Prepared in cooperation with U.S. Army Corps of Engineers

Synthesis of Downstream Fish Passage Information at Projects Owned by the U.S. Army Corps of Engineers in the Willamette River Basin, Oregon

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Cover: Photographs showing fish passage and Willamette River Basin projects in Oregon.
Top left: Lookout Point Dam tailrace looking upstream and rotary screw trap, June 1, 2017.
Top right: Juvenile Chinook salmon, June 26, 2017.
Bottom left: Research boat at Cougar Reservoir, March 3, 2011. Photograph by John Beeman, U.S. Geological Survey.
Bottom right: Portable floating fish collector in Cougar Reservoir, July 28, 2015.

All photographs by Amy Hansen, U.S. Geological Survey, unless otherwise noted.

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By Amy C. Hansen, Tobias J. Kock, and Gabriel S. Hansen

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	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.)

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

°F = (1.8 × °C) + 32.

Datum

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

Abbreviations

CI	confidence interval
CRR	cohort replacement rate
DPE	dam passage efficiency
FPE	fish passage efficiency
g	acceleration due to gravity
MW	megawatt
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
ODFW	Oregon Department of Fish and Wildlife
PFFC	portable floating fish collector
PIT	passive integrated transponder
Project	Willamette Valley Project
rm	river mile
RO	regulating outlet
RPE	reservoir passage efficiency
SAR	smolt-to-adult returns
SE	standard error
TDG	total dissolved gas
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Synthesis of Downstream Fish Passage Information at Projects Owned by the U.S. Army Corps of Engineers in the Willamette River Basin, Oregon

By Amy C. Hansen, Tobias J. Kock, and Gabriel S. Hansen

Abstract

The U.S. Army Corps of Engineers (USACE) operates the Willamette Valley Project (Project) in northwestern Oregon, which includes a series of dams, reservoirs, revetments, and fish hatcheries. Project dams were constructed during the 1950s and 1960s on rivers that supported populations of spring Chinook salmon (*Oncorhynchus tshawytscha*), winter steelhead (*O. mykiss*), and other anadromous fish species in the Willamette River Basin. These dams, and the reservoirs they created, negatively affected anadromous fish populations. Efforts are currently underway to improve passage conditions within the Project and enhance populations of anadromous fish species. Research on downstream fish passage within the Project has occurred since 1960 and these efforts are documented in numerous reports and publications. These studies are important resources to managers in the Project, so the USACE requested a synthesis of existing literature that could serve as a resource for future decision-making processes. In 2016, the U.S. Geological Survey conducted an extensive literature review on downstream fish passage studies within the Project. We identified 116 documents that described studies conducted during 1960–2016. Each of these documents were obtained, reviewed, and organized by their content to describe the state-of-knowledge within four subbasins in the Project, which include the North Santiam, South Santiam, McKenzie, and Middle Fork Willamette Rivers. In this document, we summarize key findings from various studies on downstream fish passage in the Willamette Project. Readers are advised to review specific reports of interest to insure that study methods, results, and additional considerations are fully understood.

Introduction

The U.S. Army Corps of Engineers (USACE) operates the Willamette Valley Project (Project) in northwestern Oregon, which includes a series of dams, reservoirs, revetments, and fish hatcheries. The primary purpose of the Project is flood risk management, but it also is operated to provide water for hydroelectricity, municipal and industrial water supplies, navigation, instream flows for fish and wildlife, and recreation. The hatcheries provide mitigation for salmon habitat that was lost when dams were constructed on Willamette River tributaries. In 2008, the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) determined that the Project was jeopardizing the sustainability of anadromous fish stocks in the Willamette River Basin and mandated a series of Project improvements (National Marine Fisheries Service, 2008). This resulted in a need for quality data that could be used by resource managers in the basin. Much research has occurred at Project dams and reservoirs, but reports from these studies are not available as a collective resource for managers, so the USACE contracted with the U.S. Geological Survey to synthesize all available information into a single document.

Several important anadromous, migratory, and resident fish species live in the Willamette River Basin. The NMFS listed Upper Willamette River spring Chinook salmon (*Oncorhynchus tshawytscha*) and winter steelhead (*O. mykiss*) as threatened under the Endangered Species Act in 1999 (National Marine Fisheries Service, 1999a, 1999b). Summer steelhead are not native to the Willamette Basin and were first introduced upstream of Willamette Falls as mitigation for lost winter steelhead production (Sharpe and others, 2015). These are the primary anadromous fish species in the Willamette River Basin. Additionally, the Oregon chub also resides in the basin, and in 2015 was the first fish to be delisted from the Endangered Species Act (U.S. Fish and Wildlife Service, 2015). Bull trout (*Salvelinus confluentus*) reside in the McKenzie and South Fork McKenzie Rivers, and in the Middle Fork Willamette River upstream of Hills Creek Dam. The population in the Middle Fork Willamette River was restored from the McKenzie River stock, and natural production has been documented since 2005 (Oregon Department of Fish and Wildlife [ODFW]; http://odfw.forestry.oregonstate.edu/willamettesalmonidrme/mid-willamette-bull-trout-rehabilitation-project). Lamprey (*Entosphenus tridentatus, Lampetra ayresii, Lampetra richardsoni*) are present in the Willamette River subbasin, but not commonly found in areas upstream of the dams.

This report summarizes downstream fish passage research, which has been conducted in the Willamette River since 1960. The nine dams and reservoirs we describe are located in four subbasins of the Willamette River and include the North Santiam River subbasin, South Santiam River subbasin, McKenzie River subbasin, and Middle Fork Willamette River subbasin (fig. 1). At Project dams, downstream fish passage occurs through various routes including spillways, spillway weirs, regulating outlets (ROs), diversion tunnels, fish horns, turbines, water temperature control tower, and an experimental floating collector. In many cases, fish passage options are affected by dam operations. Most of the dams are high-head projects that are operated for flood risk management, which entails lowering reservoirs in fall, minimizing reservoir levels during the winter, refilling in spring, and maintaining at maximum levels in summer (fig. 2). These changes affect potential passage routes at a given dam because some passage routes are dewatered during certain periods of the year, or located well below the surface where juvenile salmon are unlikely to pass during other times of the year. Thus, there are important links between dam operations, reservoir water elevations, and fish passage at Project dams. These factors have been addressed in various studies and are summarized in this document.

We conducted an extensive literature search and identified 116 written documents that described fish passage evaluations of anadromous fish conducted at USACE-owned dams since 1960. We then collected copies of each document and created a digital library and bibliography containing all reports and publications. A copy of this bibliography is available in section, “References Cited”. Documents reviewed but not cited in this report are shown in appendix A. The digital library that we created will be provided separately to the USACE as part of this project. Once the digital library and bibliography were assembled, we reviewed each document and identified content related to downstream fish passage at USACE-owned dams. These results were grouped by subbasin and are described in this report. Each cited document and the subbasin, year, and technology used in the study is shown in the appendix B tables. Measurement data primarily were presented using the English measurement system, except for fish size data, which were presented as millimeters using the metric system. We made no attempt to convert measurement data, and present it as-is according to the local convention. The goal of this report is to provide an overview of the existing body of research on downstream fish passage at USACE-owned dams in the Willamette River Basin. Given the number of studies that were reviewed and synthesized, it was not possible to provide specific details on study design and conclusions for each evaluation. We recommend that interested parties read specific reports of interest to fully appreciate the details provided by researchers, particularly if findings from those studies are being used to support decision-making processes.

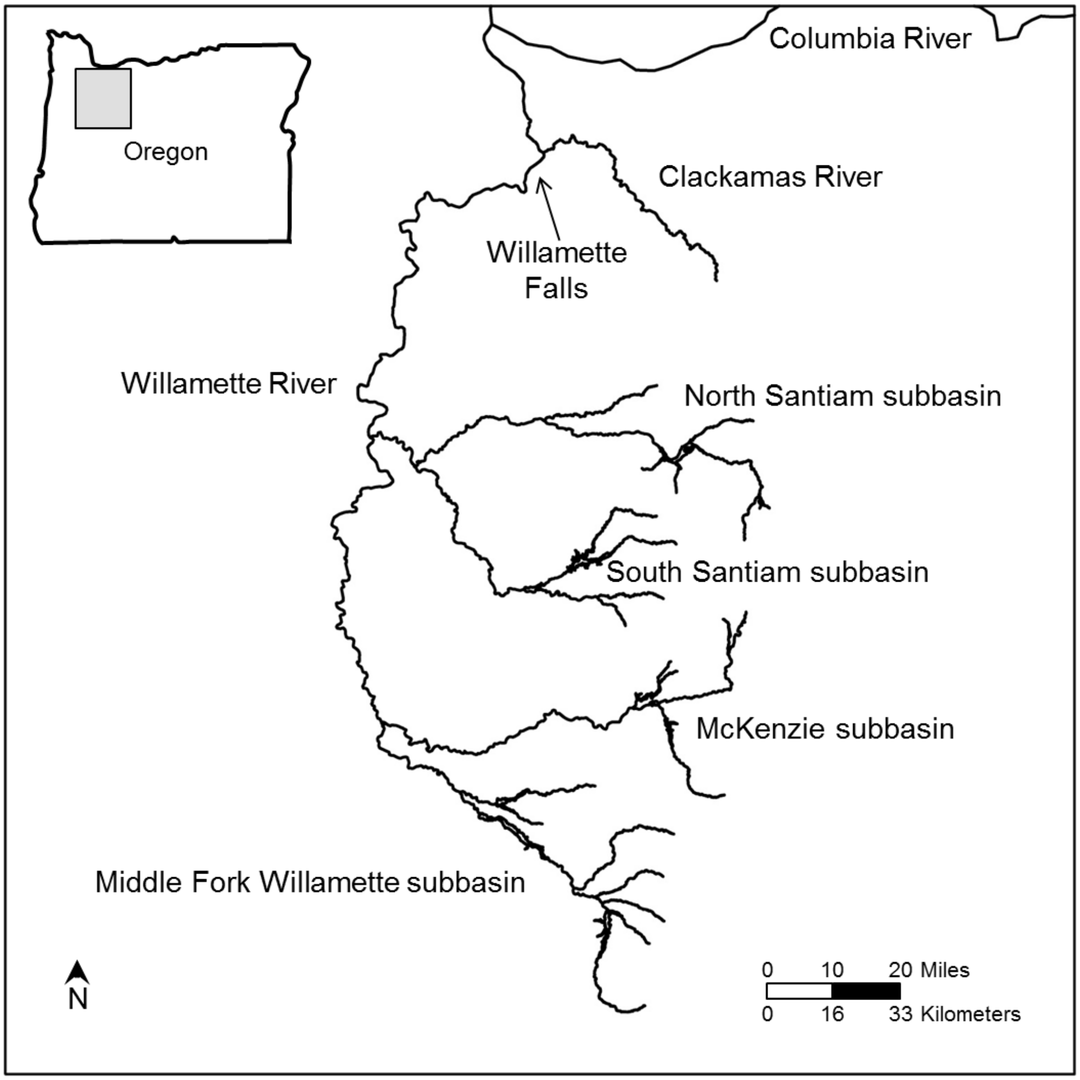

Figure 1. Map showing primary rivers and subbasins in the Willamette River Basin, Oregon. Inset of the state of Oregon with the Willamette River Basin shaded in gray is shown in the upper left corner of the map.

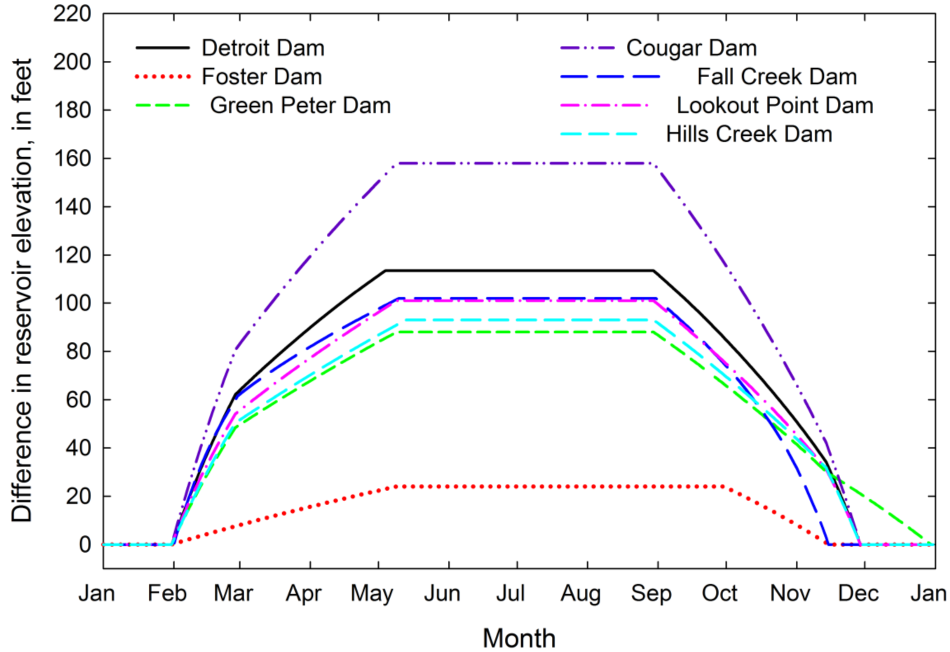

Figure 2. Graph showing planned reservoir elevation targets (rule curve) at reservoirs owned by the U.S. Army Corps of Engineers in the Willamette River Basin, Oregon. Difference in reservoir elevation is between minimum and maximum conservation pool.

North Santiam River Subbasin

Subbasin Description

The North Santiam River drains about 654 mi^2 on the western slopes of the Cascade Mountain Range in northwestern Oregon. Average daily discharge is 6,120 ft^3/s (range, 471–25,500 ft^3/s; U.S. Geological Survey [USGS] streamgage 14183000) and major tributaries include the Breitenbush River, Box Canyon Creek, Kinney Creek, and the Little North Santiam River (U.S. Geological Survey, 2016a; fig. 3). The North Santiam River is impounded by five dams including Detroit Dam, Big Cliff Dam, Minto Dam, and Upper Bennett Dam/Lower Bennett Dam (hereinafter “Bennett Dam complex”; fig. 3). Detroit and Big Cliff dams are owned and operated by the USACE. The ODFW operates Minto Dam, which is owned by the USACE. The Bennett Dam complex is owned and operated by the Salem Water Control District. A single fish hatchery, Marion Forks Hatchery, is located on the North Santiam River tributaries of Marion and Horn Creeks, about 17 mi east of Detroit, Oregon (fig. 3). The hatchery began operating in 1951 to mitigate for the development of Detroit and Big Cliff dams. Marion Forks Hatchery primarily is funded by the USACE, but ODFW contributes funding as well to enhance fishing opportunities for brook trout (*Salvelinus fontinalis*), cutthroat trout (*Oncorhynchus clarkii*), and rainbow trout (*O. mykiss*) throughout the basin (Boyd and Chilton, 2015a).

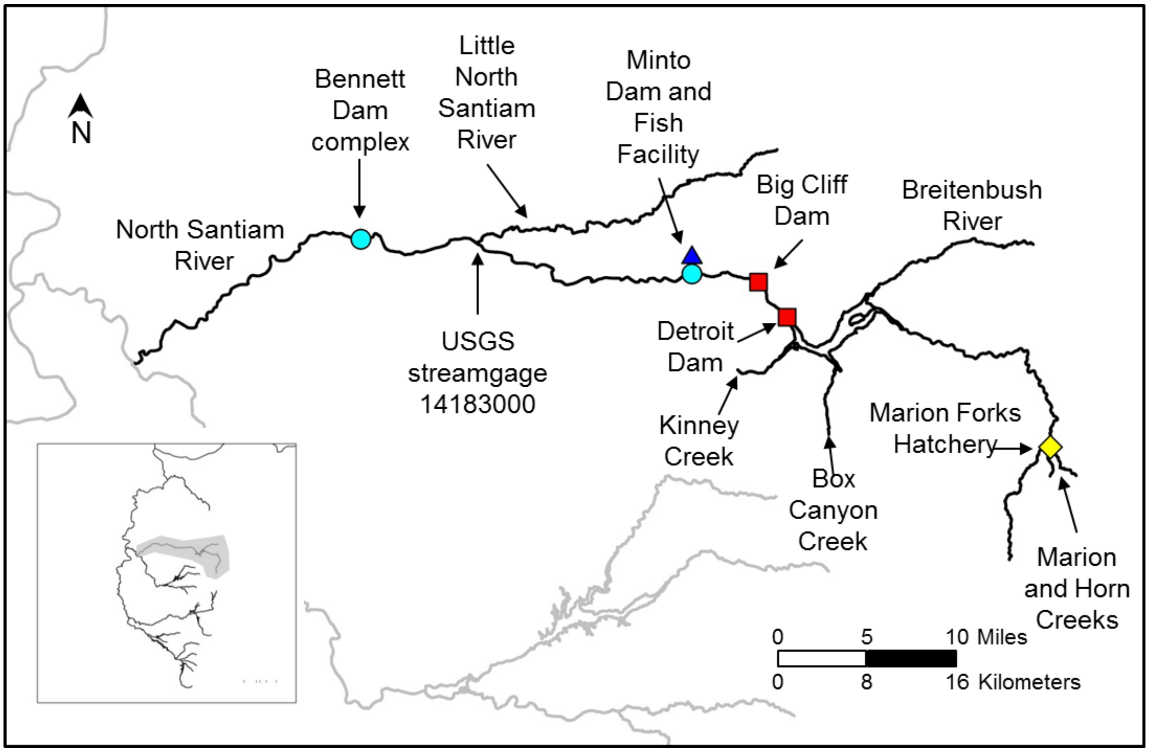

Figure 3. Map showing primary rivers in the North Santiam River subbasin (black lines), U.S. Army Corps of Engineers (USACE)-owned dams (red squares), non-USACE dams (blue circles), fish hatcheries (yellow diamonds), and adult fish facilities (blue triangles), Willamette River Basin, Oregon. Other Willamette Basin rivers outside of the North Santiam subbasin are in gray. Inset of the Willamette River Basin with the North Santiam subbasin shaded in gray is in the lower left.

Winter steelhead and the distinct North Santiam River stock of spring Chinook salmon were historically present in the North Santiam subbasin. South Santiam summer steelhead were introduced to the system and are managed by the ODFW Upper Willamette Summer Steelhead Hatchery Program to mitigate for lost production resulting from dam construction (Sharpe and others, 2013). These are the primary anadromous fish species in the North Santiam subbasin.

Adult Chinook salmon and steelhead that return to the North Santiam River can move volitionally upstream until they encounter Minto Dam, about 4 mi downstream of Big Cliff Dam. Adult collection occurs at Minto Dam, in the Minto Dam Fish Facility (fig. 3), where fish are sorted to meet releasing and hatchery production goals for the subbasin. The Minto Dam Fish Facility was rebuilt in 2013 and is used for year-round adult fish collection, spawning, and juvenile acclimation (Grenbemer and Chilton, 2014). It is funded by the USACE.

Fish production for the North Santiam subbasin occurs in various locations throughout the Willamette River Basin. Annual collection of adult spring Chinook salmon at the Minto Dam Fish Facility ranged from 825 fish in 2011 to 3,839 fish in 2015 (table 1). During 2013–15, collection of adult winter steelhead was very low (less than 200 fish per year), and collection of adult summer steelhead ranged from 266 fish in 2013 to 1,857 fish in 2014 (table 1). Unclipped adult spring Chinook salmon are released in the fish sanctuary upstream of Minto Dam, and clipped adult spring Chinook salmon are released in several locations in the North Santiam subbasin, including areas in and upstream of Detroit Reservoir (table 1). Unclipped winter steelhead are returned to the North Santiam River for spawning between Big Cliff and Minto Dams (fig. 3), an area managed as a wild fish sanctuary. Adult summer steelhead are returned to the North Santiam River downstream of Minto Dam to provide additional harvest opportunities for anglers. Spring Chinook salmon are reared at Marion Forks Fish Hatchery and releases occur downstream of Minto Dam with some released in and upstream of Detroit Reservoir. Only adipose-intact adult Chinook salmon are released in the wild fish sanctuary between Big Cliff and Minto Dams (Sharpe and others, 2016). During 2011–15, annual releases of hatchery juvenile Chinook salmon ranged from 714,370 fish in 2015 to 1,029,476 fish in 2014 (table 2). Summer steelhead are reared at hatcheries outside the North Santiam subbasin and then transferred to the Minto Dam Fish Facility for acclimation and release. Releases of hatchery summer steelhead smolts were about 120,000 fish annually in 2011–15 (table 2).

Table 1. Number of adult spring Chinook salmon and adult steelhead collected in the North Santiam River, Oregon, 2011–15.

[Data from Grenbemer and others, 2011; Boyd and Chilton, 2012a, 2014a; Sharpe and others, 2013, 2014, 2015, 2016; Grenbemer and Chilton, 2014, 2015, 2016. Adult spring Chinook salmon were released in and upstream of Detroit Reservoir. NA, not applicable]

Year	Spring Chinook salmon		Winter steelhead	Summer steelhead
	Collected	Released	Collected	Collected
2011	825	151	NA	NA
2012	1,087	257	NA	NA
2013	2,790	1,138	100	266
2014	2,878	872	179	1,857
2015	3,839	1,521	186	484

Table 2. Number of juvenile spring Chinook salmon and summer steelhead released from Marion Forks, South Santiam, Willamette, and Roaring River Hatcheries to the North Santiam River, Oregon, 2011–15.

[Data from Grenbemer and others, 2011; Boyd and Chilton, 2012a, 2014a, 2015a, 2016a. NA, not applicable]

Year	Spring Chinook salmon	Summer steelhead		
	Marion Forks Hatchery	South Santiam Hatchery	Willamette Hatchery	Roaring River Hatchery
2011	826,158	NA	65,516	55,173
2012	880,472	NA	65,516	55,173
2013	722,506	NA	67,166	56,864
2014	1,029,476	NA	68,720	54,725
2015	714,370	55,234	64,817	NA

Detroit Dam

Detroit Dam was constructed at river mile (rm) 49 on the North Santiam River in 1953 (figs. 4 and 5). The dam is a concrete structure that includes two Francis turbines capable of producing 100 megawatts (MW) of power (5,340 ft^3/s), six gated spill bays, and four ROs (fig. 5; U.S. Army Corps of Engineers, 2016a). The dam is 1,523 ft long, 463 ft high and impounds 321,000 acre-ft in Detroit Reservoir (U.S. Army Corps of Engineers, 2016a, 2016b). The primary purpose of Detroit Dam is to provide flood risk management for the Willamette Basin, but it also is operated to improve downstream water quality, to provide municipal and industrial water supplies and recreation, and to protect fish and wildlife habitat (U.S. Army Corps of Engineers, 2016a). Detroit Dam operates as a power-peaking project where power is generated for only a few hours at a time when electricity demand is high. Since 2007, summer operations at Detroit Dam have been controlled to provide downstream water temperature management through the combined release of warm surface water through shallow spill gates and cool water from deep in the reservoir through the powerhouse. Reservoir water level elevations undergo annual fluctuations greater than 100 ft as the reservoir reaches minimum pool elevation levels of 1,450 ft during winter and refills to 1,563.5 ft during summer (fig. 5; U.S. Army Corps of Engineers, 2016c). As a result, the spillway at an elevation of 1,541 ft is not accessible for passage during several months each year, and passage through the powerhouse (penstocks at an elevation of 1,419 ft) and ROs (at elevations of 1,265 and 1,340 ft, respectively) becomes more accessible for juvenile salmon as these routes are located closer to the surface when reservoir elevations are low (fig. 5). Fish passing through the RO must sound at least 110 ft at the minimum conservation pool to enter the trash rack at the opening to the gate-controlled outlet. Fish exit the RO on the downstream side of the spillway outfall. The spillway and ROs generally are not operated concurrently as the ROs primarily are used only during high discharge events in the winter or during powerhouse maintenance.

Figure 4. Photograph showing Detroit Dam on the North Santiam River, Oregon. Photograph by the U.S. Army Corps of Engineers.

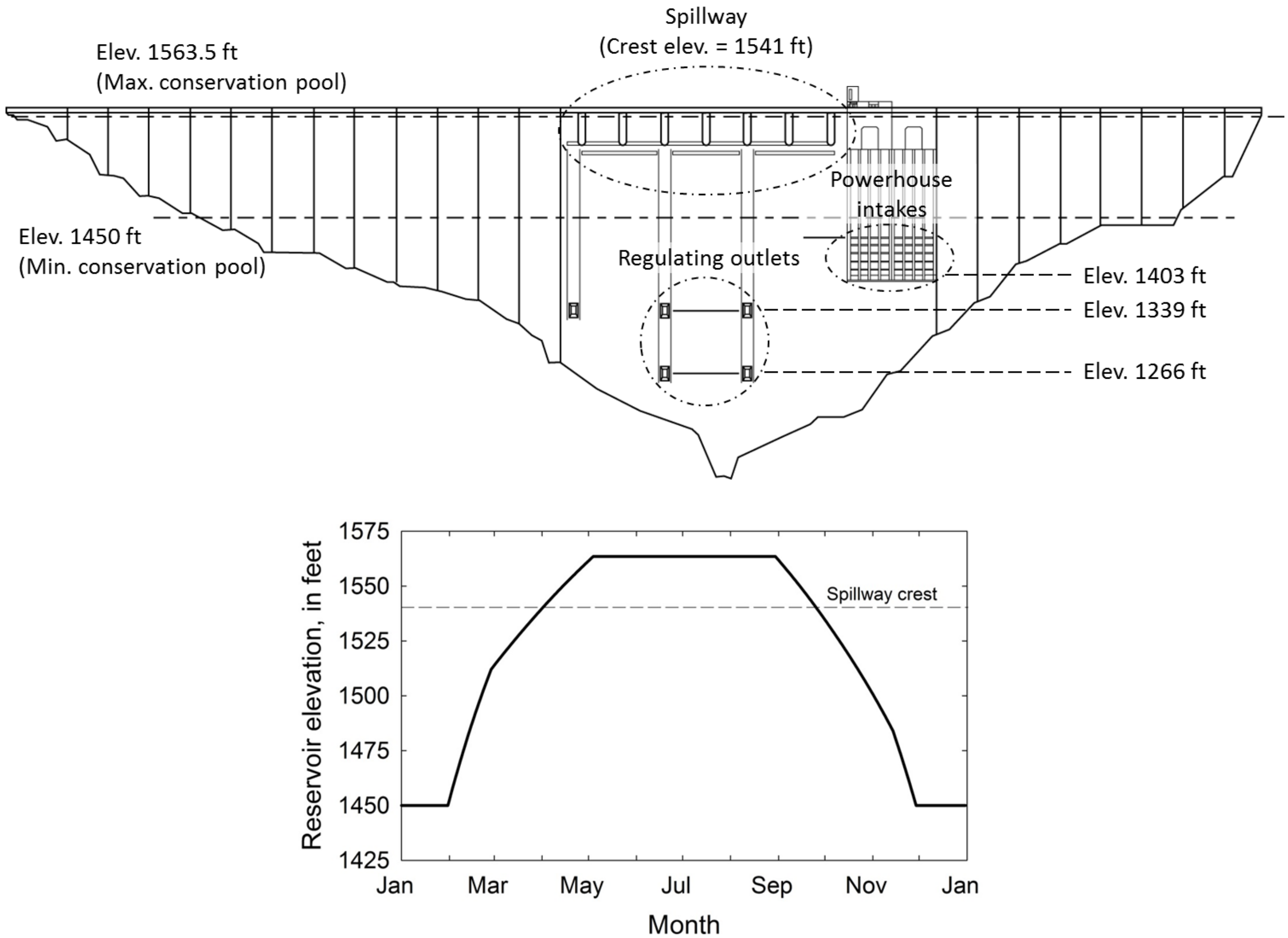

Figure 5. Schematic of the forebay side of Detroit Dam (top) showing passage route locations (circled) and elevations with minimum and maximum conservation pool elevations (dashed lines) for reference. Prescribed reservoir elevation targets for Detroit Reservoir (bottom) from January through December are shown with spillway crest elevation for reference. Top figure modified from figure 2 in Beeman, Hansel, and others, 2014a.

Big Cliff Dam

Big Cliff Dam was built in conjunction with Detroit Dam and is operated as a re-regulating facility to control water-level fluctuations that occur from hydroelectricity production at the upstream project. Big Cliff Dam is located at rm 46 on the North Santiam River and has one Kaplan turbine capable of producing 18 MW of power (3,100 ft^3/s) and three gated spill bays (figs. 3 and 6; U.S. Army Corps of Engineers, 2016a). The dam is 280 ft long and 191 ft high, impounding 6,450 acre-ft of water in Big Cliff Reservoir. Daily fluctuations from 1,182 to 1,206 ft in elevation can occur in Big Cliff Reservoir because of water releases upstream of Detroit Dam. Downstream passage at Big Cliff Dam is restricted to spillway or turbine passage.

Fish passage information in the North Santiam subbasin primarily is available for Detroit Dam. Numerous studies have been conducted in Detroit Reservoir and at Detroit Dam, and most of these evaluations have focused on juvenile Chinook salmon. However, there is limited information on juvenile steelhead as well. Little has been reported on fish passage at Big Cliff Dam, but there are studies that provide useful information on travel rates and survival in Big Cliff Reservoir. These studies are summarized in the following section of this report.

Figure 6. Photograph showing Big Cliff Dam on the North Santiam River, Oregon. Photograph by the U.S. Army Corps of Engineers.

Reservoir Entry

Outmigration data for juvenile Chinook salmon were collected upstream of Detroit Reservoir using screw traps, and results from these studies show that reservoir entry peaks during late spring and early summer. Juvenile salmon enter Detroit Reservoir from two rivers, the North Santiam and the Breitenbush Rivers (fig. 3). In the North Santiam River, peak migration occurred during April–June, and median migration occurred between May 6 and 14 during 2011–14 and on the earliest date of April 20 in 2015 (fig. 7; Romer and others, 2012, 2013, 2014, 2015, 2016). Outmigration from the Breitenbush River seems to occur earlier, based on peak collections reported during February–April 2011 and 2015 (fig. 8; Romer and others, 2012, 2016). The median date of outmigration occurred on March 8 in 2011, and on March 27 in 2015. This difference in migration timing likely is due to temperature differences in the two rivers in areas where salmon eggs are incubating. Romer and others (2012) reported that Breitenbush River water temperatures generally were warmer than North Santiam River water temperatures. In 2015, estimated abundance of Chinook salmon outmigrants in the Breitenbush River upstream of Detroit Reservoir through June 19 was 55,951 (95-percent confidence interval [CI] ±10,457; Romer and others, 2016). In early spring, fork length of juvenile Chinook salmon migrants was in the 30–40 mm range, and some subyearling fall migrants from the North Santiam River were collected with fork lengths approaching 140 mm (fig. 7). The quantity of Chinook salmon fry collected in screw traps upstream of Detroit Reservoir seemed related to the number of female adults released in the previous calendar year (Romer and others, 2012, 2013, 2014, 2015, 2016). The estimated abundance of outmigrants passing the screw trap in the North Santiam River upstream of Detroit Reservoir was 587,960 (95-percent CI ±193,708; Romer and others, 2012). There were not enough fish collected in other years to generate an abundance estimate (Romer and others, 2013, 2014, 2015).

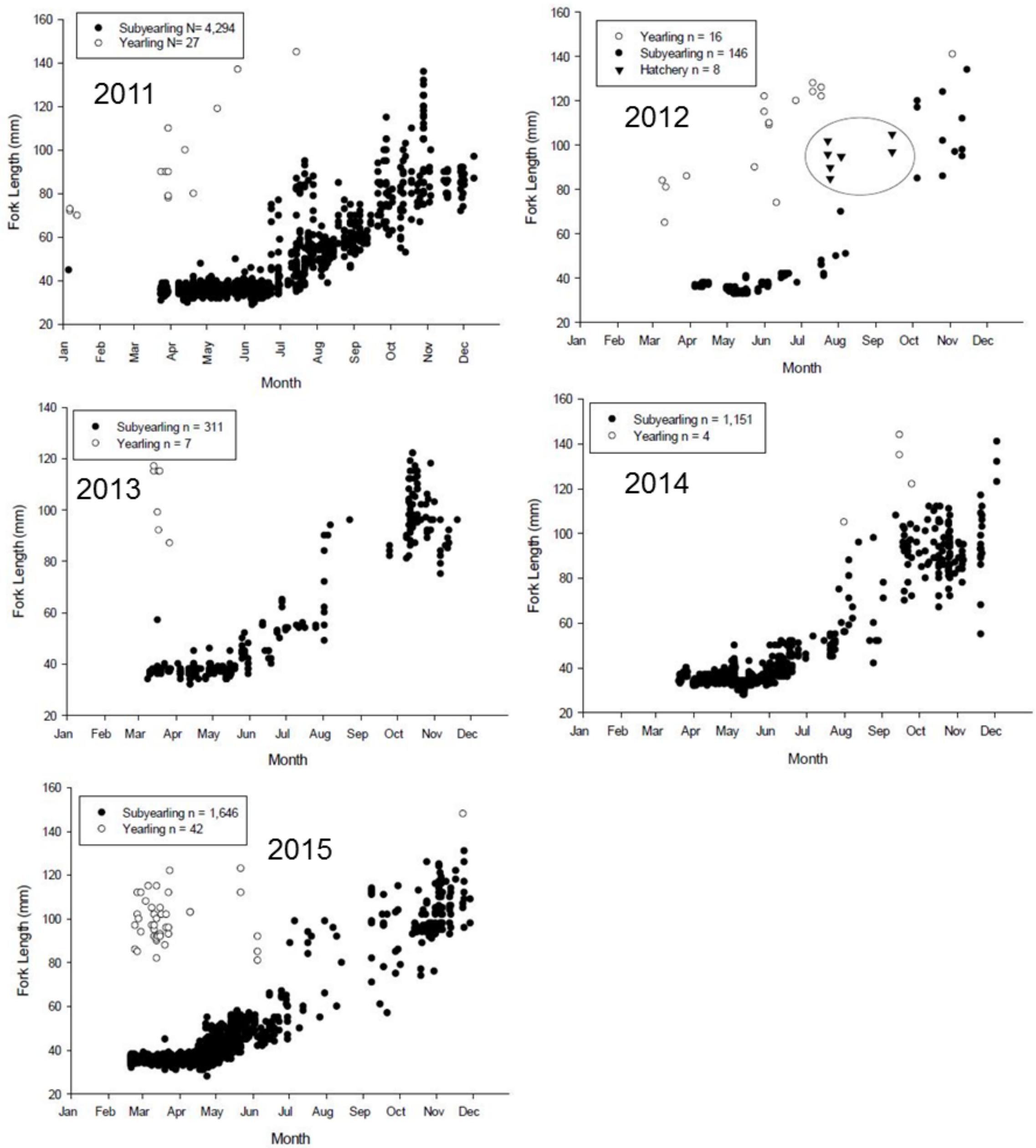

Figure 7. Graphs showing daily collection of juvenile Chinook salmon in rotary screw traps, by fork length (in millimeters [mm]) and year, upstream of Detroit Reservoir, North Santiam River, Oregon, 2011–15. Data in the circle indicate fish that were presumed to be of hatchery origin as noted by the original authors. Note the different y-axis scales on some graphs. Graphs from Romer and others, 2012, 2013, 2014, 2015, 2016.

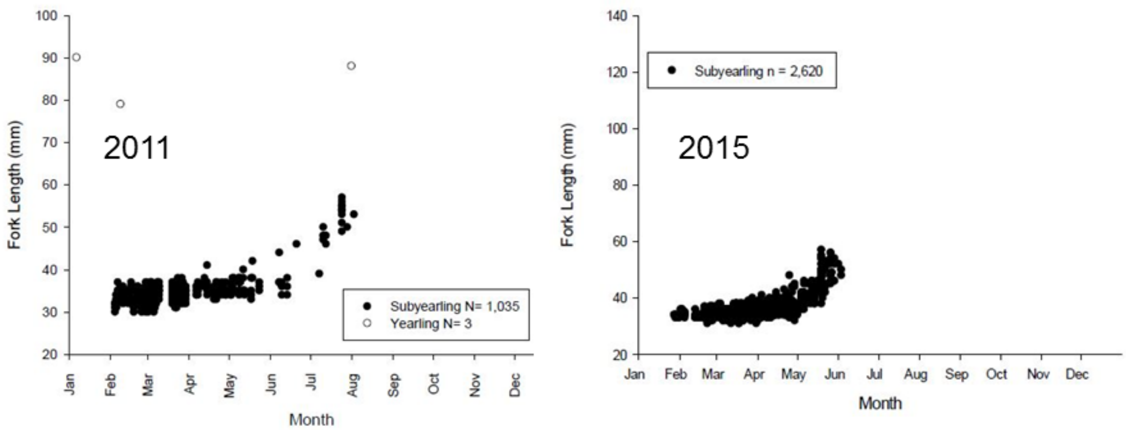

Figure 8. Graphs showing daily collection of juvenile Chinook salmon in rotary screw traps, by fork length (in millimeters [mm]) and year, upstream of Detroit Reservoir, Breitenbush River, Oregon, 2011 and 2015. Note the different y-axis scales on each of the two graphs. Graphs from Romer and others, 2012, 2016.

Acoustic telemetry studies in 2012 and 2013 showed that summer steelhead were less likely than Chinook salmon to move downstream of tributary release sites and enter Detroit Reservoir. Tagged fish were released 1.7 and 2.5 river miles upstream of Detroit Reservoir in the Breitenbush and North Santiam Rivers, respectively (table 3). Mean size of Chinook salmon was 141.6–152.7 mm and mean size of steelhead was 164.6–175.8 mm during 2012–14 (table 3). Spring fish were released during February–May, and fall fish were released during September–November. Acoustic tags were expected to last 90–150 d and the staggered release strategy insured that tagged fish were present year-round in the reservoir (Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015). Most (0.799–0.901) of the Chinook salmon moved downstream and were detected in the reservoir during the 3-month study period after each fish release (fig. 9; table 4; Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015). Tagged steelhead were less likely than Chinook salmon to move downstream of the release sites and enter Detroit Reservoir. About two-thirds of spring-released steelhead and one-quarter of fall-released steelhead were detected in the reservoir (fig. 9; table 4; Beeman, Hansel, and others 2014a; Beeman and Adams 2015). Beeman, Hansel, and others (2014a, p. 56) stated: “The fate of the fish that were never detected in the reservoir is unknown because no attempt was made to detect tagged fish in the tributaries. The undetected fish may have died, remained alive in the tributaries, or never migrated downstream to the most upstream detection array.”

Table 3. Summary statistics of fork length (in millimeters) of acoustic tagged hatchery spring Chinook salmon and summer steelhead at Detroit Reservoir, Oregon, 2012–14.

[Data from Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015; Kock and others, 2015. Spring releases occurred during March–May (reservoir filling and full conservation pool); fall releases occurred during September–November (drawdown and low conservation pool); and data collection was 68–92.5 days from release, depending on study year]

Study year	Season	Species	Release site	Number	Mean	Range	Author
2012	Spring	Chinook salmon	North Santiam River	236	142.6	114–180	Beeman, Hansel, and others, 2014a
			Breitenbush River	232	142.1	116–179	
		Steelhead	North Santiam River	100	173.4	156–180	
			Breitenbush River	100	172.7	156–180	
	Fall	Chinook salmon	North Santiam River	261	141.8	100–178	
			Breitenbush River	253	141.6	101–173	
2013	Spring	Chinook salmon	North Santiam River	197	152.4	115–181	Beeman and Adams, 2015
			Breitenbush River	197	152.7	118–181	
		Steelhead	North Santiam River	53	175.2	140–183	
			Breitenbush River	51	175.8	156–183	
			Detroit Reservoir	125	170.0	143–180	
	Fall	Chinook salmon	North Santiam River	303	149.1	118–180	
			Breitenbush River	303	148.9	115–179	
		Steelhead	North Santiam River	135	164.6	135–180	
			Breitenbush River	136	166.2	138–180	
2014	Summer	Chinook salmon	North Santiam River	997	102.7	95–123	Kock and others, 2015
			Minto Dam: live	645	102.7	95–116	
			Minto Dam: dead	25	102.4	96–112	

Table 4. Seasonal stream passage and reservoir passage efficiencies and median travel times of acoustic-tagged hatchery spring Chinook salmon and summer steelhead at Detroit Dam, Oregon, 2012–13.

[Data from Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015. STRE, Number of fish detected in the reservoir divided by number released; RPE, Number of fish detected at forebay divided by number detected in the reservoir; NA, not applicable—fish not released in this study period; NC, median travel time was not calculated because less than 50 percent of fish were detected at an area]

Season	Species	Year	STRE	RPE	Median travel time (days)	
					Release to reservoir	Reservoir to forebay
Spring	Chinook salmon	2012	0.880	0.925	2.4	10.0
		2013	0.799	0.883	1.7	7.1
	Steelhead	2012	0.615	0.870	41.2	4.4
		2013	0.663	0.855	15.9	9.1
Fall	Chinook salmon	2012	0.901	0.821	1.3	8.6
		2013	0.891	0.850	1.0	3.6
	Steelhead	2012	NA	NA	NA	NA
		2013	0.258	0.286	NC	NC

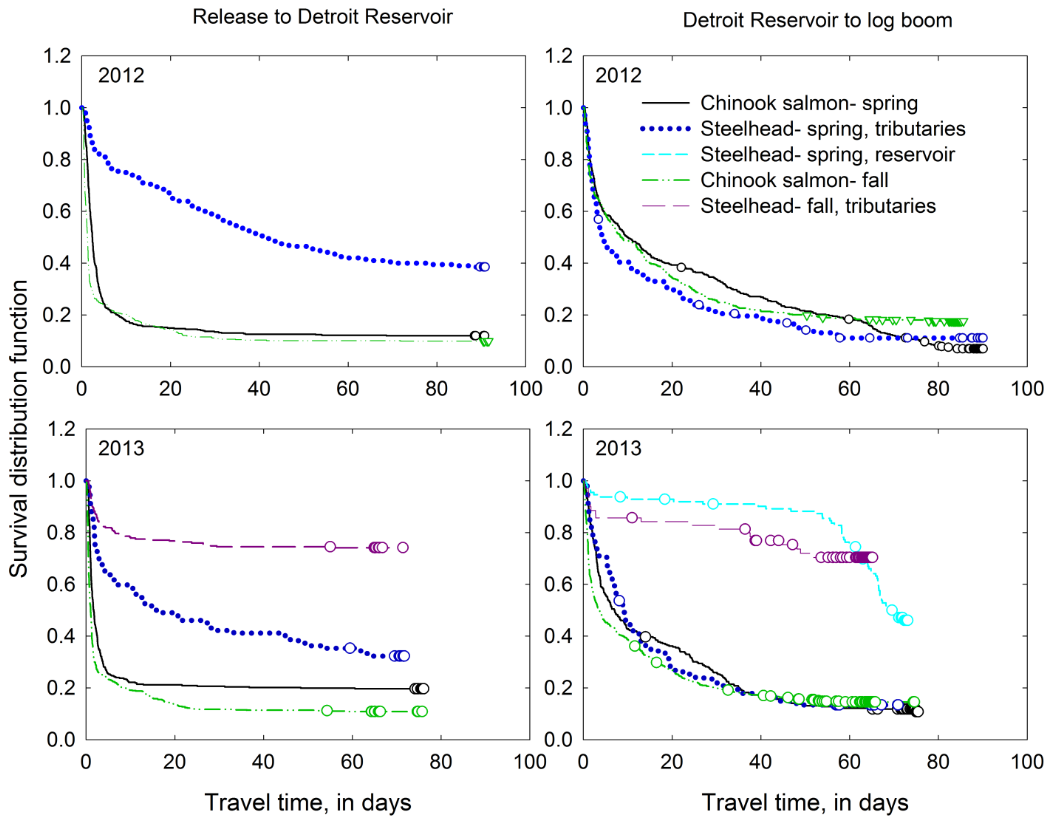

Figure 9. Graphs showing survival distribution of acoustic-tagged hatchery spring Chinook salmon and summer steelhead travel times at Detroit Dam and Reservoir, Oregon, 2012–13. Observations are right-censored (open circles) at the 90th-percentile of tag life if fish were not yet detected. Data from Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015.

Reservoir Residence and Behavior

Reservoir sampling by Monzyk and others (2012, 2014) showed that subyearling Chinook salmon were distributed throughout Detroit Reservoir during April, May, and June with 47.5–90.8 percent of fish located at the upstream end of the reservoir, near natal stream mouths during the earlier part of the study period (table 5). In these studies, fish were collected in nearshore and offshore areas with box nets, Oneida Lake traps, and depth-stratified gill nets. Average fish size was greater in lower reaches of the reservoir than in upper reaches (Monzyk and others, 2014). As the surface water temperatures increased during summer, fish occupied waters in 16 °C range and then were more evenly dispersed between sampled depths in September and October (Monzyk and others, 2012, 2013). Fish were in shallow water in November and December, when water temperatures were uniform across depths (Monzyk and others, 2013, 2014).

Subyearling Chinook salmon rearing in the reservoir had higher growth rates than fish rearing in streams (fig. 10). Growth rates in Detroit Reservoir were among the highest measured in sampled Willamette Valley reservoirs (Monzyk and others, 2015a). During 2011–14, Monzyk and others (2015a) reported growth rates of 0.73–0.90 mm/d for subyearling Chinook salmon in Detroit Reservoir (table 6).

Table 5. Percentage of subyearling Chinook salmon collected in box traps by month in three regions of Detroit Reservoir, Oregon, 2013.

