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Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) Survival in Lookout Point Reservoir, Oregon, 2018

Open-File Report 2019-1097

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

Cover:
Background image: Lookout Point Reservoir, western Oregon. (Photograph by Toby Kock, U.S. Geological Survey, April 12, 2018.)
Inset image: Subyearling Chinook salmon (*Oncorhynchus tshawytscha*). (Photograph by Amy Hansen, U.S. Geological Survey, June 21, 2017.)

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2019

Suggested citation:
Kock, T.J., Perry, R.W., Hansen, G.S., Haner, P.V., Pope, A.C., Plumb, J.M., Cogliati, K.M., and Hansen, A.C., 2019, Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) survival in Lookout Point Reservoir, Oregon, 2018: U.S. Geological Survey Open-File Report 2019–1097, 41 p., https://doi.org/10.3133/ofr20191097.

ISSN 2331-1258 (online)

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Conversion Factors

U.S. customary units to International System of Units

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

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)

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

$$(°F) \text{ as } °F = (1.8 \times °C) + 32.$$

Datum

Vertical coordinate information is referenced to National Geodetic Vertical Datum of 1929.
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
NOR	natural origin
PBT	parentage-based tagging
SRRM	staggered release-recovery model
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WFSP	Wild Fish Surrogate Program
RKM	reservoir kilometer

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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 juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in Lookout Point Reservoir, Oregon, during 2018. The study consisted of releasing three groups of genetically-marked fish into the reservoir, and sampling them monthly. Juveniles were released during April 10–13 (116,708 fish), May 15–18 (31,911 fish), and June 19–20 (11,758 fish). Reservoir sampling began in May and occurred monthly through October, consisting of 5-day events where juvenile Chinook salmon were collected using electrofishing, shoreline traps, and gill nets. Data were analyzed using a staggered release-recovery model and a parentage-based tagging (PBT) *N*-mixture model. The staggered release-recovery model provided survival estimates from three periods: mid-April to mid-May (SSRRM1); mid-May to mid-June (SSRRM2); and mid-April to mid-June (SSRRM12). 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 probability estimates for SSRRM1 ranged from 0.98520 to 0.98954; estimates for SSRRM2 ranged from 0.09338 to 0.62142; and the estimate for cumulative survival from mid-April to mid-June (SSRRM12) were 0.75211. We suspect that issues with release groups in May (R_2) and June (R_3) led to biased survival results using the staggered release-recovery model. The PBT *N*-mixture model provided survival estimates from six periods: mid-April to mid-May (SNMIX1); mid-May to mid-June (SNMIX2), mid-June to mid-July (SNMIX3), mid-July to mid-August (SNMIX4), mid-August to mid-September (SNMIX5); and mid-September to mid-October (SNMIX6). Survival estimates from the PBT *N*-mixture model were lowest for SNMIX6 (0.41620) and highest for SNMIX1 (0.79587). These results differed from those in 2017 when monthly survival increased across months. This suggests that one or more factors could have affected juvenile Chinook salmon survival in Lookout Point Reservoir. One possible factor could be copepods (which were highly prevalent on juvenile Chinook salmon during summer 2018), but environmental factors such as reserveroir elevation, discharge at Lookout Point Dam, and fish distributions within the reservoir differed between study years. Two PBT *N*-mixture models provided cumulative survival estimates from mid-April to mid-October. Estimates from the two models were 0.061 and 0.039, which suggests that survival of subyearling Chinook salmon in Lookout Point Reservoir was

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very low in 2018. Additional research is recommended to better understand inter-annual variability of subyearling Chinook salmon in the reservoir and to gain insights into factors that affect their survival.

Introduction

Estimates of survival for specific life-stages of Pacific salmon (*Oncorhynchus spp.*) are important for resource managers in impounded river systems of the western United States. During the past 2 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 are generally 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 (*O. 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.

In western Oregon, the U.S. Army Corps of Engineers (USACE) operates the Willamette Project (Project), which includes 13 dams and reservoirs, about 68 kilometers of revetments, and several fish hatcheries. The primary purpose of the Project is flood-risk management, but it is also operated to provide hydroelectricity, irrigation water, navigation, instream flows for wildlife, and recreation. A determination that the Project jeopardized Upper Willamette spring Chinook salmon and winter steelhead (*O. mykiss*) in 2008 (National Oceanic and Atmospheric Administration, 2008) spurred a series of studies and actions to reduce the Project's affects 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 methods that provide spawning opportunities in free-flowing headwaters and tributaries upstream of Project reservoirs (Sard and others, 2015). Progeny of the transported adults move downstream and spend several months rearing in Project reservoirs because 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 and others, 2015a). Thus, fishery managers are faced with determining whether it is better to focus on developing fish-passage options at dams or attempting to capture fish near the head of the reservoirs. A key piece of information that will help with these decisions is understanding survival rates of juvenile salmon rearing in reservoirs. High survival rates would likely result in decisions to focus on dam-based passage or collection efforts while low survival rates may result in decisions to 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 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 found 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 1 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. 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).

Based on recommendations from the workshop, the USACE asked the U.S. Geological Survey (USGS) to develop a study design and implementation plan that could be used to implement 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), between Hills Creek Dam and Dexter Dam, and needs downstream fish passage improvements. The reservoir supports abundant populations of several cool- and warm-water 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). In that document we proposed to evaluate juvneile Chinook salmon 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 first year of that study was completed in 2017 (Kock and others, 2019). A total of 92,015 genetically-marked fish were released in the reservoir during April–June 2017, and 3,625 of these were recaptured in sampling events during May–October 2017. The SRRM provided survival estimates from two periods: mid-April to mid-May (SSRRM1); and mid-May to mid-June (SSRRM2). 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 SSRRM1 ranged from 0.470 to 0.520. Estimates for SSRRM2 ranged from 0.968 to 0.969, and cumulative survival from mid-April to mid-June (SSRRM12) was estimated at 0.870. The PBT *N*-mixture model provided survival estimates from six periods: mid-April to mid-May (SNMIX1); mid-May to mid-June (SNMIX2); mid-June to mid-July (SNMIX3); mid-July to mid-August (SNMIX4); mid-August to mid-September (SNMIX5); and mid-September to mid-October (SNMIX6). Survival estimates from the PBT *N*-mixture model were lowest for SNMIX1 (0.461) and increased monthly to a high of 0.970 for SNMIX6. Cumulative survival from mid-April to mid-July was calculated to be 0.233, and overall survival from mid-April to mid-October was 0.188. These results seemed to indicate that survival in the reservoir was lowest early in the season when fish were small and increased as fish grew larger throughout the study. We observed that, overall, estimates of survival from the PBT *N*-mixture model were comparable to those from earlier studies of juvenile salmon survival through similar life stages (Kock and others, 2019). A second year of fry survival research was conducted in Lookout Point Reservoir during 2018. This report summarizes that study and compares results from the 2-year evaluation.

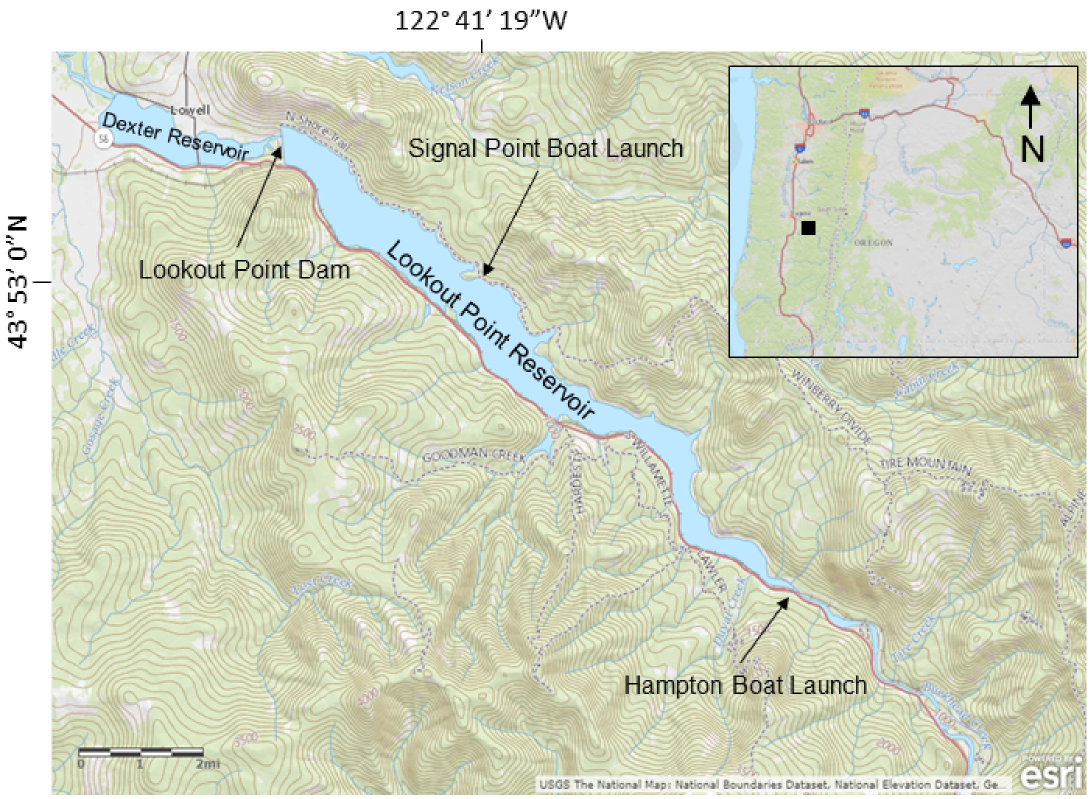

Figure 1. Map showing Lookout Point Reservoir, locations of two boat launches in the reservoir, Lookout Point Dam, and Dexter Reservoir, Middle Fork Willamette River, Oregon. [Inset shows location of Lookout Point Reservoir in Oregon.]

Methods

Environmental Conditions

Environmental and dam operation data were collected to describe how reservoir conditions changed throughout the study period and to compare conditions between 2017 and 2018. Daily water surface elevation records from the forebay of Lookout Point Dam were obtained from the USACE Northwestern Division (2019a). Water temperature data were collected by the USACE in the forebay of Lookout Point Dam and were obtained from the USACE (2019b). The USACE provided dam operations data for Lookout Point Dam in 2017 and 2018. We also collected a monthly Secchi-disk measurement during each sampling period in Lookout Point Reservoir each year to describe water clarity patterns. This measurement was taken about 350 m offshore in the reach between reservoir kilometers (RKM) 4 and 6, near the Signal Point Boat Launch (fig. 1).

Production of Study Fish

Fish production details were planned and organized during 2017 to ensure that Chinook salmon fry were available for release into Lookout Point Reservoir during the 2018 study. The study plan (Kock and others, 2016) called for the release of three groups of juvenile Chinook salmon, which would provide two survival estimates using one of the survival models we tested.

Release periods were identified for April (R_1), May (R_2), and June (R_3; 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 (NOR) Chinook salmon. Each release group was produced using a distinct group of adult Chinook salmon. This effectively created genetic marks of fish within each release group (Kock and others, 2016). The 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 Lab (FPGL) in Corvallis, Oregon, and was used to produce fish for the 2017 and 2018 studies (Kock and others, 2019).

We began working with WFSP staff on production planning during May–August 2017. 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 for 200,000 juvenile Chinook salmon with group sizes of 135,000 fish for R_1, 50,000 fish for R_2, and 15,000 fish for R_3. WFSP staff considered our sample size target, along with our request to have a 1:1 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 75 females and 75 males would cover these needs. Because of the differences in growth trajectories of the juveniles, spawning occurred over 4 days. The WFSP staff collected milt and eggs from hatchery adult spring Chinook Salmon at Willamette Hatchery, Oakridge, Oregon. Fish for the R_3 group were spawned on September 12, 2017, from eggs of 4 females and milt from 4 males. The R_2 group was comprised of eggs from 28 females and milt of 28 males that were spawned on September 12, 19, and 26, 2017. Spawning of the R_1 group was conducted on September 12, 14, 19 and 26, 2017, and consisted of eggs from 39 females and milt from 39 males. All samples were placed in individual containers, provided oxygen, then placed into a cooler for transport.

At FPGL, the milt from one male was added to the eggs of one female for fertilization, and this process was repeated for all available fish. The eggs of individual females were placed in labeled Heath trays (vertical incubation system) and water-hardened for approximately 45–50 minutes (min). A small subsample of eggs 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 in October 2017 for fish destined for the R_2 and R_3 groups and in December 2017 for fish destined for the R_1 group. Two families from the first spawn were removed from the study due 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 (n=25) 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 20 and 27, 2017, with 6–8 families represented in each of four replicates for R_2, and four families represented for R_3. R_1 fish were ponded in March 2018 with 9–10 families represented in each of 4 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. All fish were reared at the FPGL until they were transported to Lookout Point Reservoir for release.

Several factors resulted in lower-than-desired sample sizes for the release groups during 2017. WFSP staff found that average fecundity of adult female spring Chinook salmon was lower than expected and that some spawning groups (one male, one female) produced very few or no viable offspring. There was also an unexpectedly high number of juveniles with physical deformities, which tended to occur more frequently in some families. Final sample sizes for R_1, R_2, and R_3 were 116,708, 31,911, and 11,758 fish, respectively (table 1).

Table 1. Number of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) 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, Oregon, 2018.

[Numbers in parenthesis are the range of fork length and fish weight measurements. **Abbreviations**: g, gram; mm, millimeter;]

Release group	Replicate	Release date	Number released	Mean fork length (mm)	Mean weight (g)
R_1	1	April 10, 2018	29,198	45 (33–57)	0.9 (0.2–1.8)
	2	April 11, 2018	28,767	45 (32–56)	0.8 (0.3–1.6)
	3	April 12, 2018	28,988	43 (36–51)	0.7 (0.3–1.4)
	4	April 13, 2018	29,755	43 (35–54)	0.7 (0.4–1.5)
	Overall		116,708	44 (32–57)	0.8 (0.2–1.8)
R_2	1	May 15, 2018	7,465	91 (61–105)	7.8 (2.5–12.2)
	2	May 16, 2018	7,797	95 (53–110)	8.8 (1.4–14.2)
	3	May 17, 2018	8,266	90 (69–112)	7.2 (2.6–15.4)
	4	May 18, 2018	8,383	82 (47–114)	6.0 (0.8–14.0)
	Overall		31,911	89 (47–114)	7.3 (0.8–15.4)
R_3	1	June 19, 2018	5,842	91 (51–111)	8.2 (1.7–14.1)
	2	June 20, 2018	5,916	93 (55–125)	8.9 (1.4–19.3)
	Overall		11,758	92 (51–125)	8.5 (1.4–19.3)

Assessing Passage 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 the period when fish releases and collection was occurring (Kock and others, 2016). In 2017, spill operations did occur during our study period, so the study design was modified to include the operation of screw traps in the tailrace of Lookout Point Dam (Kock and others, 2019). Spill operations did not occur at Lookout Point Dam during our study in 2018. However, the USACE continued to operate the screw traps to determine if juvenile Chinook salmon were passing the dam via alternate routes.

