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Behavior and Dam Passage of Juvenile Chinook Salmon at Cougar Reservoir and Dam, Oregon, March 2012–February 2013

Open-File Report 2014–1177

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

Cover: Photograph showing forebay at Cougar Dam, Oregon, September 27, 2014.
Photograph by Philip Haner, U.S. Geological Survey.

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SALLY JEWELL, Secretary

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

U.S. Geological Survey, Reston, Virginia: 2014

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Conversion Factors

Inch/Pound to SI

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

SI to Inch/Pound

Multiply	By	To obtain
millimeter (mm)	0.03937	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)
milliliter (mL)	0.0002642	gallon (gal)
liter (L)	0.2642	gallon (gal)
gram (g)	0.03527	ounce, avoirdupois (oz)

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

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Datum

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Elevation, as used in this report, refers to distance above vertical datum.

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Abstract

The movements and dam passage of individual juvenile Chinook salmon (*Oncorhynchus tshawytscha*) were studied at Cougar Reservoir and Dam, near Springfield, Oregon, during 2012 and 2013. Cougar Dam is a high-head flood-control reservoir with a temperature control tower as its outlet enabling selective withdrawals of water at various depths to control the temperature of water passed downstream. This report describes the second year of a 2-year study with the goal of providing information to inform decisions about future downstream passage alternatives. Inferences were based on the behavior of yearling-size juvenile Chinook salmon implanted with acoustic transmitters. The fish were released near the head of the reservoir during the spring (March, April, and May) and fall (September, October, and November) of 2012. Most tagged fish were of hatchery origin (468 spring, 449 fall) because of the low number of wild fish captured from within the reservoir (0 spring, 65 fall). Detections at hydrophones placed in several lines across the reservoir and within a collective system used to estimate three-dimensional positions near the temperature control tower were used to determine fish behavior and factors affecting dam passage rates. Most tagged fish made repeated non-random migrations from one end of the reservoir to the other and took a median of 3.7–11.7 days to travel about 7 kilometers from the release site to within about 100 meters of the temperature control tower, depending on season and origin. Reservoir passage efficiency (percentage of tagged fish detected at the head of the forebay) was 97.8 percent for hatchery fish and 74.2 percent for wild fish. Tagged fish commonly were within about 100 meters of the temperature control tower, and often spent considerable time near the entrance to the tower; however, the dam passage efficiency (percentage of dam passage of fish detected at the head of the forebay) was low for fish released during the spring (11.1 percent) and moderate for fish released during the fall (58.1 percent for hatchery fish, 65.2 percent for wild fish) over the 90th percentile of the empirically determined tag life, which was about 90 days. The primary factors affecting the dam passage rate were diel period, dam discharge, and reservoir elevation, and most passage occurred during conditions of night, high dam discharge, and low reservoir elevation. Most fish entering the temperature control tower passed the dam without returning to the reservoir. The common presence of tagged fish near the tower entrance and high proportion of dam passage after tower entry suggests that the primary cause of the poor dam passage rate was the low rate of tower entry. We hypothesize that fish reject the tower entrance because of low water velocities contributing to a small flow field, an abrupt deceleration at the trash rack, or a combination of those two conditions. Results of a controlled test of head differential (the difference between water elevation outside and inside the temperature control tower) indicated weak statistical support ($P= 0.0930$) for a greater tower entry rate when the differential was 0.65–1.00 foot compared to 0.00–0.30 foot. Results from hatchery and wild fish were similar, with the exception of the reservoir passage efficiency, indicating hatchery fish were suitable surrogates for the wild fish for the purpose of this study.

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 is also operated to provide hydroelectricity, irrigation water, navigation, instream flows for wildlife, and recreation. The hatcheries provide mitigation for lost habitat. Cougar Dam and several other dams are located on tributaries of the Willamette River. The National Oceanic and Atmospheric Administration determined that the Project was jeopardizing the sustainability of anadromous fish stocks in the Willamette River Basin (National Oceanic and Atmospheric Administration, 2008).

Cougar Dam is a 158 m-high rock-fill dam on the South Fork of the McKenzie River about 63 km east of Springfield, Oregon. The dam, completed in 1964, is owned and operated by the USACE. It has a hydraulic capacity of 1,050 ft^3/s and two Francis turbine units capable of generating a total of 25 megawatts. The reservoir is used primarily for flood control; therefore, the forebay elevation is maintained at high levels during summer months and low levels during winter months. A maximum conservation pool elevation of 1,690 ft typically is reached in May, and a minimum flood-control pool elevation of 1,532 ft usually is reached in December.

Water passes the dam over a spillway with Tainter gates or through a temperature control tower installed in 2005 (fig. 1). The spillway is not used during typical operations, so all water passing downstream normally goes through the temperature control tower. Prior to installation of the temperature control tower, water passing through the dam was drawn from deep within the reservoir and often was too cold for attraction and spawning of salmon downstream. The temperature control tower allows waters from various depths of the temperature-stratified forebay to be selectively passed through the dam to control downstream water temperatures. Water within the temperature control tower can be passed downstream through a flow regulating outlet (RO) and a powerhouse penstock. The RO intake centerline is at elevation 1,488.5 ft, and the turbine penstock intake centerline is at elevation 1,429.0 ft. A fish ladder and trapping facility, completed in 2011, collects adult salmon in the tailrace for transportation upstream and provides the only means of upstream passage of adult salmon. At the time of this report there was no passage route designed for permanent downstream passage of juvenile salmon; however, operational and structural alternatives were under consideration.

Figure 1. Photographs showing forebay and water passage structures at Cougar Dam, Oregon. Left photograph shows earthen dam, cul-de-sac, and temperature control tower at western end of dam. Right photograph shows spillway Tainter gates at eastern side of the dam. Photographs taken by John Beeman, U.S. Geological Survey, November 16, 2010, during reservoir elevation of 1,580 feet.

The 2008 Willamette Biological Opinion requires improvements to operations or 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 Biological Opinion includes a requirement to install fish passage facilities (or operational alternatives) at Cougar Dam by 2014, if studies show that installation is feasible.

The study summarized in this report was designed to quantify juvenile Chinook salmon behavior in the reservoir and near the temperature control tower to help understand spatial and temporal patterns in those areas. Data from juvenile Chinook salmon implanted with acoustic transmitters with an expected tag life of about 3 months were the primary basis for inference. The study was designed to address the following objectives:

a. Determine the spatial and temporal movements of juvenile Chinook salmon throughout the reservoir.
b. Determine the spatial and temporal distribution of juvenile Chinook salmon in the Cougar Dam forebay near the temperature control tower.
c. Estimate the temporal dam passage of juvenile Chinook salmon and factors that affect the passage rate.
d. Determine if juvenile Chinook salmon of hatchery origin can be used as surrogates for naturally produced juvenile Chinook salmon.

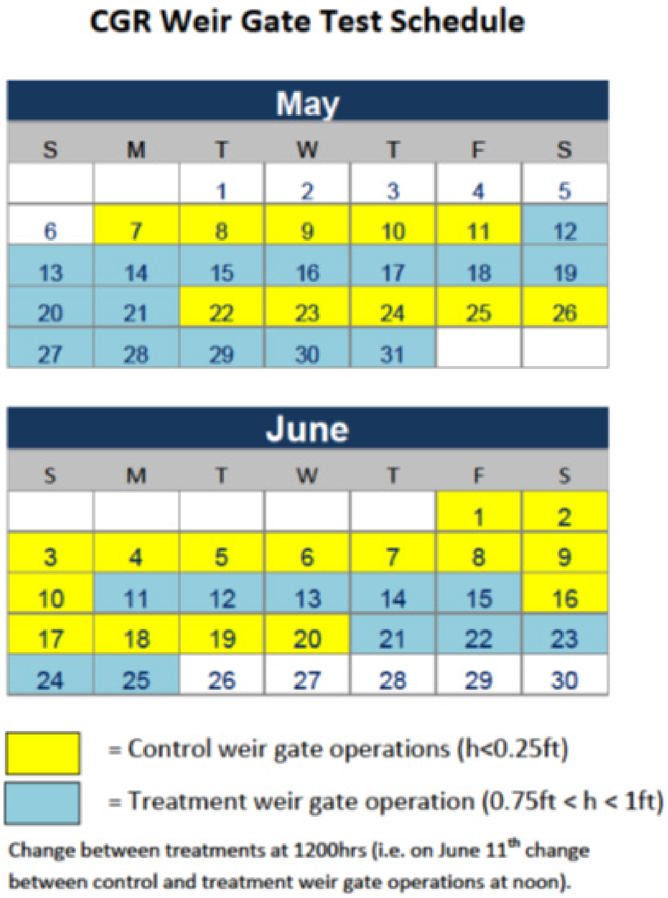
This report describes the second year of data collected from juvenile Chinook salmon implanted with acoustic transmitters in Cougar Reservoir. Beeman and others (2012a, 2013) summarized results from the fish released during 2011. This report describes results from the fish released in 2012.

Methods

Dam Operations and Environmental Conditions

Powerhouse discharge, RO discharge, forebay elevation, head over the temperature control tower weir gates, and water temperature data were summarized to document the environmental conditions that juvenile Chinook salmon experienced during the study. Hourly powerhouse discharge, RO discharge, and forebay elevation data were obtained from the USACE website *http://www.nwd-wc.usace.army.mil/cgi-bin/dataquery.pl?k=cougar.* Weir elevation and RO gate opening data were provided by the USACE. Hourly temperature data were obtained from the USACE website *http://www.nwd-wc.usace.army.mil/ftppub/water_quality/tempstrings/.* Diel periods were assigned using U.S. Naval civil twilight time for Springfield, Oregon, and were obtained at *http://aa.usno.navy.mil/data/docs/RS_OneYear.php*. 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 in cubic feet per second according to the local convention.

Data from the tagged fish in Cougar Reservoir were collected during typical seasonal dam operations, except for a controlled test of head differential during May and June 2012. Head differential was calculated from elevation data provided by the USACE as the water-surface elevation outside the tower minus the water-surface elevation inside the tower. The purpose of the test was to determine if increasing the head differential would affect entry or retention rates of fish at the temperature control tower. The test began on May 7 at 9:00 a.m. and ended on June 27 at 12:00 p.m. Head differentials during that period were controlled according to a prescribed randomized-block design of low (0–0.25 ft, control) and high (0.75–1.00 ft, treatment) based on five 10-d blocks with changes between control and treatment conditions near 12:00 p.m. (fig. 2). The ranges of head differentials used for analysis differed from those prescribed owing to operations outside the planned ranges (see section, “Results”).



CGR Weir Gate Test Schedule

May

S	M	T	W	T	F	S
		1	2	3	4	5
6	🟨 7	🟨 8	🟨 9	🟨 10	🟨 11	🟦 12
🟦 13	🟦 14	🟦 15	🟦 16	🟦 17	🟦 18	🟦 19
🟦 20	🟦 21	🟨 22	🟨 23	🟨 24	🟨 25	🟨 26
🟦 27	🟦 28	🟦 29	🟦 30	🟦 31		

June

S	M	T	W	T	F	S
					🟨 1	🟨 2
🟨 3	🟨 4	🟨 5	🟨 6	🟨 7	🟨 8	🟨 9
🟨 10	🟦 11	🟦 12	🟦 13	🟦 14	🟦 15	🟨 16
🟨 17	🟨 18	🟨 19	🟨 20	🟦 21	🟦 22	🟦 23
🟦 24	🟦 25	26	27	28	29	30

🟨 = Control weir gate operations (h<0.25ft)

🟦 = Treatment weir gate operation (0.75ft < h < 1ft)

Change between treatments at 1200hrs (i.e. on June 11th change between control and treatment weir gate operations at noon).

Figure 2. Planned randomized block design of control (head differential [h] less than [<] 0.25 feet) and treatment (0.75<h<1.0 feet) conditions of head differential at Cougar Dam, Oregon, May–June 2012.

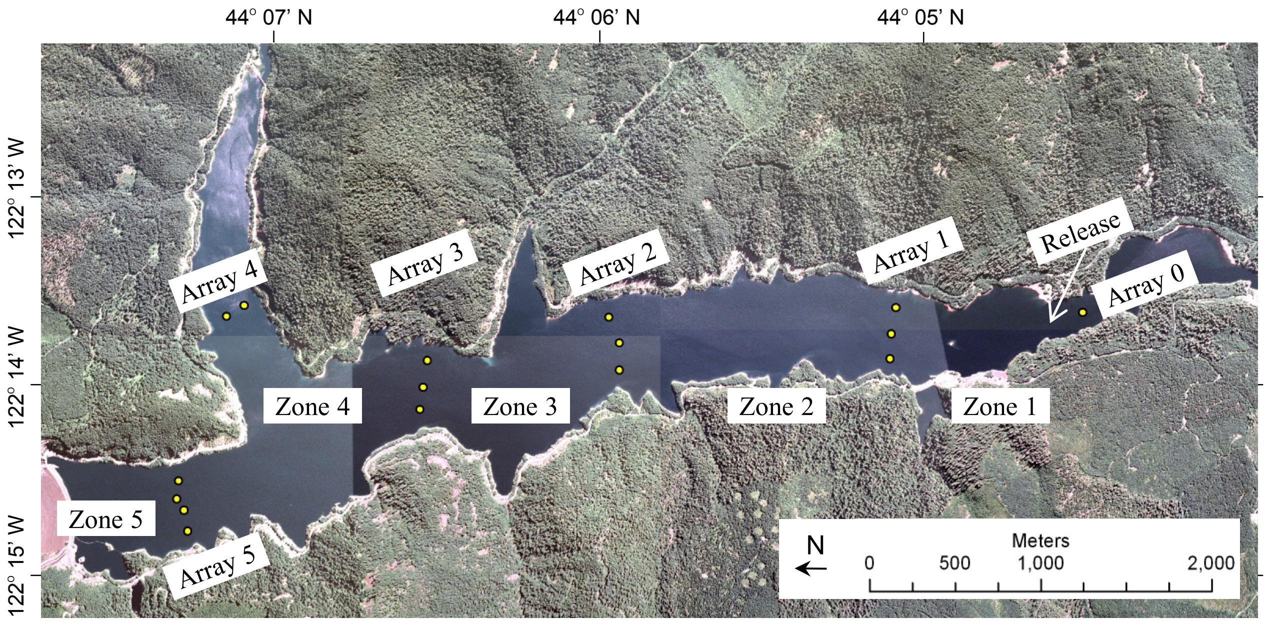
Fish Capture, Handling, Tagging, and Release

The data described in this report were collected from juvenile hatchery Chinook salmon and juvenile wild Chinook salmon (hereafter referred to as "hatchery Chinook salmon" and "wild Chinook salmon," respectively). Yearling hatchery Chinook salmon were used during the spring and subyearling hatchery Chinook salmon were used during the fall to mimic the life history of the wild fish in the reservoir. The hatchery Chinook salmon were reared at the Fish Performance and Genetics Laboratory (FPGL) in Corvallis, Oregon, delivered to Leaburg Hatchery in Leaburg, Oregon, and tagged at Cougar Dam. The hatchery Chinook salmon were held at Leaburg Hatchery for 8–29 days prior to tagging, depending on what part of the month the fish were tagged. Hatchery Chinook salmon were delivered on a regular basis by FPGL employees. For the first month of the study, about 100 hatchery Chinook salmon were delivered every other week. Thereafter, about 190 hatchery Chinook salmon were delivered once during each tagging month to increase the recovery time after transport. A total of 559 hatchery Chinook salmon between March and May 2012, and 524 hatchery Chinook salmon between September and November 2012, were transported to Leaburg Hatchery. Hatchery Chinook salmon were sorted by size prior to transportation to the Leaburg Hatchery to meet a fork-length (FL) requirement (between 95 and 180 mm FL) to mimic wild fish from Cougar Reservoir. Rearing temperatures at the FPGL were warmer than at Leaburg Hatchery, so fish were tempered by FPGL personnel during transport. Ice blocks of well water were placed in the transport tank if the temperatures between the two water sources differed by more than 6 °C. Water temperature and dissolved oxygen were checked periodically during the 3-hour transport time. Water temperatures were tempered again at the hatchery if the temperature difference was greater than 2 °C (Surgical Protocols Steering Committee, 2011). In the spring, hatchery Chinook salmon were held in an indoor Canadian trough supplied with continuous flowing river water. The Canadian trough measured 4.9 m long × 0.8 m wide × 0.45 m deep, and held 1,812 L of river water. In the fall, hatchery Chinook salmon were held outdoors in a circular pond (6.1 m wide × 0.7 m deep; 19,539 L volume) supplied with continuous flowing river water. During 1 d of every other week in the spring (March–May) and fall (September–November), hatchery Chinook salmon were netted from the fish tank at Leaburg Hatchery, placed in a 264-L transport tank, and taken to the tagging site at the Cougar Dam adult fish facility where they were held 18–30 hours prior to tagging. The recommendations from the Surgical Protocols Steering Committee (2011) were followed in all aspects of fish holding, tagging, and releasing procedures.

U.S. Geological Survey (USGS) personnel used a Lampara seine to capture wild Chinook salmon in Cougar Reservoir on six dates between October 23 and November 28, 2012. The seine was 91.4 m long and fished to a depth of approximately 7.6 m. The seine was deployed from a boat by encircling an area and hauling the net back onto the boat deck by hand. A total of 112 wild Chinook salmon were netted from within Cougar Reservoir, placed in an aerated container with fresh river water, and transported to the Cougar Dam adult fish facility where they were treated in the same manner as the hatchery Chinook salmon.

Transmitter implantation and fish recovery were completed at the Cougar Dam adult fish facility. Fish were considered suitable for tagging if they were free of major injuries, major fin damage or fungus; had no external signs of gas bubble trauma; were less than 20 percent descaled; had no visible signs of disease or deformities; and were not previously tagged other than with a coded-wire tag (Surgical Protocols Steering Committee, 2011). Fish were rejected from tagging if more than five copepods (*Salmincola californiensis*) were observed during a macroscopic examination of the branchial cavities. Fish weight and length were measured immediately prior to tagging. Each fish meeting the selection criteria was surgically implanted with an acoustic transmitter and passive integrated transponder (PIT) tag provided by the USACE using surgical procedures from the Surgical Protocols Steering Committee (2011). Acoustic transmitters meeting Juvenile Salmon Acoustic Telemetry System (JSATS) specifications (model SS300, Advanced Telemetry Systems; Isanti, Minnesota) were 10.72 mm long × 5.22 mm wide × 3.16 mm deep and had a mass of 0.31 g in air. Expected transmitter life at the nominal pulse rate interval of 16 seconds was 90 days. A 12.5-mm long full-duplex PIT tag (model SST, Biomark, Boise, Idaho) weighing 0.10 g was placed inside the body cavity along with the acoustic transmitter. 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 through electrolyte loss. To implant the transmitter, fish were anesthetized using buffered tricane methanesulfonate (MS-222, Argent Chemical Laboratories, Redmond, Washington). The MS-222 concentration varied because it affected hatchery and wild Chinook salmon differently over the range of water temperatures observed. The concentration range for hatchery Chinook salmon was inversely related to water temperature and ranged from 80 to 140 mg/L. A concentration of 90 mg/L was used for the wild Chinook salmon throughout the study. Fish were placed in a 19-L perforated recovery bucket filled with 7 L of river water immediately after surgery. Dissolved oxygen levels were maintained between 80 and 110 percent of saturation during recovery. The mean density in a recovery bucket was 13.6 g/L (range 3.0–34.3 g/L) for hatchery Chinook salmon and 6.3 g/L (range 1.5–13.3 g/L) for wild Chinook salmon, with no more than three fish per bucket. Fish placed in the recovery buckets were checked periodically during the first 10 minutes after surgery to ensure that they recovered from anesthesia. Recovery buckets then were fitted with lids and placed in a raceway provided with flowing river water where fish were held prior to release. The recovery buckets were fitted with inflated rubber tubes near their tops and floated in the outdoor raceway to allow fish access to air to adjust their buoyancy (Fried and others, 1976). During the tagging and releasing process, the water temperature, dissolved oxygen, and total dissolved gas were monitored in all holding buckets, transport tanks, and the recovery raceway.