[Data from Monzyk and others, 2014. Unmarked hatchery fry were released at the head of the Detroit Reservoir on May 15. *N*, number of fish]

Sample year	Trap type	Month	*N*	Lower	Middle	Upper
2013	Box trap	April	99	11.1	41.4	47.5
	Box trap	May	98	0	9.2	90.8
	Box trap	June	18	5.6	44.4	50.0

Table 6. Growth rate estimates (in millimeters per day) of subyearling Chinook salmon calculated from mean fork lengths in the spring and fall in Willamette Valley Project reservoirs, Oregon, 2011–14.

[Table from Monzyk and others, 2015a. ND, no data collected]

	Growth rate			
Reservoir	2011	2012	2013	2014
Detroit	0.73	[1]0.78	0.84	[1]0.90
Foster	n/a	n/a	0.80	n/a
Cougar	0.52	0.55	0.52	0.61
Lookout Point[2]	0.61	0.86	0.84	0.86
Fall Creek	ND	ND	[3]0.84	0.71

[1]Mean fork length in May estimated from screw trap upstream of reservoir.

[2]Growth rate calculated as mean size differences between April and October.

[3]Fish size in March not available. Growth rate estimated based on assumed mean length on March 15 of 34 millimeters (from Keefer and others, 2012).

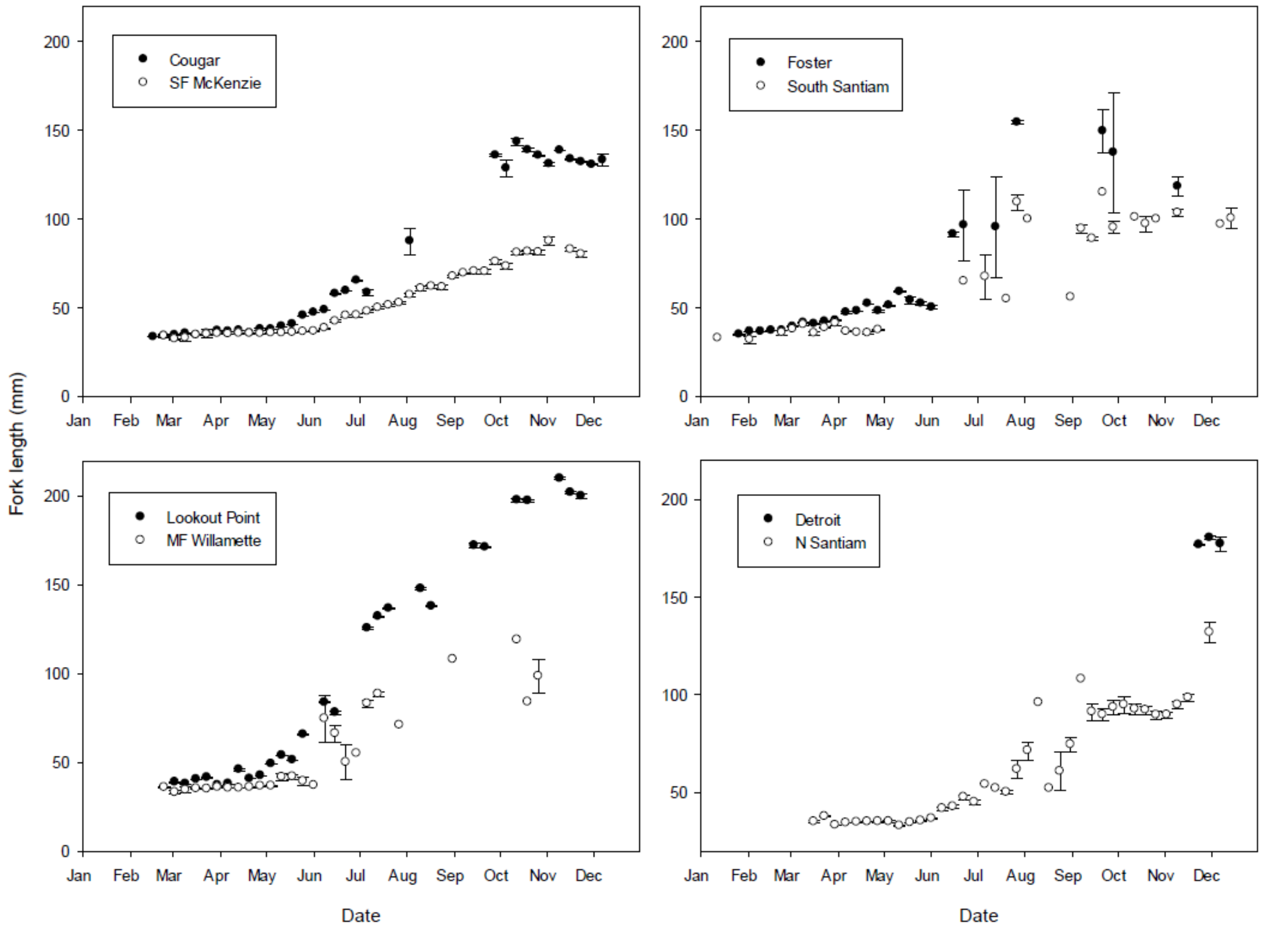

Figure 10. Graphs showing mean weekly fork lengths (in millimeters [mm]) of subyearling Chinook salmon captured in Cougar, Foster, Lookout Point, and Detroit Reservoirs and streams upstream of reservoirs, Oregon, 2014. Error bars are the standard error. For clarity, only weeks with two or more fish collected are shown. Graphs from Monzyk and others, 2015a.

Juvenile Chinook salmon and steelhead have long residence times in Detroit Reservoir. Median travel time from release to first detection in the reservoir ranged from 1.0 to 2.4 d for Chinook salmon after spring and fall releases (fig. 9; table 4; Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015). Steelhead released in spring had a median travel time of 41.2 d in 2012 and 15.9 d in 2013 during these studies (fig. 9; table 4). Less than one-half of the steelhead released in fall 2013 were detected in the reservoir after release, so median travel time was not presented (fig. 9; table 4; Beeman and Adams, 2015).

Researchers examined detection records from monitoring arrays near the head of Detroit Reservoir and in the forebay of Detroit Dam to determine the percentage of tagged fish that arrived in the dam forebay and to describe travel time through the reservoir. During most studies, more than 0.700 of the tagged Chinook salmon moved downstream and entered the forebay of Detroit Dam (table 7; Kock and others, 2015). Median travel time of acoustic-tagged fish from first detection in Detroit Reservoir until detection near the forebay was 7.1–10.0 d for Chinook salmon and 4.4–9.1 d for spring-released steelhead (fig. 9; Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015). Chinook salmon released in the fall had median travel times through the reservoir that ranged from 3.6 to 8.6 d (fig. 9; Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015).

Table 7. Forebay arrival metrics and 95-percent confidence intervals for acoustic-tagged Chinook salmon released in the North Santiam River 2.5 river miles upstream of Detroit Dam, Oregon, 2012–14.

[Data from Kock and others, 2015. Statistical results also are presented as P-values from a Chi-square test of independence that was conducted using a Bonferroni correction to control for multiple pairwise comparisons. <, less than]

Year	Release month	Number of fish released	Number of fish detected in forebay	Estimate of forebay arrival efficiency	95-percent confidence interval	P-value
2012	September	84	65	0.774	0.674–0.850	0.060
	October	90	69	0.767	0.670–0.842	0.069
	November	87	65	0.747	0.647–.0827	0.225
2013	September	78	54	0.692	0.583–0.784	1.000
	October	76	65	0.855	0.759–0.917	0.001*
	November	149	109	0.732	0.655–0.796	0.101
2014	August	997	572	0.574	0.543–0.604	<0.001*

Asterisks indicate releases that were significantly different than others in the group.

Although most fish moved downstream to the forebay of Detroit Dam after release, many tagged fish made upstream trips through the reservoir that likely resulted in extended reservoir residence times. Beeman, Hansel, and others (2014a) and Beeman and Adams (2015) used a Markov chain analysis of reservoir detection records that estimated the probability of tagged fish moving upstream in the reservoir following detection at specific monitoring arrays. This analysis showed that juvenile Chinook salmon and steelhead had bi-directional movements (upstream and downstream) throughout Detroit Reservoir (fig. 11).

Results from several studies have shown that juvenile salmon and steelhead spend a substantial amount of time in the forebay of Detroit Dam in spring and fall, and that they generally are in the upper part of the water column near the dam. Acoustic telemetry studies indicated that median forebay residence times were 13.0–26.8 d for juvenile Chinook salmon and 5.2–16.0 d for steelhead released in the spring during 2012 and 2013, with some fish spending almost 3 months in the forebay prior to passing (fig. 12; table 8; Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015). During these studies, researchers collected three-dimensional fish positions of tagged fish within about 300 ft of Detroit Dam, and these data showed that fish primarily were located along the dam face in the upper part of the water column (Beeman and Adams, 2015; fig. 13). However, fixed-location active hydroacoustic evaluations (monitoring equipment mounted on the dam) conducted during 2011 showed that fish of 90–300 mm in length were present as deep as 262 ft below the water surface during day and night in conservation pool and drawdown periods (Khan, Royer, and others, 2012). Juvenile salmon and steelhead seem to occupy deeper parts of the water column during summer, when surface temperatures increase (Monzyk and others, 2012, 2013, 2014; Khan, Royer, and others, 2012). During winter pool and refill periods, fish occupy all depths when water temperatures are similar throughout the depth of the pool (Khan, Royer, and others, 2012).

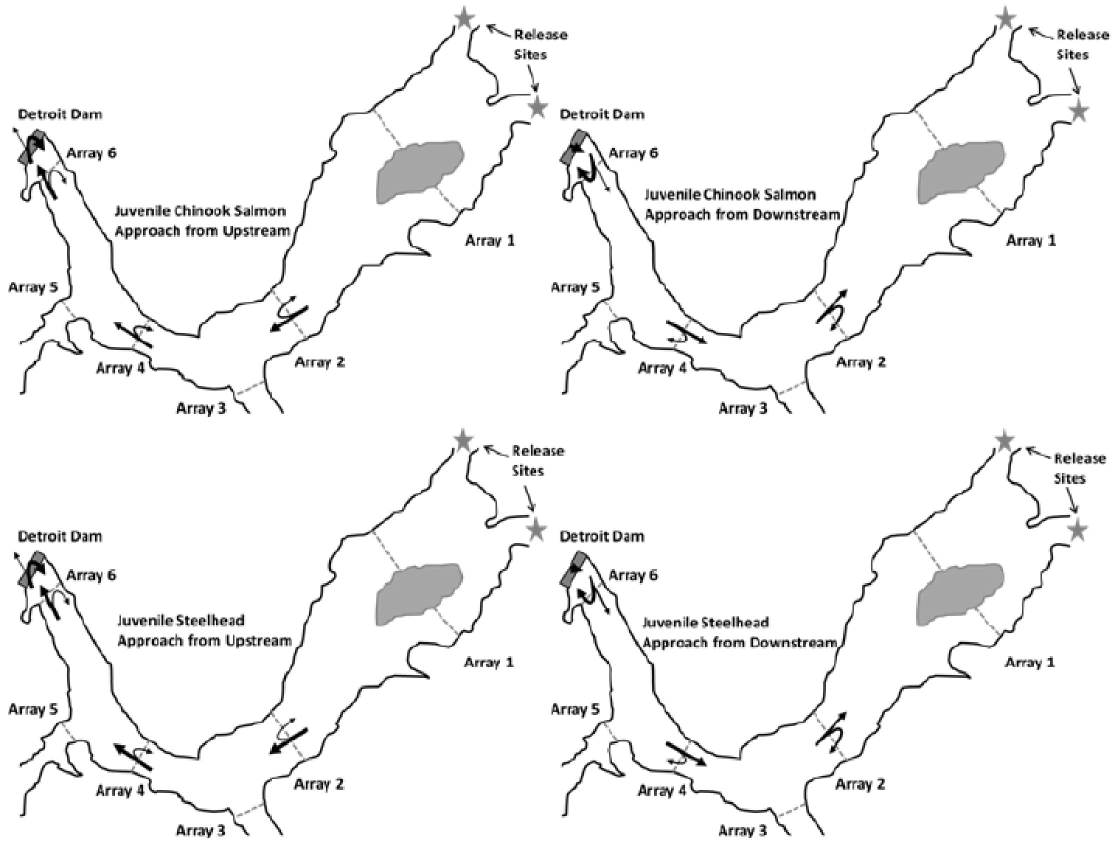

Figure 11. Movement probabilities of acoustic-tagged juvenile Chinook salmon and juvenile steelhead in Detroit Reservoir, Oregon, during the 2012 spring study period. Relative width of arrows indicates probabilities of moving from one array to an adjacent array based on the previous movement (wider is greater probability). Arrays 3 and 5 were not present for the entire season and were excluded from analysis. Data from Beeman, Hansel, and others, 2014a.

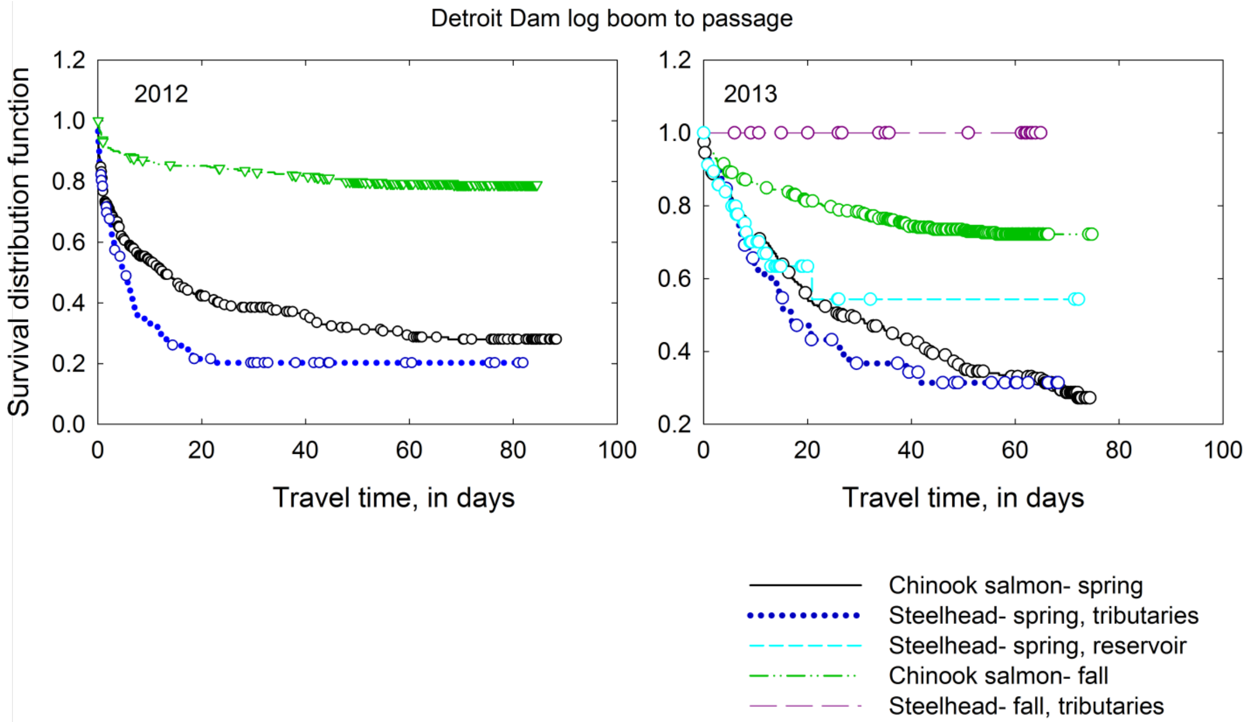

Figure 12. Graphs showing survival distribution (proportion remaining) of acoustic-tagged fish travel times from Detroit Dam forebay at 2,630 feet from the dam to passage at Detroit Dam, Oregon, 2012–13. Observations are right-censored (open circles) at the 90th percentile of tag life if fish had not passed Detroit Dam. Data from Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015.

Table 8. Forebay residence time (days) from first detection in the forebay 0.31 miles upstream of the dam until passage of acoustic-tagged juvenile fish at Detroit Dam, Oregon, 2012–13.

[Data from Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015. Maximum times represent fish not yet passed and censored at the end of the transmitter life. NC, median was not calculated as 50 percent of the fish detected in the forebay did not pass]

Season	Species	Year	Travel time		
			Median	Minimum	Maximum
Spring	Chinook salmon	2012	13.0	0.0	88.3
		2013	26.8	0.1	74.4
	Steelhead	2012	5.2	0.0	81.9
		2013	16.0	0.3	68.3
Fall	Chinook salmon	2012	NC	0.1	84.6
		2013	NC	0.1	74.8

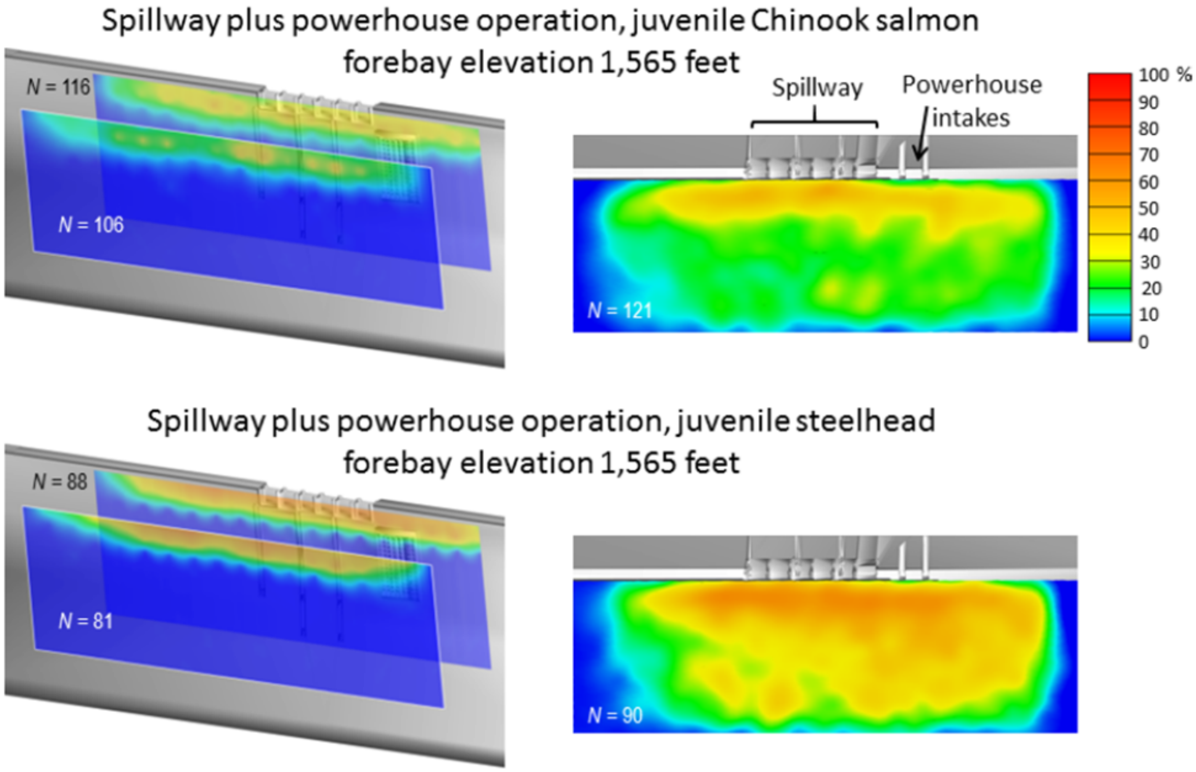

Figure 13. Distributions of the percent presence of acoustic-tagged juvenile Chinook salmon and juvenile steelhead during spillway plus powerhouse operation in the forebay of Detroit Dam, Oregon, during the 2013 spring study period. Vertical slices (left) represent distributions of fish in the 0–65 and 262–328 ft distance ranges from the dam based on 65 x 32 foot cells. Plan views (right) represent distributions along the x-y plane within 105 meters of the dam based on in 32 × 32 foot cells. Sample sizes (*N*) are numbers of fish represented. Data from Beeman and Adams, 2015.

Extended reservoir residence time of juvenile Chinook salmon and steelhead provide substantial growth opportunity which may improve survival to adulthood, however, extended residence time in Detroit Reservoir could be detrimental to juvenile salmon and steelhead because of the presence of parasitic copepods (*Salmincola californiensis*) and piscivorous predators. Copepod infection can result in atrophy, and eventually eliminate gill filaments, thereby reducing the effectiveness of gills in gas and ion exchanges, as well as damage the epithelium at attachment points near fins (Kabata and Cousens, 1977). Fish infected with copepods, particularly on the gill area, have a reduced ability to sustain swimming for long periods of time and may be more susceptible to cumulative stressors. (Herron-Seeley, 2016). Monzyk and others (2012, 2013, 2014, 2015a) monitored copepod infection rates of juvenile Chinook salmon in Detroit Reservoir, and reported annual infection rates of 58 percent in 2011, 75 percent in 2012, 93 in 2013 percent, and 90 percent in 2014. The researchers also monitored infection rates of fish captured in the North Santiam River, upstream of Detroit Reservoir, and reported that only 3–11 percent of those fish were infected (Monzyk and others, 2012, 2013, 2014, 2015a). In

2012, Monzyk and others (2013) examined monthly infection rates and reported that infection was relatively low in June (10 percent) but increased over time, as 85 percent of the fish were infected in December. The median number of copepods per yearling and subyearling Chinook salmon (intensity) collected in gill nets during May–December in Detroit Reservoir was 3 (range 0–10) (fig. 14; Monzyk and others, 2015a). They also determined that unclipped rainbow trout had a lower prevalence of infection (15–27 percent) than Chinook salmon (43–97 percent) during August–December 2012.

Nine fish species (other than Chinook salmon) were collected in box traps, Oneida Lake traps, and depth-stratified gill nets, and by electrofishing in Detroit Reservoir. Several of these were piscivorous species of which rainbow trout were the most common (Monzyk and others, 2012). Although present in Detroit Reservoir, the overall abundance of piscivorous predators is low, when compared to Lookout Point Reservoir. In spring and fall 2011, rainbow trout stomach samples contained only 4 percent fish species (Monzyk and others, 2012). A total of 0 brown bullhead in the spring and 25 percent in the fall contained fish species, but bullhead were collected in low numbers (Monzyk and others, 2012). These results indicate that predation occurs in Detroit Reservoir, but the rate appears to be low.

Dam Passage

Passage Routes and Effects of Operations

Downstream passage of juvenile salmon and steelhead at Detroit Dam is affected by several factors. Reservoir water elevations change seasonally as a result of the flood-control purpose of the dam, affecting the availability of passage routes for juvenile salmon. Reservoir elevations generally are high during summer, when the spillway and powerhouse are the most commonly available passage routes. Under these conditions, downstream passage occurs primarily through the spillway. As a reminder, the spillway is at an elevation of 1,541 ft, the powerhouse penstocks are at an elevation of 1,419 ft, and the ROs are at elevations of 1,265 and 1,340 ft, respectively, and the spillway generally is available April through October (fig. 15). Using active hydroacoustics, Khan, Royer, and others (2012) determined that 72 percent of the smolt-sized fish that were detected in their study passed through the spillway when both routes (spillway and powerhouse) were available. Similarly, of the tagged fish detected in the forebay, 59 percent of the Chinook salmon and 73 percent of the steelhead passed through the spillway at Detroit Dam during spring 2012 (Beeman, Hansel, and others, 2014a). An additional 21 percent of Chinook salmon and 9 percent of steelhead passed through an undetermined route during a fire and subsequent power outages (Beeman, Hansel, and others, 2014a). In spring 2013, about 70 percent of Chinook salmon and steelhead passed Detroit Dam, with more than 94 percent of those fish passing through the spillway (Beeman and Adams, 2015). Reservoir elevations generally are low during fall and winter (fig. 15), when the powerhouse and RO are the most commonly available passage routes. Under these conditions, juvenile salmon and steelhead pass through the powerhouse in greater proportions than through the RO (fig. 15). Khan, Royer, and others (2012) determined that 67 percent of the smolt-sized fish in their study passed through the powerhouse, and Beeman, Hansel, and others (2014a) reported that only 0.3 percent of the tagged Chinook salmon in their study passed through the RO.

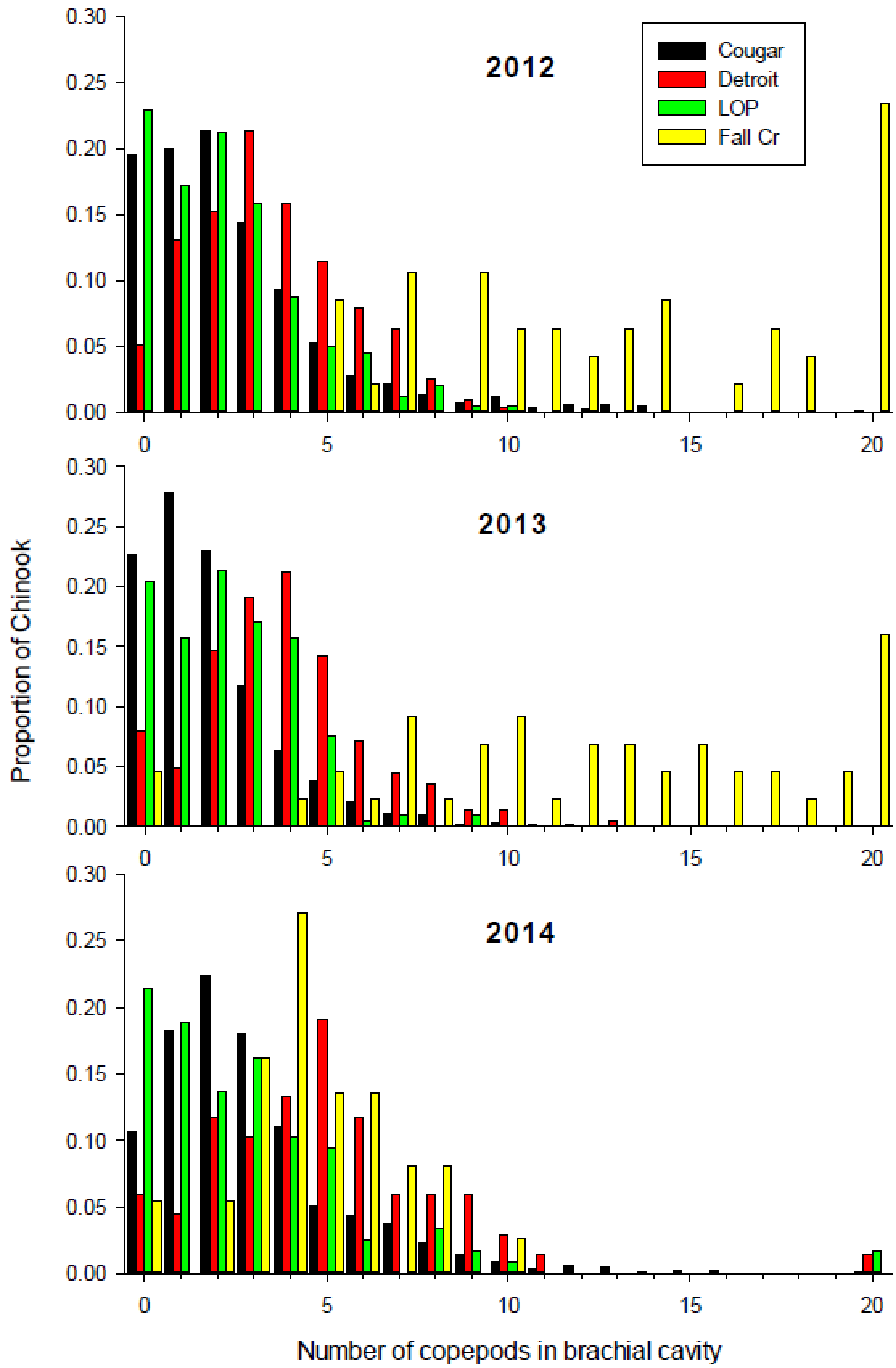

Figure 14. Graphs showing intensity of copepods (*Salmincola californiensis*) attached to the branchial cavity of subyearling Chinook salmon in four Willamette Valley Project reservoirs, Oregon, November and December, 2012–14. Data were collected from fish in Cougar and Fall Creek (Fall Cr.) tailraces in screw traps downstream of the dams and in gill nets in Detroit and Lookout Point (LOP) Reservoirs. Figure from Monzyk and others, 2015a.

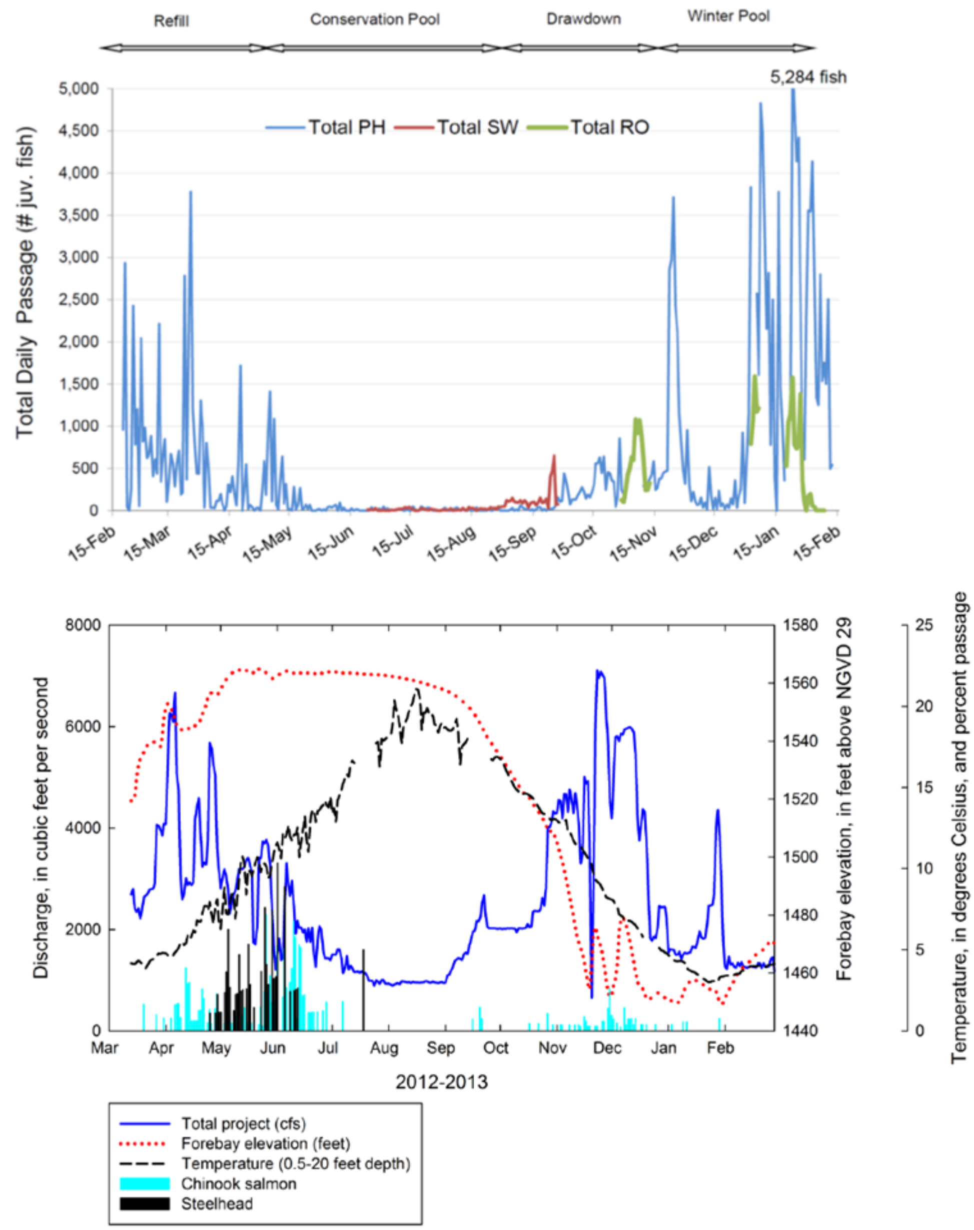

Figure 15. Graphs showing estimated total daily passage of smolt-size fish at powerhouse (PH), spillway (SW), and regulating outlet (RO) from February 20, 2011 through February 12, 2012 (top graph), and daily mean dam operations and environmental conditions at Detroit Reservoir, Oregon, from March 13, 2012, through February 21, 2013, when fish were detected in the study area (bottom graph). Arrows at the top of top graph indicate the four distinct pool elevation periods. Fish passage in bottom graph (blue and black vertical bars) is plotted as percentage of fish passing out of the number of fish available to pass. NGVD 29, National Geodetic Vertical Datum of 1929. Top graph from Khan, Royer, and others, 2012. Bottom graph from Beeman, Hansel, and others, 2014a.

The percentage of tagged fish that passed Detroit Dam during acoustic telemetry studies was high for spring-released fish. About 81 percent of Chinook salmon and steelhead passed the dam in 2012 and about 70 percent of tagged fish passed the dam in 2013. Spill was more widely available (in duration and volume) in 2012 compared to 2013. Of the fish that passed, most spring passage was through the spillway (98–100 percent; Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015). Some summer steelhead were tagged and released directly in the reservoir in spring. Of these, only 33 percent passed, and all of those fish passed through the spillway (Beeman and Adams, 2015). More than one-half of the tagged fish passed in spring when the reservoir elevation was at least 1,541 ft (the elevation of the spillway ogee; Beeman and Adams, 2015).

Tagged fish that were released during summer and fall had substantially lower passage proportions than tagged fish released during spring. Only 8 percent of the juvenile Chinook salmon released upstream of Detroit Reservoir in summer 2014 were detected passing the dam (Kock and others, 2015). One-half of those fish passed through the RO, and the remainder passed through the spillway and powerhouse (Kock and others, 2015). Fall releases of acoustic tagged Chinook salmon and summer steelhead in Detroit Reservoir tributaries in 2012 and 2013 also resulted in low dam passage rates. Of the fish released in the fall and detected in the forebay, 19.2 and 26.1 percent of Chinook salmon in 2012 and 2013, respectively, passed through the powerhouse (Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015). Summer steelhead released in fall did not pass Detroit Dam during the study period (Beeman and Adams, 2015). Most of the fish that passed Detroit Dam in fall and winter did so when the reservoir elevation was 1,450–1,500 ft, when the available routes (ROs and powerhouse) were at their shallowest (Beeman and Adams, 2015).

Seasonal and Diel Patterns

Differences in seasonal passage of juvenile salmon have been reported in several other studies. Using fixed-location active hydroacoustics, Khan, Royer, and others (2012) reported that passage of 90–300 mm fish generally was lowest during summer (June–August) and peaked during late fall and winter (November–March; fig. 15). Similarly, Romer and others (2012, 2013, 2014, 2015, 2016) operated screw traps in the tailraces of Detroit Dam in 2014–15 and Big Cliff Dam and reported that peak passage of juvenile Chinook salmon occurred in November and December. Research from Romer and others (2013) further defined yearling Chinook salmon passage as beginning in May when spill operations commenced at Detroit Dam, and also reported yearling Chinook salmon passed during August–December.

Studies have identified different results on diel passage patterns. Using fixed-location active hydroacoustics, Khan, Royer, and others (2012) reported that 90–300 mm fish seemed to pass the turbines and ROs during all hours of the day, whereas spillway passage occurred in distinct peaks in mid-morning and mid-afternoon, with low passage at night. Most acoustic-tagged Chinook salmon and summer steelhead were assigned passage at night in spring and fall (Beeman, Hansel, and others, 2014a; Beeman and Adams, 2015). In spring, almost two-thirds (64.9 percent) of Chinook salmon and about one-half (51.4 percent) of steelhead passage occurred at night (Beeman, Hansel, and others, 2014a). The rate of passage at night in spring was estimated to be 2.3 times greater than the rate of passage during the day for Chinook salmon (Beeman and Adams, 2015). In fall, most (79.5 percent of) acoustic tagged Chinook salmon passage events occurred at night (Beeman, Hansel, and others, 2014a). The rate of passage at night in fall was 19.8 times greater than during the day (Beeman and Adams, 2015).

Survival

At Detroit Dam, studies were conducted to evaluate route-specific injury and mortality rates. These studies were conducted using live fish that were tagged with HI-Z tags (balloon tags; Normandeau Associates, Inc., 2010a), with fish surrogates (sensor fish; Duncan, 2010; Duncan and Carlson, 2011) that measured variables such as collisions and shear (referred to as “events”), and with run-of-the-river fish (Romer and others, 2012, 2013, 2014). Tagged fish during the spillway evaluation were a mean length of 125 mm (range 104–171 mm; Normandeau Associates, Inc,. 2010a). Spillway passage was assessed using two gate openings (1.5 ft and 1,560 ft^3/s; 3.5 ft and 3,090 ft^3/s) and tagged fish were held for 48 h after passing the dam near full pool in July 2009. Normandeau Associates, Inc. (2010a) reported that 81–84 percent of the tagged fish survived passage through the 1.5-ft opening compared to a 64–67 percent survival through the 3.5-ft opening. Duncan (2010) reported that 93 percent of the sensor fish experienced more than one significant event (acceleration magnitude greater than 95 *g*) while passing through the spillway, and most of the collisions occurred on the spillway chute. During the turbine evaluation, turbine discharge was 2,200 ft^3/s and pool elevation was 1,513 ft, about 56 ft below full pool in October 2009 (Duncan and Carlson, 2011). Mean size of tagged fish was 191 mm (range 112–246 mm; Normandeau Associates, Inc., 2010a). All sensor fish experienced more than one significant event during powerhouse passage, and more than one-half of the events were from shear in the wicket gate/runner region (Duncan and Carlson, 2011). Direct survival at 48 h through the powerhouse was 54 percent (Normandeau Associate, Inc., 2010a). Passage through the RO was evaluated in December 2009 when the pool elevation was at 1,441 ft, near minimum pool of 1,450 ft (Duncan and Carlson, 2011). Two gate openings were evaluated—1-ft opening at 460 ft^3/s and 5-ft opening at 1,800 ft^3/s (Duncan and Carlson, 2011). Mean fork length of tagged fish was 185 mm (range 122–218 mm; Normandeau Associates, Inc., 2010a). Sensor fish passage through the ROs indicated that about 67 percent of the replicates experienced multiple significant events during 1- and 5-ft gate opening tests (Duncan and Carlson, 2011). The authors reported that the “majority of severe events for both gate openings was due to shear and occurred where the RO flow jet plunges into the stilling basin” (Duncan and Carlson, 2011, p. 3.11). Direct survival at 48 h was 72.0 percent for fish that passed through a 1-ft opening and 94.4 percent for fish that passed through a 5-ft opening (table 9; Normandeau Associates, Inc., 2010a). Duncan and Carlson (2011) concluded that passage through the RO was the safest route during their test conditions, but that turbine and spillway passage routes were deleterious for juvenile salmonids. When Chinook salmon were directly captured in downstream screw traps, mortality varied by year. Mortality of unmarked juvenile Chinook salmon collected in a rotary screw trap was 60 percent in 2011, 29 percent in 2012, and 11 percent in 2013 (Romer and others, 2012, 2013, 2014). Hatchery-reared juvenile Chinook salmon mortality also varied over the same period, with mortality reported at 43, 20, and 22 percent, respectively (Romer and others, 2012, 2013, 2014). Screw traps downstream of Detroit Dam were operated during the entire calendar year except during maintenance or flow conditions that precluded operation, but collected most of the Chinook salmon during August–December (Romer and others, 2012, 2013, 2014).

Table 9. Summary of test conditions of studies of direct passage survival through spill bays 3 and 6, regulating outlet 2, and powerhouse unit 2 at Detroit Dam, Oregon.

[Table from Normandeau and Associates, 2010a. Numbers other than survival estimates are means. Head is the difference between forebay elevation and tailrace elevation. °C, degrees Celsius; ft, foot; ft^3/s, cubic foot per second; mm, millimeter; –, not applicable or not reported]

Metric	Survival	Spill bay 3		Spill bay 6		Regulating outlet 2		Unit 2
		1.5 ft	3.5 ft	1.5 ft	3.5 ft	1.0 ft	5.0 ft	
Powerhouse discharge (ft^3/s)		0–2,000	0	0	0–2,000	2,200	2,100	2,200
Spill discharge (ft^3/s)		1,500	3,000	1,500	3,000	–	–	–
RO discharge (ft^3/s)		–	–	–	–	460	1,800	–
Elevation (ft)		1,560	1,560	1,560	1,560	1,440	1,440	1,513
Head (ft)		359.6	357.7	358.4	360.0	238.6	237.8	310.9
Temperature (°C)		15–18	15–18	15–18	15–18	5–6	5–6	13.5
Species		RBT	RBT	RBT	RBT	RBT	RBT	RBT
Total length (mm)		125	125	125	125	185	185	11
Relative survival (percent)	1 hour	88.9	83.7	90.8	82.5	74.4	97.2	58.8
	48 hour	80.6	63.6	84.0	67.4	72.0	94.4	54.1

Juvenile Chinook salmon that were tagged with a passive-integrated transponder (PIT) and released in the North Santiam River in 2012, 2013, and 2014, were monitored as adult returns to the North Santiam River (Brandt and others, 2016a; Johnson and others, 2016). Smolts were released at the head of Detroit Reservoir, Detroit Dam forebay, and Big Cliff tailrace and evaluated for smolt outmigration at the Bennett Dam complex and Willamette Falls PIT interrogation sites. Median fork length was 91 mm in 2012, 69 mm in 2013, and 74 mm in 2014 (Brandt and others, 2016a; Johnson and others, 2016). A significantly higher proportion of fish released in Big Cliff tailrace (8.38, 3.67, and 2.33 percent) were detected at Willamette Falls than fish released at the head of Detroit Reservoir in all 3 years (7.19, 2.19, 0.91 percent; Brandt and others, 2016a, Johnson and others, 2016). Additionally in 2013 and 2014, a significantly higher proportion of fish released in forebay (2.82 and 1.67 percent, respectively) were detected at Willamette Falls than of fish released at the head of the reservoir (Brandt and others, 2016a; Johnson and others, 2016). The 2014 fish released in the Big Cliff tailrace had significantly faster travel times to Bennett Dam complex, but slower travel times to Willamette Falls. This finding was explained by: (1) a greater proportion of yearling fish detected at Willamette Falls the following year than at the Bennett Dam complex in the release year; or (2) a possible difference in detection probability among age classes (Johnson and others, 2016). Of the tagged Chinook salmon released in 2012, a similar number of adults returned to Minto Dam from the head of reservoir and tailrace release groups (Johnson and others, 2016). Further survival data will be collected as the adult fish return to the North Santiam in future years.

The existing evidence suggests that juvenile salmon travel slowly through, and experience high mortality in, Big Cliff Reservoir. Beeman and Adams (2015) deployed acoustic telemetry monitoring sites from Detroit Dam to Portland, Oregon, during 2014 and monitored downstream movements of tagged fish. All tagged fish were released in the tributaries upstream of Detroit Reservoir and those that passed through Detroit Dam are described here. Researchers determined that migration rates and survival of juvenile Chinook salmon and steelhead that passed Detroit Dam and were detected in the forebay of Big Cliff Dam were lowest in the Detroit Dam-to-Big Cliff Dam reach compared to all the other reaches in their study area (table 10). Median migration rate from the tailrace of Detroit Dam to the forebay of Big Cliff Dam was 0.12–0.24 mi/d for Chinook salmon and steelhead during spring and fall study periods (Beeman and Adams, 2015). Survival estimates through this reach (2.8 river miles) were 72 percent for spring-released Chinook salmon, 78 percent for spring-released steelhead, and 62 percent for fall-released Chinook salmon. The total study area included 157 river miles (from the Detroit Dam tailrace to Portland, Oregon), and researchers determined that 60 percent of the mortality of spring-released Chinook salmon and steelhead and 80 percent of fall-released Chinook salmon occurred in the 6.8-river-mile reach between Detroit Dam and Minto Dam (Beeman and Adams, 2015).

Table 10. Estimated survival probabilities, by river reach, ending at each detection array for juvenile Chinook salmon and steelhead released in spring and fall 2013 and detected between Detroit Dam and Portland, Oregon.

[Table from Beeman and Adams, 2015. Fish were released in tributaries upstream of Detroit Reservoir or near the head of the reservoir during the spring study period and detected during pool filling and full conservation pool from May 8 to July 19, 2013, or released during the fall study period and detected during drawdown, low conservation pool, and pool refill from October 3, 2013 to April 10, 2014. No steelhead released in fall were detected downstream within the 90th percentile of the empirical tag life. Prob, probability; SE, standard error; LCI, lower 95-percent confidence interval; UCI, upper 95-percent confidence interval]

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

Survival of juvenile salmonids at Big Cliff Dam was evaluated in 1957, 1964, and 1966. In 1957, Big Cliff Dam was used as a surrogate to evaluate passage survival of subyearling and yearling Chinook salmon at McNary Dam. For this study, researchers evaluated fish survival when turbine wicket gate settings were 80- and 40-percent open, and when spill gates had 2-ft openings. Survival of subyearling fall Chinook salmon was higher (88 percent) when the wicket gate was 80-percent open than when it was 40-percent open (79-percent survival; State of Washington Department of Fisheries, 1960). Survival of spillway-passed fish was highest (94 percent) of all routes for subyearling Chinook salmon. Yearling Chinook salmon survival was evaluated using only the 80-percent wicket gate opening and the 2-ft spill gate opening, and estimates through the two routes were 91 percent and 99 percent, respectively (State of Washington Department of Fisheries, 1960). Three separate heads of 91, 81, and 71 feet and a range of wicket gate openings (proportion 0.330–1.000) were evaluated in each year. Average survival for all tests was 89.7–94.5 percent and greater than 95 percent at the best turbine efficiency for all heads (Oligher and Donaldson, 1966). The majority of the injuries in the 1964 test were internal hemorrhage (organs; 41.5–49.9 percent) and contusion (31.8–34.3 percent) in the 1966 test (Oligher and Donaldson, 1966).

