Prepared in cooperation with Portland General Electric

Monitoring Fish Abundance and Behavior, Using Multi-Beam Acoustic Imaging Sonar, at a Selective Water Withdrawal Structure in Lake Billy Chinook, Deschutes River, Oregon, 2020

Open-File Report 2022–1038

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

Cover. Lake Billy Chinook Selective Water Withdrawal surface structure, looking upstream, Deschutes River, Oregon, June 1, 2020. Photograph by Collin D. Smith, U.S. Geological Survey.

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Acknowledgments

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

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

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
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)
	Area	
hectare (ha)	2.471	acre
	Volume	
liter (L)	0.2642	gallon (gal)
hectare-meter (ha-m)	2,641,720.52	gallon (gal)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)

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

°F = (1.8 × °C) + 32.

Datums

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 the vertical datum.

Abbreviations

ANOVA	analysis of variance
CTWSRO	Confederated Tribes of the Warm Springs Reservation of Oregon
HSD	Tukey's honestly significant difference test
IQR	interquartile range
PGE	Portland General Electric Company
Project	Pelton Round Butte Hydroelectric Project
SWW	Selective Water Withdrawal
USGS	U.S. Geological Survey

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Abstract

Collection of juvenile salmonids at Round Butte Dam is a critical part of the effort to enhance populations of anadromous fish species in the upper Deschutes River because fish that are not collected at the dam may either incur increased mortality during dam passage or remain landlocked and lost to the anadromous fish population. Adaptive resolution imaging sonar systems were used to assess the behavior, abundance, and timing of fish at the entrance to the Selective Water Withdrawal (SWW) intake and fish collection structure located in the forebay of Round Butte Dam during the spring of 2020. The purpose of the SWW is to direct surface currents in the forebay to attract and collect downriver migrating juvenile salmonid smolts (Chinook salmon [*Oncorhynchus tshawytscha*], sockeye salmon [*O. nerka*], and steelhead [*O. mykiss*]) from Lake Billy Chinook and to enable operators of the SWW to withdraw water from surface and benthic elevations in the reservoir to manage downriver water temperatures. The objective of this study was to assess the abundance and behaviors of smolt-size fish (95–300 millimeters) observed near the SWW and to determine if the presence of bull trout (*Salvelinus confluentus;* >350 millimeters), the predominant predator of juvenile salmonids, influenced the behavior of downriver migrants.

Two imaging sonar units were deployed during the spring of 2020 smolt out-migration period. One unit monitored fish movements near the entrances and one unit monitored in one of the collection flumes of the SWW. The imaging sonar technology was informative for assessing abundance and spatial and temporal behaviors of smolt and bull trout-size fish. Smolt and bull trout-size fish were regularly observed near the entrance to and in the collection flume. Increased abundances were observed during the night, with corresponding increased discharge through the SWW, compared to during the day when discharge was reduced. Behavioral differences also were observed at different discharge rates, with smolt-size fish exhibiting more directed movement toward the collector during periods of increased discharge. Additionally, the presence of bull trout-size fish may have affected the behavior of smolt-size fish because a greater percentage of smolt-size fish were observed traveling away from the SWW when bull trout-size fish were present than when bull trout-size fish were absent. Increased counts of bull trout-size fish coincided with the increased abundances of smolt-size fish. Overall, the results indicate that smolt-size fish are more abundant near the entrance and in the flume of the SWW during periods of increased discharge, and bull trout-size fish were present at the SWW and may have affected smolt collection.

Introduction

Portland General Electric Company (PGE) and the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) own and operate the Pelton Round Butte Hydroelectric Project (hereinafter, Project) in central Oregon, which includes a series of three dams in the Deschutes River Canyon (fig. 1). The primary purpose of the Project is hydroelectric power generation, but it also is operated to provide flood-risk management, along with water for instream flows for wildlife and opportunities for recreation. Round Butte Dam is the largest hydroelectric dam in the state of Oregon and is located on the Deschutes River in central Oregon, approximately 16 kilometers southwest of Madras, Oregon. The dam, completed in 1964, impounds Lake Billy Chinook just below the tributary confluences of the Metolius, Deschutes, and Crooked Rivers. A juvenile bypass system, intended for routing anadromous Chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), and steelhead (*O. mykiss*) smolts around the dam, was operated following dam construction. However, low attraction flow and confounding forebay surface currents resulted in minimal collection, and fish-passage operations were terminated in 1966 (Korn and others, 1967; Baker-Jud, 2006). To restore fish passage of juvenile salmonids, PGE and CTWSRO determined that a surface-water collection facility was required as a part of a water-quality improvement and comprehensive fish-passage plan, as

