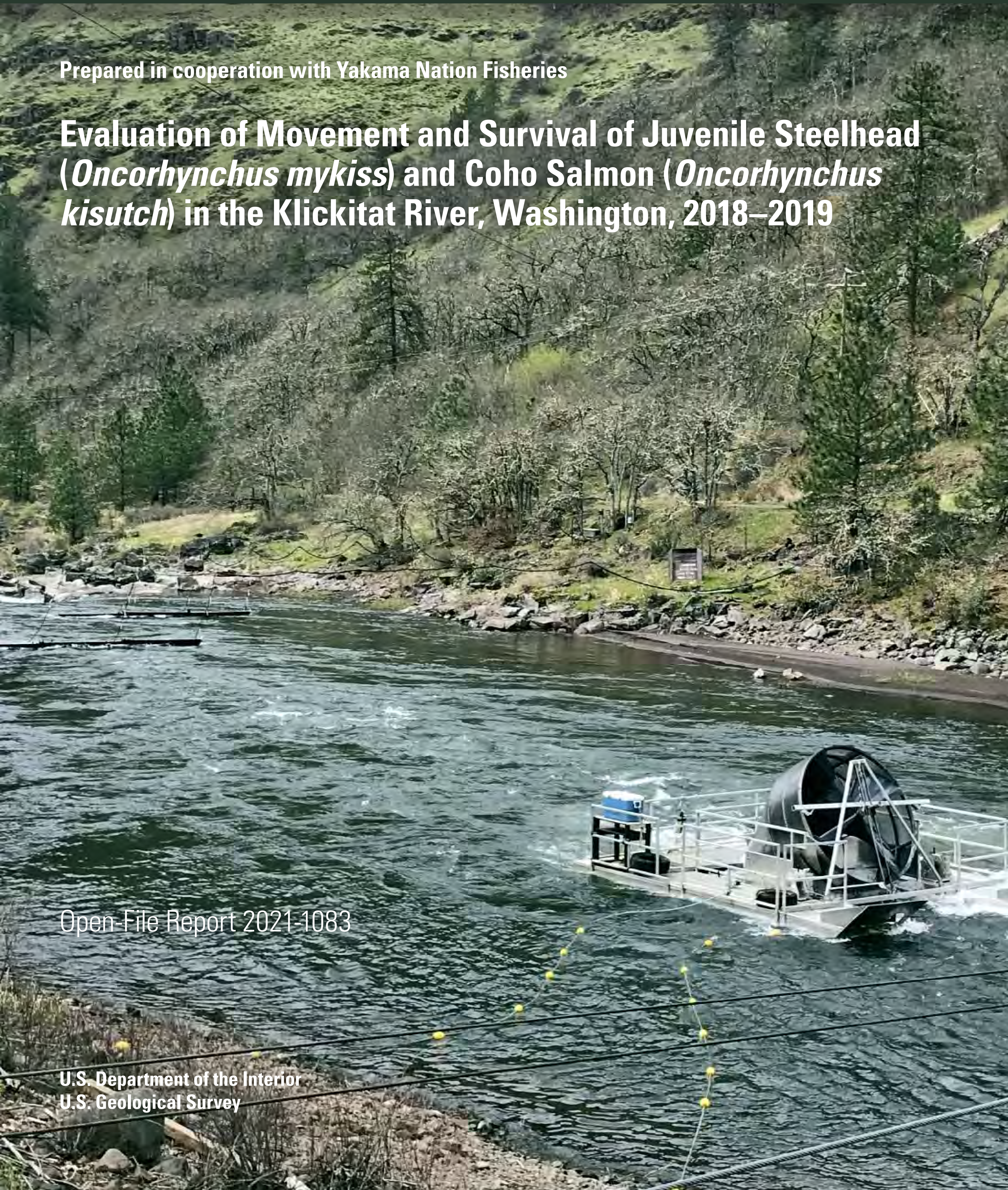
Prepared in cooperation with Yakama Nation Fisheries

Evaluation of Movement and Survival of Juvenile Steelhead (*Oncorhynchus mykiss*) and Coho Salmon (*Oncorhynchus kisutch*) in the Klickitat River, Washington, 2018–2019



Open-File Report 2021-1083

U.S. Department of the Interior
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Cover: Rotary screw trap near the Lyle Falls fishway, on the Klickitat River, Washington. Photograph taken by Jamie Sprando, U.S. Geological Survey, April 7, 2018.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	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	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
	Volume	
liter (L)	33.81402	ounce, fluid (fl. oz)
	Mass	
milligram (mg)	0.00003527	ounce, avoirdupois (oz)

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

$$°F = (1.8 \times °C) + 32.$$

Abbreviations

JSATS	juvenile salmonid acoustic telemetry system
KRD	Klickitat River delta
LFF	Lyle Falls Fishway and Adult Fish Trap Facility
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
rkm	river kilometer(s)
YNFP	Yakama Nation Fisheries Program

Evaluation of Movement and Survival of Juvenile Steelhead (*Oncorhynchus mykiss*) and Coho Salmon (*Oncorhynchus kisutch*) in the Klickitat River, Washington, 2018–2019

By Scott D. Evans[1], David S. Lindley[2], Tobias J. Kock[1], Amy C. Hansen[1], Russell W. Perry[1], Joseph S. Zendt[2], and Nicolas Romero[2]

Abstract

A 2-year telemetry study was conducted April–July in 2018 and 2019 to evaluate migration behavior and survival of juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) in the Klickitat River, Washington. A total of 612 natural-origin steelhead, collected in a smolt trap on the Klickitat River, were tagged, released, and monitored as they outmigrated through the lower 17 kilometers (km) of the Klickitat River, and in the 52 km reach between the mouth of the Klickitat River and Bonneville Dam. The primary goal of the steelhead study was to estimate survival through the Klickitat River delta, the 2 km reach located at the confluence of the Klickitat and Columbia rivers. A total of 400 hatchery-origin coho salmon were tagged and released at the Klickitat Hatchery and monitored during migration through the lower 68 km of the Klickitat River and in the Columbia River to Bonneville Dam. The primary goals of the coho salmon study were (1) to estimate survival through the Klickitat River delta and (2) to determine residence time in the Klickitat River to assess potential for interactions with rearing natural-origin fish.

Many tagged steelhead and coho salmon moved quickly downstream and left the Klickitat River shortly after release. Median elapsed time from release to Klickitat River exit ranged from 1.4 to 1.5 days for steelhead, and from 5.1 to 12.9 days for coho salmon during the two-year study. Ten percent of the tagged coho salmon in 2018 remained in the Klickitat River for 21.9–29.2 days before entering the Columbia River. In 2019, ten percent of the tagged coho salmon remained in the Klickitat River for 36.0–45.5 days before entering the Columbia River. This suggests that some hatchery fish spend considerable time in the river after hatchery release. Migration rates were consistently slow for both species in the Klickitat River delta compared to upstream reaches of the free-flowing Klickitat River and downstream reaches of the Columbia River. Similarly, reach-specific survival was highest in free-flowing reaches of the Klickitat River and lowest near the Klickitat River delta. Cumulative survival from release to sites located downstream of the Klickitat River delta were 0.78 for juvenile steelhead in both 2018 and 2019, and 0.57 and 0.61 for juvenile coho salmon in 2018 and 2019. Standardized survival estimates (survival per 100 river kilometers) were 0.243 in 2018 and 0.302 in 2019 for steelhead, and 0.100 in 2018 and 0.153 in 2019 for coho salmon. These estimates of standardized survival are low compared to similar estimates from other rivers in Washington, Oregon, Idaho, and California. This study provided new information about survival and residence time of juvenile steelhead and coho salmon in the Klickitat River. Additional studies would be helpful to understand factors affecting outmigration survival and overlap between hatchery-origin and natural-original juvenile steelhead and coho salmon in the system.

Introduction

The construction of Bonneville Dam in 1935 inundated the lower 2 kilometers (km) of the Klickitat River, which substantially altered riparian and riverine conditions in the reach. Shallow, multi-thread river channels and riparian cottonwood galleries were lost, riparian vegetation, salmonid spawning substrate, and salmonid rearing habitat were decreased, and populations of piscivorous fish such as non-native smallmouth bass (*Micropterus dolomieu)* and walleye (*Sander vitreus*), and native northern pikeminnow (*Ptychocheilus oregonensis*) are present at the Klickitat River mouth (National Marine Fisheries Service [NMFS], 2009). Additionally, anthropogenic alterations to habitat conditions, including loss of riparian vegetation, development of fish passage barriers, reduced in-stream habitat complexity, and increased fine sediment loading, along with changes in river flow, channel modifications, decreased water quality (temperature, contaminants, etc.), and

[1]U.S. Geological Survey

[2]Yakama Nation Fisheries Program

predation in the mainstem Columbia River have negatively affected anadromous fish populations in the Klickitat River (NMFS, 2009; The Watershed Company, 2016).