Tagged fish were released near the head of Cougar Reservoir. After the 18–36-hour recovery period, fish were taken by boat upstream through Cougar Reservoir to the release site about halfway between the two shorelines near the Slide Creek boat ramp (fig. 3). Recovery buckets were removed from the raceway, inspected for mortalities, and transferred to one of two insulated 1,556-L plastic tanks mounted on a flatbed trailer prior to hauling to the boat ramp at the earthen dam and transport by boat about 7.0 river kilometers to the release site. Water-quality measurements were recorded and tempering was done if the water temperature difference between the recovery bucket and the reservoir was greater than 2 °C (Surgical Protocols Steering Committee, 2011). Fish were released by partially submerging the buckets in the river and gently tipping them over.



USGS High Resolution State Orthoimagery for Oregon, 2005, 0.5 meter resolution

Figure 3. Orthoimage showing locations of zones bounded by arrays of autonomous acoustic receivers (small circles) deployed in Cougar Reservoir, Oregon, 2012. The release location is indicated with an arrow.

Acoustic Telemetry Detection Systems

Signals from acoustic transmitters were detected using two types of JSATS hydrophone systems provided by the USACE. The JSATS equipment is described in McMichael and others (2010). Acoustic signals from tagged fish in the reservoir from approximately the log boom at the boat restricted zone upstream to near the head of the reservoir were detected using autonomous hydrophones spaced across the reservoir width at six locations (fig. 3). A single autonomous hydrophone was installed inside the temperature control tower to confirm tower entry and fish passage. In 2011, we empirically determined in the eastern arm of Cougar Reservoir that 82 percent of the expected number of transmissions was detected at a range of 105 m, and 10 percent were detected at a range of 180 m. Based on that data, the hydrophones were spaced about 100 m from shorelines and 200 m from each other at a depth of about 33 m from the water surface along lines across the reservoir (hereafter referred to as “arrays”). Hydrophones were deployed using methods similar to those described by Titzler and others (2010), except that burlap bags filled with sand as anchors were used. The autonomous hydrophones were operational beginning on March 19, 2012, and were serviced at 2–3 week intervals.

Acoustic signals from tagged fish near the temperature control tower were detected using four hydrophone systems linked to one another 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 common global positioning system. The use of a common time for all hydrophones allows estimation of fish position based on time of signal arrival if hydrophone locations and the speed of sound in water throughout the study area are known. A global positioning system was used to determine locations of hydrophones deployed from floating platforms. A similar cabled hydrophone system is described by Weiland and others (2009, 2011).

The cabled hydrophone systems were installed along the temperature control tower at several elevations and from floating platforms (figs. 4 and 5). The range of the cabled hydrophone systems was assumed to be similar to that of the autonomous hydrophones, so hydrophones were spaced with overlapping coverage. This assumption seemed reasonable because each transmitter signal typically was detected by most of the cabled hydrophones.

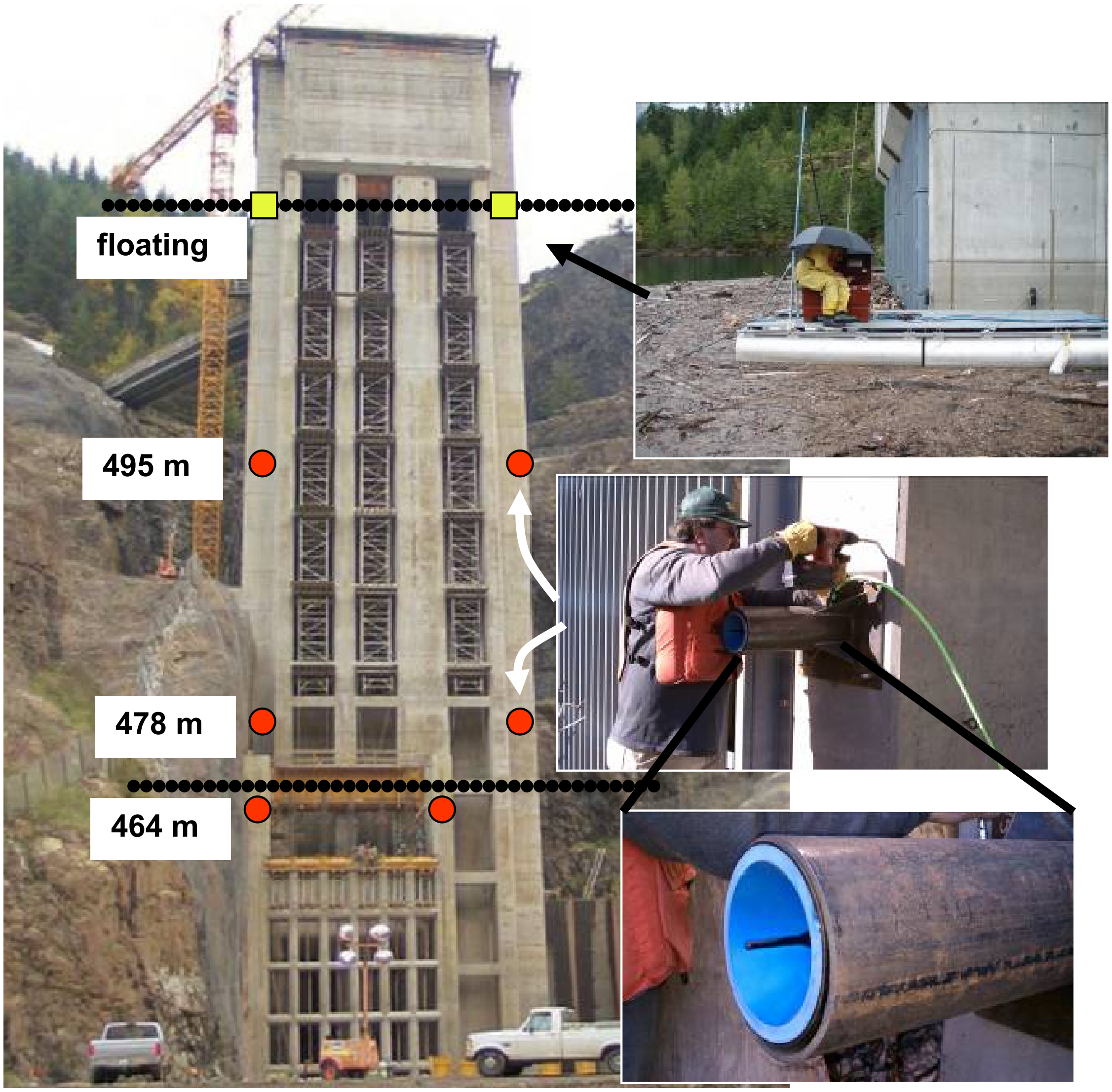
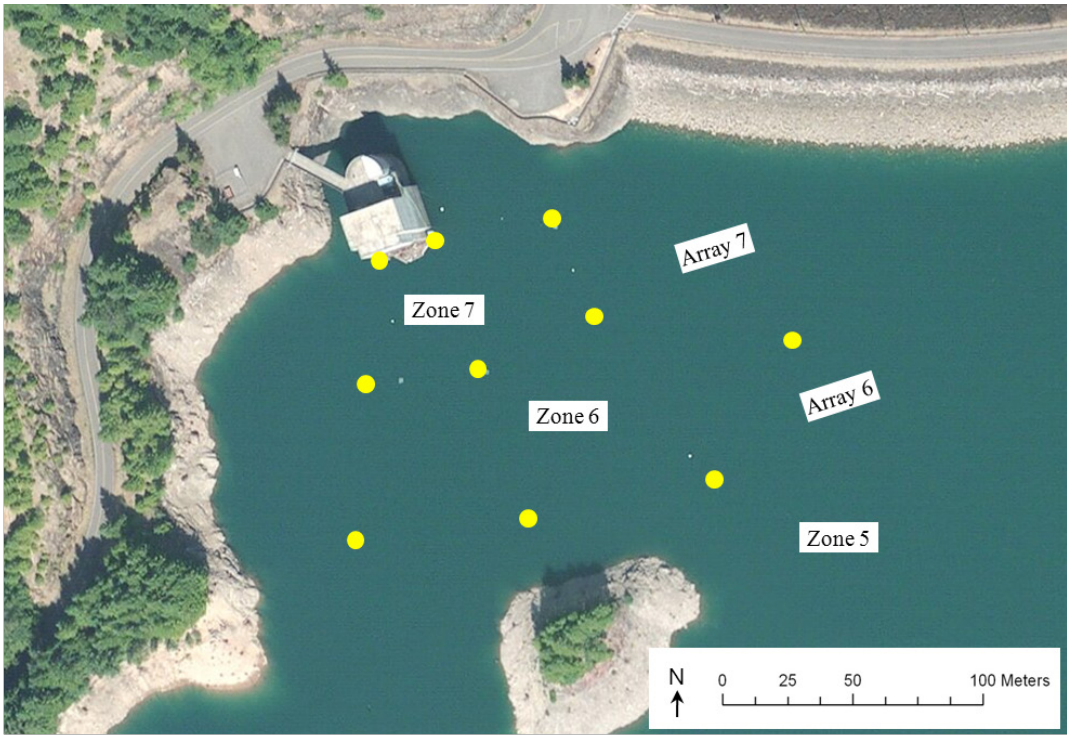


Figure 4. Photographs showing locations of cabled hydrophones nearest the temperature control tower at Cougar Dam, Oregon, 2011. Round symbols represent hydrophones affixed to the tower, and square symbols indicate those mounted from floating platforms. Numbers are hydrophone elevations. Dotted lines represent approximate locations of full and minimum conservation pool water elevations of 515 and 468 meters. Photograph during construction in 2005 provided by U.S. Army Corps of Engineers, and inset photographs taken by Amy Hansen and Scott Evans of the U.S. Geological Survey.



ESRI World Imagery, 2011, 0.5 meter resolution

Figure 5. Orthoimage showing locations of hydrophones deployed from floating platforms near the temperature control tower at Cougar Dam, Oregon, 2012.

Data Management and Analysis

Transmitter Life Tests

We selected 50 transmitters from the spring tags and 50 transmitters from the fall tags and empirically determined tag life. We used the same transmitter model in concurrent studies at Cougar and Detroit Reservoirs, so a single tag-life study was conducted using 25 tags from the tag allocation for each study. We activated the spring tags on March 26, 2012, and the fall tags on August 24, 2012, 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, and recorded detections with an Advanced Telemetry Systems model Trident SR5000 receiver by placing the hydrophone in the tank and attaching it to the external receiver using a data cable. The data were run through the same filter as the fish detection data and were summarized with the time-to-event Kaplan-Meier survivorship analysis (Hosmer and Lemeshow, 1999).

Removing False-Positive Records

Data from the hydrophones were processed to remove false-positive records prior to analysis. 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 procedures developed by Pacific Northwest National Laboratory (Mark Weiland, written commun., June 17, 2010) to remove false-positive records. The steps include 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 also were required to be present on more than one hydrophone to be retained.

A series of zones were defined to enable analysis of fish movements. Zones were bounded by arrays in the reservoir, or by concentric arcs specific distances from the temperature control tower (figs. 3, 5, and 6). General fish movements between arrays over time were plotted as an example of the raw data used in subsequent analyses.

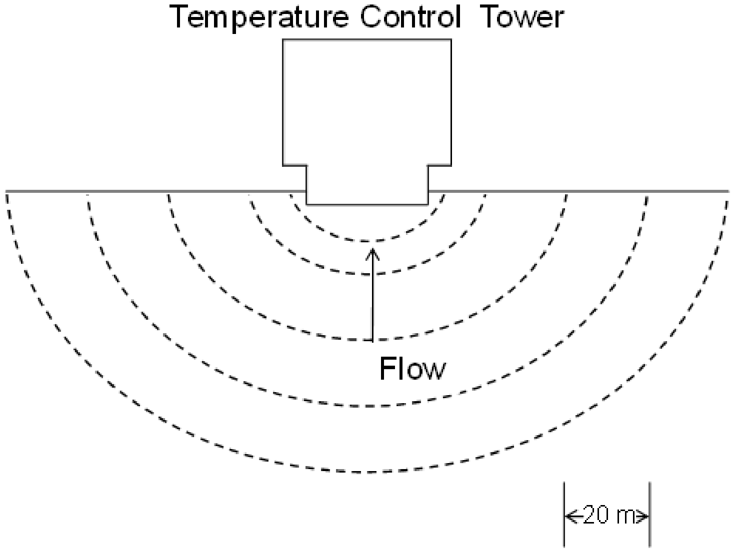


Figure 6. Diagram of zones used in analyses of data based on three-dimensional position estimates of fish near the temperature control tower at Cougar Dam, Oregon. The areas bounded by the dotted lines (from bottom up) are 95, 75, 55, 35, and 15 meters from the upstream face of the temperature control tower at Cougar Dam.

Estimating Fish Positions

Fish positions within the area monitored by the cabled-hydrophone system near the dam were estimated using software under development through a USGS subcontract with the University of Washington. The software program estimates fish positions using an iterative technique with the Gauss-Newton method to find the location that minimizes the root-mean squared misfit to all the 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 program 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 near the temperature control tower were used for this purpose.

Fish position estimates were passed through a filter to identify and to remove spurious results. The filter limited swim speeds to a burst speed of as much as 3 m/s for 20 seconds, or a sustained speed of up to 1.0 m/s for more than 20 seconds 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, and a new trip was assigned if the time elapsed between successive positions was greater than the 99th percentile (4,667 seconds). The filter identified 2.2 percent of the estimated positions.

Fish position estimates were used to describe the densities, depths, and paths of fish near the dam. Fish densities were estimated by calculating the percent presence in the monitored area near the dam. Percent presence in the horizontal plane was calculated as the percentage of fish present at least once in each 10-m × 10-m cell in the x-y plane. The median of the cumulative residence time of each fish in each cell of the horizontal plane was used as an estimate of temporal fish aggregations. The mean hourly depths of each origin were calculated from the median hourly depths of each fish.

Assigning Dam Passage

Dam passage was determined using presence data from the cabled hydrophones nearest the temperature control tower at Cougar Dam. The date and time of assumed dam passage were assigned if the first detection of the last transmitted message was at any of the hydrophones located on the tower that were closest to the water outlets. This method was chosen to limit passage assignments to fish last detected in the area generally in front of the tower when operating, and was consistent with histories of tagged fish known to have passed the dam based on detections of PIT tags downstream. Two general measures of fish passage were estimated from these data (table 1).

Table 1. Passage efficiency definitions.

["Number" refers to number of tagged fish]

Metric	Acronym	Definition
Reservoir passage efficiency	RPE	Number detected at array 5 ÷ number released
Dam passage efficiency	DPE	Number passing the dam ÷ number detected at array 5

Probability of Presence Near Cougar Dam.

We estimated the probability that a fish released at the head of the reservoir was present at least once at each sequential downstream array and near the temperature control tower. The purpose of this was to determine if fish would be available for capture by a fish collection facility near the dam, if one were present. This analysis does not indicate if undetected fish were alive or dead, only if they were detected in the area of interest while the fish tag was still active. The data were based on presence of fish detected at each reservoir array and the cabled hydrophone system nearest the dam (array 7), which detected fish about 100 m from the dam.

The probability of being present near the temperature control tower at least once was estimated using Cormack-Jolly-Seber mark-recapture methodology (Cormack, 1964; Jolly, 1965; Seber, 1965) using Program MARK (White and Burnham, 1999). We constructed models of presence and recapture (detection) probabilities for the spring and the fall study periods based on various hypotheses about differences among arrays and between fish of hatchery and wild origin. In this analysis, the “recapture probability” at an array is the probability of being detected at that array at least once. Support from the data for each model within a suite of models developed to estimate the detection and the presence probabilities was evaluated using the Akaike Information Criterion with an adjustment for effects of sample size (AICc). Burnham and Anderson (2002) suggest that when AICc values differ by less than 2 units, the support for one hypothesis over another is not meaningfully different based on the data and models considered. They also suggest that AICc differences of 4–7 indicate considerably less support for the model with the greater AICc, and differences greater than 10 indicate essentially no support for the model with the greater AICc. Supported models of detection probability were used in models of presence probability. When this resulted in more than one model of presence probability the results were estimated from model-averaged coefficients for all models with an AICc value within 10 units of the model with the lowest AICc. The probability of being present at the temperature control tower 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). Overdispersion was assessed using the median $\hat{c}$ procedure in program MARK.

Travel Times

Analyses of the timing of downstream movement in the reservoir and dam passage were conducted using time-to-event methods (Hosmer and Lemeshow, 1999). The time elapsed from fish release to two event types was described using Kaplan-Meier survivorship functions. The event types were (1) detection by any hydrophone in zone 6 (about 200 m from the tower) after release, and (2) dam passage. Fish that had not experienced an event by the 90th percentile of the empirically determined transmitter life were right censored at that time.

Cox proportional-hazards regression was used to determine the potential effects of selected variables on the rate of dam passage. 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 not included in report tables.

Models of factors supported as determinants of dam passage rate 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, forebay elevation, head over the weir gates, diel period, fork length, origin, and selected 2-way interactions) were considered in the full models if the factors met selection criteria. The selection criteria included bivariate correlations less than an absolute value of 0.8 and meeting assumptions of linearity and proportionality in the hazards. The AIC was used to assess support for competing models.

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 a two-step process (dependent on previous location), and assessed support of the hypotheses by the data using AIC.

Factors Affecting Temperature Control Tower Entry and Passage Rates

The effects of selected variables on the rates of specific events at the entrance to the temperature control tower were determined using Cox proportional-hazards regression based on detections of tagged fish near or inside the temperature control tower (Castro-Santos and Haro, 2003; Castro-Santos and Perry, 2012). The analyses were based on three event types: (1) dam passage, (2) entry into the temperature control tower, and (3) entry into the temperature control tower and returning to the reservoir without passing. The analyses were based on data in the counting-process approach incrementing each hour, change in diel period, or event type (Hosmer and Lemeshow, 1999). This approach enables time-varying covariates, such as hourly dam discharge, to be incorporated in the analysis. The following event types were identified with different censor values: moving from the area monitored within about 100 m of the temperature control tower back upstream to autonomous hydrophones in the reservoir, entering the temperature control tower and subsequently returning to the reservoir, and entering the tower and passing the dam. Additionally, detections of fish were right-censored at the 90th percentile of the empirically determined tag life as a means to control for tags ceasing operation during the events of interest. All analyses were based on a significance level of $\alpha=0.10$.