Gas bubble trauma was observed for fish collected in a screw trap operated downstream of Big Cliff Dam. Total dissolved gas levels averaged 124 percent (range 117–130 percent) in April and May 2014, and 92 percent of Chinook salmon were found dead in the screw trap (Romer and others, 2015). Supersaturation of dissolved gasses was highly correlated with spill (Romer and others, 2015). Extended holding time in the live box of the screw trap (12–24 h) may have contributed to a higher mortality rate than for fish that were able to continue downstream after passing Big Cliff Dam. In 2015, there was less spill than in 2014 and mortality was reduced in the spring. Evidence of gas bubble disease was present in December 2015 when all 40 collected salmonids had gas bubbles in their fins (Romer and others, 2016).

Genetic pedigree analysis was conducted for unclipped Chinook salmon that returned to Minto Dam on the North Santiam River. A total of 59 and 66 percent of unmarked fish that returned to Minto Dam in 2013 and 2014, respectively, were progeny of salmon released upstream of Detroit Dam (O’Malley and others, 2015). Adults returning in 2013 and 2014 were released between 2007 and 2010. The 2009 cohort replacement rate (CRR) was 1.07 for females and 0.54 for the overall population which had a 6:1 male:female sex ratio (O’Malley and others, 2015).

Summary

Much is known about downstream fish passage in the North Santiam River subbasin. Juvenile Chinook salmon primarily enter Detroit Reservoir during February–June and survival from the upstream tributaries to arrival in the forebay of Detroit Dam seems to be high. Chinook salmon fry distribute throughout Detroit Reservoir and move offshore into deeper water as summer temperatures increase. Growth rates in the reservoir are among the highest in all Willamette Valley reservoirs that have been studied. Juvenile salmon and steelhead have long residence times in Detroit Reservoir and in the forebay of Detroit Dam. Parasitic copepods are present in Detroit Reservoir and extended residence times (by juvenile salmonids) result in high rates of infection prevalence and intensity. Access to passage routes at Detroit Dam changes seasonally and fish readily pass through spill bays when reservoir elevations are high. When reservoir elevations are low, fish pass through turbines more readily than through ROs, which have deeper intake openings. The ROs seem to offer the safest route of passage, but significant mortality is possible through all routes. Overall, passage is low during summer and high during fall and spring. High passage survival has been reported at Big Cliff Dam during one study, but fish move slowly and experience substantial mortality in the reaches between Detroit Dam and Minto Dam (which include Big Cliff Dam).

South Santiam River Subbasin

Subbasin Description

The South Santiam River drains about 640 mi^2 on the western slopes of the Cascade Mountain Range in northwestern Oregon. Average daily discharge is 5,940 ft^3/s (range, 106–22,100 ft^3/s) and major tributaries include the Middle Santiam River and Quartzville Creek (U.S. Geological Survey, 2016a; USGS streamgage 14187500; fig. 16). The South Santiam River is impounded by three dams including Green Peter Dam and Foster Dam, which are owned and operated by the USACE. Lebanon Diversion Dam is located downstream of Foster Dam and is owned by the City of Albany (fig. 16). Winter steelhead and the distinct South Santiam stock of spring Chinook salmon are present in the South Santiam River subbasin, as well as cutthroat trout and mountain whitefish (*Prosopium williamsoni*; Buchanan and others. 1993). Additionally, coho salmon (*O. kisutch*) and sockeye salmon (*O. nerka*) were stocked in the South Santiam River subbasin in the 1960s (Wagner and Ingram, 1973; Buchanan and others, 1993; U.S. Army Corps of Engineers, 1995). South Santiam Hatchery is located on the South Santiam River, downstream of Foster Dam, 5 mi east of Sweet Home, Oregon. The hatchery began operation in 1968 to mitigate for the development of Foster and Green Peter Dams. The USACE funds most of the operating costs of South Santiam Hatchery, with the remaining funds coming from the ODFW. The hatchery is used for adult collection, egg incubation, and rearing of spring Chinook salmon and summer steelhead (Boyd and Chilton, 2011). Spring Chinook salmon and summer steelhead are produced at South Santiam Hatchery, but releases in the subbasin are also supplemented by South Santiam stock fish reared at Willamette Hatchery, located in the Middle Fork Willamette River subbasin. Summer steelhead are incubated at South Santiam Hatchery but most fish are transferred offsite to be released throughout the Willamette River Basin.

Volitional upstream fish passage in the South Santiam subbasin ends at Foster Dam. Returning adult salmon and steelhead are collected at the Foster Dam Fish Facility (fig. 16), which was rebuilt in 2014 to reduce direct handling of adult fish as they are sorted and transported upstream. It is used for year-round adult fish collection of winter steelhead, summer steelhead, and spring Chinook salmon. Annual collection numbers during 2011–15 ranged from 3,120 to 8,684 for Chinook salmon, from 129 to 326 for winter steelhead, and from 722 to 6,638 for summer steelhead (table 11). All adult winter steelhead are passed upstream into Foster Reservoir or river reaches upstream of the reservoir, and sockeye salmon are disposed of in the landfill (table 11; Boyd and Chilton, 2011, 2012b, 2014b). Spring Chinook salmon eggs are incubated at South Santiam Hatchery and most are then transferred to Willamette and Gnat Creek (Clatskanie, Oregon) Hatcheries for rearing. In some cases, young fish are then transferred back to South Santiam Hatchery and other acclimation locations for releases in the South Santiam River, Gnat Creek, and the Columbia River. Summer steelhead are incubated at South Santiam Hatchery and most progeny are transferred offsite to be released throughout the Willamette River Basin including South Santiam, North Santiam, McKenzie, Middle Fork Willamette, the main-stem Willamette, and the Clackamas Rivers (Boyd and Chilton, 2016b). Adult fish in excess of broodstock needs were recycled downstream, released upstream, sold or given away for human consumption, used for stream enrichment, or disposed of in the landfill depending on policies for each species. Juvenile spring Chinook salmon and summer steelhead were released in the South Santiam River from Santiam and South Willamette Hatcheries. Annual smolt releases from 2011 to 2015 ranged from 946,913 to 1,047,386 for spring Chinook salmon, and from 169,794 to 255,236 for summer steelhead (table 12).Transport of adult fish upstream of Green Peter Dam ended in the 1980s, and the downstream fish passage system was modified in 2010 to use as a test facility (U.S. Army Corps of Engineers, 1995). Adult releases and smolt releases are not occurring upstream of Green Peter Dam, so downstream fish passage at USACE-owned projects in the South Santiam subbasin currently occurs only at Foster Dam.

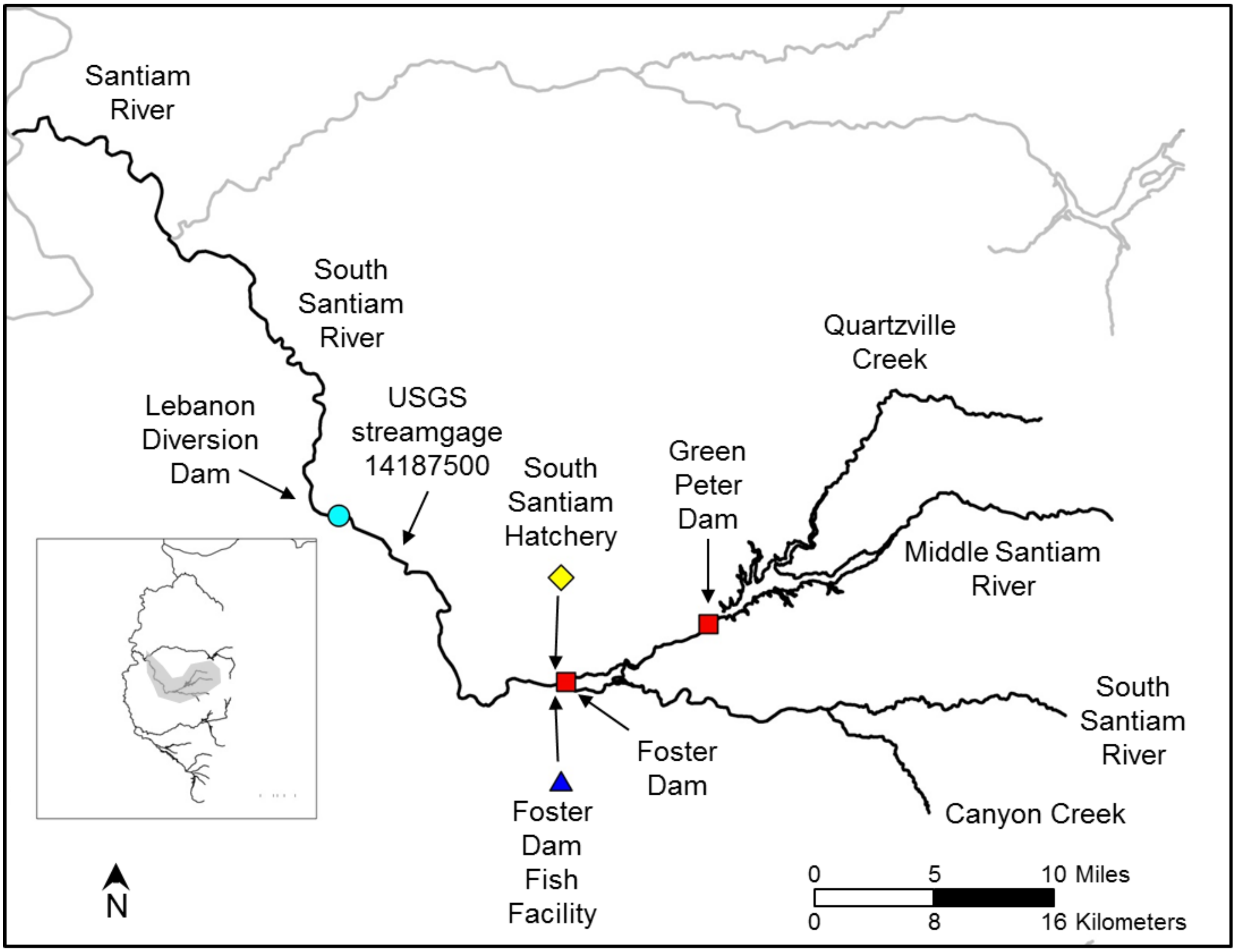

Figure 16. Map showing primary rivers in the South Santiam River subbasin (black lines), U.S. Army Corps of Engineers (USACE)-owned dams (red squares), non-USACE dam (blue circle), fish hatchery (yellow diamond), and adult fish facility (blue triangle), Willamette River Basin, Oregon. Other rivers in the Willamette Basin but not in the South Santiam subbasin are in gray. Inset of the Willamette River Basin with the South Santiam subbasin shaded in gray is in the lower left.

Table 11. Number of adult spring Chinook salmon, winter and summer steelhead, and sockeye salmon collected in the South Santiam River at the Foster Dam Fish Facility, Oregon, 2011–15.

[Data from Boyd and Chilton, 2011, 2012b, 2014b, 2015b, 2016b; Sharpe and others, 2013, 2014, 2015, 2016. Chinook salmon were released upstream of Foster Reservoir. Only adipose-intact Chinook salmon are released upstream of Foster Dam. Sockeye were disposed of in a landfill. ND, no data]

Year	Spring Chinook salmon		Winter steelhead	Summer steelhead	Sockeye salmon
	Collected	Released	Collected	Collected	
2011	8,684	1,221	315	4,878	28
2012	8,312	975	326	6,638	22
2013	4,276	927	215	4,155	3
2014	3,120	408	129	3,269	ND
2015	7,152	572	206	722	ND

Table 12. Number of spring Chinook salmon and summer steelhead smolts released from South Santiam and Willamette Hatcheries to the South Santiam River, Oregon, 2011–15

[Data from Boyd and Chilton, 2011, 2012b, 2014b, 2015b, 2016b]

Year	Spring Chinook salmon	Summer steelhead
2011	1,037,452	255,236
2012	946,913	186,409
2013	1,025,637	189,500
2014	1,047,386	197,077
2015	1,031,533	169,794

Green Peter Dam

Green Peter Dam is located at rm 5.5 on the Middle Santiam River, and was constructed in 1968 (figs. 16 and 17). The dam is 327 ft tall and 1,500 ft long, and has two Francis turbines capable of generating 80 MW of power (4,600 ft^3/s), two gated spill bays, two ROs, and juvenile fish passage bypass pipes. Four 12-in diameter steel fish bypass pipes at elevations of 910, 935, 960, and 985 ft intercept a 24-in diameter pipe along the face of the dam (fig. 18). The pipe ends in the tailrace at a fish evaluator. The fish bypass system originally used pumps for 200 ft^3/s attraction flow into a fish horn in the forebay until 1987 when use was discontinued (U.S. Army Corps of Engineers, 1995). The pipes currently are used as a test facility. An adult fish ladder leading into a hopper system originally lifted adult fish over the dam (Buchanan and others, 1993; U.S. Army Corps of Engineers, 1995). Green Peter Dam impounds 312,500 acre-ft of water in Green Peter Reservoir and is operated to generate hydroelectricity, prevent flood damage, provide municipal and industrial water supplies, and improve downstream water quality (U.S. Army Corps of Engineers, 2016a). Green Peter Dam operates as a power-peaking project where power is generated for only a few hours at a time when electricity demand is high (U.S. Army Corps of Engineers, 1995). Reservoir pool elevations typically range from 922 ft in winter to 1,010 ft in summer (figs. 2, 18). Downstream fish passage of juvenile salmon and steelhead does not currently occur at Green Peter Dam because no anadromous population exists in or upstream of the reservoir.

Figure 17. Photograph showing Green Peter Dam on the Middle Santiam River, Oregon. Photograph by the U.S. Army Corps of Engineers.

Foster Dam

Foster Dam was constructed in 1968, and is located at rm 38.5 on the South Santiam River (figs. 16 and 19). The dam is used to re-regulate intermittent discharges of water passing through Green Peter Dam, which is located 5.5 mi upstream (fig. 16). Foster Dam is 4,656 ft long and 126 ft high, and has two Kaplan turbines capable of producing 20 MW of power (3,200 ft^3/s) and four gated spill bays (fig. 20; U.S. Army Corps of Engineers, 2016a). An adult ladder is located between the spillway and the powerhouse and leads to a hopper and lift system (Wagner and Ingram, 1973; U.S. Army Corps of Engineers, 1995). An adult fish collection facility downstream of Foster Dam was rebuilt in 2014, which reduced direct handling of adult fish as they are sorted and transported upstream. A top-spill fish weir is installed in spill bay 4 to facilitate downstream surface passage for juvenile salmon and steelhead. The spillway weir is installed on stop logs for a weir crest elevation of 614 ft (spring, fall, and winter) or 633 ft (summer)—2 ft less than the reservoir elevation (fig. 20; Hughes and others, 2014). The dam impounds 28,300 acre-ft in Foster Reservoir and is authorized for flood risk management, hydropower, municipal and industrial water supplies, navigation, and other uses such as fish and wildlife habitat, water quality improvement, and recreation (U.S. Army Corps of Engineers, 2016b). Pool elevation typically ranges from 613 ft in winter to 637 ft in summer (fig. 20; U.S. Army Corps of Engineers, 2016b).

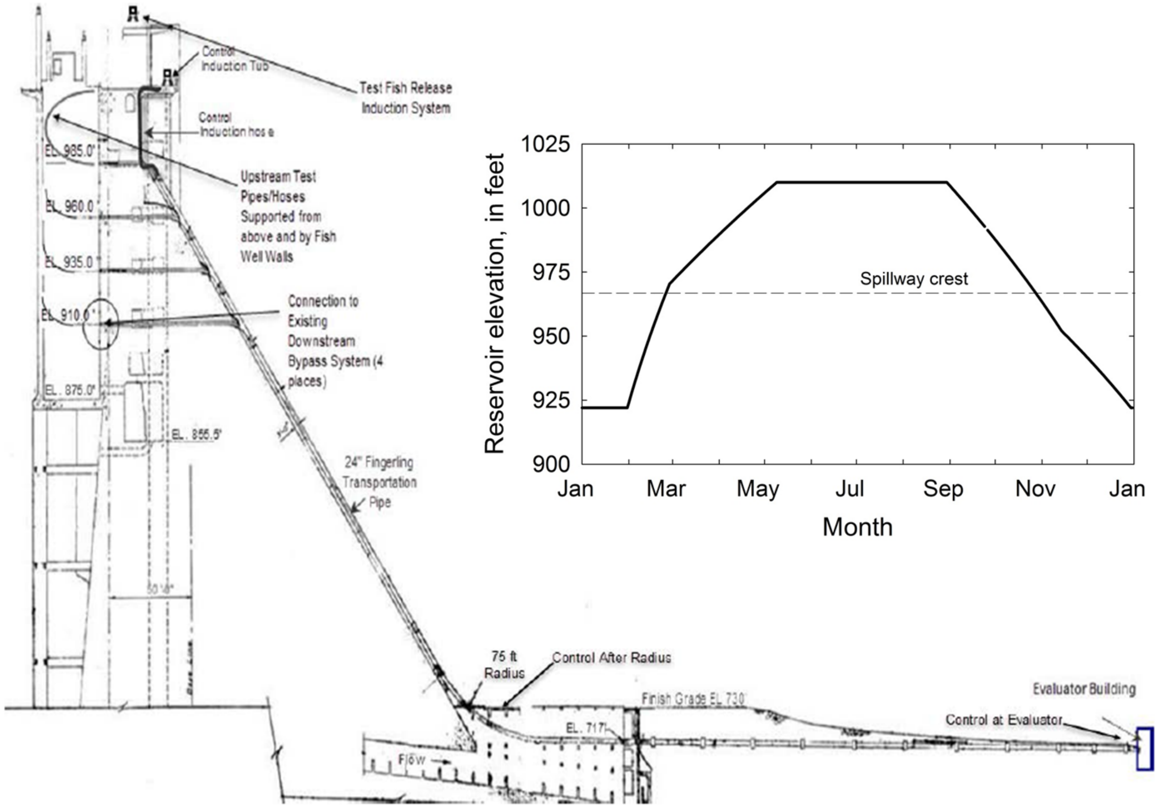

Figure 18. Side-view schematic showing the downstream juvenile fish passage bypass pipes (left), and graph showing planned reservoir elevation targets (rule curve) during the calendar year (right), at Green Peter Dam, Middle Santiam River, Oregon. Graph from Deng and others, 2015.

Figure 19. Photograph showing Foster Dam on the South Santiam River, Oregon. Photograph by the U.S. Army Corps of Engineers.

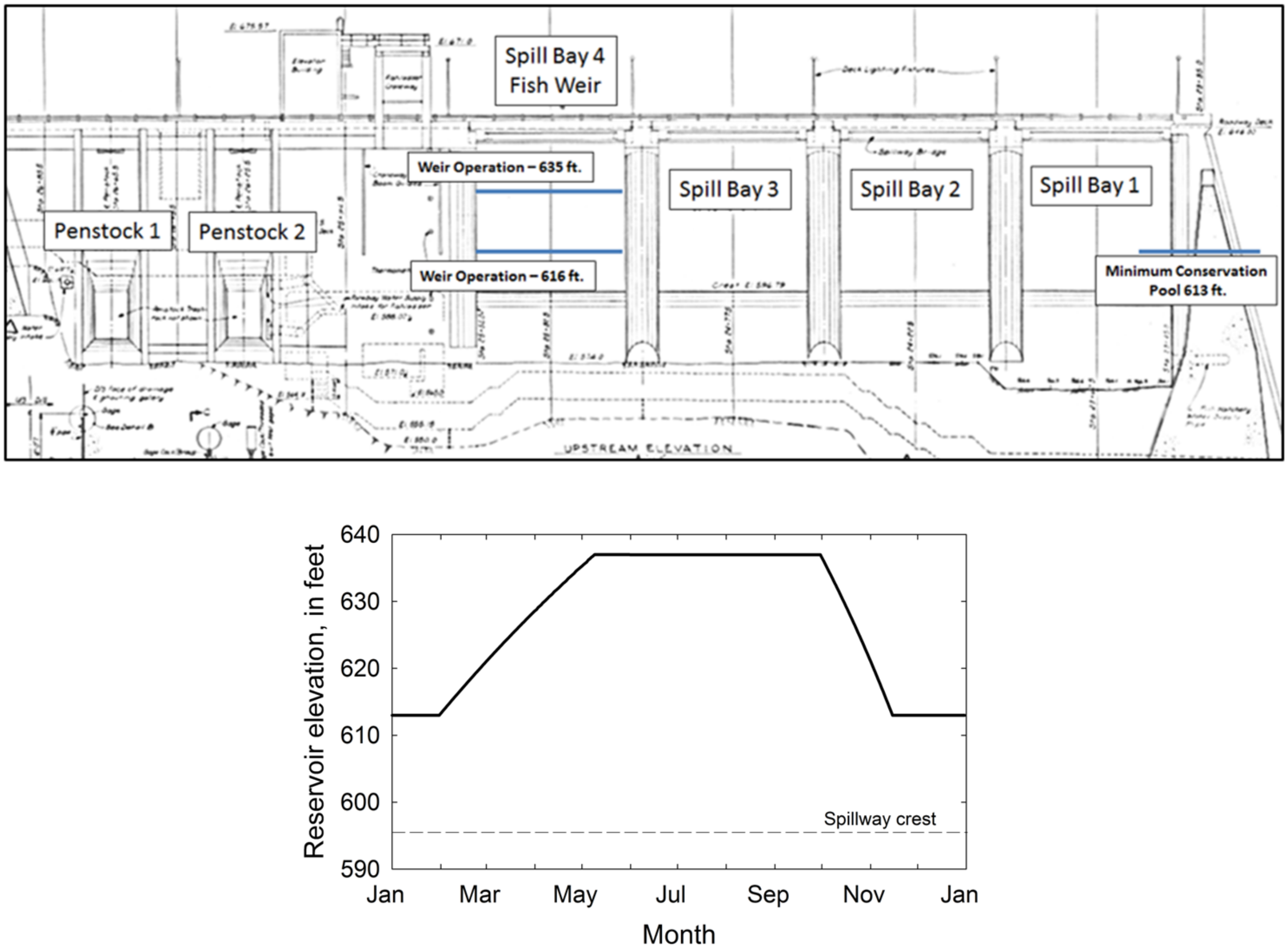

Figure 20. Schematic showing side view of Foster Dam, passage routes, and water elevations (top), and graph showing planned reservoir elevation targets (rule curve) during the calendar year (with spillway crest for reference) for Foster Reservoir (bottom), South Santiam River, Oregon. Figure from Hughes and others, 2014.

Reservoir Entry

Romer and others (2013, 2014, 2015, 2016) operated a screw trap upstream of Foster Reservoir and reported that catch of subyearling Chinook salmon peaked during February–March when most collected fish were 40 mm or smaller (fig. 21). During these studies, the median date of outmigration occurred between February 29 and March 7 (Romer and others, 2013, 2014). The first subyearling was collected on December 30, 2015, which was similar to the timing in the previous year (Romer and others, 2016). Reservoir entry occurred during low pool elevations, and yearling Chinook salmon were rarely encountered (Monzyk, Romer, and others, 2011a; Romer and others, 2012, 2013, 2014, 2015). Researchers reported that high-flow events (greater than 10,000 ft^3/s) in the South Santiam River during winter resulted in low catch the following spring (Romer and others, 2012, 2013, 2015). A high flow event in November of 2011 has been implicated in a brood failure of the 2010 Chinook salmon spawners (O'Malley and others, 2015). Genetic parentage analysis concluded that reintroduced natural-origin spring Chinook salmon constituted 74 percent in 2012 and 66 percent in 2013 of the progeny upstream of Foster Dam (O’Malley and others, 2014). Of the salmon reintroduced upstream of Foster

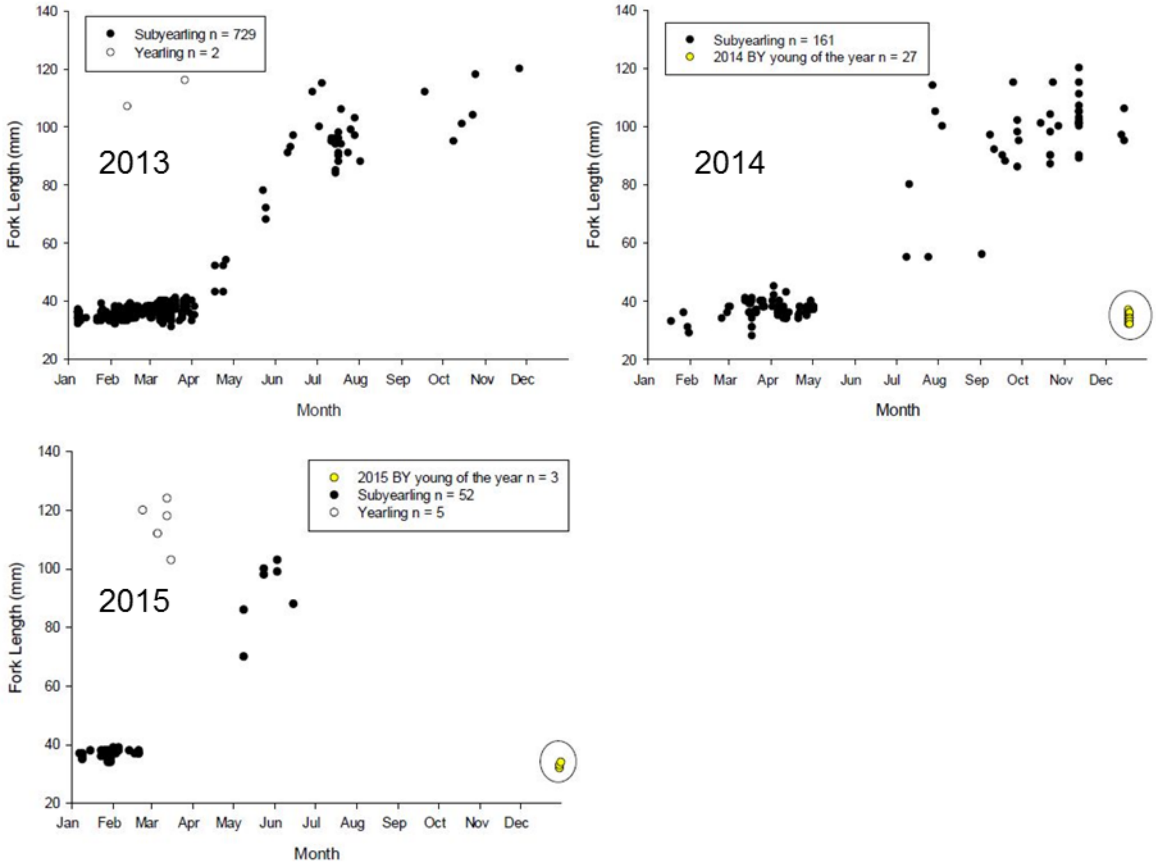

Figure 21. Graphs showing juvenile Chinook salmon collected by date and fork length (in millimeters [mm]) in a rotary screw trap upstream of Foster Reservoir on the South Santiam River, Oregon, 2013–15. Data in the circle indicate young-of-the-year juvenile Chinook salmon as noted by the original authors. Data from Romer and others, 2014, 2015, 2016.

Dam, 61 percent in 2007, 38 percent in 2008, and 48 percent in 2009 produced at least one adult recruit (Evans and others, 2016). Corresponding CRRs were 0.96 in 2007, 1.16 in 2008 and 1.56 in 2009 (Evans and others, 2016).

Naturally produced winter steelhead and rainbow trout reside in Foster Reservoir and in the South Santiam River. Field sampling efforts do not attempt to distinguish between these two groups of fish, which collectively are referred to as *O. mykiss* in reports that we reviewed. Screw trap collection of *O. mykiss* occurred during most months of the year, but the greatest number of fish were collected during July–November (fig. 22; Monzyk, Romer, and others, 2011a; Romer and others, 2012, 2013, 2014, 2015, 2016). Romer and others (2015) reported that low flows in summer and fall 2014 delayed subyearling *O. mykiss* from entering Foster Reservoir until freshets occurred in October (fig. 22). Three age classes commonly are collected in the screw trap upstream of Foster Reservoir—age-0, age-1, and age-2 (Romer and others, 2016). Yearling-sized *O. mykiss* (and larger) were collected in the upstream trap throughout the year, but few were collected in 2014 (Monzyk, Romer, and others, 2011a; Romer and others, 2012, 2014, 2015). Romer and others (2013) reported that *O. mykiss* entry into Foster Reservoir primarily occurred when the reservoir was at full-pool.

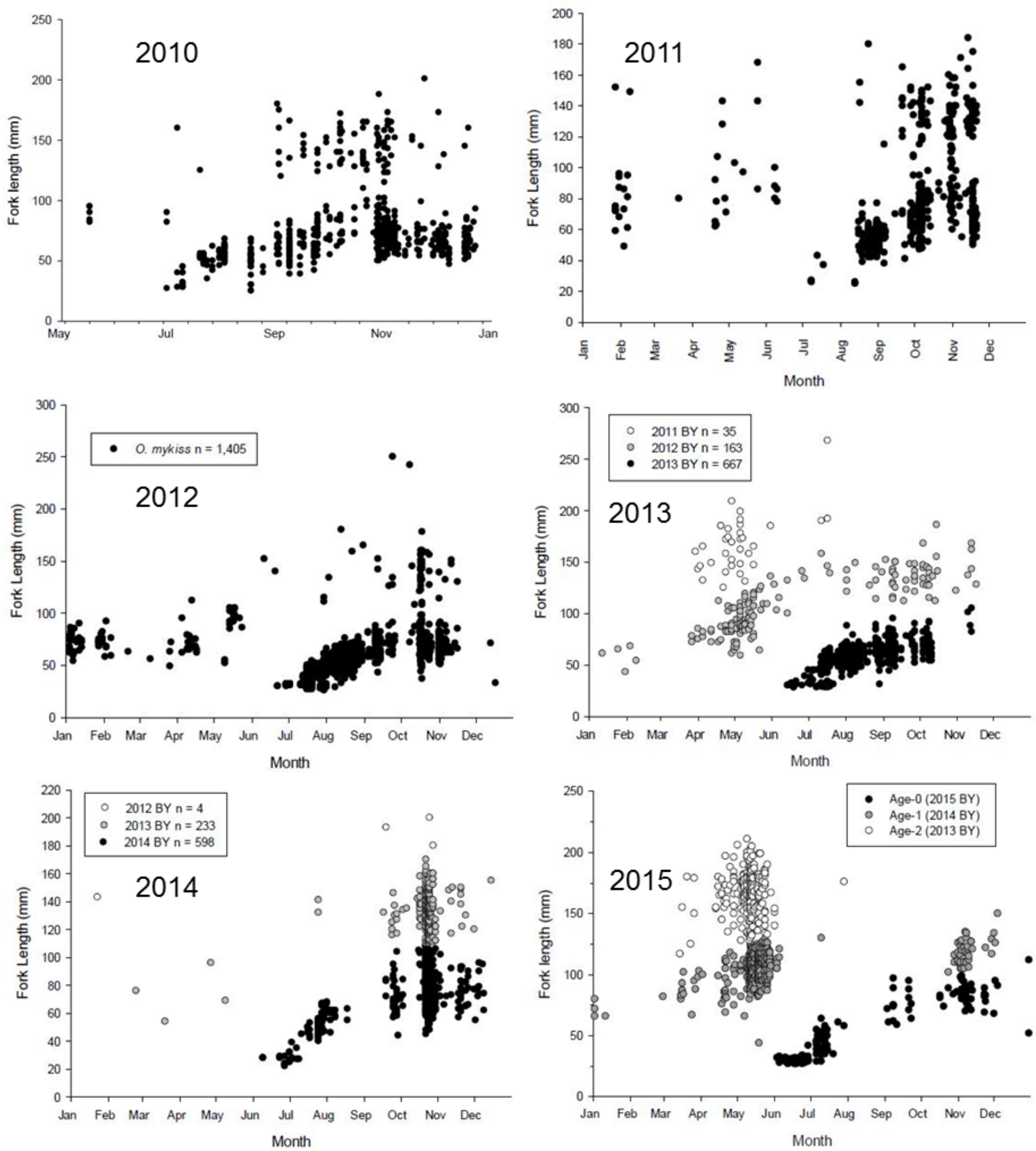

Figure 22. Graphs showing juvenile *Oncorhynchus mykiss* collected by date and fork length (in millimeters [mm]) in a rotary screw trap upstream of Foster Reservoir on the South Santiam River, Oregon, 2010–15. Note the different x- and y-axis scales. Data from Monzyk, Romer, and others, 2011a; Romer and others, 2012, 2013, 2014, 2015, 2016.

Reservoir Residence and Behavior

Subyearling and yearling Chinook salmon were collected in nearshore and offshore areas with box nets and Oneida Lake traps throughout Foster Reservoir during all parts of the year, but fish numbers were greatest in the spring (Monzyk and others, 2013, 2014, 2015a). Sampled fish were less than 50 mm fork length between January and March, and fish size steadily increased throughout the year with most small fish collected in the upper third of the reservoir (fig. 23; Monzyk and others, 2013, 2014, 2015a). However, catch decreased after May. Subyearling Chinook salmon and juvenile steelhead were distributed throughout the upper, middle, and lower sections of Foster Reservoir during spring (table 13). Fish were distributed in all nearshore areas of the reservoir between February and May, but favored the shallower north bank (Monzyk and others, 2014, 2015a). Fish that reared in Foster Reservoir were larger than those that reared in the South Santiam River (fig. 10), and mean growth rates in the reservoir were reported as 0.80 mm/d (table 6; Monzyk and others, 2014, 2015a). Age-1 *O. mykiss* were collected in greater numbers in the lower reservoir in 2013 and 2014 (Monzyk and others, 2015a).

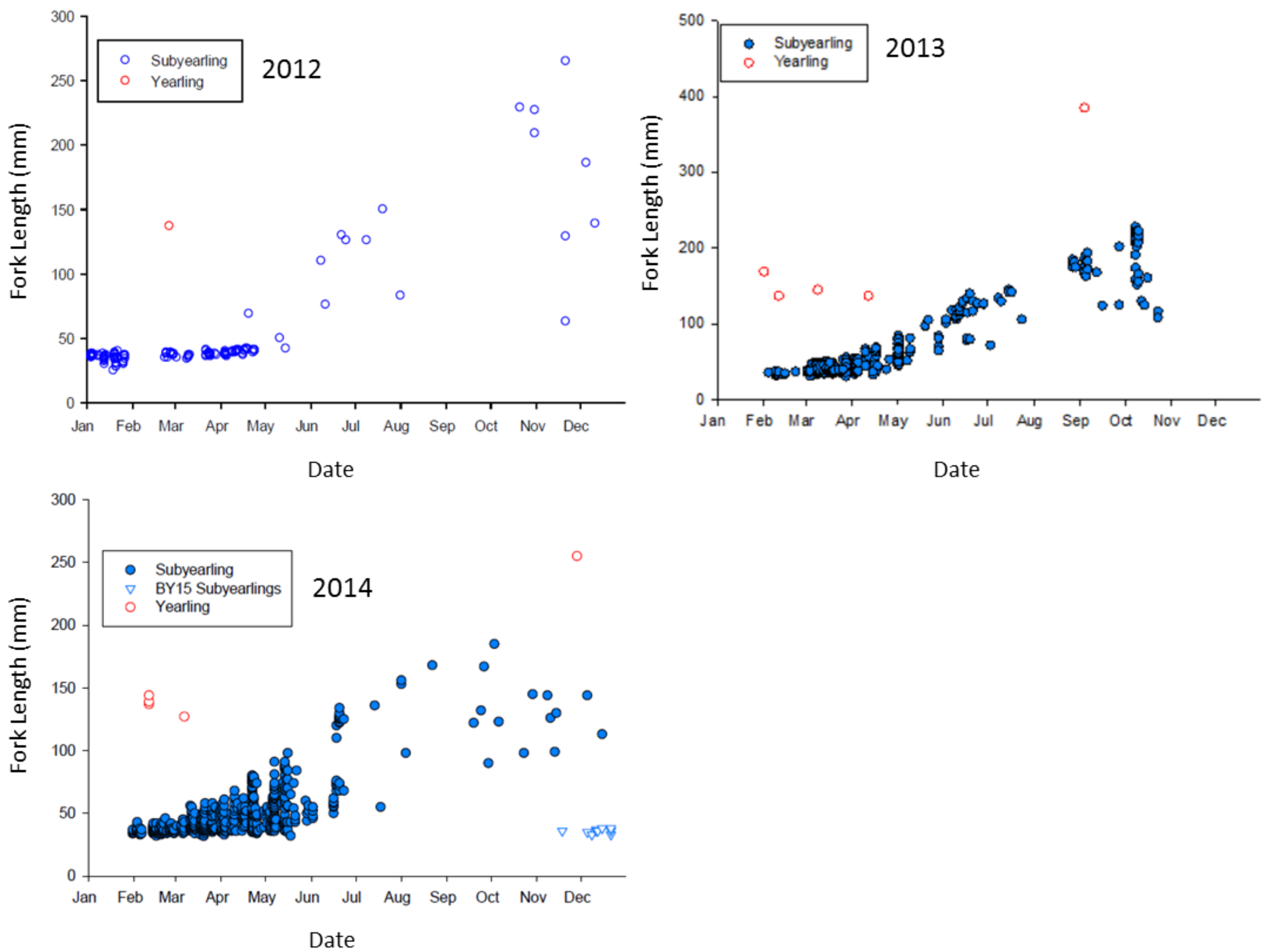

Figure 23. Graphs showing juvenile Chinook salmon collected by date and fork length (in millimeters [mm]) in Foster Reservoir, Oregon, 2012–14. Age class was determined by length-frequency analysis. Note the different y-axis scales. Data from Monzyk and others, 2013, 2014, 2015a.

Table 13. Percentage of juvenile Chinook salmon and steelhead collected in three regions (lower, middle, and upper) of Foster Reservoir, by month, 2013–14.

[Data from Monzyk and others, 2014, 2015a. Steelhead percentages are adjusted for the number of trap sets in each reservoir section. *N*, number of fish]

Sample year	Species	Trap type	Month	*N*	Lower	Middle	Upper
2013	Subyearling Chinook salmon	Box trap	March	243	36.6	39.9	23.5
		Box trap	April	43	46.5	27.9	25.6
		Small Oneida	May	83	86.7	6.0	7.2
2014	Subyearling Chinook salmon	Box trap, small Oneida	February	46	29.5	47.7	22.7
		Box trap, small Oneida	March	173	21.2	37.6	41.2
		Box trap, small Oneida	April	205	15.9	15.8	68.3
		Box trap, small Oneida	May	74	36.5	5.0	58.4
2013	Juvenile steelhead	Box trap, small Oneida	March–May	253	49.0	38.7	12.3
2014	Juvenile steelhead	Box trap, small Oneida	February–May	137	62.1	24.6	13.3

Residence time in Foster Reservoir was monitored using radio-tagged fish in spring and fall 2015, when reservoir elevation was 613 ft (low pool), and in late spring and summer, when reservoir elevation was 635 ft (high pool; Hughes and others, 2016). In this study, tagged fish were released 1.2 and 2.3 river miles upstream of Foster Dam. Mean size of tagged fish was 164 mm for yearling Chinook salmon and 175 mm for age-2 steelhead released in spring, and 173.1 mm for subyearling Chinook salmon and 144.3 mm for steelhead released in fall (Hughes and others, 2016). Yearling Chinook salmon released in spring had median residence times of 1.5 and 2.8 d during low pool and high pool conditions, respectively (Hughes and others, 2016). Spring-released steelhead had a similar residence time (1.6 d) when the reservoir was at low pool, but spent much more time (28.8 d) in the reservoir before passing at high pool (Hughes and others, 2016). Subyearling Chinook salmon were monitored at low pool only during fall and had a median residence time of 4.5 d (Hughes and others, 2016).

Parasitic copepods (*S. californiensis*) were present on juvenile Chinook salmon and *O. mykiss* in Foster Reservoir. About one-half of the juvenile Chinook salmon collected in Foster Reservoir between October and November 2013 had copepod infections, whereas none of the fish collected upstream of the reservoir were infected during the same period (Monzyk and others, 2014). Infection intensity was reported as 0–5 copepods/fish (fig. 14; Monzyk and others, 2014). Unclipped *O. mykiss* had fewer copepods than hatchery rainbow trout, but also were smaller (76 mm and 244 mm, respectively; Monzyk and others, 2013).

Various piscivorous fish were present in Foster Reservoir and were collected in Oneida Lake traps and gill nets, by electrofishing, and using screw traps downstream of the dam. The most numerous piscivorous fish were smallmouth bass (*Micropterus dolomieu Lacepède*), rainbow trout, yellow perch (*Perca flavescens*), and northern pikeminnow (*Ptychocheilus oregonensis*). Monzyk and others (2014) reported that fish (including salmonid) consumption primarily was by smallmouth bass and northern pikeminnow, but only in spring and summer. Of the 55 percent of smallmouth bass collected with non-empty stomachs, 54 percent of the stomach contents were fish consisting mostly of sculpin and salmonids (Monzyk and others, 2014). The daily consumption rate of juvenile Chinook salmon and *O. mykiss* was less than 0.148 fish per predator per day by northern pikeminnow and smallmouth bass (Monzyk and others, 2014).

Dam Passage

Passage Routes and Effects of Operations

Fixed-location active hydroacoustics at Foster Dam were used to monitor route-specific passage of 70–300 mm fish-sized targets during 2013–14. Five periods were evaluated:

1. Spring 2013 (April 1–May 31),
2. Summer 2013 (June 1–September 30),
3. Fall 2013 (October 1–November 30),
4. Winter 2013–14 (December 1–February 28), and
5. Spring 2014 (March 1–May 31) (Hughes and others, 2014).

Reservoir elevation was 635 ft during summer and 616 ft during the other periods (Hughes and others, 2014). This study showed that turbines were the predominant passage route under various operating conditions. Spillway passage routes were available during several parts of the study when turbines were concurrently operating, but 78–90 percent of the fish passed through the turbines (Hughes and others, 2014). Similarly, 70–99 percent of the fish passed through turbines when they operated in conjunction with the fish weir. During a small part of the study when alternative passage routes were concurrently available, 69 percent of the passage was through turbines, 29 percent was through the spillway, and 2 percent was through the weir (Hughes and others, 2014). Johnson (1984) noted that discharge was a strong predictor of passage at Foster Dam and reported that more fish passed through the powerhouse during high flows (>3,000 ft^3/s) than during low flows (<3,000 ft^3/s).

Passage was further evaluated using radio-tagged fish in 2015. Dam passage efficiency (DPE) was measured as the proportion of fish passing the dam out of the number of fish detected in the forebay. Dam passage efficiency of age-2 steelhead was 0.432 at low pool and 0.762 at high pool, and only 0.370 passed in spring overall (table 14; Hughes and others, 2016). Conversely, DPE of yearling Chinook salmon was 0.952 at low pool and 0.663 at high pool (table 14; Hughes and others, 2016). During low pool in the fall, DPE was 0.816 for subyearling Chinook salmon (table 14; Hughes and others, 2016). Most of the yearling Chinook salmon passed through spill bays 1–3, and most of the age-2 steelhead passed through spill bays 1–3 or the weir (table 14; Hughes and others, 2016). Passage routes were compared during concurrent block-treatment operations in 2015 (turbine+weir or spill+weir). During the weir operation, yearling Chinook salmon passed in greater proportion over the weir compared to the turbine during high pool, but passage was similar between routes at low pool (Hughes and others, 2016). Passage of tagged fish was higher through spill bay 3 than through the weir when both routes were available, at both low and high pool elevations (Hughes and others, 2016). During low pool elevations, more age-2 steelhead passed over the weir compared to the turbine, but more fish passed through the spillway than the weir (Hughes and others, 2016). Regardless of operation, weir passage of age-2 steelhead was higher than through the turbine or spillway at high pool (Hughes and others, 2016). Romer and others (2015) observed *O. mykiss* making repeated trips to the weir at Foster Dam, but these fish were not entrained in the flow and returned upstream (Hughes and others, 2014). Most subyearling Chinook salmon passed through spill bay 3 compared to the weir, and the ratio of weir to turbine passage was 2:1 (Hughes and others, 2016).

Downstream passage of juvenile salmon and steelhead does not occur at Green Peter Dam, but past studies provided some information on passage conditions there. Less than 56 percent of *O. mykiss* that were marked and released in the upper part of Green Peter Reservoir moved downstream and passed through the downstream migrant facility (Wagner and Ingram, 1973). In the same study, Wagner and Ingram (1973) reported that about 80 percent of the marked juvenile Chinook salmon passed through the facility. Buchanan and others (1993) noted decreasing numbers of winter steelhead passing

Green Peter Dam during the 1980s. Mercury vapor lights were reported to result in increased fish passage between March and May for steelhead and Chinook salmon (Wagner and Ingram, 1973). The authors also reported that steelhead and Chinook salmon passage was higher through the fish horn when water depths were at 17 ft than when they were at 25 ft (Wagner and Ingram, 1973). Juvenile Chinook salmon passage peaked in February and March, and most steelhead passed in April and May (Wagner and Ingram, 1973; Wevers and others, 1992; Buchanan and others, 1993).

Table 14. Season-wide passage and survival metrics of radio tagged yearling (March–June) and subyearling Chinook salmon (October–December), and age-2 steelhead (March–June) by pool elevation at Foster Dam, Oregon, 2015.