Three screw traps operated in the tailrace of Lookout Point Dam during April–October 2018 to collect fish that passed the dam. The traps, located 0.35 km downstream of the dam (fig. 2), began operating continuously on April 18, 2018, and stopped operating on October 30, 2018. 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 (mm); and (3) percentage of descaling. Genetic samples were obtained by removing a small portion of the caudal fin from all collected Chinook salmon juveniles to determine if they were from our study. All Chinook salmon were also marked with a PIT tag, enumerated, and transported downstream of Dexter Dam where they were released into the Willamette River.

Figure 2. Photograph showing three screw traps operated in the tailrace of Lookout Point Dam to collect fish after passage at the dam during April–October 2018. [Photograph by Todd Pierce, U.S. Army Corps of Engineers, May 2, 2017.]

Fish Releases in Lookout Point Reservoir

Fish were transported by truck to the reservoir in 1,500-liter insulated tanks that held twelve 76-liter 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 grams per liter range and were generally 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 into non-perforated containers filled with fresh water from the reservoir. Boats were used to transport the containers to predetermined locations where fish were gently released into the reservoir. Water temperature and dissolved oxygen levels were monitored throughout the transport and release process. Oxygen was supplied to transport tanks as necessary to maintain dissolved oxygen levels in the 80–120 percent range. Water temperature was manipulated using the addition of ice to ensure that fish experienced less than 0.5 °C change within a 15-min period.

The R_3 release group required additional handling because the reservoir had thermally stratified by mid-June 2018. Water temperature at Willamette Hatchery was about 14 °C when R_3 fish were picked up for release. In Lookout Point Reservoir, the 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 of the reservoir. The release apparatus consisted of four components: a conical release hopper, release pipe, intake hose, and 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 12-m-long release pipe (10.2 centimeters [cm] diameter). At the time of release, containers of study fish were gently poured into the conical release hopper and passed through the release pipe, where they entered the reservoir 12 m below the surface into water that was 14 °C.

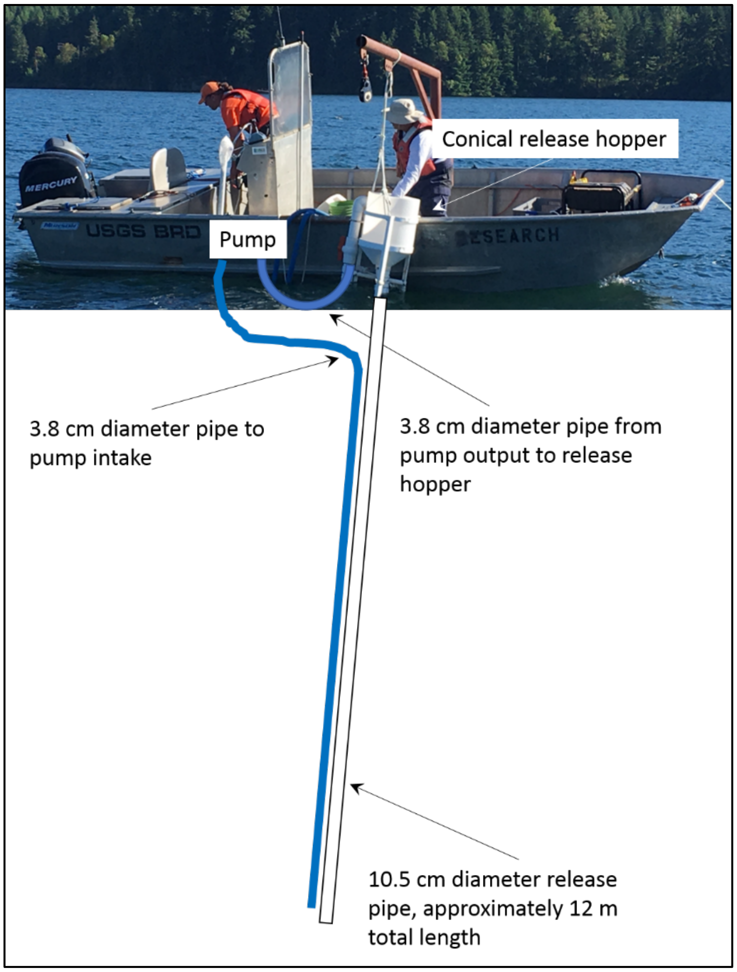

Figure 3. Diagram of release apparatus used for June releases (*R*3) (June 19–20, 2018) in Lookout Point Reservoir, Oregon, 2017.

Sampling in Lookout Point Reservoir

Monthly reservoir sampling events were conducted during consecutive 5-day periods from May to October 2018. The goal of each sampling event was to maximize collection of juvenile Chinook salmon from fry releases. We anticipated that Chinook salmon distribution in the reservoir would change throughout the study period as reported by Monzyk and others (2015a), who found that most fish were in nearshore habitat during May, in a mix of nearshore and offshore habitats 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 2). Boat electrofishing surveys were conducted in shallow, nearshore areas. For each electrofishing sampling event the boat was slowly maneuvered along the shoreline for about 10-min. Fish that were encountered and identified as a juvenile salmonid were hand-netted and placed into a live-well until the end of each 10 min period. Once the sampling event 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 traps (fig. 4). Box minnow traps were a 0.9 × 0.9 × 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 traps were a box minnow trap that was configured to include an Oneida module that attached to the front of the trap entrance (fig. 4). The Oneida module was 1.8 m tall × 3.7 m wide and designed to enhance guidance and retention of fish into the box minnow trap. Oneida traps were also 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 were also constructed of 0.3 cm black delta mesh. Gill nets were 24.4 m long and 4.6 m tall. Each gill net was comprised of three sections with different mesh sizes. Each section was 8.1 m long and mesh sizes were 12.7, 19.0, or 25.4 mm squares of monofilament material. Reservoir sampling in June was conducted using shoreline traps and gill nets. During July–October all reservoir sampling was conducted using gill nets (table 2).

We estimated that sampling effort would require about 40 gear sets per day during a four-day sampling effort to meet collection goals (Kock and others, 2016). For shoreline traps and gill nets, a single set was a 24-h period when a trap or net was in the water and available to collect fish. For boat electrofishing, a set was a 10-min period when the electrodes were on, the boat was moving, and fish collection could occur. Implementation of the 4-day sampling plan required a total of 5 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: (1) it reduced the workload associated with deploying all the sampling gear on a single day; and (2) it allowed us to assess catch 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 2. Summary of sampling events targeting juvenile Chinook salmon in Lookout Point Reservoir, Oregon, 2018.

Sampling period	Sampling technique	Number of sets	Collection dates
May	Boat electrofishing	45	May 05–May 10, 2018
	Box minnow trap	14	
	Oneida trap	37	
	Gill net	38	
June	Boat electrofishing	26	Jun 09–Jun 14[1], 2018
	Box minnow trap	5	
	Oneida trap	35	
	Gill net	167	
July	Gill net	232	Jul 13–Jul 17, 2018
August	Gill net	223	Aug 17–Aug 21, 2018
September	Gill net	237	Sep 21–Sep 25, 2018
October	Gill net	248	Oct 26–Oct 30, 2018

[1]Boat electrofishing ended on June 10, 2018

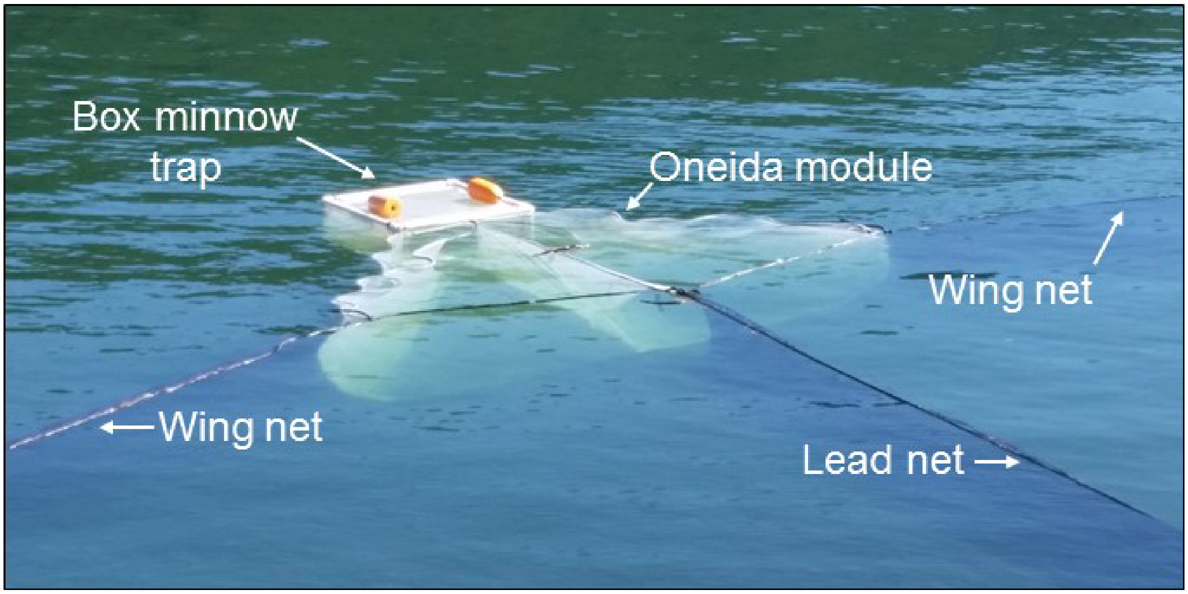

Figure 4. Photograph showing major components of an Oneida trap used to collect juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in Lookout Point Reservoir, Oregon, 2017.

Genetic Sampling

Genetic sampling and analysis was an integral part of our study design with genetic samples collected from several groups of fish (table 3). 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 comprised specific replicates within each of the release groups. Samples were also collected from juvenile Chinook salmon at SFGPL 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 assign the replicate and release group for individuals. Tissue samples (fin clips) 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 3. Number of tissue samples collected from Chinook salmon (*Oncorhynchus tshawytscha*) and submitted for genetic analysis and assignment, Lookout Point Reservoir, Oregon, 2018.

Sample description	Number of samples
Adult Chinook salmon spawners	150
Juvenile Chinook salmon prior to release	700
Juvenile Chinook salmon collected in Lookout Point Reservoir	3,249
Juvenile Chinook salmon collected in the tailrace of Lookout Point Dam	28
Total	4,127

Copepod Prevalence

Recent studies have shown that reservoir-rearing juvenile Chinook salmon can experience high infection rates from parasitic copepod *Salmincola californiensis* in Willamette

Valley reservoirs (Beeman and others, 2015; Monzyk and others, 2015b; Herron and others, 2018). Copepod infection is associated with damage to gills, skin, and muscle tissues which likely results in diminished fitness and decreased survival of juvenile Chinook salmon (Kabata and Cousens, 1977; Herron and others, 2018). We examined juvenile Chinook salmon collected in the reservoir to estimate the monthly proportion of fish that were infected. Individual fish were visually examined at the time of collection and the presence or absence of copepods was noted. Percentage of infected fish was calculated as the total number of infected fish collected each month divided by the total number of fish collected each month. Data are presented for specific groups of fish based on origin, release group, and age.

Survival Models

Staggered Release-Recovery Model

The staggered release-recovery model (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 included the release of two or more groups of juvenile Chinook salmon (R_1, $R_{2\ldots}$ R_n) with releases timed to occur at the beginning (R_1) and the end of the period of inference (R_n). Once fish were released, it was assumed that the groups distributed similarly, and reservoir sampling was conducted several times to capture fish from each release group (Skalski, 2016). Survival was estimated as the ratio of recoveries assuming a common recapture rate among groups. Survival was estimated over different periods by using 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.
5. Fish do not lose their tags.
6. 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 the model's parameters. The probability of observing 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,

πi are the cell probabilities of a multinomial likelihood function for the ith sampling occasion,

S_1 and S_2 are the survival probabilities for the 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 is also assumed common among release groups and capture occasions.

Similarly, multinomial cell probabilities 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 cell probabilities 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 probabilities can be estimated from different but sequential release groups, we fit 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: SSRRM1, SSRRM2, and SSRRM12. The parameter SSRRM1 represented survival from mid-April to mid-May and was calculated using two release group combinations: R_1, R_2, and R_3; and R_1 and R_2. The parameter SSRRM2 represented survival from mid-May to mid-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 SSRRM12 represented survival from mid-April to mid-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 above for R_2 and R_3. Estimating survival from different combinations of release groups provides survival estimates for different aggregations of time over the study period independent of the excluded release group. Likewise, multiple release combinations can aid in evaluating some of the model's assumptions (for example assumption 2 above) about how survival and recapture probabilities may be influenced by a release group. Factors such as different survivals among release groups and inadequate mixing of the release groups over time could violate model assumptions, thereby limiting the utility of the SRRM to estimate survival of small fishes. Thus, comparing alternative survival estimates among release groups is a critical step in assessing the application of the SRRM in a field setting.

Parentage-Based Tagging *N*-mixture Model

To avoid the strict assumptions required by the SRRM (namely, equal survival between release groups after the second release), we developed and tested an alternative model to the SRRM to estimate survival of Chinook salmon fry in Lookout Point Reservoir. The alternative model was motivated by the idea that replication of counts under a repeated-removal sampling design could help estimate capture probability, 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 (Kéry and Royle, 2016).

The *N*-mixture model is typically used to estimate site-level abundance by assuming that the distribution of abundance among sites follows a Poisson distribution. One natural framework for estimating abundance at each trap site (for example, each trap or gill net site) in Lookout Point Reservoir would be to fit an *N*-mixture model to 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.

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. Because we had independent estimates of the number of individuals with each PBT mark at the time of release, we treated $N_{i,0}$, the number released with PBT mark i, as known without error. For further detail on model adaptation and development, the reader is encouraged to consult Kock and others (2019). The adapted model structure yields the following form:

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

and

$$y_{i,1,k}, \ldots, y_{i,J,k} \mid N_{ik} \sim \text{Multinomial}\left(N_{ik}, \frac{\pi_{i,1,k}}{\sum_{j=1}^{J} \pi_{i,j,k}}, \ldots, \frac{\pi_{i,J,k}}{\sum_{j=1}^{J} \pi_{i,j,k}} \right), \quad (2)$$

where,

N_{ik} is the abundance of PBT family group i during primary sampling occasion k,

S_k is the survival probability between primary sampling occasions k-1 to k,

π_{ijk} is the probability that an individual from PBT family group i during primary sampling occasion k is first captured on the jth sample, and

y_{ijk} is the number of individuals from PBT family group i collected in the jth sample during the kth primary sampling occasion.