Head Differential Test

Assessment of the effects of head differential levels on entry rate into the temperature control tower was based on Cox proportional-hazards regression of data collected during the controlled experiment during May and June 2012. The effects of the treatment relative to the control were estimated as the hazard ratio and associated estimation error of a model, including (A) the treatment effect (1=control, 2=treatment) controlling for block using the STRATA statement, and (B) dam discharge. The variance was adjusted for correlations among repeated measures within individuals with robust variance estimates using the PHREG procedure of SAS/STAT® software, version 9.3, of the SAS System for Windows© (2000–2008, SAS Institute, Inc.). The fish used for analysis were those released as part of the general study that were within about 95 m of the temperature control tower during the experimental period.

Temperature Control Tower Entry and Dam Passage

Data from the fall study period were used to evaluate the effects of selected factors on the temperature control tower entry rate and dam passage rate of tagged fish within about 95 m of the temperature control tower. Main effects included dam discharge in 1,000 ft^3/s increments; diel period defined by civil twilight times at Springfield, Oregon (day=1, night=2); forebay elevation, in feet; fish fork length in 10-mm increments; and fish origin (hatchery=1, wild=2). The model assumption of proportionality of categorical factors was evaluated by examining plots of the log-negative-log of the survival distribution function against the log of time (Hosmer and Lemeshow, 1999). The model assumption of linearity of continuous covariates was assessed by examining plots of the hazards against discretized levels of the covariates for linearity (Hosmer and Lemeshow, 1999). The discharge during the period of tower entry and exit events occurred in three discrete levels, so the discharge variable was divided into three discrete ranges and the effects were examined as the effect of the intermediate and high levels relative to the low level. Details of the discrete levels are in section, “Results.” Final models in the analyses of factors affecting event types 1 and 3 were based on sequentially reducing the number of factors in the full model, beginning with the interaction terms, until all remaining factors had a probability of a greater Chi-square value less than or equal to 0.10 or were involved in interactions meeting that criterion. All Cox regression analyses were performed using the PHREG procedure of SAS/STAT® software, version 9.3, of the SAS System for Windows© (2000–2008, SAS Institute, Inc.).

Results

Definition of Spring and Fall Study Periods

We divided the data into spring and fall study periods based on the tagging periods and transmitter life. Each study period ranged from the first release until the estimated 90th percentile of tag life. The spring study period was from March 16 to August 24, 2012, and the fall study period was from September 15, 2012, to February 24, 2013. There likely were few tagged fish with active tags in the reservoir between August 22 and September 15, 2012 (fig. 7).

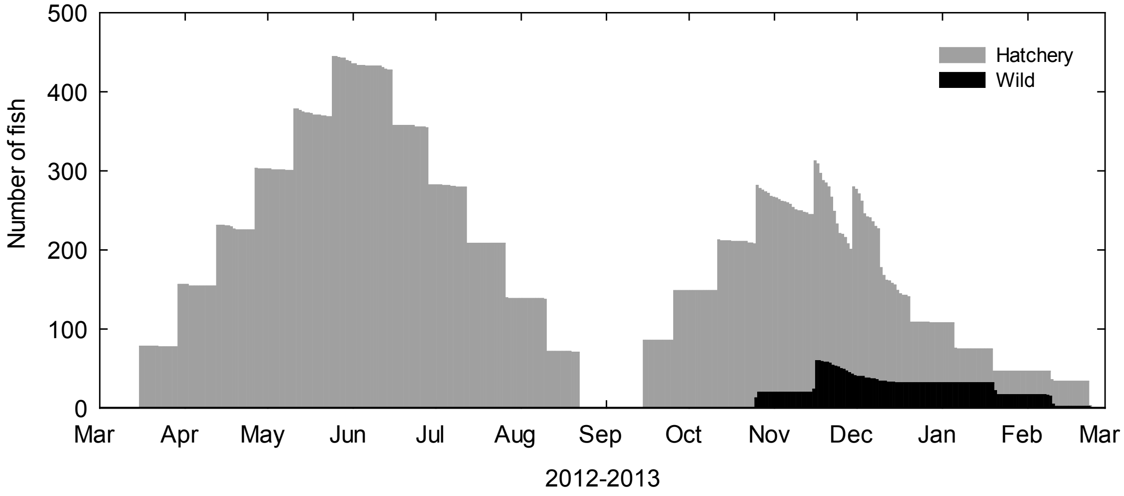


Figure 7. Graph showing estimated number of live tags available, by fish origin and date, in Cougar Reservoir, Oregon, 2012–2013.

Transmitter Life Tests

The estimated lives of the tags used during the spring and fall were similar. The median life of the spring tags tested was 96.5 days, and the maximum life was 115.8 days (fig. 8). The first tag stopped working after 87.8 days. The 90th percentile of tag life was 92.5 days. The median life of the fall tags tested was 95.8 days and the maximum life was 111.4 days. The first tag expired at 70.2 days and the 90th percentile of tag life was 87.0 days.

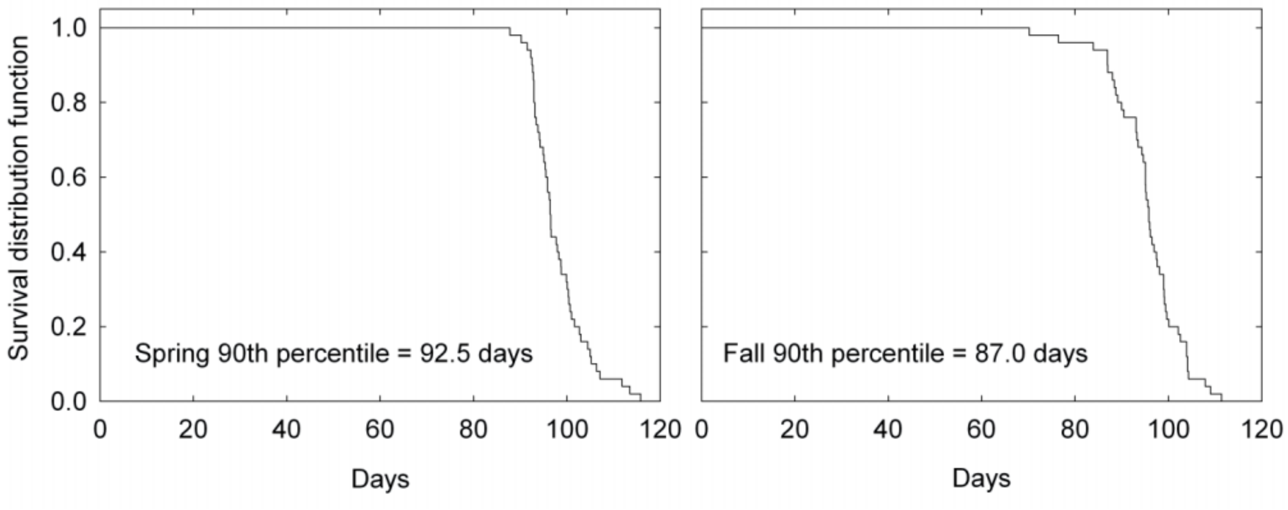


Figure 8. Graphs showing transmitter lives from extinction tests of the acoustic tag model used at Cougar Reservoir and Dam, Oregon 2012 spring and fall study periods.

Fish Capture, Handling, Tagging, and Release

During the spring study period, 468 hatchery Chinook salmon were tagged and released from March 16 to May 25, 2012. The mean fork length was 144.9 mm (range 112–180 mm; table 2). The tag-weight-to-body-weight ratio (based on the 0.41-g weight of the acoustic transmitter plus the PIT tag) ranged from 0.64 to 2.8 percent, with a mean of 1.3 percent. Pre-tag holding times for the hatchery Chinook salmon ranged from 18.0 to 21.1 h, and post-tag holding times ranged from 19.1 to 21.4 h.

Table 2. Summary statistics of fork length and weight of acoustic- and passive integrated transponder-tagged hatchery and wild juvenile Chinook salmon at Cougar Reservoir, Oregon, 2012.

[*N*, number of fish; SD, standard deviation]

Fish origin		Fork length (millimeters)			Weight (grams)		
	N	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Spring							
Hatchery	468	144.9	13.3	112–180	32.8	8.8	14.9–63.8
Fall							
Hatchery	449	147.7	14.1	98–180	34.4	10.4	9.9–67.8
Wild	65	120.8	11.0	98–159	19.7	6.2	9.1–46.6

There were 11 pre-tag mortalities and 2 post-tag mortalities during the spring study period. There was one pre-tag mortality of the 293 hatchery Chinook salmon delivered prior to the end of April (0.3 percent). There were 10 pre-tag mortalities of the 266 hatchery Chinook salmon delivered for the May tagging sessions (3.7 percent). Six of the pre-tag mortalities were sent to the U.S. Fish and Wildlife Service, Lower Columbia River Fish Health Center, in Willard, Washington, for examination. No evidence of trauma or disease was found, but it was noted that the fish had no parr marks, were very silvery, and had high concentrations of the protozoan *Hexamita* in the gut. Two of the 470 tagged hatchery Chinook salmon died between tagging and release (0.3 percent).

Both hatchery and wild Chinook salmon were tagged and released during the fall study period. We deployed the Lampara seine for 39 sets and collected 112 wild Chinook salmon. A total of 449 tagged hatchery fish were released between September 15 and November 30, 2012, and a total of 65 tagged wild fish were released between October 25 and November 30, 2012. Many of the wild fish captured were rejected from tagging owing to exceedance of the copepod criteria (*N*=26), pre-existing injuries (*N*=5), being too small (*N*=7), or other reasons (*N*=4). Prevalence of parasitic copepods in the wild fish was 75.0 percent in those rejected from tagging (*N*=40), 100.0 percent in tagged fish dying prior to release (*N*=3), and 89.2 percent in the tagged fish released (*N*=65). Parasitic copepods were not found on hatchery fish. The mean fork length was 26.9 mm longer for the hatchery Chinook salmon than for the wild Chinook salmon (table 2). The tag–weight-to-body-weight ratio (based on the 0.41 g weight of the acoustic transmitter plus the PIT tag) ranged from 0.6 to 4.1 percent (average of 1.3 percent) for the hatchery Chinook salmon, and ranged from 0.9 to 4.5 percent (average of 2.3 percent) for the wild Chinook salmon. Pre-tag holding times ranged from 18.3 to 29.2 hours for the hatchery Chinook salmon and from 19.0 to 22.0 hours for the wild Chinook salmon. Post-tag holding times ranged from 18.0 to 22.0 hours for hatchery Chinook salmon and 18.0 to 19.1 hours for wild Chinook salmon.

Pre-tag mortalities during the fall study period were more prevalent than during the spring study period. There was one pre-tag mortality of the 247 hatchery Chinook salmon delivered prior to late October (0.4 percent), and 20 pre-tag mortalities of the 277 hatchery Chinook salmon delivered the last week of October (7.2 percent). Pre-tag mortality of wild fish was 1.8 percent (2 of 112). Post-tag mortality was zero for hatchery Chinook salmon and 4.4 percent (3 of 68) for wild Chinook salmon.

Environmental Conditions and Dam Operations

Dam operations and environmental conditions varied during the spring study period. Total project discharge peaked in April and decreased throughout the remainder of the spring study period (fig. 9). The mean hourly project discharge was 1,171.2 ft^3/s (range 430.0–3,140.0 ft^3/s), and was similar during the day and night; the mean daily project discharge, shown in figure 9 and table 3, was lower than the hourly values due to variation within days. During the spring study period, the project discharge typically passed through both the powerhouse and the regulating outlet. The turbine(s) and RO operated concurrently 54.2 percent of the time, the turbine(s) were operated without the regulating outlet 28.2 percent of the time, and the regulating outlet was operated without the turbines 17.7 percent of the time. Mean hourly discharge was 679.3 ft^3/s (range 0.0–2,300.0 ft^3/s) through the regulating outlet, and 491.9 ft^3/s (range 0.0–1,020.0 ft^3/s) through the powerhouse. In accordance with the planned rule curve for the reservoir, the forebay elevation increased until early May, and the reservoir remained full through August (surface-water elevation range 1,630.3–1,689.9 ft). The temperature of the top 13–19 ft of the reservoir increased steadily until mid-summer and averaged 10.6 °C (range 4.7–18.8 °C). The mean hourly head (depth over the upper weir gates) was 18.5 ft (range 0.0–54.9 ft). The head followed trends in discharge during the spring study period except during the head differential test in May and June.

The dam operating conditions during the head differential test in May and June varied from the planned conditions. Variation in head differential (primarily during the treatment condition) resulted in conditions commonly being outside the prescribed ranges, so to increase the amount of data available, the bounds used for analysis were altered from the originally planned 0–0.25 ft and 0.75–1.00 ft to 0–0.30 ft and 0.65–1.00 ft for the control and treatment, respectively (fig. 10). Additionally, dam discharge, a variable known to affect tower entry and dam passage rates of Chinook salmon at Cougar Dam (Beeman and others, 2013), varied within blocks (fig. 11). Dam discharge during the test ranged from 780 to 1,720 ft^3/s and averaged 1,210 ft^3/s. The differences of average discharge between treatments within a block ranged from 30 ft^3/s during block 5 to 440 ft^3/s during block 4. The largest difference in range of discharge within a block occurred in block 3, where the range was 910 ft^3/s during the control condition and 150 ft^3/s during the treatment condition. The smallest difference in range of discharge within a block occurred in block 5 (100 ft^3/s control, 70 ft^3/s treatment). Forebay elevation varied little during the test, ranging from 1,688.3 to 1,689.9 ft (average of 1,689.3 ft).

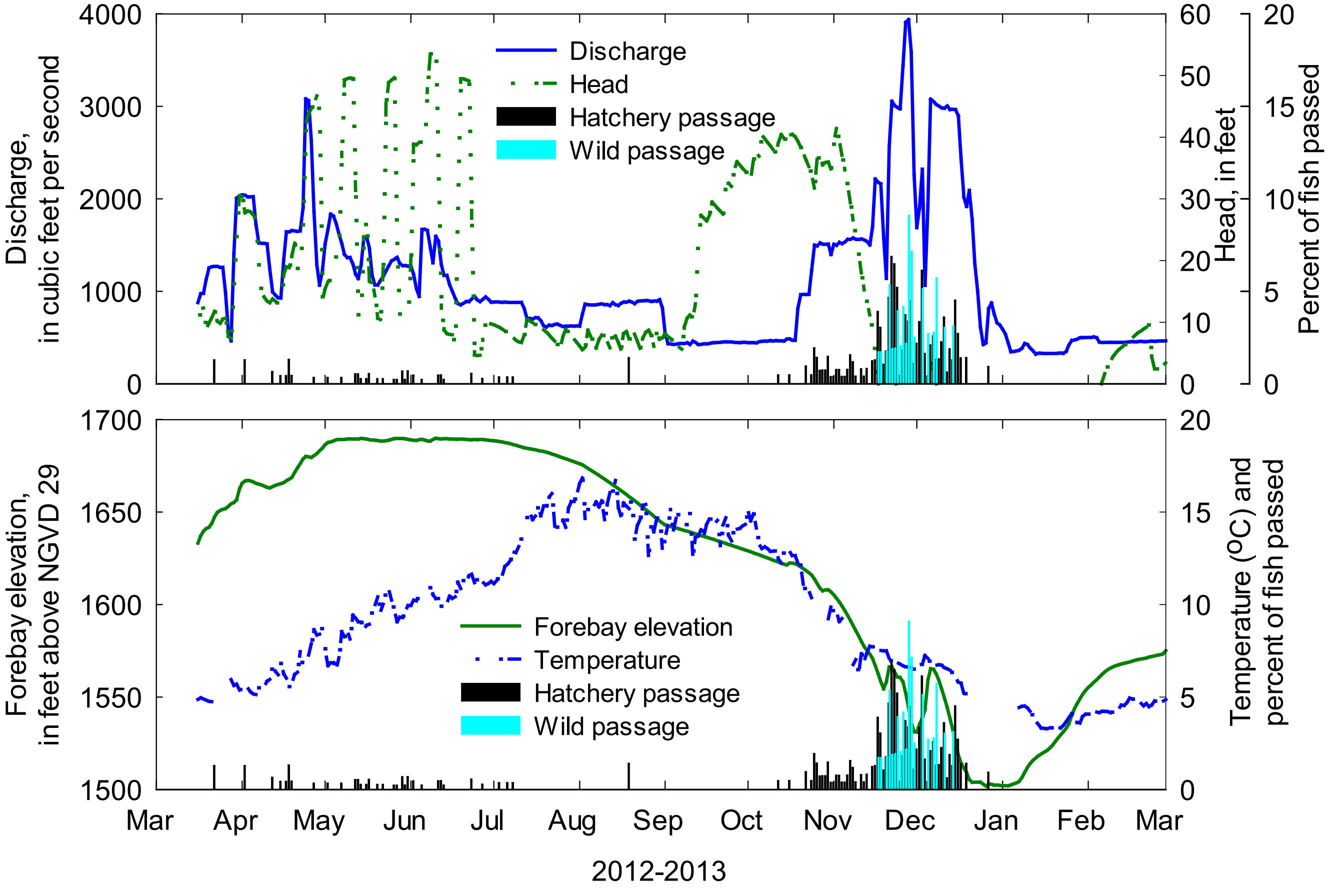


Figure 9. Graphs of mean daily project discharge and head over the weir gates (top), and forebay elevation and water temperature (bottom) at Cougar Reservoir, Oregon, March 13, 2012–March 1, 2013. Water temperature is the average of the upper 13–19 feet of the water column near the temperature control tower. Additionally, both graphs show daily passage of juvenile hatchery and wild Chinook salmon as a percentage of fish in the reservoir available to pass (vertical bars).

Table 3. Mean hourly summary statistics of dam operations and environmental conditions at Cougar Reservoir, Oregon, 2012 spring study period.