In 2009, the Yakama Nation Fisheries Program (YNFP) initiated a physical habitat assessment of the Klickitat River delta (KRD), the 2 km reach of the Klickitat River that is hydrologically influenced by the Columbia River, to identify factors limiting salmonid production. This assessment included collection of water surface elevation and water temperature data at several locations within the confluence of the Klickitat and Columbia rivers. This information will be utilized by YNFP to evaluate inundation frequency of landforms and approximately describe water temperature distributions in the vicinity of the KRD. The KRD is hydrologically influenced by Bonneville Dam operations; water velocities have been altered and water depths fluctuate daily, which could potentially result in increased transit times and predation of juvenile salmonids outmigrating through the reach. We developed a study plan to collect information on these factors that focused on juvenile natural-origin steelhead (*Oncorhynchus mykiss*) and hatchery-origin coho salmon (*O. kisutch*). The primary goal of the study was to determine reach-specific travel times and survival of tagged fish in the lower Klickitat River, through the KRD, and in a reach of the Columbia River (downstream of its confluence with the Klickitat River). A secondary objective of the study was to determine how long hatchery-origin juvenile coho salmon remained in the river after hatchery release to assess the potential for negative effects on natural-origin juvenile salmon and steelhead rearing in the river.

Methods

Environmental Conditions

Klickitat River flow data were collected from a streamgage operated by the U.S. Geological Survey near Pitt, Washington (U.S. Geological Survey, 2020). The streamgage recorded river flow data in 15-minute intervals and we downloaded these records and processed them to provide a daily average of river flow on the Klickitat River during April–July in 2018 and 2019.

Fish Tagging and Release

Juvenile steelhead and coho salmon were tagged and released to assess research objectives. Juvenile steelhead were of natural-origin and collected in a rotary screw trap located at river kilometer (rkm) 4.3 (fig. 1). Juvenile coho salmon were of hatchery-origin and tagged at the Klickitat Hatchery (rkm 68; fig. 1) during the week prior to hatchery release.

On each collection date, juvenile steelhead were removed from the rotary screw trap, placed into floating 18.9-liter (L) plastic containers (maximum of three steelhead per container) in a 1,586 L transport tank, and transported to the Lyle Falls Fishway and Adult Fish Trap Facility (LFF; fig. 1). At the LFF, the 18.9 L plastic containers were transferred into a 340.7 L tank that received flow-through river water. Fish were held in this manner for approximately 24 hours prior to tagging. On each tagging date, steelhead were removed from the tank and surgically tagged with an acoustic transmitter and passive integrated transponder (PIT-tag; Model FDX 12; Biomark, Inc., Boise, Idaho, USA) using methods described by Liedtke and others (2012). Tagged fish were then returned to the floating 18.9 L plastic containers, placed into a 1,586 L tank, and held for approximately 20 hours to monitor for short-term mortality. On each release date, steelhead were transported upstream by vehicle from the LFF to Pitt Bridge (13.2 rkm; ~20-minute transport time) and released.

On each collection date, coho salmon were netted from the hatchery rearing pond and placed into 340.7 L tanks with flow-through river water where they recovered for approximately 24 hours prior to tagging. The tagging methods for coho salmon were identical to those previously described for juvenile steelhead. After post-tag holding, tagged fish were transferred from the holding tank and released into the hatchery holding pond. Tagged coho salmon remained in the hatchery holding pond with untagged coho salmon for 6 days in 2018 and 3 days in 2019, after which the gateway to the Klickitat River was opened and fish could volitionally leave the holding pond and initiate downstream migration.

We used two models of acoustic transmitters for coho salmon in each respective year of the study. Steelhead and coho salmon were both tagged with the same transmitter in 2018 (Model SS300; Advanced Telemetry Systems, Inc., Asanti, Minnesota), which was 11.9 millimeters (mm) long, 6.3 mm wide, 3.7 mm tall, and 430 milligrams in weight in air. The 2018 transmitters operated at a pulse rate interval of 3.0 seconds and had a manufacturer-estimated operating life of 45 days. In 2019, we used a smaller acoustic transmitter (Model SS400; Advanced Telemetry Systems, Inc., Asanti, Minnesota) for coho salmon tagging that was 15.0 mm long, 3.3 mm in diameter, 210 milligrams in weight in air, operated at a pulse rate interval of 3.0 seconds, and had a manufacturer-estimated operating life of 48 days. In 2019, steelhead were tagged with the same transmitter used in 2018.

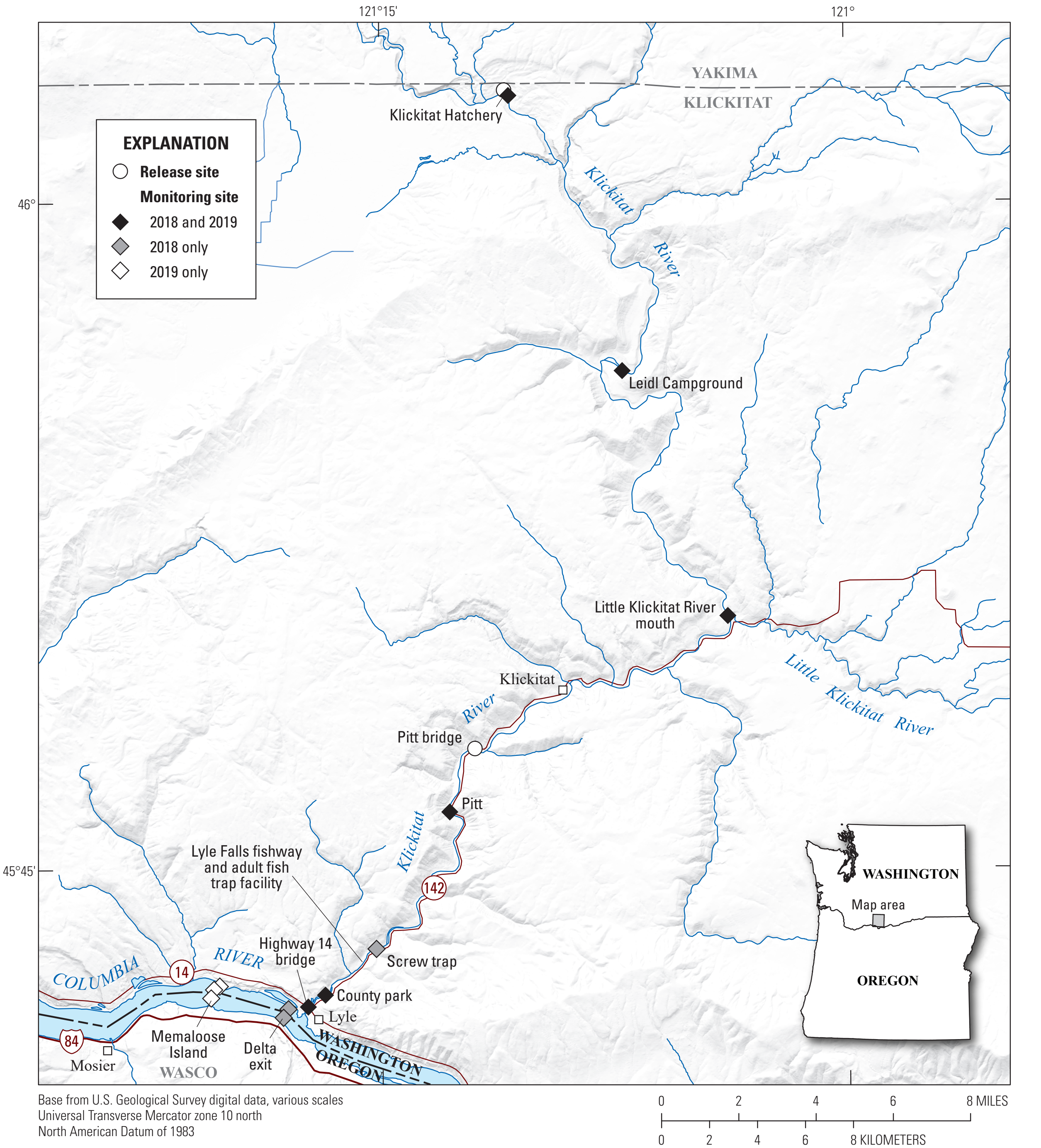

Figure 1. Locations of fish release sites and the acoustic telemetry monitoring sites used to detect tagged fish in the Klickitat and Columbia rivers, Washington. Each black diamond represents locations of two acoustic receivers used in both 2018 and 2019. Each gray diamond represents locations of two acoustic receivers used only in 2018. White diamonds at Memaloose Island represent seven receivers used only in 2019.