The likelihood of the data y_{ijk} and the survival and collection probability parameters S_k and p_{jk} is then the product of Equations (1) and (2) over all PBT family groups $i \in \{1, \ldots, R\}$, and all primary sampling occasions $k \in \{1, \ldots, K\}$, where the relationship between unconditional per-sample capture probability p_{jk} and π_{ijk} is governed by the recursive equation

$$\pi_{jk} = \frac{\pi_{j-1,k}}{p_{j-1,k}} p_{jk} \left(1 - p_{j-1,k}\right), \quad (3)$$

where,

p_j is the probability of capturing an individual on the jth removal sample, and

π_1. is p_1.

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 1. This model can be fit in either a maximum likelihood or a 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 a primary sampling occasion.

Constraining Survival and Detection Parameters

Although N-mixture model adaptation described above allows for unbiased estimation of survival and capture probabilities, both simulations (Kock and others, 2016) and a prior year study analysis (Kock and others, 2019) indicated that at the low capture probabilities encountered when sampling Chinook fry via either gillnets or electrofishing, allowing survival and collection probabilities to vary independently between sampling occasions led to uninformed estimates for these parameters. Simulation analyses demonstrated that many more fry would need to be collected to estimate independent occasion-specific survival and collection probabilities than were feasible given personnel and time constraints. Furthermore, we determined that capture probabilities required to accurately estimate unique parameters for each sampling period could not be achieved with available sampling methods.

Although we found that the PBT *N*-mixture model could not be used to estimate occasion-specific *p* and interval-specific *S*, we further determined 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, 2019). We considered various constraints on *p* and *S* that would balance achieving unbiased estimation with avoidance of unrealistic assumptions about underlying processes to generate a suite of models for these parameters.

For the parameter *p*, we hypothesized that capture probability might vary among sampling gear used (electrofishing, gill net, and box trap), and that for a given gear type, 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. Capture probability was therefore modeled as follows:

$$\text{logit}\left(p_{kg}\right) = a_{g,0} + a_{g,1}x_{p,k}, \quad (4)$$

where,

logit() is the logit link function,

$a_{g,0}$ and $a_{g,1}$ are the intercept and offset for capture probability for gear type g, and

$x_{p,k}$ is a binary covariate set to zero for $k = (1, 2)$ and one for $k = (3, 4, 5, 6)$.

For survival, we fit two distinct models to the data. The first model assumed a constant per-30-day survival, *S*, from the time of first release in April to the final sampling occasion in October. The second model for survival assumed that monthly survival was a function of time of year to allow survival to vary over time while still tying monthly survival to a time-varying covariate (in this case, time since release). In this second model survival has the form

$$\text{logit}\left(S_k\right) = b_0 + b_1 x_{S,k}, \quad (5)$$

where,

logit() is the logit link function,

b_0 and b_1 are the intercept and slope 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} represents a constant daily capture probability for gear *g* across sampling occasions 1 and 2 or 3–6, whereas in this second model 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 two models fit were compared via LOOIC, an information criterion used to compare models fit through Bayesian analysis (Vehtari and others, 2017).

The PBT *N*-mixture models provided seven survival estimates: the constant per-30 day survival from the first model ($S_{\text{NMIXconst}}$), and six period-specific survival estimates from the second model, (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

Lookout Point Reservoir was not refilled in 2018, which is normal based on conditions observed during most years since 2013 (fig. 5). The USACE developed a "rule curve" for Lookout Point Reservoir in 2011 which 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-autumn, and winter months. However, the rule curve is typically not followed during late-spring and summer months because high water demand does not allow the reservoir to fill during these periods. During 2011–16 and 2018, reservoir refill levels failed to meet the rule curve maximum of about 282 m (fig. 5). This was not the case during 2017, however, due to an abnormally high snowpack that allowed the reservoir to reach the maximum refill target in early-May (fig. 5).

Outflow at Lookout Point Dam also differed between 2017 and 2018 (fig. 6). In 2018 outflow was steady at around 1,000 ft^3/sec during March–May, increased to a maximum of about 4,000 ft^3/sec in late-May and June, then decreased to the 1,500–2,000 ft^3/sec range during July–November (fig. 6). Conversely, outflow was higher and more variable at Lookout Point Dam in 2017 (fig. 6). Peak outflow of about 10,000 ft^3/sec was observed in late-March which was followed by variable outflow conditions during April–October (fig. 6).

Water temperature in the forebay of Lookout Point Dam was approximately 8 °C at the surface in early April 2018 (fig. 7). The reservoir began to stratify in early May and remained stratified through October. Maximum surface temperature was about 22 °C during July and August and temperatures greater than 18 °C were present in the top 20 m of the water column during August and September (fig. 7). These conditions were generally like those observed in 2017 although maximum surface temperature was greater (24 °C) in 2017 (fig. 7).

Water clarity in Lookout Point Reservoir decreased from May to September 2018 (fig. 8). The Secchi disk measurement in May 2018 was 4.75 m compared to 2.34 m in September 2018. Except for May, all monthly Secchi disk measurements were lower in 2018 than in 2017 (fig. 8).

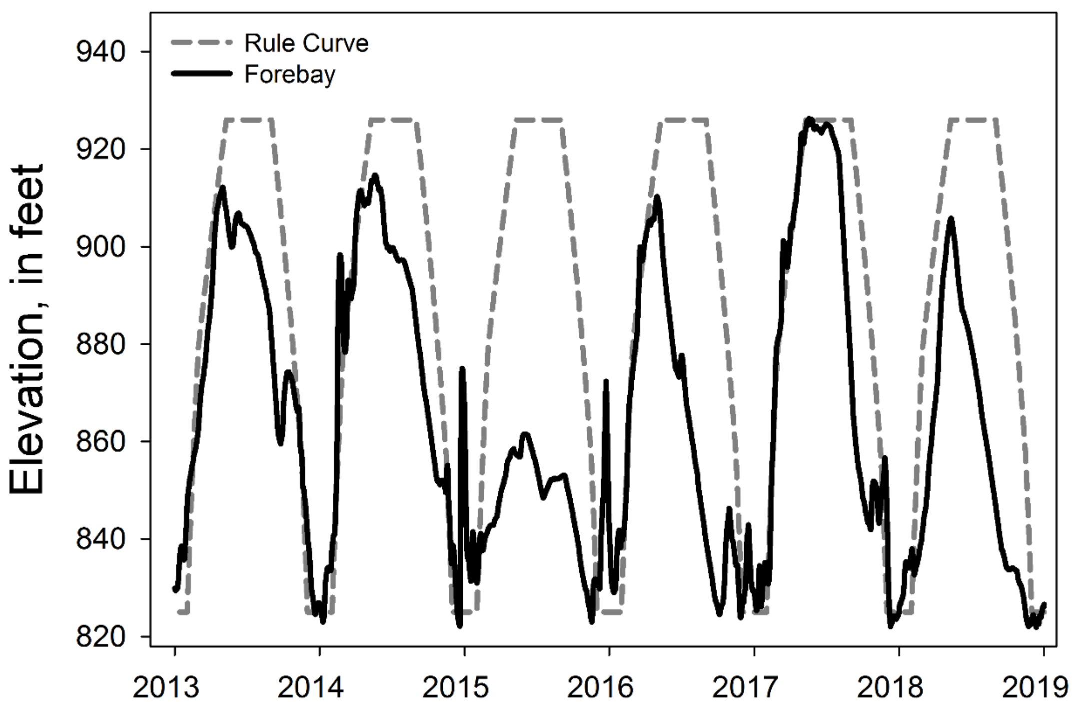

Figure 5. Graph showing forebay elevation and rule curve for Lookout Point Reservoir, Oregon, 2013–18.

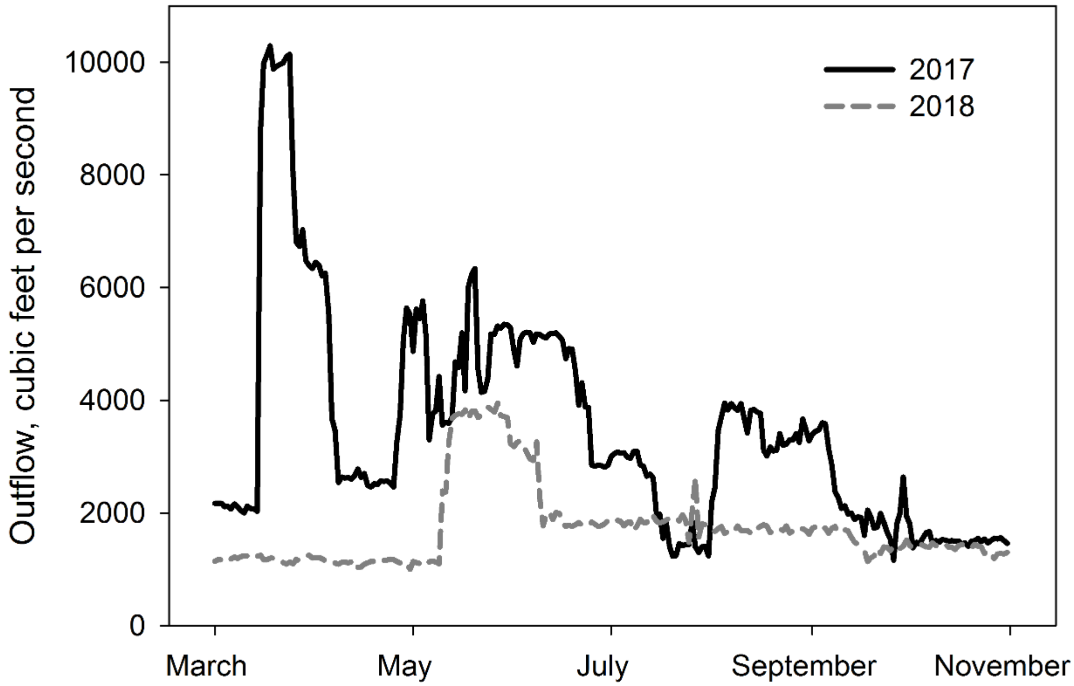

Figure 6. Graph showing outflow at Lookout Point Dam, Oregon, March–November 2017 and 2018.

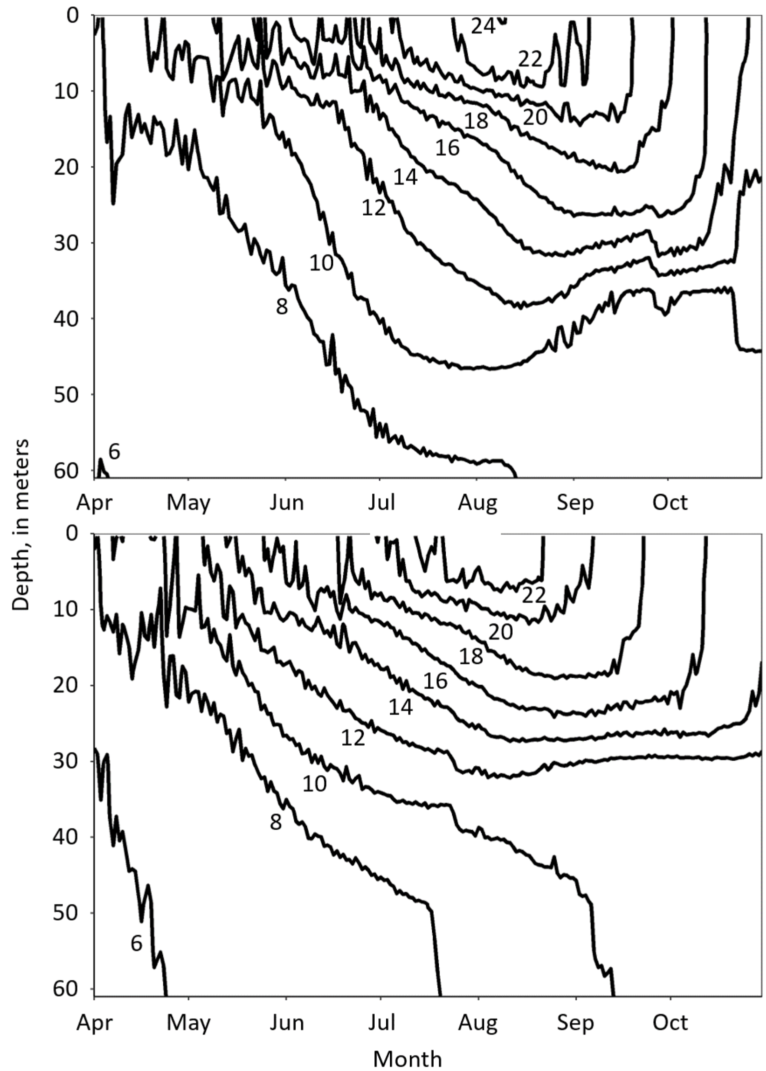

Figure 7. Graphs showing water temperature profiles for the forebay of Lookout Point Reservoir during April–October 2017 (top) and 2018 (bottom). [Numbers embedded in plots are the temperatures, in degrees Celsius, for individual temperature bands.]

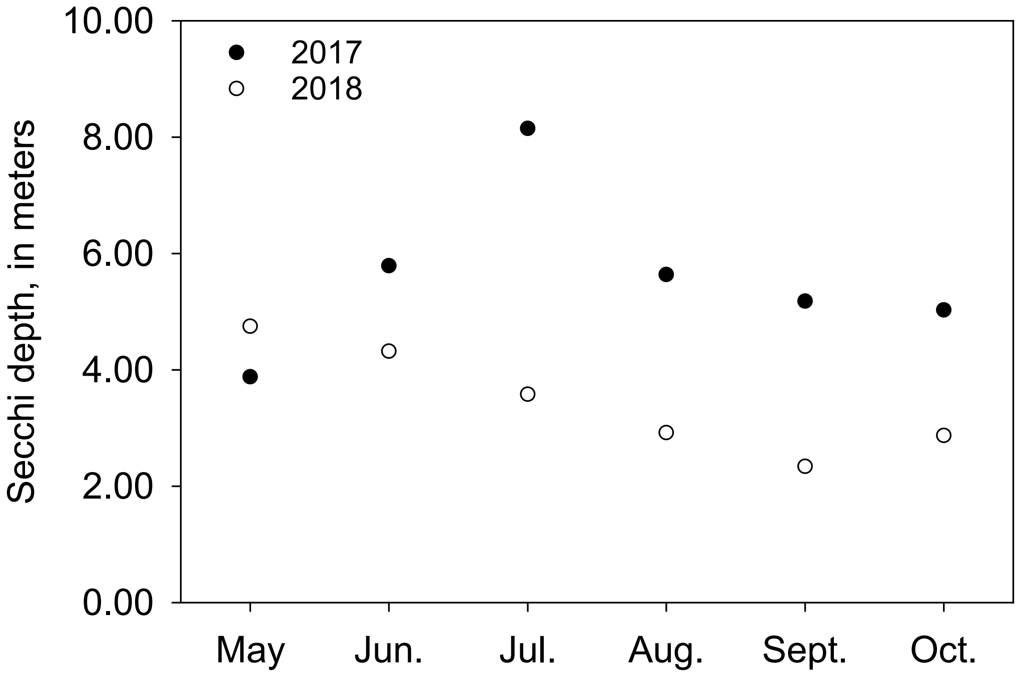

Figure 8. Secchi depth measurements in Lookout Point Reservoir, Oregon, during May–October 2017 and 2018.