[SD, standard deviation; ft^3/s, cubic feet per second]

	Period	Mean	Median	Range	SD
Total project (ft^3/s)	Overall	1,171.2	1,010.0	430.0–3,140.0	463.3
	Day	1,162.9	1,000.0	430.0–3,130.0	451.6
	Night	1,183.3	1,040.0	430.0–3,140.0	479.9
Powerhouse (ft^3/s)	Overall	491.9	500.0	0.0–1,020.0	339.5
	Day	482.4	500.0	0.0–1,020.0	342.7
	Night	505.9	510.0	0.0–950.0	334.5
Regulating outlet (ft^3/s)	Overall	679.3	760.0	0.0–2,300.0	520.5
	Day	680.6	770.0	0.0–2,300.0	509.2
	Night	677.4	760.0	0.0–2,240.0	536.8
Forebay elevation (feet)	Overall	1,677.3	1,683.1	1,630.3–1,689.9	14.0
	Day	1,678.1	1,684.0	1,632.6–1,689.9	13.4
	Night	1,676.0	1,681.2	1,630.3–1,689.8	14.6
Head over the weir gates (feet)	Overall	18.5	10.7	0.0–54.9	15.0
	Day	18.2	10.7	4.6–54.8	14.7
	Night	18.7	10.7	0.0–54.9	15.3
Water temperature (degrees Celsius)	Overall	10.6	10.5	4.7–18.8	3.6
	Day	10.5	10.4	4.7–18.5	3.4
	Night	10.8	10.8	4.7–18.8	4.0
Regulating outlet (percentage of total)	Overall	52.8	59.7	0.0–100.0	37.9
	Day	53.7	60.0	0.0–100.0	38.0
	Night	51.4	59.5	0.0–100.0	37.7

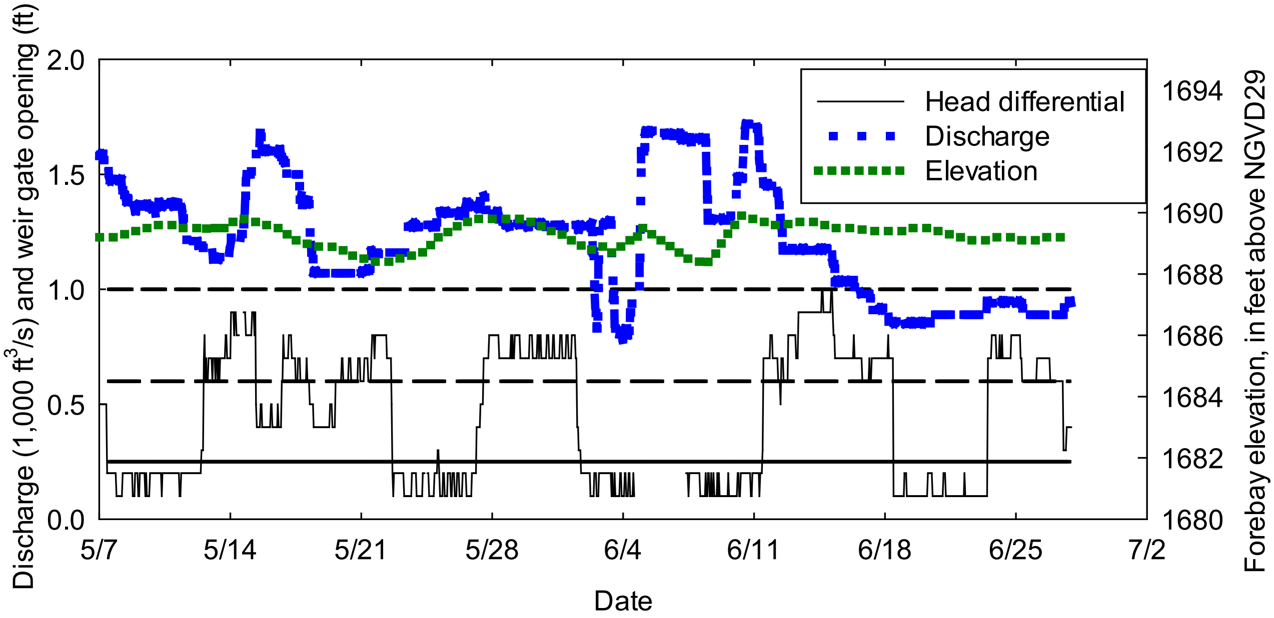


Figure 10. Graph showing hourly dam operating conditions during the head differential test at Cougar Dam, Oregon, May–June 2012. Shading indicates control (no shading) and treatment (shaded) conditions. Horizontal lines indicate upper limit of the head differential of the control condition (solid line, 0.30 foot) and lower and upper limits of the treatment condition (dashed lines, 0.65–1.00 foot) used for analysis.

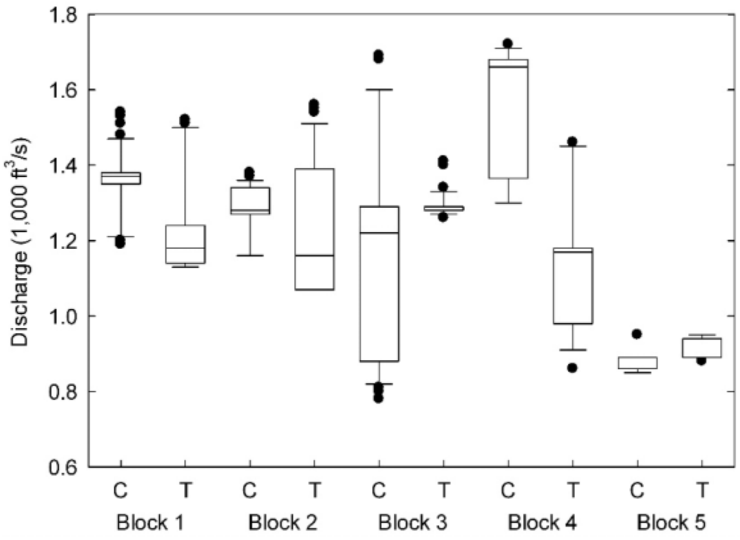


Figure 11. Boxplot summarizing dam discharges during the head differential test at Cougar Dam, Oregon, May–June 2012. Data from control (C) and treatment (T) conditions during each block are summarized. Boundaries of boxplots are 25th and 75th percentiles, the horizontal line within a box is the median, whiskers are 10th and 90th percentiles, and circles indicate outliers.

During the fall study period, the dam discharge generally was greater than during the spring study period, and reservoir elevation and water temperature decreased throughout most of the period. Hourly total project discharge peaked in December (6,780.0 ft^3/s) and was greater than 2,000 ft^3/s from November 15 through December 20, 2012, except during 5 dates (fig. 9, table 4). Total project discharge was less than 500 ft^3/s prior to October 19, 2012, and after January 3, 2013. The turbine(s) operated throughout the fall study period, except from December 15, 2012, through January 12, 2013. Mean hourly powerhouse discharge was 526.9 ft^3/s (range 0.0–1,490.0 ft^3/s), and mean hourly RO discharge was 574.0 ft^3/s (range 0.0–6,780.0 ft^3/s). Forebay elevation decreased from 1,637.1 to a low of 1,500.7 ft in late December, and then increased as the reservoir began to fill in January. The weir gates in the temperature control tower were out of the water after 4 p.m. on November 12, 2012, except for a few days in late November. Water temperature in the top 13–19 ft of the water column near the temperature control tower decreased from 16.2 to 3.1 °C and averaged 7.9 °C.

Table 4. Mean hourly summary statistics of dam operations and environmental conditions at Cougar Reservoir, Oregon, 2012 fall study period.

[SD, standard deviation; ft^3/s, cubic feet per second]

	Period	Mean	Median	Range	SD
Total project (ft^3/s)	Overall	1,100.9	490.0	270.0–6,780.0	947.8
	Day	1,040.9	470.0	270.0–6,780.0	916.4
	Night	1,146.4	500.0	310.0–4,040.0	968.7
Powerhouse (ft^3/s)	Overall	526.9	450.0	0.0–1,490.0	376.0
	Day	561.2	460.0	0.0–1,490.0	367.7
	Night	501.0	450.0	0.0–1,190.0	380.1
Regulating outlet (ft^3/s)	Overall	574.0	0.0	0.0–6,780.0	809.2
	Day	479.7	0.0	0.0–6,780.0	778.3
	Night	645.5	350.0	0.0–3,860.0	824.9
Forebay elevation (feet)	Overall	1,568.1	1,565.3	1,500.7–1,637.1	43.7
	Day	1,571.3	1,567.1	1,500.7–1,637.0	44.0
	Night	1,565.6	1,563.6	1,500.8–1,637.1	43.4
Head over the weir arrays (feet)	Overall	13.4	3.1	0.0–43.4	16.2
	Day	12.7	1.4	0.0–42.7	16.0
	Night	14.3	4.8	0.0–43.4	16.4
Water temperature (degrees Celsius)	Overall	7.9	6.7	3.1–16.2	3.9
	Day	8.0	6.8	3.1–16.2	3.9
	Night	7.8	6.7	3.1–16.2	3.9
Regulating outlet (percentage of total)	Overall	34.7	0.0	0.0–100.0	40.7
	Day	29.1	0.0	0.0–100.0	38.1
	Night	39.0	32.5	0.0–100.0	42.1

Movements within the Reservoir

General Fish Behavior

Tagged fish commonly travelled repeatedly throughout the reservoir. A pattern of directional downstream and upstream movements was evident in most fish, as indicated in figures 12, 13, and 14. Detections of some fish ended prior to the expected life of the transmitter. In some cases, this reflects dam passage, and in other cases, the cause is unknown. During the spring study period, individual hatchery Chinook salmon made 1–32 trips from the log boom or upstream to within 25 m of the tower, with an average of 8.6 trips. During the fall study period, individual hatchery Chinook salmon made 1–33 trips from the log-boom array or upstream to within 25 m of the tower, and individual wild Chinook salmon made 1–3 trips. The average number of trips to within 25 m of the tower during the fall study period was 7.2 for hatchery Chinook salmon and 1.3 for wild Chinook salmon.

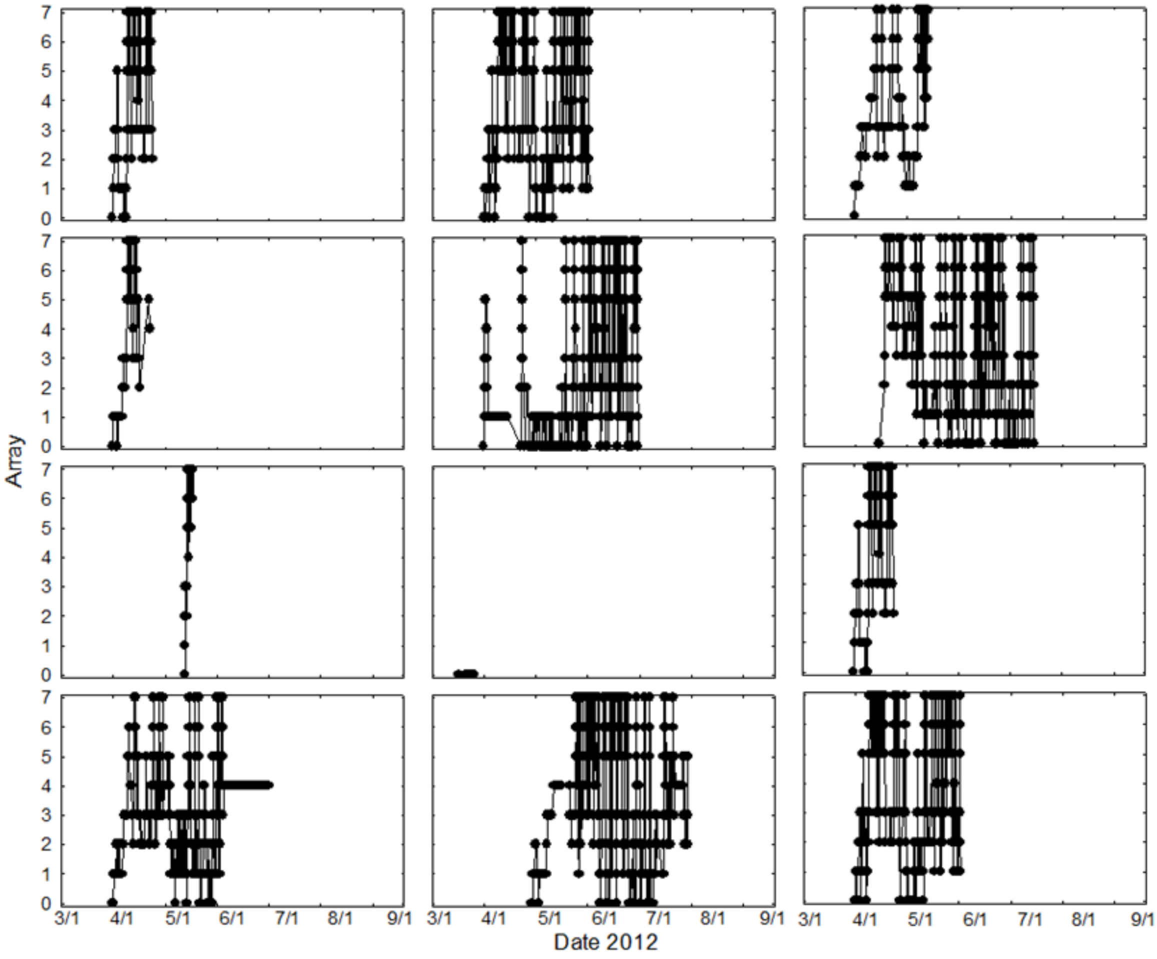


Figure 12. Graphs of the movements of 12 randomly selected juvenile hatchery Chinook salmon released at Cougar Reservoir, Oregon, spring 2012. Arrays 0–5 are in the main portion of Cougar Reservoir and arrays 6 and 7 are in the cul-de-sac near the temperature control tower (see figures 3 and 5).

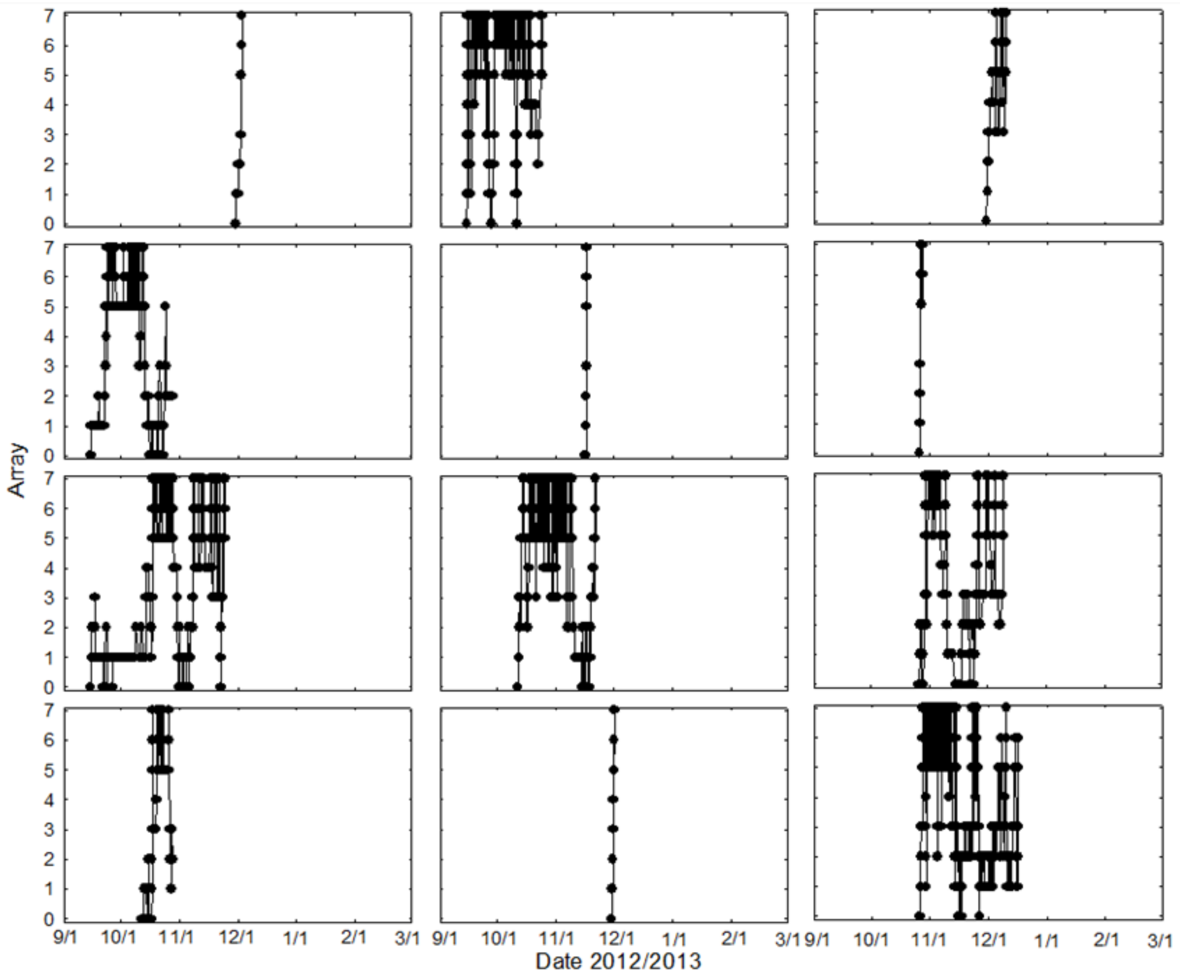


Figure 13. Graphs of the movements of 12 randomly selected juvenile hatchery Chinook salmon released at Cougar Reservoir, Oregon, fall 2012. Arrays 0–5 are in the main portion of Cougar Reservoir and arrays 6 and 7 are in the cul-de-sac near the temperature control tower (see figures 3 and 5).

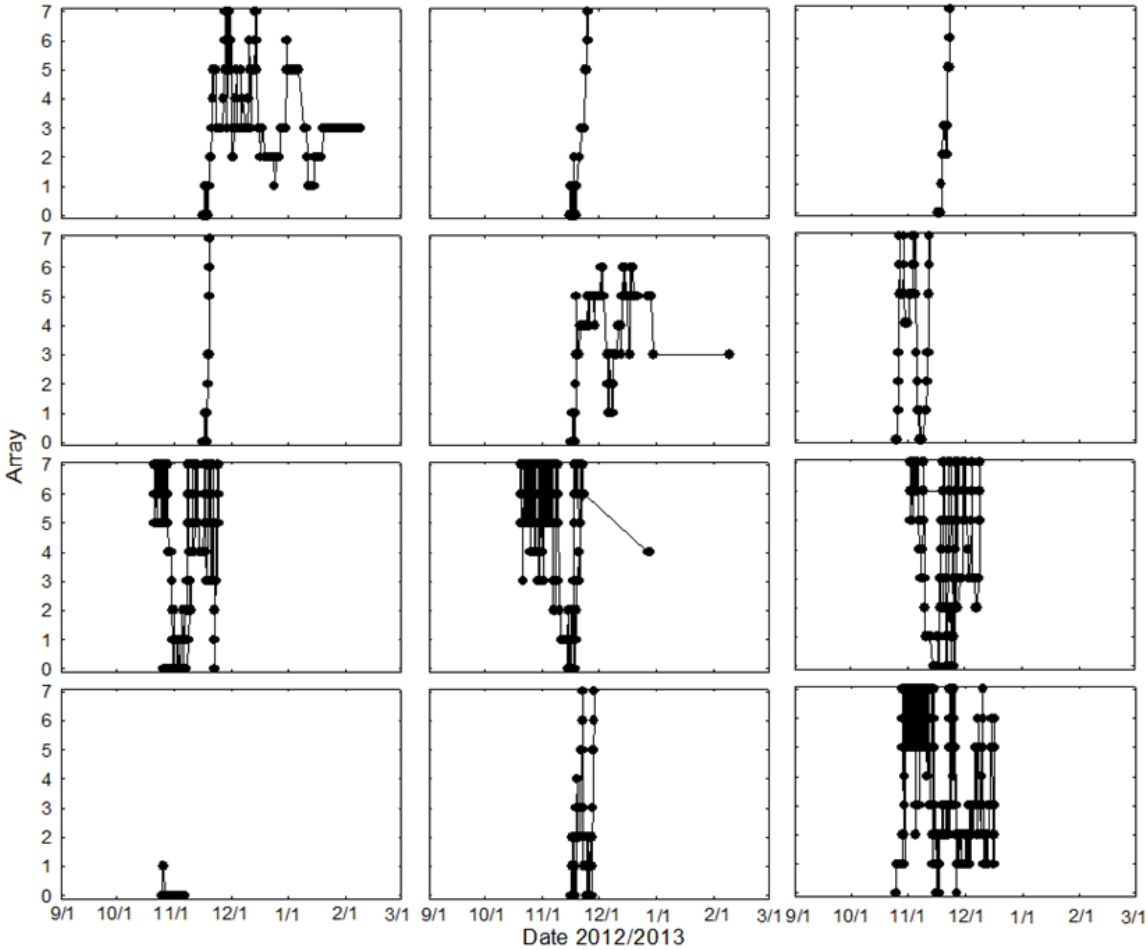


Figure 14. Graphs of the movements of 12 randomly selected juvenile wild Chinook salmon released at Cougar Reservoir, Oregon, fall 2012. Arrays 0–5 are in the main portion of Cougar Reservoir and arrays 6 and 7 are in the cul-de-sac near the temperature control tower (see figures 3 and 5).

