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Evaluation of Chinook Salmon (*Oncorhynchus tshawytscha*) Fry Survival in Lookout Point Reservoir, Western Oregon, 2017

Open-File Report 2019–1011

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

Cover: Photograph showing Lookout Point Reservoir, Oregon. Photograph by Jamie Sprando, U.S. Geological Survey, September 14, 2017.
Inset photograph: Nearshore fish trap in the forebay of Lookout Point Dam, Oregon. Photograph by Amy Hansen, U.S. Geological Survey, June 22, 2017.

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Contents

Figures

Tables

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
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 (m)	1.094	yard (yd)
	Volume	
liter (L)	33.81402	ounce, fluid (fl. oz)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

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

$$°F = (1.8 \times °C) + 32.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

FPGL	Fish Performance and Genetics Laboratory
MCMC	Monte Carlo Markov Chain
PBT	parentage-based tagging
PIT	passive integrated transponder
Project	Willamette Project
rkm	river kilometer
SRRM	staggered release-recovery model
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WFSP	Wild Fish Surrogate Program

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By Tobias J. Kock[1], Russell W. Perry[1], Gabriel S. Hansen[1], Philip V. Haner[1], Adam C. Pope[1], John M. Plumb[1], Karen M. Cogliati[2], and Amy C. Hansen[1]

Abstract

A field study was conducted to estimate survival of fry-sized juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in Lookout Point Reservoir, western Oregon, during 2017. The field study consisted of releasing three groups of genetically marked fish in the reservoir and monthly fish sampling. Fish were released during April 18–19 (43,950 fish), May 30–June 2 (44,145 fish), and on June 28, 2017 (3,920 fish). Reservoir sampling began in May and occurred monthly through October, consisting of 5-day events where juvenile Chinook salmon were collected using various gear types (electrofishing, shoreline traps, gill nets). Data were analyzed using two models: (1) a staggered release-recovery model (SRRM), and (2) a parentage-based tagging (PBT) *N*-mixture model. The SRRM provided survival estimates from two periods: (1) mid-April to late May (S_{SRRM1}), and (2) late May to late June (S_{SRRM2}). Multiple estimates of survival were possible for each period using different combinations of recovery data from the three groups of fish that were released. Survival estimates for S_{SRRM1} ranged from 0.470 to 0.520. Estimates for S_{SRRM2} ranged from 0.968 to 0.969; cumulative survival from mid-April to late June (S_{SRRM2}) was estimated at 0.870. We suspect that issues with the third release group led to biased survival results using the SRRM. The PBT *N*-mixture model provided survival estimates from six periods: (1) mid-April to mid-May (S_{NMIX1}), (2) mid-May to mid-June (S_{NMIX2}), (3) mid-June to mid-July (S_{NMIX3}), (4) mid-July to mid-August (S_{NMIX4}), (5) mid-August to mid-September (S_{NMIX5}), and (6) mid-September to mid-October (S_{NMIX6}). Survival estimates from the PBT *N*-mixture model were lowest for S_{NMIX1} (0.461) and increased monthly to a high of 0.970 for S_{NMIX6}. Cumulative survival from mid-April to mid-July was 0.233 and overall survival from mid-April to mid-October was 0.188. This suggests that most mortality occurred early in the study when juvenile Chinook salmon were small. This could be because these fish were most vulnerable to predation in the reservoir at that time. We determined that mortality of juvenile Chinook salmon was high in the reservoir during this study and similar estimates of parr-to-

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smolt survival have been observed in other systems. Additional analyses are required, including results from the second year of study (2018), and potentially similar evaluations will need to be made at other locations to determine if reservoir mortality is a limiting survival factor for Chinook salmon in the Middle Fork Willamette River.

Introduction

Estimates of survival for specific life stages of Pacific salmon (*Oncorhynchus* spp.) are important data for resource managers tasked with managing impounded river systems of the Western United States. During the past two decades, techniques have been developed and refined to estimate survival of smolt and adult life stages. These techniques rely on data collected from fish marked with tags (passive integrated transponders [PIT tags]) or transmitters (radio and acoustic transmitters) and generally are applied to populations of actively migrating fish (Skalski and others, 1998; Muir and others, 2001; Perry and others, 2010; Skalski and others, 2016). However, in places like the Willamette River, Oregon, resource managers need to understand survival patterns for subyearling Chinook salmon (*Oncorhynchus tshawytscha*), specifically those in the fry and parr life stages. Estimation of survival for these life stages is challenging because fish are too small to be tagged with a PIT tag or an active transmitter, and methods for estimating survival of fish in this size class have not been tested and proven.

The U.S. Army Corps of Engineers (USACE) operates the Willamette Project (hereinafter, "Project") in western Oregon that includes 13 dams and reservoirs, about 68 km of revetments, and several fish hatcheries. The primary purpose of the Project is flood risk management, but it also is operated to provide hydroelectricity, irrigation water, navigation, instream flows for wildlife, and recreation. The Project was determined to jeopardize Upper Willamette River spring Chinook salmon and winter steelhead (*O. mykiss*; National Oceanic and Atmospheric Administration, 2008), which has spurred a series of studies and actions to reduce Project effects on these populations. Fish passage is one of the key issues in the Project. Passage for adult salmon and steelhead is accomplished using trap-and-haul, which provides spawning opportunities in free-flowing headwaters and tributaries upstream of some Project reservoirs (Sard and others, 2015). Progeny of the transported adults move downstream and spend several months rearing in Project reservoirs because downstream passage options are limited at the high-head dams in the system (Keefer and others, 2013; Beeman and others, 2014; Kock and others, 2015; Monzyk, Emig, Romer, and Friesen, 2015). For example, at Lookout Point Dam, resource managers need to determine the feasibility of improving downstream fish passage. An important part of this decision is determining if efforts should focus on developing fish passage options at Lookout Point Dam, or near the head of Lookout Point Reservoir. A key piece of information that will help with these decisions is understanding survival rates of salmon fry rearing in the reservoirs; high survival rates likely would result in decisions to focus on dam-based passage or collection efforts, whereas low survival rates may result in decisions to solely focus on collecting fish as they enter the reservoirs.

The need for study designs to estimate fry survival has been recognized and several potential options have been proposed. Skalski and others (2009) reviewed 20 fish-marking techniques and 16 release-recapture study designs to identify approaches that would be useful for estimating fry survival. They reported that 11 of the study designs were capable of estimating survival parameters, 5 of the methods required unique fish marks, the 6 remaining methods used batch-specific marks, and all potential methods required the release of more than one group of marked fish (Skalski and others, 2009). The application of these methods within the Project was further refined in October 2015 when the USACE convened the Willamette Valley Downstream Fish Passage Research, Monitoring, and Evaluation Workshop in Portland, Oregon. Participants at the workshop were familiar with the Project and identified five approaches that were of interest, along with several potential locations where fry survival data were most needed. The approaches and locations that were identified in the workshop are presented in Skalski (2016).

In 2016, the USACE asked the U.S. Geological Survey (USGS) to develop a study design and implementation plan that could be used to conduct a pilot study to estimate fry survival in Lookout Point Reservoir during 2017. Lookout Point Reservoir spans 16 km of the Middle Fork Willamette River (fig. 1). The reservoir supports abundant populations of several cool water and warmwater fish species that are known to prey on juvenile salmonids (Romer and Monzyk, 2014; Brandt and others, 2016). Given these factors, the assessment of fry survival in Lookout Point Reservoir was identified as a research priority by the USACE, which resulted in the funding of USGS to develop the study design and implementation plan in 2016 (Kock and others, 2016). That document proposed to evaluate Chinook salmon fry survival by releasing three groups of hatchery-produced Chinook salmon juveniles into Lookout Point Reservoir, conducting monthly removal sampling during April–October 2016, and estimating survival using two models—a staggered release-recovery model (SRRM) and a parentage-based tagging (PBT) *N*-mixture model (Kock and others, 2016). The USACE funded a study in 2017 and this report describes our findings from the evaluation.

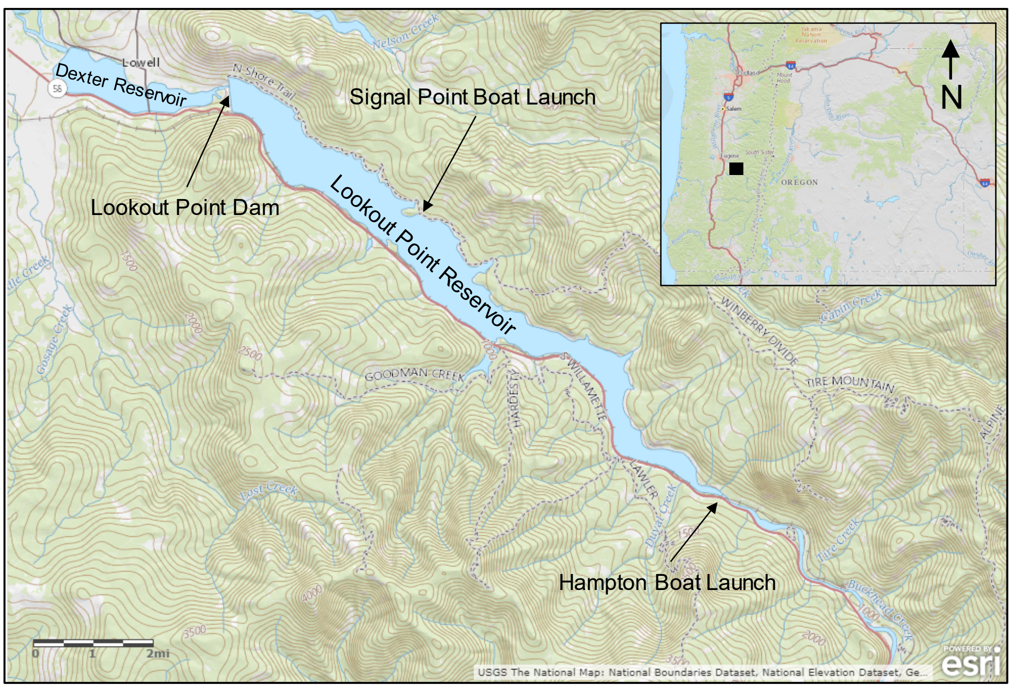

Figure 1. Map image of Middle Fork Willamette River showing two boat launches in Lookout Point Reservoir, Lookout Point Dam, and Dexter Reservoir, western Oregon. Inset shows location of Lookout Point Reservoir in the State of Oregon.

Methods

Environmental Conditions

Environmental and dam operation data were collected to describe how reservoir conditions changed throughout the study period. This information was collected to document reservoir conditions in 2017, because there is the potential for factors such as reservoir water elevations and dam operations to affect distribution patterns of fish in the reservoir. Daily water surface elevation records from the forebay of Lookout Point Dam were obtained from the USACE Northwestern Division web page (http://www.nwd-wc.usace.army.mil/dd/common/dataquery/www/). Water temperature data were collected by the USACE in the forebay of Lookout Point Dam and were obtained for this study from the web page, http://www.nwd-wc.usace.army.mil/ftppub/water_quality/tempstrings/. The USACE provided dam operation data for Lookout Point Dam in 2017. Finally, we collected a monthly Secchi disk measurement during each sampling period in Lookout Point Reservoir to describe water clarity patterns in the reservoir. This measurement was taken about 350 m offshore from the Signal Point Boat Launch (fig. 1).

Production of Study Fish

Fish production details were planned and organized during 2016 to ensure that Chinook salmon fry were available for release into Lookout Point Reservoir during the 2017 pilot study. The study plan (Kock and others, 2016) entailed the release of three groups of juvenile Chinook salmon, with releases in April (R_1), June (R_2), and July (R_3) 2017 (table 1). The goal of the releases was to introduce study fish into the reservoir to match the physical size and spatial distribution of natural-origin Chinook salmon. Each release group was produced using a distinct group of adult Chinook salmon, effectively creating genetic marks of fish within each group (Kock and others, 2016). The Oregon State University Wild Fish Surrogate Program (WFSP) was identified as the lead entity responsible for producing Chinook salmon fry for the study. The WFSP produces juvenile salmon and steelhead for research in the Willamette River Basin at the Fish Performance and Genetics Laboratory (FPGL) in Corvallis, Oregon.

Table 1. Release date, sample size, and fork length targets used to plan the production of juvenile Chinook salmon for a study in Lookout Point Reservoir, western Oregon, 2017.

[Actual release dates, number of fish released, and average fork length of released fish also are shown]

Release group	Target release date	Actual release date	Target release number	Actual release number	Target fork length (millimeters)	Actual average fork length (millimeters)
R_1	April 14	April 18–19	75,000	43,950	48	42
R_2	June 16	May 30–June 2	50,000	44,145	97	94
R_3	July 15	June 28	10,000	3,920	120	107

We began working with WFSP staff on production planning during May–August 2016. Much of the planning focused on details related to sample size targets, fish size targets, release date targets, within-release group replication, and desired ratios of male-to-female spawners. The total sample size request was 135,000 juvenile Chinook salmon with group sizes of 75,000 fish for R_1, 50,000 fish for R_2, and 10,000 fish for R_3 (table 1). WFSP staff considered our sample size target, along with our request to have a 2:1 ratio of male-to-female spawners to identify the total number of spawning adults required to produce study fish. Based on the desired number of offspring and estimated fecundity of 4,000 eggs per female spawner, the WFSP determined that 22–25 females with 44–50 males would cover these needs. Because of the differences in growth trajectories of the juveniles, spawning occurred on two separate days, one in early September and the other in late September 2016. Fish produced from the early spawning date were assigned to the R_2 and R_3 groups because they required additional time to reach size targets for the study. The WFSP staff collected samples from hatchery adult spring Chinook salmon at Willamette Hatchery, Oakridge, Oregon. The first spawn date was September 9, 2016, when eggs from 22 females and milt from 44 males were collected. The second spawn date was September 26, 2016, when eggs from 22 females and milt from 44 males were collected. The WFSP had concerns with lower than desired fish numbers after the first spawn but were unable to request additional adults at the second spawn because of uncertainty that the hatchery would meet its own production needs. All samples were placed in individual containers, provided oxygen, and then placed in a cooler for transport.