Assessing Passage at Lookout Point Dam

White crappie were the primary species collected in screw traps located downstream of Lookout Point Dam during 2018 (table 4). Other species such as sculpin, bluegill, and black crappie were collected as well. A total of 30 juvenile Chinook salmon were collected in screw traps downstream of the dam (table 4). One of these was too large to have been from the 2018 year class. Genetic samples from the remaining fish were submitted for analysis. One of those failed to genotype. Genetic results were obtained from the remaining 28 fish. Seventy percent (19 fish) of the juvenile Chinook salmon collected in the screw traps failed to assign to parents used to produce study fish and were believed to be of natural origin. The remaining eight fish assigned to parents used to produce study fish including 4 fish from the R_1 release group and 4 fish from the R_2 release group.

Table 4. Number of each fish species captured by screw traps in the Lookout Point Dam tailrace, Oregon, 2018.

Species	Number collected
Brown bullhead	3
Black crappie	17
Bluegill	20
Chinook salmon	30
Cutthroat trout	1
Largemouth bass	8
Largescale sucker	4
Northern pikeminnow	1
Rainbow trout	2
Redside shiner	1
Sculpin spp.	27

Species	Number collected
Speckled dace	1
Walleye	1
White crappie	30,869*
Yellow bullhead	2

*Numbers of white crappie were estimated on some days due to large numbers of fish in the trap.

Fish Releases in Lookout Point Reservoir

Groups of study fish were released into Lookout Point Reservoir in mid-April, mid-May, and mid-June 2018. R_1 fish were released during April 10–13, 2018. The number of fish in each replicate ranged from 29,047 to 30,028 and the total release comprised 117,938 fish (table 5). Fish in the R_1 group were released 10.5–14.5 rkm upstream of Lookout Point Dam (fig. 9). Four replicates of R_2 fish were released during May 15–May 18, 2018. Replicate group counts ranged from 7,584 to 8,568 fish for a total release of 32,432 fish (table 5). R_2 fish releases occurred 7 to 14 rkm upstream of the dam (fig. 9). The R_3 fish were all released during June 19–20, 2017. Counts in the two replicates were 5,999 and 5,999 fish for a total release group of 11,998 fish (table 5). The R_3 fish were released in the lower portion of Lookout Point Reservoir, 3–7 rkm upstream of Lookout Point Dam (fig. 9).

Table 5. Release information for juvenile Chinook salmon in Lookout Point Reservoir, Oregon 2018.
[Numbers in parenthesis are the range of fork length and fish weight measurements. **Abbreviations**: g, gram; mm, millimeter]

Release group	Replicate	Release date	Number released	Mean fork length (mm)	Mean weight (g)
R_1	1	April 10, 2018	29,555	45 (33–57)	0.9 (0.2–1.8)
	2	April 11, 2018	29,047	45 (32–56)	0.8 (0.3–1.6)
	3	April 12, 2018	29,308	43 (36–51)	0.7 (0.3–1.4)
	4	April 13, 2018	30,028	43 (35–54)	0.7 (0.4–1.5)
	Overall		117,938	44 (32–57)	0.8 (0.2–1.8)
R_2	1	May 15, 2018	7,584	91 (61–105)	7.8 (2.5–12.2)
	2	May 16, 2018	7,887	95 (53–110)	8.8 (1.4–14.2)
	3	May 17, 2018	8,393	90 (69–112)	7.2 (2.6–15.4)
	4	May 18, 2018	8,568	82 (47–114)	6.0 (0.8–14.0)
	Overall		32,432	89 (47–114)	7.3 (0.8–15.4)
R_3	1	June 19, 2018	5,999	93 (55–125)	8.9 (1.4–19.3)
	2	June 20, 2018	5,999	91 (51–111)	8.2 (1.7–14.1)
	Overall		11,998	92 (51–125)	8.5 (1.4–19.3)

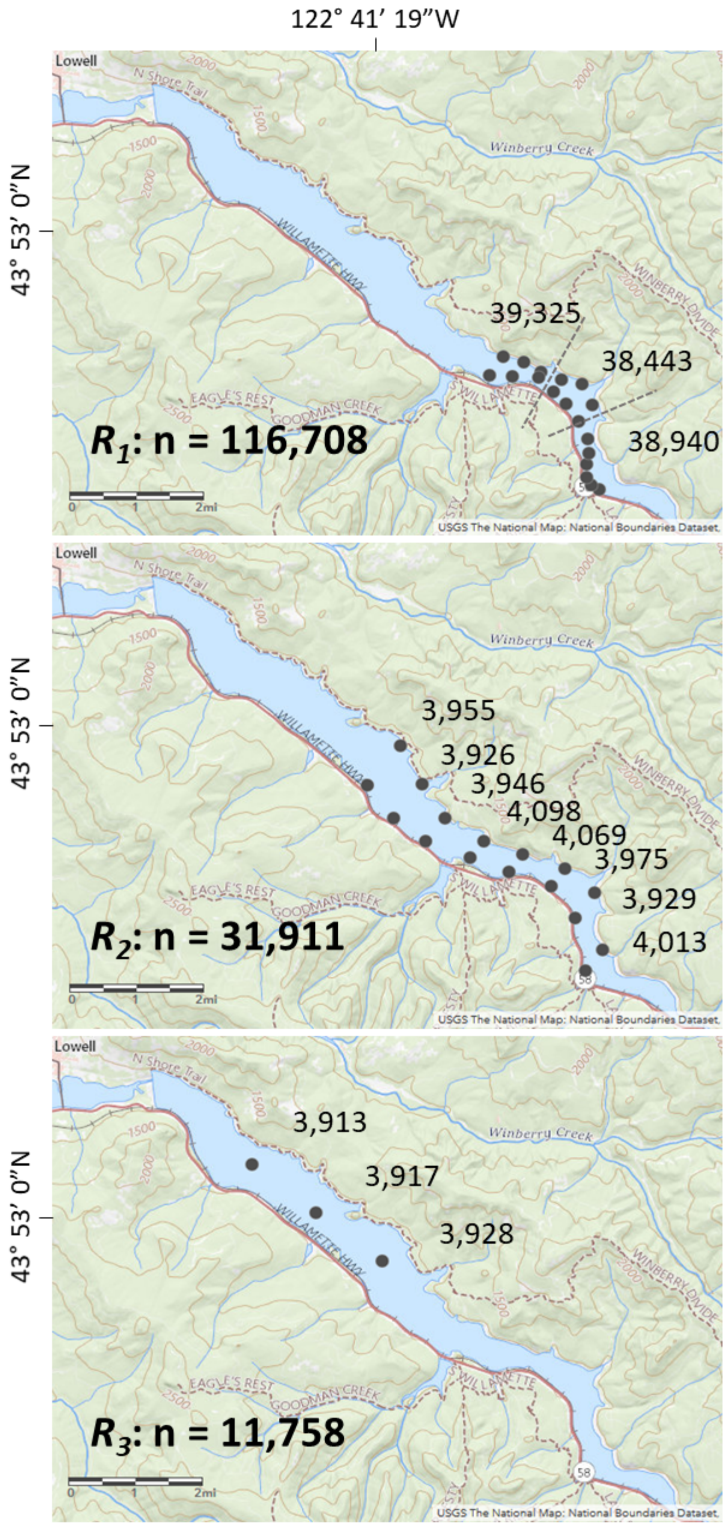

Figure 9. Maps showing numbers and locations of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) released during April (R_1) May (R_2), and June (R_3) in Lookout Point Reservoir, Oregon, 2017.

Sampling in Lookout Point Reservoir

Of the 3,725 juvenile Chinook salmon collected in reservoir sampling events during May–October 2018, most (2,964 fish; 80 percent) were subyearlings (table 6). Monthly catch of subyearlings in 2018 ranged from 330 fish in June to 592 fish in July (fig. 10). Subyearlings collected in May were about 55 mm long (median, fig. 11). Size data from monthly collection efforts showed that subyearlings grew steadily throughout the study period and were about 197 mm in October (fig. 11). An assortment of other fish species were encountered as bycatch during collection events (table 6).

Sampling gear was deployed throughout the reservoir during May–August 2018, but declining reservoir elevations precluded sampling in the upper portion of the reservoir during July–October (fig. 12). In May, the greatest proportion of juvenile Chinook salmon were collected near the head of Lookout Point Reservoir in May (fig. 12). In June, fish were captured throughout the reservoir and during July–October 2018 most juvenile Chinook salmon were collected in the lower one-half of the reservoir. Sampling gear was deployed at progressively deeper locations in the water column from May–September 2018 as the reservoir stratified during summer months and juvenile Chinook salmon moved deeper (fig. 13). This pattern relaxed slightly in October as the reservoir began to cool, but sampling gear and fish collection still occurred at depths greater than 8 m (fig. 13).

Distribution patterns of subyearlings within Lookout Point Reservoir differed during spring–autumn in 2017 and 2018 (fig. 14). During May, most juvenile Chinook salmon were collected in the upper 8 rkm of the reservoir in both years, but a substantial proportion of the catch in 2017 was also in the lower 8 rkm (fig. 14). In June and July 2017, nearly all the subyearling Chinook salmon were collected in the lower 5 rkm of the reservoir whereas in 2018 catch was spread throughout most of the reservoir. In August and September, subyearling Chinook salmon were captured primarily in the lower 6 rkm of the reservoir during both years although in 2017 some fish were also collected were also collected between rkm 8 and rkm 12. Distribution of subyearling Chinook salmon was most similar between years during October (fig. 14)

Table 6. Species type and number of individuals encountered monthly during reservoir sampling efforts in Lookout Point Reservoir, Oregon, May–October, 2018.

Family/species		Collection period						
Common name	**Scientific name**	**May**	**June**	**July**	**August**	**September**	**October**	**Total**
Salmonidae								
Chinook salmon	*Oncorhynchus tshawytscha*	626	608	787	650	566	488	3,725
Rainbow trout	*Oncorhynchus mykiss*	192	36	27	29	8	0	292
Cyprinidae								
Northern pikeminnow	*Ptychocheilus oregonensis*	23	113	0	0	1	36	173
Oregon chub	*Oregonichthys crameri*	1	0	0	0	0	0	1
Redside shiner	*Richardsonius balteatus*	6	6	1	0	0	0	13
Dace spp.	*Rhinichthys spp.*	6	309	0	0	0	0	315
Catostomidae								
Sucker spp.	*Catostomus spp.*	415	131	1	0	0	1	548

Family/species		Collection period						
Common name	Scientific name	May	June	July	August	September	October	Total
Ictaluridae								
Brown bullhead	*Ameiurus nebulosus*	2	236	104	29	21	7	399
Yellow bullhead	*Ameiurus natalis*	2	0	0	0	0	0	2
Centrarchidae								
Crappie spp.	*Pomoxis spp.*	259	492	19	269	41	412	1,492
Lepomis spp.	*Lepomis spp.*	23	226	0	0	1	1	251
Bass spp.	*Micropterus spp.*	62	380	0	0	2	7	451
Percidae								
Walleye	*Sander vitreus*	2	12	0	0	1	46	61
Cottidae								
Sculpin spp.	*Cottus spp.*	243	906	24	8	35	1	1,217
Salamandridae								
Rough-skinned newt	*Taricha granulosa*	35	67	0	0	0	0	102
Emydidae								
Western pond turtle	*Actinemys marmorata*	0	2	0	0	0	0	2

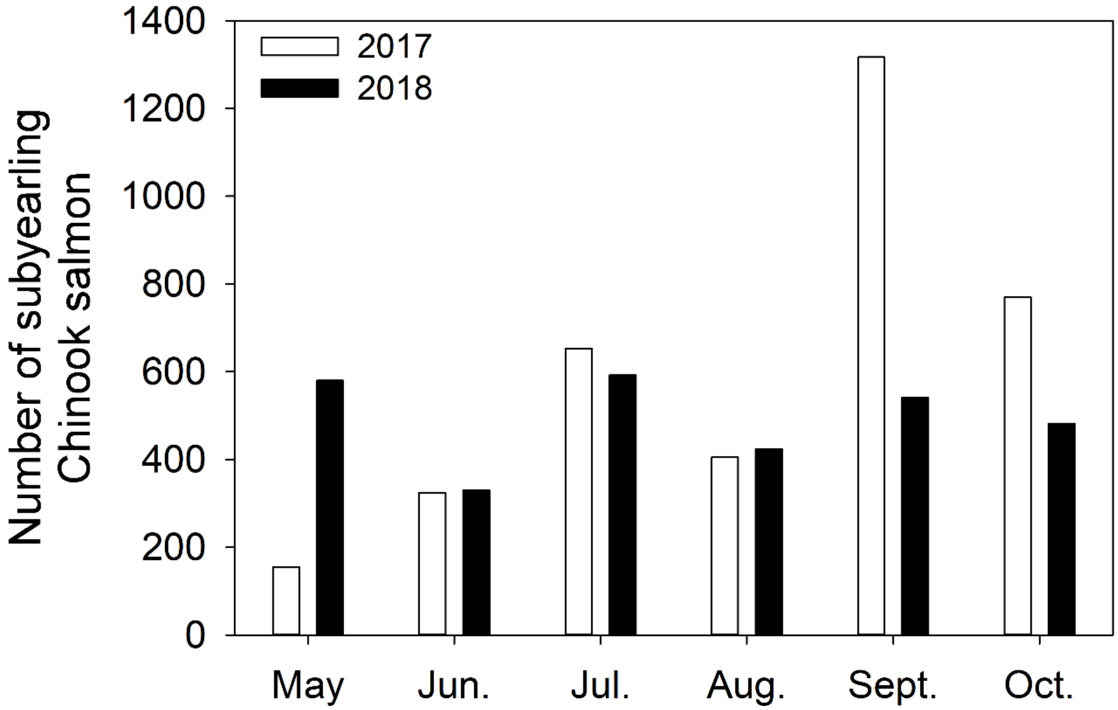

Figure 10. Graph showing number of subyearling Chinook salmon (*Oncorhynchus tshawytscha*) collected during reservoir sampling, Lookout Point Reservoir, Oregon, May–October 2017 and 2018.