Timing of Detection

The timing of the tagged fish detections, an indicator of animal movement, was similar among arrays during the spring study period, but varied among arrays during the fall study period (fig. 15). During the spring study period, the percentage of total hatchery Chinook salmon detections varied little among hours throughout the day and night at all arrays except array 0, the nearest to the release site. During the fall study period, hatchery Chinook salmon activity generally was greater at night than during the day. There was also a distinct increase in activity in the morning near the temperature control tower, in the afternoon at the head of the reservoir (array 0) and near the log boom (array 5), and in the evening in the eastern arm of the reservoir (array 4). No pattern was evident in the detection timing data from the wild Chinook salmon.

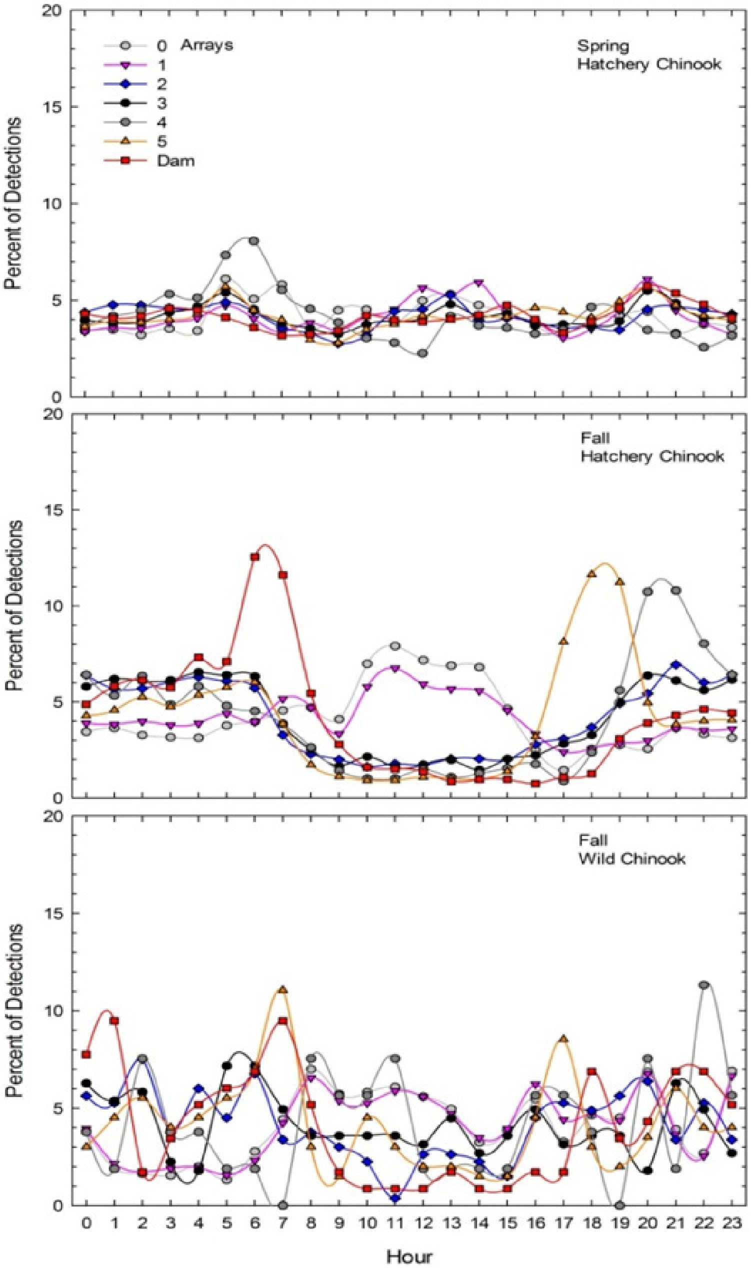


Figure 15. Graphs showing hour of detection of juvenile hatchery and wild Chinook salmon in Cougar Reservoir and within 100 meters of the water temperature control tower at Cougar Dam, Oregon, 2012 spring and fall study periods.

Travel Time from Release to the Temperature Control Tower and to Dam Passage

Travel time varied by season, fish origin, and area of the reservoir. During the spring study period, 87 percent (409 of 486) of the hatchery Chinook salmon released were detected at the temperature control tower, and their median travel time from release to the tower was 9.7 days (fig. 16). A total of 11.2 percent (46 of 409) of the hatchery Chinook salmon released in spring and detected at the temperature control tower passed Cougar Dam (46 of 409). During the fall study period, 94.4 percent (424 of 449) of the hatchery Chinook salmon and 64.6 percent (42 of 65) of the wild Chinook salmon were detected at the temperature control tower. The median travel time during the fall study period was significantly shorter for hatchery fish (3.7 days) than for wild fish (11.7 days; Wilcoxon test, χ^2=32.3, df=1, *P*<0.0001), and the median travel time from first detection at the temperature control tower until passage was significantly longer for hatchery fish (42.6 days) than for wild fish (5.9 days; Wilcoxon test, χ^2= 17.3, df= 1, *P*<0.0001). Of the fish detected at the tower during the fall study period, 59.7 percent (253) of hatchery Chinook salmon and 71.4 percent (30) of wild Chinook salmon were detected passing Cougar Dam.

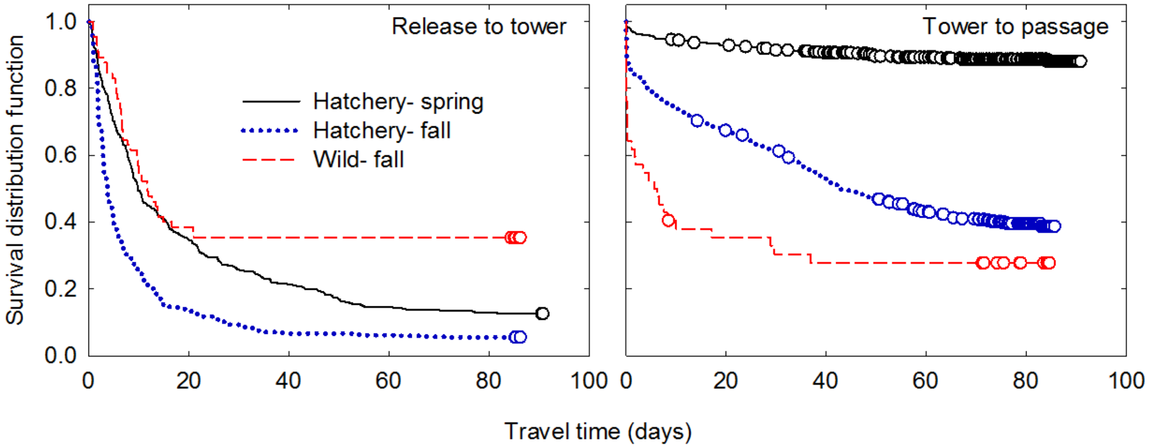


Figure 16. Graphs of travel time (days) from release to the temperature control tower and from the temperature control tower to passage for juvenile hatchery and wild Chinook salmon at Cougar Dam, Oregon, 2012 spring and fall study periods. Open circles indicate censored observations.

Probability of Presence Near the Temperature Control Tower

The probabilities of presence at each reservoir array and at Cougar Dam were determined from the model-averaged estimates of models supported by the data. We evaluated two models of presence probability for the spring study period and five models for the fall study period. Comparison of the two models of detection probability for the spring study period indicated that only the model that assumed differences in detection probabilities among arrays was supported by the data (model 1, table 5), and estimated detection probabilities ranged from 0.933 (SE 0.012) to 0.998 (SE 0.002) among arrays. During the fall study period, the estimates of detection probabilities were all 1.0 for both hatchery and wild Chinook salmon, so the model with a common detection probability was used and all detection probabilities were fixed at 1.0.

Table 5. Suite of models of detection probabilities evaluated for the analysis of presence probabilities of juvenile hatchery and wild Chinook salmon released into Cougar Reservoir, Oregon, 2012 spring and fall study periods.

[Models of detection probability (P) included array or a common detection probability for all arrays (.). Models for the spring study period had a common presence probability model with an array effect. During the fall study period, P was 1.000 for all arrays for hatchery and wild fish. AICc, Akaike Information Criterion; delta AICc, difference from model with smallest AICc; Num par, 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
Spring						
1 P(array)	823.551	0.000	1.000	1.000	11	71.534
2 P(.)	886.733	63.183	0.000	0.000	6	137.978
Fall						
3 P(.)	381.956	0.000	1.000	1.000	12	0.000

Both models of presence evaluated for the spring study period and three of the five models evaluated for the fall study period were supported by the data in varying degrees (tables 6 and 7). During the spring study period, the model that assumed differences in presence probability among arrays and the model that assumed a constant presence probability both received similar support (delta AICc less than 2, table 6). In the fall study, all three of the supported models included some effect of fish origin (models 1–3, table 7). The fall model best supported by the data included fish origin effects only (model 1) and received substantially more support than the other two models with additive or multiplicative effects of fish origin and array (models 2 and 3, delta AICc of about 4 and 6, table 7). Tests of overdispersion were not calculable, which was likely a result of the high detection probabilities and, therefore, low expected overdispersion, so no adjustments for overdispersion were applied.

Table 6. Suite of models used in the estimation of presence probabilities of juvenile hatchery Chinook salmon released into Cougar Reservoir, Oregon, 2012 spring study period.

[Models of presence probability (M) included array effects or a common value fitted to all arrays (.). AICc, Akaike Information Criterion; delta AICc, difference from model with smallest AICc; Num par, number of parameters]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
1 M(array), P(array)	822.301	0.000	0.651	1.000	7	71.534
2 M(.), P(array)	823.551	1.250	0.349	0.535	11	64.726

Table 7. Suite of models used in the estimation of presence probabilities of juvenile hatchery and wild Chinook salmon released into Cougar Reservoir, Oregon, 2012 fall study period.

[Models of presence probability (M) included a combination of fish-origin and array effects, or a common value fitted to all arrays (.). AICc, Akaike Information Criterion; delta AICc, difference from model with smallest AICc; Num par, number of parameters; +, an additive effect; *, a multiplicative effect]

Model	AICc	Delta AICc	AICc weights	Model likelihood	Num par	Deviance
1 M(origin), P(.)	376.153	0.000	0.831	1.000	3	12.294
2 M(origin+array), P(.)	379.961	3.808	0.124	0.149	7	8.073
3 M(origin*array), P(.)	381.956	5.803	0.046	0.055	12	0.000
4 M(.), P(.)	417.732	41.579	0.000	0.000	1	57.880
5 M(array), P(.)	422.458	46.305	0.000	0.000	6	52.579

The probability of hatchery Chinook salmon released at the head of Cougar Reservoir migrating downstream to within about 100 m of Cougar Dam during the spring and fall study periods was considerably higher than the estimate for wild Chinook salmon in the fall (fig. 17). During both the spring and fall study periods, the probability of the presence of hatchery fish at an array decreased gradually with distance from the release site, whereas, during the fall study period, the probability of the presence of wild fish decreased at a greater rate. Although the trends were similar, the probabilities of hatchery Chinook salmon presence from the spring study period were slightly lower than probabilities from the fall study period. During the spring study period, the estimated cumulative probability that a hatchery Chinook salmon was present near the temperature control tower at least once was 0.889 (SE 0.013). During the fall study period, the cumulative probability of presence near the temperature control tower was 0.964 (SE 0.006) for the hatchery fish and 0.686 (SE 0.036) for the wild fish.

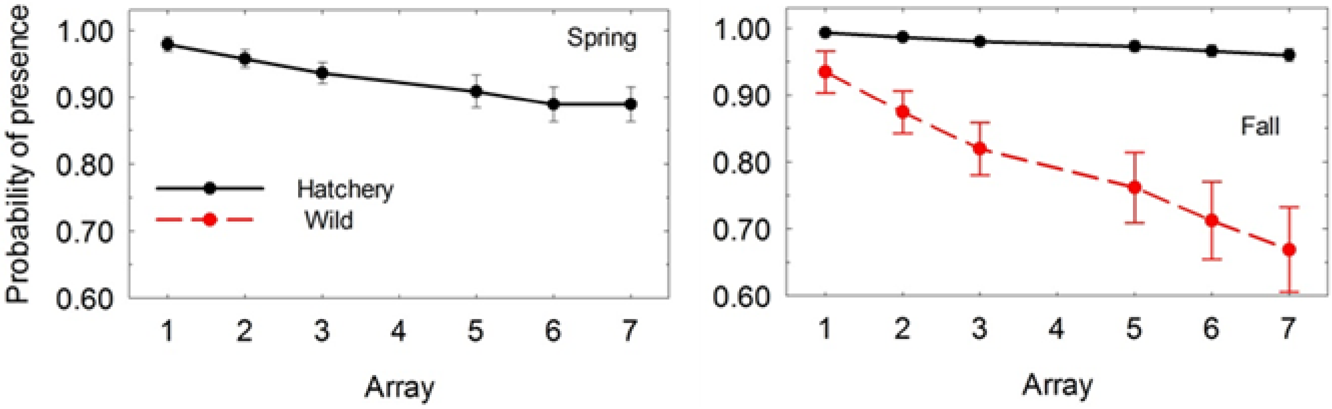


Figure 17. Graphs showing cumulative probabilities (± 95-percent confidence intervals) of being present at least once at reservoir arrays 1, 2, 3, 5, and arrays 6 and 7 near the temperature control tower for juvenile hatchery and wild Chinook salmon released into Cougar Reservoir, Oregon, 2012 spring and fall study periods. Array 4 in the eastern arm of the reservoir was not used in this analysis because fish can migrate to the temperature control tower without entering that area.

Movement Probabilities within the Reservoir

The movement probabilities of hatchery and wild Chinook salmon between reservoir arrays indicated that fish movements generally were directionally persistent, except during the fall study period when fish had a greater tendency to mill near the dam and the head of the reservoir (figs. 18 and 19). Directionally persistent means that fish moving downstream tended to continue moving downstream until they reached the dam and, in turn, that fish moving upstream tended to continue moving upstream until they reached the head of the reservoir. Milling movements occurred when fish moving upstream away from the dam demonstrated an increased tendency to reverse their direction while near the forebay log boom and move back to the dam, or when fish moving downstream away from the head of the reservoir tended to reverse their direction near array 1 and move back upstream near the head of the reservoir.

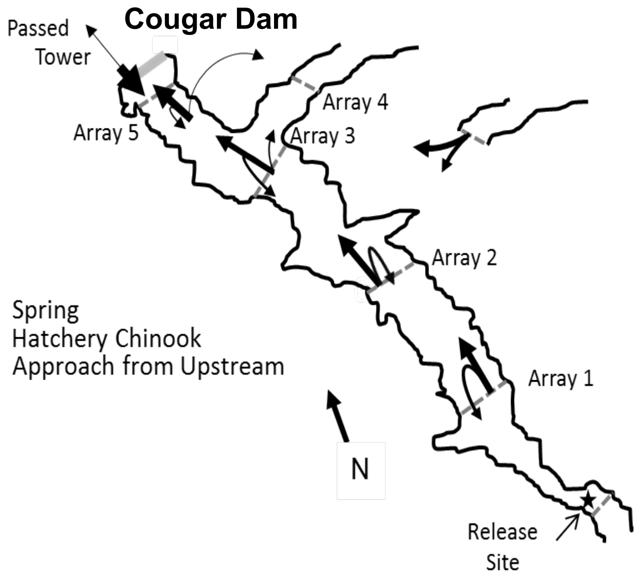


Figure 18. Diagrams showing movement probabilities of juvenile hatchery Chinook salmon released into Cougar Reservoir, Oregon, 2012 spring study period. Relative width of arrows indicates probabilities of moving from one array to an adjacent array based on the previous movement (see appendix table A1 for probabilities). Probabilities at arrays 3 and 5 do not include fish coming from array 4. Probabilities from array 4 are shown to the right of each diagram.

