelhead - spring						
2 P(site)	170.034	0.000	0.813	1.000	6	0.195
3 P(.)	172.974	2.940	0.187	0.230	6	3.135
Chinook salmon - fall						
4 P(site)	360.008	0.000	0.597	1.000	7	0.862
5 P(.)	360.796	0.788	0.403	0.674	6	3.748

Table D2. Suite of 12-occasion models for the analysis of detection probabilities of juvenile Chinook salmon and steelhead by individual bridge from Detroit Dam to Portland. Oregon, during the 2013 spring and fall study periods.

[Models of detection probability (P) include individual bridge, a common value fitted for all bridges at each site (site), or a common value fitted to all bridges and sites (.). All models shared a common survival probability model with a reach effect. AICc is Akaike Information Criterion with an adjustment for effects of sample size. Num par is number of parameters. A ĉ value of 1.000 was applied to all models during spring. In the fall, a ĉ value of 4.0 was applied to the models and a quasi-likelihood modification was made to the AICc]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
Chinook salmon – spring						
1 P(bridge)	764.839	0.000	0.754	1.000	9	9.450
2 P(site)	767.226	2.386	0.229	0.303	8	13.877
3 P(.)	772.383	7.544	0.017	0.023	7	21.071
Steelhead - spring						
4 P(bridge)	225.014	0.000	0.894	1.000	9	12.766
5 P(site)	230.069	5.055	0.071	0.080	9	17.820
6 P(.)	231.543	6.529	0.034	0.038	7	23.542
Chinook salmon - fall						
7 P(bridge)	159.721	0.000	0.957	1.000	12	12.123
8 P(site)	166.758	7.037	0.028	0.030	10	23.365
9 P(.)	168.140	8.419	0.014	0.015	7	30.986

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Director, Western Fisheries Research Center
U.S. Geological Survey
6505 NE 65th Street
Seattle, Washington 98115
http://wfrc.usgs.gov/

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