[Data from Hughes and others, 2016. Low and high pools were at elevations of 613 and 635 feet, respectively. NA, not applicable; ND, no data reported]

Species	Route or metric	Passage		Survival (standard error)	
		Low pool	High pool	Low pool	High pool
Yearling Chinook salmon					
	Dam-passage survival			0.641 (0.025)	0.760 (0.041)
	Turbine Unit 1	0.326	0.018	0.511 (0.045)	0.500 (0.354)
	Weir	0.171	0.358	0.627 (0.062)	0.522 (0.082)
	Spill bays 1–3	0.503	0.624	0.725 (0.032)	0.916 (0.035)*
	Weir effectiveness	1.2	2.2	NA	NA
	Spill bay effectiveness	1.1	2.7	NA	NA
Juvenile steelhead- age 2					
	Dam-passage survival			0.631 (0.048)	0.631 (0.037)
	Turbine Unit 1	0.148	0.006	0.563 (0.124)	1.000 (0.000)
	Weir	0.426	0.971	0.667 (0.073)	0.621 (0.038)
	Spill bays 1–3	0.426	0.023	0.608 (0.075)	0.750 (0.217)
	Weir effectiveness	2.9	6.0	NA	NA
	Spill bay effectiveness	0.9	0.1	NA	NA
Subyearling Chinook salmon					
	Dam-passage survival	ND	NA	0.876 (0.011)	NA
	Turbine Unit 1–2	0.189	NA	ND	NA
	Turbine Unit 1	ND	NA	0.797 (0.037)	NA
	Turbine Unit 2	ND	NA	0.715 (0.078)	NA
	Weir	0.110	NA	0.883 (0.033)	NA
	Spill bays 1–3	0.701	NA	ND	NA
	Spill bay 3	ND	NA	0.901 (0.013)	NA
	Spill bay 2	ND	NA	0.857 (0.081)	NA
	Spill bay 1	ND	NA	0.500 (0.354)	NA
	Weir effectiveness	4.2	NA	ND	NA
	Spill bay effectiveness	1.8	NA	ND	NA

*An asterisk indicates a significant difference between spill bays 1–3 and fish weir survival.

Seasonal and Diel Patterns

Most subyearling Chinook salmon passed Foster Dam between January and May based on collection at a screw trap downstream of the powerhouse in 2012 and 2013 (Romer and others, 2013, 2014; Hughes and others, 2014). Some young-of-the-year fry that were collected in the screw trap were likely from redds located downstream of Foster Dam (Romer and others, 2015, 2016). The mean size of subyearling Chinook salmon that were collected in the screw trap during January–April was about 37 mm (Romer and others, 2013, 2014, 2015). Wevers and others (1992) reported in their study that *O. mykiss* passage occurred through Foster Dam in late April and mid-May. Three size classes of *O. mykiss* were collected downstream of the dam, which indicated that passage occurs for various ages of fish (age 0–2; Romer and others, 2013, 2014, 2015, 2016). Subyearling *O. mykiss* collection in the screw trap downstream of the Foster Dam powerhouse was documented between August and January and peaked in October–December (Romer and others, 2013, 2014). Downstream collections and PIT detections indicated that larger *O. mykiss* may have passed Foster Dam in spring but were not collected in the ODFW screw traps downstream of the powerhouse (Romer and others, 2014, 2015).

Several studies have documented diel passage timing, but some results differ between studies. Hughes and others (2014) reported that juvenile salmon-sized fish passed through the powerhouse, spillway, and spillway weir during all hours of the day. Johnson (1984) reported that powerhouse passage numbers were similar between daytime and nighttime hours, but noted that passage was higher through the spillway during nighttime hours than during the day. Most radio-tagged yearling and subyearling Chinook salmon (88–98 percent) passed Foster Dam at night, regardless of route and pool elevation, during both spring and fall study periods (Hughes and others, 2016). Radio-tagged steelhead readily passed at night during low pool elevation (84 percent), but about 37 percent of the fish passed through the weir during the day when pool elevations were high in the spring (Hughes and others, 2016).

Survival

Passage survival has been evaluated at Foster Dam using sensor fish, live fish tagged with HI-Z tags, and radio-tagged fish that passed the dam and were monitored moving downstream. Weir passage survival was evaluated at two reservoir elevations (616 and 634 ft) using multiple release locations. Researchers reported that sensor fish had at least one major strike, collision, or shear event (acceleration magnitude greater than 95 *g*) during December 2012 passage through the weir, and that 81 percent of the releases resulted in at least one major event (Duncan, 2013a). The event occurred “at the concrete chute, on the chute as the unit moved down the spillway, at the terminus of the chute as it plunged into the stilling basin and in the stilling basin/tailrace” (Duncan, 2013a, p. 3.5). Events occurred at all elevations and release locations tested. Weir passage survival of juvenile *O. mykiss* (mean 212 mm total length; range 118–260 mm) was higher when reservoir elevations were low (elevation 616 ft, 99.5 percent) than when they were high (elevation 634 ft, 94.4 percent; table 15; Normandeau Associates, Inc., 2013). Weir survival for adult steelhead (mean 708 mm total length; range 605–865 mm) was 100 percent at low pool and 77.5 percent at high pool (table 15; Normandeau Associates, Inc., 2013).

Table 15. Summary of test conditions of studies of passage survival through turbine unit 1 (juvenile steelhead) and the spillway weir (spill bay 4; juvenile and adult steelhead) at Foster Dam, Oregon.

[Summarized from Normandeau and Associates, Inc., 2013. Numbers other than survival estimates are means. Ad, Adult; Juv, Juvenile; Head, difference between forebay elevation and passage route centerline elevation; Tur, Turbine; °C, degrees Celsius; ft, foot; ft^3/s, cubic foot per second; mm, millimeters; MW, megawatt; , not applicable or not reported]

Metric	Tur	Tur	Tur	Tur	Weir Juv	Weir Ad	Tur	Tur	Tur	Weir Juv	Weir Ad
Powerhouse generation (MW)	3	5	6	7	–	–	4.9	6.5	9	–	–
Powerhouse discharge (ft^3/s)	1,880	2,130	2,300	2,450	2,348	2348	1,532	1,340	1,373	687	687
Weir discharge (ft^3/s)	144	153	101	162	160	160	167	160	165	187	187
Non-weir spill discharge (ft^3/s)	3,006	3,681	3,540	3,575	959	959	0	0	0	0	0
Elevation (ft)	616	616	616	616	616	616	634	634	634	634	634
Head (ft)	86.6	85.4	85.8	86	87.9	87.9	108	107.8	107.4	108.3	108.3
Temperature (°C)	7.5	8	8	7	7.5	7.5	8	8.5	8.5	8.5	8.5
Total length (mm)	213	213	213	213	212	708	213	213	213	212	708
Relative survival (percentage)											
1 hour	81.0	83.7	78.0	87.6	99.5	100.0	88.0	82.9	83.3	96.8	83.7
48 hour	79.0	81.6	74.0	85.4	99.5	100.0	88.2	75.9	79.3	94.4	77.5

Foster Dam turbine passage through unit 1 was evaluated at the same two pool elevations as the weir test and at seven turbine outputs (2.8–9.0 MW). Sixty-two percent of the sensor fish experienced a major event during powerhouse passage at Foster Dam, 24 percent experienced multiple events, and almost one-quarter were lost or damaged while passing through turbines (Duncan, 2013a). Most of the severe events occurred in the wicket gate-runner region of the turbine regardless of reservoir elevation or powerhouse operation (Duncan, 2013a). The 48-h mortality rates of HI-Z fish were three to five times higher than Columbia and Snake River Dams (Duncan, 2013a). The mean probability of a strike in powerhouse unit 1 was 0.244–0.577, and the mean probability of injury was 0.122–0.228, over both reservoir elevations and configurations tested (Duncan, 2013a). Normandeau Associates, Inc. (2013) reported the lowest 48-h turbine survival to be associated with the 6.0–6.5 MW operation at either low (74.0 percent) or high pool (75.9 percent). There was higher turbine survival at the 7.0 MW output at low pool (85.4 percent), and the highest turbine survival estimate (88.2 percent) was at high pool at the 4.9 MW output (table 15; Normandeau Associates, Inc., 2013). Average survival of juvenile salmonids through the powerhouse from December 1968 to June 1969 was 89.9 percent (Wagner and Ingram, 1973). Steelhead kelts had 41 percent mortality through the powerhouse in 1970, leading researchers to surmise that few kelts would survive to return and spawn again (Wagner and Ingram, 1973).

Hughes and others (2016) provided single-release estimates of dam passage survival of juvenile Chinook salmon and steelhead at Foster Dam in 2015. Estimates were obtained for fish that passed through the dam and were either detected (alive) or not detected (presumed dead) on a monitoring array located 11 river miles downstream of the dam. Fish passage occurred during low (613 ft) and high (635 ft) reservoir elevations. Dam-passage survival was 0.631 for age-2 steelhead at both pool elevations, and was similar for yearling Chinook salmon at low pool (table 14; Hughes and others, 2016). At high pool, dam-passage survival was 0.760 for yearling Chinook salmon (table 14; Hughes and others, 2016). In fall, most of the subyearling Chinook salmon passed through spill bays 1–3, and survival was high through bays 2 and 3 (0.857–0.901; table 14; Hughes and others, 2016). Survival through bay 1 was 0.500 (Hughes and others. 2016). Survival through the weir and turbines was high (0.715–0.883), but few fish passed through those routes (table 14; Hughes and others, 2016).

A study is underway in 2017 to measure total dissolved gas (TDG) concentrations downstream of Foster Dam, specifically during spillway or fish weir operations. Researchers are evaluating TDG concentration (surface water and hyporheic zone) and dissipation more than 20 river kilometers downstream of the dam.

Juvenile fish survival through Green Peter Reservoir and Dam was low in studies that occurred in the 1960s to 1990s. Survival of hatchery spring Chinook salmon passing through the reservoir and downstream bypass in the 1980s was less than 1 percent, whereas survival in the 1960s was 12–23 percent (Buchanan and others, 1993). The authors also noted that "freefall spill," when reservoir elevation was at 614 ft, was a better condition for fish passage than "throttled spill," which was regulated using a partially opened spill gate at reservoir elevations of 622 ft. Smolt survival in Green Peter Reservoir was characterized as "low" by Wevers and others (1992), owing to piscivorous fish species that were present. In 1970–71, mortality through the downstream migrant facility at Green Peter Dam was minimal and injured 1.4 percent of the juvenile Chinook salmon (Wagner and Ingram, 1973). However, the authors noted that this estimate was based on a small sample size. Additional runs of different flow levels with larger sample sizes have been conducted, but results are not published.

In May 2013, mechanical sensor fish were used to study passage conditions through the bypass pipe at Green Peter Dam. Flow through the 24-in pipe was 7.5 ft^3/s (Duncan, 2013b). Significant events (acceleration magnitude greater than 95 *g*) occurred regularly within the induction system and piping (Duncan, 2013b). A total of 23 percent of sensor fish experienced significant events in the "transition region where the injection system and the 24-in pipe flows merged", which included shear and collisions (Duncan, 2013b, p. 5The greatest median shear value (143.4 *g*; maximum 173.2 *g*) and the greatest median collision magnitude (124.5 *g*; maximum 171.9 *g*) in all areas measured were in the 24-in pipe flow (Duncan, 2013b).

In 2015, direct survival of juvenile Chinook salmon and steelhead and physical conditions using mechanical sensor fish released in the Green Peter Dam bypass pipes at two entrance elevations (910 and 935 ft), were evaluated. The tests were conducted using four gate control valve openings (full open [100 percent open], and 75-, 50-, and 25-percent closed [Normandeau Associates, Inc., 2015]); flow through the 24-in pipe was 4.8 ft^3/s (Deng and others, 2015). The estimated survival rates relative to the control sites was only significantly different for juvenile Chinook salmon (mean 202 mm, range 131–290 mm) at the 910-ft pipe elevation and a 75-percent closed gate control valve (92.4 percent; table 16; Normandeau Associates, Inc.. 2015). The estimated survival rates relative to those of the control sites at the other three gate control valve settings at the 910-ft pipe elevation was more than 97.0 percent. Similarly, fish survival at the four settings at the 935 ft pipe elevation ranged from 97.0 to 99.5 percent (table 16; Normandeau Associates, Inc., 2015). Estimated survival of juvenile steelhead (mean 225 mm, range 121–300 mm) ranged from 97.0 to 100.0 percent for all combinations of pipe elevations and valve openings (table 16; Normandeau Associates, Inc., 2015). Furthermore, survival estimates of young-of-the-year steelhead (mean 76 mm, range 51–100 mm) were 98–100 percent for test conditions at the two pipe elevations and at 100 and 25 percent control valve openings (Normandeau Associates, Inc., 2015). The 24-in pipe was the area with the highest percentage of releases with significant events (Deng and others, 2015). Significant event magnitudes generally were higher at the 935 ft elevation compared to the 910 ft elevation (Deng and others, 2015). Of the valve settings and elevations tested, the greatest average pressure rate of change was at the 75-percent closed setting (fig. 24; Deng and others, 2015).

Table 16. 48-hour survival and malady-free rates of juvenile Chinook salmon and steelhead using all or the lower two control sites, at Green Peter Dam, Oregon, 2015.

[Normandeau and Associates, Inc., 2015 data from Deng and others, 2015. All table numbers except elevations are percentages]

Gate valve setting	Pipe elevation (feet)	Using all control sites				Using the lower two control sites			
		48 hour survival		Malady-free		48 hour survival		Malady-free	
		Chinook salmon	Steel-head	Chinook salmon	Steel-head	Chinook salmon	Steel-head	Chinook salmon	Steel-head
Full open	910	98.5	100.5	94.3	99.5	98.0	100.0	92.9	99.0
	935	99.5	97.5	98.5	96.5	99.0	97.0	97.0	96.0
25 percent closed	910	98.5	100.0	100.0	100.0	98.0	100.0	99.0	100.0
	935	99.5	100.0	99.5	98.5	99.0	100.0	98.0	98.0
50 percent closed	910	97.5	100.0	93.3	98.5	97.0	100.0	91.9	98.0
	935	98.5	100.0	95.4	97.5	98.0	100.0	93.9	97.0
75 percent closed	910	92.4	100.0	89.2	99.5	91.9	100.0	87.9	99.0
	935	97.5	100.0	97.4	96.5	97.0	100.0	96.0	96.0

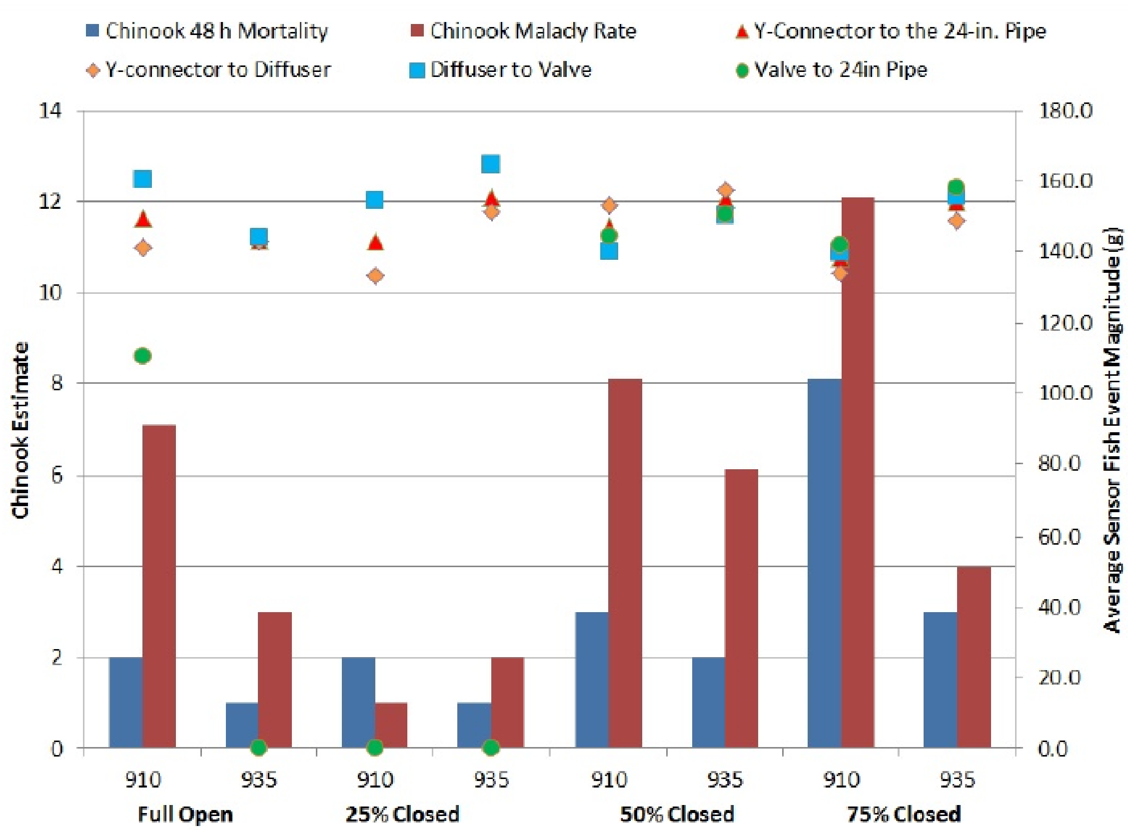

Figure 24. Graph showing juvenile Chinook salmon malady (inverse is malady-free) and mortality (inverse is survival) estimates compared with sensor fish significant event magnitudes (in acceleration due to gravity, *g*) for the y-connector to 24-inch pipe location and sub-regions of that location, Green Peter Dam, Middle Santiam River, Oregon. Bottom axis is reservoir elevation (910 and 935 feet) and four gate control valve openings. Graph from Deng and others, 2015.

Summary

In the South Santiam River subbasin, downstream fish passage of juvenile Chinook salmon and steelhead currently occurs only at Foster Dam, and there is a solid body of literature describing studies that have been conducted at the dam and in Foster Reservoir. Juvenile Chinook salmon enter the reservoir primarily during February–March, whereas juvenile steelhead enter during summer and fall (July–November). Reservoir growth rates are high, but fish that remain in the reservoir are susceptible to predation as well as copepod infection. Most fish pass Foster Dam during late winter and spring, but passage during fall is common too. Most studies have shown that fish will pass during all hours of the day, but some routes have higher passage rates at night. Passage occurs predominantly through the turbines, followed by spill bays and then the spillway weir. Several studies have shown that passage mortality can be substantial through all routes at Foster Dam, but differences are apparent under various reservoir elevations

McKenzie River Subbasin

Subbasin Description

The McKenzie River drains about 1,337 mi^2 on the western slopes of the Cascade Mountain Range in northwestern Oregon. The river is 90 mi long and has an average daily discharge of 8,500 ft^3/s (range, 2,410–29,900 ft^3/s; U.S. Geological Survey, 2016a, U.S. Geological Survey, 2016b; USGS streamgage 14165500) as measured near the mouth. A substantial diversion of water occurs upstream at Walterville during summer (Nikolas Zymonas, Oregon Department of Fish and Wildlife, written commun., March 13, 2017). McKenzie River tributaries include the Blue River, Smith River, South Fork McKenzie River, and Mohawk River (fig. 25). A total of six major dams are present in the subbasin, four of which are owned by the Eugene Water and Electric Board. These include Smith River Dam on the Smith River, Carmen Diversion Dam and Trail Bridge Dam on the upper McKenzie River, and Leaburg Dam on the lower McKenzie River (fig. 25). The two remaining dams, Cougar Dam on the South Fork McKenzie River and Blue River Dam on the Blue River, are owned by the USACE (fig. 25). Anadromous fish populations are not present upstream of Blue River Dam, so this project will not be further discussed in this report.

Spring Chinook salmon and summer steelhead are the primary anadromous fish species in the McKenzie River subbasin, and bull trout and lamprey also rear in this subbasin. Summer steelhead are produced in the McKenzie River subbasin, but are not managed to support naturally producing populations. Two hatcheries are operated, Leaburg and Mc Kenzie Fish Hatcheries (fig. 25). Summer steelhead, cutthroat trout, and triploid rainbow trout are reared at the Leaburg Hatchery. Cutthroat trout and triploid rainbow trout are produced to support in-basin mitigation fisheries, and summer steelhead smolts are produced and released in the McKenzie River each year during April. During 2011–15, releases of summer steelhead smolts from Leaburg Hatchery ranged from 105,289 to 115,064 fish annually (table 17). Juvenile spring Chinook salmon are produced at McKenzie Fish Hatchery, and annual production numbers ranged from about 1.7 million fish in 2011 to about 605,000 fish in 2015 (table 17). These fish are released as yearlings to outmigrate to the ocean with releases occurring during February and March each year.

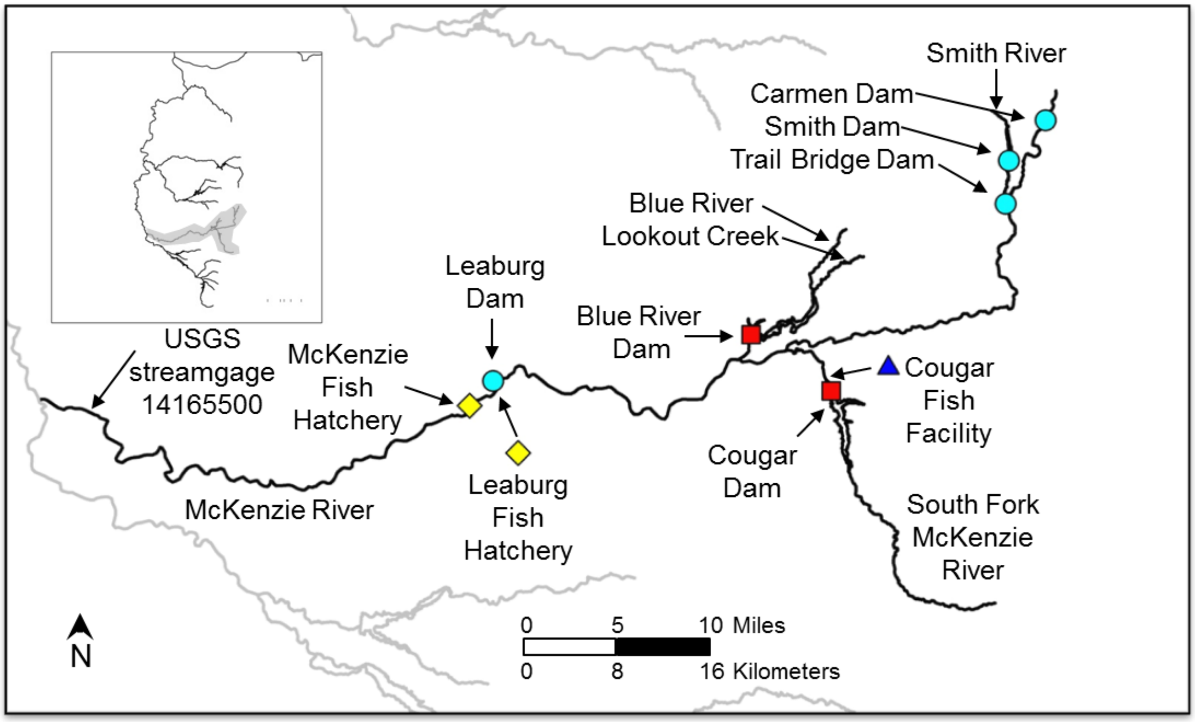

Figure 25. Map showing primary rivers in the McKenzie River subbasin (black lines), U.S. Army Corps of Engineers (USACE)-owned dams (red squares), non-USACE dams (blue circles), fish hatcheries (yellow diamonds), and adult fish facility (blue triangle), Willamette River Basin, Oregon. Other rivers in the Willamette Basin but not in the McKenzie subbasin are in gray. Inset of the Willamette River Basin with the McKenzie subbasin shaded in gray is in the upper left.

Table 17. Number of juvenile summer steelhead and spring Chinook salmon released from Leaburg and McKenzie Fish Hatcheries to the McKenzie River, Oregon, 2011–15.

[Data from Withalm and others, 2011, 2012, 2014, 2015, 2016; Cummings and others, 2011, 2012; Kremers and Chilton, 2014, 2015, 2016]

Year	McKenzie Fish Hatchery	Leaburg Fish Hatchery
	Spring Chinook salmon	Summer steelhead
2011	1,700,800	111,596
2012	867,467	115,064
2013	853,979	106,095
2014	604,750	107,628
2015	604,752	105,289

There are no fish ladders on Blue River Dam, Trail Bridge Dam, or Cougar Dam that directly allow returning fish to enter upstream reservoirs, so returning adult salmon and steelhead are either captured in fish traps, or spawn in the main-stem McKenzie River, South Fork McKenzie River downstream of Cougar Dam, or tributaries. Adult returns to Leaburg Hatchery primarily are comprised of summer steelhead, and these fish are recycled to provide additional fishing opportunities for anglers (Withalm and others, 2014). Spring Chinook salmon are captured in the Leaburg Hatchery trap, and these fish generally are transported to McKenzie Fish Hatchery. Adult collection at McKenzie Fish Hatchery is almost exclusively of adult spring Chinook salmon, averaging 4,433 fish per year during 2003–13 (Kremers and Chilton, 2015). The few summer steelhead that are collected at McKenzie Fish Hatchery are returned to the McKenzie River, upstream of the trap. A new trapping facility, including an adult ladder completed in 2010, operates in the tailrace of Cougar Dam to collect bull trout and clipped and unclipped adult spring Chinook salmon for release upstream of Cougar Reservoir. From 6 to 17 adult bull trout were collected at the trap and released upstream of Cougar Reservoir annually during 2013–16 (table 18). No lamprey were collected in those same years at the Cougar trap; however, lamprey were counted at Leaburg Dam. The number of clipped and unclipped spring Chinook salmon that were released in the upper McKenzie River ranged from 629 to 1,052 fish during 2010–14 (table 18). Release of adult fish does not occur upstream of Blue River Dam, and summer steelhead are not released in any of the upper parts of the watershed. Small numbers of spring Chinook salmon adults are released upstream of Trail Bridge Dam in anticipation of the construction of adult and juvenile passage facilities there, but downstream passage of juveniles is not monitored. Thus, downstream anadromous fish passage at USACE-owned dams in the McKenzie River subbasin occurs only for juvenile spring Chinook salmon at Cougar Dam.

Table 18. Number of clipped and unclipped adult spring Chinook salmon and bull trout released upstream of Cougar Reservoir, South Fork McKenzie River, Oregon, 2010–16.

[Data from Sharpe and others, 2013, 2014, 2015, 2016; Chad Helms, U.S. Army Corps of Engineers, written commun., May 15, 2017. ND, no data]

Year	Number of Chinook salmon	Number of bull trout
2010	1,052	ND
2011	730	ND
2012	952	ND
2013	629	16
2014	898	6
2015	757	17
2016	ND	7

Cougar Dam

Cougar Dam was built in 1963 and is located at rm 4.4 on the South Fork McKenzie River (fig. 25). The dam impounds 153,500 acre-ft, and its primary purpose is to provide flood control protection for the Willamette Valley. However, it also is operated to generate hydroelectricity, provide recreational opportunities, improve water quality, provide municipal and industrial water supplies, and protect fish and wildlife habitat (U.S. Army Corps of Engineers, 2016b). Cougar Dam is 1,600 ft long, 452 ft high, and primarily is comprised of a rock fill structure that spans the valley floor (fig. 26; U.S. Army Corps of Engineers, 2016a). Structures for passing water (and fish) are located on the sides of the dam; on the east side is an emergency spillway that only serves to pass water during extreme flood events, and on the west side (in a cul-de-sac) is a water intake tower that passes water to the RO or the powerhouse (figs. 26, 27). The intake tower originally was constructed to include five fish horns that provided fish collection routes across a range of water elevations (fig. 28). The original intake tower was modified in 2004 when a water temperature control tower (hereinafter "temperature control tower") was constructed. The temperature control tower can be used to selectively withdraw water from different depths in the reservoir to control downstream water temperatures during periods when reservoir elevations exceed 1,561 ft. At the intake tower, water can be bypassed around the powerhouse through the RO or passed into the powerhouse through a penstock (figs. 29, 30). The powerhouse contains two Francis turbines capable of producing 25 MW of power (1,050 ft^3/s). Water elevations undergo substantial changes during the year and generally range from 1,532 ft in winter to 1,690 ft in summer (fig. 29; U.S. Army Corps of Engineers, 2016c). However, in recent years, reservoir elevations have been as low as 1,450 ft during winter to facilitate maintenance and construction projects at the dam. Fish passing through the horns or into the current intake tower enter the tower at the various elevations and then sound down as much as 270 ft to the elevation of the RO (1,485 ft) or penstock chute (1,425 ft). Fish passing the RO exit the chute in the RO outfall adjacent to the powerhouse tailrace. During extensive reservoir drawdown, fish passage through the gated diversion tunnel is possible, with fish entering the tunnel outside the cul-de-sac and exiting the tunnel in the powerhouse tailrace. Fish passage options at Cougar Dam were expanded in 2014 when the USACE constructed a portable floating fish collector (PFFC) to assess the efficacy of collecting juvenile Chinook salmon at the dam rather than passing through the RO or powerhouse (fig. 31). The PFFC is a surface collector with an inclined ramp and pump-actuated flow used to capture fish in a hopper for collection and transport downstream of the dam.

Figure 26. Photograph showing Cougar Dam, Oregon. Photograph by the U.S. Army Corps of Engineers.

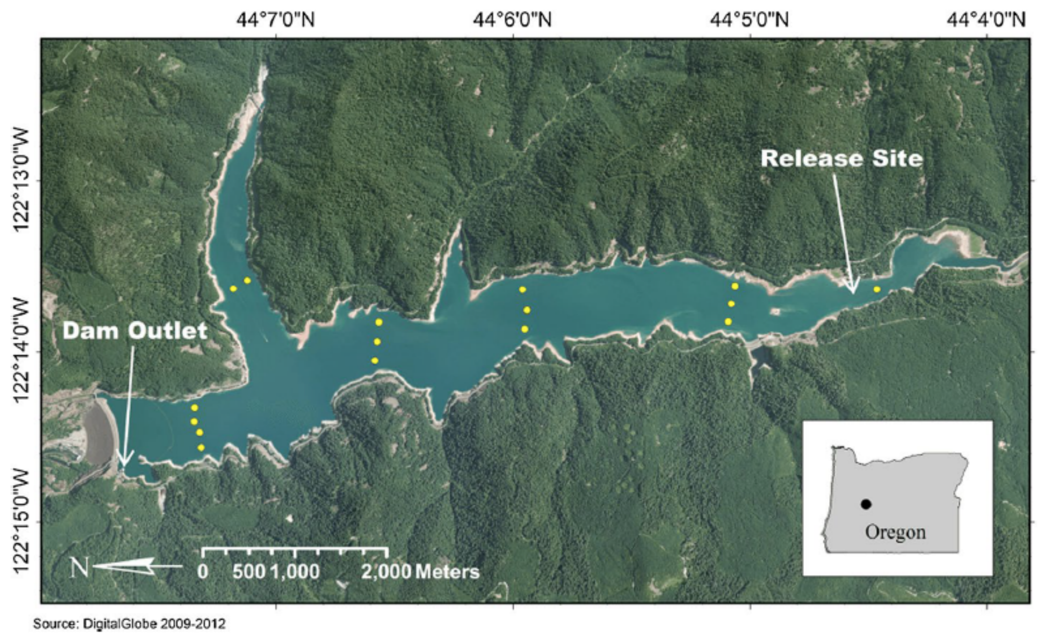

Figure 27. Orthoimage showing arrays of autonomous acoustic receivers (small circles) deployed in Cougar Reservoir, Oregon, 2012. Cul-de-sac is located in the northwestern corner of the reservoir at the dam outlet. Release location of acoustic tagged fish is indicated with an arrow. Figure from Beeman and others, 2015.

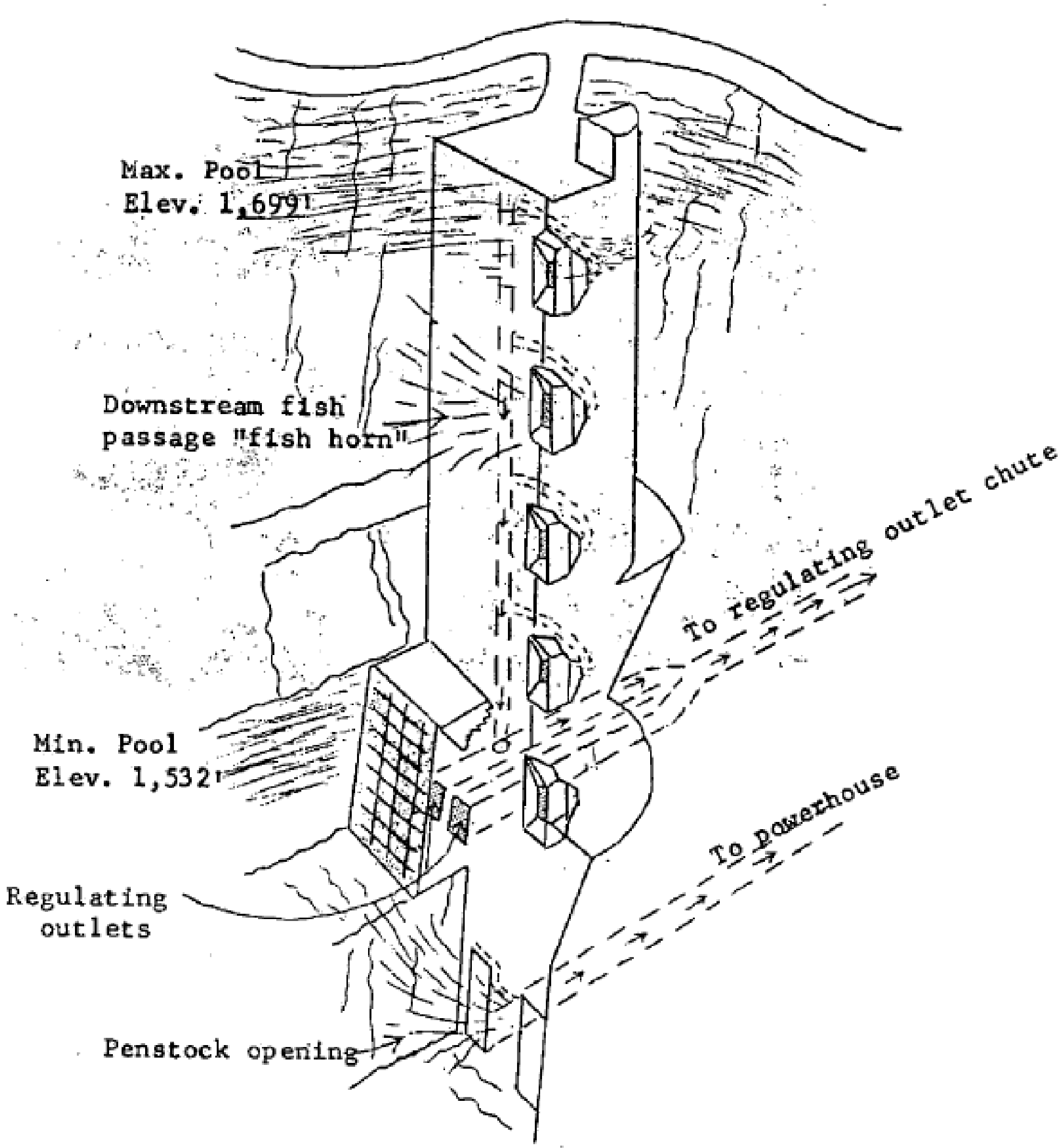

Figure 28. Schematic showing intake structure on the tower including five fish horns for downstream passage, regulating outlet, and penstock opening, Cougar Dam, South Fork McKenzie River, Oregon. Minimum conservation pool and maximum pool elevation are shown at 1,532 and 1,699 feet, respectively. Figure from Ingram and Korn, 1969.

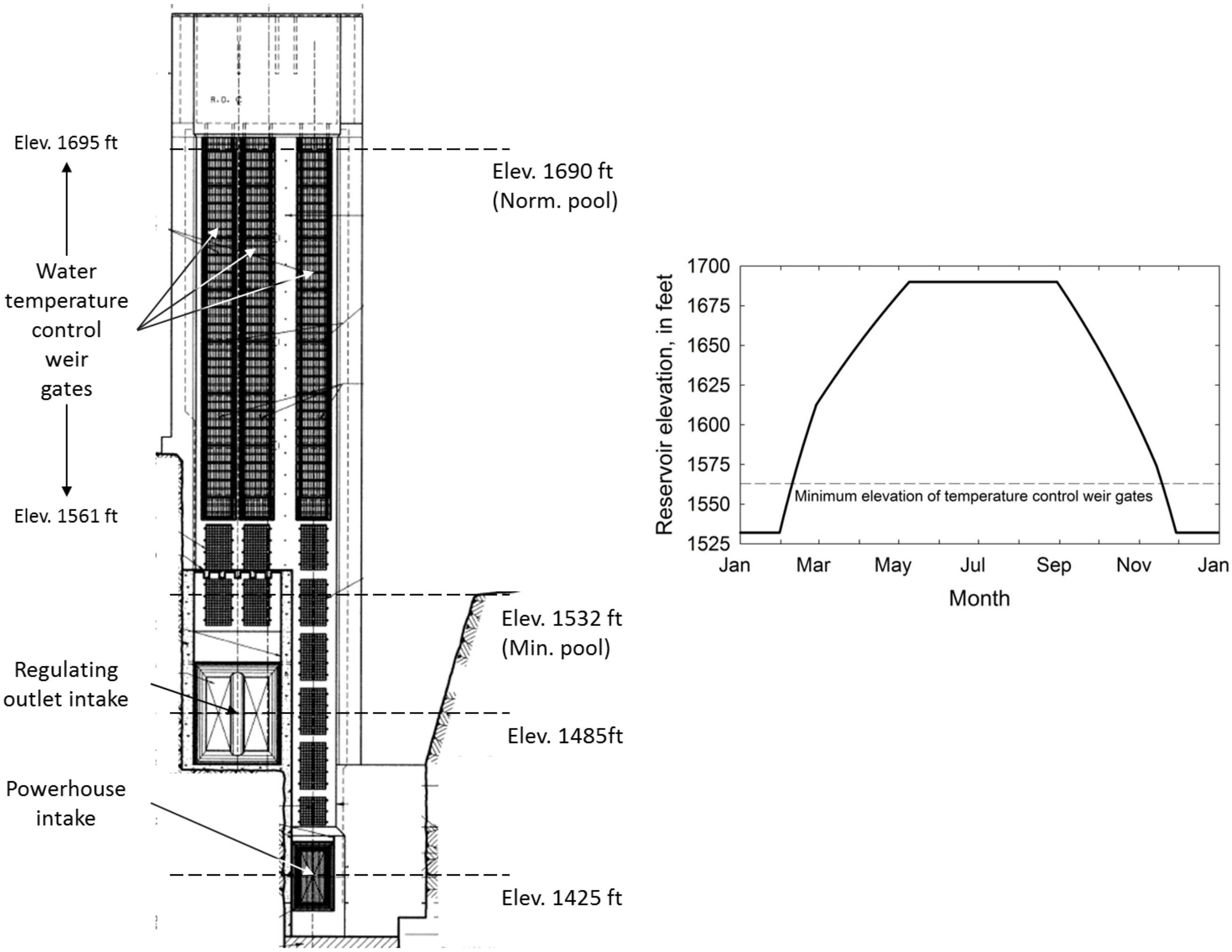

Figure 29. Schematic showing front view of the water temperature control, intakes, and elevations (left), and graph showing planned reservoir elevation targets (rule curve) during calendar year (with minimum operational elevation of the temperature control weir gate for reference) for Cougar Reservoir (right), South Fork McKenzie River, Oregon. Figure modified from U.S. Army Corps of Engineers.

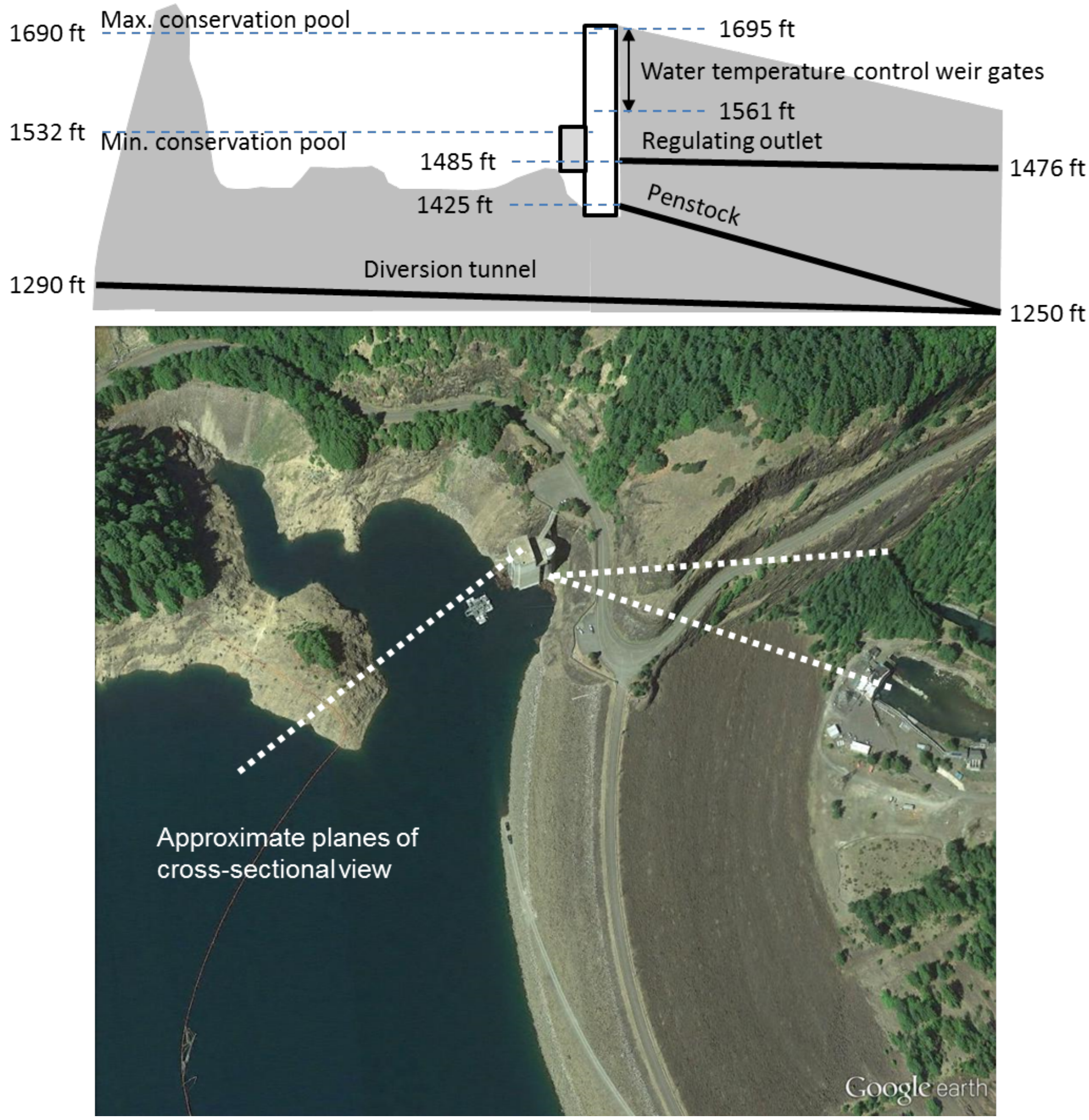

Figure 30. Schematic showing cross-sectional representation of Cougar Dam, including water temperature control tower (white box), minimum and maximum conservation pools, operational range of the water temperature control weir gates, intake gates, and outlets (top); and image showing plan-view of cross-sectional view (bottom), South Fork McKenzie River, Oregon. Top figure based on appendix A, figure 1, in Zymonas and others, 2011.

Figure 31. Photographs showing portable floating fish collector in Cougar Reservoir during construction with pertinent features (left) and position of the portable floating fish collector relative to the water temperature control tower in the cul-de-sac of Cougar Dam and Reservoir (right), South Fork McKenzie River, Oregon, July 2015. Left photograph by Collin D. Smith, U.S. Geological Survey, March 26, 2014; right photograph by Jamie M. Sprando, U.S. Geological Survey, July 28, 2015.

Reservoir Entry

Several studies have provided information about the timing of emergence and downstream dispersal of juvenile Chinook salmon in Cougar Reservoir. A screw trap was operated 0.6 river miles upstream of Cougar Reservoir during multiple years and collected data on downstream dispersal timing and fish size. Results from these studies showed that collection typically began in February and continued through December, and that most fish were captured moving downstream between March and May during pool refill or full conservation pool (fig. 32; Monzyk, Romer, and others 2011a, 2012; Zymonas and others, 2011; Romer and others, 2012, 2013, 2014, 2015, 2016). Median emigration date was estimated to occur between late April and mid-May (Monzyk, Romer, and others, 2011a; Romer and others, 2012, 2013, 2014, 2015). The earliest median migration data was April 9 in 2015 likely due to warmer than average temperatures (Romer and others, 2016). These findings support observations of reservoir entry timing made during other studies conducted in the 1960s and 1980s (Bureau of Commercial Fisheries, 1960; Ingram and Korn, 1969; Zakel and Reed, 1984). The ODFW estimated that between 152,159 and 685,723 subyearling Chinook salmon migrated past the upstream screw trap annually during 2010–14 (table 19; Monzyk, Romer, and others, 2011a; Romer and others, 2012, 2013, 2014, 2015; Zymonas and others, 2011). Some of the estimates likely were underestimated because of the increasing number of redds observed downstream of the screw trap and, therefore, not included in the abundance estimates. Chinook salmon fry that were captured in February had fork lengths of 40 mm or less, and most fish captured in December were yearlings (with fork lengths of about 100 mm; fig. 32).