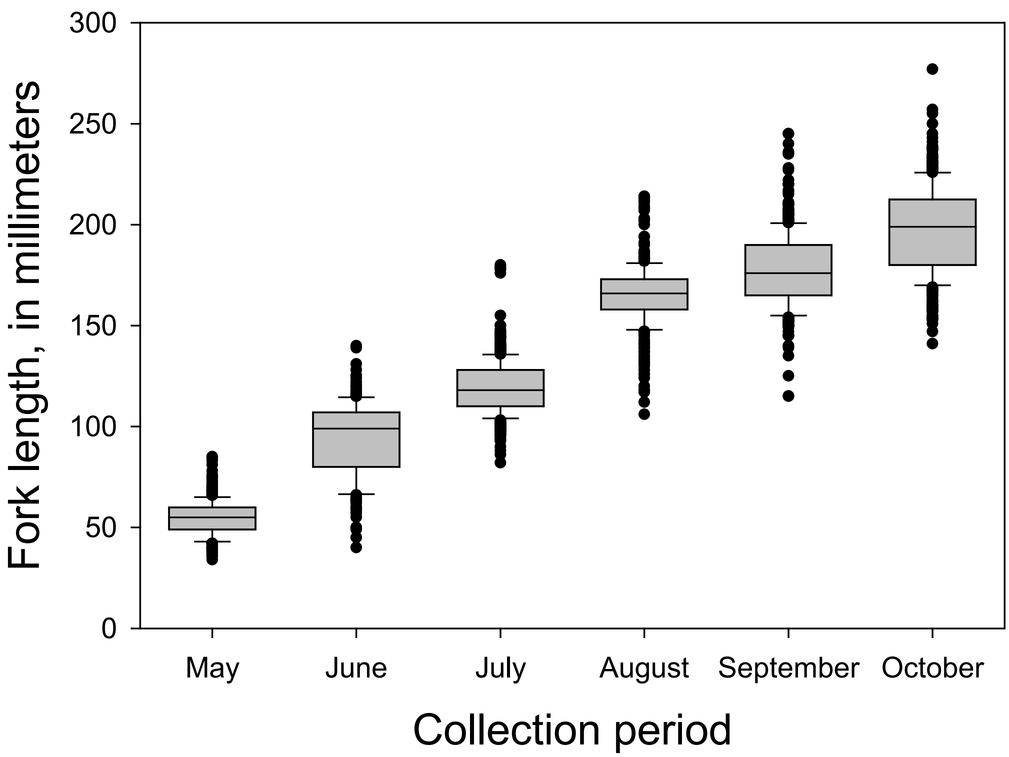

Figure 11. Graph showing monthly fork length distributions of subyearling Chinook salmon (*Oncorhynchus tshawytscha*) collected in Lookout Point Reservoir, Oregon, May–October. 2018. [The line within the box is the median fork length, box boundaries represent the 25th and 75th percentiles, whiskers are the 10th and 90th percentiles, and dots represent outliers.]

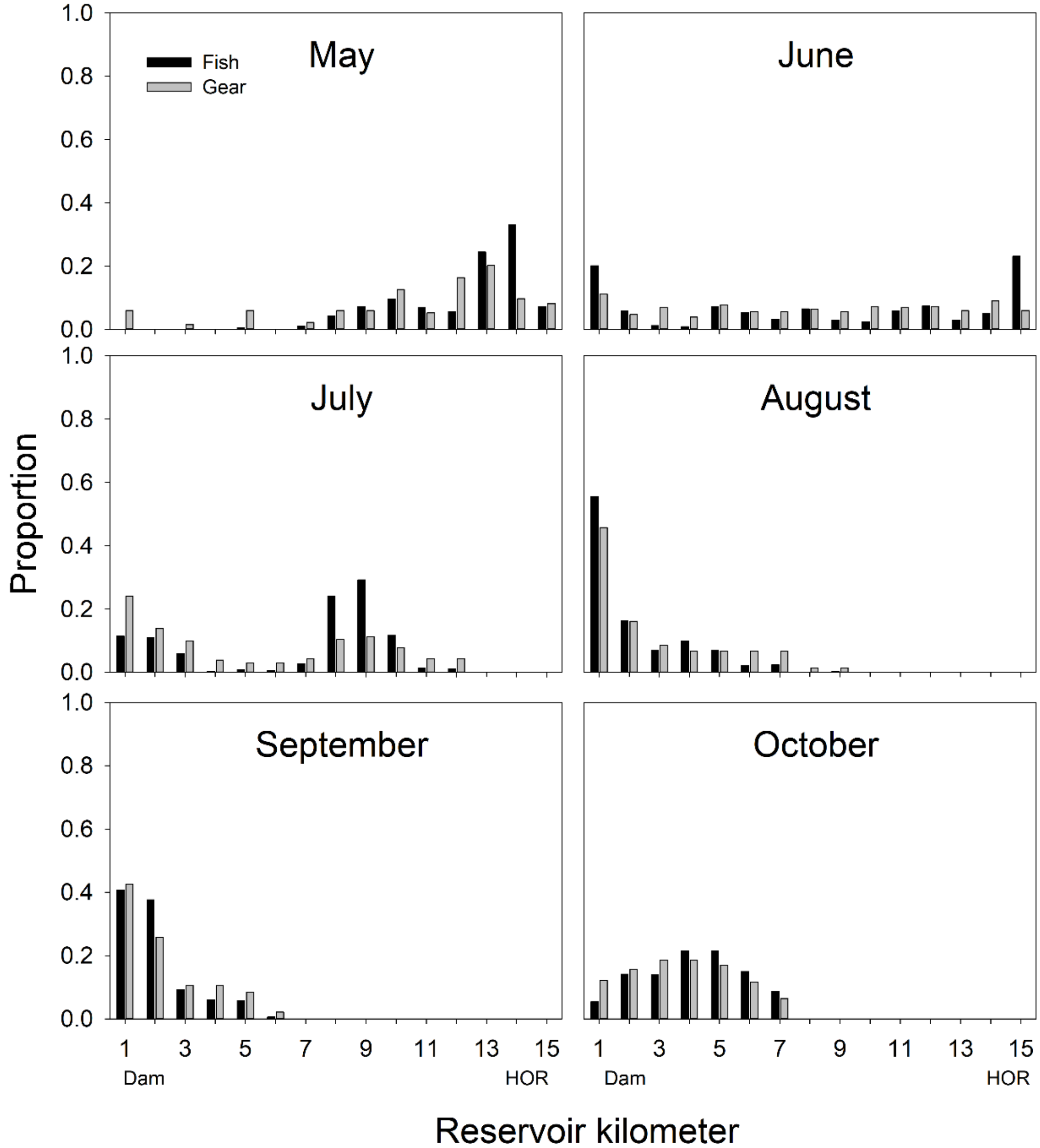

Figure 12. Graphs showing monthly proportion of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) captured and sampling gear deployed along the length of Lookout Point Reservoir, Oregon, during May–October 2018. [For reference, Lookout Point Dam (Dam) is located at river kilometer 0, and the head of Lookout Point Reservoir (HOR) is located at river kilometer 16. See figure 1.]

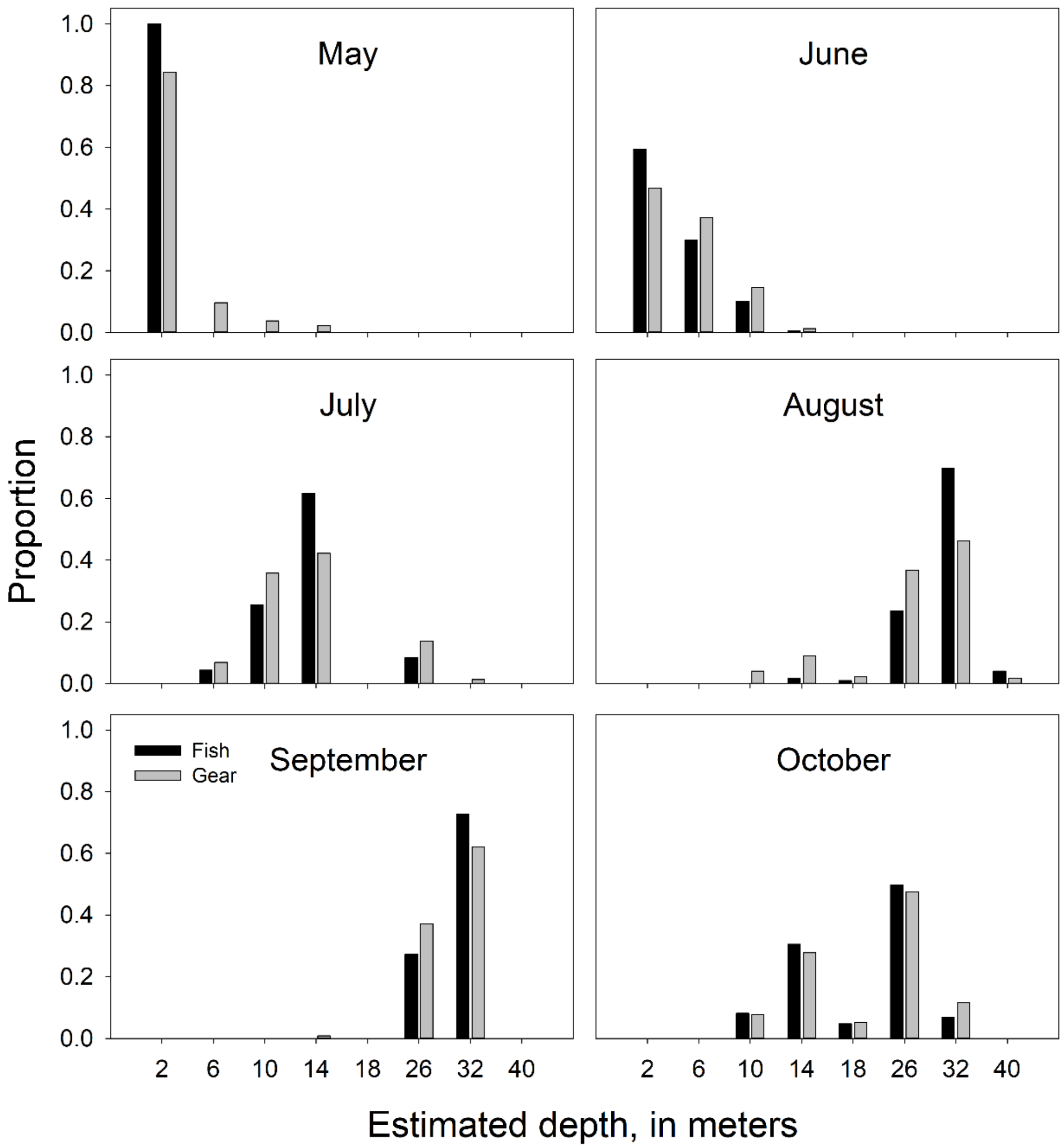

Figure 13. Graphs showing proportion of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) captured and sampling gear deployed by month and depth strata in Lookout Point Reservoir, Oregon, during May–October 2018.

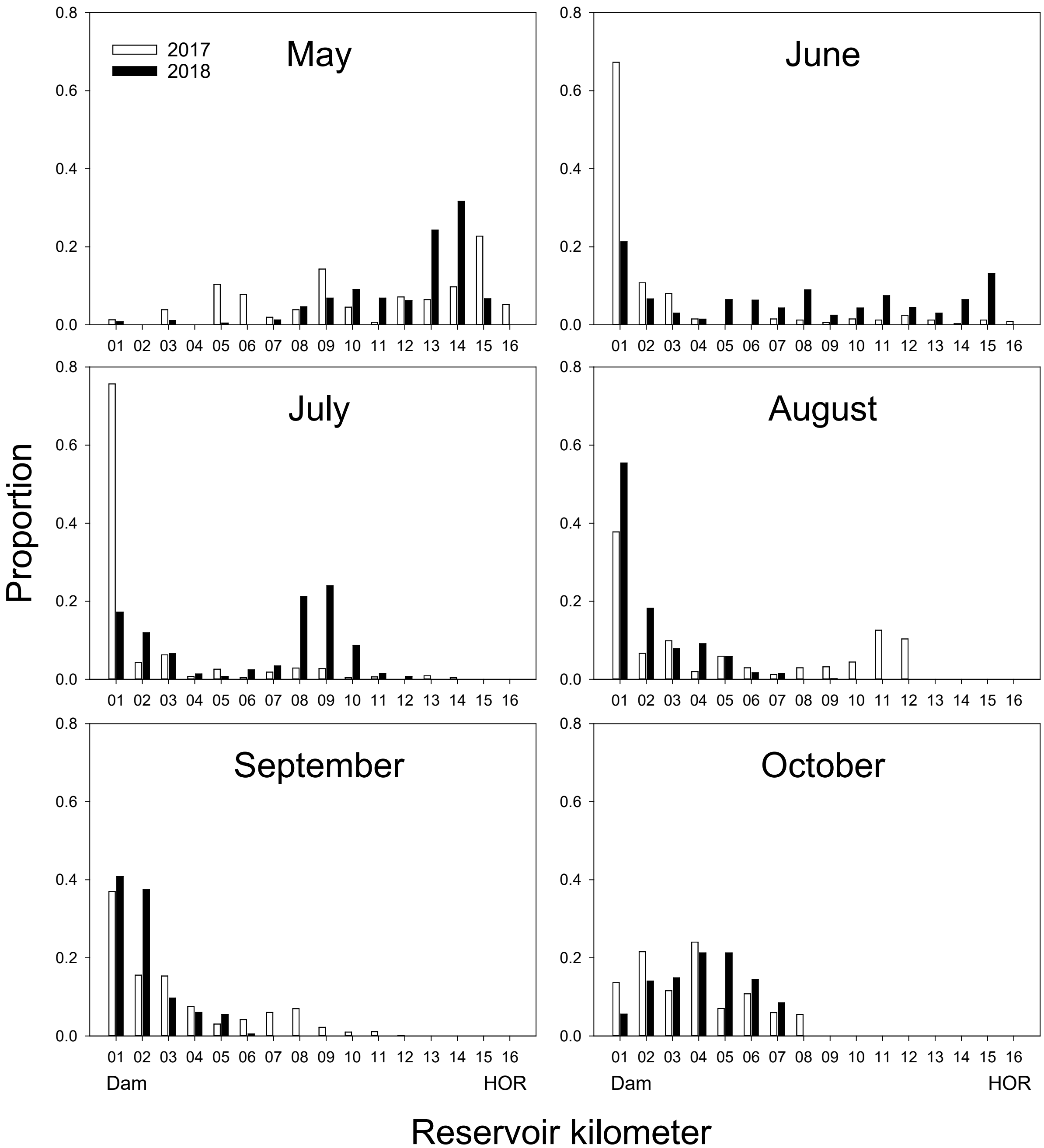

Figure 14. Graphs showing proportion of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) captured and sampling gear deployed by month along the length of Lookout Point Reservoir, Oregon, during May–October 2017 and 2018. [For reference, Lookout Point Dam (Dam) is located at river kilometer 0 and the head of Lookout Point Reservoir (HOR) is located at river kilometer 16. See figure 1.]