Evaluation of Transmitter Operating Life and Tag Loss

For survival studies conducted using active transmitters, it is important to understand factors such as tag life and tag loss, which are associated with survival modeling assumptions (Skalski and others 1998). We conducted a laboratory study to assess tag life and tag loss at the U.S. Geological Survey Columbia River Research Laboratory. A subset of transmitters was randomly selected from those used during the study and implanted into juvenile Chinook salmon that were held in 1.5-meter circular fiberglass tanks that received flow-through temperature-controlled water. Sample sizes for the laboratory study included 38 Model SS300 transmitters in 2018, 73 Model SS300 transmitters in 2019, and 30 Model SS400 transmitters in 2019. Tagged fish were fed a 1.5 percent maintenance diet six times a day using automated feeders. A single receiver in each of the two tanks monitored the transmitters until all stopped functioning. Tanks were checked daily Monday–Friday each week for shed tags and fish mortalities and cleaned three times per week. The experiments were terminated on day 91 in 2018 and day 75 in 2019 when it was determined that all tags had stopped operating.

Fish Monitoring Array

We used the juvenile salmon acoustic telemetry system (JSATS; McMichael and others, 2010) during the study. Monitoring sites consisted of autonomous JSATS hydrophone/receiver combinations (hereafter receivers; Model SR5000; Advanced Telemetry Systems, Inc., Asanti, Minnesota) which included (1) a hydrophone mounted underwater; (2) a receiver housed on shore that stored data until downloaded-ing occurred, and (3) a cable that connected the hydrophone to the receiver. We deployed at least two receivers at each monitoring site to increase detection probabilities. Seven sites were operated on the Klickitat River during 2018, six sites were operated on the Klickitat River in 2019, and one site was operated on the Columbia River in both years (fig. 1). Monitoring sites on the Klickitat River were located at the Klickitat Hatchery (rkm 68.6), Leidl Campground (rkm 51.5), the mouth of the Little Klickitat River (rkm 32.7), 2.8 km downstream of the Pitt Bridge (rkm 14.1), at the screw trap operated by YNFP (rkm 4.3; 2018 only), at County park (rkm 1.0), the Highway 14 Bridge (rkm 0), the delta exit (rkm 289.5; 2018 only), and at Memaloose Island (rkm 286.5; 2019 only). All sites contained two acoustic receivers except the Delta exit site (four receivers) and the Memaloose Island site (seven receivers). Monitoring sites were operated continuously during the study until or beyond the expected operating life of the acoustic transmitters.

Additional fish monitoring infrastructure in the Klickitat and Columbia rivers was used to provide supplementary detections of study fish. PIT tag detections from PIT antennas located on the screw trap, near the screw trap on a floating PIT array, and at the LFF, were pooled with JSATS detections at the screw trap site in 2018. In 2019, PIT tag detections at the screw trap, floating PIT array, and LFF were used in lieu of acoustic detections near the screw trap site. JSATS arrays, installed and maintained by the Pacific Northwest National Laboratory (PNNL) at Bonneville Dam in 2018, were pooled with PIT detections at Bonneville Dam and the Columbia River estuary and used as the farthest downstream monitoring site in 2018. In 2019, PNNL did not install JSATS arrays at Bonneville Dam so PIT detections at Bonneville Dam and the Columbia River estuary were pooled and used as the farthest downstream monitoring site.

Data Analysis

Acoustic telemetry data records were processed to remove false-positive detections prior to analyzing fish movement data. False-positive detections are defined as a transmitter detection that is recorded on a telemetry receiver when the transmitter was not actually present at the site. False-positive detections are common in most active telemetry systems (Beeman and Perry, 2012) so we used an automated proofing program to identify and remove these. This program removed detection records if (1) the detection record was from a tag code that was not released during the study, (2) the detection record matched criteria that indicated the detection likely resulted from reflections of valid tag signals (multipath), (3) the detection record did not match a multiple of the tag pulse interval, or (4) the detection record was not followed by at least three valid records of that transmitter on each receiver (McMichael and others, 2010).

A dataset was created by merging the processed acoustic telemetry and PIT detection records with biological data collected during tagging. A PIT tag dataset was created by querying the Columbia Basin PIT Tag Information System website (www.ptagis.org) for detections of tagged fish at PIT tag sites in the Klickitat and Columbia rivers (Pacific States Marine Fisheries Commission, 2020). The tagging and release data, processed telemetry data, and PIT tag data were merged and sorted chronologically for each fish in the study. Detections that occurred before a fish's release date and time were removed and the resulting final dataset was queried to summarize fish detections at specific sites in the study area. These summaries were used to describe movements of tagged fish and to create capture histories that were analyzed using mark-recapture survival models.

Capture histories were created to summarize detection histories for each fish in the study and facilitate survival estimation. These histories were short (seven digits for steelhead and nine digits for coho salmon) numeric strings that represented whether fish were detected (1) or undetected (0) at monitoring sites in the study area. For coho salmon, all capture histories began with a 1 which represented release at the Klickitat Hatchery. Subsequent locations in the capture history represented detection or non-detection at the following sites:

- Leidl Campground
- Little Klickitat River mouth
- 2.8 km downstream of Pitt Bridge
- Rotary screw trap, floating PIT array, LFF
- County park
- Highway 14 Bridge
- Delta exit (in 2018) or Memaloose Island (in 2019)
- PNNL JSATS sites and PIT sites at Bonneville Dam, and PIT sites in the Columbia River estuary (in 2018) or PIT sites at Bonneville Dam and the estuary (in 2019)

Capture histories for steelhead were similarly constructed except that only the last six monitoring sites were used since steelhead were released at the Pitt Bridge (table 1).

Reach-Specific Survival

We used a single release-recapture survival model (Cormack, 1964; Jolly, 1965; Seber, 1965; Skalski, 1998) to estimate migration survival in study reaches. The seven-digit and nine-digit capture histories were used to provide detection information at each monitoring site for steelhead and coho salmon, respectively. Data were analyzed in the framework of a Cormack-Jolly-Seber mark-recapture model using the RMark package (Laake, 2013), which calls program MARK (White and Burnham, 1999) from within R (R Core Team, 2018). To examine the effects of covariates on survival, we created a set of candidate models and compared their fit using Akaike's Information Criterion, with an adjustment for effects of sample size (AIC_C; Burnham and Anderson, 2002). Selection of the best fitting Cormack-Jolly-Seber model involved (1) identifying the best-fitting model for detection probability parameters and (2) using the best-fitting detection probability model to identify the best-fitting model for survival probability parameters. Parameter estimates for detection and survival probabilities for coho salmon and steelhead datasets were obtained from the best-fitting model.

Standardized survival estimates were calculated (survival per 100 rkm) to allow for comparison of survival rates between species and for comparison of survival rates from this study to similar studies in other basins. Tagged coho salmon traveled through a greater number of reaches (1–7) than tagged steelhead (reaches 3–7), so cumulative survival estimates from these reaches were scaled to survival per 100 rkm, which allowed us to compare survival estimates from reaches common for both tagged coho salmon and steelhead, as well as to similar studies in other basins.

Table 1. Monitoring sites and reaches used on the Klickitat and Columbia rivers for estimating survival of juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*), 2018–2019.

[Survival was not estimable in reach 8 because it represents the joint probability of surviving and being detected. Reach 7 and reach 8 lengths changed in 2019 compared to 2018. km, kilometers]

Reach number	Reach length 2018/2019 (km)	2018 reach description	2019 reach description
		Steelhead	
3	2.8/2.8	Release to 2.8 km below Pitt Bridge	Release to 2.8 km below Pitt Bridge
4	9.8/9.8	2.8 km below Pitt Bridge to screw trap	2.8 km below Pitt Bridge to screw trap (PIT only)
5	3.3/3.3	Screw trap to county park	Screw trap (PIT only) to county park
6	1.0/1.0	County park to Highway 14 Bridge	County park to Highway 14 Bridge
7	1.0/4.2	Highway 14 Bridge to delta exit	Highway 14 Bridge to Memaloose Island
8	52.3/49.1	Delta exit to Bonneville Dam or estuary	Memaloose Island to Bonneville Dam (PIT only) or estuary
		Coho salmon	
1	17.1/17.1	Release to Leidl Campground	Release to Leidl Campground
2	18.8/18.8	Leidl Campground to Little Klickitat R. mouth	Leidl Campground to Little Klickitat R. mouth
3	18.6/18.6	Little Klickitat R. mouth to 2.8 km below Pitt Bridge	Little Klickitat R. mouth to 2.8 km below Pitt Bridge
4	9.8/9.8	2.8 km below Pitt Bridge to screw trap	2.8 km below Pitt Bridge to screw trap (PIT only)
5	3.3/3.3	Screw trap to county park	Screw trap (PIT only) to county park
6	1.0/1.0	County park to Highway 14 Bridge	County park to Highway 14 Bridge
7	1.0/4.2	Highway 14 Bridge to delta exit	Highway 14 Bridge to Memaloose Island
8	52.3/49.1	Delta exit to Bonneville Dam or estuary	Memaloose Island to Bonneville Dam (PIT only) or estuary

Results

Environmental Conditions

River flows were generally similar in 2018 and 2019 and flow conditions each year during April–July approximated average flows for these months during 2013–2017 (fig. 2). River flows in early April 2019 were high, peaking at 5,570 cubic feet per second (ft^3/s) on April 8, 2019 (fig. 2). During 2018 and 2019, flows were generally above 2,000 ft^3/s from mid-April until late May, then decreased steadily during June to about 1,000 ft^3/s where they remained through July.