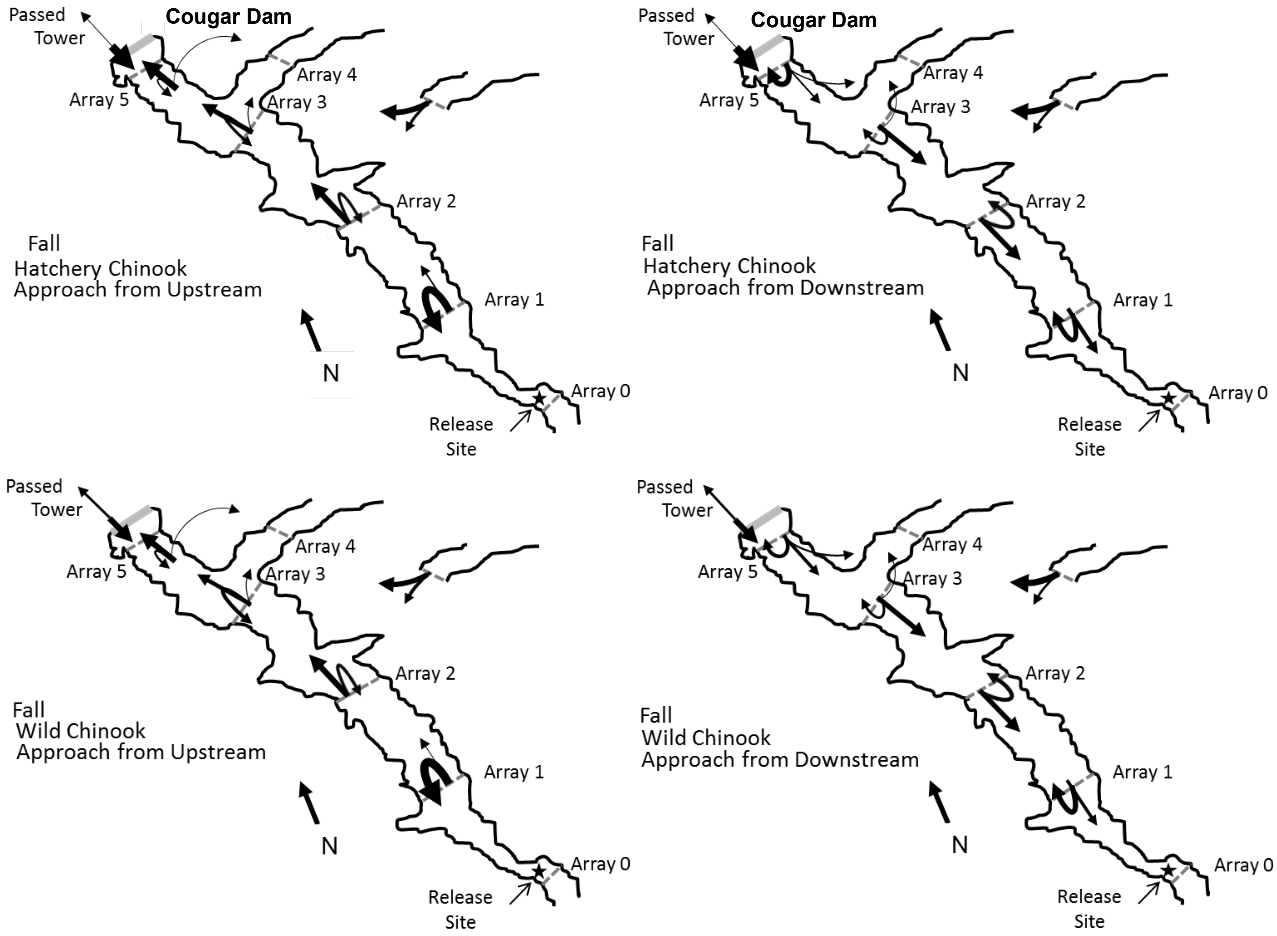


Figure 19. Diagrams showing movement probabilities of juvenile hatchery and wild Chinook salmon released into Cougar Reservoir, Oregon, 2012 fall study period. Relative width of arrows indicates probabilities of moving from one array to an adjacent array based on the previous movement (see appendix table A3 for probabilities). Probabilities at arrays 3 and 5 do not include fish coming from array 4. Probabilities from array 4 are shown to the right of each diagram.

Specific examples of these movement patterns are shown in the movement probabilities in appendix tables A1 and A3. An example of the more prevalent directional movement behavior from the spring study period is shown by the probability of a hatchery Chinook salmon located at array 2 moving downstream to array 3 after having been previously located at arrays 1 or 3. The probability of moving from array 2 to array 3 was greater for fish whose prior location had been upstream at array 1 and were continuing to move downstream (0.66) than it was for fish that had been located downstream at array 3 and had reversed their direction at array 2 before moving to array 3 again (0.45). Generalized to the entire reservoir, this behavior leads to the persistent upstream and downstream movements shown in figures 12, 13, and 14. A specific example of the milling-type movement is demonstrated by hatchery Chinook salmon in the fall study period that had been near the dam (array 7), moved upstream to the forebay log-boom area (array 5), and then were more likely to return back to the dam (0.63) than they were to continue moving upstream to arrays 3 (0.23) or 4 (0.14; appendix table A3).

Models assuming non-random movements (two-step Markov chain) were clearly supported over those assuming random movements (one-step Markov chain) of the hatchery fish, but support for models with data from the wild fish in the fall study period often was ambiguous. There was virtually no support for the one-step Markov chain models in eight out of the nine comparisons for the hatchery Chinook salmon in the spring and the fall study periods (appendix A). These results generally indicate the typical upstream and downstream movements observed in figures 12, 13, and 14. However, there was considerable model-selection uncertainty in seven of the nine comparisons between the one- and two-step Markov models for the wild Chinook salmon (appendix A). This uncertainty most likely was owing to the small number of wild Chinook salmon released (65) and the low probability of presence at downstream arrays compared to the hatchery group.

The probability that a Chinook salmon approaching Cougar Dam from the forebay log boom would pass the dam was considerably higher for the wild fish during the fall study period than it was for the hatchery fish during the spring or the fall study periods. The probability that a wild fish detected near the log boom passed Cougar Dam during the fall study period was about 0.28, based on 125 approaches. Out of about 10,000 approaches to the dam, the probability that a hatchery fish would pass the dam was less than 0.01 during the spring study period and about 0.05 during the fall study period.

Behavior of Fish Near the Temperature Control Tower

Tagged fish were present throughout the monitored area in the cul-de-sac and often were concentrated temporally upstream of the entrance to the temperature control tower during the fall and winter. During the spring study period, there were 158–352 tagged fish (depending on the reservoir elevation bin) positioned in the area within about 200 m from the temperature control tower and there was little evidence of fish being concentrated spatially or temporally (fig. 20). The results from the spring study period were similar during the reservoir filling, full, and drawdown periods. The tagged fish were slightly more spatially concentrated during the fall study period and showed distinct temporal concentrations slightly southeast of the entrance to the temperature control tower (fig. 21). The cumulative residence was greatest prior to October 1, 2012, with a median residence of 188.5 minutes in an area slightly upstream of the tower. The tagged fish also were most often in that area between October 1 and December 21, 2012, when most of the passage of tagged fish was occurring. The median residence time in that area peaked at 21.9 minutes, and may have been shorter than the peak time from the previous period because of the differences in the tendencies of fish to pass the dam. Relatively few tagged fish were in the monitored area after December 21, 2012, but the data available suggest a similar area of use as the reservoir began to fill (figs. 21*C* and 21*D*).

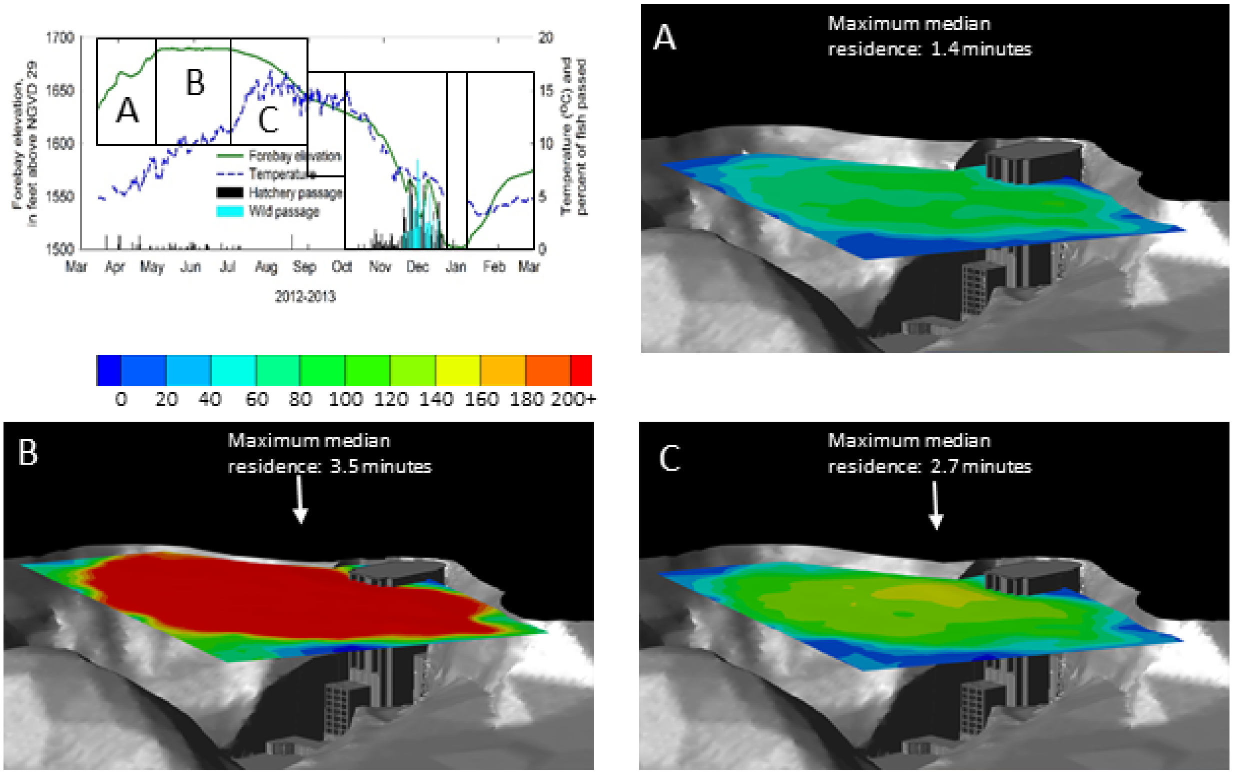


Figure 20. Spatiotemporal density graph of juvenile hatchery Chinook salmon released into Cougar Reservoir and positioned within about 200 meters from temperature control tower at Cougar Dam, Oregon, 2012 spring study period. Inset shows reservoir elevations, water temperatures, and fish passage percentages during the reservoir filling (A, median elevation of 1,664 ft, *N*=158 fish), full (B, median elevation of 1,689 ft, *N*=352 fish), and drawdown (C, median elevation of 1,676 ft, *N*=162 fish) periods. Colors of interpolated surface indicate the number of tagged fish present, and the height of the surface indicates the median cumulative residence time of individual fish based on 10 × 10-meter cells.

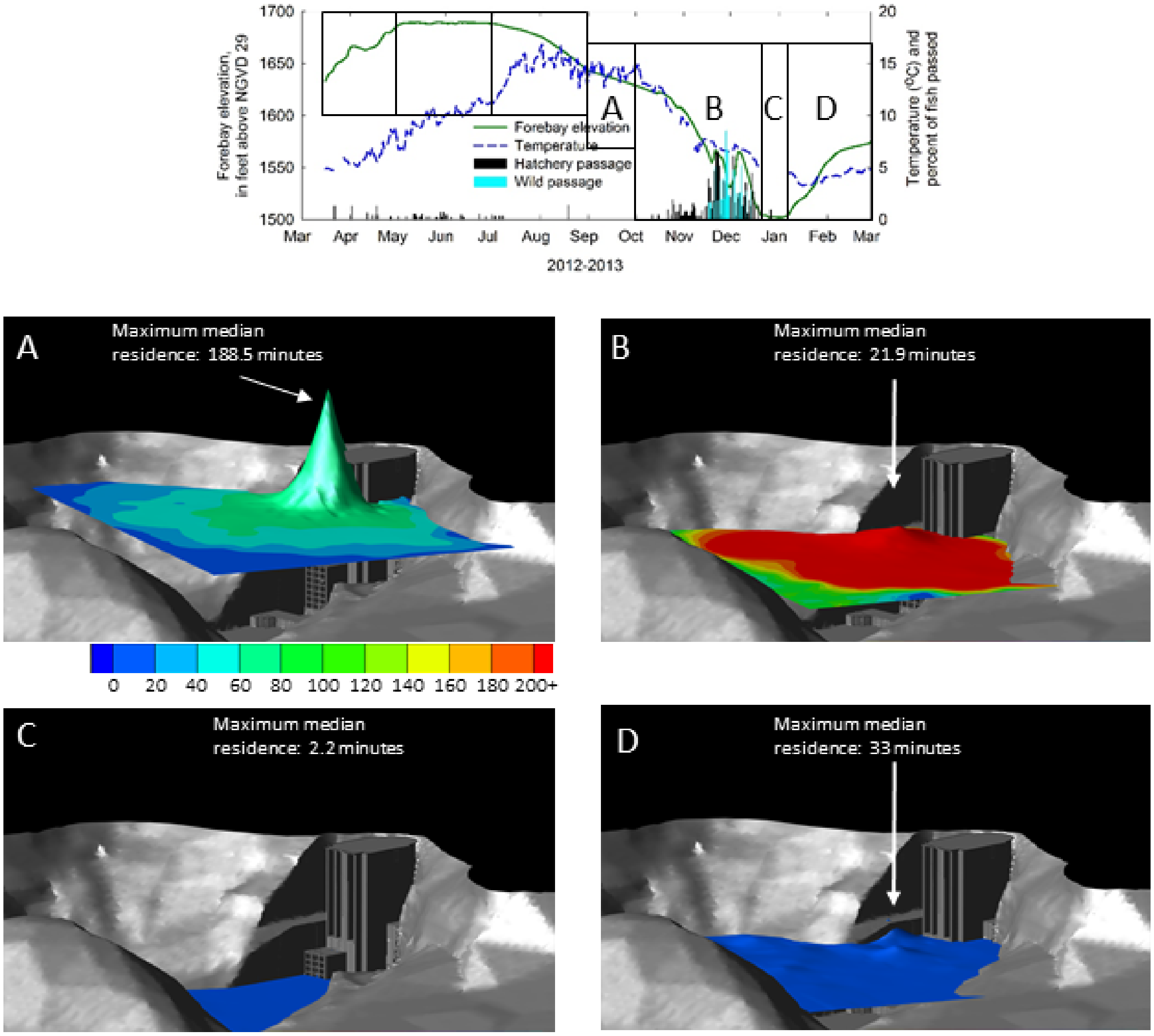


Figure 21. Spatiotemporal density graph of juvenile hatchery and wild (B only) Chinook salmon released into Cougar Reservoir and positioned within about 200 meters from temperature control tower at Cougar Dam, Oregon, 2012 fall study period. Inset shows reservoir elevations, water temperatures, and fish passage percentages during reservoir drawdown prior to fish passage (A, median elevation of 1,637 ft, *N*=94 fish), during most fish passage (B, median elevation of 1,582 ft, *N*=444 fish), after most fish passage (C, median elevation of 1,503 ft, *N*=8 fish), and during reservoir refill (D, median elevation of 1,556 ft, *N*=13 fish). Colors of interpolated surface indicate the number of tagged fish present and the height of the surface indicates the median cumulative residence time of individual fish based on 10 × 10-meter cells.

Depths of tagged fish within 25 m of the tower varied between species, reservoir elevations, and diel periods (fig. 22). When the reservoir elevation was greater than or equal to 1,630 ft during the spring study period, the mean hourly depths of Chinook salmon ranged from 12.3 to 28.4 ft and were highly variable (fig. 22). In addition, the tagged fish were shallower during the day than the night during this condition (table 8). When the elevation was less than 1,571 ft during the spring study period, which occurred as the reservoir was filling, only one tagged Chinook salmon was present.

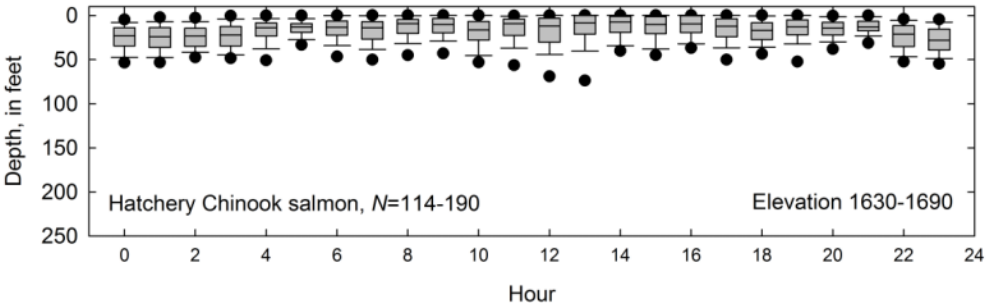


Figure 22. Boxplots of the hourly depths of juvenile hatchery Chinook salmon with position estimates within 25 meters of Cougar Dam, Oregon, 2012 spring study period. Data summarized are the median hourly depths of each fish present at the elevation ranges indicated. Boxes range from the 25th to 75th percentiles with a line indicating the median, whiskers represent the 10th and 90th percentiles, and dots represent the 5th and 95th percentiles. Incomplete boxes contained insufficient data. Sample sizes represent the number of fish (*N*) in the hourly boxes.

Table 8. Summary of the mean of the median hourly depths of each fish with position estimates within 25 meters of Cougar Dam, Oregon, 2012 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 deviation; na, not applicable. Elevation bins without data are not shown]

Study season	Species	Reservoir elevation bin	Diel period	Sample size	Depth below water surface (feet)	
					Mean	SE
Spring	Hatchery Chinook salmon	≥ 1,630	Day	339	12.5	12.3
			Night	336	20.1	11.9
		1571 to < 1630	Day	1	24.2	na
			Night	0	na	Na
Fall	Hatchery Chinook salmon	≥1,630	Day	65	13.4	8.6
			Night	65	18.8	7.4
		1,571 to <1,630	Day	251	22.9	12.3
			Night	252	26.6	14.5
		1,532 to < 1,571	Day	87	32.2	32.4
			Night	118	39.9	46.1
Fall	Wild Chinook salmon	1,571 to <1,630	Day	6	29.9	19.1
			Night	4	19.4	12.8
		1,532 to <1,571	Day	11	19.8	8.5
			Night	21	39.8	30.0

In the fall, hatchery Chinook salmon were present over a wide range of elevation bins. When the reservoir elevation was greater than or equal to 1,630 ft, fish depths were similar to those during this condition in the spring study period (fig. 23). Tagged fish from the fall study period were present in greatest numbers within 25 m of the tower when the reservoir elevation was between 1,571 and 1,630 ft. Their mean hourly estimated depths ranged from 21.7 to 36.0 ft and were similar in the day and night during all elevation bins available (table 8). Few tagged wild fish were present within 25 m of the tower during the fall study period.