At FPGL, the milt from two males were added to the eggs of each female for fertilization. The eggs of individual females were placed in labeled Heath trays (vertical incubation system) and water hardened for about 45–50 min. A small subsample was collected from each female to check for fertilization success. At the eyed-egg stage for each spawn time, eggs were shocked, picked, and inventoried. This occurred on October 4, 2016, for fish destined for the R_2 and R_3 groups, and on December 6, 2016, for fish destined for the R_1 group. One family from the first spawn and three families from the second spawn were removed from the study owing to unfertilized or unviable eggs that resulted in complete loss of family groups. Eggs were inventoried for each female by counting and weighing a small subset of eggs, and then by weighing the entire group of eggs.

Based on egg inventories for each female and estimated post-hatch loss, replicate groups within each release group were formed at ponding. For R_2 and R_3 groups, fish were ponded on November 14, 2016, with 4–5 families represented in each of four replicates for R_2, and 2 families represented for each of two replicates for R_3. R_1 fish were ponded on March 20, 2017, with 4–5 families represented in each of four replicates. Family groupings and inventories were recorded for each tank. Throughout rearing, fish were fed the WFSP experimental low-lipid diet (formulated by Bozeman Fish Technology Center; 11–12-percent lipid content), following the surrogate program rearing protocol using adaptive feeding. Once fish were actively on feed, they were fed according to the desired growth trajectory to reach target sizes on requested target dates. WFSP staff recorded mortalities in each tank daily and sampled fish from each tank monthly to monitor growth. Feed amounts were adjusted weekly to account for inventory and growth. Fish from the R_1 group were reared at the FPGL until they were transported to Lookout Point Reservoir for release. Fish from the R_2 and R_3 groups were reared at the FPGL until February 2017, when they were transported to Willamette Hatchery for rearing until reservoir release.

Several factors resulted in lower-than-desired sample sizes for the release groups during 2017. WFSP staff noted that average fecundity of adult female spring Chinook salmon was lower than expected and that some spawning groups (2 males, 1 female) produced very few or no viable offspring. An unexpected number of juveniles with physical deformities also were present, and these tended to occur more frequently in some families than in others. Additionally, environmental conditions in 2017 lead to new additions to our study design (see section, "Assessing Passage During Spill Operations at Lookout Point Dam") that required releasing some study fish at new locations. For these reasons, final sample sizes for R_1, R_2, and R_3 were 43,950, 44,145 and 3,920 fish, respectively (table 1).

Assessing Passage During Spill Operations at Lookout Point Dam

A primary assumption of the models we used was that Lookout Point Reservoir was "closed" during the study period. This means that fish were not leaving the reservoir during fish release and collection periods (Kock and others, 2016). Our study design assumed that spill operations would not occur at Lookout Point Dam during the study period and that other non-spill passage routes were located too deep for juvenile salmonids to pass, thereby satisfying the assumption of a closed system. However, spill operations were implemented at Lookout Point Dam during April–June 2017 because of above-average regional snowpack in the winter of 2016–17. This required a study design modification to attempt to quantify fish passage during spill operations in the spring.

The USACE operated three screw traps in the tailrace of Lookout Point Dam during May–June 2017 to collect fish that passed the dam. The traps, located 0.35 km downstream of the dam (fig. 2), began operating continuously on May 11, 2017, and stopped operating on June 30, 2017. Traps were checked daily on weekdays during the operating period by USACE staff. For each collected fish, the following information was recorded: (1) species type, (2) fork length (in millimeters), and (3) percentage of descaling. Chinook salmon juveniles smaller than 130 mm may have been from release groups in our study, so a genetic sample was collected by removing a portion of the caudal fin. Unclipped Chinook salmon were marked with a PIT tag. Clipped Chinook salmon were counted and all Chinook salmon that were collected in screw traps were transported downstream of Dexter Dam and released in the Willamette River.

Figure 2. Photograph showing three screw traps operating in the tailrace of Lookout Point Dam to collect fish after passage at the dam, Middle Fork Willamette River, western Oregon, May–June 2017. Photograph by Todd Pierce, U.S. Army Corps of Engineers, May 2, 2017.

Four groups of clipped Chinook salmon were released upstream of the screw traps to estimate collection efficiency. These fish originally were part of the R_1 release group but were removed from the R_1 group when the study design was altered to include the operation of screw traps in the tailrace of the dam. Each of the four release groups contained about 1,000 fish, and each group was uniquely marked with fin clips (table 2). On each release date, fish were transported by boat and released immediately downstream of Lookout Point Dam. USACE personnel monitored the presence of these fish in the screw traps throughout the study period. The percentage of marked fish recaptured was determined by dividing the total number of recaptured fish from each group by the total number of released fish in that same group. This information was then used to estimate the total number of genetically marked fish that may have passed Lookout Point Dam during May 11–June 30, 2017 following release in Lookout Point Reservoir (see section, “Fish Releases in Lookout Point Reservoir”). These estimates were calculated by dividing the number of genetically marked Chinook salmon captured in screw traps by the estimated collection efficiency of the screw traps.

Table 2. Release date, location of fin clip used to mark fish, number of fish released, number of fish recaptured, and percentage of fish recaptured for an assessment of capture efficiency of screw traps in the tailrace of Lookout Point Dam, western Oregon, 2017.

Release date	Fin-clip location	Number released	Number recaptured	Percent recaptured
May 16	Left ventral	991	19	1.9
May 24	Left pectoral	994	36	3.6
June 1	Right pectoral	1,066	22	2.1
June 15	Right ventral	1,063	25	2.4

Fish Releases in Lookout Point Reservoir

Fish were transported by truck to the reservoir in 1,500-L insulated tanks that each held twelve 76-L perforated plastic transport containers. Each tank contained a support frame that held containers upright and a pump was used to circulate oxygenated water within the tank. Holding densities in the transport containers were maintained at 20–50 g/L and generally were similar for all containers within each holding tank, for each transport period. At the reservoir, containers were transferred from the transport tank onto boats where they were placed in non-perforated containers filled with fresh reservoir water. Boats transported the containers to predetermined release sites where fish were gently poured into the reservoir. Water temperature and dissolved oxygen levels were monitored throughout transport and release. Oxygen was supplied to transport tanks as necessary to maintain dissolved oxygen levels at 80–120 percent. Water temperature was manipulated by adding ice to ensure that fish experienced less than 0.5 °C change per 15 min during transport. Reservoir water temperature was measured by a separate crew prior to the start of each transport. Water temperature manipulations during transport were targeted to ensure that fish were released in the reservoir at temperatures that were within 0.5 °C of those in transport containers.

The R_3 release group required additional handling because the reservoir had thermally stratified by late June 2017. Water temperature at Willamette Hatchery was about 14 °C when R_3 fish were picked up for release. In Lookout Point Reservoir, surface temperature was about 19 °C at that time. We developed a release apparatus that allowed us to avoid releasing study fish into warm surface water on the reservoir. The release apparatus consisted of four components: (1) a conical release hopper, (2) a release pipe, (3) an intake hose, and (4) a water pump (fig. 3). The water pump was used to draw water through the intake hose from about 12 m below the surface where water temperature was 14 °C. The pumped water was passed into the conical release hopper and then through the release pipe (10.2-cm diameter), which was 12 m long. At the time of release, containers of study fish were gently poured into the conical release hopper where they volitionally swam through the release pipe, entering the reservoir 12 m below the surface in water that was 14 °C.

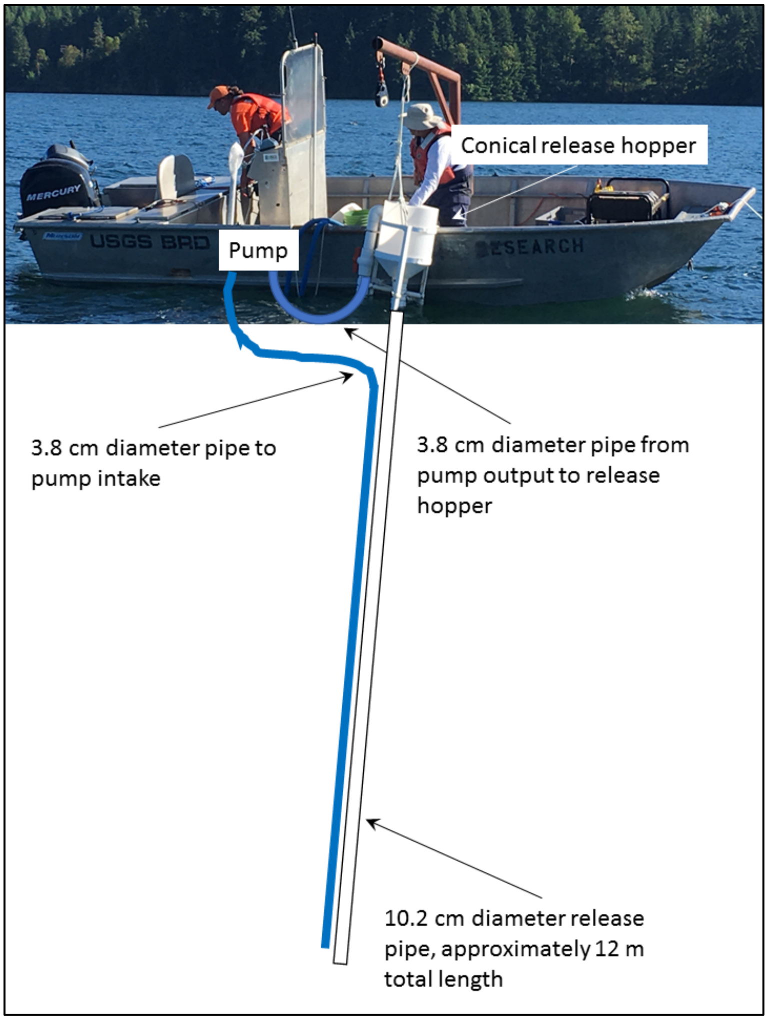

Figure 3. Photograph and diagram showing release apparatus used for release group R_3 releases in Lookout Point Reservoir, western Oregon, 2017. cm, centimeter; m, meter.

Sampling in Lookout Point Reservoir

Monthly reservoir sampling was conducted during 5-day periods from May to October 2017. The goal of sampling was to maximize collection of subyearling Chinook salmon. We anticipated that Chinook salmon distribution in the reservoir would change throughout the study as reported by Monzyk, Emig, Romer, and Friesen (2015), who determined that most fish in Lookout Point Reservoir were in nearshore habitat during May, in a mix of nearshore and offshore habitat during June, and in offshore habitat during July–October. We used several sampling techniques to target fish in these habitats. In May, boat electrofishing, shoreline traps, and gill nets were used to collect juvenile Chinook salmon (table 3). Boat electrofishing surveys were conducted in shallow, nearshore areas. During electrofishing, the boat was slowly driven along a shoreline for about 10 min. Fish that were encountered and identified as juvenile salmonids were hand-netted and placed in a live well. Once sampling was complete, fish were processed, and non-target species were returned to the reservoir. Two types of shoreline traps were used—box minnow traps and Oneida Lake traps (fig. 4). Box minnow traps comprised a 0.9 m × 0.9 m × 0.9 m polyvinyl chloride frame covered with 0.3-cm white delta mesh that included a 101-mm throated opening. The traps were configurable to include lead and wing nets to guide fish to the opening. We used two sizes of lead and wing nets—short nets were 6.1 m long and 0.9 m tall, long nets were 12.2 m long and 0.9 m tall. All lead and wing nets were constructed of 0.3-cm black delta mesh. Oneida Lake traps were a box minnow trap that was configured to include an Oneida Lake trap module that attached to the front of the trap entrance (fig. 4). The Oneida Lake trap module was 1.8 m tall × 3.7 m wide and was designed to enhance guidance and retention of fish into the box minnow trap. Oneida Lake traps also were configurable with lead and wing nets of two sizes—short nets were 6.1 m long and 1.8 m tall, long nets were 12.2 m long and 1.8 m tall. These also were constructed of 0.3-cm black delta mesh. Gill nets were 24.4 m long and 4.6 m tall. Each gill net comprised three 8.1-m long sections that contained 12.7-, 19.0- or 25.4-mm mesh squares of monofilament material. In June, reservoir sampling was shoreline traps and gill nets. During July–October, all reservoir sampling was conducted using gill nets (table 3).