Fish Tagging and Release

A total of 272 steelhead and 250 coho salmon were tagged and released in 2018 (tables 2, 3). Steelhead tagging occurred during April 18–June 8, 2018 and coho salmon tagging occurred during May 9–11, 2018. Fork lengths ranged from 133 to 229 mm for steelhead and from 90 to 133 mm for coho salmon during 2018. A total of 340 steelhead and 150 coho salmon were tagged and released in 2019 (tables 2, 3). Steelhead tagging occurred during April 17–June 13, 2019 and coho salmon tagging occurred during May 3–4, 2019. Fork lengths ranged from 136 to 257 mm for steelhead and from 99 to 136 mm for coho salmon during 2019.

Evaluation of Transmitter Operating Life

The median operating life of transmitters in 2018 was 35.4 days and the maximum operating life was 42.2 days based on results of our laboratory evaluation of transmitter operating life (fig. 3). In 2019, the median operating life of Model SS300 transmitters was 41.0 days and the maximum operating life was 50.0 days (fig. 3). The median operating life of Model SS400 transmitters was 66.0 days and the maximum operating life was 76.2 days (fig. 3) in 2019. There were no mortalities or shed transmitters during transmitter evaluation studies in either year.

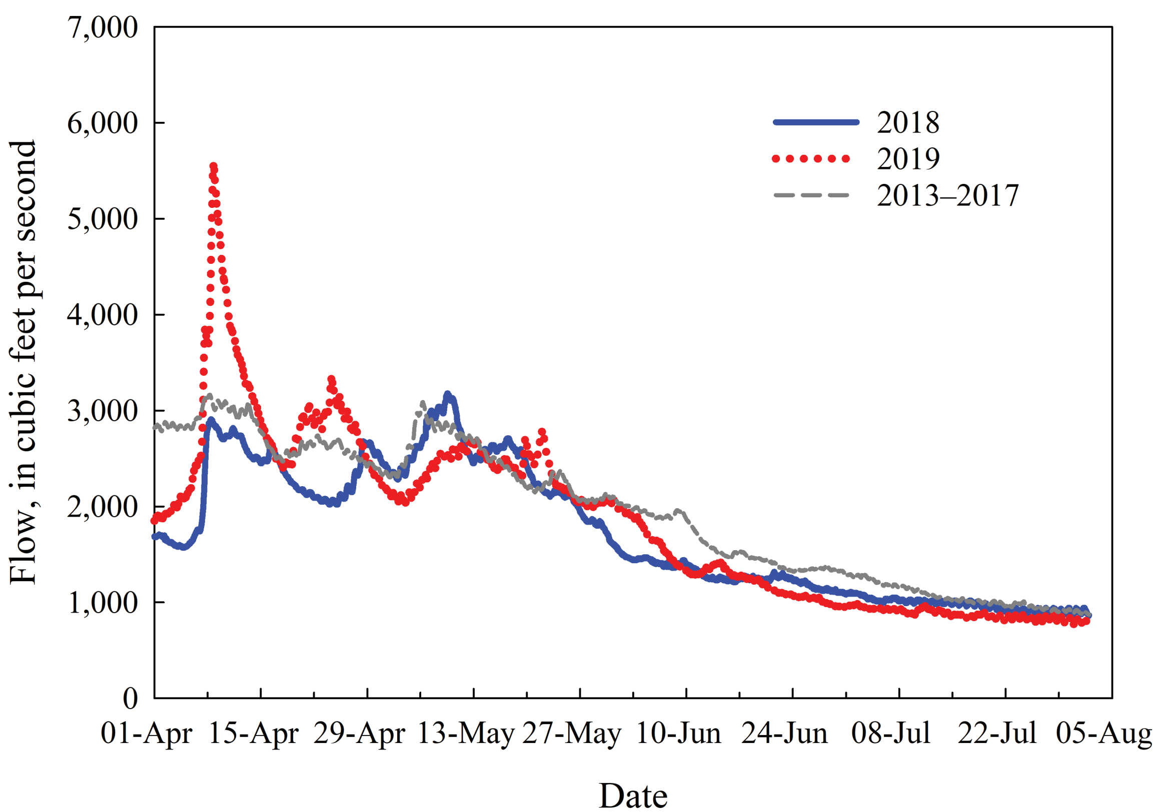

Figure 2. Klickitat River discharge comparison by years at Pitt, Washington, April–August 2013–2019. Data in this graph are daily means for river discharge.

Table 2. Number and fork length range of juvenile steelhead (*Oncorhynchus mykiss*) that were acoustic-tagged and released weekly in the Klickitat River, Washington, April–June 2018–2019.

Species	Release date	Number of fish	Fork length range (millimeters)
Steelhead	April 18, 2018	26	138–215
Steelhead	April 25, 2018	49	143–225
Steelhead	May 2, 2018	41	133–229
Steelhead	May 16, 2018	21	145–215
Steelhead	May 24, 2018	50	152–212
Steelhead	June 1, 2018	53	159–219
Steelhead	June 7, 2018	19	168–210
Steelhead	June 8, 2018	13	156–209
2018 total		272	133–229
Steelhead	April 17, 2019	36	136–225
Steelhead	April 24, 2018	50	146–257
Steelhead	May 8, 2019	53	144–205
Steelhead	May 15, 2019	53	138–208
Steelhead	May 22, 2019	53	146–216
Steelhead	May 30, 2019	27	158–226
Steelhead	May 31, 2019	15	151–251
Steelhead	June 5, 2019	9	160–193
Steelhead	June 6, 2019	11	156–213
Steelhead	June 7, 2019	16	151–210
Steelhead	June 8, 2019	13	155–209
Steelhead	June 13, 2019	4	155–192
2019 total		340	136–257

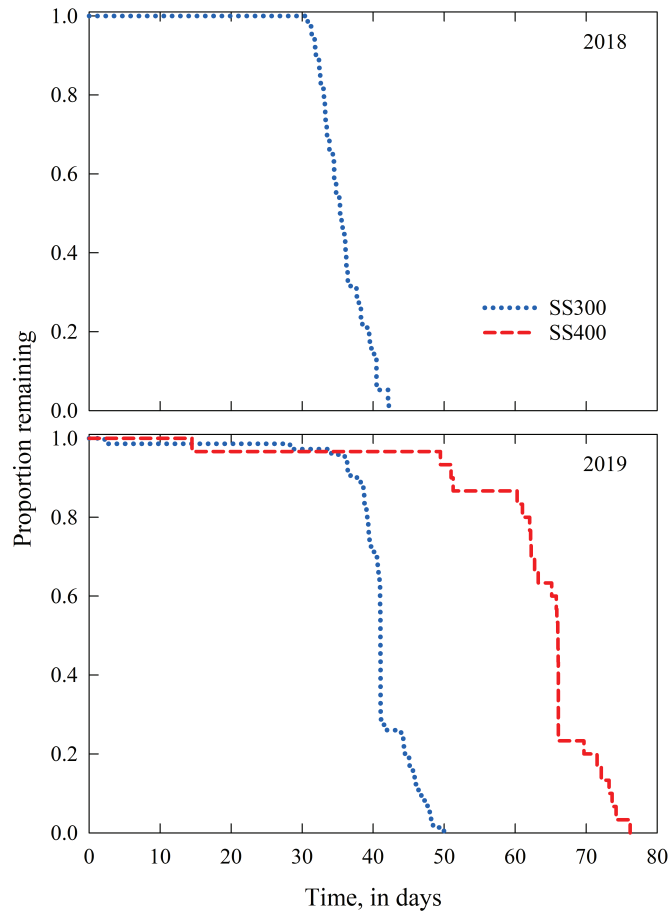

Figure 3. Proportion of operating acoustic transmitters over time (in days) based on laboratory evaluation of transmitter models used in juvenile steelhead (*Oncorhynchus mykiss*; SS300; blue dotted line) and juvenile coho salmon (*O. kisutch*; SS300; blue dotted line in 2018 and SS400; red dashed line in 2019) in the Klickitat River, Washington, 2018–2019.

Table 3. Number and fork length range of juvenile coho salmon (*Oncorhynchus kisutch*) that were acoustic-tagged and released in the Klickitat River, Washington, May 2018 and 2019.