During most years, small numbers of yearling Chinook salmon were collected in the smolt traps (fig. 32). Catch of yearling Chinook salmon generally occurred between February and May, but some fish were collected through July (Monzyk, Romer, and others, 2011a; Zymonas and others, 2011; Romer and others, 2012). The collected fish often were precocious males that were believed to be moving upstream, presumably from Cougar Reservoir to spawn (Monzyk, Romer, and others, 2011a; Zymonas and others, 2011; Romer and others, 2012). The yearling Chinook salmon that were captured during these studies frequently were infected with parasitic copepods. The presence of the copepods was suggested to indicate that these fish had spent time in Cougar Reservoir, where infection most likely occurred (Monzyk, Romer, and others, 2011a; Zymonas and others, 2011).

Table 19. Number of female adult Chinook salmon released and estimated number of subyearling Chinook salmon (abundance) migrating past the screw trap, by year, 0.6 river miles upstream of Cougar Reservoir, South Fork McKenzie River, Oregon, 2010–14.

[Data from Monzyk, Romer, and others, 2011a; Zymonas and others, 2011; Romer and others, 2012, 2013, 2014, 2015. CI, confidence interval; ND, no data presented]

Study year	Adult females released	Brood year	Abundance	±95 percent CI
2009	288	2008	297,644	54,034
2010	629	2009	685,723	72,519
2011	320	2010	152,159	26,665
2012	336	2011	228,241	34,715
2013	448	2012	557,526	66,031
2014	337	2013	415,741	56,164
2015	ND	2014	219,755	42,166

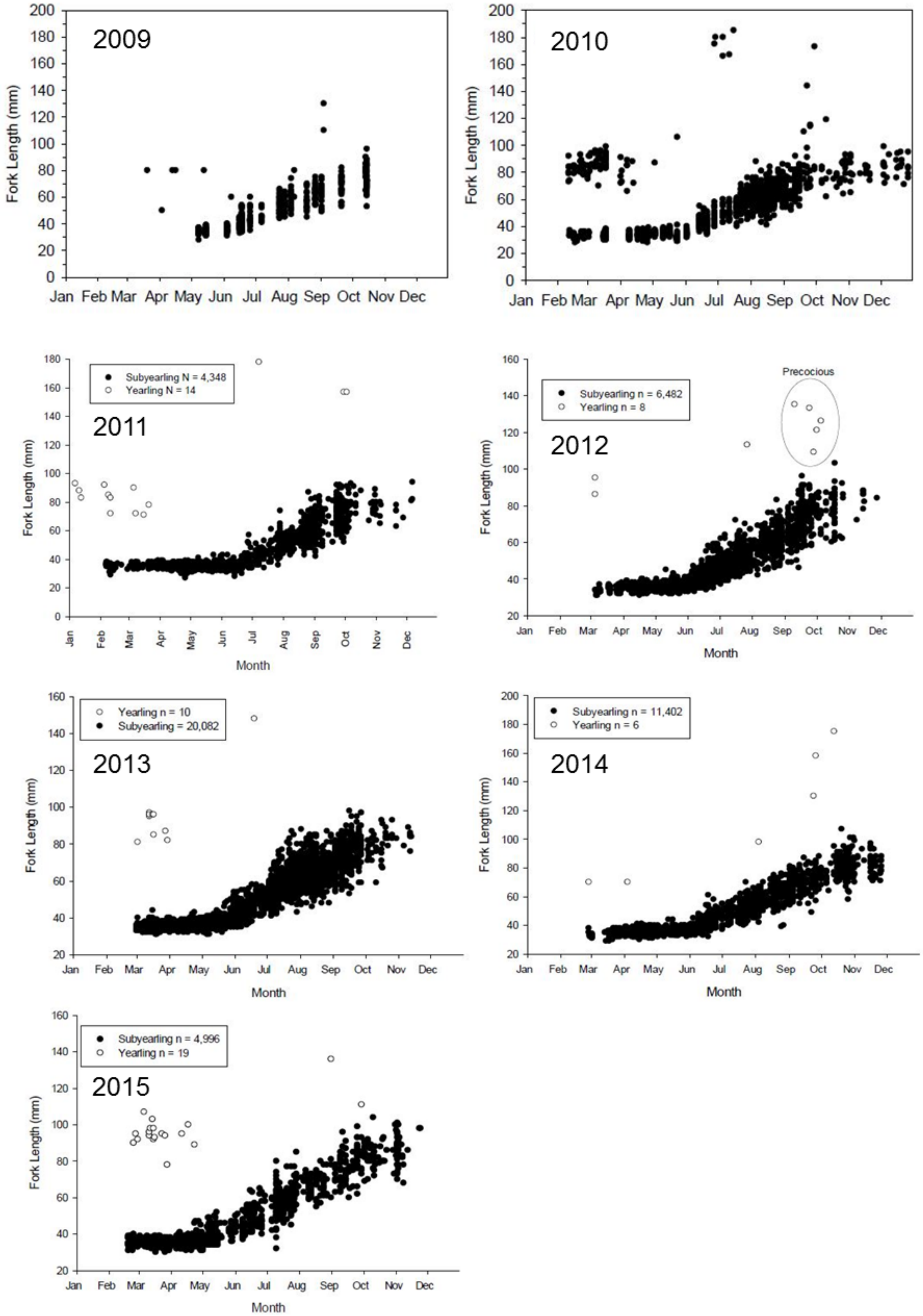

Figure 32. Graphs showing juvenile Chinook salmon collected by date and fork length (in millimeters [mm]) in a rotary screw trap upstream of Cougar Reservoir on the South Fork McKenzie River, Oregon, 2009–15. Data in the circle indicate precocious males as noted by the original authors. Note the different y-axis scales. Data from Zymonas and others, 2011; Romer and others, 2012, 2013, 2014, 2015, 2016.

Reservoir Residence and Behavior

Studies conducted in Cougar Reservoir showed that juvenile Chinook salmon primarily were distributed in the upper part of the reservoir early in the year but then moved downstream towards the dam as the year progressed. Monzyk, Romer, and others (2011b) and Monzyk and others (2013, 2014, 2015a) reported that most (69.0–79.0 percent) of the juvenile Chinook salmon that were collected in nearshore and offshore areas with box traps and small Oneida Lake traps in April were located in the upper one-third of the reservoir (table 20). By June, as much as 40.2 percent of the fish were collected in the lower one-third of the reservoir, near Cougar Dam (table 20; Monzyk and others, 2014, 2015a). Fry occupied areas with various habitat types (flat or steep, cobble or silt/sand, absent or present vegetation) throughout Cougar Reservoir, and increasing inflow was believed to result in greater dispersion throughout the reservoir (Monzyk, Romer, and others, 2011b; Monzyk and others, 2012, 2013). Monzyk and others (2012, p. 20) reported that “the wide range of sizes of subyearlings collected near the head of the reservoir suggest that some juvenile fish likely rear in these areas after reservoir entrance.” Researchers also reported seasonal differences in behavior that may be related to water temperature. Chinook salmon were collected along shorelines in traps as fry, but then moved offshore by June as water temperatures increased (Monzyk and others, 2013, 2014). In fall, when surface temperatures dropped to 17 °C, Monzyk, Romer, and others (2011b) observed actively feeding schools of fish 3–23 ft from shore. Ploskey and others (2012) used mobile active hydroacoustics during day and night to monitor densities of fish-sized targets in Cougar Reservoir, and noted that densities increased throughout the year, peaking in November and December during reservoir drawdown and low pool.

Acoustic cameras were mounted on floating platforms in front of the water temperature control tower in multiple years to quantify fish movement. From March 1, 2010, to January 31, 2011, Khan, Johnson, and others (2012a) reported that juvenile fish abundance was correlated to forebay elevation, velocity over the tower intake gate weirs, and reservoir inflows. Abundance of detections peaked for all fish between 6:00 a.m. and 6:00 p.m. in spring and fall of 2013 (Adams and others, 2015). In spring 2013, fish greater than (>) 300 mm were deeper than fish 30–60 mm, 60–90 mm, and 90–250 mm during all hours except the crepuscular periods (Adams and others, 2015). In fall, all fish 30–300 mm were less than 12 ft deep between 11:00 a.m. and 4:00 p.m., whereas fish >300 mm were deeper in the other hours (Adams and others, 2015).

Table 20. Percentage of juvenile Chinook salmon collected, by month, in three regions (upper, middle, and lower) of Cougar Reservoir, South Fork McKenzie River, Oregon, 2013–14.

[Data from Monzyk and others, 2014, 2015a]

Sample year	Trap type	Month	*N*	Lower	Middle	Upper
2013	Box trap	April	4,718	11.0	19.9	69.0
	Box trap	May	5,186	10.7	26.4	63.0
	Box trap	June	2,217	22.1	23.3	54.7
	Small Oneida	June	2,233	29.1	28.8	42.2
2014	Box trap	April	1,219	7.1	13.9	79.0
	Box trap, small Oneida	May	2,565	12.0	13.5	74.5
	Box trap, small Oneida	June	1,977	40.2	17.2	42.6

Subyearling Chinook salmon that reared in the reservoir grew at different rates than those reared in streams. Fish reared in Cougar Reservoir were 30–40 mm larger by November than those rearing in streams upstream of the reservoir (fig. 10; Monzyk, Romer, and others, 2011b; Monzyk and others, 2012, 2015c). The mean growth rate of fish in Cougar Reservoir was 0.52–0.61 mm/d from spring to fall during 2011–14 (table 6; Monzyk and others, 2015a). This growth rate is the lowest among reservoirs in the Project, based on sampling conducted by ODFW. Monzyk and others (2015a) suggested that lower growth rates in Cougar Reservoir could be affected by factors such as cool water temperatures, density-dependent relations, and copepod parasitism.

Acoustic telemetry studies showed that most tagged fish moved downstream and entered the forebay of Cougar Dam after release near the head of the reservoir. These studies were conducted using hatchery (adipose clipped) and unclipped juvenile Chinook salmon. Acoustic-tagged hatchery fish ranged from 95 to 180 mm fork length, and unclipped fish ranged from 97 to 207 mm fork length (table 21). More than 0.850 of the hatchery fish and 0.692–0.778 of the unclipped fish were detected in the forebay of Cougar Dam (table 22; Beeman and others, 2013, 2016a, 2016b; Beeman, Hansel, and others, 2014b). Acoustic telemetry detection gates provided information on travel times from release near the head of the reservoir to arrival at two locations—the upstream edge of the forebay near the log boom, and the temperature control tower, depending on year. Median travel times to the log boom or temperature control tower were 6–12 d (table 22, fig. 33; Beeman and others, 2013, 2016a, 2016b; Beeman, Hansel, and others, 2014b).

Table 21. Summary statistics of fork length (in millimeters) of acoustic tagged hatchery and unclipped Chinook salmon at Cougar Reservoir, South Fork McKenzie River, Oregon 2011–15.

[Data from Beeman and others, 2013, 2016a, 2016b; Beeman, Hansel, and others, 2014b. Spring releases occurred during March–May (reservoir filling and full conservation pool) and fall releases occurred during September–November (drawdown and low conservation pool). Data collection was 66–144 days from release, depending on study year.]

Study year	Season	Origin	*N*	Mean	Range	Author
2011	Spring	Hatchery	415	121.4	95–152	Beeman and others, 2013
		Unclipped	28	120.6	99–150	
	Fall	Hatchery	358	122.8	99–160	
		Unclipped	118	129.4	97–207	
2012	Spring	Hatchery	468	144.9	112–180	Beeman, Hansel, and others, 2014b
	Fall	Hatchery	449	147.7	98–180	
		Unclipped	65	120.8	98–159	
2014	Spring	Hatchery	430	164.2	115–180	Beeman and others, 2016b
		Unclipped[1]	4	114.3	104–135	
		Unclipped[2]	1	160		
2015	Fall	Hatchery	532	135.3	99–180	Beeman and others, 2016a
		Unclipped[2]	2	129.5	124–135	

[1] Unclipped fish collected in lampera seine.

[2] Unclipped fish collected in portable floating fish collector.

Table 22. Reservoir passage efficiency and dam passage efficiency of acoustic tagged juvenile Chinook salmon released near Slide Creek boat ramp by year and season, Cougar Reservoir, South Fork McKenzie River, Oregon, 2011–15.

[Data from Beeman and others, 2013, 2016a, 2016b; Beeman, Hansel, and others, 2014b. Median, minimum, and maximum travel time are in days from release near Slide Creek boat ramp to the tower (2011–12) or the log boom (2014–15). RPE, reservoir passage efficiency or number of fish detected in the forebay out of the number of fish released in the study; DPE, dam passage efficiency or number of fish that passed Cougar Dam (tower or portable floating fish collector) out of the number of fish detected in the forebay; 95-percent CI, upper and lower 95-percent confidence interval; NR, not reported]

Year	Season–Rearing	RPE (95-percent CI)	DPE (95-percent CI)	Travel time, in days		
				Median	Minimum	Maximum
	Spring–hatchery					
2011		0.864 (0.831, 0.897)	0.135 (0.100, 0.171)	9.6	0.6	63.6
2012		0.902 (0.871, 0.926)	0.111 (0.085, 0.145)	9.7	NR	NR
2014		0.932 (0.904, 0.952)	0.108 (0.028, 0.086)	2.2	NR	NR
	Spring–unclipped					
2011		0.692 (0.515, 0.870)	0.333 (0.116, 0.551)	9.1	3.3	36.4
	Fall–hatchery					
2011		0.854 (0.817, 0.891)	0.296 (0.245, 0.347)	10.7	0.5	126.3
2012		0.978 (0.960, 0.988)	0.581 (0.534, 0.626)	3.7	NR	NR
2015		0.941 (0.921, 0.961)	0.244 (0.206, 0.282)	4.1	NR	NR
	Fall–unclipped					
2011		0.778 (0.702, 0.853)	0.330 (0.233, 0.426)	5.7	0.6	52.5
2012		0.742 (0.621, 0.835)	0.652 (0.508, 0.773)	11.7	NR	NR

Acoustic tagged fish moved throughout the reservoir, and in many cases made multiple trips upstream during the life of the acoustic tags (66–129 d; Beeman and others, 2013; Beeman, Hansel, and others, 2014b). Beeman and others (2013) and Beeman, Hansel, and others (2014b) conducted a Markov chain analysis to describe probabilities of upstream and downstream movements between acoustic detection gates in Cougar Reservoir. Results from this analysis showed that tagged fish made directional movements through the reservoir that frequently included upstream trips. Movements of hatchery fish released in the spring are shown in figure 34, but this pattern was true for spring- and fall-released fish (hatchery and unclipped) as well (Beeman and others, 2013; Beeman, Hansel, and others, 2014b). Detections of acoustic-tagged fish at the upstream end of the dam forebay and near the face of the dam showed that tagged fish had wandering behavior patterns near the dam. On average, tagged hatchery fish made 7 trips between the upstream edge of the forebay and the face of the dam compared to 1.3 trips for tagged unclipped fish (Beeman and others, 2013, 2016a; Beeman, Hansel, and others, 2014b).

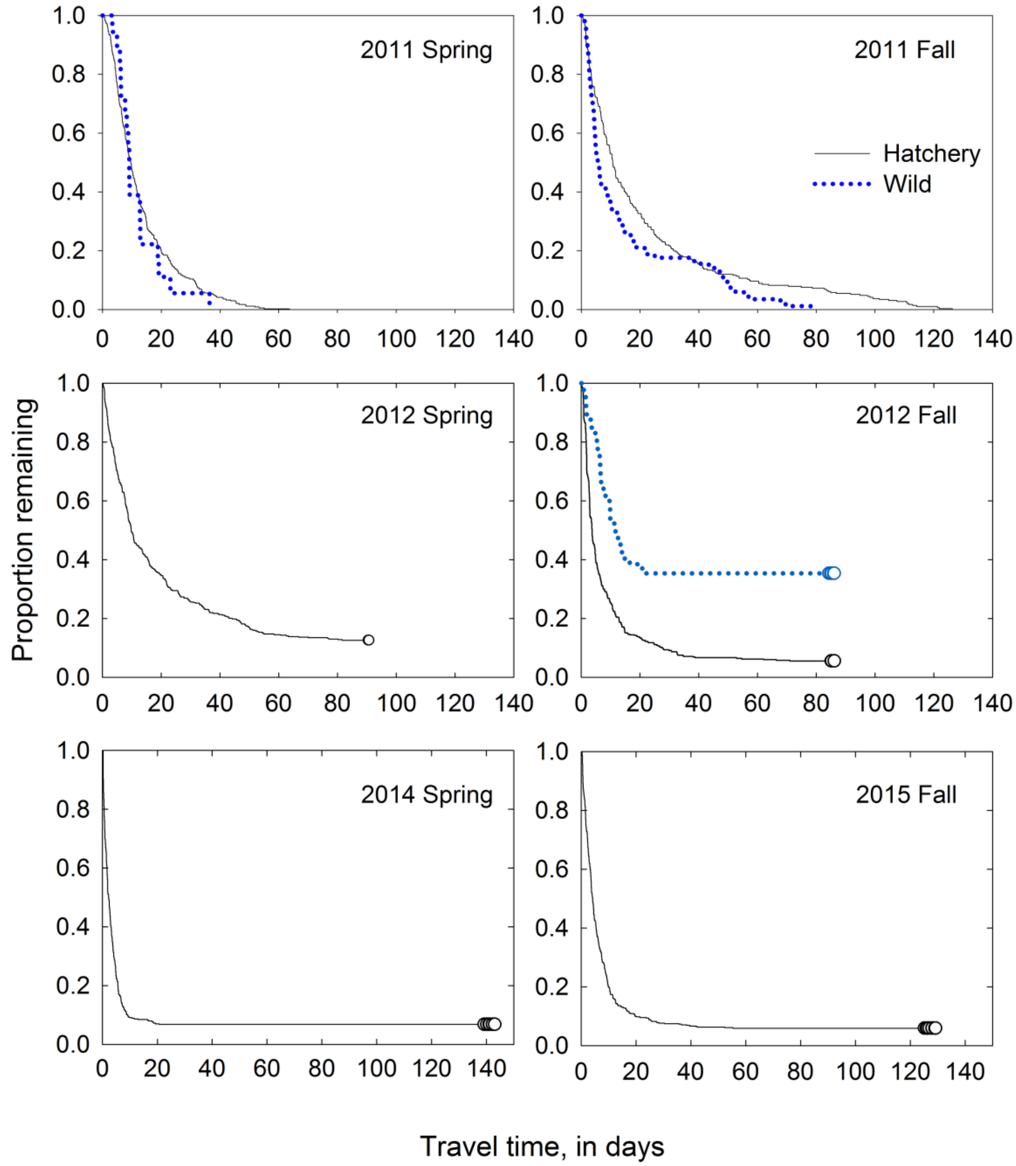

Figure 33. Graphs showing survival distribution (proportion remaining after passage) of acoustic-tagged fish travel times from release near the head of Cougar Reservoir, South Fork McKenzie River, Oregon, to the temperature control tower during 2011–12, or to the log boom during 2014–15. Observations are right-censored (open circles) at the 90th percentile of tag life if fish were not detected at the temperature control tower or log boom. Graphs modified from Beeman and others, 2013, 2016a, 2016b; Beeman, Hansel, and others, 2014b.

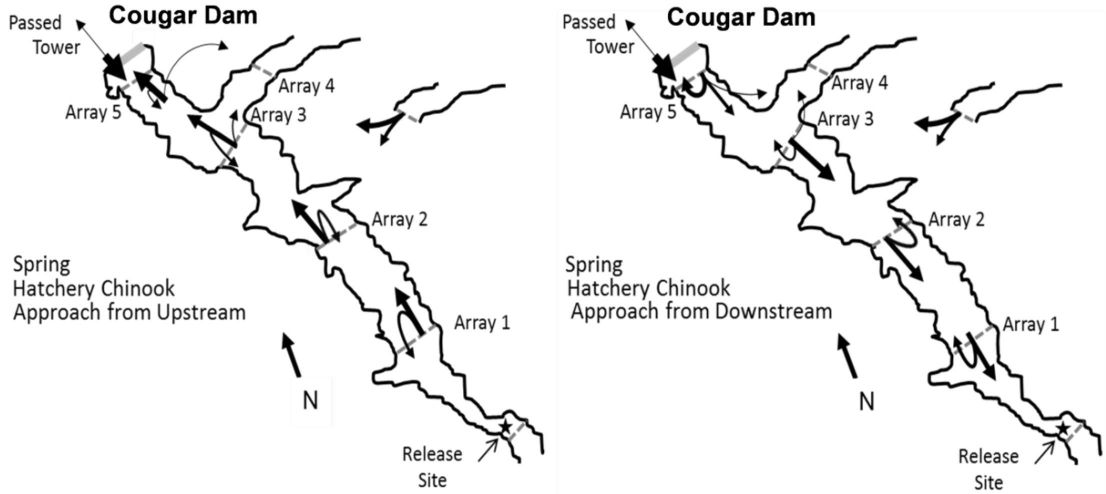

Figure 34. Diagrams showing movement probabilities of juvenile hatchery Chinook salmon acoustic tagged and released in Cougar Reservoir, South Fork McKenzie River, Oregon, spring 2012. Relative width of arrows indicate probabilities of moving from one array to an adjacent array based on the previous movement. Probabilities at arrays 3 and 5 do not include fish coming from array 4. Probabilities from array 4 are shown to the right of each diagram. Figure from Beeman, Hansel, and others, 2014b.

Prevalence and intensity of copepod (*S. californiensis*) infection in Cougar Reservoir was high, whereas predator presence was low. Less than 10 percent of the fish sampled in a trap located upstream of the reservoir were infected during July–November, whereas 13–89 percent of the fish in the reservoir were infected during a similar time period (Monzyk and others, 2012, 2013, 2014, 2015a). Most of the reservoir fish had parasites attached on the branchial cavities (fig. 14; Beeman and others, 2015; Monzyk and others, 2013, 2015b), whereas in-stream fish had attachments on fins (Monzyk and others, 2015b). As time and fish size increased, infection intensity increased (Monzyk and others, 2013, 2014, 2015b). Seven percent of yearling fish had 20 or more parasites on their branchial cavities (Monzyk and others. 2013). The presence and intensity of copepods in branchial cavities may affect long-term movements of fish in reservoirs, based on data collected using acoustic-tagged fish (Beeman and others, 2015). Monzyk, Romer, and others (2011b) and Monzyk and others (2012) reported few species and low abundance of piscivorous predators collected in box traps and Oneida Lake traps in Cougar Reservoir throughout the year.

Acoustic tagged fish were present throughout the cul-de-sac during the year, but were concentrated upstream of the entrance to the temperature control tower during fall and winter (fig. 35; Beeman, Hansel, and others, 2014b). From October 1 to December 12, 2012, when reservoir elevation decreased by about 100 ft and most passage occurred, fish commonly were present near the tower entrance (fig. 35). These data later were used to inform decisions related to deployment of the PFFC. There was no indication of spatial or temporal patterns during spring, which included reservoir filling, full, and drawdown conditions (Beeman, Hansel, and others, 2014b).

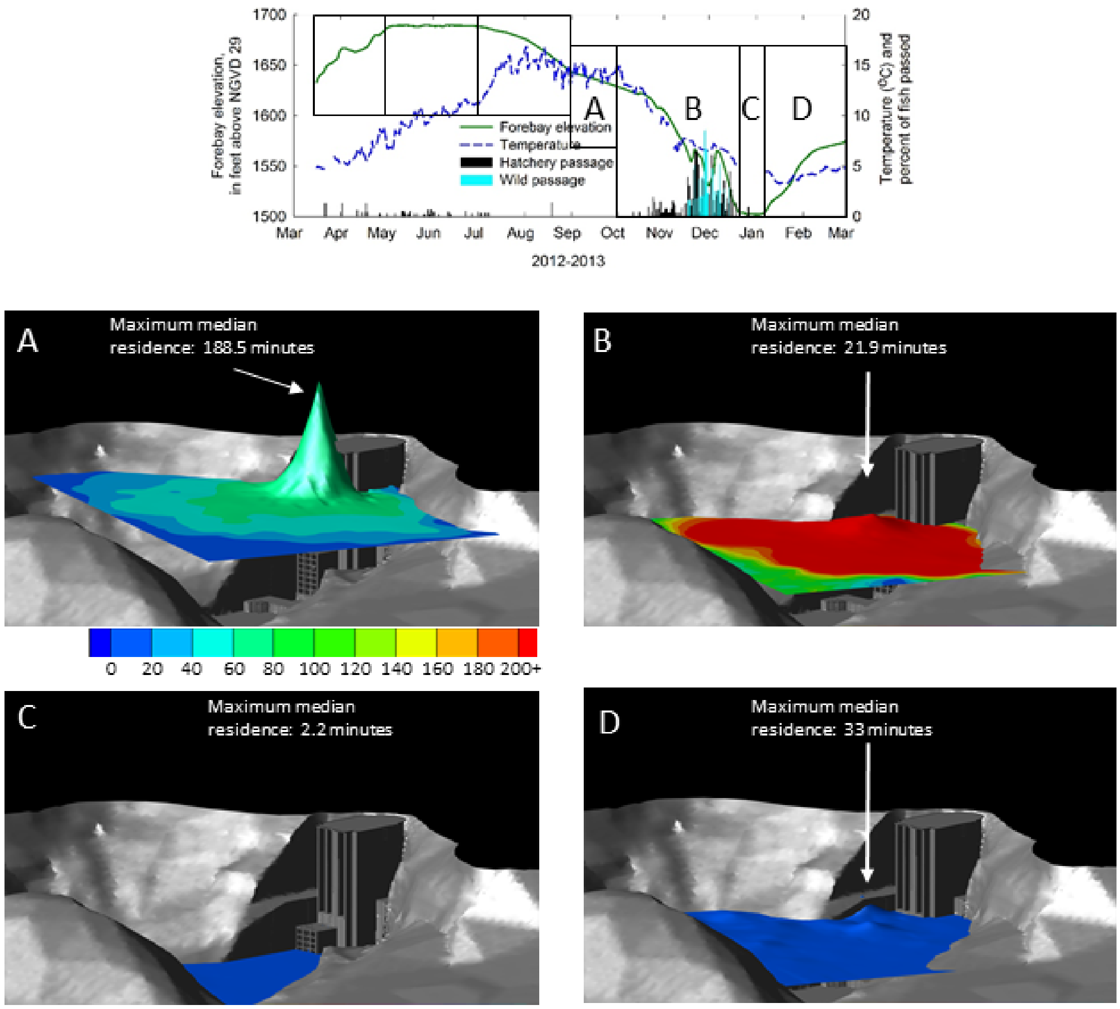

Figure 35. Graphs showing spatiotemporal density of juvenile hatchery and unclipped acoustic tagged juvenile Chinook salmon released in Cougar Reservoir and positioned within about 656 feet (200 meters) from temperature control tower at Cougar Dam, South Fork McKenzie River, Oregon, 2012 fall study period. Both hatchery and unclipped tagged Chinook salmon were included in graph B. Inset shows reservoir elevations, water temperatures, and fish passage percentages during reservoir drawdown prior to fish passage (A, median elevation of 1,637 feet, *N*=94 fish), during most fish passage (B, median elevation of 1,582 ft, *N*=444 fish), after most fish passage (C, median elevation of 1,503 feet, *N*=8 fish), and during reservoir refill (D, median elevation of 1,556 feet, *N*=13 fish). Colors of interpolated surface indicate the number of tagged fish present, and the height of the surface indicates the median cumulative residence time of individual fish based on 10 × 10-meter cells. Figure from Beeman, Hansel, and others, 2014b.

Fish depths varied throughout the year and diel period. Fish tended to be deeper at night than during the day (Beeman and others, 2016b; Ploskey and others, 2012). As shallow water temperatures warmed in summer and cooled in winter, fish depth followed a preferred water temperature range. From September to October 2015, when surface water temperature was as high as 20 °C, acoustic tagged fish generally were about 27 ft deep (Beeman and others, 2016a). Habitat preference indices indicated that acoustic tagged fish in the cul-de-sac preferred 13–15 °C in the summer, which corresponded to a mean depth of 29–54 ft (Beeman and others 2016b). Deeper nets deployed in Cougar Reservoir collected more juvenile Chinook salmon than shallower nets during summer (Ingram and Korn, 1969; Monzyk, Romer, and others, 2011b; Monzyk and others 2012).

Dam Passage

Passage Routes and Effects of Operations

A wealth of information is available on route-specific passage of juvenile Chinook salmon at Cougar Dam. Results from several studies indicate that passage is highest through the RO. Passage of unclipped fish was evaluated using traps downstream of Cougar Dam, where researchers determined that a total of 71 percent of the fish that were collected were in the trap located in the RO channel (Taylor, 2000). Similarly, an estimated 84.9 percent of live subyearling Chinook salmon collected in the downstream screw traps in 2015 were collected in the RO trap (RO, 33,078 [95-percent CI of ±5,211]; powerhouse, 5,862 [95-percent CI of ±2,036]; Romer and others, 2016). The RO provides a shallower passage route from the reservoir than the powerhouse, which likely contributes to higher passage through that route. Romer and others (2012) reported that 91 percent of the fish passed through the RO when discharge was similar between the two routes, but RO passage decreased to 44 percent when two-thirds of the discharge was passed through the powerhouse (Romer and others, 2012). Studies by Monzyk, Hogansen, and others (2011) and Zymonas and others (2011) also indicated that RO passage increased with increasing discharge through the route.

Several studies to measure route of passage of tagged fish were conducted where marked fish were released directly in front of the temperature control tower. Fish predominantly passed through the RO—about 51 percent of the fish passed through the RO when discharge was 530 ft^3/s through the RO and 100–1,060 ft^3/s through the powerhouse; 64 percent of the fish passed through the RO when RO discharge increased to 2,700 ft^3/s and powerhouse discharge was 1,080 ft^3/s (Monzyk, Hogansen, and others, 2011). Both tests occurred during winter low pool (about 1,540 ft) and PIT-tagged fish were about 110–210 mm (Monzyk, Hogansen, and others, 2011). Radio and acoustic telemetry studies produced similar results. During one week in early November 2011 when discharge was about 500 ft^3/s through each route, 94 percent of the radio tagged fish passed through the RO at a mean forebay elevation of 1,579.78 ft (mean fish size 132.4 mm [range 102–166 mm]; Beeman and others, 2012). Passage probabilities of radio tagged fish during one week in early November 2012 were 92 percent through the RO and 8 percent through the powerhouse (mean fish size 148.2 mm [range 105–179 mm]; Beeman, Evans, and others, 2014). Mean forebay elevation was 1,588.6 ft and mean discharge was 1,000.0 ft^3/s powerhouse/547.7 ft^3/s RO during the day and 228.0 ft^3/s powerhouse/1,333.4 ft^3/s RO during the night (Beeman, Evans, and others, 2014). Romer and others (2012, 2013, 2014) reported that fry-sized fish passed Cougar Dam through both routes and were influenced by increased total discharge.

Some fish entered the temperature control tower and returned to the reservoir. Beeman, Hansel, and others (2014b) reported that 31 percent of the acoustic tagged fish in their fall study entered the temperature control tower and returned back upstream to the dam forebay. Of these fish, 48 percent eventually passed through the tower. Few fish exhibited this behavior in spring (Beeman, Hansel, and others, 2014b). The rate of entering and returning from inside the tower was greatest when discharge was low and the depth over the weir gates was high—generally in fall and prior to the end of downstream temperature mitigation when reservoir elevations were about 1,561 ft (often prior to early October). The rate of this behavior was 90 percent higher during the day than the night and primarily occurred when discharge was at a mean of 460 ft^3/s (range 420–540 ft^3/s; Beeman, Hansel, and others, 2014b).

The diversion tunnel is rarely used at Cougar Dam, but it is occasionally operated to draw the reservoir down for construction or maintenance needs. In some instances, research was ongoing when the diversion tunnel was accessible for fish passage, which provided useful information. The diversion tunnel was used prior to and during construction of the water temperature control tower and during trash rack repair at the base of the tower in early 2016. Prior to construction of the temperature control tower, the reservoir was drawn down and water was discharged through the diversion tunnel. Zymonas and others (2011, p. 5) reported that “appreciable numbers” of Chinook salmon fry were collected after passage through the diversion tunnel during April–June 2002 and February–May 2003. Few tagged fish with live tags were in the reservoir during the drawdown in early 2016 and no fish were detected downstream, although detection probabilities of the acoustic sites in the tailrace were poor during high flows (Beeman and others, 2016a). No acoustic tagged fish were detected at downstream PIT sites during this period.

Collection of juvenile Chinook salmon through the PFFC was evaluated during 2 years and was very low. During spring 2014, 397 acoustic tagged fish were detected in the forebay of Cougar Dam but only 1 was collected in the PFFC (0.2 percent; Beeman and others, 2016b). Modifications to the PFFC in winter 2014–15 included raising the trap 1.5 ft, changing the anchor locations to move the PFFC closer to the tower, and modifying the dewatering screens to reduce vibration (Beeman and others, 2016a). These changes had little effect on improving performance, as only 1 percent of acoustic tagged fish were collected in the PFFC during fall 2015 (Beeman and others, 2016a). Subyearling and yearling Chinook salmon were PIT-tagged and released (*N*=3,002) at the head of the reservoir in spring and fall 2014 and 2015, and less than 1 percent of these were eventually collected in the device (Beeman and others, 2016a, 2016b). Positioning of acoustic-tagged fish showed that juvenile Chinook salmon were temporally concentrated in the outflow of the PFFC, which was aimed toward the intake of the temperature control tower, rather than in front of the PFFC entrance (Beeman and others, 2016a). Two of the six acoustic tagged fish that were collected in the PFFC entered the device during daylight hours (Beeman and others, 2016a, 2016b). Acoustic camera evaluations at the PFFC entrance showed that fish of all size groups (30–300 mm) were detected in greatest numbers during crepuscular periods (Beeman and others, 2016b).

Seasonal and Diel Patterns

Downstream fish passage has been intensely studied at Cougar Dam and results from these studies show that changes in water level elevations have a strong effect on passage. Water level elevations in the reservoir generally are high during late spring and summer (fig. 29), and multiple studies have shown that few fish pass under these conditions. Results from acoustic telemetry studies conducted in 2011, 2012 and 2014 showed that only 0.111–0.333 of the tagged fish passed Cougar Dam during spring (table 22). Fish passage in this period primarily occurred during April–July, and generally peaked during periods of increasing discharge (Beeman and others, 2013, 2016b; Beeman, Hansel, and others, 2014b). These findings support studies conducted shortly after the construction of Cougar Dam. Ingram and Korn (1969) reported that the normal outmigration period for juvenile Chinook salmon in Cougar Reservoir likely ended by June 30. Juvenile Chinook salmon were detected passing Leaburg Dam in spring (Schroeder and others 2016). Some Chinook salmon fry passed Cougar Dam and were collected in screw traps (Zymonas and others, 2011; Romer and others, 2016). The earliest capture of fry downstream of Cougar Dam was on January 21, 2015, when reservoir elevation was low (small area compared to high pool), water temperature was warmer than average, and the PFFC was in operation (Romer and others, 2016).

Several studies have shown that downstream fish passage increases during fall as reservoir water elevations decrease (Romer and others, 2016). Beeman and others (2013, 2016b) and Beeman, Hansel, and others (2014b) reported that 0.244–0.652 of the juvenile hatchery and unclipped Chinook salmon that were monitored passed Cougar Dam during fall (table 22). Acoustic tagged subyearling Chinook salmon passage occurred in November and December, but extended into March when discharge rates were greater than 1,000 ft^3/s (Beeman and others, 2013, 2016a, 2016b; Beeman, Hansel, and others, 2014b). This finding was supported by results from several other studies (Taylor, 2000; Romer and others, 2013, 2015) in which researchers reported that dam passage increased during fall, when reservoir water elevations were low and discharge through the dam was increased. The reported catch of yearling Chinook salmon downstream of Cougar Dam occurred during January–July (Monzyk, 2010; Zymonas and others, 2011; Romer and others, 2012, 2013, 2014). Catch of subyearling Chinook salmon in downstream traps peaked during November–February (Zymonas and others, 2011; Romer and others, 2012, 2013, 2014). Romer and others (2015) reported that 83 percent of the subyearling Chinook salmon passed in November 2014 during RO discharge and low reservoir elevations. Numerous yearlings exited the reservoir in November 2013 (8-fold increase compared to other years), which was speculated to be the result of a deep drawdown that occurred in 2013 followed by a period of low discharge (Romer and others, 2014, 2015). Prior to construction of the temperature control tower, 21–28 percent of fish released in front of the fish horns and upstream of Cougar Reservoir passed the dam in late fall or early winter (Ingram and Korn, 1969).

Most passage at Cougar Dam seems to occur at night. Beeman and others (2013) and Beeman, Hansel, and others (2014b) reported that 74–94 percent of the acoustic-tagged fish that passed Cougar Dam during spring and fall 2011 and 2012 did so during the night. In two studies, diel releases of tagged fish occurred at the upstream edge of the Cougar Dam forebay and in front of the water temperature control tower, and most of the fish (93 percent and 87 percent, respectively) that passed the dam from these releases did so during the night (Beeman and others, 2012; 2014c). Beeman, Hansel, and others (2014b, p. 43) conducted an analysis of covariate effects on passage at Cougar Dam, which indicated that passage of acoustic-tagged fish in fall was “about 36 times greater at night than during the day (hazard ratio=35.771), and increased 29.5 percent for each 10 ft decrease in forebay elevation (hazard ratio=0.705).” They also noted that passage rate increased within increasing fork length, but did not report differences between hatchery and unclipped fish (Beeman, Hansel, and others, 2014b).

Survival

Route-specific passage survival has been evaluated multiple times at Cougar Dam. In the 1960s, Ingram and Korn (1969) studied mortality of juvenile Chinook salmon passing through the fish horns and reported that 68 percent of the fish were killed from the point of horn entry to the end of the RO tailrace. The fish horn entrances were 10–45 feet while fish collected in gill nets were at a depth of 0–15 feet (Ingram and Korn 1969). The deep entrances to the fish horns likely influenced the low numbers of fish passing the dam. Only 28.2 and 21.1 percent of hatchery Chinook salmon released at the head of Cougar Reservoir passed the dam in spring 1965 and 1966, respectively (Ingram and Korn, 1969). Taylor (2000) evaluated passage mortality during 1998–99 and noted that 7 percent of the fish died while passing through the powerhouse compared to 32 percent passing through the RO. The authors also observed that mortality increased with increasing fish size (Taylor, 2000). Zymonas and others (2011) collected fish in the RO tailrace and powerhouse tailrace and documented post-collection mortality rates. They reported that 18 percent of the fish that passed through the powerhouse died compared to 42 percent of the fish that passed through the RO. Additionally, the authors reported that 27 percent of the fish that were collected at rm 2.8 did not survive (Zymonas and others, 2011). Mortality of fish held 72 h after passage was higher in the RO (36 percent) than in the powerhouse (19 percent), and was influenced by a combination of low reservoir elevation, discharge, and fish length for each route (Zymonas and others, 2011).

Injury and direct survival through the RO and powerhouse was measured using mechanical sensor fish and balloon-tagged Chinook salmon during December 16–18, 2009, and January 18–21, 2010, respectively (table 23). Fish in the RO study were a mean length of 172 mm (range 127–209 mm), and in the powerhouse study were a mean length of 179 mm (range 124–230 mm; Normandeau Associates, Inc., 2010b). Study conditions included a 1.5-ft RO opening at 440 ft^3/s and 3.7-ft RO opening at 1,040 ft^3/s when the reservoir elevation was near winter low pool (1,532–1,541 ft; Normandeau Associates, Inc., 2010b; Duncan, 2011). The turbine evaluation included three separate treatment conditions for unit 2: (1) minimum wicket opening and 340 ft^3/s, (2) maximum wicket opening and 550 ft^3/s, and (3) peak efficiency wicket opening and 455 ft^3/s (Normandeau Associates, Inc., 2010b). Duncan (2011) used sensor fish and reported a high incidence of one or more significant strike, collision, or shear events (acceleration magnitude greater than 95 *g*) in the RO and powerhouse outlets (more than 92 percent). Nearly 86 percent of trials resulted in multiple significant events during passage through the powerhouse and RO. Most of the events experienced by the sensor fish during RO passage were on the RO chute. All the sensor fish experienced more than one significant event of collision or shear during powerhouse passage, and all events were in the runner region. During powerhouse passage, 80 percent of the most severe events were a collision or strike event during the minimum wicket gate opening. Shear events increased during maximum and peak efficiency operation and blade strike increased with fish size (Duncan, 2011). Mortality through the RO and powerhouse was delayed 24–48 h after passage. Normandeau Associates, Inc. (2010b) reported that 1-h direct survival using balloon tags was about 92 percent through the RO and 58–65 percent through the powerhouse, depending on operation. However, 48 h after passage, survival of fish that passed through the RO was 85–88 percent, depending on treatment. In contrast, direct survival 48 h after passage was 36–42 percent through the powerhouse (Normandeau Associates, Inc., 2010b). Survival and malady-free rate through the RO at a 1.5-ft opening was higher for smaller fish (<160 mm) than for fish larger than 160 mm (Normandeau Associates, Inc., 2010b). Results were not significantly different through the RO at a 3.7-ft opening. The malady-free rate was less than 36 percent for each of the turbine operating conditions

(Normandeau Associates, Inc., 2010b). Fish smaller than 160 mm had higher 48-h survival and malady-free rates during some of the turbine conditions. A similar study using PIT-tagged fish and screw traps in the tailraces was conducted concurrently. Relative survival of PIT-tagged fish to Leaburg Dam was 85 percent at the 1.5-ft RO opening compared to 104 percent at the 3.7-ft RO opening (table 23; Monzyk, 2010). In a separate study, Romer and others (2012) reported greater mortality of PIT-tagged fish through the RO during discrete drawdown flow conditions in November 2011.

Table 23. Summary of test conditions of studies of passage survival through the regulating outlet (RO) at Cougar Dam, South Fork McKenzie River, Oregon, 2009–12.

[Table from Beeman, Evans, and others, 2014. Radio telemetry 2011 data from Beeman and others, 2012; radio telemetry 2012 data from Beeman, Evans, and others, 2014; balloon tag data from Normandeau and Associates, Inc., 2010b; and PIT-tag data from Monzyk, 2010. Numbers other than survival estimates are means. Head, the difference between forebay elevation and passage route centerline elevation; RO, regulating outlet; °C, degrees Celsius; ft, foot; ft^3/s, cubic foot per second; mm, millimeter; –, not applicable or not reported]

Metric	Type	Study						
		Radio telemetry			Balloon tag		PIT tag	
		2011	2012		2009		2009	
		November	November	December	1.5 ft RO	3.7 ft RO	1.5 ft RO	3.7 ft RO
Total discharge (ft^3/s)	Overall	1,110	1,566	1,821	–	–	–	–
RO discharge (ft^3/s)	Day	–	548	1,855	440	1,040	440	1,040
	Night	–	1,333	1,800	–	–	–	–
	Overall	540	1,024	1,821	–	–	–	–
RO gate opening (ft)	Day	1.25	1.21	7.34	1.5	3.7	1.51	3.7
	Night	1.25	3.18	7.55	–	–	–	–
Elevation (ft)		1,580	1,589	1,507	1,532	1,532	1,532	1,532
Head (ft)		91.3	100.1	18.4	43.5	43.5	43.5	43.5
Temperature (°C)		7.2	6.7	5.1	10.5	10.5	–	–
Fork length (mm)		132.4	148.2	160.1	172.3	172.3	–	–
Single-release survival (percent)	To Leaburg Dam	19.3	47.2	55.9	–	–	–	–
Relative survival (percent)	To Leaburg Dam	–	51.8	63.6	–	–	85	104
	1 hour	–	–	–	91.7	92.6	–	–
	48 hour	–	–	–	84.6	88.3	–	–

Estimated survival of fish passing through the temperature control tower to 2.4 river miles downstream of the dam was about 40 percent for both routes (Beeman and others, 2012). Survival of tagged fish that passed through the RO and were detected at Leaburg Dam was 19.3 percent in November 2011, 47.2 percent in November 2012, and 55.9 percent in December 2012 (table 23; Beeman and others, 2012; Beeman, Evans, and others, 2014). Assessment of barotrauma and mechanical damage after passage through the RO and powerhouse was evaluated for fish collected in screw traps in 2012. A total of 74.4 percent of Chinook salmon had barotrauma after RO passage compared to 43.6 percent after powerhouse passage (Romer and others, 2013). Mechanical damage was evident in 52.1 percent of RO fish and 69.2 percent of powerhouse fish (Romer and others, 2013). Combined barotrauma and mechanical damage were present in 23.5 percent of Chinook salmon (Romer and others, 2013).

Live fry were collected in downstream traps during March–June in multiple years, which showed that fry can traverse the reservoir and pass through both the RO and powerhouse and survive (Romer and others, 2012, 2013, 2014, 2015, 2016). Zymonas and others (2011) also reported fry collected in downstream traps in early spring regardless of reservoir elevation. In 2015, an estimated 17.7 percent (95-percent CI of 4.5–37.3 percent) of juvenile Chinook salmon survived from the screw trap upstream of Cougar Reservoir to the screw traps downstream of Cougar Dam (Romer and others, 2016). A similar estimate was reported in 2013, but may have been overestimated (17.5 percent; 95-percent CI of 11.6–25.0 percent; Romer and others, 2016). The authors note that the estimates include "natural mortality incurred through predation, stochastic environmental conditions, parasites, disease while rearing in the reservoir, and dam-associated mortality" but not "delayed dam passage mortality from potential complications such as mechanical injuries, barotrauma and gas bubble disease or complications facilitated by reservoir rearing such as increased parasite infection intensity" (Romer and others, 2016, p. 38).