We estimated that sampling would require about 40 gear sets per day during a 4-day effort to meet collection goals (Kock and others, 2016). Shoreline traps and gill nets were fished for 24 h, which constituted a set. For boat electrofishing, a set consisted of 10 continuous min of active sampling. Implementation of the 4-day sampling plan required a total of five sampling days on the reservoir. On the first day, 60–75 percent of the sampling gear was deployed, allowed to fish overnight, and checked the following morning (second sampling day). This provided two benefits—it reduced the workload associated with deploying all sampling gear on a single day and it allowed us to assess capture numbers from the gear deployed on the first sampling day to determine if there were locations where juvenile Chinook salmon were concentrated. If so, we had information that allowed us to target these concentrations with the remaining sampling gear that was deployed on the second day. Thus, on the second sampling day, fish were removed from the gear that was deployed on the first sampling day, and the remaining gear was deployed in areas where catch was highest on the first sampling day.

Table 3. Sampling techniques, effort (number of sets), and collection dates for monthly reservoir sampling events targeting juvenile Chinook salmon in Lookout Point Reservoir, western Oregon, 2017.

Collection period	Sampling technique	Number of sets	Collection dates
May	Boat electrofishing	63	[1]May 21–25
	Box minnow trap	56	
	Oneida Lake trap	13	
	Gill net	40	
June	Oneida Lake trap	72	June 23–27
	Gill net	126	
July	Gill net	193	July 18–22
August	Gill net	184	August 13–17
September	Gill net	182	September 13–17
October	Gill net	190	October 12–16

[1]Boat electrofishing ended on May 24.

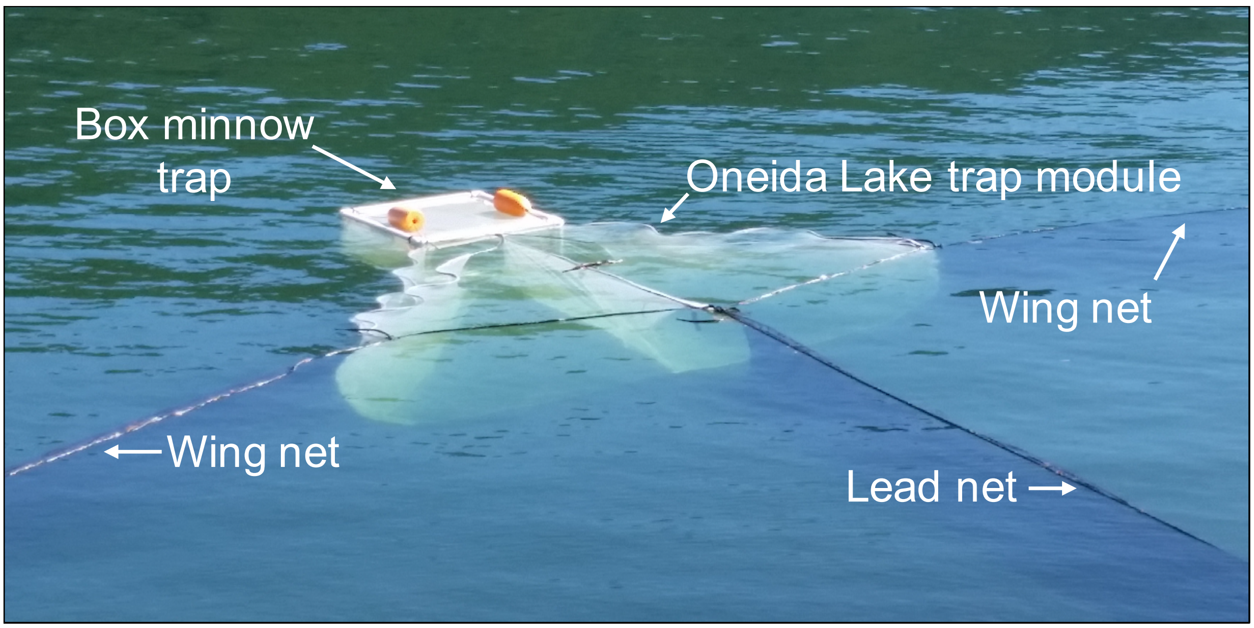

Figure 4. Photograph showing major components of an Oneida Lake trap used to collect juvenile Chinook salmon in Lookout Point Reservoir, western Oregon, 2017.

Genetic sampling

Genetic sampling and analysis from several groups of fish were an integral part of our study design (table 4). Tissue samples were obtained from all adult Chinook salmon that were spawned to produce study fish. Data from these samples were used to determine which family groups constituted specific replicates within each of the release groups. Samples also were collected from juvenile Chinook salmon at the Smith Farms Genetics and Performance Lab and Willamette Hatchery on each release day. These samples were analyzed to determine if there was evidence of mixing between groups of fish in different replicates or release groups. Finally, samples were obtained from subyearling Chinook salmon collected in Lookout Point Reservoir and in screw traps in the tailrace of Lookout Point Dam. Data from these samples were used to determine the replicate and release group from which each individual fish originated. Tissue samples were fin clips that were stored in 95-percent ethanol. Genetic analysis and assignments were completed by staff at the Coastal Oregon Marine Experiment Station in Newport, Oregon.

Table 4. Number of tissue samples collected and submitted for genetic analysis and assignment during an evaluation in Lookout Point Reservoir, western Oregon, 2017.

Sample description	Number of samples
Adult Chinook salmon spawners	120
Juvenile Chinook salmon prior to release	420
Juvenile Chinook salmon collected in Lookout Point Reservoir	3,625
Juvenile Chinook salmon collected in the tailrace of Lookout Point Dam	60
Total	**4,225**

Survival Models

Staggered Release-Recovery Model

The SRRM was presented by Skalski (2016) as one approach for estimating fry survival when fish are present in Project reservoirs, but too small for marking with a PIT tag. The model design includes the release of two or more groups of juvenile Chinook salmon (R_1, R_2... R_n) with releases made at the beginning (R_1) and the end of the period of inference (R_n). Once fish are released, it is assumed that the groups distribute similarly, and reservoir sampling is conducted several times to capture fish from each release group (Skalski, 2016). Survival is essentially estimated as the ratio of recoveries given a common recapture rate among groups. Survival is estimated over time periods between combinations of the sequential release groups. Skalski (2016) summarized the five primary assumptions under the SRRM design:

1. All fish act independently,
2. All release groups share the same recapture and survival rates after the last release,
3. Sample sizes of all release groups are known without error,
4. Recovery numbers are correctly reported and assigned to the correct release group, and
5. Fish do not lose their tags.

Under the SSRM, the recovery counts were treated as outcomes under a multinomial distribution, and we used Monte Carlo Markov Chain (MCMC) methods to estimate model parameters. The likelihood of recovery counts for the first release of fish may be expressed as:

$$\begin{aligned} \pi_1 &= S_1 S_2 P \\ \pi_2 &= S_1 S_2 (1-P)\lambda \\ \pi_3 &= (1-S_1 S_2) + S_1 S_2 (1-P)(1-\lambda), \end{aligned} \tag{1}$$

where π_i are the multinomial cell probabilities for the ith likelihood expression;
S_1 and S_2 are the survival rates for period between subsequent fish releases (that is, R_1, R_2, and R_3);
P is the recapture probability assumed to be common among release groups; and
λ is the joint probability of surviving and being recaptured, which also is assumed common among release groups.

Similarly, the likelihood for the second release group can be expressed as:

$$\begin{aligned} \pi_4 &= S_2 P \\ \pi_5 &= S_2 (1-P)\lambda \\ \pi_6 &= (1-S_2) + S_2 (1-P)(1-\lambda). \end{aligned} \tag{2}$$

The likelihood for the third release group of fish may be expressed as:

$$\begin{aligned} \pi_7 &= \lambda \\ \pi_8 &= (1-\lambda). \end{aligned} \tag{3}$$

Because survival and recapture rates can be estimated from different but sequential release groups, we fitted the survival model using (1) all releases, (2) just R_1 and R_2, (3) just R_2 and R_3, and (4) just R_1 and R_3. Using these release group combinations, we estimated three survival parameters: S_{SRRM1}, S_{SRRM2}, and S_{SRRM12}. The parameter S_{SRRM1} represented survival from mid-April to late May and was calculated using two release group combinations: R_1, R_2, and R_3; and R_1 and R_2. The parameter S_{SRRM2} represented survival from late May to late June and was calculated using two release group combinations: R_1, R_2, and R_3; and R_2 and R_3. The last parameter, S_{SRRM12}, represented survival from mid-April to late June and was calculated using the release groups R_1 and R_3. When any two release groups were used in model fitting, the likelihood was simplified to be similar in form to the likelihoods reported for R_2 and R_3. Estimating survival from different combinations of release groups provided survival estimates for different aggregations of time over the study independent of the excluded release group. Likewise, multiple release combinations provided insight into some of model assumptions (for example, assumption 2 noted earlier in this section) about how survival and recapture probabilities were influenced by release groups. Factors such as poor collection success (that is, low recapture probability), different survivals, and inadequate mixing of the release groups could limit the capability of the SRRM to estimate survival of small fishes, so this study represented a critical step in assessing the utility of the approach to estimate the survival of juvenile Chinook salmon in a field setting.

Percentage-Based Tagging *N*-mixture Model

We developed and tested an alternative model to the SRRM to estimate survival of juvenile Chinook salmon in Lookout Point Reservoir. Our goal was to design a model that could estimate survival without using a paired-release design (such as the SRRM) to avoid the strict assumptions required by the paired-release model (namely, equal survival between release groups after the second release). The alternative model development was motivated by the idea that replication of counts under a repeated-removal sampling design could help estimate capture probability, thus allowing for unbiased estimation of survival from one sampling occasion to the next. Much of the theory behind this alternative model structure is derived from the class of models known as *N*-mixture models.

The Standard *N*-mixture Model with a Removal Sampling Protocol

N-mixture models are a class of hierarchical models that estimate animal abundance and capture probability from repeated-point counts replicated in space (Kéry and Royle, 2016). Specifically, let y_{ij} represent the number of individuals sampled at site i ($i = 1, \ldots, R$) on the jth sampling occasion ($j = 1, \ldots, J$). Under a removal sampling protocol, the sample counts arise from a multinomial distribution:

$$y_{i1}, \ldots, y_{iJ}, N_i - \sum_{j=1}^{J} y_{ij} \sim \text{Multinomial}\left(N_i, \pi_{i1}, \ldots, \pi_{iJ}, \pi_{i0}\right), \tag{4}$$

where N_i is the abundance at site i,
π_{ij} is the probability that an individual at site i is first captured on the jth sample, and
π_{i0} is the probability of not being captured over all J samples.

The primary assumption is that the sampled population is closed to immigration, emigration, mortality, and recruitment over the J samples. The probability of first capturing an individual on sample j (π_{ij}) is a function of the per-sample capture probability:

$$\pi_j = \frac{\pi_{j-1}}{p_{j-1}} p_j \left(1 - p_{j-1}\right), \tag{5}$$

where p_j is the probability of capturing an individual on the jth removal sample, and $\pi_1 = p_1$.

Although N_i can be estimated directly for each site (Dorazio and others, 2005), *N*-mixture models leverage information across sites by assuming that the distribution of site-specific abundance follows a Poisson distribution:

$$N_i \sim \text{Poisson}\left(\lambda\right), \tag{6}$$

where λ is the mean abundance across R sites.

The integrated likelihood function for this multinomial-Poisson mixture model has a convenient computational form that reduces to the product of conditionally independent Poisson distributions (Royle, 2004):

$$f\left(\mathbf{y} \mid \lambda, p\right) = \prod_{i=1}^{R} \prod_{j=1}^{J} \text{Poisson}\left(\lambda \pi_{ij}\right), \tag{7}$$

where $\mathbf{y}$ is the $R \times J$ matrix of sample counts.

Model parameters (λ and p) can be estimated in both maximum likelihood (Fiske and Chandler, 2011) and Bayesian frameworks (Kéry and Schaub, 2012).

This hierarchical model provides a flexible framework for estimating abundance. The mean abundance parameter (λ) can be modeled as a function of site-specific covariates to draw inference on factors affecting abundance. Additionally, capture probability can be modeled as a function of both site-specific and occasion-level covariates associated with each of the j samples at site i.

Adapting the *N*-mixture Model to Estimate Fry Survival

The N-mixture model is couched in the context of site-level abundance following a Poisson distribution across sites. We considered this framework for estimating abundance at each trap site (for example, each trap or gill net site) in Lookout Point Reservoir by conducting repeated daily removal samples at each site. However, this approach posed several challenges. First, the set of J samples at each site cannot be considered a closed sample because fish can move freely in and out of the sampling area each day. Second, since trapping relies on fish moving through the traps or nets, the spatial area over which individuals are at risk of capture is unknown, making it difficult to estimate fish density (number of fish per unit area). Third, even if site-specific density could be estimated, estimation of reservoir-wide abundance would necessitate extrapolating from sampled to unsampled areas. For these reasons, we determined that the N-mixture model could not be used to estimate reservoir-wide abundance and survival of fry.