Genetic Analysis

Sixty tissue samples were obtained from juvenile Chinook salmon collected in screw traps operated 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 were presumably of natural origin. The remaining samples assigned to R_1 (6 fish; 10 percent) and R_2 (24 fish; 40 percent) groups.

Sixty-four percent of samples collected in Lookout Point Reservoir failed to assign to parents from the study (table 7) and were presumably of natural origin. The percentage of samples assigned to parents was 7–57 percent for R_1, 0–10 percent for R_2, 1–6 percent for R_3 (table 7). Fork length distributions for each group at the time of collection are shown in fig. 15. Natural-origin subyearling Chinook salmon were about 15–20 mm larger in 2017 than in 2018 at monthly sampling intervals (fig. 15).

Table 7. Results from genetic analysis that assigned individual juvenile Chinook salmon *(Oncorhynchus tshawytscha)* to specific release groups during the study in 2018.

[**Unassigned:** Refers to samples that did not assign to hatchery parents used to produce fish for the study and were presumably of natural origin. R_1: April. R_2: May. R_3: June]

Collection period	Unassigned	R_1	R_2	R_3
May	248 (43 percent)	332 (57 percent)	na	na
June	161 (49 percent)	134 (41 percent)	35 (10 percent)	na
July	324 (55 percent)	217 (37 percent)	9 (2 percent)	36 (6 percent)
August	265 (63 percent)	138 (33 percent)	6 (1 percent)	13 (3 percent)
September	436 (81 percent)	92 (17 percent)	1 (0 percent)	10 (2 percent)
October	434 (92 percent)	34 (7 percent)	0 (0 percent)	5 (1 percent)
Total	1,868 (64 percent)	947 (32 percent)	51 (2 percent)	64 (2 percent)

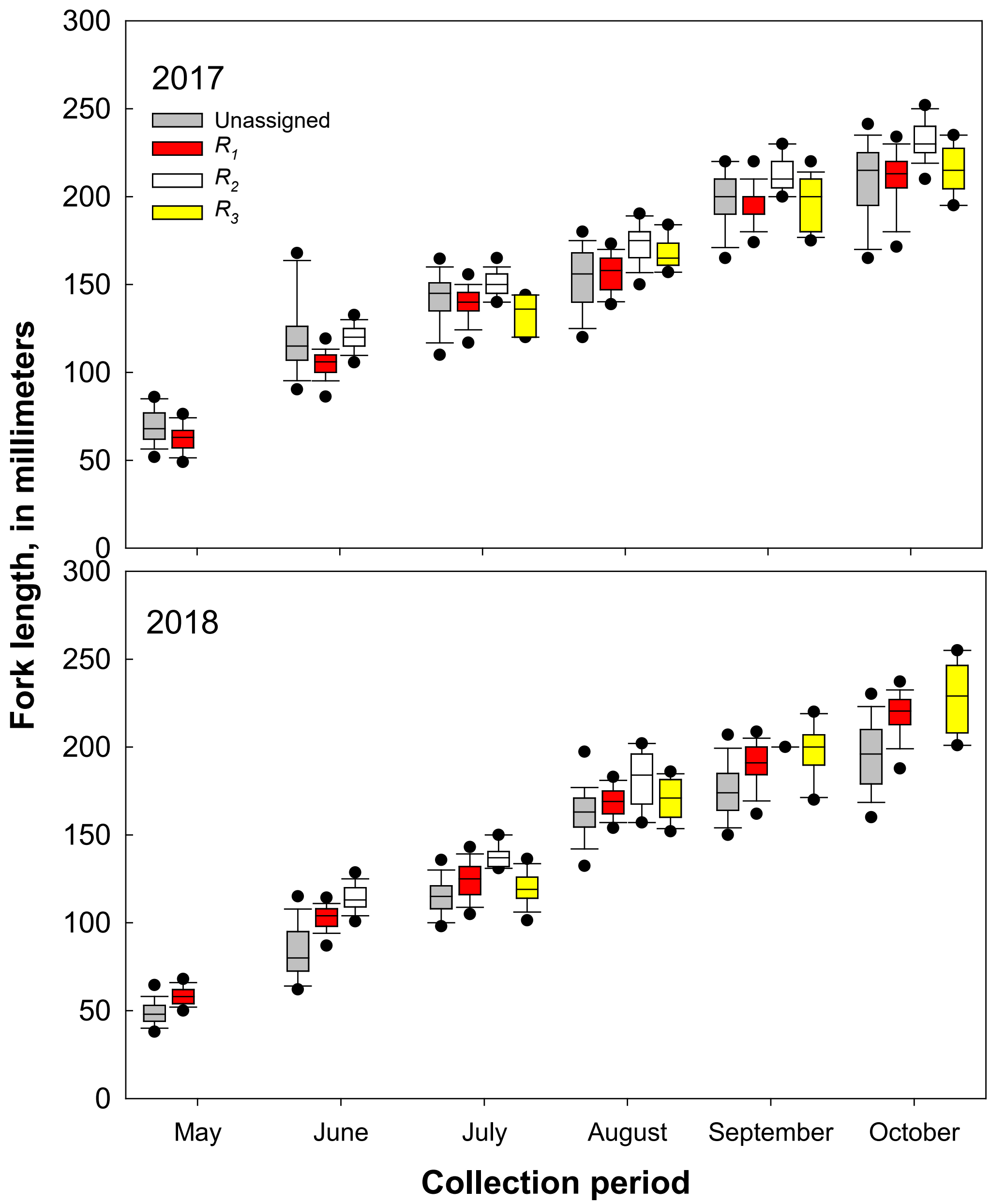

Figure 15. Graph showing fork length distributions for groups of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) by month in Lookout Point Reservoir, Oregon, 2017. [Boxes represent 25th and 75th percentile; lines within the boxes are the medians; whiskers are the 10th and 90th percentile; and dots represent the 5th and 95th percentile. Some release groups were not available for collection during May (R_2) and June (R_3) due to release timing.]

Copepod Prevalence

The percentage of subyearlings with copepods was low early in the study period but increased rapidly as the study progressed (fig. 16). The proportion of subyearlings with copepods ranged from 5 to 33 percent during June and July 2018. This increased to 90 percent or greater for R_1, R_2, and R_3 fish by September 2018. The percentage of natural origin subyearlings with copepods did not exceed 66 percent during any month of the study. Nearly all the yearling Chinook salmon had copepods throughout the study (fig. 16).

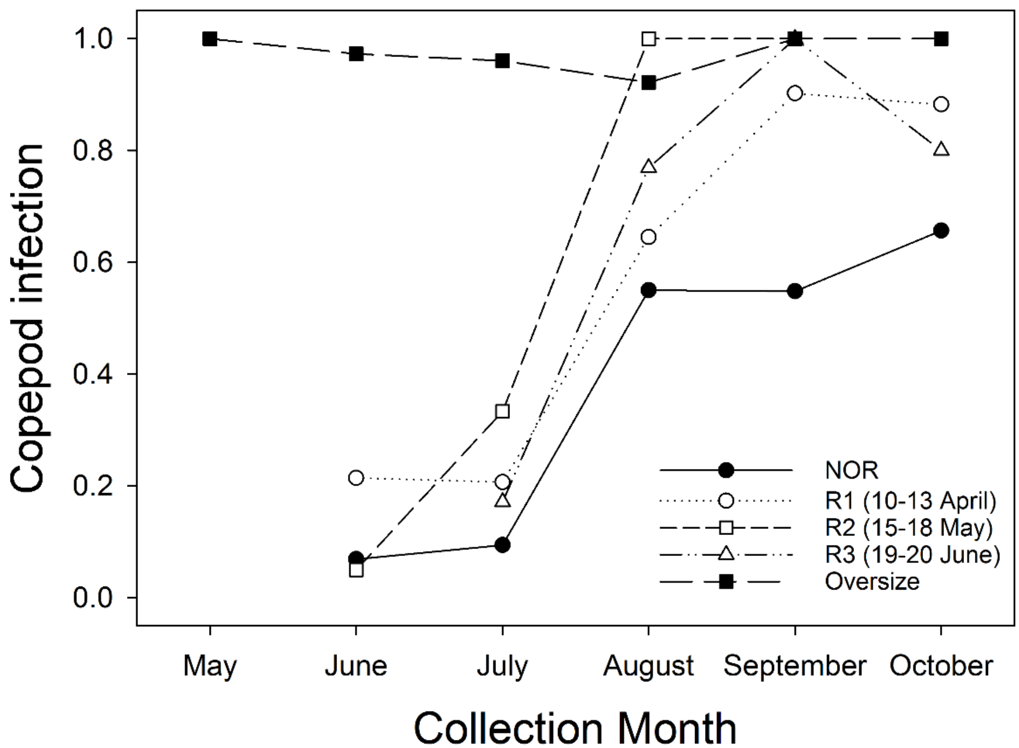

Figure 16. Graph showing proportion of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) infected with the copepod *Salmincola californiensis* in Lookout Point Reservoir, Oregon, during May–October 2018. [Data are presented for natural-origin (NOR) subyearling Chinook salmon, subyearling Chinook salmon were produced for this study and released in the reservoir (April [R_1] to June [R_3]), and for yearling Chinook salmon (Oversize).]

Estimating Reservoir Survival of Subyearling Chinook Salmon

Staggered Release-Recovery Model

Recapture rates were low throughout the study period. Multiple release group combinations were examined and estimates of recapture probabilities ranged from 0.00117 to 0.01303 (table 8). Comparison of recapture probabilities obtained from fitting the SRRM to different release group combinations supported the conclusion that recapture probabilities were unequal 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 above, whereby all release groups must share a common recapture and survival probability after the last release.

Estimates of survival for SSRRM1 based on different release group combinations ranged from 0.98520 to 0.98954 (table 9; fig. 17). Estimates standardized to a 30-day interval ranged from 0.98729 to 0.99103 (table 9). Survival probability estimates for SSRRM2 were substantially different (0.62142 and 0.09338) using two different release group combinations (table 9; fig. 17). The estimated cumulative survival probability for April–June (product of SSRRM1 and SSRRM2) using all release groups was 0.61492. Alternatively, the estimated cumulative survival probability during this same period using R_1 and R_3 was 0.75211 (table 9).

Table 8. 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 (*Oncorhynchus tshawytscha*) in Lookout Point Reservoir, Oregon, 2018

Release combination	Parameter	Mean	Standard deviation	2.5 (percent)	50.0 (percent)	97.5 (percent)
R_1, R_2, R_3	P	0.00189	0.00029	0.00134	0.00187	0.00246
R_1, R_2	P	0.00117	0.00010	0.00098	0.00117	0.00138
R_2, R_3	P	0.01303	0.00436	0.00581	0.01233	0.02182
R_1, R_3	P	0.00156	0.00024	0.00112	0.00154	0.00203
R_1, R_2, R_3	λ	0.00552	0.00069	0.00424	0.00549	0.00689
R_1, R_2	λ	0.00363	0.00016	0.00332	0.00363	0.00396
R_2, R_3	λ	0.00553	0.00069	0.00418	0.00550	0.00685
R_1, R_3	λ	0.00556	0.00066	0.00432	0.00552	0.00681

Table 9. Summary statistics and survival estiamtes of posterior distributions for survival probabilities (S) for each survival interval (S_{SRRM1}–S_{SRRM12}) for different release group combinations of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in Lookout Point Reservoir, Oregon, 2018.

[Survival estimates standardized to a 30-day interval]

Release combination	Parameter	Mean	Standard deviation	2.5 (percent)	50.0 (percent)	97.5 (percent)
Summary statistics						
All	S_{SRRM1}	0.98954	0.01022	0.96942	0.99261	1.00000
	S_{SRRM2}	0.62142	0.08316	0.47005	0.61425	0.79162
1 & 2	S_{SRRM1}	0.98520	0.01438	0.95611	0.98954	1.00000
2 & 3	S_{SRRM2}	0.09338	0.02575	0.04628	0.09055	0.14413
1 & 3	S_{SRRM12}	0.75211	0.09319	0.57799	0.74648	0.93864
Survival estimates standardized to a 30-day interval						
All	S_{SRRM1}	0.99103	0.00879	0.97374	0.99366	1.00000
	S_{SRRM2}	0.64842	0.07879	0.50345	0.64208	0.80862
1 & 2	S_{SRRM1}	0.98729	0.01237	0.96226	0.99103	1.00000
2 & 3	S_{SRRM2}	0.11549	0.02892	0.06260	0.11265	0.17319
1 & 3	S_{SRRM12}	0.88023	0.04816	0.78956	0.87898	0.97631

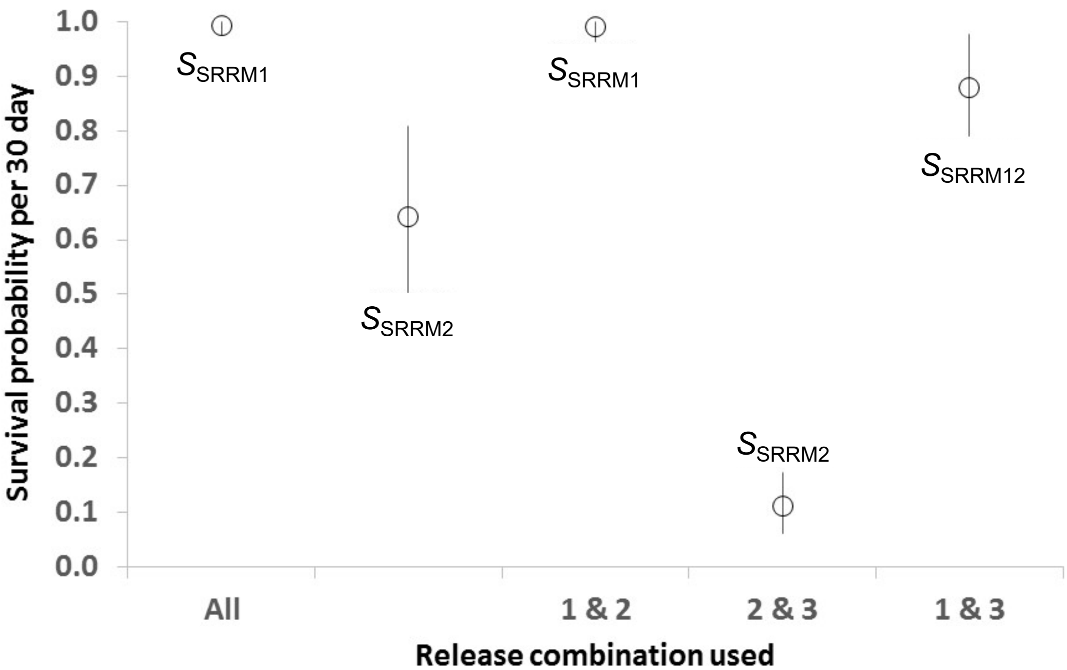

Figure 17. Survival probabilities for different release group combinations of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in Lookout Point, Reservoir, Oregon, 2018. [Error bars are credible intervals based and 2.5th and 97.5th percentiles of the posterior distributions of the parameters.]