Species	Release date	Number of fish	Fork length range (millimeters)
Coho salmon	May 9, 2018	84	90–133
Coho salmon	May 10, 2018	83	95–127
Coho salmon	May 11, 2018	83	91–131
2018 total		250	90–133
Coho salmon	May 3, 2019	84	99–136
Coho salmon	May 4, 2019	66	99–130
2019 total		150	99–136

Travel Time and Migration Rate

Many tagged steelhead and coho salmon migrated quickly downstream and left the Klickitat River within days of release, but some coho salmon had extended residence time in the river (fig. 4). The median travel time for steelhead from release at Pitt Bridge to first detection at the Highway 14 Bridge (mouth of the Klickitat River) was 1.4 days (range = 0.3–22.8 days) in 2018 and 1.5 days (range = 0.2–34.5 days) in 2019. The median travel time for coho salmon from release at the Klickitat Hatchery to first detection at the Highway 14 Bridge was 5.1 days (range = 0.7–29.2 days) in 2018 and 12.9 days (range = 0.7–45.5 days) in 2019. Ten percent of the tagged coho salmon in 2018 remained in the Klickitat River for 21.9–29.2 days before entering the Columbia River. In 2019, ten percent of the tagged coho salmon remained in the Klickitat River for 36.0–45.5 days before entering the Columbia River. Reach-specific migration rates were slowest in the reach where steelhead were released and in the KRD reach (fig. 5). Reach-specific migration rates for coho salmon were more variable than for steelhead but coho salmon also moved slowly in the reach where they were released and in the KRD (fig. 6). For additional information on reach-specific travel times, see tables 1.1, 1.2.

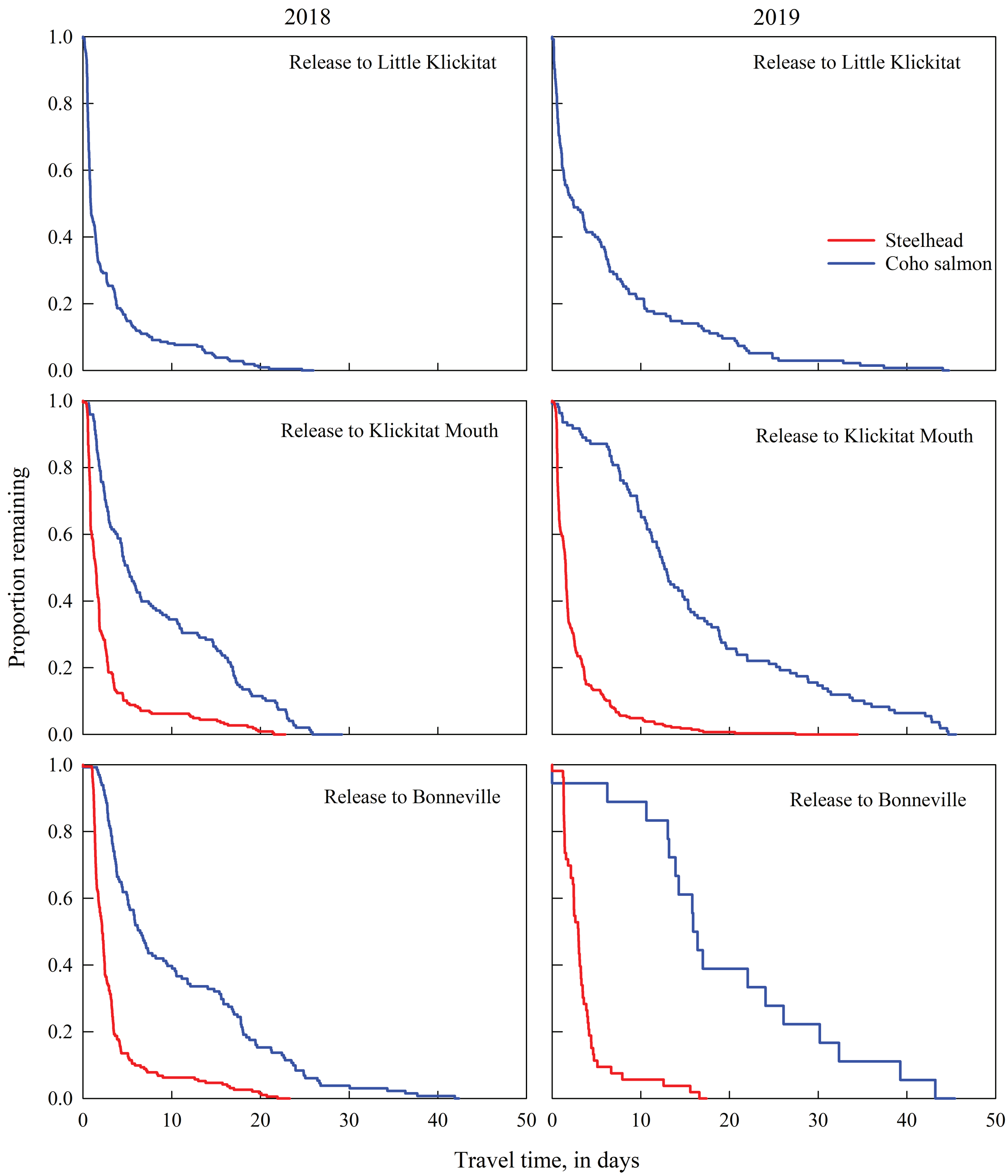

Figure 4. Travel time distributions for tagged steelhead and coho salmon (*Oncorhynchus kisutch*) to three locations in the study area: the Little Klickitat River mouth (upper plots; coho salmon only), the Klickitat River mouth (middle plots), and Bonneville Dam (bottom plots), 2018–2019. Travel times for steelhead were calculated from the time of release at rkm 16.9 in the Klickitat River. Travel times for coho salmon were calculated from the time of last detection in the hatchery holding pond at rkm 68.6.

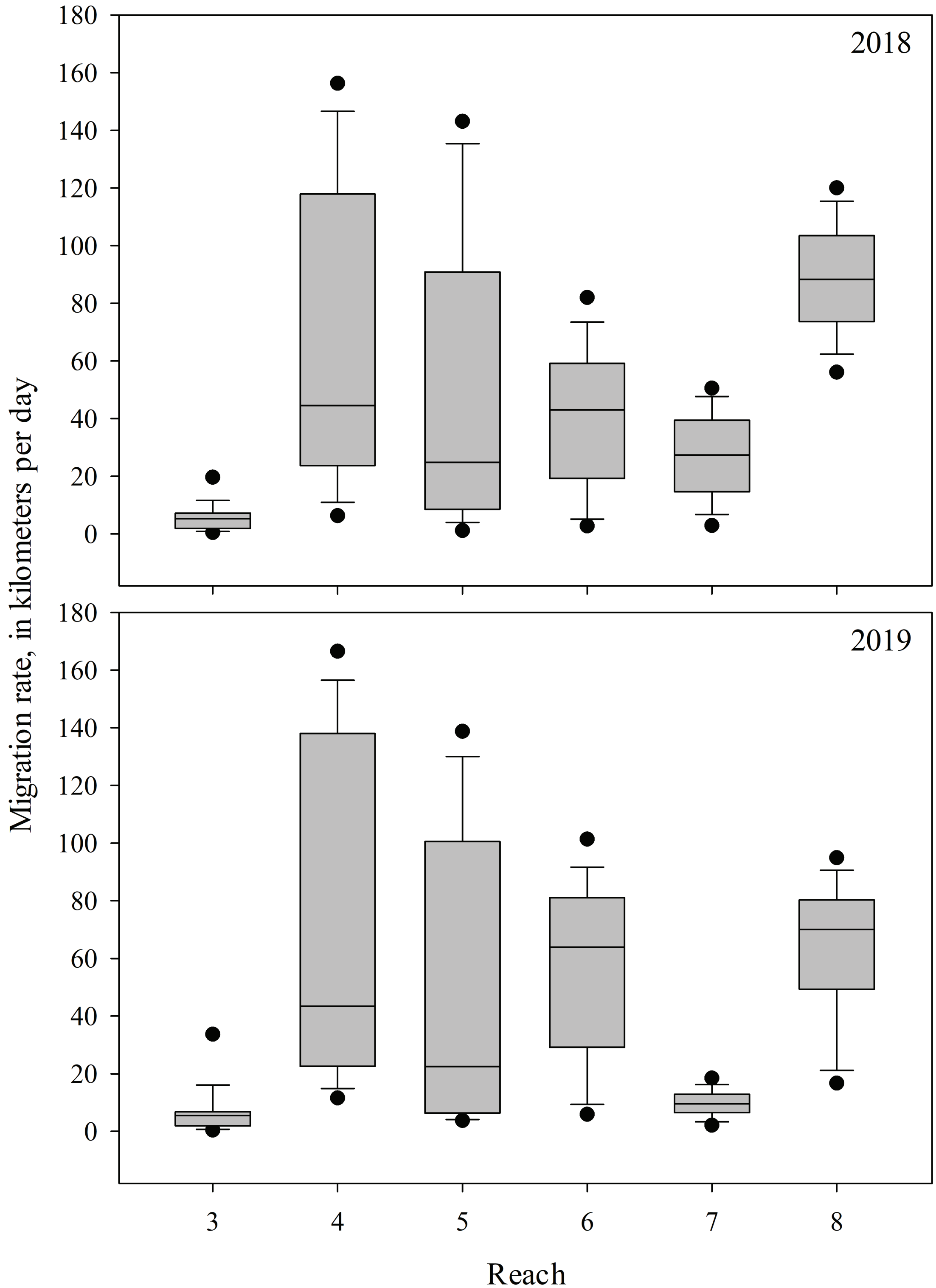

Figure 5. Reach-specific migration rates for juvenile steelhead (*Oncorhynchus mykiss*) in the Klickitat and Columbia rivers, 2018–2019. Black lines within boxes represent the median, boxes represent the 1st and 3rd quartiles, and whiskers represent minima and maxima (determined by quartile ±1.5 × interquartile range). Black circles represent 5th/95th percentile outliers determined by points outside the whisker range.