The use of PBT methods for the Lookout Point study provided an opportunity for recasting the N-mixture model by using information from each PBT mark. PBT identifies offspring from each male-female pairing, thereby providing many unique batch marks. By viewing repeated sample counts as replicated across PBT batch marks instead of replicated across sampling sites, the N-mixture model can be used to estimate abundance of fry. Thus, if we now let y_{ij} represent the number of fry captured from PBT mark i on sample j over all reservoir sampling locations, then R is the total number of unique PBT marks, N_i is the abundance of fry with each PBT mark, λ is the mean abundance over all PBT marks, and $R\lambda$ is the expected value of the total abundance of fry in the reservoir.

To estimate survival from a release group of hatchery-reared fry, we adapted the N-mixture model to allow for a series of monthly primary sampling occasions with secondary occasions formed from removal samples occurring over consecutive days. Consider a release group where G is the total number of fry released in the reservoir, the number of unique PBT marks is known, and the population is sampled at some later date such that mortality occurs between release and sampling. Because we had independent estimates of the number of individuals with each PBT mark at the time of release from both hatchery egg counts and sampled weights at the time of release (see section, "Production of Study Fish"), we treated $N_{i,0}$, the number released with PBT mark i, as known without error. Thus, in relation to the standard N-mixture model, we viewed $N_{i,0}$ as a realization of the Poisson distribution with the constraint that $\sum_{i=1}^{R} N_{i,0} = G$, under the assumption of a common mean number of offspring among family groups.

For a single primary sampling occasion with S fraction of G surviving, the number of fish with each PBT mark surviving from release to recapture (N_i) is distributed binomially conditional on $N_{i,0}$:

$$N_i \mid N_{i,0} \sim \text{Binomial}\left(N_{i,0}, S\right). \tag{8}$$

The capture counts for the ith PBT mark can be expressed using a multinomial distribution conditional on N_i and on the total probability of capture over J secondary sampling occasions:

$$y_{i1}, \ldots, y_{iJ} \mid N_i \sim \text{Multinomial}\left(N_i, \frac{\pi_{i1}}{\sum_{j=1}^{J} \pi_{ij}}, \ldots, \frac{\pi_{iJ}}{\sum_{j=1}^{J} \pi_{ij}} \right), \tag{9}$$

where π_{ij} is the probability of first capturing an individual with PBT mark i on the jth sample, as described in equation 4.

To extend this study design over K primary sampling occasions, the likelihood must account for removal of fry from the population at previous sampling occasions such that:

$$N_{i,k} \mid N_{i,k-1} \sim \text{Binomial}\left(N_{i,k-1} - \sum_{j=1}^{J} y_{i,j,k-1}, S_k \right), \tag{10}$$

where $y_{i,j,0}$ is 0 for all i and j.

Extending the multinomial distribution for the removal sample to K primary sampling occasions, we have

$$y_{i,1,k}, \ldots, y_{i,J,k} \mid N_{ik} \sim \text{Multinomial}\left(N_{ik}, \frac{\pi_{i,1,k}}{\sum_{j=1}^{J} \pi_{i,j,k}}, \ldots, \frac{\pi_{i,J,k}}{\sum_{j=1}^{J} \pi_{i,j,k}} \right). \tag{11}$$

The likelihood of the data (y_{ijk}) given the parameters (S_k and p_k) of this model is then the product of equations 9 and 10 over all K primary occasions and R PBT marks. Note that the constraints on $N_{i,k}$ arising from known release numbers and the modeling of survival across primary sampling occasions allowed us to replace the Poisson distribution typically used to estimate abundance in N-mixture models with the Binomial distribution given in equation 9. This model can be fit in either a maximum likelihood or Bayesian framework. Because the conditional likelihood formulation involves the unobserved latent abundance of each PBT mark (N_{ik}), we elected to construct the model in a Bayesian framework where latent abundances can be directly simulated, and parameters can be estimated using MCMC techniques.

This form of the model includes several assumptions. First, the number of individuals with each PBT mark at the time of release is assumed known without error. Second, the model assumes equivalent reservoir survival and capture probabilities among PBT marks. These assumptions should be fulfilled if PBT marks are well mixed in the reservoir such that the distribution of PBT marks is similar among sampling locations. Because y_{ij} represents the total number of captures over all reservoir sampling sites, p represents the proportion of each PBT marked group in the reservoir first captured on sample j. Thus, closure means that fish remain in the reservoir and are available for capture, and that no mortality occurs over the J days of sampling during primary sampling occasions.

Constraining Survival and Detection Parameters

Prior to conducting this study, we assessed the ability of the PBT *N*-mixture model to estimate model parameters given low expected capture probabilities (Kock and others, 2016). For example, based on prior studies of reservoir fry sampling, we thought that a realistic proportion of captured fry over an intensive 4–5-day sampling effort might be as low as 1 percent. Therefore, simulations assumed daily capture probabilities as low as 0.0025 to assess whether the model could estimate survival and capture probabilities. We determined that allowing detection and survival parameters to vary independently among primary occasions led to biased or uninformative estimates for both detection and survival parameters at lower capture probabilities. Furthermore, we noted that capture probabilities required to accurately estimate unique parameters for each sampling period could not be achieved with available sampling methods.

Although our simulations showed that the PBT *N*-mixture model could not be used to estimate occasion-specific p and interval-specific S, further simulation results showed that if capture probability was similar among primary sampling occasions or survival varied systematically with covariates such as fish size or time, then information across multiple primary sampling occasions could be used to fit simpler models that could estimate parameters without bias when capture probabilities were low (Kock and others 2016). We considered various constraints on p and S that would balance achieving unbiased estimation with avoidance of unrealistic assumptions about underlying processes. For example, simulations showed that assuming constant capture probability and survival across primary sampling occasions resulted in precise, unbiased estimates when data were simulated in this manner. However, we do not expect survival of newly released fry in April to be the same as that of much larger juvenile Chinook salmon in late summer or fall, nor do we expect capture probability through electrofishing in May to be the same as gill net sampling in September when juvenile Chinook salmon have primarily moved offshore.

We hypothesized that capture probability might vary among sampling gear used (electrofishing, gill net, and box trap), and that for a given gear, capture probability would depend on whether fish were nearshore or offshore. We further assumed that fry were nearshore during the first two primary sampling occasions and offshore thereafter. Additionally, we assumed that monthly survival was a function of time of year, since larger juvenile Chinook salmon from later in the season are likely to survive at a higher rate than smaller fry-sized fish from earlier in the year. Therefore, we modeled survival and capture probability as follows:

$$\text{logit}\left(p_k\right) = b_{p,0} + b_{p,1}x_{p,k}$$
$$\text{logit}\left(S_k\right) = b_{S,0} + b_{S,1}x_{S,k} \quad , \qquad (12)$$

where logit () is the logit link function,
$b_{pg,0}$ and $b_{pg,1}$ are the slope and intercept for capture probability for gear type *g*,
$x_{p,k}$ is a binary covariate set to zero for k = (1, 2) and one for k = (3, 4, 5, 6),
$b_{S,0}$ and $b_{S,1}$ are the slope and intercept for survival, and
$x_{S,k}$ is a continuous covariate indicating the number of months from the first fry release to primary sampling occasion *k*.

Parameter p_{kg} thus represents a constant daily capture probability for gear *g* across sampling occasions 1 and 2 or 3–6, whereas parameter S_k represents a standardized per-30-day survival for primary occasion *k*. We used standard normal prior distributions for all slope and intercept parameters. The PBT *N*-mixture model provided survival estimates from six periods: (1) mid-April to mid-May (S_{NMIX1}), (2) mid-May to mid-June (S_{NMIX2}), (3) mid-June to mid-July (S_{NMIX3}), (4) mid-July to mid-August (S_{NMIX4}), (5) mid-August to mid-September (S_{NMIX5}), (6) and mid-September to mid-October (S_{NMIX6}).

Results

Environmental Conditions

Water storage levels were higher than normal in Lookout Point Reservoir during 2017 owing to above-average snowpack in the region during winter 2016–17. The USACE developed a “rule curve” for Lookout Point Reservoir that established year-round water elevation targets to assist with managing reservoir water levels (fig. 5). In most years the reservoir has been managed to follow the rule curve during early spring, late fall, and winter. However, reservoir elevations typically are lower than the rule curve during late spring and summer because the reservoir does not fill completely during these periods. During 2011–16, reservoir refill levels failed to meet the rule curve maximum of about 282 m (fig. 5). This was not the case during 2017, however, when snowmelt allowed the reservoir to reach the maximum refill target in early May (fig. 5). Reservoir water elevation remained at or near 282 m until mid-July, resulting in maximum reservoir water elevations that met the rule curve target, but exceeded normal conditions in late spring and early summer (fig. 5). Spill occurred on most days during May and early June (fig. 6).

Water temperature in the forebay of Lookout Point Dam was about 9 °C throughout the water column in April 2017 but the reservoir thermally stratified during the subsequent months (fig. 7). By early August, surface temperatures were 24 °C and exceeded 18 °C in the upper 12 m of the water column. The reservoir began cooling in September and surface temperatures in the forebay of Lookout Point Dam were about 15 °C by the end of the study in mid-October (fig. 7). Turbidities were low throughout the study period, with Secchi depth measurements in the 3–6 m range during most months of the study, except in July, when depth was 8.15 m (table 5).

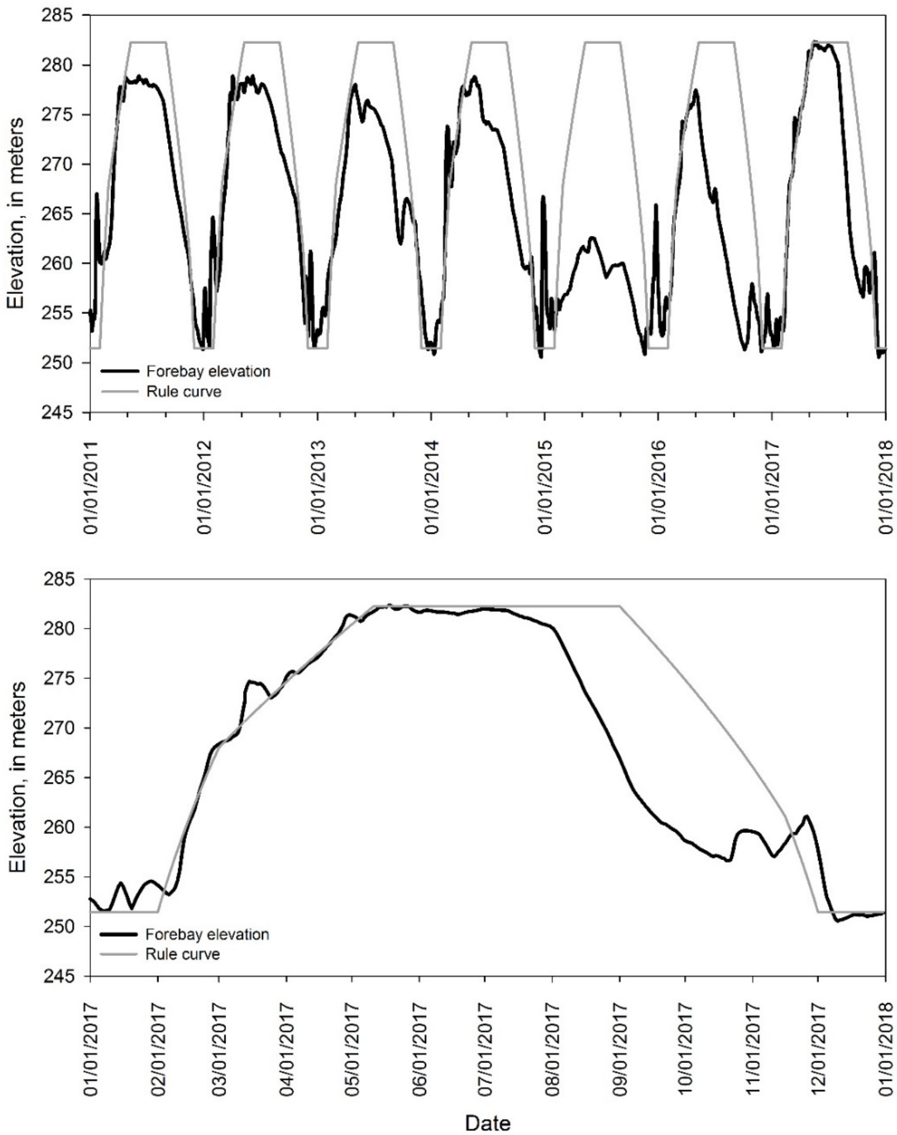

Figure 5. Graphs showing forebay elevation in meters above North American Vertical Datum of 1988 and rule curve for Lookout Point Reservoir, western Oregon, 2008–17 (top graph) and 2017 (bottom graph).