Parentage-Based Tagging N-mixture Model

The two *N*-mixture models yielded fundamental parameter estimates relating to capture probability and survival of Chinook salmon fry in Lookout Point Reservoir from May to October 2017. Model comparison as measured by LOOIC (Vehtari and others, 2017) strongly favored survival as a function of time since release over a constant monthly survival (table 10). This comparison, in combination with the negative slope estimate $b_{S,1}$ provide evidence that fry survival in Lookout Point Reservoir in 2018 decreased over summer and autumn months. Slope, intercept, and offset parameters for both models are shown in table 11.

Capture probability estimates derived from these fundamental parameters and the logit link function used in the analysis varied by season and gear but were largely in agreement for both models fit. The lowest capture probability estimate for both models was for box traps used in May and June, and the highest capture probability for both models was for gill nets used during July–October 2017 (fig. 18; table 12). Capture probability estimates are very low for both models, but the posterior distribution indicates reasonable credible intervals that show little influence of the prior distribution. As the simulations discussed in the Methods section indicated, such low capture probabilities are unlikely to be estimable without the constraints enforced by the choice of model structure for this analysis.

Survival estimates from both models were similar to the extent that model constraints allowed (fig. 19). The constant survival model estimated a per-30-day survival of 0.628, which fell within the range of per-30-day survival estimates for the monthly survival model (range 0.416 to 0.796; fig. 19; table 12). The fundamental parameter $b_{S,1}$ measures the change in survival per month since the first release. Because the entire credible interval of this parameter ($b_{S,1}$; median, -0.341; 95-percent credible interval from -0.450 to -0.239) is less than zero, the data support a pattern of lower survival later in the calendar year. The estimated 3-month cumulative survival probability for April–June was 0.388 for the monthly survival model and 0.248 for the constant survival model (product of S_{NMIX1}-S_{NMIX3} and $S_{NMIXconst}^3$, respectively). The estimated 6-month cumulative survival probability for April–October (product of S_{NMIX1}-S_{NMIX6}) was 0.047 for the monthly survival model and 0.061 for the constant survival model (product of S_{NMIX1}-S_{NMIX6} and $S_{NMIXconst}^6$, respectively).

Table 10. Goodness-of-fit and model comparison metrics for two models fit to Chinook salmon (*Oncorhynchus tshawytscha*) fry collection data in Lookout Point Reservoir, Oregon, 2018.

[LOOIC score is a model selection information criteria score developed by Vehtari and others (2017) for Bayesian model comparison.]

Model description	LOOIC	ΔLOOIC
Monthly survival as function of time since release	7,488.2	0
Constant monthly survival	1,6605	9,116

Table 11. Fundamental parameter estimates for the effect of gear type and season on capture probability, and survival probability estimates of Chinook salmon (*Oncorhynchus tshawytscha*) fry in Lookout Point Reservoir, Oregon, 2018.

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

Parameter	Model	Median	Lower confidence interval	Upper confidence interval
$a_{1,0}$	Constant survival	-7.97941	-8.17438	-7.77928
$a_{1,1}$	Constant survival	1.07146	0.86729	1.29551
$a_{2,0}$	Constant survival	-9.02095	-9.26849	-8.77344
$a_{3,0}$	Constant survival	-7.20654	-7.36964	-7.05406
$S_{constant}$	Constant survival	0.62793	0.58319	0.67598
$a_{1,0}$	Monthly survival	-8.32218	-8.54132	-8.12671
$a_{1,1}$	Monthly survival	1.17895	0.95270	1.38811
$a_{2,0}$	Monthly survival	-9.35073	-9.60320	-9.09463
$a_{3,0}$	Monthly survival	-7.53051	-7.71632	-7.36557
b_0	Monthly survival	1.36071	0.96414	1.77676
b_1	Monthly survival	-0.34060	-0.45033	-0.23878

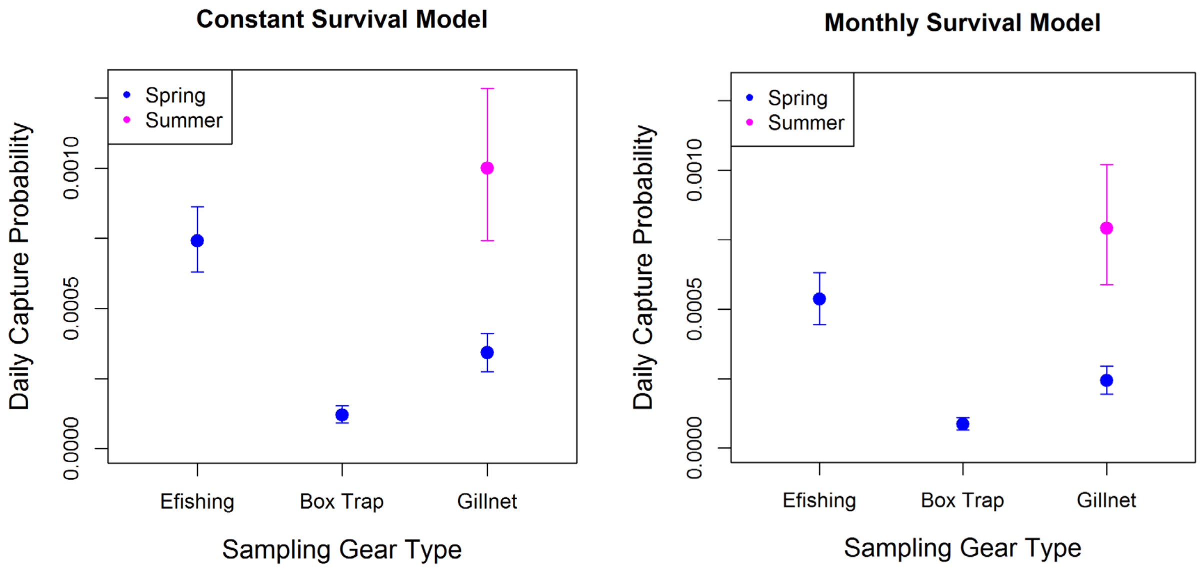

Figure 18. Graphs showing daily capture probability estimates under two models analyzed for three sampling gear types used to collect Chinook salmon (*Oncorhynchus tshawytscha*) fry in Lookout Point Reservoir, Oregon, 2018. [Spring indicates May–June, summer indicates July–October. Only gill net sampling was used in summer. Whiskers denote lower and upper bounds of the 95-percent credible intervals.]

Table 12. Derived parameter estimates for capture probability and 30-day survival probability of Chinook salmon (*Oncorhynchus tshawytscha*)) fry in Lookout Point Reservoir, western Oregon, 2018.

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

Parameter	Model	Median	Lower confidence interval	Upper confidence interval
p_{11}	Constant survival	0.00034	0.00028	0.00041
p_{21}	Constant survival	0.00100	0.00074	0.00128
p_{12}	Constant survival	0.00012	0.00009	0.00015
p_{13}	Constant survival	0.00074	0.00063	0.00086
$S_{NMIXconst}$	Constant survival	0.62793	0.58319	0.67598
p_{11}	Monthly survival	0.00024	0.00019	0.00030
p_{21}	Monthly survival	0.00079	0.00059	0.00102
p_{12}	Monthly survival	0.00009	0.00007	0.00011
p_{13}	Monthly survival	0.00054	0.00044	0.00063
S_{NMIX1}	Monthly survival	0.79587	0.72711	0.85826
S_{NMIX2}	Monthly survival	0.73498	0.66965	0.79420
S_{NMIX3}	Monthly survival	0.66415	0.61018	0.71949
S_{NMIX4}	Monthly survival	0.58456	0.54102	0.63608
S_{NMIX5}	Monthly survival	0.50028	0.45456	0.54989
S_{NMIX6}	Monthly survival	0.41620	0.35751	0.47282

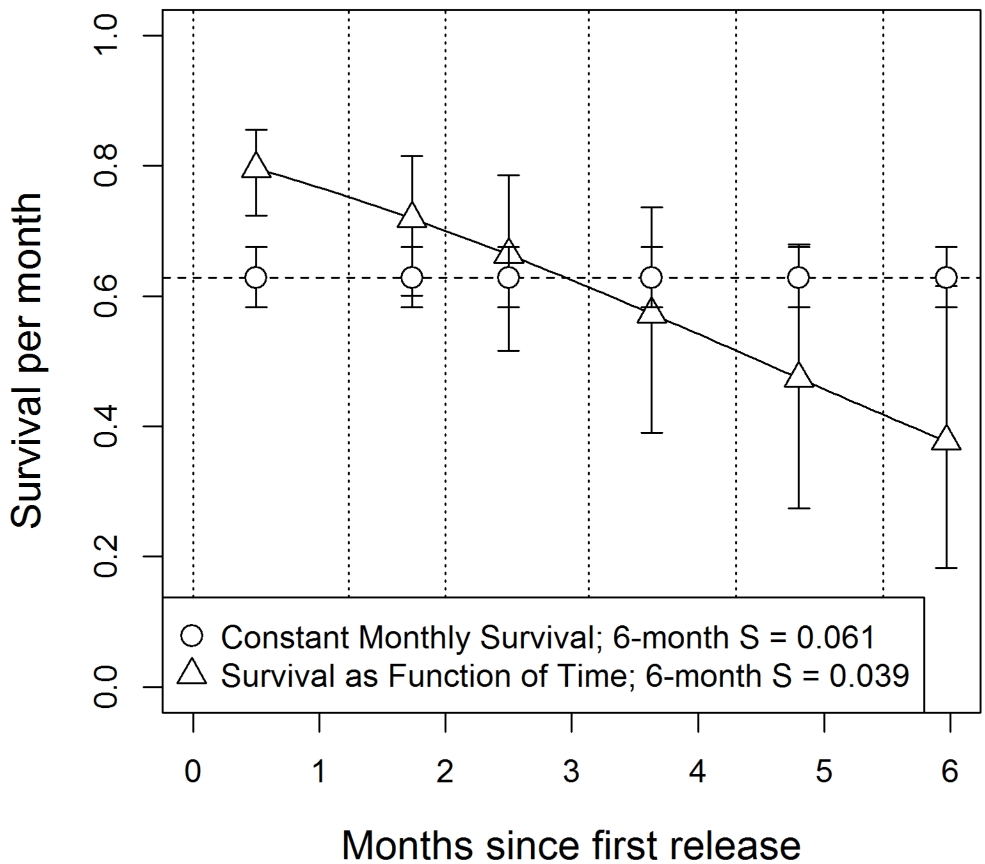

Figure 19. Graph showing 30-day survival probabilities during 6 months of sampling juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in Lookout Point Reservoir, Oregon, 2018 for two models fit. [Dotted vertical lines represent primary sampling occasions. Whiskers denote lower and upper bounds of the 95-percent credible intervals.]

Discussion

Survival estimates for subyearling Chinook salmon in Lookout Point Reservoir during April–October 2018 were substantially lower than estimates from the same period in 2017 (Kock and others, 2019). Models that estimated survival as a function of time since release yielded cumulative April–October survival estimates of 0.188 in 2017 and 0.039 in 2018, nearly a five-fold difference. Data on total catch of Chinook salmon juveniles during reservoir sampling events provides evidence that survival rates were lower in 2018 than in 2017. The total catch of juvenile Chinook salmon was 3,923 fish in 2017 compared to 3,725 fish in 2018. However, nearly twice as many Chinook salmon juveniles were released in 2018 (162,368 fish) compared to 2017 (92,015 fish; Kock and others, 2019). Results from these models also indicated differences in patterns of mortality between years. The 2017 results suggested that mortality was high early in the study period and decreased over time (Kock and others, 2019). Conversely, in 2018, results indicated that mortality was initially low but then increased over time. These differences are also supported by recovery data from various release groups. In 2017, most of subyearling Chinook salmon (64 percent) that were recovered were from the R_2 release group, followed by fish from the R_1 (33 percent) and R_3 groups (3 percent; Kock and others, 2019). In

2018, nearly all the subyearling Chinook salmon that were collected were from the R_1 release group (89 percent), followed by fish from the R_3 (6 percent) and R_2 groups (5 percent). While recoveries of fish from the R_3 release groups were low during both years, recovery of R_2 fish was much lower in 2018 than in 2017 which suggests that mortality rates were high during summer months in that year.

We lack data to definitively determine what factors resulted in different survival estimates between years, but reservoir conditions, fish distribution patterns, and emerging information on copepods warrant consideration. Winter 2016–17 was characterized by above-average snowpack in the Willamette Basin, whereas winter 2017–2018 conditions were close to normal. These differences were apparent in conditions observed in Lookout Point Reservoir during subsequent spring and summer months. In 2017, water level elevations were abnormally high (842–926 feet) in Lookout Point Reservoir during spring and early summer. Water elevations during similar periods in 2018 were close to normal (831–906 feet). Discharge at Lookout Point Dam during 2017 was more than twice as high as in 2018 during much of the study period. These factors may have affected when fish entered, and how they distributed through, the reservoir. In 2017, subyearling Chinook salmon also appeared to moved downstream through the reservoir earlier than they did in 2018. Based on monthly comparisons, we also observed that NOR subyearling Chinook salmon captured in 2017 were larger than NOR subyearling Chinook salmon captured in the reservoir during 2018. In 2017 subyearling Chinook salmon also appeared to move downstream through the reservoir earlier than they did in 2018, based on catch data. We did not collect data on distribution patterns of piscivorous fish species in the reservoir during our study, but the higher survival in 2017 could be due to less spatial overlap with predators than in 2018. Similarly, the larger size of subyearling Chinook salmon in 2017 may have resulted in reduced temporal exposure to predation, which could explain why mortality was lower in the first study year.

The disparate trends in mortality patterns between years suggests that factors other than predation could be important as well. The increasing survival trend observed in 2017 is consistent with previous observations that mortality in juvenile fishes is commonly size-dependent, with higher mortality rates associated with decreasing fish size (Sogard, 1997). The decreasing survival trend observed in 2018 was unexpected and could be linked to mortality related to copepod infection. We found that the majority of subyearling Chinook salmon were infected with copepods during August–October 2018. Copepod infection has been shown to affect swimming performance and result in significant tissue damage to the host, which likely affects survival (Sutherland and Witrock, 1985; Herron and others, 2018). Evaluations of copepod effects on subyearling Chinook salmon in the Willamette Basin are currently underway at Oregon State University (oral communication, Rachel Neuenhoff, USACE), so additional information on potential effects to survival should be available in the future. While our study provides valuable information on reservoir survival rates for subyearling Chinook salmon in Lookout Point Reservoir, additional research will be required to understand the inter-annual variability that occurs in the system and to determine which factors are important determinants of mortality.