Summary

Much is known about downstream fish passage in Cougar Reservoir and at Cougar Dam on the South Fork McKenzie River. Fry emerge from redds in February and March and move downstream into the reservoir primarily during March–May. Juvenile Chinook salmon have long residence times in Cougar Reservoir, where growth rates are moderate compared to other reservoirs in the Project. Passage rates are low at Cougar Dam and fish that reside for long periods in the reservoir are susceptible to copepod infection. Reservoir fluctuations are substantial and seem to affect dam passage because most fish pass during fall and winter when reservoir elevations are low. Along with reservoir fluctuations, conditions at the tower entrance also seem to affect fish passage because many tagged juveniles congregate near the tower entrance in spring and fall. Fish that pass the dam do so primarily during nighttime hours. Fish passage is higher through the RO than through the powerhouse, and passage survival also is higher through the former route. The PFFC was constructed to evaluate collection in the forebay of Cougar Dam and was determined to be ineffective. Fishery managers are considering options for improving collection at the project.

Middle Fork Willamette River Subbasin

Subbasin Description

The Middle Fork Willamette River drains about 1,340 mi^2 on the western slopes of the Cascade Mountain Range. Average daily discharge is 7,210 ft^3/s (range, 9–20,200 ft^3/s) and the overall length of the river is 115 mi (U.S. Geological Survey, 2016a, 2016b; USGS streamgage 14152000). Major tributaries include Fall Creek, the North Fork Middle Fork Willamette River, Salmon Creek, Salt Creek, and Hills Creek. Four major dams are present in the Middle Fork Willamette River subbasin, and all are owned and operated by USACE. These include Fall Creek Dam, Dexter Dam, Lookout Point Dam, and Hills Creek Dam (fig. 36).

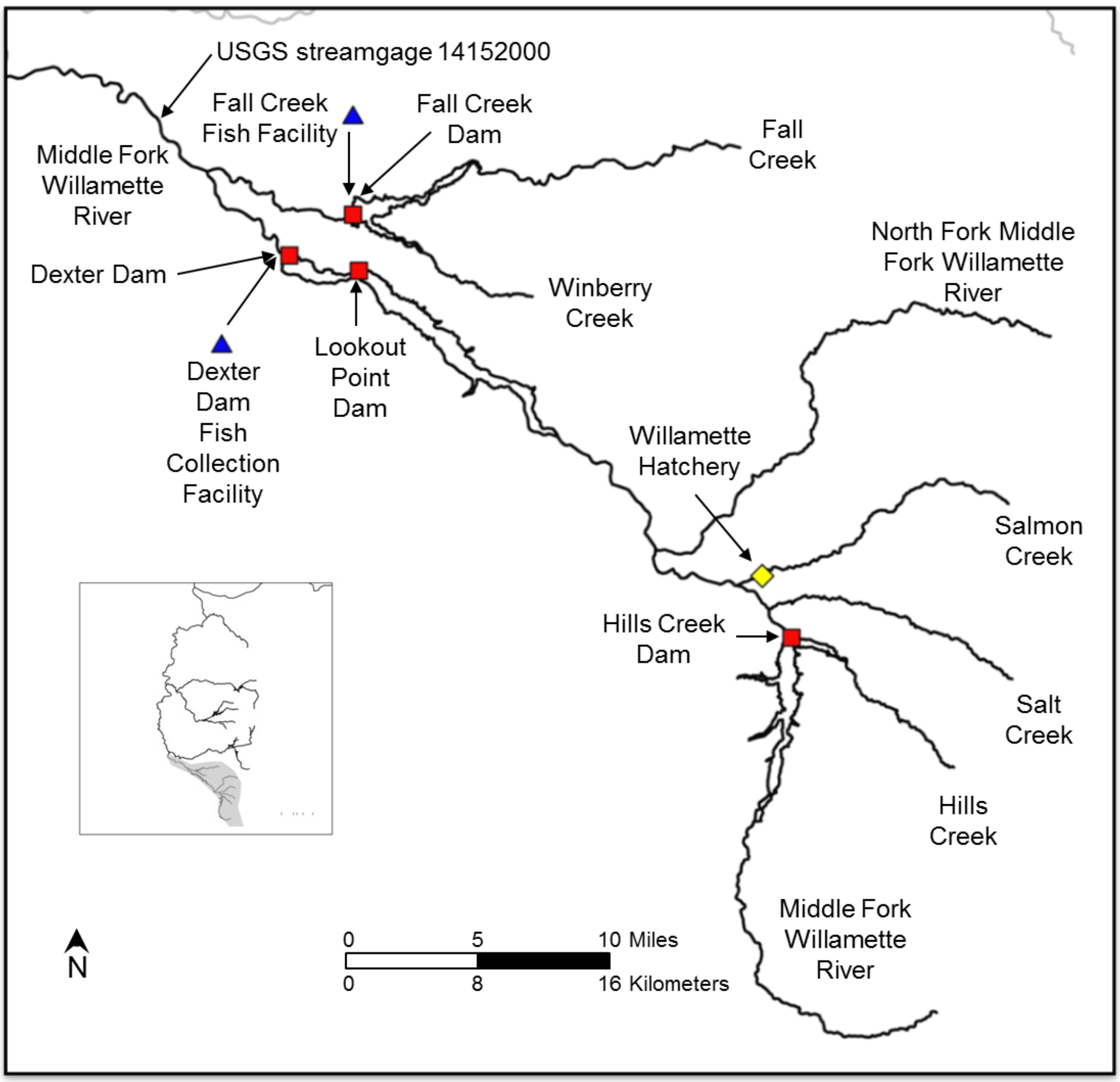

Figure 36. Map showing primary rivers in the Middle Fork River Willamette subbasin (black lines), U.S. Army Corps of Engineers (USACE)-owned dams (red squares), fish hatchery (yellow diamond), and adult fish facilities (blue triangles), Willamette River Basin, Oregon. Other rivers in the Willamette Basin but not in the Middle Fork Willamette subbasin are in gray. Inset of the Willamette River Basin with the Middle Fork Willamette subbasin shaded in gray is in the middle left.

The primary anadromous fish species in the Middle Fork Willamette River subbasin are spring Chinook salmon and summer steelhead. Bull trout also are present upstream of Hills Creek Dam. Willamette Hatchery, operated by ODFW on Salmon Creek, is the primary hatchery in the Middle Fork Willamette River subbasin (fig 36). Two stocks of spring Chinook salmon are produced at Willamette Hatchery (Willamette and South Santiam stocks), along with South Santiam stock summer steelhead and triploid rainbow trout. Releases of spring Chinook salmon smolts in the Middle Fork Willamette River subbasin ranged from 1,344,814 to 1,861,022 fish annually during 2011–15 (table 24). Summer steelhead populations in the Middle Fork Willamette River subbasin are managed to provide a mitigation fishery, not to support a naturally producing population. During 2011–15, summer steelhead smolt releases in the subbasin ranged from 68,376 to 136,870 fish annually (table 24). Triploid rainbow trout are produced to mitigate lost harvest opportunities in the Upper Willamette River watershed. Juvenile rainbow trout were released in various waterbodies, including Hills Creek Reservoir. Annual release numbers ranged between 28,748 and 149,055 (table 24). Trophy-size and legal harvest-size trout also were released in various waterbodies in the area; from 120,921 to 402,153 trout were released annually during 2012–15 (table 24). Willamette Hatchery staff oversees operation of the Dexter Dam Fish Collection Facility (hereinafter "Dexter Facility"), which is located downstream of Dexter Dam (fig. 36). The Dexter Facility conducts adult fish collection, spawning, and juvenile fish acclimation. Juvenile fish are reared and acclimated in the ponds and released directly in the Middle Fork Willamette River.

Adult salmon and steelhead can move upstream volitionally in the Middle Fork Willamette River subbasin until they reach Dexter or Fall Creek Dams (fig. 36). Both projects lack adult fish ladders that provide volitional upstream passage, but have fish ladders leading to fish collection facilities. At these facilities, adult salmon and steelhead are collected, sorted, and transported to specific locations for release (Dexter or Fall Creek Reservoirs) or hatchery broodstock. Only unclipped Chinook salmon are released upstream of Fall Creek Dam. During 2011–15, annual collection of adult spring Chinook salmon at the Dexter Facility ranged from 3,352 to 9,670 fish (table 25). Fish collected at the Dexter Facility were either retained as broodstock for spawning in a hatchery, or released upstream of Hills Creek or Lookout Point Reservoirs (table 25). Summer steelhead adults collected at the Dexter Facility and not taken for broodstock are released back in the Middle Fork Willamette River downstream of Dexter Dam. At the Fall Creek Fish Facility, collected unclipped adult Chinook salmon are released in Fall Creek. Summer steelhead that are collected are recycled downstream of Fall Creek Dam.

Table 24. Number of spring Chinook salmon and summer steelhead smolts, and juvenile rainbow trout released in the Middle Fork Willamette River subbasin from Willamette Fish Hatchery on Salmon Creek, Oregon, 2011–15.

[Data from Peck and other, 2011, 2012, 2014, 2015, 2016. Spring Chinook salmon were released at the Dexter Fish Collection Facility into Lookout Point Reservoir, Hills Creek Reservoir, and Middle Fork Willamette River. Summer steelhead were released at the Dexter Facility. Triploid rainbow trout were transferred to Leaburg Hatchery or released in various waterbodies in the subbasin. NA, not applicable]

Year	Spring Chinook salmon	Summer steelhead	Rainbow trout		
			Transfer	Released[1]	Released[2]
2011	1,723,772	91,885	552,306	191,436	308,201
2012	1,823,764	136,870	477,412	28,748	401,070
2013	1,663,513	70,312	458,617	NA	332,028
2014	1,861,022	76,187	493,853	NA	402,153
2015	1,344,814	68,376	356,957	149,055	120,921

[1]Rainbow trout were released as fingerlings.

[2]Rainbow trout were released as trophy- or legal harvest-size.

Table 25. Number of adult spring Chinook salmon collected at Dexter Fish Collection Facility and Fall Creek Dam Fish Facility and moved to Willamette Hatchery for broodstock, upstream of Hills Creek or Lookout Point Reservoirs, Oregon, 2011–15.

[Data from Peck and others, 2011 2012, 2014, 2014, 2016; Sharpe and others, 2013, 2014, 2015, 2016. Both clipped and unclipped adults were released upstream of Hills Creek Dam, and unclipped adults were released upstream of Fall Creek Dam. Fall Creek indicates adult fish collected at Fall Creek Dam and transported upstream of Fall Creek Reservoir. NA, not applicable]

Year	Collected	Broodstock	Hills Creek	Lookout Point	Fall Creek
2011	7,074	NA	1,576	1,741	365
2012	8,433	2,166	2,043	2,520	338
2013	8,757	3,015	2,113	1,966	467
2014	3,352	2,711	1,005	1,065	456
2015	9,670	2,764	1,897	1,086	259

Hills Creek Dam

Hills Creek Dam was built in 1961 at rm 47.8 on the Middle Fork Willamette River (figs. 36 and 37; U.S. Army Corps of Engineers, 2016a). The dam is 2,235 ft long and 304 ft high, and impounds 355,000 acre-ft of water in Hills Creek Reservoir (U.S. Army Corps of Engineers, 2016a, 2016b). The major part of the dam is an earthen structure. There are two Francis turbines capable of producing 30 MW of power (1,800 ft^3/s), three gated spill bays, and two ROs located on the east side of the dam (U.S. Army Corps of Engineers, 2011, 2016a). The primary purpose of the project is flood control and water storage, but it also serves to generate hydroelectricity, provide recreational opportunities, and provide and protect fish and wildlife habitat (U.S. Army Corps of Engineers, 2016b). Hills Creek Reservoir is managed in a typical flood-control manner where reservoir elevations are low during the winter (1,448 ft during December–January) and high during summer (1,541 ft during May–August; U.S. Army Corps of Engineers, 2016c).

Figure 37. Photograph showing Hills Creek Dam and Hills Creek Reservoir on the Middle Fork Willamette River, Oregon. Photograph by the U.S. Army Corps of Engineers.

Lookout Point Dam

Lookout Point Dam is located at rm 21.3 on the Middle Fork Willamette River and was built in 1954 (figs. 36, 38). The dam impounds 477,700 acre-ft of water in Lookout Point Reservoir (U.S. Army Corps of Engineers, 2016b). The primary purpose at Lookout Point Dam is flood control, but it also serves to generate hydroelectricity and to provide municipal and industrial water supplies and recreational opportunities. Lookout Point Dam operates as a power-peaking project where power is generated for only a few hours when electricity demand is high. The dam is 3,175 ft long and 276 ft high (U.S. Army Corps of Engineers, 2016a). Operating structures on Lookout Point Dam include three Francis turbines capable of producing 120 MW of power (9,300 ft^3/s), five gated spill bays, and four ROs (U.S. Army Corps of Engineers, 2016b). Downstream fish passage at Lookout Point Dam is through the powerhouse, spillway, or ROs. Regulating outlet passage requires fish to sound at least 100 ft below minimum conservation pool, enter the RO channel, and then be passed to the spillway outfall in the tailrace (fig. 38). Reservoir water elevations in Lookout Point Reservoir are managed to reach a low of 825 ft during November–January. Refill begins thereafter and the reservoir reaches full-pool (929 ft) during summer (fig. 39; U.S. Army Corps of Engineers, 2016c).

Figure 38. Photograph showing Lookout Point Dam and Lookout Point Reservoir on the Middle Fork Willamette River, Oregon. Photograph by the U.S. Army Corps of Engineers.

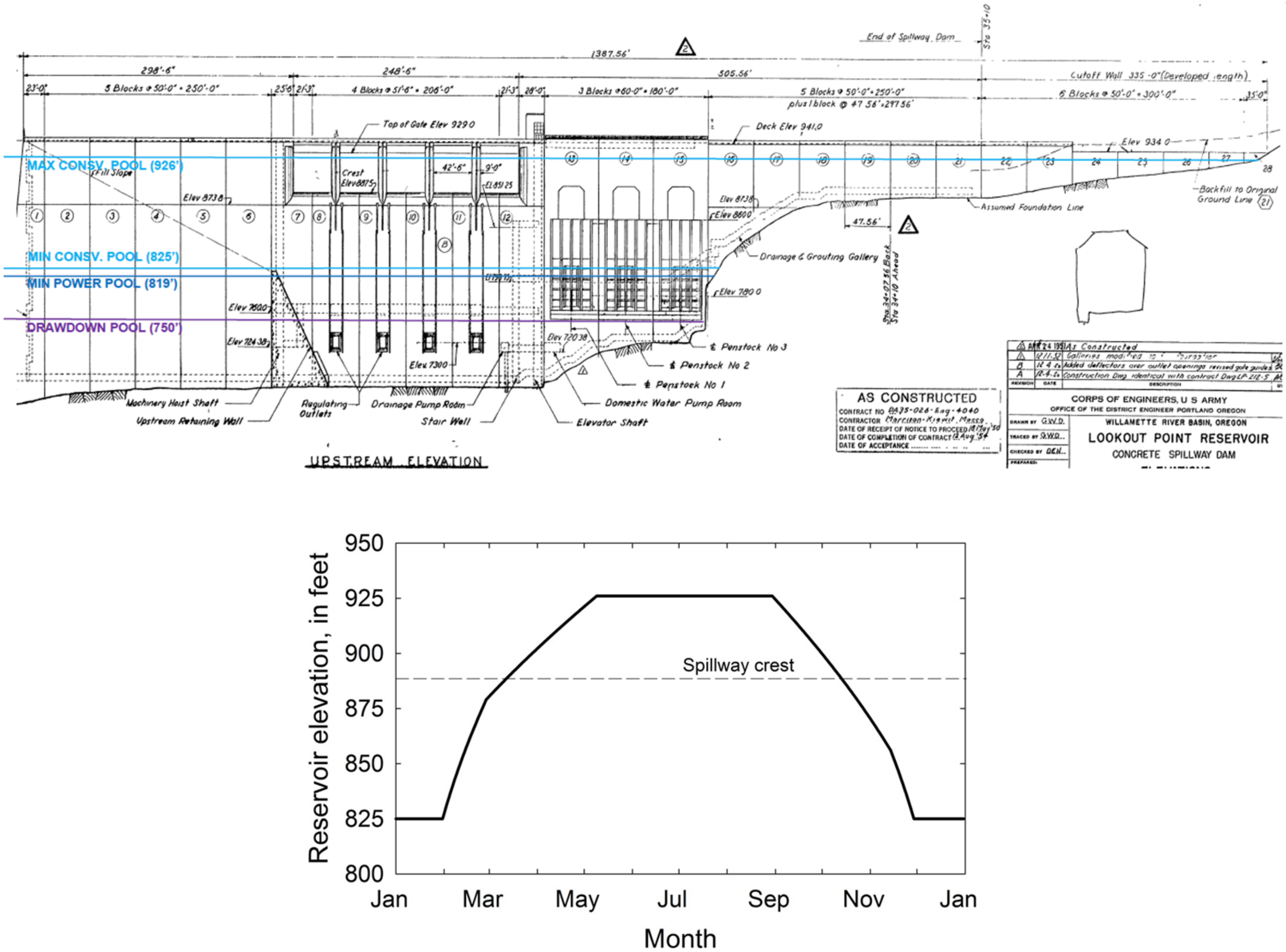

Figure 39. Schematic showing upstream side of Lookout Point Dam with reservoir pool elevations (top) and graph showing planned reservoir elevation targets (rule curve) during the calendar year (with spillway cress for reference) for Lookout Point Reservoir (bottom), Middle Fork Willamette River, Oregon. Schematic provided by U.S. Army Corps of Engineers.

Dexter Dam

Dexter Dam was built in 1954 and is located at rm 18 on the Middle Fork Willamette River, 3 mi downstream of Lookout Point Dam (figs. 36 and 40; U.S. Army Corps of Engineers, 2016a). Dexter Dam is operated as a re-regulating project to control inconsistent water discharge from power production that occurs upstream at Lookout Point Dam. It is authorized for flood control management, hydroelectricity generation, and as a potable water supply for the town of Lowell, and to provide municipal and industrial water supplies and recreational opportunities (U.S. Army Corps of Engineers, 2016a). Dexter Dam impounds 29,900 acre-ft of water in Dexter Reservoir, where water-level fluctuations are common owing to the re-regulating operations at the dam. Dexter Dam is 2,738 ft long and 93 ft high, and has one Kaplan turbine with capable of producing 15 MW of power (4,200 ft^3/s) and seven gated spill bays (U.S. Army Corps of Engineers, 2016b). Downstream fish passage at Dexter Dam is restricted to spillway or powerhouse passage routes. The Dexter Facility is located in the tailrace of Dexter Dam, and is operated to collect upstream migrants, and to acclimate and rear juvenile salmon and steelhead prior to release.

Figure 40. Photograph showing Dexter Dam and Dexter Reservoir on the Middle Fork Willamette River, Oregon. Photograph by the U.S. Army Corps of Engineers.

Fall Creek Dam

Fall Creek Dam was built in 1966 is located at rm 7.2 on Fall Creek, a tributary of the Middle Fork Willamette River (figs. 36 and 41). The dam impounds Fall Creek Reservoir and stores 115,100 acre-ft of water (U.S. Army Corps of Engineers, 2016b). The dam is managed for flood risk management, navigation, municipal and industrial water supplies, fish and wildlife habitat, water quality improvement, and recreation (US. Army Corps of Engineers, 2016b). Fall Creek Dam is 5,100 ft long, 205 ft high, and primarily consists of an earthen dam structure. It has two ROs and two emergency spill bays, but no turbines (U.S. Army Corps of Engineers, 2016a). Fish horns originally were installed on Fall Creek Dam to provide downstream fish passage. Fish horns can draw water from three elevations (800, 765, 720 ft) in the reservoir (fig. 42). Water is passed through fish horns from March 15 to October 15 each year to provide water for the adult facility; however, downstream fish passage through the horns is not prioritized because of fish injury and low survival (Todd Pierce, U.S. Army Corps of Engineers, written commun., May 25, 2017). Downstream fish passage is either through the fish horns or the ROs. Fish entering the fish horns are passed down below the dam in fish passage pipes into the tailrace. Fish passing through the RO sound as close as 100 ft to enter the RO intake, and then are passed to the tailrace. A collection facility is located in the tailrace of Fall Creek Dam to collect adult fish that migrate upstream and enter the facility (U.S. Army Corps of Engineers, 2016a). Fall Creek Reservoir normally is filled to 830 ft during May–August and then held for flood control at 758 ft during November–January (fig. 42; U.S. Army Corps of Engineers, 2016b). In recent years, deep drawdown operations (run-of-river, 680-ft reservoir elevation) have been implemented during winter to pass juvenile salmonids downstream (Nesbit and others, 2014).

Figure 41. Photograph showing Fall Creek Dam and Fall Creek Reservoir on the Middle Fork Willamette River, Oregon. Photograph by the U.S. Army Corps of Engineers.

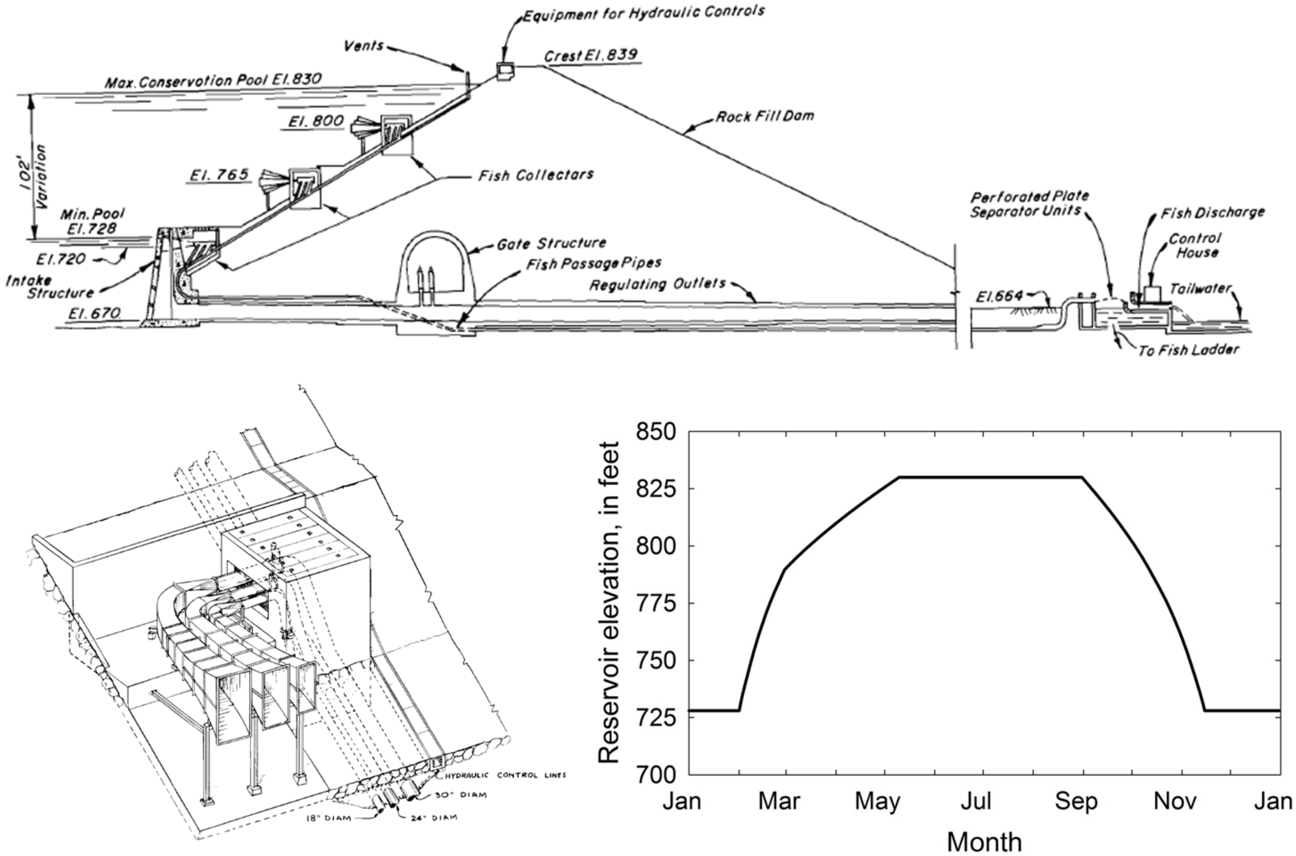

Figure 42. Schematic showing the side view of Fall Creek Dam including minimum and maximum conservation pools, three sets of fish horns ("fish collectors"), fish passage pipes, and tail water (top); close-up of one set of the fish horns (bottom left); and graph showing planned reservoir elevation targets (rule curve) during calendar year for Fall Creek Reservoir (bottom right), Fall Creek, Oregon. Top and bottom left schematic from Smith and Korn, 1970.

Reservoir Entry

In the Middle Fork Willamette River subbasin, downstream movement of Chinook salmon fry primarily occurs during February–June. Studies conducted using screw traps located upstream of reservoirs in the subbasin indicated that most fish collected during this period were subyearling Chinook salmon (Keefer and others, 2012, 2013). The authors also reported that collection of juveniles was low during September–February. Upstream of Hills Creek Reservoir, peak fry migration was during March–May, and the median migration date was March 29 in 2015; however, some of the fry migration may have been missed prior to trap installation in early March (fig. 43; Romer and others, 2016). In Fall Creek, catch peaked during February and March when collected fish had an average length of 34 mm (Keefer and others, 2012, 2013). During these studies, fish collected in upper Fall Creek primarily were juvenile Chinook salmon, whereas most fish collected downstream of Fall Creek Dam were non-native species (Keefer and others, 2013). Romer and others (2012, 2013, 2014, 2015) evaluated outmigration patterns into Lookout Point Reservoir during multiple years and reported that juvenile Chinook salmon primarily were captured during January–June (fig. 44). They reported that the median date of outmigration into Lookout Point Reservoir occurred between March 28 and April 12 during 2011–14. Subyearling Chinook salmon were captured with fork lengths in the 31–129 mm range (fig. 44), and these fish were larger than their counterparts that were collected during the same years in Cougar Reservoir (Monzyk, Romer, and others, 2011a; Romer and others, 2013). The fish in the upper size range suggests some individuals likely overwintered in the North Fork Middle Fork after emergence (Romer and others, 2013, 2016). In the North Fork Middle Fork Willamette River, peak catch of outmigrants occurred during March–May, and the median migration date was May 16 in 2015 (mean length, 48 mm; fig. 43; Keefer and others, 2012; Romer and others, 2016).

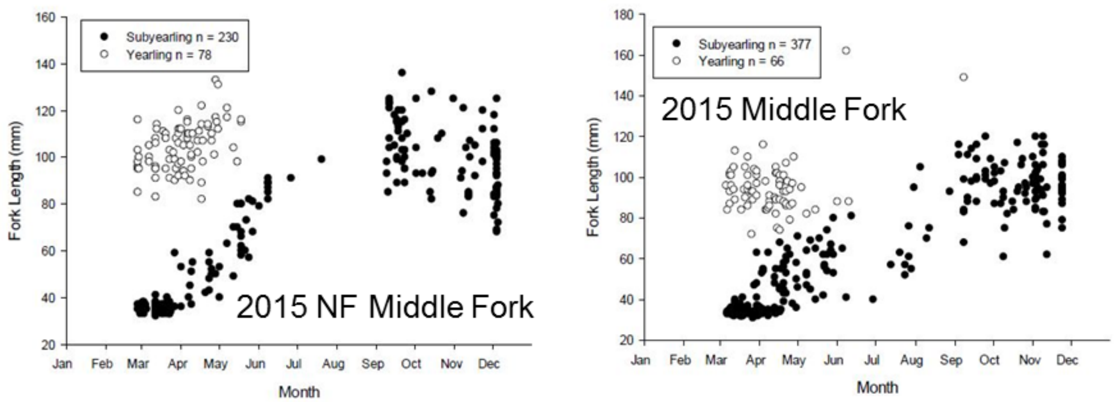

Figure 43. Graphs showing juvenile Chinook salmon collected by date and fork length (in millimeters [mm]) in rotary screw traps on the North Fork (NF) Middle Fork Willamette River and on the Middle Fork Willamette River upstream of Hills Creek Reservoir, Oregon, 2015. Note the different y-axis scales. Data from Romer and others. 2016.

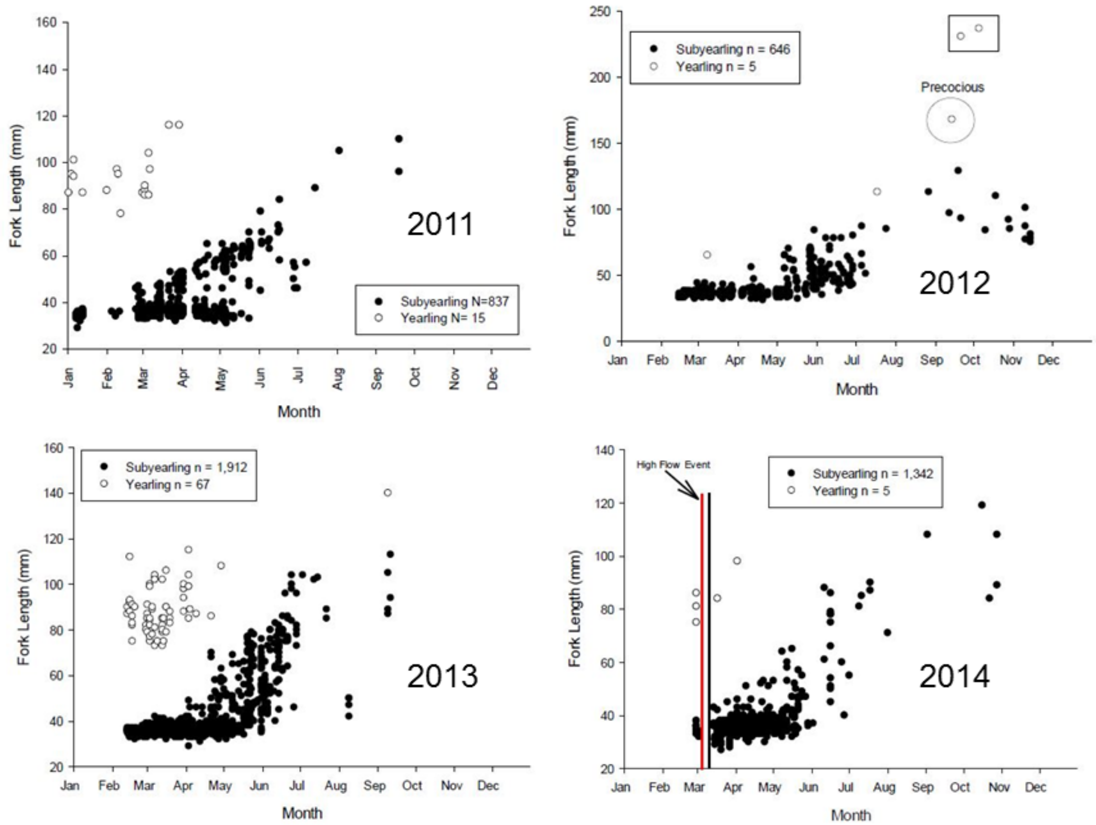

Figure 44. Graphs showing juvenile Chinook salmon collected by date and fork length (in millimeters [mm]) in a rotary screw trap upstream of Lookout Point Reservoir on the Middle Fork Willamette River, Oregon, 2011–14. Data in the circle indicate a precocious male, and data in the rectangle indicates possible age-2 fish as noted by the original authors. Note the different y-axis scales. Data from Romer and others, 2012, 2013, 2014, 2015.

Reservoir Residence and Behavior

Reservoir sampling was conducted during multiple years in Lookout Point Reservoir, which provided a substantial amount of information on distribution and growth patterns in that part of the Middle Fork Willamette River subbasin. Monzyk, Hogansen, and others (2011, 2013, 2014, 2015a) collected fish in Lookout Point Reservoir in nearshore and offshore areas with box nets, Oneida Lake traps, and depth-stratified gill nets, and noted that most subyearling Chinook salmon were located near shorelines in the upper one-third of the reservoir during April and May (table 26). Yearling Chinook salmon were not collected near the head of the reservoir (Monzyk and others, 2012). Smaller fish and greater numbers of fish were collected near the upper reservoir than in the middle or lower reservoir during the spring (Monzyk and others, 2014, 2015a). Juvenile Chinook salmon began moving offshore in June and were distributed throughout the reservoir with larger fish generally located farther downstream (Monzyk and others, 2014, 2015a). Distribution of fry in Lookout Point Reservoir was bimodal in the summer, with greater numbers of fish near the dam and at the head of the reservoir than in mid-reservoir (Monzyk and others, 2015a). By October and November, more parr were collected near the dam than in July and August (Monzyk and others 2015a).

Table 26. Percentage of juvenile Chinook salmon collected in three regions (lower, middle, and upper) of Lookout Point Reservoir, by month, 2013–14.

[Data from Monzyk and others, 2014, 2015a. *N*, number of fish]

Sample year	Trap type	Month	*N*	Lower	Middle	Upper
2013	Floating box trap	March	1,012	8.7	11.9	79.4
	Floating box trap	April	684	10.1	29.7	60.2
	Floating box trap	May	182	5.5	7.1	87.4
	Floating box trap	June	2	0	50.0	50.0
	Small Oneida	June	6	0	0	100.0
2014	Box trap	March	87	31.0	33.2	35.9
	Box trap, small Oneida	April	894	4.1	6.4	89.5
	Box trap, small Oneida	May	713	1.5	26.7	71.8

As water temperatures peaked during summer, juvenile Chinook salmon moved deeper in the water column. In July and August, fish collected in depth-stratified gill nets were in depths corresponding with temperatures of 14–16 °C, with median fish depths reported at 52 ft during August and September (Monzyk and others, 2012, 2013, 2014). Fish returned nearer to the surface as temperatures cooled in fall, with mean depths reported at 7.5 ft during November (Monzyk and others, 2014). At Lookout Point Dam, Khan, Johnson, and others (2012b) used fixed-location active hydroacoustics to monitor fish, and reported that most of the 65–300 mm fish were located in the 16–33 ft range during most of the year in 2010. Reservoir elevations in 2010 generally followed the rule curve (fig. 39).

Growth rates in reservoirs of the Middle Fork Willamette River subbasin generally are high. In Lookout Point Reservoir, researchers reported growth rates of 0.73–0.99 mm/d, which were slightly higher than those in Fall Creek Reservoir (0.71–0.84 mm/d; Monzyk and others, 2012, 2013; Romer and others, 2012; Brandt and others, 2016a). When adjusted for similar study periods, growth rates in Lookout Point Reservoir were 0.61–0.86 mm/d (table 6; Monzyk and others 2015a). In a paired-release study that included fish released directly into Lookout Point Reservoir and downstream of the reservoir, Brandt and others (2016a) reported that fish rearing in the reservoir had significantly higher growth rates (0.73–0.90 mm/d) than tailrace-released fish (0.31–0.65 mm/d). Subyearling Chinook salmon that reared in Lookout Point Reservoir had higher growth rates than fish that reared in the Middle Fork Willamette River upstream of the reservoir, growing as long as 200 mm in winter in the reservoir and less than 150 mm in the river (fig. 10). Subyearling Chinook salmon reared in Fall Creek Reservoir and passed through Fall Creek Dam were a mode of 160–165 mm length compared to 100–130 mm length of fish that reared in the streams (Korn and Smith, 1971). Although reservoir growth rates are high in the Middle Fork Willamette River subbasin, juvenile Chinook salmon also face challenges in these systems.

Juvenile Chinook salmon have high infection rates by parasitic copepods in Lookout Point and Fall Creek Reservoirs. In Lookout Point Reservoir, Monzyk and others (2013, 2014) reported that copepod infection rates increased over time, and were nearly 100 percent by December. Fish sampled in Fall Creek Reservoir had the highest intensity of infection of all Project reservoirs (fig. 14). Monzyk and others (2013) reported that average infection included 13 copepods per fish in Fall Creek Reservoir, and nearly one-quarter of all fish sampled had more than 20 parasites on their branchial cavities.

A greater number and higher abundance of piscivorous species were present in Lookout Point Reservoir than in Cougar or Detroit Reservoirs (Monzyk, Romer, and others, 2011b, 2012). Few walleye (*Sander vitreus*) were collected, but they consumed the greatest number of juvenile salmonids per predator (Monzyk and others, 2012). However, northern pikeminnow had a larger effect on the juvenile salmon population because they were the most numerous of the piscivorous species (Monzyk, Romer, and others, 2011b, 2012, 2013, 2014). Most of the Chinook salmon consumption was in spring and was estimated to be 0.160–0.188 fish per day per predator for northern pikeminnow, largemouth bass, and walleye (Monzyk and others, 2013). These studies also showed that the abundance and size of predator species varied annually because of differences in year-class recruitment and type of collection gear used (Monzyk and others, 2014; Brandt and others, 2016b).

Dam Passage

Passage Routes and Effects of Operations

Route-specific passage information is limited for dams in the Middle Fork Willamette River subbasin. Khan, Johnson, and others (2012b) used fixed active hydroacoustics to monitor passage at Lookout Point Dam and reported that passage of 90–300 mm fish increased with increasing discharge. They also determined that passage through the ROs was low during summer (when reservoir elevations are high) and winter (when reservoir elevations are low), and estimated that passage efficiency through these routes was less than 1 percent (0.4 percent; Khan, Johnson, and others, 2012b). Turbines operated nearly continuously throughout the study period and the ROs operated during project discharge peaks in early June and late November through February (Khan, Johnson, and others, 2012b). At Hills Creek Dam, spring Chinook salmon (101–406 mm long) were 1.5 times more likely to pass through turbines than through ROs and to be collected in screw traps from July 1999 to January 2000 (Larson, 2000). Fish passage through the fish horns at Fall Creek Dam has been shown to be low. Smith and Korn (1970) reported that 1.1–15.6 percent of the yearling Chinook salmon that they released at the head of the reservoir eventually moved downstream and passed through the fish horns. During a drawdown from September 24 to December 8, 2013, entrainment through the fish horns at Fall Creek Dam was 0.37 percent (95-percent CI of 0–1.1 percent) for PIT-tagged hatchery fish, and 1.76 percent (95-percent CI of 1.51–2.01 percent) for unclipped fish (Normandeau Associates, Inc. and Pierce, 2014). During deep reservoir drawdown operations to the streambed level of 680 ft, fish exited the reservoir through the ROs as a shallow passage route. In 1969, Fall Creek Reservoir was "almost completely evacuated" to provide successful Chinook salmon emigration and reduce predator fish populations (Korn and Smith, 1971, p. 291). Fewer juvenile Chinook salmon were collected in gill nets after the complete reservoir evacuation compared to a normal evacuation (Korn and Smith, 1971). In a radio telemetry study with 160–216 mm Chinook salmon, more than 95 percent of tagged fish passed within 48 h of release when the reservoir elevation decreased from 720 to about 700 ft and the average RO gate opening was 5–7 ft (Nesbit and others, 2014). During the drawdowns from 2011 to 2013, Chinook salmon collection in the downstream trap peaked when pool elevation was decreasing rapidly and near 728 ft (Greg Taylor, U.S. Army Corps of Engineers, written commun., May 25, 2017). In the fourth year of deep drawdown, the percentage of fish collected in the downstream trap was about 50 percent Chinook salmon compared to less than 10 percent between 2006 and 2012 (Greg Taylor, U.S. Army Corps of Engineers, written commun., May 25, 2017). The count of crappie (*Pomoxis* spp.) collected was about 3,500–8,500 prior to deep drawdowns, and less than 10 after 2 years of the winter reservoir lowering strategy (Greg Taylor, U.S. Army Corps of Engineers, written commun., May 25, 2017). In a screw trap installed after the 2015 drawdown, no yearling Chinook salmon were collected indicating that most yearling Chinook salmon passed during the drawdown (Romer and others, 2016). A total of 130 subyearling Chinook salmon were collected in the same time period (December 1–15, 2015; Romer and others, 2016).

Seasonal and Diel Patterns

Data collected using screw traps in the Middle Fork Willamette River subbasin provided a wealth of information on passage timing at Project dams. Keefer and others (2013) reported that dam passage at Fall Creek, Lookout Point, and Hills Creek Dams primarily occurred in late fall and winter when reservoir elevations were low and fish could access turbines and ROs (fig. 45). During these studies, passage peaked during November–January (Keefer and others, 2012, 2013). A total of 95–98 percent of the fish that were collected downstream of Fall Creek Dam were non-natives (juvenile black crappie [*Pomoxis nigromaculatus*], juvenile bluegill [*Lepomis macrochirus*]), whereas fish collected downstream of Hills Creek Dam primarily were native fish species that included many juvenile Chinook salmon. In the tailrace of Lookout Point Dam, Keefer and others (2013) noted that juvenile Chinook salmon comprised most of the catch of native fish in some years, but not in others. White crappie (*Pomoxis annularis*) was abundant passing Lookout Point Dam during 2007–09 (Keefer and others, 2013).

Passage through Fall Creek Dam was related to increased discharge and was highest in November (Homolka and Smith, 1991; Keefer and others, 2012, 2013). Unclipped Chinook salmon migrated through the fish horns in every month of the study period between May and October, but peaked during May–June (Normandeau Associates, Inc. and Pierce, 2014). Expected timing of juvenile Chinook salmon passing through Fall Creek Dam was in the spring, but the fish horn entrance was deeper than the fish depths and the attraction flows were too low (Korn and Smith, 1971). Mercury-vapor light attracted fish to and in the fish horns in June 1968 and May 1969 (Smith and Korn, 1970; Korn and Smith, 1971). Downstream migrants passed Fall Creek Dam during night or crepuscular periods (Smith and Korn, 1970; Homolka and Smith, 1991). Passage through Lookout Point Dam was related to increased discharge (Keefer and others, 2012; Khan, Johnson, and others, 2012b), and a small proportion of fish passed in spring (Khan, Johnson, and others 2012b). Most of the fish (salmonids and non-salmonids) passed between late October and January; however, many of the December and January fish collected in downstream screw traps were non-salmonids (Khan, Johnson, and others, 2012b).

Passage through Lookout Point Dam predominantly was in winter and at night. Of the fish that passed through Lookout Point Dam between December and May, most Chinook salmon were yearlings (Khan, Johnson, and others, 2012b; Romer and others, 2012). Turbine passage was predominant in December and January (Khan, Johnson, and others, 2012b). Fry were collected as early as February downstream of Lookout Point Dam (Romer and others, 2013). Fish passed during summer 2012 and 2013, when planned but atypical spill occurred, whereas periods with no spring spill primarily had fall passage (Romer and others, 2013, 2014). Juvenile Chinook salmon that were PIT-tagged passed Lookout Point Dam in July and August (Brandt and others, 2016a). In 1991, 75 percent of smolts passed during the rapid (1,500 ft^3/s) drawdown period from early September to October (Downey and Smith, 1992). Most of the smolt-size fish passed in the morning crepuscular periods, except in December and January when fish passed at all hours (Khan, Johnson, and others, 2012b).

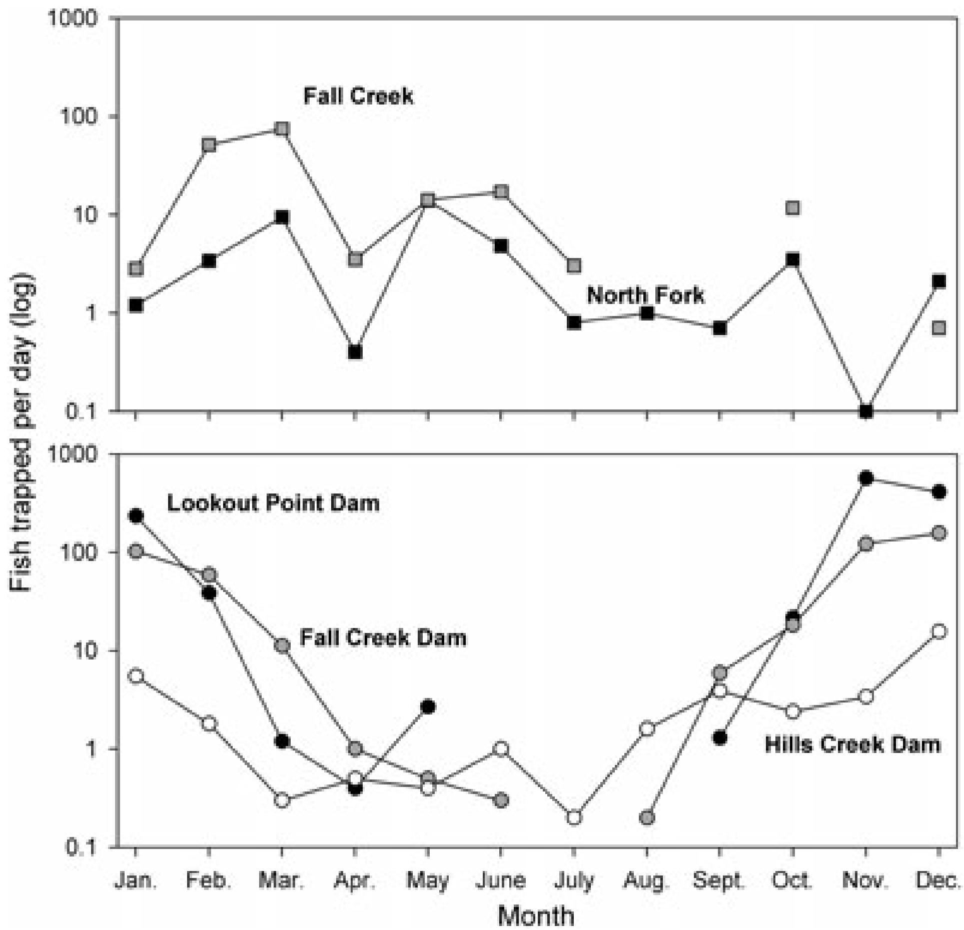

Figure 45. Graphs showing numbers of fish collected in rotary screw traps per day (log scale) in Fall Creek upstream of the reservoir (gray boxes) and North Fork Middle Fork Willamette River (black boxes), and at Fall Creek (gray circles), Lookout Point (black circles), and Hills Creek (open circles) Dams, Middle Fork Willamette River subbasin, Oregon, all years combined. Results are not weighted by trapping effort. Figure from Keefer and others, 2013.