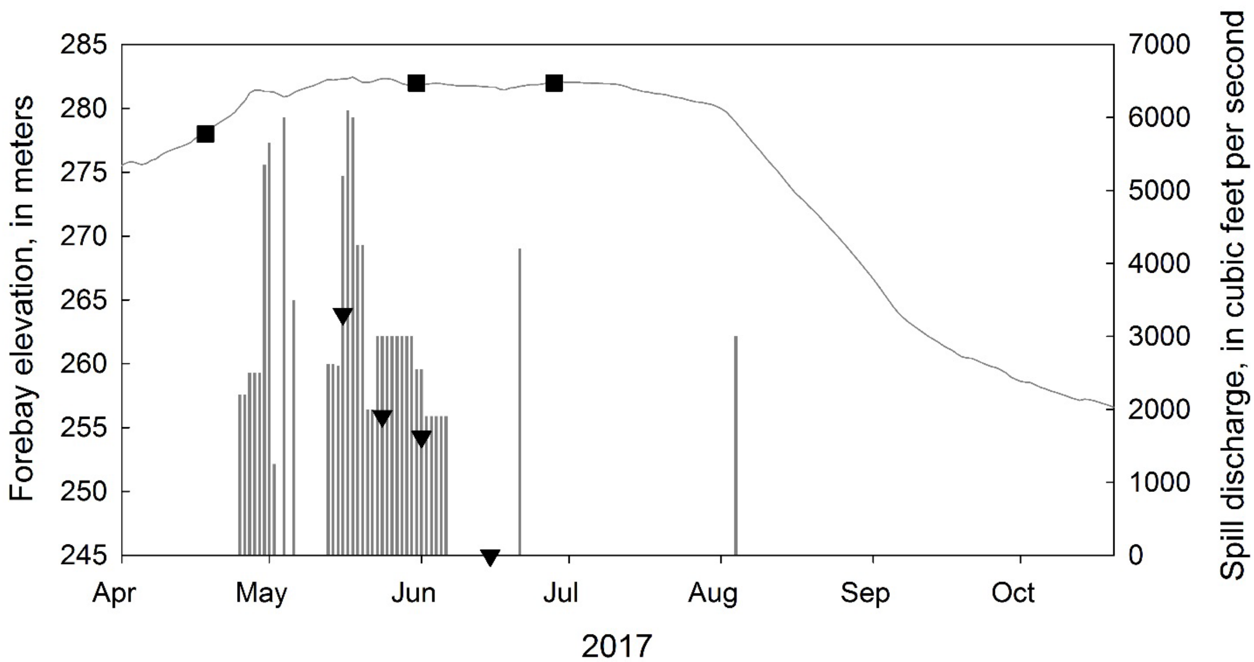

Figure 6. Graph showing forebay elevation (gray line) in meters above North American Vertical Datum of 1988, maximum daily discharge through the spillway (gray bars), and timing of fish releases in Lookout Point Reservoir, western Oregon, 2017. Fish releases in the reservoir are represented by black squares and fish releases in the tailrace of Lookout Point Dam are represented by black triangles.

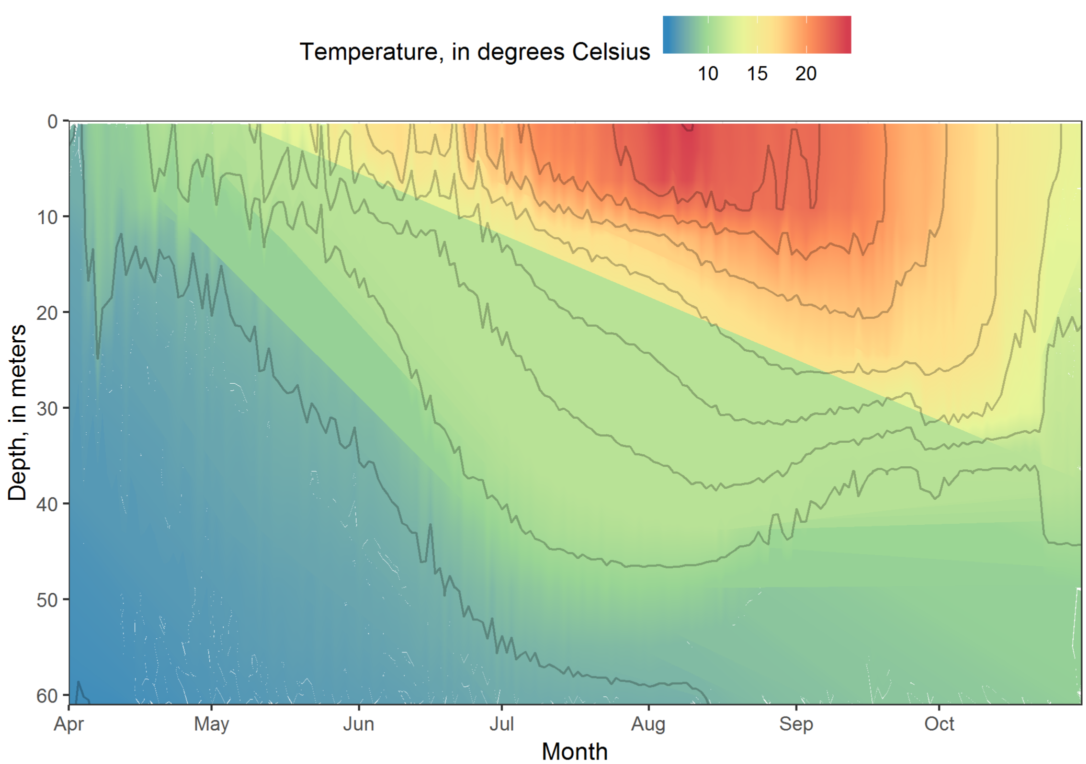

Figure 7. Graph showing mean daily reservoir temperature by water depth from the U.S. Army Corps of Engineers temperature string in the Lookout Point Dam forebay, western Oregon, April–October 2017.

Table 5. Secchi depths obtained monthly in Lookout Point Reservoir, western Oregon, May–October 2017.

Sample date	Secchi depths (meters)
May 25	3.88
June 26	5.79
July 20	8.15
August 18	5.64
September 16	5.18
October 12	5.03

Assessing Passage During Spill Operations at Lookout Point Dam

A total of 4,114 marked juvenile Chinook salmon were released in the tailrace of Lookout Point Reservoir to evaluate collection efficiency of the three screw traps. Groups of fish were released on May 16 and 24, and June 1 and 15, 2017 (table 2). The number of marked fish that were recaptured in the screw traps was low (36 fish or less) from each group. The percentage of fish recaptured from each group (collection efficiency of the screw traps) ranged from 1.9 to 3.6 percent (table 2). A total of 236 juvenile Chinook salmon were collected in screw traps downstream of Lookout Point Dam during May 11–June 30, 2017. Most collected Chinook salmon (102 fish) were fin-clipped fish released to evaluate the collection efficiency of the screw traps. The remaining collected Chinook salmon were yearlings or older based on their size (74 fish) or were subyearlings (60 fish). Genetic analysis of subyearlings indicated that 30 fish were genetically marked as part of our study. Based on these results, we estimated that the total number of genetically marked Chinook salmon that passed Lookout Point Dam during May 11–June 30, 2017, ranged from 833 to 1,579 fish. Other species (such as largescale sucker, sculpin, and bluegill) were collected in screw traps as well (table 6).

Table 6. Number of each fish species captured in the Lookout Point Dam tailrace, western Oregon, 2017.

Species	Number collected
Black crappie	2
Bluegill	7
Chinook salmon	236
Cutthroat trout	1
Largescale sucker	15
Northern pikeminnow	2
Rainbow trout	6
Redside shiner	6
Sculpin	13
Walleye	5

Fish Releases in Lookout Point Reservoir

Groups of study fish were released in Lookout Point Reservoir in mid-April, late May to early June, and late June 2017. The four replicates of R_1 fish were transported and released during April 18–19, 2017. The number of fish in each replicate ranged from 10,112 to 11,426 and the total release comprised 43,950 fish (table 7). Fish in the R_1 group were released 12–17 river kilometers (rkm) upstream of Lookout Point Dam (fig. 8). The two replicates of R_2 fish were released during May 30–June 1, 2017. The replicates contained 21,734 and 22,411 fish, respectively, for a total release of 44,145 fish (table 7). R_2 fish were released 4 to 16 rkm upstream of the dam (fig. 8). The R_3 fish were all released on June 28, 2017. Counts of the two replicates were 1,516 and 2,404 fish for a total release group of 3,920 fish (table 7). The R_3 fish were released 2–6 rkm upstream of Lookout Point Dam (fig. 8).

Table 7. Number of juvenile Chinook salmon released within each replicate and release group, release date, mean fork length, and mean weight of released fish for a study in Lookout Point Reservoir, western Oregon, 2017.

[Numbers in parenthesis are the range of mean fork length and fish weight measurements]

Release group	Replicate	Release date	Number released	Mean fork length (millimeters)	Mean weight (grams)
R_1	1	April 18	11,426	42 (31–48)	0.7 (0.2–1.2)
	2	April 19	10,112	45 (39–50)	0.8 (0.5–1.2)
	3	April 18	11,366	42 (31–48)	0.7 (0.2–1.2)
	4	April 19	11,046	44 (37–50)	0.7 (0.5–1.0)
	Overall		43,950	42 (31–50)	0.7 (0.2–1.2)
R_2	1	May 30–31	21,734	97 (71–116)	10.1 (3.7–16.5)
	2	May 31–June 1	22,411	92 (68–113)	7.9 (3.0–15.6)
	Overall		44,145	94 (68–116)	9.0 (3.0–16.5)
R_3	1	June 28	1,516	117 (102–130)	17.9 (11.4–24.0)
	2	June 28	2,404	97 (55–119)	10.1 (1.6–19.6)
	Overall		3,920	107 (55–130)	13.8 (1.6–24.0)

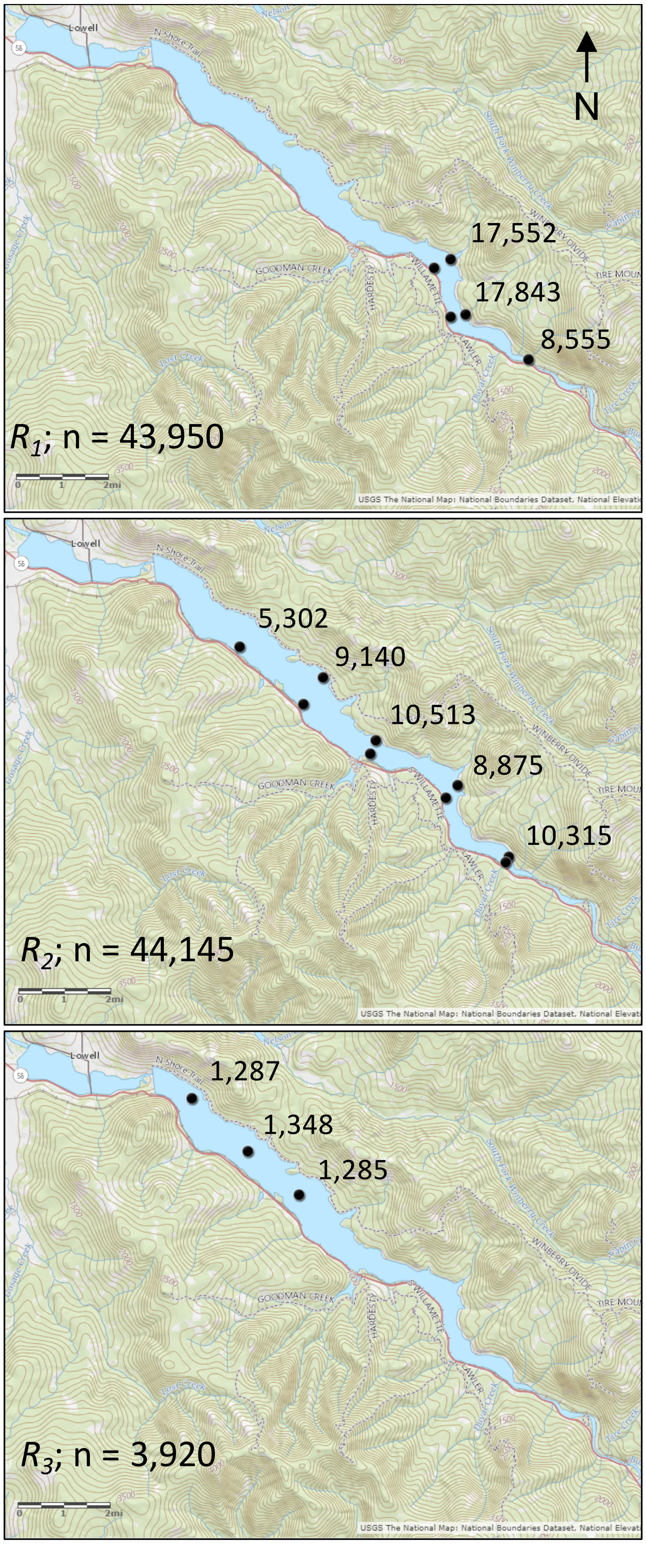

Figure 8. Images showing release locations and number of juvenile Chinook salmon released in Lookout Point Reservoir, western Oregon, April 18–19 (R_1 group), May 30–June 1 (R_2 group), and June 28 (R_3 group), 2017.

Sampling in Lookout Point Reservoir

A total of 3,923 juvenile Chinook salmon were collected in reservoir sampling during May–October 2017, most of which (3,572 fish; 91 percent) were subyearlings (table 8). Monthly catch of Chinook salmon juveniles ranged from 167 fish in May to 1,422 fish in September. Subyearling Chinook salmon collected in May had a median fork length of about 66 mm (fig. 9). Size data from monthly collection efforts show that fish grew steadily throughout the study and had a median fork length greater than 215 mm in October (fig. 9). Assorted other fish species were encountered as bycatch during collection events (table 8).