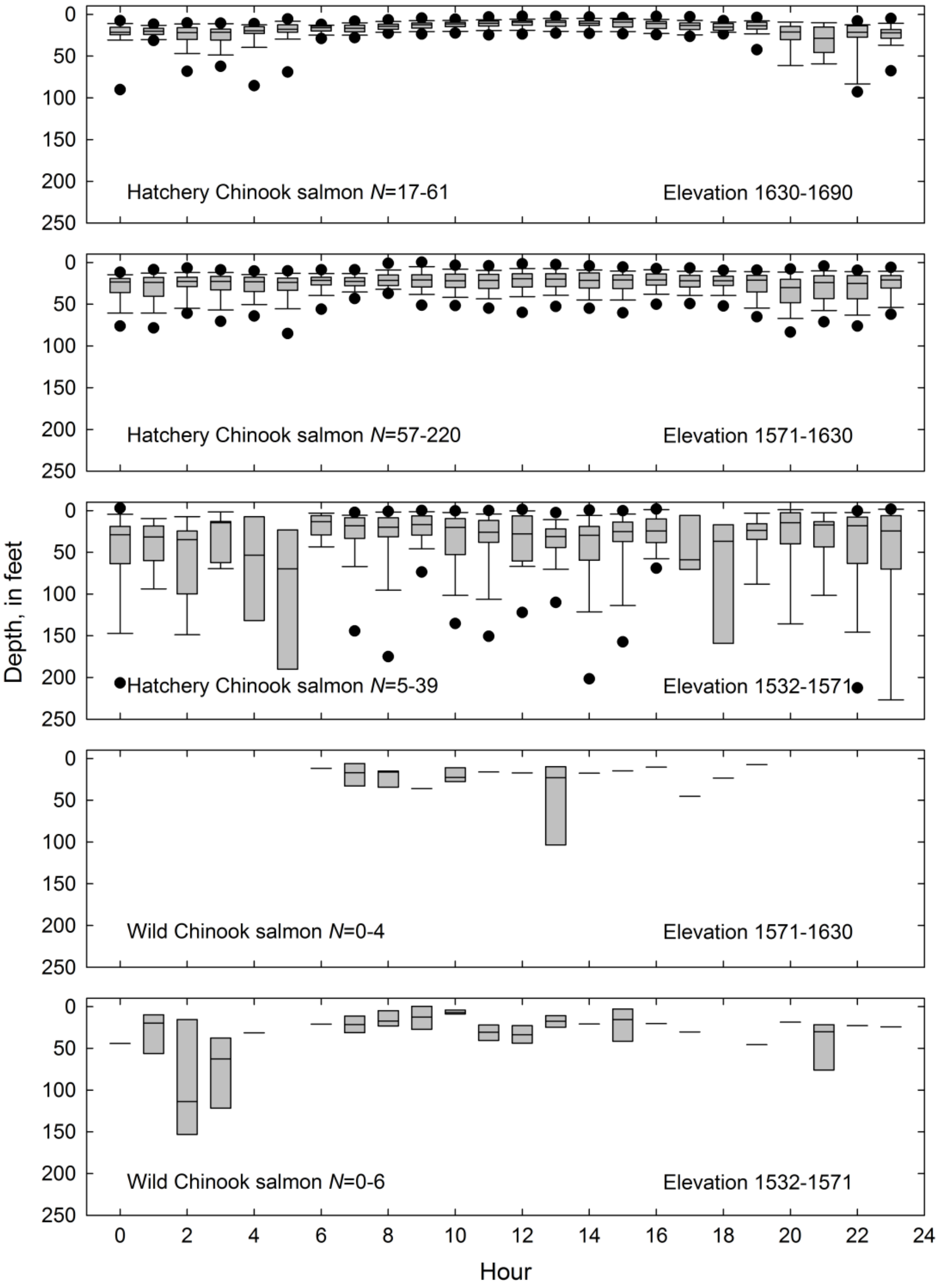


Figure 23. Boxplots of the hourly depths of juvenile hatchery and wild Chinook salmon with position estimates within 25 meters of Cougar Dam, Oregon, 2012 fall study period. Data summarized are the median hourly depths of each fish present at the elevation ranges indicated. Boxes range from the 25th to 75th percentiles with a line indicating the median, whiskers represent the 10th and 90th percentiles, and dots represent the 5th and 95th percentiles. Incomplete boxes contained insufficient data. Sample sizes represent the number of fish (*N*) in the hourly boxes.

Dam Passage

Dam passage occurred primarily during periods of elevated discharge, and was most prevalent during the fall study period when reservoir elevations were low. The seasonal timing of the tagged fish that passed the dam is indicated by vertical bars in figure 9. The dates of dam passage of the tagged hatchery fish ranged from March 22 to August 20, 2012, for fish released in the spring, and from October 12 to December 27, 2012, for fish released in the fall. The spring study period ended on August 24, 2012, at the 90th percentile of the tag life of fish from the last release date; however, 11 tagged fish passed the dam after the 90th percentile of the tag life. Tagged wild fish released in the fall passed Cougar Dam from November 17, 2012, to February 22, 2013. Most dam passage during the spring occurred during May and June. Most dam passage during the fall occurred from October 25 to December 19 for hatchery fish and from November 17 to December 14, 2012, for wild fish. This report includes data collected until February 24, 2013.

During the 90th percentile of the tag life, 10.0 percent (47 of 468) of hatchery fish released in the spring passed the dam. Most hatchery fish (74.5 percent, 35 of 47) tagged in the spring had passage events during the night (fig. 24). Additionally, 11 fish passed after the 90th percentile of the tag life so therefore a total of 58 hatchery Chinook salmon released in spring passed during 2012. Four of the 11 fish were detected at one or more downstream PIT systems at the screw trap in the Cougar Dam Regulating Outlet tailrace, Leaburg Dam, Walterville Canal, and the Sullivan Project at Willamette Falls after the acoustic tag stopped working. These four fish were detected at the PIT sites 191–233 days after release. The probability of detection at PIT systems downstream of Cougar Dam is low, so most fish with acoustic tag records indicating dam passage were not detected at PIT systems downstream.

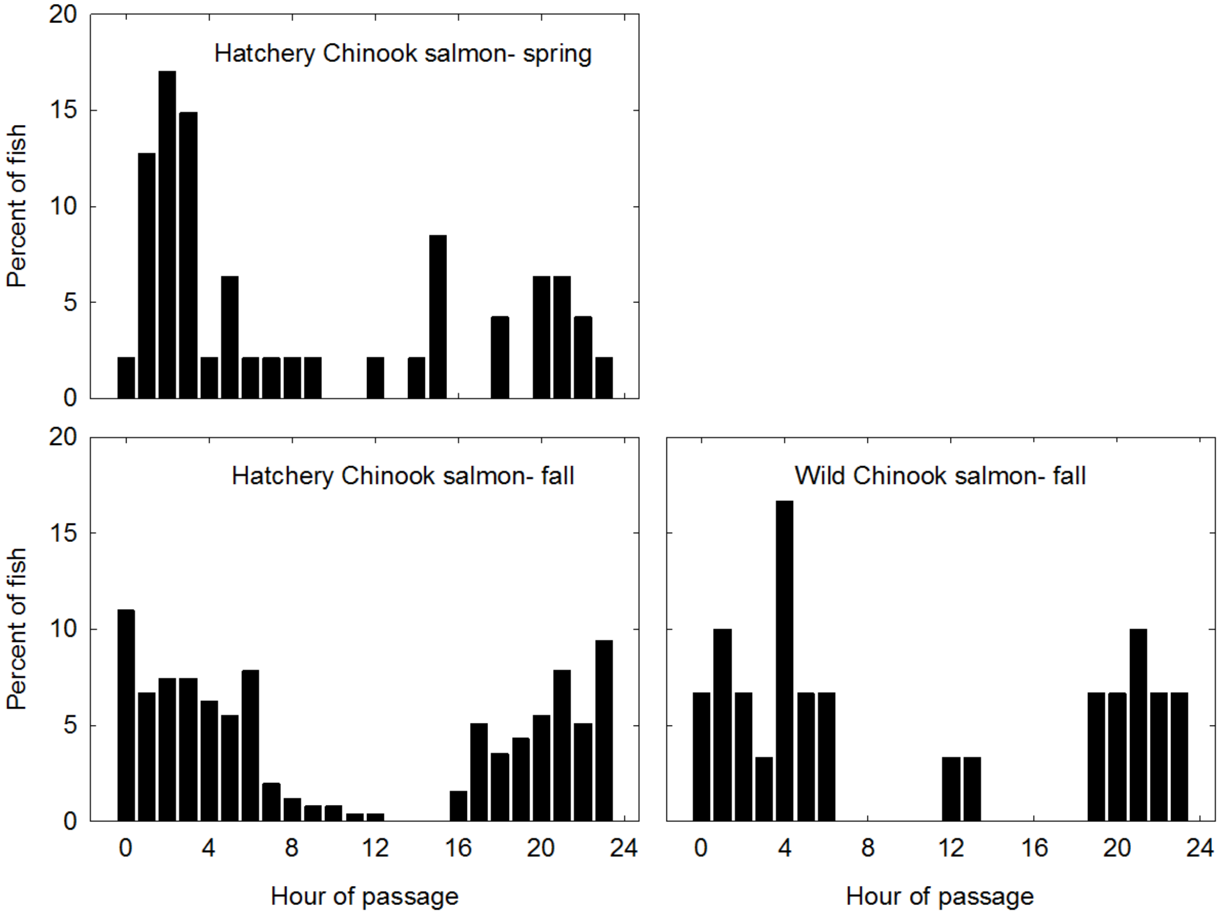


Figure 24. Graphs showing percentage of juvenile Chinook salmon passing Cougar Dam, Oregon, by hour, season, and rearing group, 2012 spring and fall study periods.

During the 90th percentile of the tag life, 56.8 percent of hatchery fish (255 of 449) and 46.2 percent (30 of 65) of wild fish released in the fall passed the dam. A total of 240 of 255 hatchery fish (94.1 percent) and 28 of 30 wild fish (93.3 percent) tagged in the fall had passage events during the night (fig. 24). Additionally, one wild fish passed 13 days after the 90th percentile of the tag life. Thirty-two fish were detected at one or more of the downstream PIT detection sites. Of the 15 fish collected in the Cougar tailrace screw traps operated by Oregon Department of Fish and Wildlife, 12 were collected in the RO tailrace trap and 3 were collected in the powerhouse tailrace trap. Four of the 12 fish in the RO tailrace trap were dead when examined. Nine hatchery and two wild fish were detected at the Leaburg PIT site, eight hatchery fish were detected at the Walterville Canal PIT site, and one hatchery fish was detected at the Sullivan Project PIT site.

Reservoir and Dam Passage Efficiencies

Passage metrics varied by season, fish origin, and reservoir elevation. Most tagged fish were detected at the head of the forebay (array 5). During the spring study period, the RPE was 0.902 and the DPE was 0.111 (table 9). During the fall study period, the RPE was 0.978 for hatchery fish and 0.742 for wild fish. The season-wide estimate of DPE for hatchery fish was slightly smaller than the estimate for wild fish, but the 95-percent confidence intervals for the two fish overlapped considerably, indicating that the estimates were similar. The season-wide estimates of DPE during the fall study period were also higher than during the spring study period. Estimates of DPE increased as the reservoir elevation decreased, but estimates at elevations of less than 1,532 ft had small sample sizes and did not continue this pattern (table 10). Additionally, there were few wild fish from which to make estimates outside the 1,571–1,532 ft elevation range. The DPEs of hatchery and wild fish were similar in the 1,571–1,532 ft range.

Table 9. Seasonal passage metric estimates, standard errors, and lower and upper 95-percent confidence intervals from the study of acoustic-tagged juvenile Chinook salmon at Cougar Dam, Oregon, 2012 spring and fall study periods.

[Reservoir passage efficiency (RPE) is the proportion of fish released near the head of the reservoir detected near the boat-restricted zone line, and dam passage efficiency (DPE) is the proportion of the fish detected at the boat-restricted zone line that passed the dam. Sample size is the number of tagged fish in the denominator of the estimate.]

Study period	Fish origin	Metric	Sample size	Estimate	Standard Error	95-percent confidence interval	
						Lower	Upper
Spring	Hatchery	RPE	468	0.902	0.014	0.871	0.926
		DPE	422	0.111	0.015	0.085	0.145
Fall	Hatchery	RPE	449	0.978	0.007	0.960	0.988
		DPE	439	0.581	0.024	0.534	0.626
	Wild	RPE	62	0.742	0.056	0.621	0.835
		DPE	46	0.652	0.070	0.508	0.773

Table 10. Dam passage efficiency estimates, standard errors, and lower and upper 95-percent confidence intervals by reservoir elevation from the study of acoustic-tagged juvenile Chinook salmon at Cougar Dam, Oregon, 2012 spring and fall study periods.

[Sample size is the number of tagged fish in the denominator of the estimate. <, less than]

Study period	Fish origin	Elevation (feet)	Sample size	Estimate	Standard Error	95-percent confidence interval Lower	95-percent confidence interval Upper
Spring	Hatchery	1,690 to 1,571	422	0.111	0.015	0.085	0.145
Fall	Hatchery	1,690 to 1,571	284	0.169	0.022	0.130	0.217
		<1,571 to 1,532	282	0.642	0.029	0.584	0.696
		<1,532 to 1,516	77	0.273	0.051	0.186	0.381
		<1,516 to 1,500	34	0.147	0.061	0.065	0.301
	Wild	1,690 to 1,571	8	0.000	0.000	0.000	0.324
		<1,571 to 1,532	43	0.651	0.073	0.502	0.776
		<1,532 to 1,516	8	0.250	0.153	0.072	0.591
		<1,516 to 1,500	4	0.000	0.000	0.000	0.490

Head Differential Test

Few of the 364 tagged fish present near the temperature control tower during the head differential test entered the temperature control tower. Ten tagged fish entered during the control condition and 19 tagged fish entered during the treatment condition. The number of tagged fish present per block ranged from 137 to 285. All but one tagged fish that entered the temperature control tower passed without returning to the reservoir. The fish that returned to the reservoir entered the temperature control tower during the control condition of block 3 on June 6, and was there for 10.05 hours between 6:25 a.m. and 4:28 p.m. prior to returning to the reservoir.

The data and models weakly supported a statistical treatment effect. Dam discharge, a variable known to affect tower entry and dam passage rates of Chinook salmon at Cougar Dam (Beeman and others, 2013), varied within blocks so discharge was controlled for in the analysis by including it in the model. The final model included significant effects of treatment (*P*=0.0930) and discharge (*P*=0.0720; table 11). The treatment*discharge interaction term was not supported (χ^2=2.0582, df =1, *P*=0.7457) in the full model (not shown), indicating the effect of discharge was similar between treatments. The estimated rate of tower entry during the treatment condition relative to the control condition controlling for block and discharge (the hazard ratio) was 1.91 (95-percent confidence interval [CI] of 0.90–4.06), indicating the rate of tower entry was 1.91 times greater during the treatment condition than during the control condition. The estimated effect of discharge controlling for block and treatment was an increase in tower entry rate of 4.90 times for each 1,000 ft^3/s increase in discharge.

Table 11. Regression coefficients from analyses of the rate at which juvenile Chinook salmon entered the temperature control tower during the head differential test at Cougar Dam, Oregon, May–June 2012.

[DF, degrees of freedom; Parm., parameter; Pr > ChiSq, probability of a larger Chi-Square value under the hypotheses that the parameter estimate=0; <, less than. Results are based on a significance threshold of alpha = 0.10. Significant variables include treatment level (1=control, 2=treatment), and discharge in 1,000 cubic feet per second (ft^3/s) increments]

Variable	DF	Parm.	Standard error	Chi-square	Pr > ChiSq	Hazard ratio	95-percent hazard ratio confidence limits	
Treatment	1	0.646	0.385	2.821	0.0930	1.91	0.90	4.06
Discharge	1	1.588	0.883	3.236	0.0720	4.90	0.87	27.63

Factors Affecting the Rate of Fish Entering and Exiting the Temperature Control Tower

Few tagged fish entered the temperature control tower and returned to the reservoir during the spring study period, but the behavior was common during part of the fall study period. The behavior was exhibited by hatchery fish from September 17 to November 9, 2012, but was not present in the data from wild fish. However, few tagged wild fish were present during this period because the releases of wild fish did not begin until October 24, 2012.

The behavior of entering the temperature control tower and returning to the reservoir occurred in 31 percent (138 of 433) of the tagged hatchery fish positioned within 95 m of the temperature control tower during the fall study period. This behavior was exhibited on 51 of the 55 dates by 1–51 out of 11–136 tagged fish present in the area on each date. The rate ranged from 0 to 78.9 percent of the fish available per day. The rate increased during late September, peaked on October 2, and decreased sharply until October 19, after which it remained at a low rate until the behavior ceased after November 9, 2012. This behavior was most prevalent during the day; it was exhibited by 87 fish only during the day, 6 fish only during the night, and 45 fish during both day and night. Sixty-seven of these fish (48 percent) subsequently passed the dam. During the day, individual fish exhibited the behavior a median of 8.5 times (range 1–113 times), and during the night, they exhibited the behavior a median of 2 times (range 1–16 times). The dam operating and environmental conditions during the period of this behavior included a median discharge of 470 ft^3/s (range 420–1,171 ft^3/s), a median forebay elevation of 1,622.5 ft (range 1,584.6–1,636.2 ft), and a median water temperature of 13.0 °C (range 3.2–16.2 °C; fig. 9) in the upper 13–19 ft of water. The depth of water over the weir gates was a median of 35.9 ft and ranged from 0 to 43.4 ft.

The rate of the behavior was greatest when the discharge was low and the depth over the weir gates was high; these conditions occurred prior to early October. The depth over the weir gates increased from about 5 to 43.4 ft, beginning on the morning of September 8, 2012, as part of temperature control measures continuing until the morning of November 17, 2012, when reservoir elevation was lower than the top of the lowest weir gates and the water was passed through the RO bypass. During the period of this behavior, the discharge was generally at one of three discrete values: (1) low (median 460 ft^3/s, range 420–540 ft^3/s) until October 19, (2) intermediate (median 970 ft^3/s, range 720–1,080 ft^3/s) from October 19 until about October 24, and (3) high (median 1,510 ft^3/s, range 1,260–1,710 ft^3/s) from about October 24 until the behavior ceased on November 9, 2012.

Diel period and dam discharge were identified as factors affecting the rate of tower entry without dam passage. The model indicated that the rate of the fish behavior was greatest during the day relative to the night and at the lowest of the three discharge levels (table 12). The model indicated that the rate of the behavior during the night was about 10 percent of the rate of the behavior during the day (hazard ratio=0.098, 95-percent CI of 0.077–0.125). Another way to express the result is that the rate during the day was 90 percent greater than the rate at night. The rates of the behavior at the intermediate and highest discharge levels were much lower than the rate at the lowest discharge level, indicating that the behavior occurred primarily during the low discharge level. The rates of the behavior at the high and intermediate discharge levels were 7.8 and 11.1 percent, respectively, of the rate at the low discharge level. This result may have been owing to the combination of low discharge and high depth over the weir gates creating a low water velocity at the tower entrance and little head (depth) differential between the reservoir and tower wet well.

Table 12. Regression coefficients from analyses of the effects of selected variables on the rate at which juvenile Chinook salmon entered and exited the temperature control tower at Cougar Dam, Oregon, 2012 fall study period.

[Results are based on analysis of tagged juvenile Chinook salmon with three-dimensional position estimates within 95 meters of the temperature control tower. DF, degrees of freedom; Parm., parameter; Pr > ChiSq, probability of a larger Chi-Square value under the hypothesis that the parameter estimate=0; <, less than. Results are based on a significance threshold of alpha=0.10. Significant variables include diel period (1=day, 2=night) and the effects of intermediate (Intermediate Q; 720–1,080 cubic feet per second [ft^3/s]) and high (High Q; 1,260–1,710 ft^3/s) discharge levels relative to a low level (420–540 ft^3/s. Treatment block was controlled for in the model using the STRATA statement]

Variable	DF	Parm.	Standard error	Chi-square	Pr > ChiSq	Hazard ratio	95-percent hazard ratio confidence limits	
Diel period	1	-2.321	0.122	361.881	< 0.0001	0.098	0.077	0.125
High Q	1	-2.553	0.134	361.135	< 0.0001	0.078	0.060	0.101
Intermediate Q	1	-2.196	0.270	65.894	< 0.0001	0.111	0.065	0.189

Factors Affecting the Rate of Dam Passage

The analysis of factors affecting the rate of dam passage was restricted to the fall study period because 32 of 47 dam passage events of fish positioned within 95 m of the temperature control tower during the spring study period occurred during the head differential test which was analyzed separately. Factors affecting the rate of dam passage, therefore, were based on data from the fall study period, which is when most passage events of fish positioned within 95 m of the temperature control tower occurred during the entire study (241 of 288).