The difference in survival estimates between 2017 and 2018 was substantial, but inter-annual variability in reservoir survival rates for subyearling Chinook salmon should be expected and has been previously observed. Studies conducted in Howard Hansen Reservoir on the White River, Washington during 1991 and 1992 reported survival estimates for Chinook salmon of 1.1 percent and 14.5 percent, respectively (Dilley and Wunderlich, 1993). In the Willamette Basin, reservoir survival of subyearling Chinook salmon was evaluated several times in Fall Creek Reservoir, producing fingerling-to-smolt survival estimates of 13.5 percent in 1973, 11.2 percent in 1974, 19.7 percent in 1990, and 28.5 percent in 1991 (Smith, 1976; Homolka and Smith, 1991; Downey and Smith, 1992). These examples illustrate the variability that has been observed for reservoir survival of Chinook salmon juveniles at specific locations. However, it should be noted that most estimates were in the 10–20 percent range. Our 2017 estimate from Lookout Point Reservoir (18.8 percent; Kock and others, 2019) is also within this range. However, the 2018 estimate (3.9 percent) is substantially lower than most estimates, and only the 1.1 percent survival estimate from Dilley and Wunderlich (1993) is lower, among studies we examined. This may indicate that survival in Lookout Point Reservoir during 2018 was abnormally low and may serve as a limiting factor for Chinook salmon in the Middle Fork Willamette River.

Results from this 2-year evaluation have yielded insights into the performance and utility of using the staggered release-recovery model and PBT *N*-mixture model to produce fry survival estimates in Lookout Point Reservoir. Based on our previous work to develop the field study design, both models provide statistically sound techniques for estimating fry survival in Lookout Point Reservoir, but each model has different assumptions and use the data in different ways (Kock and others, 2016). For the staggered release-recovery model, had all model assumptions been met, then constructing survival estimates from different combinations of release groups should have led to similar estimates of survival for common periods. However, we found wide variation among common survival parameters estimated from different release groups, providing evidence that the model's assumptions had been violated. Cumulative survival from April to June 2017 was estimated using information from all release groups and found to be 0.52 (Kock and others, 2019). Survival was also estimated for this period using information only from R_1 and R_3 and found to be 0.87. In 2018, we found that discrepancies in survival estimates were even greater for some periods. Estimates for SSRRM2 differed by 53 percent using all release combinations (0.62142) versus only R_2 and R_3 information (0.09338). Similarly, cumulative survival from April to June was estimated to be 0.61492 using all release combinations compared to 0.75211 using only R_1 and R_3 information. These differences suggest that the assumption that all release groups share both the same recapture and survival rates after the last release was not met during either year of study in Lookout Point Reservoir. This finding should not be surprising when considering that release groups entered the reservoir at different times of the year, under different environmental conditions, and at different size classes. For example, R_1 fish were released when they were about 45 mm long and entered the reservoir when water temperatures were cool. These fish resided in Lookout Point Reservoir for at least a month longer than their R_2 and R_3 counterparts. During this time, they were subjected to predation pressure and became acclimated to conditions in the reservoir, whereas R_2 and R_3 fish spent a greater proportion of their lives in a hatchery setting and entered the reservoir when they were larger and water temperatures were increasing. Given these factors, it seems unreasonable to assume that they would experience similar survival as their R_1 counterparts.

As with the staggered release-recovery model, the PBT *N*-mixture model has its own set of assumptions, advantages, and disadvantages. Results from the PBT *N*-mixture model have been encouraging because we derive similar cumulative survival estimates regardless of whether survival is estimated as a constant across months or as varying across months. This indicates that total cumulative survival estimates are relatively robust and not considerably affected by model structure. The PBT *N*-mixture model is also able to produce stable parameter estimates in the presence of very low recapture probabilities common in a large field study such as our 2-year effort in Lookout Point Reservoir. However, there are several disadvantages. First, although multiple release groups are not strictly required, the model should theoretically allow separate estimates of survival for each release group. However, during the initial model fitting phase, we found that the model had difficulty estimating separate parameters by release group. Therefore, we were forced to estimate common survival and capture probabilities among release groups, which is similar to the assumption of the staggered release model. We suspect that decreasing captures over time owing to mortality is one process making it difficult to estimate parameters separately, whereas periodic releases increases the number of fish available for capture, thereby allowing parameters to be estimated, albeit in common among release groups. Another disadvantage is that very low capture probabilities makes it impossible to estimate unique survival and capture probabilities for each sampling period and occasion, which requires constraining parameters as constants or as functions of covariates.

Based on these observations, we recommend that future studies continue to employ multiple release groups, which we found to be a necessary component of the study design that allowed parameters to be estimated from both the staggered release-recovery and PBT *N*-mixture model. Given multiple release groups, both models can be applied to recapture data, and their results compared, to aid in understanding fry survival in Lookout Point Reservoir. However, in comparing models, we found that estimates from the PBT *N*-mixture model were less variable among alternative model structures relative to the staggered release-recovery model. Furthermore, the PBT *N*-mixture model more fully uses information contained in the data by making use of replicated daily captures by family group within each sampling week. In contrast, the staggered release model pools captures among family groups and also pools over all capture occasions after release. For these reasons, we believe parameter estimates obtained under the PBT *N*-mixture model are likely more robust to assumption violations than those estimates under the staggered release-recovery model.

In summary, two large field studies were conducted in Lookout Point Reservoir during 2017 and 2018 to estimate survival of subyearling Chinook salmon. Reservoir conditions were considerably different between years, as were estimates of survival. In 2017, mortality appeared to be greatest when fish were small and cumulative survival rates were similar to those reported from other studies in large reservoirs throughout the Pacific Northwest. In 2018, mortality appeared to be low when fish were small, but it increased over time. This suggests that fish were succumbing to factors other than predation. Data collected on copepod prevalence during the 2018 study period provides one possible mechanism for mortality. Understanding what occurred during 2018 appears to be important because cumulative survival during that year is one of the lowest estimates among available studies. The PBT *N*-mixture model appears to be a reliable option for evaluating survival of subyearling Chinook salmon in reservoirs of the Willamette Valley. However, additional research will likely be required to better understand which factors are important determinants of subyearling Chinook salmon survival in these reservoirs.

Acknowledgments

We thank Ryan Koch, Rob Chitwood, and other staff at the Smith Farm Genetics and Performance Laboratory who worked diligently to produce study fish. Greg Taylor, Todd Pierce and other USACE staff with the Willamette Valley Project operated screw traps during the study and provided access for equipment storage at Lookout Point Dam. Kathleen O’Malley and Sandra Bohn conducted genetic and parentage analyses and were valuable research partners for this project.

References Cited

Beeman, J.W., Hansen, A.C., and Sprando, J.M., 2015, Observational data on the effects of infection by the copepod Salmincola californiensis on the short- and long-term viability of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) implanted with telemetry tags: Animal Biotelemetry, v. 3, p. 1–7.

Beeman, J.W., Hansel, H.C., Hansen, A.C., Evans, S.D., Haner, P.V., Hatton, T.W., Kofoot, E.E., Sprando, J.M., and Smith, C.D., 2014, Behavior and dam passage of juvenile Chinook salmon at Cougar Reservoir and Dam, Oregon, March 2012–February 2013: U.S. Geological Survey Open-File Report 2014-1177, 52 p., https://pubs.usgs.gov/of/2014/1177/.

Brandt, J.R., Monzyk, F.R., Romer, J.D., and Emig, R., 2016, Status and trends of predator species in Lookout Point Reservoir: Report by the Oregon Department of Fish and Wildlife to the U.S. Army Corps of Engineers, 44 p.

Dilley, S.J., and Wunderlich, R.C., 1993, Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992: Report by the U.S. Fish and Wildlife Service, Olympia, Washington, 70 p.

Downey, T.W., and Smith, E.M., 1992, Evaluation of spring Chinook salmon rearing program in Blue River Reservoir, 1989: Annual Progress Report from the Oregon Department of Fish and Wildlife, Portland, Oregon, 25 p.

Herron, C.L., Kent, M.L., and Schreck, C.B., 2018, Swimming endurance in juvenile Chinook salmon infected with *Salmincola californiensis*: Journal of Aquatic Animal Health, v. 30, p. 81–89.

Homolka, K., and Smith, E.M., 1991, Evaluation of spring Chinook salmon and winter steelhead passage at Fall Creek Dam, 1990: Report by the Oregon Department of Fish and Wildlife to the U.S. Army Corps of Engineers, Portland, Oregon, 52 p.

Kabata, Z, and Cousens, B., 1977, Host-parasite relationships between sockeye salmon, *Oncorhynchus nerka,* and *Salmincola californiensis* (Copepoda: Lernaeopodidae): Journal of the Fisheries Research Board of Canada, v. 34, p. 191–202.

Keefer, M.L., Taylor, G.A., Garletts, D.F., Helms, C.K., Gauthier, G.A., Pierce, T.M., and Caudill, C.C., 2013, High-head dams affect downstream fish passage timing and survival in the Middle Fork Willamette River: River Research and Applications, v. 29, p. 483–492.

Kock, T.J., Perry, R.W., Hansen, G.S., Haner, P.V., Pope, A.C., Plumb, J.M., Cogliati, K.M., and Hansen, A.C., 2019, Evaluation of Chinook Salmon (*Oncorhynchus tshawytscha*) fry survival in Lookout Point Reservoir, Western Oregon, 2017: U.S. Geological Survey Open-File Report 2019-1011, 42 p., https://pubs.er.usgs.gov/publication/ofr20191011.

Kock, T.J., Perry, R.W., Monzyk, F.R., Pope, A.C., and Plumb, J.M., 2016, Development of a study design and implementation plan to estimate juvenile salmon survival in Lookout Point Reservoir and other reservoirs of the Willamette Project, western Oregon: U.S. Geological Survey Open-File Report 2016–1211, 25 p., https://doi.org/10.3133/ofr20161211.

Kock, T.J., Beeman, J.W., Hansen, A.C., Hansel, H.C., Hansen, G.S., Hatton, T.W., Kofoot, E.E., Sholtis, M.D., and Sprando, J.M., 2015, Behavior, passage, and downstream migration of juvenile Chinook salmon from Detroit Reservoir to Portland, Oregon, 2014–15: U.S. Geological Survey Open-File Report 2015-1220, 40 p., https://pubs.er.usgs.gov/publication/ofr20151220.

Monzyk, F.R., Emig, R., Romer, J.D., and Friesen, T.A., 2015a, Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs: Report by the Oregon Department of Fish and Wildlife to the U.S. Army Corps of Engineers, 56 p.

Monzyk, F.R., Friesen, T.A., and Romer, J.D., 2015b, Infection of juvenile salmonids by Salmincola californiensis (Copepoda: Lernaeopodidae) in reservoirs and streams of the Willamette River Basin, Oregon: Transactions of the American Fisheries Society, v. 144, p. 891–902.

Muir, W.D., Smith, S.G., Williams, J.G., Hockersmith, E.E., and Skalski, J.R., 2001, Survival estimates for migrant yearling Chinook salmon and steelhead tagged with passive integrated transponders in the lower Snake and lower Columbia rivers, 1993–1998: North American Journal of Fisheries Management, v. 21, p. 269–282.

National Oceanic and Atmospheric Administration, 2008, Endangered Species Act section 7(a)(2) consultation biological opinion and Magnuson-Stevens Fishery Conservation and Management Act essential fish habitat consultation–Consultation on the Willamette River Basin Flood Control Project: National Oceanic and Atmospheric Administration Fisheries Log Number FIWR12000/02117, June 11, 2008, accessed May 2015 at http://www.nwr.noaa.gov/Salmon-Hydropower/Willamette-Basin/Willamette-BO.cfm.

Perry, R.W., Skalski, J.R., Brandes, P.L., Sandstrom, P.T., Klimley, P., Ammann, A., and MacFarlane, B., 2010, Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento-San Joaquin River delta: North American Journal of Fisheries Management, v. 30, p. 142–156.

Romer, J.D., and Monzyk, F.R., 2014, Predatory fish in Lookout Point and Foster reservoirs: Presentation at the U.S. Army Corps of Engineers' Willamette Basin Fisheries Science Review, Portland, Oregon, accessed April 27, 2016, at http://odfw.forestry.oregonstate.edu/willamettesalmonidrme/reservoir-research-publications.

Sard, N.M., O'Malley, K.G., Jacobson, D.P., Hogansen, M.J., Johnson, M.A., and Banks, M.A., 2015, Factors influencing spawner success in a spring Chinook salmon (*Oncorhynchus tshawytscha*) reintroduction program: Canadian Journal of Fisheries and Aquatic Sciences, v. 72, p. 1390–1397.

Skalski, J.R., Smith, S.G., Iwamoto, R.N., Williams, J.G., and Hoffman, A., 1998, Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia rivers: Canadian Journal of Fisheries and Aquatic Sciences, v. 55, p. 1484–1493.

Skalski, J.R., Buchanan, R.A., and Griswold, J., 2009, Review of marking methods and release-recapture designs for estimating the survival of very small fish: examples from the assessment of salmonid fry survival: Reviews in Fisheries Science, v. 17, p. 391–401.

Skalski, J.R., Weiland, M.A., Ham, K.D., Ploskey, G.R., McMichael, G.A., Colotelo, A.H., Carlson, T.J., Woodley, C.M., Eppard, M.B., and Hockersmith, E.E., 2016, Status after 5 years of survival compliance testing in the Federal Columbia River Power System (FCRPS): North American Journal of Fisheries Management, v. 36, p. 720–730.

Smith, M., 1976, Rearing spring Chinook salmon in Willamette River reservoirs: Annual Report by the Oregon Department of Fish and Wildlife, Portland, Oregon, 46 p.

Sogard, S.M., 1997, Size-selective mortality in the juvenile stage of teleost fishes—A review: Bulletin of Marine Science, v. 60, no. 3, p. 1129—1157.

Sutherland, D.R., and Wittrock, D., 1985, The effects of *Salmincola californiensis* (Copepoda: Lernaeopodidae) on the gills of farm-raised rainbow trout, *Salmo gairdneri*: Canadian Journal of Zoology, v. 63, p. 2893–2901.

U.S. Army Corps of Engineers Northwest Division, 2019a, Columbia River basin water management: U.S. Army Corps of Engineers Northwest Division, accessed April 2019 at http://www.nwd-wc.usace.army.mil/dd/common/dataquery/www/.

U.S. Army Corps of Engineers Northwest Division, 2019b, Water temperature string reports: U.S. Army Corps of Engineers Northwest Division, accessed April 2019 at http://www.nwd-wc.usace.army.mil/ftppub/water_quality/tempstrings/.

Vehtari, A., Gelman, A., and Gabry, J., 2017, Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC: Statistics and Computing, v. 27, no. 5, p. 1413—1432, https://doi.org/10.1007/s11222-016-9696-4.

Publishing support provided by the U.S. Geological Survey
Science Publishing Network, Tacoma Publishing Service Center

For more information concerning the research in this report, contact the
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Kock and others—**Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) Survival in Lookout Point Reservoir, Oregon, 2018**—Open-File Report 2019-1097

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20191097