Sampling gear was deployed throughout the reservoir during May–August but declining reservoir elevations precluded sampling in the upper part of the reservoir during September and October. The spatial differences in gear distribution throughout the reservoir is shown by month in figure 10. Juvenile Chinook salmon were collected in relatively similar proportions throughout the reservoir in May, near Lookout Point Dam during June–August, and between the dam and rkm 8 in September and October (fig. 10). Sampling gear was deployed at progressively deeper locations in the water column during May–September as the reservoir stratified during summer (fig. 11). This pattern became less pronounced in October as the reservoir began to cool, but sampling gear and fish collection still occurred at depths greater than 8 m (fig. 11).

Table 8. Numbers of different species encountered monthly during reservoir sampling in Lookout Point Reservoir, western Oregon, May–October 2017.

Species	Collection period						
	May	June	July	August	September	October	Total
Chinook salmon	167	408	678	462	1,422	786	3,923
Rainbow trout	25	68	58	139	58	4	352
Cutthroat trout	2	0	0	0	0	0	2
Northern pikeminnow	19	7	2	2	22	7	59
Redside shiner	15	0	1	0	1	0	17
Dace spp.	1	1	0	0	0	0	2
Sucker spp.	889	50	21	8	26	5	999
Brown bullhead	68	5	2	2	57	9	143
Crappie spp.	57	113	15	64	1,863	2,363	4,475
Lepomis spp.	5	16	0	0	14	9	44
Bass spp.	151	9	3	2	177	70	412
Walleye	4	29	7	22	45	24	131
Sculpin spp.	20	332	5	4	8	1	370
Rough-skinned newt	2	0	0	0	0	0	2

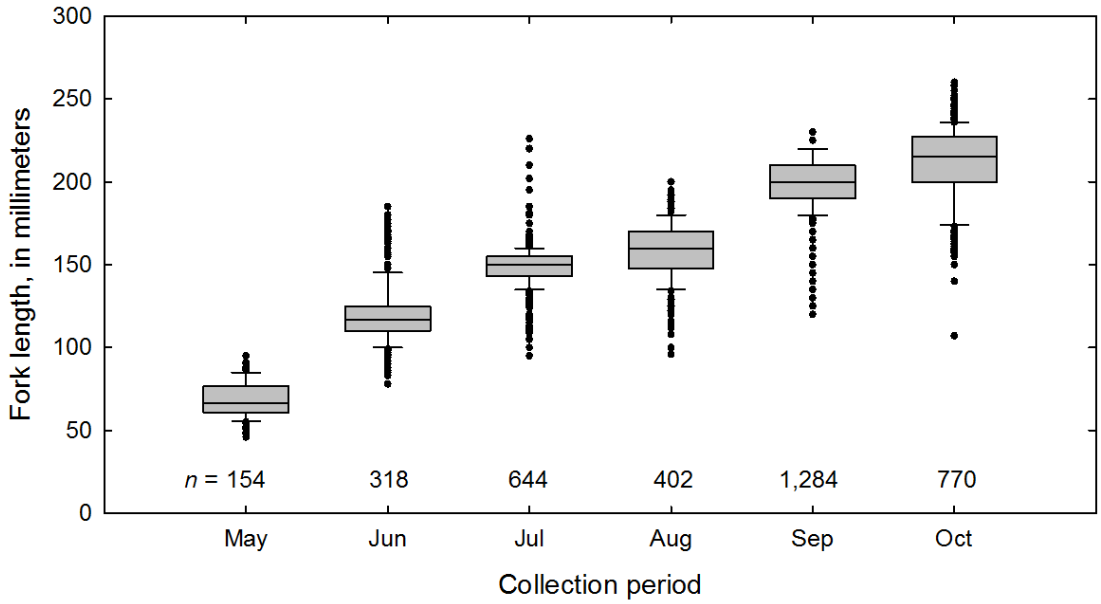

Figure 9. Boxplots showing monthly fork length distributions of subyearling Chinook salmon collected in Lookout Point Reservoir, western Oregon, May–October 2017. Line within the box is the median fork length, box boundaries represent the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots represent outliers. Number of Chinook salmon collected each month also are shown.

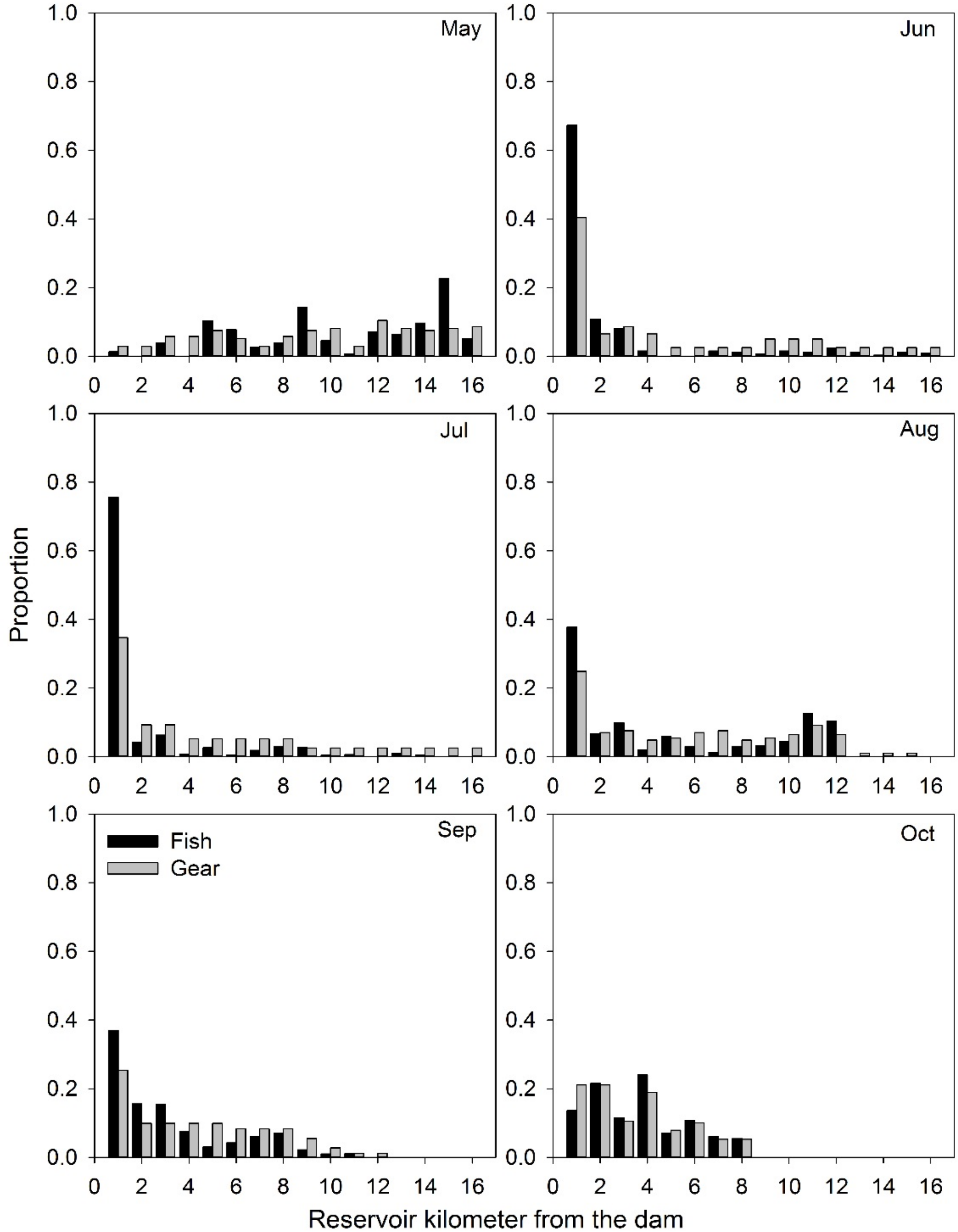

Figure 10. Graphs showing monthly proportion of juvenile Chinook salmon captured (Fish) and sampling gear (Gear) deployed along the length of Lookout Point Reservoir, western Oregon, May–October 2017. For reference, Lookout Point Dam is located at river kilometer 0 and the head of Lookout Point Reservoir is located at river kilometer 16.

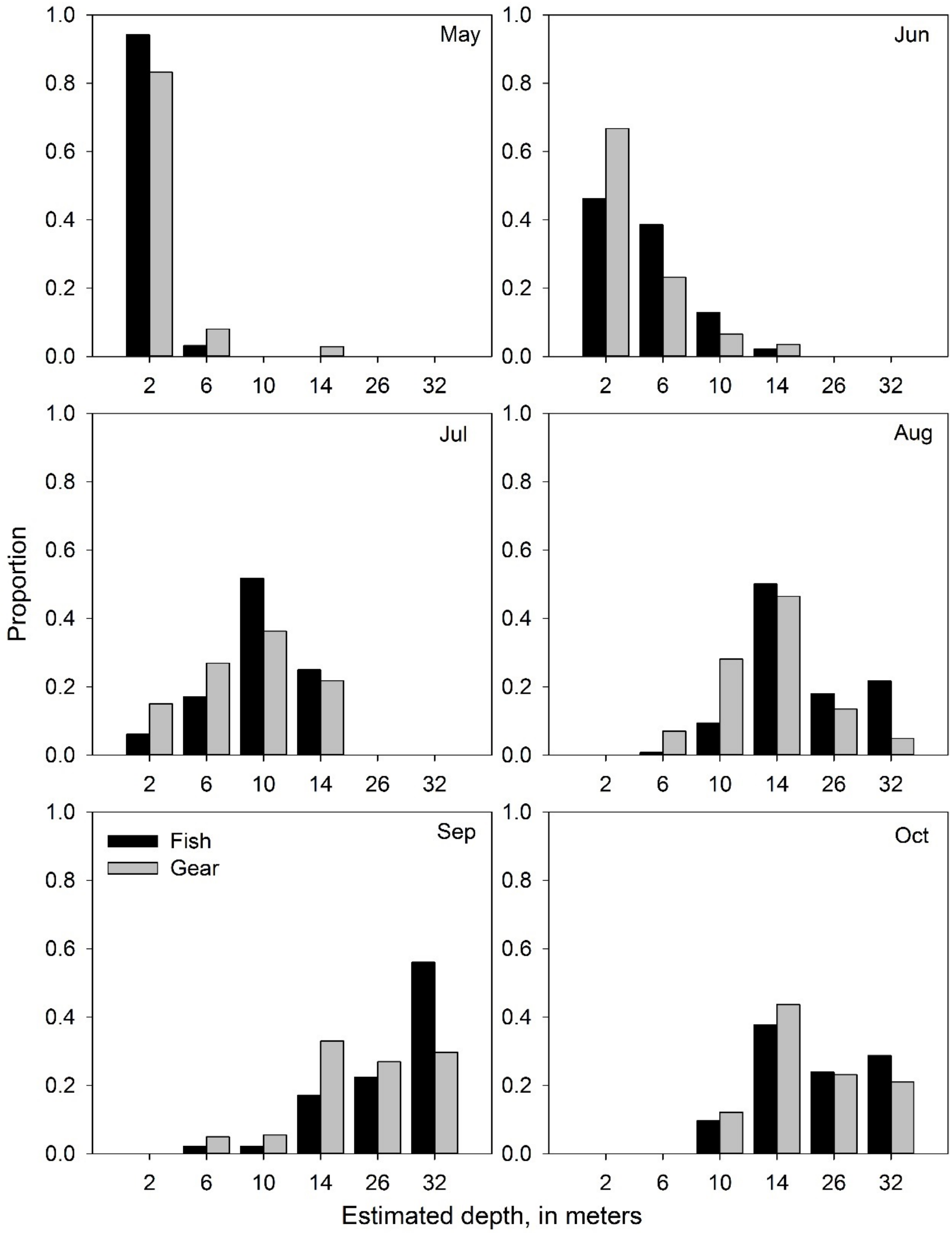

Figure 11. Graphs showing monthly proportion of juvenile Chinook salmon captured (Fish) and sampling gear (Gear) deployed by depth strata in Lookout Point Reservoir, western Oregon, May–October 2017.

Genetic Analysis

Sixty tissue samples were obtained from juvenile Chinook salmon collected in screw traps in the tailrace of Lookout Point Dam. Of these, 30 samples (50 percent) failed to assign to parents used to produce study fish. These fish presumably were of natural origin. The remaining samples assigned to R_1 (6 fish; 10 percent) and R_2 (24 fish; 40 percent) groups.

The largest percentage of samples (61 percent) from fish collected in Lookout Point Reservoir failed to assign to parents from the study (table 9). The percentage of samples that assigned to the R_1 group ranged from 7 to 22 percent in monthly collections. The largest percentage of samples for study fish were assigned to the R_2 group and ranged from 8 to 68 percent by month. Very few samples assigned to the R_3 group (table 9). Fork length distributions for each group at the time of collection are shown in figure 12.

Table 9. Results from genetic analysis that assigned individual juvenile Chinook salmon to specific release groups during the study at Lookout Point Reservoir, western Oregon, 2017.