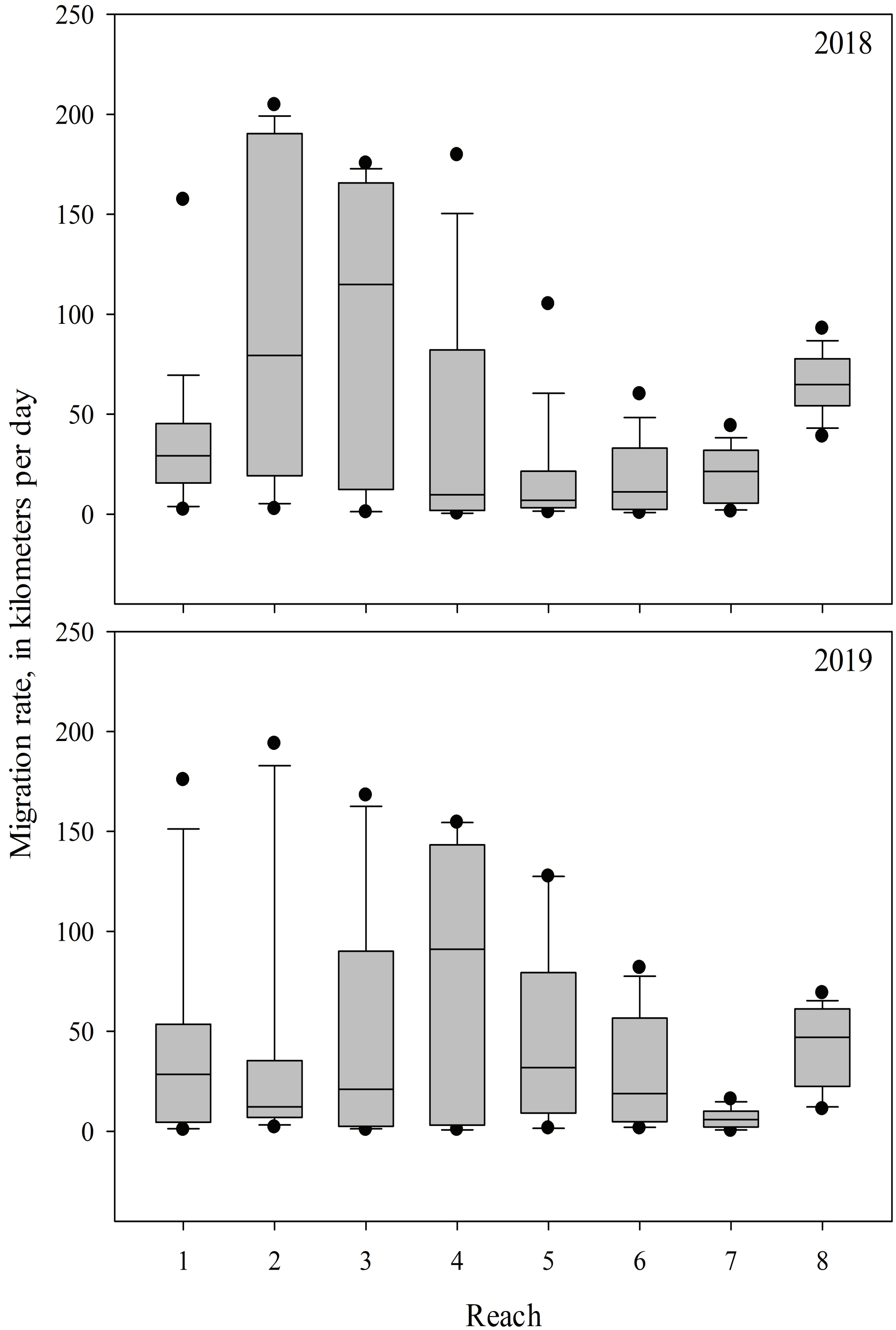

Figure 6. Box plot showing the reach-specific migration rates for juvenile coho salmon (*Oncorhynchus kisutch*) in the Klickitat and Columbia rivers, 2018–2019. Black lines within boxes represent the median, boxes represent the 1st and 3rd quartiles, and whiskers represent minima and maxima (determined by quartile ±1.5 × interquartile range). Black circles represent 5th/95th percentile outliers determined by points outside the whisker range.

Fish Movement through Klickitat River delta (KRD)

Several tagged fish were detected moving upstream in the KRD during the study, which could be indicative of predation by piscivorous fish species because most of these fish were never detected downstream of the KRD afterwards. In 2018, 24 steelhead and 10 coho salmon were detected moving upstream in the KRD, between sites located at the Highway 14 Bridge and county park, and the delta exit and Highway 14 Bridge (for some fish, both reaches). Many of these fish made multiple upstream trips between these sites. None of the steelhead and only three of the coho salmon that exhibited upstream movements within the KRD were subsequently detected at Bonneville Dam in 2018. In 2019, three steelhead and four coho salmon were detected moving upstream in the KRD, between the Highway 14 Bridge and county park. Only one coho salmon was eventually detected downstream of the KRD (at Memaloose Island).

Fish Survival

Reach-specific apparent survival in 2018 ranged from 0.92 to 1.00 for steelhead and from 0.81 to 1.00 for coho salmon (fig. 7; table 1.3). In 2019, reach-specific survival ranged from 0.91 to 1.00 for steelhead and from 0.83 to 1.00 for coho salmon (fig. 7; table 1.3). Survival was lowest in reach 5 (screw trap to county park) for steelhead in both study years (0.90 in 2018 and 0.91 in 2019) and for coho salmon in 2018 (0.81). In 2019, reach-specific survival for coho salmon was lowest in reach 7 (0.83). Cumulative survival from release to the Delta exit was 0.78 for steelhead and 0.57 for coho salmon in 2018 (fig. 8). Cumulative survival from release to Memaloose Island was 0.78 for steelhead and 0.61 for coho salmon in 2019 (fig. 8). Survival per 100 rkm in reaches 3–7 (reaches that both species traveled through) for steelhead was 0.24 and 0.30 in 2018 and 2019, respectively. For coho salmon, survival per 100 rkm in reaches 3–7 was 0.10 in 2018 and 0.15 in 2019. Survival per 100 rkm in reaches 1–7 for coho salmon was 0.45 in 2018 and 0.51 in 2019 (table 4).

PIT Detections at Bonneville Dam and in the Columbia River Estuary

In 2018, 23 steelhead and 14 coho salmon were detected on PIT antennas at Bonneville Dam, and five steelhead and no coho salmon were detected in the PIT estuary trawl. Additionally, fourteen PIT tags from study fish (seven steelhead, seven coho salmon) were recovered on East Sand Island. In 2019, 45 steelhead and 14 coho salmon were detected on PIT antennas at Bonneville Dam and eight steelhead and four coho salmon were detected in the PIT estuary trawl. PIT tags from seven steelhead tagged during this study were recovered from East Sand Island.