Survival

Mortality generally was high through dams in the Middle Fork Willamette River subbasin. Mortality generally increased as the size of fish increased (fig. 46). Mortality downstream of Hills Creek, Lookout Point, and Fall Creek Dams was 25–64 percent for unmarked Chinook salmon and 8–57 percent for marked Chinook salmon. Keefer and others (2011, 2013) determined that mortality was higher for larger fish. Mortality through Hills Creek Dam was 53.2 percent during 2003–04 (Keefer and others, 2012). Larson (2000) reported that 59 percent of the fish that passed through the powerhouse were killed in 1999 compared to 32 percent for RO-passed fish. Mortality increased as fish size and reservoir elevations increased (fig. 46; Keefer and others, 2012). Lookout Point Dam mortality was 25.2 percent and increased as fish size and reservoir elevations increased (fig. 46; Keefer and others, 2012). Paired-released Chinook salmon from upstream of Lookout Point Dam and downstream of Dexter Dam experienced some mortality based on recoveries in downstream trapping sites (Brandt and others, 2016a). Reservoir-released fish had significantly higher growth rates than fish released in the tailrace, and more fish released in the reservoir generally returned to Willamette Falls than fish released in the tailrace (Brandt and others, 2016a).

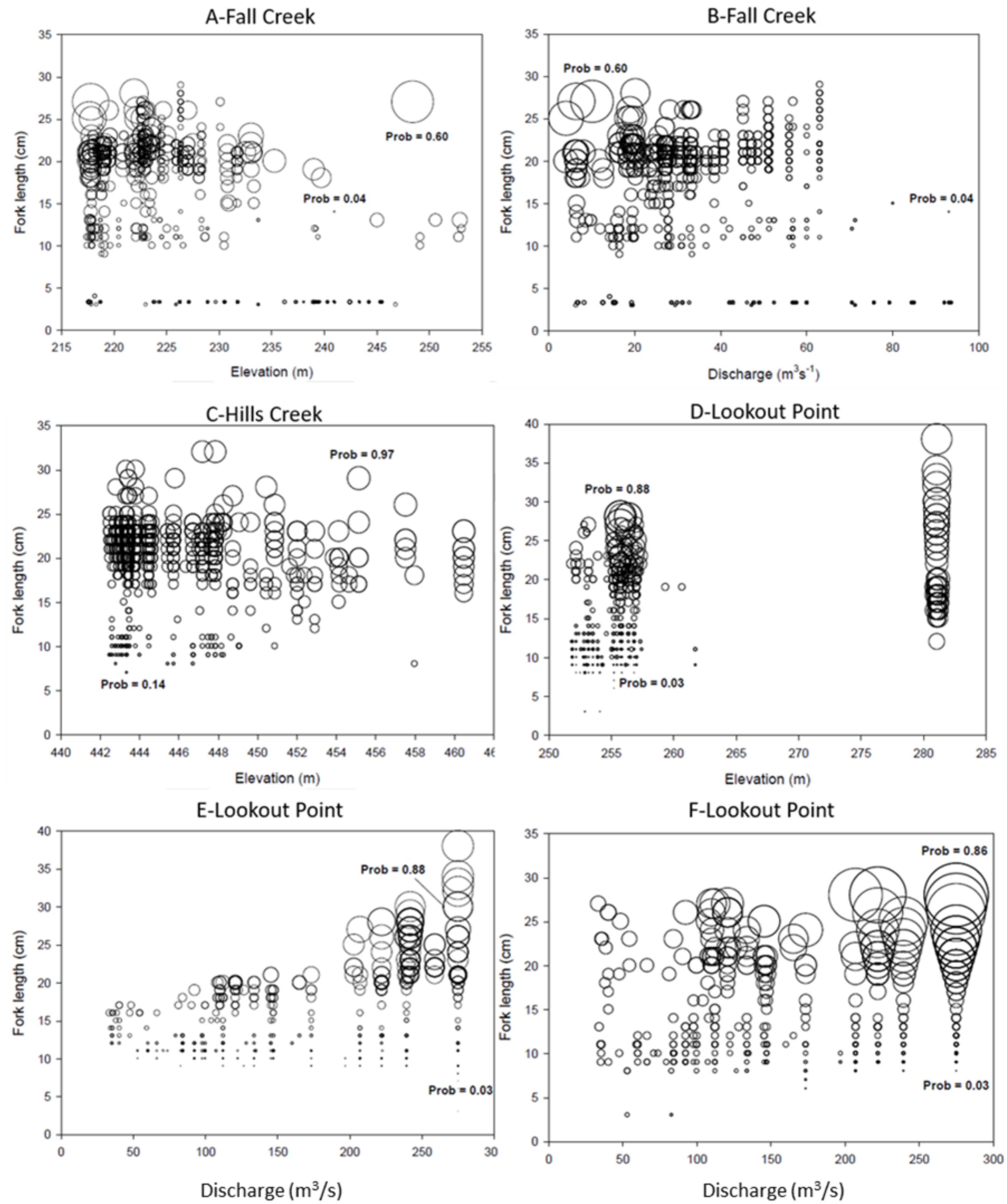

Figure 46. Graphs showing relation between reservoir elevation, discharge, Chinook salmon fork length, and the probability of salmon mortality from dam passage as predicted from logistic regression models at Fall Creek (A, B), Hills Creek (C), and Lookout Point (D, E, F) Dams. The logistic regression model for panel E was mortality = fork length + reservoir elevation + river discharge + (fork length×reservoir elevation) + (fork length×river discharge), and for panel F was mortality = fork length + river discharge + (fork length×river discharge). Larger bubbles indicate higher mortality probability. Graphs from Keefer and others, 2011. cm, centimeter; m, meter; m^3/s, cubic meter per second.

At Fall Creek Dam, mortality rates varied by passage route. Keefer and others (2012) reported that overall mortality for fish that passed through Fall Creek Dam during their study was 13.8 percent and survival decreased with decreasing reservoir elevations. In the early 1990s, Downey and Smith (1992) reported that mortality of the juvenile Chinook salmon that passed through the RO was 41 percent. Similarly, Chinook salmon mortality was 31.2 percent after RO passage and more than 70 percent within three days of passing through the RO and collection in a screw trap (Homolka and Smith, 1991). Survival increased as head and reservoir elevation decreased (Homolka and Smith, 1991). The fish horns seem to have very low survival based on an estimate from that same study, which reported that 68.3 percent of the horn-passed fish were killed (Downey and Smith, 1992). A radio telemetry study conducted in 2012 during fall drawdown estimated that survival from release to the Fall Creek Reservoir forebay was greater than 99 percent during two treatment conditions, but project and dam survival (boat restricted zone to tailrace and all fish passing the dam, respectively) was about 79 percent when pool elevation was 728 ft (Nesbit and others, 2014). In contrast, when pool elevation was 703 ft at release, project and dam survival was about 98 percent (Nesbit and others, 2014). In 2014, direct survival of balloon-tagged fish (mean length 72 mm) released in each of upper three fish horns at Fall Creek Dam was about 90 percent at 48 h, but almost one-half of the fish sustained injuries during passage (Normandeau Associates, Inc. and Pierce, 2014). About one-half of the unclipped fish survived the initial passage, but survival dropped to about 11 percent at 48 h (Normandeau Associates, Inc. and Pierce, 2014). Reservoir elevation was 825 ft during the May 2013 study, and discharge through the upper set of horns was 213 ft^3/s (Normandeau Associates, Inc. and Pierce, 2014).

Summary

A solid body of literature is available on general patterns of downstream passage in the Middle Fork Willamette River subbasin, but less is known about route-specific passage and survival than in other subbasins. Reservoir entry occurs during January–June and fish generally are located in the upper parts of the reservoir during early spring, and then disperse downstream as the year progresses. Growth rates in reservoirs of the subbasin are high, particularly in Lookout Point Reservoir, but juvenile salmon face challenges in these reservoirs, which have high copepod infection rates and substantial predator communities. Most passage occurs during late fall and winter when reservoir elevations are low and passage routes through the turbines and ROs are accessible. Several studies have shown that passage mortality is high at dams in the Middle Fork Willamette River subbasin, and that larger salmon are more likely to be killed than smaller salmon. Managers have implemented winter drawdown operations at Fall Creek Reservoir to pass juvenile salmon downstream, and this action seems to be successful based on high reservoir survival estimates and dam passage rates (Greg Taylor, U.S. Army Corps of Engineers, written commun., May 25, 2017).

Conclusions

Downstream fish passage has been evaluated in reservoirs and at dams owned by the U.S. Army Corps of Engineers (USACE) since the 1950s when the Willamette Valley Project (Project) in northwestern Oregon was first established. This has resulted in a substantial body of information on the topic. In some cases, the existing information is of limited value because passage no longer occurs at a given project (Green Peter Dam), or because passage through a given route is no longer possible (fish horns at Cougar Dam). However, many of the studies that were conducted decades ago provide information that can be used to understand if run timing differences exist, or if passage proportions and survival are changed when dam modifications occur. In recent years, research on downstream fish passage has intensified, with multiple studies occurring annually in each subbasin. These studies have shed much light on life history patterns in the Willamette River Basin, and have provided detailed information on passage timing, and in several cases, on route-specific passage proportions and survival.

Results from studies conducted on early life stages of juvenile Chinook salmon show common patterns in the basin. Fry emerge in early spring (February–March) and move downstream shortly thereafter. They disperse downstream, along shorelines in the upper parts of Project reservoirs during spring, and eventually distribute throughout the reservoir and move offshore into deeper water as temperatures warm in summer. In most cases, juvenile salmon spend several months in reservoirs where they grow quickly. The fast growth may benefit juvenile salmon, but other factors such as high copepod infection rates and substantial predator communities present challenges to juvenile salmon in reservoirs. These long residence times are often due to dam operations limiting passage routes during full or nearly full pool. Dam passage occurs primarily in fall and winter, when reservoir elevations are low and passage routes such as turbines and regulating outlets are easily accessible. Studies have shown that fish will readily pass through spill bays when reservoir elevations are high but dam operations do not always provide this option. Most studies have shown that passage mortality is common when fish pass Project dams, and route-specific studies have indicated that some routes have very low survival (about 50 percent; powerhouse at Detroit Dam). In several cases, fish that pass a given project enter another downstream reservoir where migration delay and mortality is common (Big Cliff Reservoir). These life history patterns are well understood in the Willamette River Basin, but resource managers have additional questions that will require more complex research such as where do these fall emigrants overwinter, and how much do these life history strategies contribute to adult returns in the different subbasins.

The development of safe passage or collection devices is of primary interest at Project dams to facilitate downstream passage, but these solutions are expensive and success is not guaranteed. Studies have shown that existing passage routes at Project dams generally have lower-than-adequate passage and survival to support sustainable natural populations upstream of dams. For example, spillway passage survival at Detroit Dam ranged from 64 to 84 percent, and turbine passage survival at Cougar Dam ranged from 36 to 42 percent. Conversely, passage survival at run-of-river dams on the Snake and Columbia Rivers seems to be much higher based on dam passage survival studies that were conducted from 2010 to 2014. These studies reported that total mortality at each dam ranged from 1 to 4 percent for yearling Chinook salmon, from 1 to 3 percent for steelhead, and from 3 to 7 percent for subyearling Chinook salmon (Skalski and others, 2016). Limited passage at Project dams can have indirect effects as well. For example, juvenile steelhead can residualize in Project reservoirs if dam passage options are limited and reservoir growth rates are high (Sharpe and others, 2011). For these reasons, fishery managers are exploring options to develop fish collection devices that allow fish to pass dams throughout the year and have high survival rates.

During the past decade, much interest and effort has been focused on the construction and deployment of forebay collectors at high-head dams. These devices were developed to capitalize on the surface-oriented preferences of juvenile salmon and steelhead and have had promising results in places like the Baker River, Washington, and the Clackamas River, Oregon, (Puget Sound Energy, 2015; Ackerman and Pyper, 2016). However, in other places like the Lewis River, Washington, and Deschutes River, Oregon, collection rates have been low (PacifiCorp, 2016; Portland General Electric, 2016). These devices have the potential to greatly improve passage conditions at Project dams, but managers must realize that their success is not guaranteed. In addition to developing new devices at dams, managers are considering how operational changes can be used to increase the number of successful outmigrants in the Project.

In some cases, reservoir drawdowns have been used to flush juvenile salmon out of Project reservoirs, but drawdowns typically occur in fall or early winter, and juvenile Chinook salmon are still exposed to long residence times from spring entry. However, studies have not yet been conducted to determine if this strategy results in higher outmigrant survival than scenarios where fish are allowed to pass the Project volitionally and move downstream at a larger size. Rearing in Project reservoirs where growth rates are high results in large smolts and may result in higher smolt-to-adult return rates, but the current rates will not support a sustainable population. In general, increases in smolt size are associated with increased smolt survival, but little is known about spring and summer survival of Chinook salmon fry in Project reservoirs. Therefore, managers are unable to determine if the potential benefits of rearing large smolts in these locations is offset by high mortality rates in the reservoirs. A study is currently planned in 2017 to evaluate spring and summer survival of Chinook salmon fry in Lookout Point Reservoir (Kock and others, 2016). This would be the first evaluation of its kind, and results from the study should be insightful for resource managers. However, additional studies will be required to understand how outmigration survival changes throughout the migration season and for different sizes and age classes of outmigrants. In particular, questions arise regarding whether it is better to (1) facilitate downstream passage for juvenile Chinook salmon early in the season, shortly after they initiate outmigration from their emergence locations; (2) develop safe passage alternatives for fish later in the season when they are larger; or (3) provide downstream passage options for all life stages.

For this project, our goals were to (1) conduct an extensive review of the existing body of available literature on downstream fish passage at USACE-owned dams in the Willamette River Basin, and (2) synthesize this information into a single document that can serve as a resource for fishery managers and other interested parties in the basin. We have made an extensive effort to achieve these goals and believe that the information contained herein will be useful to many people in the coming years. We are aware of several studies that have been completed, but do not currently have documents available for review and inclusion at this time. For that reason, we recommend revisiting this project at some point in the future to provide new updates and ensure that all available information is eventually assimilated into a central document. The existing body of research on downstream fish passage in the Willamette Basin is impressive, but there are many important questions that remain. We hope that future studies will be able capitalize on this synthesis and use the information we have provided to design studies that can address future questions and support management decisions aimed at improving downstream fish passage conditions in the Willamette River.

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References Cited

Ackerman, N.K., and Pyper, B., 2016, Evaluation of juvenile salmonid passage through the River Mill hydroelectric development: Report from Portland General Electric to the Federal Energy Regulatory Commission, 51 p.

Adams, N.S., Smith, C.D., Plumb, J.M., Hansen, G.S., and Beeman, J.W., 2015, An evaluation of fish behavior upstream of the water temperature control tower at Cougar Dam, Oregon, using acoustic cameras, 2013: U.S. Geological Survey Open-File Report 2015-1124, 62 p., accessed November 2016, at http://dx.doi.org/10.3133/ofr20151124.

Beeman, J.W., and Adams, N.S., eds., 2015, In-reservoir behavior, dam passage, and downstream migration of juvenile Chinook salmon and juvenile steelhead from Detroit Reservoir and Dam to Portland, Oregon, February 2013–February 2014: U.S. Geological Survey Open-File Report 2015-1090, 92 p., accessed December 2016, at http://dx.doi.org/10.3133/ofr20151090.

Beeman, J.W., Evans, S.D., Haner, P.V., Hansel, H.C., Hansen, A.C., Hansen, G.S., Hatton, T.W., Kofoot, E.E., and Sprando, J.M., 2016a, Evaluation of the biological and hydraulic performance of the portable floating fish collector at Cougar Reservoir and Dam, Oregon, September 2015–January 2016: U.S. Geological Survey Open-File Report 2016–1197, 98 p., accessed November 2016, at https://doi.org/10.3133/ofr20161197.

Beeman, J.W., Evans, S.D., Haner, P.V., Hansel, H.C., Hansen, A.C., Hansen, G.S., Hatton, T.W., Sprando, J.M., Smith, C.D., and Adams, N.S., 2016b, Evaluation of the biological and hydraulic performance of the portable floating fish collector at Cougar Reservoir and Dam, Oregon, 2014: U.S. Geological Survey Open-File Report 2016-1003, 127 p., accessed November 2016, at http://dx.doi.org/ 10.3133/ofr20161003.

Beeman, J.W., Evans, S.D., Haner, P.V., Hansen, A.C., Hansel, H.C., Smith, C.D., and Sprando, J.M., 2014, Passage and survival probabilities of juvenile Chinook salmon at Cougar Dam, Oregon, 2012: U.S. Geological Survey Open-File Report 2014-1038, 64 p., accessed November 2016, at http://dx.doi.org/10.3133/ofr20141038/.

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., 2014b, 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., accessed November 2016, at http://dx.doi.org/10.3133/ofr20141177/.

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., 2014a, Behavior and dam passage of juvenile Chinook salmon and juvenile steelhead at Detroit Reservoir and Dam, Oregon, March 2012–February 2013: U.S. Geological Survey Open-File Report 2014-1144, 62 p., accessed December 2016, at http://dx.doi.org/10.3133/ofr20141144.

Beeman, J.W., Hansel, H.C., Hansen, A.C., Haner, P.V., Sprando, J.M., Smith, C.D., Evans, S.D., and Hatton, T.W., 2013, Behavior and dam passage of juvenile Chinook salmon a Cougar Reservoir and Dam, Oregon, March 2011–February 2012: U.S. Geological Survey Open-File Report 2013-1079, 48 p., accessed November 2016, at http://pubs.usgs.gov/of/2013/1079/.

Beeman, J.W., Hansen, A.C., Evans, S.D., Haner, P.V., Hansel, H.C., and Smith, C.D., 2012, Passage probabilities of juvenile Chinook salmon through the powerhouse and regulating outlet at Cougar Dam, Oregon, 2011: U.S. Geological Survey Open-File Report 2012-1250, 26 p., accessed November 2016, at http://pubs.usgs.gov/of/2012/1250/.

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, no. 20, doi:10.1186/s40317-015-0056-5, accessed November 2016, at http://www.animalbiotelemetry.com/content/3/1/20.

Boyd, B., and Chilton, G., 2011, Operations report for South Santiam Hatchery, January 1, 2011 through December 31, 2011: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 22 p.

Boyd, B., and Chilton, G., 2012b, Operations report for South Santiam Hatchery, January 1, 2012 through December 31, 2012: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 28 p.

Boyd, B., and Chilton, G., 2014b, Operations report for South Santiam Hatchery, July 1, 2013 through June 30, 2014: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 23 p.

Boyd, B., and Chilton, G., 2015b, Operations report for South Santiam Hatchery, July 1, 2014 through June 30, 2015: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 25 p.

Boyd, B., and Chilton, G., 2016b, Operations report for South Santiam Hatchery, July 1, 2015 through June 30, 2016: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 24 p.

Boyd, C. and Chilton, G., 2012a, Operations report for Marion Forks Hatchery, January 1, 2012 through December 31, 2012: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 23 p.

Boyd, C. and Chilton, G., 2014a, Operations report for Marion Forks Hatchery, July 1, 2013 through June 30, 2014: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 23 p.

Boyd, C. and Chilton, G., 2015a, Operations report for Marion Forks Hatchery, July 1, 2014 through June 30, 2015: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 23 p.

Boyd, C. and Chilton, G., 2016a, Operations report for Marion Forks Hatchery, July 1, 2015 through June 30, 2016: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 19 p.

Brandt, J.R., Friesen, T.A., Johnson, M.A., and Olmsted, P.M., 2016a, Migration, survival, growth, and fate of hatchery juvenile Chinook salmon released above and below dams in the Willamette River Basin: Annual Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, task order W9127N-10-2-0008-0025, 83 p.

Brandt, J.R., Monzyk, F.M., Romer, J.D. and Emig, R, 2016b, Status and trends of predator species in Lookout Point Reservoir: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, task order W9127N-10-2-0008, 41 p.

Buchanan, D.V., Wade, M.G., and Higley, D.L., 1993, Restoration of the native winter steelhead run on the South Santiam River above Foster Dam: Completion report, Fish Research Project, Oregon Department of Fish and Wildlife, Portland, Oregon, 63 p.

Bureau of Commercial Fisheries, 1960, Downstream migrant studies South Fork McKenzie River 1957, 1959, 1960: Department of Interior Bureau of Commercial Fisheries, Portland, Oregon, 24 p.

Cummings, K., Kremers, K., and Chilton, G., 2011, Operations report for McKenzie River Hatchery, January 1, 2011 through December 31, 2011: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 22 p.

Cummings, K., Kremers, K., and Chilton, G., 2012, Operations report for McKenzie River Hatchery, January 1, 2012 through December 31, 2012: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 19 p.

Deng, Z.D., Duncan, J.P., Arnold, J.L., Fu, T., and Johnson, G.E., 2015, Willamette Valley high head bypass downstream passage prototype evaluation—Sensor fish evaluation of bypass pipes at Green Peter Dam: Report of Pacific Northwest National Laboratory, Richland, Washington, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract DE-AC05-76RL01830, 78 p.

Downey, T.W., and Smith, E.M., 1992, Evaluation of spring Chinook salmon passage at Fall Creek Dam, 1991: Oregon Department of Fish and Wildlife, Portland, Oregon.

Duncan, J.P., 2010, Evaluation of fish passage conditions for juvenile salmonids using sensor fish at Detroit Dam, Oregon: Report of Pacific Northwest National Laboratory, Richland, Washington, for U.S. Army Corps of Engineers, Portland, Oregon, contract DE-AC05-76RL01830, 140 p.

Duncan, J.P., 2011, Characterization of fish passage conditions through a Francis turbine and regulating outlet at Cougar Dam, Oregon, using sensor fish, 2009–2010: Pacific Northwest National Laboratory, Richland, Washington, 172 p.

Duncan, J.P., 2013b, Assessment of passage conditions through the complete 24-in downstream bypass pipe at Green Peter Dam: Report of Pacific Northwest National Laboratory, prepared for U.S. Army Corps of Engineers Portland District, Portland, Oregon, Willamette Valley Project.

Duncan, J.P., 2013a, Characterization of fish passage conditions through the fish weir and turbine unit 1 at Foster Dam, Oregon, using sensor fish, 2012: Report of Pacific Northwest National Laboratory, Richland, Washington, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract DE-AC05-76RL01830, 188 p.

Duncan, J.P., and Carlson, T.J., 2011, Characterization of fish passage conditions through a Francis turbine, spillway, and regulating outlet at Detroit Dam, Oregon, using sensor fish, 2009: Report of Pacific Northwest National Laboratory, Richland, Washington, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract DE-AC05-76RL01830, 280 p.

Evans, M.L., Johnson, M.A., Jacobsen, D., Wang, J., Hogansen, M., and O'Malley, K., 2016, Evaluating a multi-generational reintroduction program for threatened salmon using genetic parentage analysis: Canadian Journal of Fisheries and Aquatic Sciences, v. 73, no. 5, p., 844–852, accessed March 6, 2016, at https://doi.org/10.1139/cjfas-2015-0317.

Grenbemer, G., Boyd, C., and Chilton, G., 2011, Operations report for Marion Forks Hatchery, January 1, 2011 through December 31, 2011: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 23 p.

Grenbemer, G., and Chilton, G., 2014, Operations report for Minto Fish Facility, July 1, 2013 through June 30, 2014: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers, 12 p.

Grenbemer, G., and Chilton, G., 2015, Operations report for Minto Fish Facility, July 1, 2014 through June 30, 2015: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers, 13 p.

Grenbemer, G., and Chilton, G., 2016, Operations report for Minto Fish Facility, July 1, 2015 through June 30, 2016: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers, 13 p.

Herron-Seeley, C.L., 2016, The impact of parasitic copepod *Salmincola californiensis* on swimming ability and oxidative burst activity in response to stress in juvenile Chinook salmon: Corvallis, Oregon State University, Master's thesis.

Homolka, K., and Smith, E.M., 1991, Evaluation of spring Chinook salmon and winter steelhead passage at Fall Creek Dam, 1990: Oregon Department of Fish and Wildlife, Salem, Oregon, 38 p.

Hughes, J.S., Bellgraph, B.J., Kim, J., Vernon, C.V., Fischer, E.F., Green, E.D., Liss, S.A., Deters, K.A. and Johnson, G.E., 2016, Evaluation of juvenile salmonid passage and behavior at Foster Dam using radio telemetry, 2015: Final report of Pacific Northwest National Laboratory prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract DE-AC05-76RL01830, 105 p.

Hughes, J.S., Kim, J., Vazquez, J.A., and Johnson, G.E., 2014, Hydroacoustic evaluation of juvenile salmonid passage and distribution at Foster Dam, 2013–2014: Report of Pacific Northwest National Laboratory prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract DE-AC05-76RL01830, 82 p.

Ingram, P., and Korn, L., 1969, Evaluation of fish passage facilities at Cougar Dam on the South Fork McKenzie River in Oregon: Report of Fish Commission of Oregon Research Division prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, Willamette Valley Project, Contract Number DA-35-026-CIVENG-64-295, 82 p.

Johnson, L., 1984, Hydroacoustic evaluation of elevated flow for passing downstream migrating juvenile salmon and steelhead at Foster Dam, Oregon, 16–21 April, 1984: Report of Biosonics, Inc., Seattle, Washington for Oregon Department of Fish and Wildlife, 89 p.

Johnson, M.A., Friesen, T.A, Olmsted, P.M., and Brandt, J.R., 2016, Migration survival, growth and fate of hatchery juvenile Chinook salmon released above and below dams in the Willamette River Basin: Report of Oregon Department of Fish and Wildlife Upper Willamette Research, Monitoring, and Evaluation prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, Willamette Valley Project, task order W9127N-10-2-0005, 0009, 0018, 0025 and 0034.

Kabata, Z., and Cousens, B., 1977, Host-parasite relationships between sockeye salmon, *Oncorhynchus nerka*, and *Salmincola californiensis* (Copepoda: Lernaeopodidae): Journal of 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., 2011, Downstream fish passage above and below dams in the Middle Fork Willamette River—A multi-year summary: Draft technical report 2011–12 of University of Idaho and U.S. Army Corps of Engineers, Portland, Oregon, 72 p.

Keefer, M.L., Taylor, G.A., Garletts, D.F., Helms, C.K., Gauthier, G.A., Pierce, T.M. and Caudill, C.C., 2012, Reservoir entrapment and dam passage mortality of juvenile Chinook salmon in the Middle Fork Willamette River: Ecology of Freshwater Fish, v. 21, no. 2, p. 222–234.

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.

Khan, F., Johnson, G.E., Royer, I.M., Hughes, J.S., Fischer, E.S., Trott, D.M., and Ploskey G.R., 2012b, Hydroacoustic evaluation of juvenile salmonid passage and distribution at Lookout Point Dam, 2010: Report of Pacific Northwest Laboratory, Richland, Washington, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract DE-AC05-76RL01830, 74 p.

Khan, F., Johnson, G.E., Royer, I.M., Phillips, N.R., Hughes, J.S., Fischer, E.S., Ham, K.D., and Ploskey, G.R., 2012a, Acoustic imaging evaluation of juvenile salmonid behavior in the immediate forebay of the water temperature control tower at Cougar Dam, 2010: Report of Pacific Northwest National Laboratory, Richland, Washington, for U.S Army Corps of Engineers, Portland District, Portland, Oregon, contract DE-AC-5-76RL01830, 50 p.

Khan, F., Royer, I.M., Johnson, G.E. and Ham, K.D., 2012, Hydroacoustic evaluation of juvenile salmonid passage and distribution at Detroit Dam, 2011: Report of Pacific Northwest National Laboratory, Richland, Washington, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract DE-AC05-76RL01830, 76 p.

Kock, T.J., Beeman, J.W., Hansen, A.C., Hansel, H.C., Hansen, G.S., Hatton, T.W., Kofoot, .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, 30 p., accessed December 2016, at http://dx.doi.org/10.3133/ofr20151220.

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., accessed January 2017, at https://doi.org/10.3133/ofr20161211.

Korn, L. and Smith E.M., 1971, Rearing juvenile salmon in Columbia River Basin storage reservoirs, *in* Special publication no. 8, Reservoir Fisheries and Limnology: Washington, D.C., American Fisheries Society, p. 287–298.

Kremers, K., and Chilton, G., 2014, Operations report for McKenzie River Hatchery, July 1, 2013, through June 30, 2014: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 19 p.

Kremers, K., and Chilton, G., 2015, Operations report for McKenzie River Hatchery, July 1, 2014, through June 30, 2015: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 21 p.

Kremers, K., and Chilton, G., 2016, Operations report for McKenzie River Hatchery, July 1, 2015, through June 30, 2016: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 21 p.

Larson, D.C., 2000, Spawning migration movements and emigration through Hills Creek on spring Chinook salmon (*Oncorhynchus tshawytscha*) in the Upper Middle Fork Willamette River, Lane County: Oregon: U.S. Forest Service, Middle Fork Ranger District, Oakridge, Oregon, 22 p.

Monzyk, F.R., 2010, Cougar Dam route passage survival indices based on release-recapture of PIT-tagged hatchery fish: Report of Oregon Department of Fish and Wildlife, Oregon, prepared for U.S. Army Corps of Engineers, Portland, Oregon, 18 p.

Monzyk, F.R., Emig, R., Romer, J.D., and Friesen, T.A., 2013, Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0007, 72 p., accessed November 2016, at http://oregonstate.edu/dept/ODFW/willamettesalmonidrme/sites/default/files/reservoir-research/life-history_characteristics_in_reservoirs_annual_report_2012_-final.pdf.

Monzyk, F.R., Emig, R., Romer, J.D., and Friesen, T.A., 2014, Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0020, 85 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, doi:10.1080/00028487.2015.1052558.

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 of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0027, 52 p.

Monzyk, F.R., Hogansen, M., Romer, J.D., and Friesen, T.A., 2011, Cougar Dam route selection study—Evaluating fish passage using spill: Addendum report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, cooperative agreement W9127N-10-2-0008, task order 0002, 15 p.

Monzyk, F.R., Romer, J.D., Emig, R., and Friesen, T.A., 2011b, Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008, 38 p.

Monzyk, F.R., Romer, J.D., Emig, R., and Friesen, T.A., 2011a, Pilot head-of-reservoir juvenile salmonid monitoring: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0001, 21 p.

Monzyk, F.R., Romer, J.D., Emig, R., and Friesen, T.A., 2012, Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0007, 60 p., accessed November 23, 2015, at http://oregonstate.edu/dept/ODFW/willamettesalmonidrme/sites/default/files/reservoir-research/life-history_characteristics_in_reservoirs_annual_report_2012_-final.pdf.

National Marine Fisheries Service, 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 FINWRl2000/02117, June 11, 2008., accessed November 2016, at http://www.nwr.noaa.gov/Salmon-Hydropower/Willamette-Basin/Willamette-BO.cfm.

National Marine Fisheries Service, 1999b, Endangered and threatened species—Threatened status for three Chinook salmon evolutionarily significant units (ESUs) in Washington and Oregon, and endangered status for one Chinook salmon ESU in Washington: Federal Register 64, no. 56,, p. 14,308–14,328.

National Marine Fisheries Service, 1999a, Endangered and threatened species—Threatened status for two ESUs of steelhead in Washington and Oregon: Federal Register, v. 64, no. 57, p. 14,517–14,528.

Nesbit, M.G., Axel, G.A., Sanford, B.P., Burke, B.J., Frick, K.E., and Lamb, J.J., 2014, Passage behavior and survival of juvenile spring Chinook salmon at Fall Creek Dam, 2012: Report of Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, 31 p.

Normandeau Associates, Inc., 2010b, Estimates of direct survival and injury of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) passing a regulating outlet and turbine at Cougar Dam, Oregon: Draft report of Normandeau Associates, Inc., Drumore, Pennsylvania, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract number W912EF-08-D-005, task order DT01, 160 p.

Normandeau Associates, Inc., 2010a, Estimates of direct survival and injury of rainbow trout (*Oncorhynchus mykiss*) passing spillway, turbine, and regulating outlet at Detroit Dam, Oregon: Report of Normandeau Associates, Inc., Drumore, Pennsylvania, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W912EF-08-D-0005-DT01, 182 p.

Normandeau Associates, Inc., 2013, Estimates of direct effects of steelhead salmon during downstream passage through a turbine and weir at Foster Dam, Oregon: Report of Normandeau Associates, Inc., Drumore, Pennsylvania, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W912EF-08-D-0005-DT04, 203 p.

Normandeau Associates, Inc., 2015, Biological fish injury and survival evaluation at Green Peter Dam, Oregon, 2015: Report of Normandeau Associates, Inc., Drumore, Pennsylvania, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W912ER-14-D-0002, 89 p.

Normandeau Associates, Inc., and Pierce, T., 2014, Estimates of direct effects of downstream passage through the fish horns at Fall Creek Dam: Report of Normandeau Associates, Inc., Drumore, Pennsylvania, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W912EF-08-D-0005, 37 p.

Oligher, R.C., and Donaldson, I.J., 1966, Fish passage through turbines—Tests at Big Cliff Hydroelectric Plant: U.S. Army Corps of Engineers Walla Walla District, Walla Walla, Washington, 31 p.

O'Malley, K.G., Evans, M.L., Johnson, M.A., Banks, M.A., Jacobson, D. and Hogansen, M, 2014, Genetic parentage analysis of spring Chinook salmon on the South Santiam River—Insights into population productivity and reintroduction strategies: Report of Oregon State University, Corvallis, and Oregon Department of Fish and Wildlife, Newport, Oregon, prepared for U.S. Army Corps of Engineers, Portland, Oregon, 44 p.

O'Malley, K.G., Evans, M.L., Johnson, M.A., Jacobson, D. and Hogansen, M, 2015, An evaluation of spring Chinook salmon reintroduction above Detroit Dam, North Santiam River, using genetic pedigree analysis: Report of Oregon State University, Corvallis, and Oregon Department of Fish and Wildlife, Newport, Oregon, prepared for U.S. Army Corps of Engineers, Portland, Oregon, 23 p.

PacifiCorp, 2017, Lewis River fish passage program 2016 annual report: Report by PacifiCorp to the Federal Energy Regulatory Commission, 184 p.

Peck, D., Edmunds, T., and Chilton, G., 2011, Operations report for Willamette Hatchery, January 1, 2011 through December 31, 2011: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 33 p.

Peck, D., Edmunds, T., and Chilton, G., 2012, Operations report for Willamette Hatchery, January 1, 2012 through December 31, 2012: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 32 p.

Peck, D., Edmunds, T., and Chilton, G., 2014, Operations report for Willamette Hatchery, July 1, 2013 through June 30, 2014: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 25 p.

Peck, D., Edmunds, T., and Chilton, G., 2015, Operations report for Willamette Hatchery, July 1, 2014 through June 30, 2015: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 26 p.

Peck, D., Edmunds, T., and Chilton, G., 2016, Operations report for Willamette Hatchery, July 1, 2015 through June 30, 2016: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 28 p.

Ploskey, G.R., Zimmerman, S.A., Hennen, M.J., Batten, G.W., and Mitchell, T.D., 2012, Hydroacoustic estimates of fish density distributions in Cougar Reservoir, 2011: Draft report of Pacific Northwest National Laboratory, Richland, Washington, 78 p.

Portland General Electric, 2016, Pelton Round Butte 2015 fish passage annual report: Report by Portland General Electric to the Federal Energy Regulatory Commission, 33 p.

Puget Sound Energy, 2015, Downstream fish passage 2013 annual report for the Baker River Hydroelectric Project: Puget Sound Energy, 50 p.

Romer, J.D., Monzyk, F.R., Emig, R., and Friesen, T.A., 2012, Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0006, 42 p., accessed October 25, 2013, at http://oregonstate.edu/dept/ODFW/willamettesalmonidrme/sites/default/files/reservoir-research/outmigration_monitoring_annual_2011.pdf.

Romer, J.D., Monzyk, F.R., Emig, R., and Friesen, T.A., 2013, Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0006, 52 p., accessed November 23, 2015, at http://oregonstate.edu/dept/ODFW/willamettesalmonidrme/sites/default/files/reservoir-research/outmigration_monitoring_annual_report_2012.pdf.

Romer, J.D., Monzyk, F.R., Emig, R., and Friesen, T.A., 2014, Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0019, 60 p.

Romer, J.D., Monzyk, F.R., Emig, R., and Friesen, T.A., 2015, Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0026, 55 p.

Romer, J.D., Monzyk, F.R., Emig, R., and Friesen, T.A., 2016, Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs: Report of Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W9127N-10-2-0008-0035, 45 p.

Schroeder, R.K., Whitman, L.D., Cannon, B., and Olmsted, P., 2016, Juvenile life-history diversity and population stability of spring Chinook salmon in the Willamette River Basin, Oregon: Canadian Journal of Fishery Aquatic Science, v. 73, p. 1–14.

Sharpe, C.S., Beckman, B.R., Cooper, K.A., and Hulett, P.L., 2007, Growth modulation during juvenile rearing can reduce rates of residualism in the progeny of wild steelhead broodstock: North American Journal of Fisheries Management, v. 27, p. 1,355–1,368.

Sharpe, C.S., Cannon, B., DeBow, B., Friesen, M., Olmsted, P., Schroeder, R.K., Tinus, C.A., and Whitman, L., 2013, Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2011 hatchery baseline monitoring: Report of Oregon Department of Fish and Wildlife, Corvallis, for U.S. Army Corps of Engineers, task order W9127N-11-2-0002-0006, 94 p.

Sharpe, C.S., Cannon, B., DeBow, B., Friesen, T.A., Hewlett, D., Olmsted, P., and Sinnott, M., 2015, Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2013 hatchery baseline monitoring: Report of Oregon Department of Fish and Wildlife, Corvallis, for U.S. Army Corps of Engineers, task order W9127N-12-2-0004-1009, 118 p.

Sharpe, C.S., Cannon, B., DeBow, B., Friesen, T.A., Hewlett, D., Olmsted, P., and Sinnott, M., 2016, Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2014 hatchery baseline monitoring: Report by the Oregon Department of Fish and Wildlife, Corvallis, for U.S. Army Corps of Engineers, 109 p.

Sharpe, C.S., Cannon, B., Friesen, B., Hewlett, D., and Olmsted, P., 2014, Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2012 hatchery baseline monitoring: Report of Oregon Department of Fish and Wildlife, Corvallis, for U.S. Army Corps of Engineers, task order W9127N-12-2-0004-0009, 107 p.

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, 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, no. 4, p. 720–730.

Smith, E.M., and Korn, L., 1970, Evaluation of fish facilities and passage at Fall Creek Dam on Big Fall Creek in Oregon: Report of Fish Commission of Oregon prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, contract no. DA-35-026-CIVENG-66-400, 83 p.

State of Washington Department of Fisheries, 1960, Research relating to mortality of downstream migrant salmon passing McNary and Big Cliff Dams, *in* U.S. Army Corps of Engineers, 1960, Progress report on fisheries engineering research program: U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon, 1,159 p., accessed December 2016, at https://catalog.hathitrust.org/Record/009189767.

Taylor, G.A., 2000, Monitoring of downstream fish passage at Cougar Dam in the South Fork McKenzie River Oregon, 1998–00: Oregon Department of Fish and Wildlife, Springfield, 9 p.

U.S. Army Corps of Engineers, 1995, South Santiam fishery restoration draft reconnaissance study, South Santiam sub-basin study, general investigation: U.S. Army Corps of Engineers, Portland District, Portland, Oregon, 320 p.

U.S. Army Corps of Engineers, 2011, Comprehensive plan for research, monitoring, and evaluation in the Willamette River Basin: Draft report of U.S. Army Corps of Engineers, Portland District. Portland, Oregon, 349 p.

U.S. Army Corps of Engineers, 2016a, About our Willamette Valley locations Web page: U.S. Army Corps of Engineers Portland District Web site, accessed December 1, 2016, at http://www.nwp.usace.army.mil/Locations/Willamette-Valley/.

U.S. Army Corps of Engineers, 2016c, Reservoir and river level information Web page: U.S. Army Corps of Engineers Portland District Web site, accessed December 1, 2016, at http://www.nwp.usace.army.mil/Missions/Water.aspx.

U.S. Army Corps of Engineers, 2016b, Map (Columbia River Basin water management): U.S. Army Corps of Engineers Northwestern Division Web page, accessed December 1, 2016, at http://www.nwd-wc.usace.army.mil/dd/common/sysmap/www/index.html.

U.S. Fish and Wildlife Service, 2015, Endangered and threatened wildlife and plants—Removing the Oregon chub from the Federal list of endangered and threatened wildlife: Federal Register, v. 80, no. 33, 9,126–9,150 p.

U.S. Geological Survey, 2016b, Geographic Names Information System (GNIS): U.S. Geological Survey Web page, accessed November 21, 2016, at http://geonames.usgs.gov/apex/f?p=gnispq.

U.S. Geological Survey, 2016a, National Water Information System: U.S. Geological Survey Web page, accessed November 21, 2016, at http://waterdata.usgs.gov/nwis/.

Wagner, E., and Ingram, P., 1973, Evaluation of fish facilities and passage at Foster and Green Peter Dams on the South Santiam River drainage in Oregon: Final report of Fish Commission of Oregon Management and Research Division prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract no. DACW57-68-C-0013, 117 p.

Wevers, M., Wetherbee, J., and Hunt, W., 1992, Santiam and Calapooia sub-basin fish management plan: Oregon Department of Fish and Wildlife, Portland, Oregon, 173 p.

Withalm, E., Morgan, S., Davis, J., and Chilton, G, 2016, Operations report for Leaburg Hatchery, July 1, 2015 through June 30, 2016: Report of Oregon Department of Fish and Wildlife, for prepared U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 29 p.

Withalm, E., Morgan, S., Davis, K., Hulett-Guard, J., Welch, S., and Chilton, G., 2011, Operations report for Leaburg Hatchery, January 1, 2011 through December 31, 2011: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 34 p.

Withalm, E., Morgan, S., Davis, K., Hulett-Guard, J., Welch, S., and Chilton, G., 2012, Operations report for Leaburg Hatchery, January 1, 2012 through December 31, 2012: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 30 p.

Withalm, E., Morgan, S., Davis, J., Hulett-Guard, J., Welch, S., and Chilton, G., 2014, Operations report for Leaburg Hatchery, July 1, 2013 through June 30, 2014: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 25 p.

Withalm, E., Morgan, S., Davis, J., Hulett-Guard, J., Welch, S., and Chilton, G, 2015, Operations report for Leaburg Hatchery, July 1, 2014 through June 30, 2015: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers and Oregon Department of Fish and Wildlife, 29 p.

Zakel, J.C., and Reed, D.W., 1984, Downstream migration of fish at Leaburg Dam, McKenzie River, Oregon, 1980 to 1983: Oregon Department of Fish and Wildlife information reports 84-13, Research and Development Section, Corvallis, Oregon, 20 p.

Zymonas, N.D., Tranquilli, J.V., and Hogansen, M, 2011, Monitoring and evaluation of impacts to bull trout (*Salvelinus confluentus*) and spring Chinook (*Oncorhynchus tshawytscha*) in the South Fork McKenzie River from construction of water temperature control facilities at Cougar Dam, Oregon: Report of Oregon Department of Fish and Wildlife prepared for U.S. Army Corps of Engineers, Project Number W66QKZ13186766, 306 p.

Appendix A. Documents that Were Originally Identified as Potentially Useful but Were not Cited in this Report

Bennett, D.E., 1988, 1987 Willamette River spring Chinook salmon run: Oregon Department of Fish and Wildlife, contract 87-011.

Bennett, D. E., 1989, 1988 Willamette River spring Chinook salmon run: Oregon Department of Fish and Wildlife, contract 88-031.

Bourret, S.L., Kennedy, B.P., Caudill, C.C., and Chittaro, P.M., 2014, Using otolith chemical and structural analysis to investigate reservoir habitat use by juvenile Chinook salmon *Oncorhynchus tshawytscha*: Journal of Fish Biology, v. 85, p. 1,507–1,525.

Cannon, B., Emig, R., Friesen, T.A., Johnson, M., Olmsted, P., Schroeder R.K., Sharpe, C.S., Tinus, C.A., and Whitman, L., 2011, Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding 2010: Oregon Department of Fish and Wildlife, Corvallis, prepared for U.S. Army Corps of Engineers, Portland, Oregon, p. 130.

Caudill, C.C., Bourret, S., Kennedy, B.P., and Borgerson, L., 2011, Comparative survival of reservoir reared and reservoir bypassed spring Chinook salmon in the Willamette River Basin phase 1—Feasibility of using otolith and scale analyses to characterize life history variation in spring Chinook salmon in three Willamette Valley project reservoirs and tributaries: Idaho Cooperative Fish and Wildlife Research Unit, Draft technical report 2011-7.

Clements, S., Jepsen, D., Karnowski, M., and Schreck, C.B., 2005, Optimization of an acoustic telemetry array for detecting transmitter-implanted fish: North American Journal of Fisheries Management, v. 25, no. 2, p. 429–436.

Coutant, C.C., and Whitney, R.R, 2000, Fish behavior in relation to passage through hydropower turbines—A review: Transactions of the American Fisheries Society, v. 129, p. 351–380.

Craig, J.A., and Townsend, L.D., 1946, An investigation of fish-maintenance problems in relation to the Willamette Valley Project: U.S. Fish and Wildlife Service, special science report, v. 33, p. 74.