[Unassigned refers to samples that did not assign to hatchery parents used to produce fish for the study. Numbers outside parentheses are number of samples, and numbers in parentheses are percentages of samples. The symbol – identifies cells where no data were available]

Collection period	Unassigned	Release group		
		R_1	R_2	R_3
May	119 (78)	33 (22)	–	–
June	150 (49)	27 (9)	130 (42)	–
July	151 (25)	40 (7)	405 (68)	3 (1)
August	245 (64)	51 (13)	77 (20)	9 (2)
September	913 (69)	200 (15)	186 (14)	15 (1)
October	593 (77)	109 (14)	59 (8t)	9 (1)
Total	2,201 (61)	466 (13)	881 (25)	36 (1)

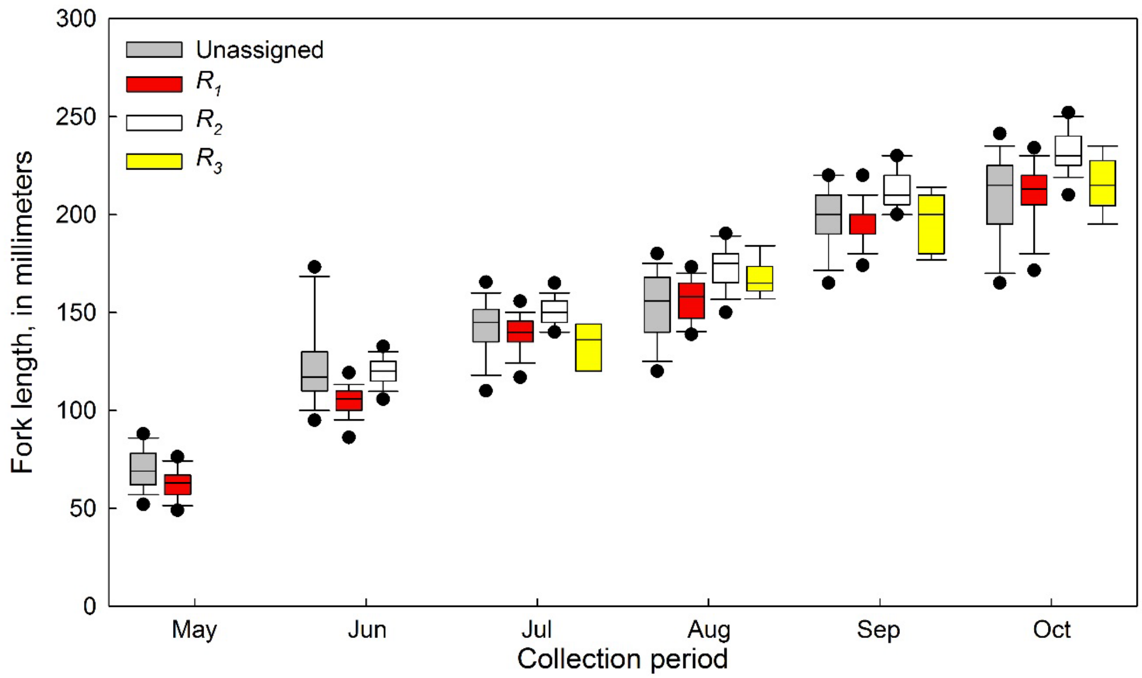

Figure 12. Boxplots showing fork length distributions for groups of juvenile Chinook salmon for each collection period in Lookout Point Reservoir, western Oregon, 2017. Line within the box is the median fork length, box boundaries represent the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

Estimating Reservoir Survival of Subyearling Chinook Salmon

Staggered Release-Recovery Model

Recapture rates of released Chinook salmon were low throughout the study. Multiple release group combinations were examined, and recapture probabilities ranged from 0.00074 to 0.00244 (table 10). Comparison of recapture probabilities when estimating the SRRM to different release group combinations supported the conclusion that recapture probabilities were not equal among release groups. For example, recapture probabilities associated with R_1 were lower than those for R_2 or R_3. These findings suggest a violation of assumption 2 discussed in section, “Survival Models—Staggered Release-Recovery Model,” whereby all release groups must share a common recapture and survival probability after the last release.

Estimates of mean survival probabilities for S_{SRRM1} ranged from 0.46954 to 0.52003 (table 11; fig. 13). Standardized estimates during this period for S_{SRRM1} ranged from 0.60386 to 0.64643 (table 11). Standardized survival probability estimates for S_{SRRM2} were nearly identical (0.96291 and 0.96484) using two different release group combinations (table 11; fig. 13). The estimated cumulative survival probability for April–June (product of S_{SRRM1} and S_{SRRM2}) using all release groups was 0.52. Alternatively, the estimated cumulative survival probability during this same period using R_1 and R_3 was 0.86997 (table 11).

Comparison of survival probabilities when fitting the model to recovery counts from different release groups supported the conclusion that survival estimates may have been influenced by particular release groups. For example, all survival estimates associated with R_3 were high (table 11). Therefore, given the low recapture probabilities associated with R_1 and the high survival estimates associated with R_3, the survival estimates obtained under the SRRM likely are biased owing to violations of assumption 2.

Table 10. Summary statistics of posterior distributions for recapture probabilities (*P*) and joint probabilities of survival and recapture (*λ*) for different release group combinations of juvenile Chinook salmon in Lookout Point Reservoir, western Oregon, 2017.

Release combination	Parameter	Mean	Standard deviation	2.5 (percent)	50 (percent)	97.5 (percent)
R_1, R_2, R_3	*P*	0.00244	0.00021	0.00203	0.00243	0.00286
R_1, R_2	*P*	0.00136	0.00027	0.00086	0.00134	0.00190
R_2, R_3	*P*	0.00307	0.00028	0.00252	0.00306	0.00363
R_1, R_3	*P*	0.00074	0.00016	0.00045	0.00072	0.00107
R_1, R_2, R_3	λ	0.01696	0.00075	0.01554	0.01690	0.01846
R_1, R_2	λ	0.01943	0.00066	0.01811	0.01943	0.02069
R_2, *R3*	λ	0.01643	0.00077	0.01504	0.01637	0.01800
R_1, R_3	λ	0.01047	0.00115	0.00857	0.01027	0.01278

Table 11. Summary statistics of posterior distributions of survival probabilities (S) for each survival interval (S_{SRRM1}–S_{SRRM12}) for different release group combinations of juvenile Chinook salmon in Lookout Point Reservoir, western Oregon, 2017.

[Survival estimates standardized to a 30-day interval also are shown]

Release combination	Parameter	Mean	Standard deviation	2.5 (percent)	50 (percent)	97.5 (percent)
Summary statistics						
R_1, R_2, R_3	S_{SRRM1}	0.52003	0.03046	0.46267	0.51904	0.58155
	S_{SRRM2}	0.96939	0.02788	0.91294	0.97734	1.00000
R_1, R_2	S_{SRRM1}	0.46954	0.02846	0.41575	0.46881	0.52717
R_2, R_3	S_{SRRM2}	0.96771	0.02962	0.90717	0.97621	1.00000
R_1, R_3	S_{SRRM12}	0.86997	0.08726	0.70980	0.88224	0.99999
Survival estimates standardized to a 30-day interval						
R_1, R_2, R_3	S_{SRRM1}	0.64643	0.02523	0.59820	0.64586	0.69672
	S_{SRRM2}	0.96484	0.03191	0.90024	0.97390	1.00000
R_1, R_2	S_{SRRM1}	0.60386	0.02440	0.55705	0.60348	0.65258
R_2, R_3	S_{SRRM2}	0.96291	0.03387	0.89367	0.97260	1.00000
R_1, R_3	S_{SRRM12}	0.94163	0.04090	0.86517	0.94844	1.00000

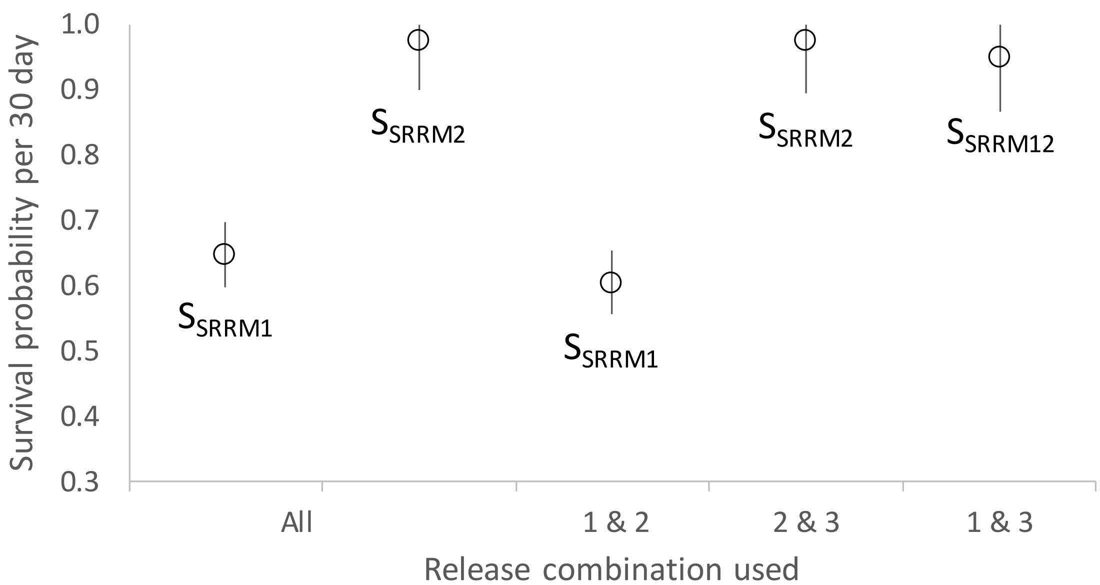

Figure 13. Graph showing survival probabilities for different release group combinations of juvenile Chinook salmon in Lookout Point Reservoir, western Oregon, 2017. Error bars are credible intervals based and percentiles 2.5 and 97.5 of the posterior distributions of the parameters.

PBT *N*-mixture Model

The *N*-mixture model yielded fundamental parameter estimates relating to capture probability and survival of Chinook salmon fry in Lookout Point Reservoir from May to October 2017. Slope, intercept, and offset parameters are shown in table 12.

Capture probability estimates derived from these fundamental parameters and the logit link function used in the analysis varied by season and gear. The lowest capture probability (0.000051; 95-percent credible interval, 0.000027–0.000077) was for box traps used in May and June, and the highest capture probability (0.00187; 95-percent credible interval, 0.00125–0.00252) was for gill nets used during July–October 2017 (fig. 14). Capture probability estimates are all very low yet estimates indicate reasonable credible intervals and do not seem to be influenced by the prior distribution. The model structure implemented for analysis likely played a significant role in the ability to estimate capture probability parameter.

Survival estimates derived from the model increased over time (fig. 15). The fundamental parameter $b_{S,1}$ measures the increase (or decrease) of survival by increasing values of its covariate—in this case, the number of months since the first release. Because the entire credible interval for the estimate of this parameter ($b_{S,1}$; median, 0.72585; 95-percent credible interval 0.50212–1.10499; table 12) is greater than 0, the data support a correlation between higher survival and later periods in the calendar year for the months we sampled. Monthly survival probability estimates were 0.46073 for S_{NMIX1}, 0.64322 for S_{NMIX2}, 0.78676 for S_{NMIX3}, 0.88326 for S_{NMIX4}, 0.93988 for S_{NMIX5}, and 0.97001 for S_{NMIX6} (fig. 15; table 13). The estimated cumulative survival probability for April–June (product of S_{NMIX1}-S_{NMIX3}) was 0.23316, and the estimated cumulative survival probability for April–October (product of S_{NMIX1}-S_{NMIX6}) was 0.18775.

Table 12. Fundamental parameter estimates for the relation between gear type, season, and capture probability, and the relation between days since first release and survival probability of Chinook salmon fry in Lookout Point Reservoir, western Oregon, 2017.

[Lower and upper confidence intervals denote lower and upper bounds of the 95-percent credible intervals, respectively]

Parameter	Median	Lower confidence interval	Upper confidence interval
$b_{p1,0}$	-7.58592	-7.77012	-7.39270
$b_{p1,1}$	1.30561	0.97105	1.60271
$b_{p2,0}$	-9.87919	-10.36733	-9.39991
$b_{p3,0}$	-8.04354	-8.39256	-7.70469
$b_{S,0}$	-0.15739	-0.37478	0.07789
$b_{S,1}$	0.72585	0.50212	1.10499

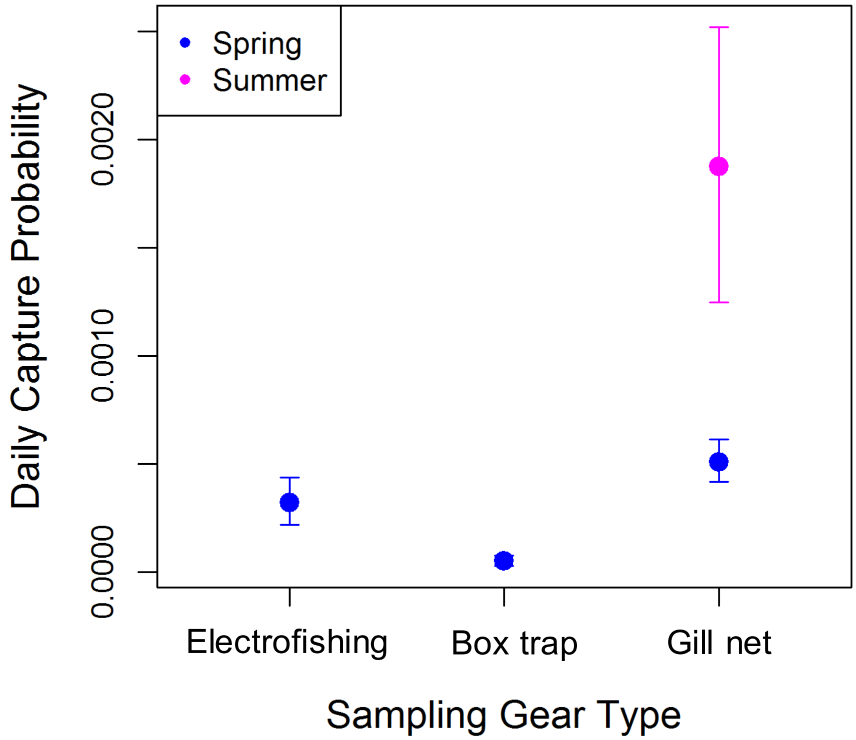

Figure 14. Graph showing daily capture probability for three sampling gear types used to collect Chinook salmon fry in Lookout Point Reservoir, western Oregon, 2017. Spring indicates May–June, summer indicates July–October. Only gill net sampling was used in summer. Whiskers denote lower and upper bounds of the 95-percent credible intervals.