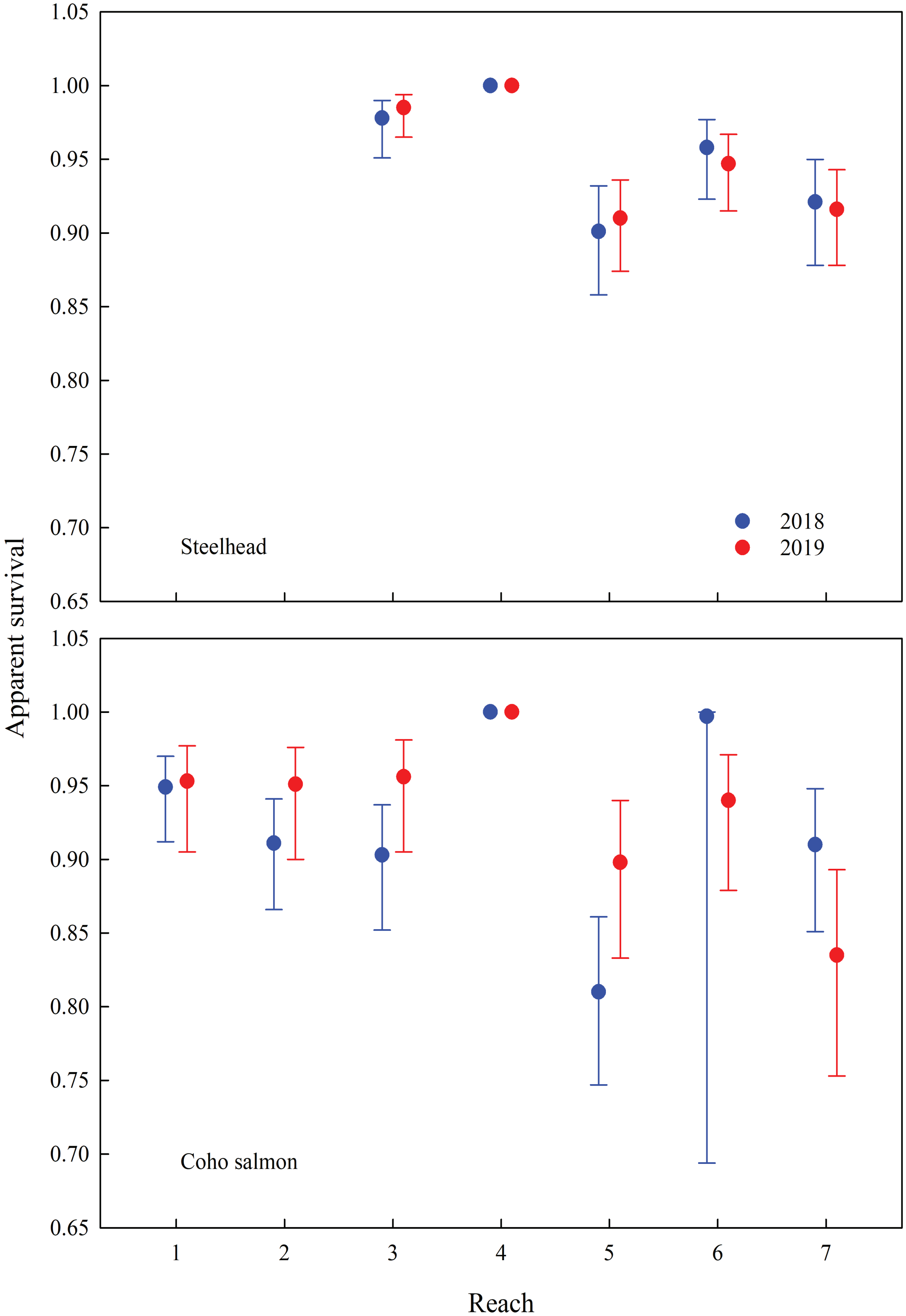

Figure 7. Apparent survival, by reach, for juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) in the Klickitat River, 2018–2019. Whiskers represent minima and maxima (determined by quartile ±1.5 × interquartile range).

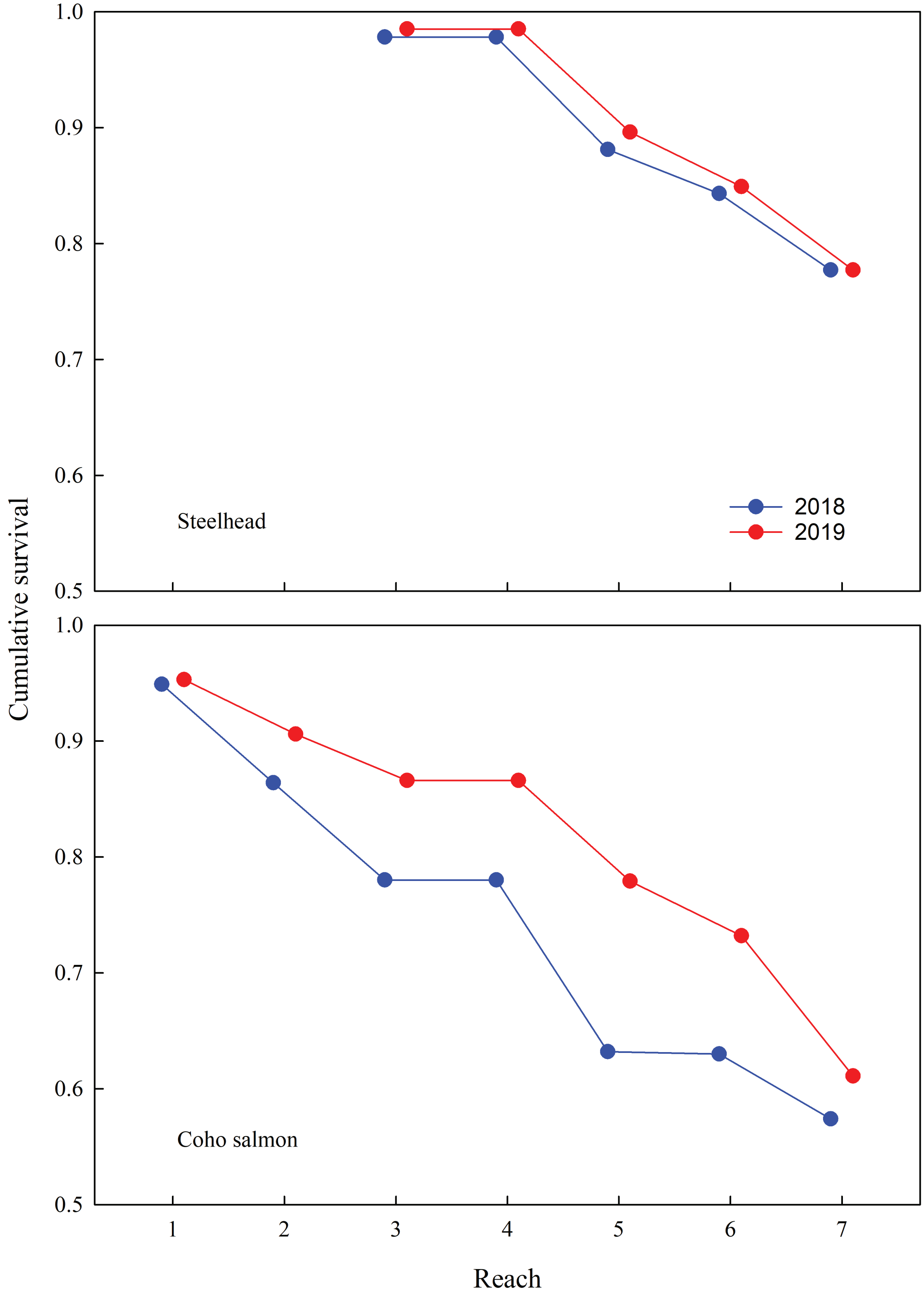

Figure 8. Cumulative survival, by reach, for juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) in the Klickitat River, 2018–2019.

Table 4. Standardized survival estimates (survival per 100 river kilometers [rkm]) for natural-origin juvenile steelhead (*Oncorhynchus mykiss*) and hatchery-origin coho salmon (*O. kisutch*) acoustic-tagged and released in the Klickitat River, 2018–2019.

[Survival per 100 rkm reaches 1-7 could not be calculated for steelhead because steelhead encountered only reaches 3-7. NA, not applicable]

Species	Year	Survival per 100 rkm reaches 1–7	Survival per 100 rkm reaches 3–7
Steelhead	2018	NA	0.243
Coho salmon	2018	0.453	0.100
Steelhead	2019	NA	0.302
Coho salmon	2019	0.511	0.153

Discussion

This study provided new information and insights regarding outmigration behavior and survival of juvenile salmonids in the Klickitat River. We found that migration rates and survival were generally highest in free-flowing reaches of the river and declined near the KRD. Downstream movement rates were relatively high (and variable) in reaches upstream and downstream of the KRD, but migration rates were consistently slow when tagged fish encountered the KRD. Although we documented this behavior, the mechanism driving the behavior remains unclear. Several studies have shown that juvenile salmon alter their migration behavior when encountering river confluences and transitions between free-flowing and backwater areas created by dams, and these behavior changes have been attributed to factors such as water temperature, water velocity, and turbulence (Tiffan and others, 2009a; Tiffan and others, 2009b; Holbrook and others, 2011). In the KRD, outmigrants encounter conditions which differ substantially from those in free-flowing sections of the Klickitat River. Water velocity and turbulence decreases substantially due to backwater effects of the impounded Columbia River. Additionally, water depths are shallow in parts of the lower section of the KRD, because of a large sediment flat located at the Klickitat River mouth. Thus, potential mechanisms for the reduced migration rates include lack of orientation signals resulting from reduced velocity and turbulence, or a behavioral response to shallow water conditions where fish feel vulnerable to predation. The KRD supports piscivorous predator populations, so juvenile steelhead and salmon that delay in the reach are increasingly vulnerable because migration delays have been shown to increase exposure to predators in other locations (Rieman and others, 1991; Blackwell and Krohn, 1997; Venditti and others, 2000). Although other possible explanations for the upstream movements by tagged fish in the KRD exist (predation by river otters (*Lontra canadensis*), residualization, and increased rearing time), we believe the behavior is likely due to predation by piscivorous fish that occurred within the reach. If this is true, predation is an important factor influencing outmigration survival of juvenile steelhead and salmon near the mouth of the Klickitat River.