Cramer, D., 1995, Evaluation of downstream migrant bypass system: Portland General Electric, T.W. Sullivan Plant, Willamette Falls, Oregon.

Cramer, S.P., Willis, C.F., Cramer, D., Smith, M., Downey, T., and Montagne, R, 1996, Status of Willamette River spring Chinook salmon in regards to the Federal Endangered Species Act, Part 2: Gresham, Oregon, S.P. Cramer and Associates, Inc., 138 p.

Downey, T.W., Homolka, K., and Day, W.H., 1992, Annual progress report—Willamette River salmon studies: Report of Oregon Department of Fish and Wildlife, Salem, Fish Research Report, project F-119-R-8, 22 p.

Downey, T.W., Homolka, K., and Day, W.H., 1993, Annual progress report—Willamette River salmon studies: Report of Oregon Department of Fish and Wildlife, Salem, Fish Research Report, project F-119-R-8, 28 p.

Fish Commission of the State of Oregon, 1960, Evaluation of the ability of an artificial outlet to attract downstream migrant salmonids from the reservoir at Lookout Point Dam, *in* U.S. Army Corps of Engineers, 1960, Progress report on fisheries engineering research program: U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon, p. 26–29.

Friesen, T.A., ed., 2005, Biology, behavior, and resources of resident and anadromous fish in the lower Willamette River: Final Report of Research of Oregon Department of Fish and Wildlife, Clackamas, Oregon, 2000–2004, for City of Portland, Bureau of Environmental Services, Portland, Oregon, 246 p.

Friesen, T.A., Vile, J.S., and Pribyl, A.L., 2007, Outmigration of juvenile Chinook salmon in the lower Willamette River, Oregon: Northwest Science, v. 81, p. 173–190.

Gregory, S., Ashkenas, L., and Nygaard, C., 2007, Summary report to assist development of ecosystem flow recommendations for the Coast Fork and Middle Fork of the Willamette River, Oregon: Report of Oregon State University Department of Fisheries and Wildlife, Corvallis, for The Nature Conservancy and U.S. Army Corps of Engineers, Portland, Oregon, 237 p.

Harnish, R.A., Vernon C.R., Green, E.D., and McMichael, G.A., 2015, Ecological interactions between hatchery summer steelhead and wild *Oncorhynchus mykiss* in the Willamette River Basin, 2014: Report of Pacific Northwest National Laboratory, Richland, Washington, prepared for U.S. Department of Energy, contract DE-AC05-76RL01830, 51 p.

Herb, G., 1972, Effects on low flows below Big Cliff Reservoir, North Santiam River, on fish and other aquatic organisms—Fourth progress report on fisheries engineering research program, 1966–1972: U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Howell, P.J, Hutchinson, J., and Hooton, R., 1988, McKenzie sub-basin fish management plan: Oregon Department of Fish and Wildlife, Northwest Region, Corvallis, Oregon.

Hughes J.S., Bellgraph, B.J., Vazquez, J.A., Vernon, C.V., Kim, J.K., and Johnson, G.E., 2015, Optimization of radio telemetry deployment at Foster Dam, 2014: Report of Pacific Northwest National Laboratory, Richland, Washington, prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, contract DE-AC05-76RL01830, 40 p.

Hughes J.S., Johnson, G.E., Ploskey, G.R., Hennen, M.J., Fischer, E.S., and Zimmerman, S.A., 2013, Optimization of hydroacoustic equipment deployment at Foster Dam, 2013: Prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington, PNNL-22359.

Johnson, G.E., Khan, F., Ploskey, G.R., Hughes, J.S., and Fischer, E.S., 2010, Optimization of hydroacoustic equipment deployments at Lookout Point and Cougar Dams, Willamette Valley Project, 2010: Pacific Northwest National Laboratory, Richland, Washington.

Johnson, M.A., and Friesen, T.A., 2010, Spring Chinook salmon hatcheries in the Willamette Basin—Existing data, discernable patterns and information gaps: Report of Oregon Department of Fish and Wildlife, Corvallis, Oregon, prepared for U.S. Army Corps of Engineers, Portland, Oregon, task Order NWPPM-09-FH-05.

Karchesky, C.M., Pyper, B.J., Hanks, M.E., and Cramer, D.P, 2010, Final report—Evaluation of spring Chinook salmon downstream migration at the Willamette Falls Project, spring 2010: Report of Normandeau Associates, Inc., for Portland General Electric.

Keefer, M.L., and Caudill, C.C., 2010, A review of adult salmon and steelhead life history and behavior in the Willamette River Basin—Identification of knowledge gaps and research needs: Report of University of Idaho Department of Fish and Wildlife Resources prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, Technical Report 2010-8, 66 p.

Khan, F., Royer, I.M., Hughes, J.S., Fischer, E.S., Johnson, G.E., and Ploskey, G.R., 2011, Optimization of hydroacoustic equipment deployment at Detroit Dam, 2011: Report of Pacific Northwest Laboratory, Richland, Washington, prepared for U.S. Army Corps of Engineers, Portland, Oregon.

Larson, D.W., 1982, Comparison of reservoirs with dissimilar selective withdrawal capabilities—Effects on reservoir limnology and release water quality: Canadian Water Resources Journal, v. 7, no. 2, p. 90–111.

Lindsay, R.B., Kenaston, K.R., Schroeder, R.K., Grimes, J.T., Wade, M.G., Homolka, K., and Borgerson, K., 1997, Spring Chinook salmon in the Willamette and Sandy Rivers: Oregon Department of Fish and Wildlife, Salem, Annual Progress Report (task 1.2—The proportion of wild fish in natural spawning populations), Fish Research Report, project F-163-R-01.

Lindsay, R.B., Schroeder, R.K. and Kenaston, K.R., 1998, Spring Chinook salmon in the Willamette and Sandy Rivers: Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, Fish Research Report, project F-163-R-03.

Lindsay, R.B., Schroeder, R.K., and Kenaston, K.R., 2000, Spring Chinook salmon in the Willamette and Sandy Rivers: Report of Oregon Department of Fish and Wildlife, Salem, Fish Research Report, project F-163–R-05, 37 p.

Massey, J.B. 1967, Summary report on juvenile downstream migrant fish passage and protection studies at Willamette Falls, Oregon—Final report: Oregon State Game Commission, Columbia River Fishery Development Program, 64 p.

Mattson, C.R., 1962, Early life history of Willamette River spring Chinook salmon: Oregon Fish Commission, Clackamas, 56 p.

McMichael G.A., Harnish, R.A., Hanson, A.C., and Vernon, C.R., 2013, Ecological interactions between hatchery summer steelhead and wild *Oncorhynchus mykiss* in the Willamette Basin: Report of Pacific Northwest National Laboratory, Richland, Washington, prepared for U.S. Army Corps of Engineers, Portland, Oregon, 37 p.

Myers, J., Busack, C., Rawding, D., and Marshall, A., 2003, Historical population structure of Willamette and lower Columbia River Basin Pacific salmonids: Report of National Marine Fisheries Service, Northwest Fisheries Science Center, and Washington Department of Fish and Wildlife.

Myers, J., Busack, C., Rawding, D., Marshall, A., Teel, D., VanDoornik, D.M., and Maher, M.T., 2006, Historical population structure of Pacific salmonids in the Willamette River and lower Columbia River Basins: National Oceanic and Atmospheric Administration technical memorandum, NMFS-NWFSC-73, 311 p.

National Marine Fisheries Service, 2011, Anadromous salmonid passage facility design: National Marine Fisheries Service, Northwest Region, Portland, Oregon, 135 p.

Normandeau Associates, Inc., 2014, Condition of juvenile salmonids passed through the entire length of the Green Peter 24 inch bypass pipe: Report of Normandeau Associates, Inc., Drumore, Pennsylvania, prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract W912EF-08-D-0005-DT05, 7 p.

Northwest Power and Conservation Council, 2016, Staff paper—Review of fish passage technologies at high head dams: Northwest Power and Conservation Council, 174 p., accessed January 2017, at https://www.nwcouncil.org/media/7490900/2016-14.pdf.

Oregon Department of Fish and Wildlife, 1990, McKenzie River, Willamette River sub-basin, salmon and steelhead production plan: Northwest Power Planning Council, Portland, Oregon, 90 p.

Oregon Department of Fish and Wildlife and National Marine Fisheries Service, 2011, Upper Willamette River conservation and recovery plan for Chinook salmon and steelhead: Oregon Department of Fish and Wildlife and National Marine Fisheries Service Northwest Region, 462 p.

Oregon Water Resources Department and U.S. Army Corps of Engineers, 1998, Willamette Basin reservoirs—An overview of U.S. Army Corps of Engineers dams and reservoirs on Willamette River tributaries: Brochure of Oregon Water Resources Department and U.S. Army Corps of Engineers, 8 p.

Pierce, T.M., 2013, Upper Middle Fork Willamette River reservoir entry monitoring: Report of U.S. Army Corps of Engineers Aquatic Stewardship to the Army Corps of Engineers, 5 p.

Pierce, T.M., and Erickson, N.M., 2013, Fall Creek fish horn evaluator 2013: Report of U.S. Army Corps of Engineers Aquatic Stewardship to the U.S. Army Corps of Engineers, 9 p.

Romer, J.D., and Monzyk, F.R., 2014, Adfluvial life history in spring Chinook salmon from Quartzville Creek, Oregon: North American Journal of Fisheries Management, v. 34, no. 5, p. 885–891.

Rutz, G.L., Sholtis, M.D., Adams, N.S., and Beeman, J.W., 2014, Investigation of methods for successful installation and operation of Juvenile Salmon Acoustic Telemetry System (JSATS) hydrophones in the Willamette River, Oregon, 2012: U.S. Geological Survey Open-File Report 2014-1112, 26 p., accessed December 2016, at https://pubs.er.usgs.gov/publication/ofr20141112.

Schilt, C.R., 2007, Developing fish passage and protection at hydropower dams: Applied Animal Behavior Science, v. 104, p. 295–325.

Schreck, C.B., Snelling, J.C., Ewing, R.D., Bradford, C.S., Davis, L.E., and Slater, C.H., 1994, Migratory characteristics of juvenile spring Chinook salmon in the Willamette River: Completion report to Bonneville Power Administration, contract DE-AI79-88BP92818, project 88-160-3.

Schroeder, R.K., and Kenaston, K.R., 2004, Spring Chinook salmon in the Willamette and Sandy Rivers: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, Fish Research Report, project F-163-R-09, 64 p.

Schroeder, R.K., Kenaston, K.R., and Krentz, L.K., 2005, Spring Chinook salmon in the Willamette and Sandy Rivers—With 1996–2004 summaries: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, Fish Research Report, project F-163-R-10, 90 p.

Schroeder, R.K., Kenaston, K.R., and Lindsay, R.B, 1999, Spring Chinook salmon in the Willamette and Sandy rivers: Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, Fish Research Report, project F-163-R-04.

Schroeder, R.K., Kenaston, K.R., and Lindsay, R.B, 2001, Spring Chinook salmon in the Willamette and Sandy Rivers: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, Fish Research Report, project F-163-R-06, 33 p.

Schroeder, R.K., Kenaston, K.R., and Lindsay, R.B., 2002, Spring Chinook salmon in the Willamette and Sandy Rivers: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, Fish Research Report, project F-163-R-07, 36 p.

Schroeder, R.K., Kenaston, K.R., and Lindsay, R.B, 2003, Spring Chinook salmon in the Willamette and Sandy Rivers: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, Fish Research Report, project F-163-R-08, 48 p.

Schroeder, R.K., Kenaston, K.R., and McLaughlin, L.K., 2007, Spring Chinook salmon in the Willamette and Sandy Rivers: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, Fish Research Report, project F-163-R-11/12, 62 p.

Sheer, M.B., and Steel, E.A., 2006, Lost watersheds—Barriers, aquatic habitat connectivity, and salmon persistence in the Willamette and lower Columbia River Basins: Transactions of the American Fisheries Society, v. 135, p. 1,654–1,669.

Smith, E.M., 1977, Improving survival of spring Chinook hatchery smolts in the Willamette River: Report of Oregon Department of Fish and Wildlife Federal Aid Progress Reports, Fisheries 1977, Portland, project 88E25045, 30 p.

Smith, E.M., 1979, Willamette River spring Chinook evaluation—Marion Forks Hatchery evaluation, McKenzie River Hatchery evaluation: Report of Oregon Department of Fish and Wildlife Federal Aid Progress Reports, Portland, Oregon, project F-102-R-1, 30 p.

Smith, E.M., Williams, R.H., and Zakel, J.C., 1978, Improving survival of spring Chinook hatchery smolts in the Willamette River: Report of Oregon Department of Fish and Wildlife Federal Aid Progress Reports, Fisheries 1978, Portland, project 88E25045, 38 p.

Smith, E.M., Williams, R.H., and Zakel, J.C., 1982, Willamette River salmon studies—Marion Forks Hatchery evaluation, McKenzie River Hatchery evaluation: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report project F-102-R-3, 60 p.

Smith, E.M., Williams, R.H., and Zakel, J.C., 1983, Willamette River salmon studies—McKenzie River Hatchery evaluation: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, project F-102-R-5, 20 p.

Smith, E.M., Williams, R.H., and Zakel, J.C., 1984, Willamette River salmon studies—McKenzie River Hatchery evaluation: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, project F-102-R-5, 18 p.

Smith, E.M., and Zakel, J.C., 1980,Willamette River salmon studies—Improving survival of spring Chinook smolts from Willamette River hatcheries, Marion Forks Hatchery evaluation, McKenzie River Hatchery evaluation: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, project F-102-R-2, 62 p.

Smith, E.M., and Zakel, J.C., 1981, Willamette River salmon studies—Improving survival of spring Chinook smolts from Willamette River hatcheries, Marion Forks Hatchery evaluation, McKenzie River Hatchery evaluation: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, project F-102-R-3, 40p.

Smith, E.M., Zakel, J.C., and Day, W.H., 1985, Willamette River salmon studies—McKenzie River Hatchery evaluation: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, project F-102-R-6, 18 p.

Smith, E.M., Zakel, J.C., Day, W.H., Homolka, K., and Buckman, M.A., 1987, Willamette River salmon studies: Report of Oregon Department of Fish and Wildlife, Salem, Annual Progress Report, project F-102-R-6, 18 p.

Smith, L.W., 2002, A framework of ecosystem processes for evaluating effects of dams on endangered species: Northwest Science, v. 76, no. 4, p. 361–366.

Smith, M., 1976, Rearing spring Chinook salmon in Willamette River reservoirs: Closing report of Oregon Department of Fish and Wildlife prepared for Columbia River Fishery Development Program, Portland, Oregon, project 88E25070, 46 p.

Stillwater Sciences, 2006, Fish entrainment at the Carmen-Smith Hydroelectric Project, upper McKenzie River Basin, Oregon: Final report of Stillwater Sciences, Arcata, California, prepared for Eugene Water and Electric Board, Eugene, Oregon.

Street, L.E., and Faber, D.M., 2015, Willamette project juvenile salmonid PIT interrogation system development—North Santiam River near Bennett Dams: Report of Oregon Department of Fish and Wildlife, prepared for U.S. Army Corps of Engineers, Portland, Oregon, project W9127N-10-2-0008, 22 p.

Unrein, J.R., Chitwood, R., Noakes, D.L.G., and Schreck, C.B., 2013, Wild spring Chinook surrogate project: Report of Oregon Cooperative Fish and Wildlife Research Unit, Oregon State University Department of Fisheries and Wildlife, Oregon Hatchery Research Center, and the U.S. Geological Survey Oregon Cooperative Fish and Wildlife Research Unit, 29 p.

U.S. Army Corps of Engineers, 1962, Green Peter Project, Middle Santiam River, Oregon, design memorandum no. 13, fish facilities: U. S. Army Engineer District, Portland, Oregon, 112 p.

U.S. Army Corps of Engineers, 1963, Foster Reservoir, South Santiam River, Oregon, design memorandum no. 9 and supplements A, B, C, spillway, power intake and fish facilities: U. S. Army Engineer District, Portland, Oregon, 193 p.

U.S. Army Corps of Engineers, 1997, Middle Fork Willamette River, Oregon fisheries restoration reconnaissance report: U.S. Army Corps of Engineers, Portland, Oregon.

U.S. Army Corps of Engineers, 2013, Downstream fish enhancement for juvenile salmonids at Hills Creek, Fall Creek, and Cougar Dams 2013–2020: Draft environmental assessment of U.S. Army Corps of Engineers, Portland, Oregon District, 71 p.

U.S. Fish and Wildlife Service, 1958, A detailed report on fish and wildlife resources affected by Hills Creek Reservoir Project, Oregon: U.S. Fish and Wildlife Service, 27 p.

Ward, D.L., Nigro, A.A., Farr, R.A., and Knutsen, C.J., 1994, Influence of waterway development on migrational characteristics of juvenile salmonids in the lower Willamette River, Oregon: North American Journal of Fisheries Management, v. 14, p. 362–371.

West Fork Environmental, 2014, Efficiency tests of PIT detection system: Report of West Fork Environmental prepared for U.S. Army Corps of Engineers, Portland, Oregon, contract no. W9127N-14-P-0031, Mod 3, 16 p.

Willis, C., Cramer, S., Cramer, D., Smith, M., Downey, T., and Montagne, R., 1995, Status of Willamette River spring Chinook salmon in regards to the Federal Endangered Species Act, part 1, 84 p.

Witty, K.L., and Cramer, S.P., 2001, Impacts of hatchery rainbow trout on naturally produced spring Chinook salmon and winter steelhead in the Upper Willamette River Basin: Report of S.P. Cramer and Associates, Inc., for US Army Corps of Engineers, 92 p.

Appendix B. Tables of Documents, Technology, Year of Study, and Location of Study by Author, Year, and Subbasin Included in the Synthesis

Table B1. North Santiam River Subbasin Documents.

Author and year	Title	Technology	Year of study	Location of study
Beeman and Adams, 2015	In-reservoir behavior, dam passage, and downstream migration of juvenile Chinook salmon and juvenile steelhead from Detroit Reservoir and Dam to Portland, Oregon, February 2013–February 2014	Acoustic telemetry, PIT	2013–2014	Detroit Dam
Beeman, Hansel, and others, 2014a	Behavior and dam passage of juvenile Chinook salmon and juvenile steelhead at Detroit Reservoir and Dam, Oregon, March 2012–February 2013	Acoustic telemetry, PIT	2012–2013	Detroit Dam
Boyd and Chilton, 2012a	Operations report for Marion Forks Hatchery January 1, 2012 through December 31, 2012	Hatchery propagation	2012	Marion Forks Hatchery
Boyd and Chilton, 2014a	Operations report for Marion Forks Hatchery July 1, 2013 through June 30, 2014	Hatchery propagation	2013–2014	Marion Forks Hatchery
Boyd and Chilton, 2015a	Operations report for Marion Forks Hatchery July 1, 2014 through June 30, 2015	Hatchery propagation	2014–2015	Marion Forks Hatchery
Boyd and Chilton, 2016a	Operations report for Marion Forks Hatchery July 1, 2015 through June 30, 2016	Hatchery propagation	2015–2016	Marion Forks Hatchery
Brandt and others, 2016a	Migration, survival, growth, and fate of hatchery juvenile Chinook salmon released above and below dams in the Willamette River Basin	PIT	2011–2013	Detroit, Minto, Hills Creek, Lookout Point, Dexter Dams
Duncan, 2010	Evaluation of fish passage conditions for juvenile salmonids using sensor fish at Detroit Dam, Oregon	Sensor Fish	2009	Detroit Dam

Author and year	Title	Technology	Year of study	Location of study
Duncan and Carlson, 2011	Characterization of fish passage conditions through a Francis turbine, spillway, and regulating outlet at Detroit Dam, Oregon, using sensor fish, 2009	Sensor Fish	2009	Detroit Dam
Grenbemer and others, 2011	Operations report for Marion Forks Hatchery January 1, 2011 through December 31, 2011	Hatchery propagation	2011	Marion Forks Hatchery
Grenbemer and Chilton, 2014	Operations report for Minto Fish Facility July 1, 2013 through June 30, 2014	Hatchery propagation	2013–2014	Minto Fish Facility
Grenbemer and Chilton, 2015	Operations report for Minto Fish Facility July 1, 2014 through June 30, 2015	Hatchery propagation	2014–2015	Minto Fish Facility
Grenbemer and Chilton, 2016	Operations report for Minto Fish Facility July 1, 2015 through June 30, 2016	Hatchery propagation	2015–2016	Minto Fish Facility
Johnson and others, 2016	Migration survival, growth and fate of hatchery juvenile Chinook salmon released above and below dams in the Willamette River Basin	PIT	2014	Detroit, Big Cliff, Lookout Point, Dexter Dams
Khan, Royer, and others, 2012	Hydroacoustic evaluation of Juvenile salmonid passage and distribution at Detroit Dam, 2011	Active hydroacoustics	2011	Detroit Dam
Kock and others, 2015	Behavior, passage, and downstream migration of juvenile Chinook salmon from Detroit Reservoir to Portland, Oregon, 2014–15	Acoustic telemetry	2014–2015	Detroit Dam
Monzyk and others, 2013	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2012	Detroit, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2014	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2013	Detroit, Foster, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2015b	Infection of juvenile salmonids *by Salmincola californiensis* (Copepoda: Lernaeopodidae) in reservoirs and streams of the Willamette River Basin, Oregon	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2012–2013	Detroit, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2015a	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2014	Detroit, Foster, Cougar, Lookout Point, Fall Creek Dams

Author and year	Title	Technology	Year of study	Location of study
Monzyk, Romer, and others, 2011a	Pilot head-of-reservoir juvenile salmonid monitoring	Rotary screw traps	2010	Detroit, Foster, Cougar, Lookout Point Dams
Monzyk and others, 2012	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Floating box trap, gill net, Oneida Lake trap	2011	Detroit, Foster, Cougar, Lookout Point Dams
Normandeau Associates, Inc., 2010a	Estimates of direct survival and injury of rainbow trout (*Oncorhynchus mykiss*) passing spillway, turbine, and regulating outlet at Detroit Dam, Oregon	HI-Z balloon tags	2009	Detroit Dam
Oligher and Donaldson, 1966	Fish passage through turbines: Tests at Big Cliff Hydroelectric Plant	Mark-recapture	1964, 1966	Big Cliff Dam
O'Malley and others, 2015	An evaluation of spring Chinook salmon reintroduction above Detroit Dam, North Santiam River, using genetic pedigree analysis	Genetic pedigree analysis	2007–2014	Detroit Dam
Romer and others, 2012	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2011	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2013	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2012	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2014	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2013	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2015	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2014	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2016	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2015	Detroit, Foster, Cougar, Lookout Point Dams
Schroeder and others, 2016	Juvenile life-history diversity and population stability of spring Chinook salmon in the Willamette River Basin, Oregon	PIT, seines, traps	2004–2013	North Santiam, South Santiam, McKenzie Rivers
Sharpe and others, 2013	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2011, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2011	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers

Author and year	Title	Technology	Year of study	Location of study
Sharpe and others, 2015	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2013, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2013	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2016	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2014, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2014	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2014	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2012, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2012	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
State of Washington Department of Fisheries, 1960	Research relating to mortality of downstream migrant salmon passing McNary and Big Cliff Dams, *in* U.S. Army Corps of Engineers, 1960, Progress report on fisheries engineering research program	Scoop nets	1957	Big Cliff Dam
Wevers and others, 1992	Santiam and Calapooia sub-basin fish management plan	Fish management plan	1992	North Santiam, South Santiam Rivers

Table B2. South Santiam River Subbasin Documents.

Author and year	Title	Technology	Year of study	Location of study
Boyd and Chilton, 2011	Operations report for South Santiam Hatchery January 1, 2011 through December 31, 2011	Hatchery propagation	2011	South Santiam Hatchery
Boyd and Chilton, 2012b	Operations report for South Santiam Hatchery January 1, 2012 through December 31, 2012	Hatchery propagation	2012	South Santiam Hatchery
Boyd and Chilton, 2014b	Operations report for South Santiam Hatchery July 1, 2013 through June 30, 2014	Hatchery propagation	2013–2014	South Santiam Hatchery
Boyd and Chilton, 2015b	Operations report for South Santiam Hatchery July 1, 2014 through June 30, 2015	Hatchery propagation	2014–2015	South Santiam Hatchery
Boyd and Chilton, 2016b	Operations report for South Santiam Hatchery July 1, 2015 through June 30, 2016	Hatchery propagation	2015–2016	South Santiam Hatchery
Buchanan and others, 1993	Restoration of the native winter steelhead run on the South Santiam River above Foster Dam	Creel surveys, hydroacoustics, Floy tags, manual counts, radio telemetry	1979–1988	Green Peter Dam, Foster Dam
Deng and others, 2015	Willamette Valley high head bypass downstream passage prototype evaluation: sensor fish evaluation of bypass pipes at Green Peter Dam	Sensor fish	2015	Green Peter Dam
Duncan, 2013b	Assessment of passage conditions through the complete 24-in downstream bypass pipe at Green Peter Dam	Sensor fish	2013	Green Peter Dam
Duncan, 2013a	Characterization of fish passage conditions through the fish weir and turbine unit 1 at Foster Dam, Oregon, using sensor fish, 2012	Sensor fish	2012	Foster Dam
Hughes and others, 2016	Evaluation of juvenile salmonid passage and behavior at Foster Dam using radio telemetry, 2015	Radio telemetry	2015	Foster Dam
Hughes and others, 2014	Hydroacoustic evaluation of juvenile salmonid passage and distribution at Foster Dam, 2013–2014	Hydroacoustics	2013–2014	Foster Dam
Johnson, 1984	Hydroacoustic evaluation of elevated flow for passing downstream migrating juvenile salmon and steelhead at Foster Dam, Oregon 16–21 April, 1984	Hydroacoustics	1984	Foster Dam
Monzyk and others, 2014	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, gill nets, screw	2013	Detroit, Foster, Cougar, Lookout Point, Fall Creek Dams

Author and year	Title	Technology	Year of study	Location of study
		trap, seine		
Monzyk and others, 2015a	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2014	Detroit, Foster, Cougar, Lookout Point, Fall Creek Dams
Monzyk, Romer, and others, 2011a	Pilot head-of-reservoir juvenile salmonid monitoring	Rotary screw traps	2010	Detroit, Foster, Cougar, Lookout Point Reservoirs
Normandeau Associates, Inc., 2013	Estimates of direct effects of steelhead salmon during downstream passage through a turbine and weir at Foster Dam, Oregon	HI-Z balloon tags	2012	Foster Dam
Normandeau Associates, Inc., 2015	Biological fish injury and survival evaluation at Green Peter Dam, Oregon, 2015	Direct release-recapture	2015	Green Peter Dam
O'Malley and others 2014	Genetic parentage analysis of spring Chinook salmon on the South Santiam River—Insights into population productivity and reintroduction strategies	Genetic parentage analysis	2007–2013	Foster Dam
Romer and others, 2012	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2011	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2013	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2012	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2014	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2013	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2015	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2014	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2016	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2015	Detroit, Foster, Cougar, Lookout Point Dams
Schroeder and others, 2016	Juvenile life-history diversity and population stability of spring Chinook salmon in the Willamette River Basin, Oregon	PIT, seines, traps	2004–2013	North Santiam, South Santiam, McKenzie Rivers
Sharpe and others, 2013	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2011, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2011	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2015	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2013, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2013	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers

Author and year	Title	Technology	Year of study	Location of study
Sharpe and others, 2016	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2014, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2014	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2014	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—: 2012, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2012	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
U.S. Army Corps of Engineers, 1995	South Santiam fishery restoration draft reconnaissance study, South Santiam sub-basin study, general investigation	Reconnaissance study	1995	Green Peter, Foster Dams
Wagner and Ingram, 1973	Evaluation of fish facilities and passage at Foster and Green Peter Dams on the South Santiam River drainage in Oregon	Manual counts, floy tags, scoop traps, draft tube nets, gill nets, spawning surveys	1968–1971	Green Peter, Foster Dams
Wevers and others, 1992	Santiam and Calapooia sub-basin fish management plan	Fish management plan	1992	North Santiam, South Santiam Rivers

Table B3. McKenzie River Subbasin Documents.

Author and year	Title	Technology	Year of study	Location of study
Adams and others, 2015	An evaluation of fish behavior upstream of the water temperature control tower at Cougar Dam, Oregon, using acoustic cameras, 2013	DIDSON, Blueview, and ARIS acoustic cameras	2013	Cougar Dam
Beeman and others, 2012	Passage probabilities of juvenile Chinook salmon through the powerhouse and regulating outlet at Cougar Dam, Oregon, 2011	Radio telemetry, PIT	2011	Cougar Dam
Beeman and others, 2013	Behavior and dam passage of juvenile Chinook salmon a Cougar Reservoir and Dam, Oregon, March 2011–February 2012	Acoustic telemetry, PIT	2011–2012	Cougar Dam
Beeman, Evans, and others, 2014	Passage and survival probabilities of juvenile Chinook salmon at Cougar Dam, Oregon, 2012	Radio telemetry, PIT	2012	Cougar Dam
Beeman, Hansel, and others, 2014b	Behavior and dam passage of juvenile Chinook salmon at Cougar Reservoir and Dam, Oregon, March 2012–February 2013	Acoustic telemetry, PIT	2012–2013	Cougar Dam
Beeman and others, 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	Acoustic telemetry, PIT	2011–2012	Cougar Reservoir
Beeman and others, 2016a	Evaluation of the biological and hydraulic performance of the portable floating fish collector at Cougar Reservoir and Dam, Oregon, September 2015–January 2016	Acoustic telemetry, PIT	2015–2016	Cougar Dam
Beeman and others, 2016b	Evaluation of the biological and hydraulic performance of the portable floating fish collector at Cougar Reservoir and Dam, Oregon, 2014	Acoustic telemetry, PIT	2014	Cougar Dam
Bureau of Commercial Fisheries, 1960	Downstream migrant studies South Fork McKenzie River 1957, 1959, 1960	Fyke nets, scoop traps	1957, 1959, 1960	Cougar Dam site
Cummings and others, 2011	Operations report for McKenzie River Hatchery, January 1, 2011 through December 31, 2011	Hatchery propagation	2011	McKenzie River Hatchery
Cummings and others, 2012	Operations report for McKenzie River Hatchery, January 1, 2012 through December 31, 2012	Hatchery propagation	2012	McKenzie River Hatchery
Duncan, 2011	Characterization of fish passage conditions through a Francis turbine and regulating outlet	Sensor fish	2009–2010	Cougar Dam

Author and year	Title	Technology	Year of study	Location of study
	at Cougar Dam, Oregon, using sensor fish, 2009–2010			
Ingram and Korn, 1969	Evaluation of fish passage facilities at Cougar Dam on the South Fork McKenzie River in Oregon	Manual counts, spawning surveys, Oneida Lake traps, gill nets, mark-recapture	1956–1967	Cougar Dam
Khan, Johnson, and others, 2012a	Acoustic imaging evaluation of juvenile salmonid behavior in the immediate forebay of the water temperature control tower at Cougar Dam, 2010	DIDSON, Blueview acoustic cameras	2010	Cougar Dam
Kremers and Chilton, 2014	Operations report for McKenzie River Hatchery, July 1, 2013, through June 30, 2014	Hatchery propagation	2013–2014	McKenzie River Hatchery
Kremers and Chilton, 2015	Operations report for McKenzie River Hatchery, July 1, 2014, through June 30, 2015	Hatchery propagation	2014–2015	McKenzie River Hatchery
Kremers and Chilton, 2016	Operations report for McKenzie River Hatchery, July 1, 2015, through June 30, 2016	Hatchery propagation	2015–2016	McKenzie River Hatchery
Monzyk, 2010	Cougar Dam route passage survival indices based on release-recapture of PIT-tagged hatchery fish	PIT	2009–2010	Cougar Dam
Monzyk and others, 2013	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, screw trap, seine	2012	Detroit, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2014	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, screw trap, seine	2013	Detroit, Foster, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2015b	Infection of juvenile salmonids by *Salmincola californiensis* (Copepoda: Lernaeopodidae) in reservoirs and streams of the Willamette River Basin, Oregon	Oneida Lake trap, floating box trap, screw trap, seine	2012–2013	Detroit, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2015a	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, screw trap, seine	2014	Detroit, Foster, Cougar, Lookout Point, Fall Creek Dams
Monzyk, Hogansen, and others, 2011	Cougar Dam route selection study—Evaluating fish passage using spill	PIT	2010–2011	Cougar Dam
Monzyk, Romer, and others, 2011b	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Snorkel survey, minnow trap, beach seine, Oneida Lake trap, hoop net, lampara seine, mid-	2010	Cougar, Lookout Point Reservoirs

Author and year	Title	Technology	Year of study	Location of study
		water trawl, hook-and-line		
Monzyk, Romer, and others, 2011a	Pilot head-of-reservoir juvenile salmonid monitoring	Rotary screw traps	2010	Detroit, Foster, Cougar, Lookout Point Reservoirs
Monzyk and others, 2012	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Floating box trap, Oneida Lake trap	2011	Detroit, Cougar, Lookout Point Reservoirs
Normandeau Associates, Inc., 2010b	Estimates of direct survival and injury of juvenile Chinook salmon (*Oncorhynchus tshawytscha*), passing a regulating outlet and turbine at Cougar Dam, Oregon	HI-Z balloon tags	2009–2010	Cougar Reservoir
Ploskey and others, 2012	Hydroacoustic estimates of fish density distributions in Cougar Reservoir, 2011	Hydroacoustics	2011	Cougar Reservoir
Romer and others, 2012	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2011	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2013	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2012	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2014	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2013	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2015	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2014	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2016	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2015	Detroit, Foster, Cougar, Lookout Point Dams
Schroeder and others, 2016	Juvenile life-history diversity and population stability of spring Chinook salmon in the Willamette River Basin, Oregon	PIT, seines, traps	2004–2013	North Santiam, South Santiam, McKenzie Rivers
Sharpe and others, 2013	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2011, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2011	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2015	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2013, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2013	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2016	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2014, hatchery baseline	Spawning surveys, carcass sampling, underwater video,	2014	North Santiam, South Santiam, McKenzie, Middle Fork

Author and year	Title	Technology	Year of study	Location of study
	monitoring	fin clips, coded wire tags		Willamette Rivers
Sharpe and others, 2014	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2012, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2012	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Taylor, 2000	Monitoring of downstream fish passage at Cougar Dam in the South Fork McKenzie River Oregon 1998–00	Rotary screw traps	1998–2000	Cougar Dam
Withalm and others, 2016	Operations report for Leaburg Hatchery, July 1, 2015 through June 30, 2016	Hatchery propagation	2015–2016	Leaburg Hatchery
Withalm and others, 2011	Operations report for Leaburg Hatchery, January 1, 2011 through December 31, 2011	Hatchery propagation	2011	Leaburg Hatchery
Withalm and others, 2012	Operations report for Leaburg Hatchery, January 1, 2012 through December 31, 2012	Hatchery propagation	2012	Leaburg Hatchery
Withalm and others, 2014	Operations report for Leaburg Hatchery, July 1, 2013 through June 30, 2014	Hatchery propagation	2013–2014	Leaburg Hatchery
Withalm and others, 2015	Operations report for Leaburg Hatchery, July 1, 2014 through June 30, 2015	Hatchery propagation	2014–2015	Leaburg Hatchery
Zakel and Reed, 1984	Downstream migration of fish at Leaburg Dam, McKenzie River, Oregon, 1980 to 1983	Inclined-plane trap	1980–1983	Leaburg Dam
Zymonas and others, 2011	Monitoring and evaluation of impacts to bull trout (*Salvelinus confluentus*) and spring Chinook (*Oncorhynchus tshawytscha*) in the South Fork McKenzie River from construction of water temperature control facilities at Cougar Dam, Oregon	Rotary screw traps, PIT, radio telemetry, trap nets, snorkel surveys, spawning surveys	2001–2010	Cougar Dam

Table B4. Middle Fork Willamette River Subbasin Documents.

Author and year	Title	Technology	Year of study	Location of study
Brandt and others, 2016a	Migration, survival, growth, and fate of hatchery juvenile Chinook salmon released above and below dams in the Willamette River Basin	PIT	2011–2013	Detroit, Minto, Hills Creek, Lookout Point, Dexter Dams
Brandt and others, 2016b	Status and trends of predator species in Lookout Point Reservoir	Boat electrofishing, Oneida Lake traps, sinking gill nets, and floating gill nets	2013–2015	Lookout Point Reservoir
Downey and Smith, 1992	Evaluation of spring Chinook salmon passage at Fall Creek Dam, 1991	Mark-recapture	1991	Fall Creek Dam
Homolka and Smith, 1991	Evaluation of spring Chinook salmon and winter steelhead passage at Fall Creek Dam, 1990	Mark-recapture (fin clips, gill nets, RST)	1990	Fall Creek Dam
Johnson and others, 2016	Migration survival, growth and fate of hatchery juvenile Chinook salmon released above and below dams in the Willamette River Basin	PIT	2014	Detroit, Big Cliff, Lookout Point, Dexter Dams
Keefer and others, 2011	Downstream fish passage above and below dams in the Middle Fork Willamette River—A multi-year summary	Rotary screw traps	2003–2010	Lookout Point, Hills Creek, Fall Creek Dams; North Fork Middle Fork and Fall Creeks
Keefer and others, 2012	Reservoir entrapment and dam passage mortality of juvenile Chinook salmon in the Middle Fork Willamette River	Rotary screw traps	2003–2010	Lookout Point, Hills Creek, Fall Creek Dams; North Fork Middle Fork and Fall Creeks
Keefer and others, 2013	High-head dams affect downstream fish passage timing and survival in the Middle Fork Willamette River	Rotary screw traps	2003–2010	Lookout Point, Hills Creek, Fall Creek Dams; North Fork Middle Fork and Fall Creeks
Khan, Johnson, and others, 2012b	Hydroacoustic evaluation of juvenile salmonid passage and distribution at Lookout Point Dam, 2010	Hydroacoustics	2010	Lookout Point Dam
Kock and others, 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,	Parentage-Based Tagging (PBT) N-mixture model	2016	Lookout Point Reservoir

Author and year	Title	Technology	Year of study	Location of study
	western Oregon			
Larson, 2000	Spawning migration movements and emigration through Hills Creek on spring Chinook salmon (*Oncorhynchus tshawytscha*) in the Upper Middle Fork Willamette River, Lane County	Radio telemetry, spawning surveys, rotary screw trap	1999–2000	Hills Creek Dam
Korn and Smith, 1971	Rearing juvenile salmon in Columbia River Basin storage reservoirs	Mark-recapture	1966–1970	Fall Creek Dam
Monzyk and others, 2013	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2012	Detroit, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2014	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2013	Detroit, Foster, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2015b	Infection of juvenile salmonids by *Salmincola californiensis* (Copepoda: Lernaeopodidae) in reservoirs and streams of the Willamette River Basin, Oregon	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2012–2013	Detroit, Cougar, Lookout Point, Fall Creek Dams
Monzyk and others, 2015a	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Oneida Lake trap, floating box trap, gill nets, screw trap, seine	2014	Detroit, Foster, Cougar, Lookout Point, Fall Creek Dams
Monzyk, Romer, and others, 2011b	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Snorkel survey, minnow trap, beach seine, Oneida Lake trap, hoop net, lampara seine, mid-water trawl, hook-and-line	2010	Cougar, Lookout Point Reservoirs
Monzyk, Romer, and others, 2011a	Pilot head-of-reservoir juvenile salmonid monitoring	Rotary screw traps	2010	Detroit, Foster, Cougar, Lookout Point Reservoirs
Monzyk and others, 2012	Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs	Floating box trap, gill net, Oneida Lake trap	2011	Detroit, Cougar, Lookout Point Reservoirs
Nesbit and others, 2014	Passage behavior and survival of juvenile spring Chinook salmon at Fall Creek Dam, 2012	Radio telemetry	2012	Fall Creek Dam

Author and year	Title	Technology	Year of study	Location of study
Normandeau Associates, Inc., and Pierce, 2014	Estimates of direct effects of downstream passage through the fish horns at Fall Creek Dam	Direct release-recapture, PIT, rotary screw trap	2013	Fall Creek Dam
Peck and others, 2011	Operations report for Willamette Hatchery, January 1, 2011 through December 31, 2011	Hatchery propagation	2011	Willamette Hatchery
Peck and others, 2012	Operations report for Willamette Hatchery, January 1, 2012 through December 31, 2012	Hatchery propagation	2012	Willamette Hatchery
Peck and others, 2014	Operations report for Willamette Hatchery, July 1, 2013 through June 30, 2014	Hatchery propagation	2013–2014	Willamette Hatchery
Peck and others, 2015	Operations report for Willamette Hatchery, July 1, 2014 through June 30, 2015	Hatchery propagation	2014–2015	Willamette Hatchery
Peck and others, 2016	Operations report for Willamette Hatchery, July 1, 2015 through June 30, 2016	Hatchery propagation	2015–2016	Willamette Hatchery
Romer and others, 2012	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2011	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2013	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2012	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2014	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2013	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2015	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2014	Detroit, Foster, Cougar, Lookout Point Dams
Romer and others, 2016	Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs	Rotary screw traps, PIT	2015	Detroit, Foster, Cougar, Lookout Point Dams
Sharpe and others, 2013	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2011, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2011	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2015	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2013, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2013	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2016	Work completed for compliance with the 2008 Willamette Project biological opinion, USACE funding—2014, hatchery baseline monitoring	Spawning surveys, carcass sampling, underwater video, fin clips, coded wire tags	2014	North Santiam, South Santiam, McKenzie, Middle Fork Willamette Rivers
Sharpe and others, 2014	Work completed for compliance with the 2008 Willamette Project biological opinion,	Spawning surveys, carcass sampling,	2012	North Santiam, South Santiam, McKenzie,

Author and year	Title	Technology	Year of study	Location of study
	USACE funding—2012, hatchery baseline monitoring	underwater video, fin clips, coded wire tags		Middle Fork Willamette Rivers
Smith and Korn, 1970	Evaluation of fish facilities and passage at Fall Creek Dam on Big Fall Creek in Oregon	Manual counts, spawning surveys, trap and haul, fish horns, mark-recapture	1965–1969	Fall Creek Dam

Table B5. Out of Basin and Other Documents, Webpages.

Author and year	Title	Technology	Year of study	Location of study
Ackerman and Pyper, 2016	Evaluation of juvenile salmonid passage through the River Mill hydroelectric development	PIT	2015	River Mill Dam
Craig and Townsend, 1946	An investigation of fish-maintenance problems in relation to the Willamette Valley Project	Synthesis	1940, 1941, 1942	Willamette Projects
Herron-Seeley, 2016	The impact of parasitic copepod *Salmincola californiensis* on swimming ability and oxidative burst activity in response to stress in juvenile Chinook salmon	Fish health	2016	Willamette River Basin
Kabata and Cousens, 1977	Host-parasite relationships between sockeye salmon, *Oncorhynchus nerka*, and *Salmincola californiensis* (Copepoda: Lernaeopodidae)	Fish health	1977	Laboratory
National Marine Fisheries Service, 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	Biological opinion	2008	Willamette River Basin
National Marine Fisheries Service, 1999b	Endangered and threatened species—Threatened status for three Chinook salmon evolutionarily significant units (ESUs) in Washington and Oregon, and endangered status for one Chinook salmon ESU in Washington	Final rule	1999	Upper Willamette River spring-run Chinook salmon
National Marine Fisheries Service, 1999a	Endangered and threatened species—Threatened status for two ESUs of steelhead in Washington and Oregon	Final rule; notice of determination	1999	Upper Willamette River Steelhead
PacifiCorp, 2017	Lewis River fish passage program 2016 annual report	Rotary screw trap, floating surface collector, acoustic telemetry, PIT	2015	Lewis River
Portland General Electric, 2016	Pelton Round Butte 2015 fish passage annual report	Project operations	2015	Pelton, Round Butte Dams
Puget Sound Energy, 2015	Downstream fish passage 2013 annual report for the Baker River Hydroelectric Project	Floating surface collectors, PIT	2013	Baker River Hydroelectric Project
Skalski and others, 2016	Status after 5 years of survival compliance testing in the Federal Columbia River Power System (FCRPS)	Acoustic telemetry	2010–2014	Columbia-Snake River Basin

Author and year	Title	Technology	Year of study	Location of study
Sharpe and others, 2007	Growth modulation during juvenile rearing can reduce rates of residualism in the progeny of wild steelhead broodstock	Hatchery research	2000–2002	Kalama Falls Hatchery
U.S. Army Corps of Engineers, 2011	Comprehensive plan for research, monitoring, and evaluation in the Willamette River Basin	Fish management plan	2011	Willamette River Basin
U.S. Army Corps of Engineers, 2016a	About our Willamette Valley locations Web page	Web page	2016	Willamette River Basin
U.S. Army Corps of Engineers, 2016c	Reservoir and river level information Web page	Web page	2016	Willamette River Basin
U.S. Army Corps of Engineers, 2016b	Project description, hydrologic data, powerhouse, and dam and reservoir info Web page	Web page	2016	Willamette River Basin
U.S. Fish and Wildlife Service, 2015	Endangered and threatened wildlife and plants—Removing the Oregon chub from the Federal list of endangered and threatened wildlife	Final rule	2015	Willamette River Basin
U.S. Geological Survey, 2016b	Geographic Names Information System (GNIS) Web page	Web page	2016	Not applicable
U.S. Geological Survey, 2016a	National Water Information System Web page	Web page	2016	Not applicable

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Hansen and others—Synthesis of Downstream Fish Passage Information at U.S. Army Corps of Engineers Projects in Willamette River Basin, Oregon—Open-File Report 2017–1101

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