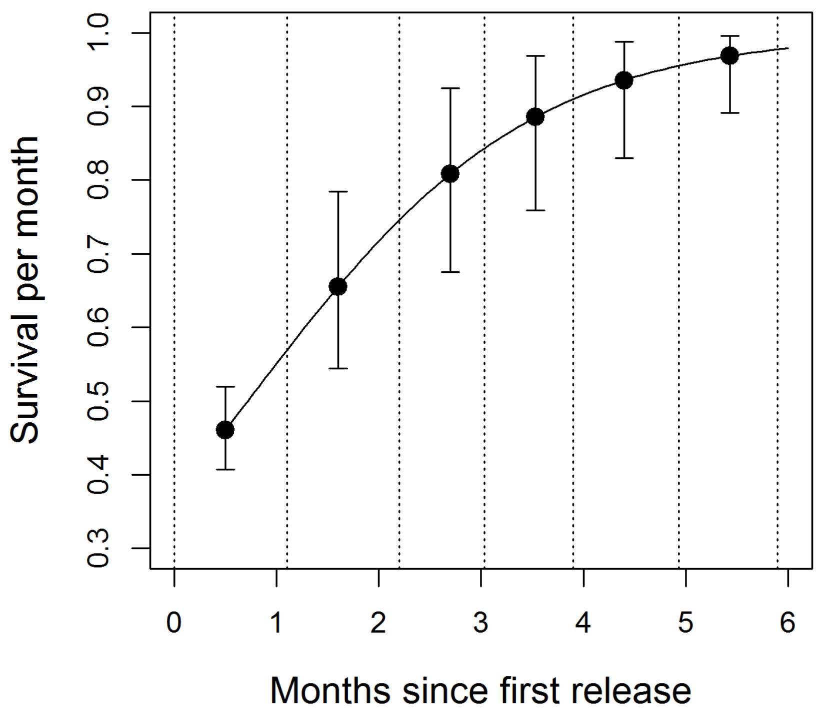

Figure 15. Graph showing 30-day survival probabilities during 6 months of sampling Chinook salmon fry in Lookout Point Reservoir, western Oregon, 2017. Dotted vertical lines represent primary sampling occasions. Whiskers denote lower and upper bounds of the 95-percent credible intervals.

Table 13. Derived parameter estimates for capture probability and 30-day survival probability of Chinook salmon fry in Lookout Point Reservoir, western Oregon, 2017.

[Lower and upper confidence intervals denote lower and upper bounds of the 95-percent credible intervals, respectively]

Parameter	Median	Lower confidence interval	Upper confidence interval
p_{11}	0.00051	0.00042	0.00061
p_{21}	0.00187	0.00125	0.00252
p_{12}	0.00005	0.00003	0.00008
p_{13}	0.00032	0.00022	0.00044
S_{NMIX1}	0.46073	0.40739	0.51946
S_{NMIX2}	0.64322	0.58351	0.71860
S_{NMIX3}	0.78676	0.71380	0.88455
S_{NMIX4}	0.88326	0.82034	0.96500
S_{NMIX5}	0.93988	0.89048	0.99108
S_{NMIX6}	0.97001	0.93532	0.99802

Discussion

Mortality rates of fry-sized Chinook salmon were high in Lookout Point Reservoir during April–October 2017. Previous studies have shown that Chinook salmon fry predominantly enter the reservoir during March–April (Romer and others, 2016) where they reside for several months before passing Lookout Point Dam during November–January (Keefer and others, 2013). Chinook salmon fry are small (about 40 mm fork length) when they enter the reservoir where growth rates are high; many fish are 200 mm fork length or greater in the fall when dam passage occurs (Monzyk and others, 2014). Our study was designed to estimate survival of subyearling Chinook salmon in the reservoir during April–October when juvenile Chinook salmon are present and vulnerable to predation by piscivorous fish species (Monzyk and others, 2014; Kock and others, 2016). We estimated that 19 percent of the subyearling Chinook salmon survived from mid-April, when fry-sized fish were released, to mid-October when we stopped sampling. Estimates from the PBT *N*-mixture model indicate that survival was lowest from mid-April to mid-May and increased throughout the study. Most of the mortality (77 percent) occurred during the first four months (April–July) of the study. This mortality likely occurred because subyearling Chinook salmon were small during this period and vulnerable to predation. These results corroborate findings from other studies where researchers have shown that survival decreases with decreasing fish size for various Pacific salmon species (Healey, 1982; West and Larkin, 1987; Duffy and Beauchamp, 2011; Henderson and Cass, 2011).

Reservoir survival rates were low for juvenile Chinook salmon in Lookout Point Reservoir, but similar results have been observed in other locations. Numerous studies have evaluated juvenile Chinook salmon survival in the Snake River Basin, Idaho. In that system, Chinook salmon parr were PIT-tagged in tributaries during summer as subyearlings and then monitored at mainstem dams on the Snake River when they outmigrated as yearlings the following spring. Tagging and detection records were analyzed by various researchers to determine if factors such as habitat, predator species, and stream location affected survival. These studies reported parr-to-smolt survival estimates ranging from 8 to 33 percent (Paulsen and Fisher, 2001; Levin and others, 2002; Achord and others, 2007). In Oregon, Coche (1964) evaluated the production potential for juvenile steelhead in Whistler's Bend Impoundment, a small reservoir, and reported that juvenile steelhead survival was 49 percent from late March to mid-October as fish grew from about 33 to 87 mm. Prior to the initiation of that study, all fish were removed from the reservoir so that mortality was not associated with predation by other fish species. At several other locations, researchers reported that juvenile Chinook salmon survival was low in reservoirs including Howard Hanson Reservoir (Green River, Washington; 1–15-percent survival; Dilley and Wunderlich, 1993), Blue River Reservoir (Blue River, Oregon; 14-percent survival; Downey and Smith, 1990), Happy Valley Reservoir (Quartz Creek, Oregon; 9–16-percent survival; Higley and Bond, 1973), Fall Creek Reservoir (Winberry and Murphy Creeks, Oregon; 20-percent survival; Homolka and Smith, 1991), and Green Peter Reservoir (Middle Santiam River, Oregon; 17-percent survival; Wagner and Ingram, 1973). Most estimates from these studies were obtained by comparing the number of collected outmigrants at the dam to the number of parr-sized fish originally released in the reservoir and did not account for factors such as capture probability of the trap and for fish that survived in the reservoir but failed to pass the dam. Thus, the estimates should be interpreted cautiously. However, these findings indicate that parr-to-smolt survival can be low in reservoirs, which we determined to be true in Lookout Point Reservoir during 2017.

It is difficult to determine if reservoir mortality in Lookout Point Reservoir is a limiting factor for Chinook salmon in the Middle Fork Willamette River. This study is the first empirical evaluation of which we are aware that has been conducted to estimate survival of Chinook salmon fry; little is known about mortality during this life stage. Additionally, our results are from a single year, so we cannot assess inter-annual variability of survival in Lookout Point Reservoir. Survival estimates for juvenile Chinook salmon in Howard Hanson Reservoir more than doubled from 1991 to 1992 (Dilley and Wunderlich, 1993), and similar variability is possible in Lookout Point Reservoir as factors such as dam operations, reservoir elevations, and water temperature vary annually, potentially affecting fish distribution patterns and predator activity. At the time of this writing (2018), fieldwork was nearly complete for a second year of evaluation in Lookout Point Reservoir, so future analyses should provide insights about survival variability in the system.

We know little about reservoir survival rates in healthy Chinook salmon populations. This limits our ability to make inferences about how this factor may be affecting the Middle Fork Willamette River Chinook salmon population. It may be necessary to evaluate reservoir survival of subyearling Chinook salmon at other locations in the future to provide context for results from this study. Other factors should be considered as well. Our study was designed to assess survival of subyearling Chinook salmon in the reservoir. Fish that survived to the end of our study still faced passage at Lookout Point Dam, where passage survival is low (Keefer and others, 2013). Additionally, concerns are emerging about potential survival consequences related to copepod *Salmincola californiensis* infections that occur in the reservoir (Monzyk, Emig, Romer, and Friesen, 2015). Although predation and disease may negatively affect Chinook salmon populations in the system, growth opportunity in the reservoir may offset these mortality sources to some extent. Growth rates in Lookout Point Reservoir are very high (Monzyk, Friesen, and Romer, 2015), so outmigrants that survive and pass the dam are large and potentially have high smolt-to-adult survival rates. Early evidence from releases of PIT-tagged Chinook salmon juveniles upstream and downstream of dams in the Willamette River suggest that upstream fish groups have higher return rates as adults than the downstream groups (Johnson and others, 2016). This phenomenon also was observed in the Snake River, Idaho, with fall-run Chinook salmon (Connor and others, 2005). Alternatively, downstream passage at Lookout Point Dam seems to be restricted to specific time periods, which may limit life history diversity, a factor shown to be important for stabilizing smolt production in Willamette Basin Chinook salmon populations (Schroeder and others, 2015). Given these factors, much remains to be learned about reservoir survival implications for Chinook salmon in the Middle Fork Willamette River.

The PBT *N*-mixture study design has two potential advantages over the staggered release-recovery study design. First, the PBT *N*-mixture study design only requires the release of one group of hatchery-reared Chinook salmon juveniles. This is advantageous because it allows us to release a single group of fish (R_1) in the spring and monitor their survival through time. It also alleviates concerns associated with releasing the second and third groups of fish (R_2 and R_3) when conditions are challenging. Fish released in June and July spend considerably more time in the hatchery environment than those released in April (R_1). They also are larger (than R_1 fish) at the time of release, and concessions may need to occur to release them safely in the reservoir if surface temperatures are high. The second advantage is that the PBT *N*-mixture design can provide survival estimates between sampling occasions, rather than between periods when groups of fish are released, which will provide greater temporal resolution for identifying key periods of mortality. These advantages seem to have been realized for this study, based on results from 2017. We noted that S_{SRRM2} estimates varied substantially when different combinations of release groups were used in the calculation. Survival estimates from the SRRM analysis were consistently higher than those from the *N*-mixture analysis, particularly for the survival estimate between R_2 and R_3. One potential explanation for this discrepancy could relate to the assumption under the SRRM that survival among different release groups is equal after both groups have been released. The R_3 group from the 2017 study was released during very warm conditions, requiring a release apparatus to release fish 12 m below the reservoir surface. Additionally, field crews noted some behavioral concerns among fish in R_3 that could have indicated poor health among these fish pre-release. The consequences of violating the equal survival assumption would be biased survival estimates; if survival among fish in the third release group was worse than that of other fish after their release, SRRM survival estimates would have been biased high. These lines of evidence suggest that it may be problematic to rely on the assumptions necessary for the SRRM approach to work. The *N*-mixture approach does not rely on this assumption to produce unbiased estimates of survival and thus may be a better option in the future. Additional insights into these approaches may be forthcoming, pending results from the 2018 study. In 2018, we implemented an approach like that of 2017 that included three release groups and six monthly sampling events. Environmental conditions were markedly different between these 2 years in Lookout Point Reservoir. In 2017, the reservoir filled completely, which may have affected our ability to sample fish during April and May. Reservoir water levels during these periods were high and extended into the shoreline vegetation. Technicians observed that juvenile Chinook salmon were present in these inundated shorelines where they were not susceptible to collection with electrofishing or shoreline traps. Thus, sampling in April and May could have been negatively biased. In 2018, the reservoir failed to refill and sampling in spring was conducted along unvegetated shorelines. Analysis and comparison of results between data from the 2 years should shed light on how these factors affected the two study designs. These factors may provide further insight into the performance of the study designs and may lead to additional recommendations if a fry survival study is warranted in the future.

Summary

We determined that the SRRM and PBT *N*-mixture study designs were able to provide estimates of reservoir survival of fry-sized Chinook salmon in a field setting. These survival estimates provide new information to resource managers in the Willamette River Basin. However, additional information may be required in the future to provide context for our results, and to inform management actions aimed at recovering Chinook salmon populations in the Middle Fork Willamette River.

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