The analysis of data from the fall study period was based on 422 hatchery fish and 40 wild fish with position estimates within 95 m of the temperature control tower, and a total of 241 passage events of hatchery fish and 26 passage events of wild fish. Analyses of hatchery and wild fish were done separately because of the disparity in their sample sizes. The fish passage dates ranged from October 12 to December 27, 2012, for hatchery fish, and from November 16 to December 14, 2012, for wild fish. Dam operations and environmental conditions during the longer of these two periods were typical for the season, with mean hourly forebay elevation decreasing from 1,623.2 to 1,500.7 ft (except in response to freshets), mean hourly water temperature decreasing from 13.4 to 5.0 °C, mean hourly discharge ranging from 400 to 6,780 ft^3/s, and mean hourly water depth (head) over the weir gates ranging from 0 to 43.4 ft (figs. 9 and 10).

The results indicate that the dam passage rates of hatchery fish within 95 m of the temperature control tower were affected by dam discharge, forebay elevation, photoperiod, and fish size. Dam passage rates of hatchery fish were about 36 times greater at night than during the day (hazard ratio=35.771), and increased 29.5 percent for each 10 ft decrease in forebay elevation (hazard ratio=0.705; table 13). Note that the hazards indicate the effect of an increase in the covariate, but here the result for forebay elevation is expressed as the effect of a decrease (for example, -1×[0.705-1]×100 percent=29.5 percent). An interaction between fork length and discharge was supported (P=0.0075), indicating that the effect of discharge was slightly greater for large fish than for small fish. For example, the model predicts that each 1,000 ft^3/s increase in discharge increases the dam passage rate of a 133-mm fish (the 10th percentile of FL) by a factor of 1.75 (95-percent CI of 1.38–2.23), and increases the dam passage rate of a 167-mm fish (the 90th percentile of FL) by a factor of 2.66 (95-percent CI of 2.23–3.18). The dam passage rate of the median-size hatchery fish (145 mm) is predicted to increase by a factor of 2.03 (95-percent CI of 1.72–2.39) for each 1,000 ft^3/s increase in discharge. The interaction also indicates that the passage rate of hatchery fish increases with fish size.

The results for wild fish were similar to results for hatchery fish. The model based on data from wild fish indicated that discharge and forebay elevation affected dam passage rates, but fish size did not (table 13). The lack of support for a size effect may be owing to the generally smaller size of the wild fish (median 123.5 mm FL, range 100–159 mm FL) than the hatchery fish (median 148 mm FL, range 98–180 mm FL) in these data or perhaps the smaller range in sizes (wild fish range=59 mm FL, hatchery fish range=82 mm FL); it also may represent a true difference between fish of the two groups. All but 2 of the 28 dam passage events of wild fish occurred at night, so diel period was not included in the model. The estimated effect of a 1,000 ft^3/s increase in discharge was an almost doubling of passage rate of wild fish (hazard ratio=1.924, 95-percent CI of 1.228–3.017), compared to a 2.03 (95-percent CI of 1.72–2.39) factor increase for the median-size hatchery fish. Note that the confidence intervals of the hazards for the hatchery and wild fish overlap considerably, indicating the similarity of the estimated effects of discharge based on the data available. The estimated effects of changes in forebay elevation were similar for wild and hatchery fish, with a hazard ratio of 0.762 for wild fish (a 23.8-percent increase in passage rate per 10 ft of elevation decrease) and 0.705 for hatchery fish (a 39.5-percent increase in passage rate per 10 ft of elevation decrease); the 95percent CIs of these hazard ratios also overlap considerably.

Table 13. Regression coefficients from analyses of the effects of selected variables on the rate of dam passage for juvenile Chinook salmon at Cougar Dam, Oregon, 2012 fall study period.

[Results are based on analysis of tagged juvenile Chinook salmon with three-dimensional position estimates within 95 meters of the temperature control tower. DF, degrees of freedom; Parm., parameter; Pr > ChiSq, probability of a larger Chi-Square value under the hypothesis that the parameter estimate = 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), diel period (Diel; 1= day, 2=night), dam discharge in 1,000 ft^3/s increments (Discharge), forebay elevation in feet (Fbelev), and an interaction between FL.10 and discharge (Fl*discharge)]

Variable	DF	Parm.	Standard error	Chi-square	Pr > ChiSq	Hazard ratio	95-percent hazard ratio confidence limits	
				Origin = Hatchery				
Fl.10	1	-0.294	0.130	5.143	0.0233	(1)	(1)	(1)
Diel period	1	3.577	0.468	58.510	< 0.0001	35.771	14.304	89.453
Discharge	1	-1.082	0.719	2.266	0.1323	(1)	(1)	(1)
Fbelev	1	-0.349	0.034	108.159	< 0.0001	0.705	0.660	0.753
Fl*discharge	1	0.123	0.046	7.141	0.0075	(1)	(1)	(1)
				Origin = Wild				
Discharge	1	0.655	0.229	8.145	0.0043	1.924	1.228	3.017
Fbelev	1	-0.272	0.165	2.728	0.0986	0.762	0.552	1.052

[1] Hazards of variables involved in interactions.

Discussion

This report describes the second year of a 2-year study designed to provide baseline information about juvenile Chinook salmon behavior and dam passage at Cougar Reservoir and Dam to inform decisions about future downstream passage alternatives. The study differs from previous and concurrent studies of juvenile salmonids at Cougar Reservoir and Dam by describing the behaviors of individuals tagged with active transmitters, which enabled quantitative assessments of the migration behaviors within the reservoir and the factors affecting dam passage rate throughout most of each year.

The results were based on Chinook salmon of hatchery and wild origin with a FL range of 98–180 mm. The minimum fish size was dictated by the mass of the transmitter used and the protocols of the Surgical Protocols Steering Committee (2011). The hatchery fish were reared as part of a program at Oregon State University using experimental hatcheries to provide wild-fish surrogates because wild fish have been difficult to catch from within Cougar Reservoir (Beeman and others, 2013). The hatchery fish used in the spring were representative of the sizes of wild fish that entered the reservoir as fry during spring 2011, and were similar to sizes of wild yearlings measured by ODFW during 2010 and 2011 surveys in the reservoir (Monzyk and others, 2011a, 2011b, 2012). The hatchery fish used in the fall were subyearlings designed to represent fry that entered the reservoir during spring 2012. However, the FL of wild subyearlings in the reservoir during the fall generally is less than 100 mm, and most tagged fish had FLs greater than 100 mm, so the hatchery fish in the fall better represented the size of wild yearlings (Monzyk and others, 2012). Most fish captured in the Cougar Dam tailraces in the fall were similar in size to the fish tagged, indicating that the tagged fish reasonably represented the fish that passed the dam during the fall (Romer and others, 2012). Tagged wild fish were an average of 27 mm smaller than the hatchery fish, and were used only during the fall study period in 2012 because of the low catch rate observed during the spring of the previous year (Beeman and others, 2013).

The results from each of the 2 years were similar. Most tagged juvenile Chinook salmon in Cougar Reservoir were near the temperature control tower at least once and repeatedly migrated from one end of the reservoir to the other end in a non-random manner. Catches of untagged wild yearling Chinook salmon in passive traps throughout the reservoir also suggest fish are widely distributed during the spring (Monzyk and others, 2012). The dam passage rate of the tagged fish was greatest during fall and winter. A similar seasonal pattern of untagged fish at Cougar Dam was noted in data from acoustic cameras at the temperature control tower (Khan and others, 2012) and in rotary trap catches in the dam tailraces (Monzyk and others, 2011a; 2012), and is typical of other high-head flood-control reservoirs on tributaries of the Willamette River (Keefer and others, 2011, 2013). The repetitive non-random migration throughout the reservoir likely was a result of the low dam passage rate, particularly during spring and summer.

The effects of several factors affecting the dam passage rate were quantified. Diel period was the most influential factor, with passage rate much greater at night than during the day. This pattern is consistent with data from radio-tagged fish released in Cougar Reservoir during November and December (Beeman and others, 2012b, 2014) and the data from acoustic-tagged fish released in 2011 (Beeman and others, 2013). The effect of diel period on passage rate may be owing to diel differences in visual cues and velocity responses that reduce fish avoidance of tower entry at night (Vowles and Kemp, 2012). Dam discharge, reservoir elevation, and fish length (hatchery Chinook salmon only) also were significant factors affecting dam passage rate. The mechanism of the effect of dam discharge is assumed to be an increase in the size of the attraction area caused by increases in flow fields as discharge increases. The benefit of reducing reservoir elevation is assumed to be the increase of water velocities and flow fields for a given discharge by reducing reservoir volume. We were unable to determine if the effect of reservoir elevation determined during fall and winter also would apply to spring and summer, because the reservoir refilled during the spring and was full during the summer. The available data suggest that low reservoir elevation resulted in increased dam passage rate. Given this finding, it is possible that dam passage rate during spring and summer could be increased if low reservoir elevations are operationally possible at those times.

Results from hatchery fish often were similar to results from wild fish. Most tagged fish were of hatchery origin and wild fish were only tagged during the fall study period in 2012. During the fall study period the RPE of hatchery fish (0.978) exceeded the RPE of wild fish (0.742) and their 95-percent confidence intervals did not overlap, but their DPEs were similar (0.581 for hatchery fish, 0.652 for wild fish) and had overlapping confidence intervals. The difference between the RPEs of hatchery and wild fish may be owing to fish size, as wild fish were smaller than hatchery fish and data from hatchery fish may indicate that RPE may be related to size (data not shown). Another difference between hatchery and wild fish was the prevalence of parasitic copepods, which was 89 percent for the wild fish released and 0 percent for the hatchery fish released. The factors affecting dam passage rates of hatchery and wild fish were similar; the primary factors were diel period, discharge, and reservoir elevation, but fish length also positively affected the passage rate of hatchery fish. The effects of the factors on fish from each group (as measured by their hazard ratios and 95-percent confidence intervals) were similar. Fish length was not supported as a factor affecting passage rate of wild fish, perhaps because their size range was smaller than the size range of hatchery fish. Diel period was an important determinant of passage rate for each group, but it was not included in regression models of wild fish because all but 2 of their 28 passage events occurred at night. Overall, the data and models indicate that the results from yearling-size hatchery fish were similar to the results from yearling-size wild fish.

The available evidence indicates that the low dam passage rate of juvenile Chinook salmon at Cougar Dam primarily is a function of the low rate of fish entering the temperature control tower. Diagnosis of factors contributing to passage-route performance often is aided by dividing the passage process into component parts, for which we use the conceptual zones of Sweeney and others (2007). The most upstream zone is the Approach zone (330–33,000 ft from the entrance), where fish first encounter the effects of the dam. For this study, we considered this to be downstream of the log boom, or perhaps the entrance to the cul-de-sac. Most tagged fish were present near the temperature control tower at least once, and during some conditions, they congregated near the tower entrance for extended periods; this result supports the conclusion that most fish pass through the Approach zone. The next zone is the Discovery zone (33–330 ft upstream of the entrance), where fish first encounter the flow net of the outlet or outlets. Once again, most tagged fish released were detected near the entrance to the temperature control tower, and we conclude that the location of the tower entrance is suitable for fish to discover it. However, the Discovery zone is limited by the small velocity gradients at the tower entrance. The last zone is the Decision zone (0–33 ft from the entrance), where fish decide whether to enter or reject the route. At Cougar Dam, the first Decision zone is at or near the face of the tower entrance, but fish also must remain within the tower long enough to pass the dam. Results from studies in 2011 and 2012 indicate that tagged fish commonly were present near the temperature control tower, but the passage rate was low during most times of the year (Beeman and others, 2012a). Khan and others (2012) reported that the highest untagged fish densities viewed with an acoustic camera at the tower entrance were during May and June, yet relatively few of the fish present entered the tower during that period. Additionally, we found that acoustic-tagged fish that entered the tower usually passed the dam without returning to the reservoir, except during a specific operating condition during fall 2012. These results support the conclusion that the low rate of dam passage largely is because of a low tower entry rate, which we hypothesize is owing to rejection in the Decision zone occurring at the entrance to the tower.

The cause of rejection at the Decision zone likely is due to hydraulic and structural conditions at the entrance to the tower. One of the most important factors in design of efficient surface passage routes for juvenile salmonids is a smooth acceleration from low velocities to those sufficient to entrain fish without avoidance or rejection of the route (Haro and others, 1998; Enders and others, 2009). The water velocities at the entrance to the temperature control tower typically are less than 1 ft/s, and likely never reach the juvenile salmonid capture velocity of about 7 ft/s. Increasing water velocities at the tower entrance likely would increase the fish entry rate, but achieving capture velocities is not necessarily required to pass fish. For example, the ice-trash sluiceway at The Dalles Dam (The Dalles, Oregon) on the Columbia River is considered an efficient surface flow outlet, but does not achieve capture velocity (Sweeney and others, 2007). In addition to the low water velocities at the entrance, the trash racks likely cause a decrease in acceleration, which often is noted as a cause of poor route performance (Haro and others, 1998; Sweeney and others, 2007).

It may be possible to increase tower entry rate by manipulating operations at the existing structure. Results from this study have shown that increasing head differential may have merit as a means to increase tower entry rate. Head differential at Cougar Dam normally is maintained in the 0–0.25 ft range to reduce the stresses on the tower structure; however, increasing the differential can increase the rate of tower entry. Tower entry rate might be significantly increased by using larger head differentials than those tested during the 2012 study; however, the rate would need to be increased substantially to pass a large proportion of the fish from the reservoir. For example, increasing the spring and summer 2011 hatchery Chinook salmon DPE of 0.135 to 0.800 would require an almost six-fold increase in the tower entry rate. Additionally, the water velocities at the tower entrance might be increased operationally by using fewer than all three of the entrance slots. However, the presence of the existing trash racks likely would still cause an abrupt reduction in acceleration that may reduce the benefit of this action. Removing or modifying some of the trash racks may increase tower entry rate by lessening the decrease in acceleration at the tower entrance. A combination of these and other actions may be required to appreciably increase dam passage at the existing facility. Each of these actions also may have effects on dam safety and maintenance that must be considered together with the potential for improvements in fish passage.

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Appendix A. Transition Probabilities and Model Comparisons from the Assessment of Upstream and Downstream Movements of Juvenile Chinook Salmon in Cougar Reservoir, 2012 Spring and Fall Study Periods

Table A1. Transition probabilities of hatchery Chinook salmon (*Oncorhynchus tshawytscha*) moving from one detection array to an adjacent detection array, given the previous array location prior to the current array in Cougar Reservoir, Oregon, 2012 spring study period.

		Probability of moving from current array to adjacent array													
		1 to 0	**1 to 2**	**2 to 1**	**2 to 3**	**3 to 2**	**3 to 4**	**3 to 5**	**4 to 3**	**4 to 5**	**5 to 3**	**5 to 4**	**5 to 7**	**7 to 5**	**7 to Pass**
Previous array	0	0.36	0.64												
	1			0.32	0.68										
	2	0.59	0.41			0.28	0.17	0.55							
	3			0.59	0.41				0.42	0.58	0.15	0.06	0.79		
	4					0.56	0.17	0.27			0.15	0.10	0.74		
	5					0.65	0.09	0.26	0.40	0.60				>0.99	<0.01
	7										0.36	0.12	0.52		

Table A2. Markov model comparisons for movements of hatchery Chinook salmon (*Oncorhynchus tshawytscha*) in Cougar Reservoir, Oregon, 2012 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. Delta Akaike Information Criterion (AIC) values relative to the full model indicate the one-step model received substantial support (SS) or no support (NS)]

Model	AIC	Delta AIC	Model Support
Full model	191.02	0.00	
M010=M210; M012=M212	686.50	495.48	NS
M121=M321; M123=M323	912.98	721.96	NS
M232=M432=M532	1,684.06	1,493.04	NS
M234=M434=M534	358.51	167.50	NS
M235=M435=M535	1,181.95	990.93	NS
M343=M543; M345=M545	189.97	-1.05	SS
M353=M453=M753	1,141.19	950.17	NS
M354=M454=M754	291.06	100.04	NS
M357=M457=M757	1,339.11	1,148.09	NS

Table A3. Transition probabilities of hatchery and wild Chinook salmon moving from one detection array to an adjacent detection array, given the previous array location prior to the current array in Cougar Reservoir, Oregon, 2012 fall study period.

			Probability of moving from current array to adjacent array													
Previous array			1 to 0	1 to 2	2 to 1	2 to 3	3 to 2	3 to 4	3 to 5	4 to 3	4 to 5	5 to 3	5 to 4	5 to 7	7 to 5	7 to Pass
	Hatchery	0	0.85	0.15												
		1			0.34	0.66										
		2	0.45	0.55			0.33	0.13	0.54							
		3			0.55	0.45				0.34	0.66	0.18	0.08	0.74		
		4					0.64	0.09	0.27			0.13	0.13	0.74		
		5					0.60	0.08	0.32	0.31	0.69				0.95	0.05
		7										0.23	0.14	0.63		
	Wild	0	0.96	0.04												
		1			0.36	0.64										
		2	0.40	0.60			0.44	0.12	0.44							
		3			0.53	0.47				0.40	0.60	0.25	0.06	0.69		
		4					0.50	0.25	0.25			0.20	0.12	0.68		
		5					0.59	0.11	0.30	0.27	0.73				0.72	0.28
		7										0.35	0.22	0.43		

Table A4. Markov model comparisons for movements of hatchery and wild Chinook salmon in Cougar Reservoir, Oregon, 2012 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. Delta Akaike Information Criterion (AIC) values indicate the one-step model received substantial support (SS), considerable support (CS), or no support (NS)]

	Hatchery			Wild		
Model	AIC	Delta AIC	Model support	AIC	Delta AIC	Model support
Full model	177.69	0.00		119.26	0.00	
M010=M210; M012=M212	1,409.94	1,232.25	NS	356.81	237.55	NS
M121=M321; M123=M323	383.29	205.60	NS	124.80	5.54	CS
M232=M432=M532	538.16	360.47	NS	118.80	-0.46	SS
M234=M434=M534	196.67	18.97	NS	117.39	-1.87	SS
M235=M435=M535	441.98	264.29	NS	120.13	0.87	SS
M343=M543; M345=M545	177.18	-0.51	SS	118.24	-1.02	SS
M357=M457=M757	281.97	104.28	NS	127.82	8.57	NS
M353=M453=M753	236.38	58.69	NS	118.53	-0.73	SS
M354=M454=M754	225.83	48.14	NS	124.47	5.21	CS

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