Mortality rates of juvenile steelhead and coho salmon outmigrating from the Klickitat River appear to be abnormally high compared to results from studies in other rivers in Washington, Oregon, Idaho, and California. Standardized survival estimates were lower than estimates from most studies in other rivers in the region. Standardized survival estimates (survival per 100 rkm) ranged from 0.100 to 0.302 for juvenile steelhead and coho salmon, based on survival estimated through reaches 3–7 in the study area. These estimates are substantially lower than estimates from studies previously conducted throughout the Pacific Northwest that ranged from 0.443 to 0.904 (table 5). Simpson (2019; 2020) did find that juvenile steelhead survival was low (0.007–0.021) in studies conducted on the lower Hood River, Oregon. The low survival observed during our study was unexpected because a large portion of the migration corridor we monitored was the free-flowing Klickitat River, whereas other studies were conducted in rivers where dams are present, flows are tightly regulated, predation and disease have been well documented, and water quality concerns are present (Rieman and others, 1991; Schaller and others, 1999; Williams and others, 2001; Bartholow, 2005; Perry and others, 2010; Quiñones and others, 2014; Robinson and others, 2020). One possible explanation for the higher survival in some of these other rivers is that some of the rivers were larger and the subsequent greater water volume may have provided those fish more safety from predators.

Survival estimates from this study did not include mortality that occurred as fish moved through the lower portion of the Bonneville Pool, passed Bonneville Dam, and migrated through the lower Columbia River. Several PIT tags from juvenile steelhead and coho salmon tagged during the study were recovered on islands located at the Columbia River mouth. These islands are known nesting areas for avian predators (Evans and others, 2012), which confirms that additional mortality was experienced by study fish during outmigration. Additional research would be useful to better understand the magnitude of mortality that occurs during outmigration for juvenile salmon and steelhead from the Klickitat River.

Table 5. Standardized survival estimates (survival per 100 river kilometers) for hatchery-origin juvenile salmonids from various studies conducted on rivers in Washington, Oregon, Idaho, and California, 1993–2016.

Source	Species	Location	Study years	Survival per 100 rkm
Beeman and others, 2012	Coho salmon (*Oncorhynchus kisutch*)	Klamath River, California	2006–2009	0.725–0.854
Beeman and others, 2009	Coho salmon	Trinity and Klamath rivers, California	2008	0.639–0.721
Hand and others, 2014	Chinook salmon (*O. tshawytscha*)	Deschutes River, Oregon	2014	0.773
Kock and others, 2015	Chinook salmon	North Santiam, Santiam and Willamette Rivers, Oregon	2014	0.534–0.634
Perry and others, 2010	Chinook salmon	Sacramento River, California	2006–2007	0.443–0.564
Williams and others, 2005	Chinook salmon	Snake River, Idaho/Washington	1993–2003	0.794–0.904
Kock and others, 2016	Chinook salmon	Yakima River, Washington	2016	0.573–0.836
Kock and others, 2016	Coho salmon	Yakima River, Washington	2016	0.592–0.806

A secondary objective of this study was to describe residence time of hatchery-origin juvenile coho salmon in the Klickitat River following release at the Klickitat Hatchery. If hatchery-reared fish spend a substantial amount of time in the Klickitat River, they could have a negative effect on natural-origin juvenile salmon and steelhead by competing for space and resources. We found that coho salmon had median residence times (elapsed time from last detection at the Klickitat Hatchery to first detection at the Klickitat River mouth) of 5 days in 2018 and 13 days in 2019. In addition, a portion of the tagged coho salmon released from the Klickitat Hatchery spent 29–46 days in the Klickitat River before entering the Columbia River during the two-year study. The difference in residence time between study years may have been influenced by river flow or the time that fish exited the hatchery holding pond and entered the Klickitat River, but a multi-year study would be required to fully understand delay by hatchery-reared fish. These results show that some hatchery-origin coho salmon move quickly downstream and out of the Klickitat River while others spend several weeks before leaving. Several million hatchery-origin Chinook salmon, coho salmon and steelhead are annually released in the Klickitat River so extended residence time by even a small portion of these groups has potential implications for natural-origin juveniles rearing in the system. Future studies evaluating residence time, habitat use, and overlap between hatchery-origin and natural-origin juveniles may be required to better understand these dynamics.

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Appendix 1. Travel Time, Survival, and Detection Probability Tables

Table 1.1. Travel time in days through each study reach of the Klickitat and Columbia rivers for juvenile steelhead (*Oncorhynchus mykiss*), 2018–2019.

[*n*, sample size]

Reach	*n*	Median (days)
	2018	
3	262	0.53 (0.04–22.68)
4	105	0.22 (0.06–18.22)
5	92	0.13 (0.02–20.55)
6	226	0.02 (0.01–1.51)
7	206	0.04 (0.02–1.22)
8	190	0.59 (0.35–8.50)
	2019	
3	332	0.51 (0.04–33.71)
4	43	0.23 (0.06–7.83)
5	32	0.15 (0.02–0.90)
6	285	0.02 (0.01–0.54)
7	262	0.10 (0.05–1.65)
8	53	0.75 (0.53–5.13)

Table 1.2. Travel time in days through each study reach of the Klickitat and Columbia rivers for juvenile coho salmon (*Oncorhynchus kisutch*), 2018–2019.

[*n*, sample size]

Reach	*n*	Median (days)
	2108	
1	230	0.60 (0.08–23.81)
2	209	0.14 (0.09–20.81)
3	180	0.13 (0.10–24.6)
4	59	1.00 (0.05–28.03)
5	44	0.47 (0.03–9.68)
6	149	0.09 (0.01–14.79)
7	132	0.05 (0.02–7.81)
8	123	0.81 (0.50–16.53)
	2019	
1	142	0.60 (0.09–33.91)
2	135	0.46 (0.09–44.55)
3	128	1.87 (0.10–31.03)
4	7	0.11 (0.06–13.75)
5	6	0.15 (0.03–2.18)
6	109	0.05 (0.01–15.52)
7	91	0.17 (0.06–4.79)
8	18	1.11 (0.76–4.72)

Table 1.3. Apparent survival through each study reach of the Klickitat and Columbia Rivers for juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*), 2018–2019.

[95 percent confidence interval shown in parentheses]

Reach	Estimate
2018	
Steelhead	
Release to 2.8 km downstream of Pitt Bridge	0.98 (0.95–0.99)
2.8 km downstream of Pitt Bridge to screw trap	1.00 (1.00–1.00)
Screw trap to county park	0.90 (0.86–0.93)
County park to Highway 14 Bridge	0.96 (0.92–0.98)
Highway 14 Bridge to delta exit	0.92 (0.88–0.95)
Coho Salmon	
Hatchery to Leidl Campground	0.95 (0.91–0.97)
Leidl Campground to Little Klick. R. mouth	0.91 (0.87–0.94)
Little Klick. R. mouth to 2.8 km downstream of Pitt Bridge	0.90 (0.85–0.94)
2.8 km downstream of Pitt Bridge to screw trap	1.00 (1.00–1.00)
Screw trap to county park	0.81 (0.75–0.86)
County park to Highway 14 Bridge	1.00 (0.69–1.00)
Highway 14 Bridge to delta exit	0.91 (0.85–0.95)
2019	
Steelhead	
Release to 2.8 km downstream of Pitt Bridge	0.99 (0.96–0.99)
2.8 km downstream of Pitt Bridge to screw trap	1.00 (1.00–1.00)
Screw trap to county park	0.91 (0.87–0.94)
County park to Highway 14 Bridge	0.95 (0.92–0.97)
Highway 14 Bridge to Memaloose Is.	0.92 (0.88–0.94)
Coho salmon	
Hatchery to Leidl Campground	0.95 (0.90–0.98)
Leidl Campground to Little Klick. R. mouth	0.95 (0.90–0.98)
Little Klick. R. mouth to 2.8 km downstream of Pitt Bridge	0.96 (0.90–0.98)
2.8 km downstream of Pitt Bridge to screw trap	1.00 (1.00–1.00)
Screw trap to county park	0.90 (0.83–0.94)
County park to Highway 14 Bridge	0.94 (0.88–0.97)
Highway 14 Bridge to Memaloose Is.	0.83 (0.75–0.89)

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Director, Western Fisheries Research Center
U.S. Geological Survey
6505 NE 65th Street
Seattle, Washington 98115-5016
https://www.usgs.gov/centers/wfrc

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