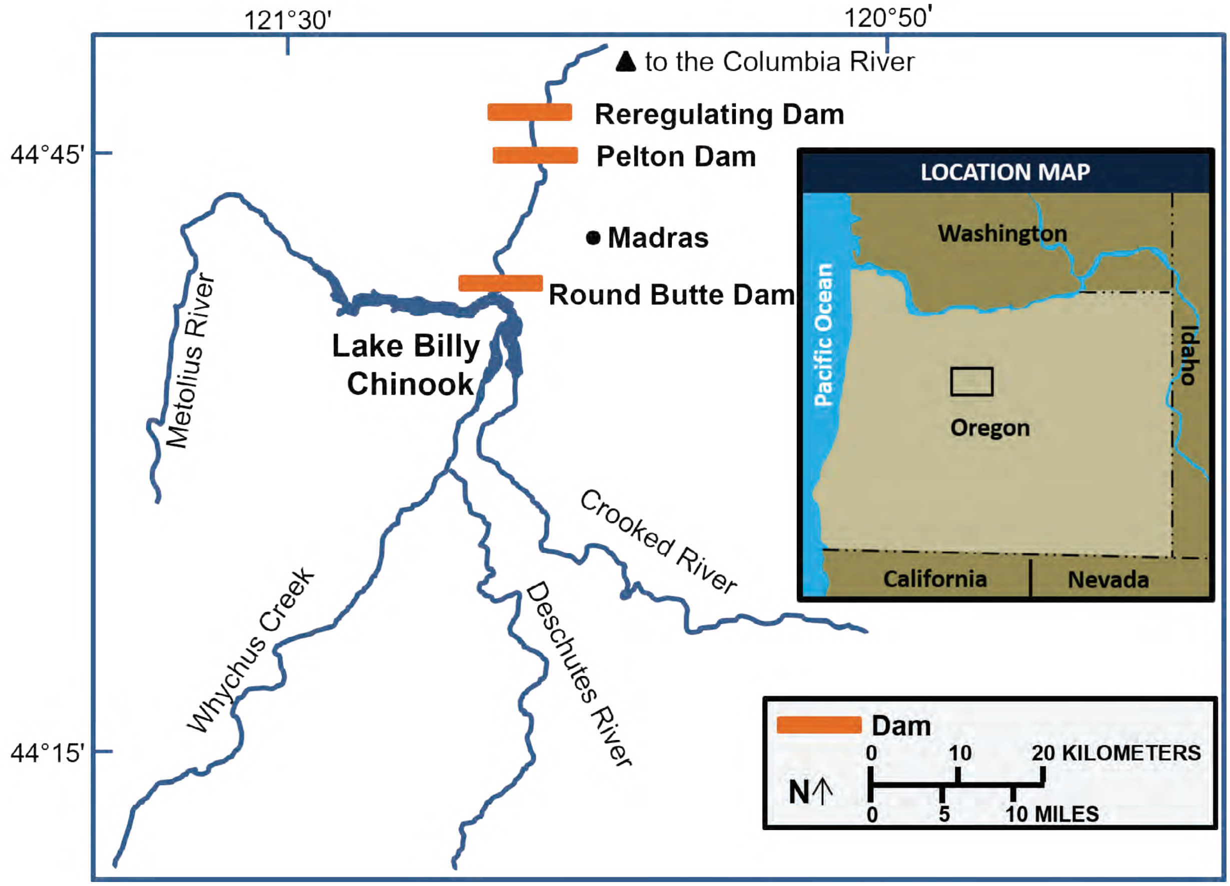

Figure 1. Deschutes River showing Round Butte Dam and Lake Billy Chinook, Oregon.

mandated by the Federal Energy Regulatory Commission for Project relicensing (Portland General Electric Company 2004; Federal Energy Regulatory Commission, 2005). The use of these pre-passage collection devices is preferable, as they offer an alternative to common spillway and turbine routes, which have been associated with elevated mortality rates (Sweeney and others, 2007; Keefer and others, 2013). Previous studies in other reservoirs have reported that surface collection and bypass can be a viable method to improve survival of out-migrating smolts (Sweeney and others, 2007; Adams and others, 2014).

In 2009, a Selective Water Withdrawal (SWW) facility installed in the forebay of Lake Billy Chinook alongside Round Butte Dam began operations. The purpose of the SWW is twofold. First, it directs surface currents in the forebay toward the intake structure and attracts downriver migrating juvenile salmonid smolts (hereinafter, smolts) including Chinook salmon, sockeye salmon, and steelhead into the SWW entrances where they may be collected for subsequent transport around the Project. Second, the SWW enables operators to withdraw reservoir water from surface and benthic elevations from the Lake Billy Chinook forebay to manage water temperatures in the Deschutes River below Round Butte Dam.

The objective of this study was to use imaging sonar to summarize the presence and behavior of juvenile salmonids and predator activity at the SWW during the spring of 2020. Information about fish arrival timing, abundance, movement, and behavior at the SWW during normal operating flow conditions can be used to inform operation decisions about downstream passage alternatives. This information should enable a better characterization of the response of smolts in relation to biological and environmental factors such as fish size, discharge, and the presence of piscivorous fish such as bull trout (*Salvelinus confluentus*). Imaging sonar is capable of recording near-video-quality sonar images in a wide variety of habitats and environmental conditions (Tiffan and others, 2005; Doehring and others, 2011; Able and others, 2014). An advantage of using imaging sonar for behavioral observations of aquatic species is that the images are constructed from data collected from target ensonification, and not from methods requiring visual observation. Therefore, data collection can occur in turbid conditions (Liedtke and others, 2013) without altering fish behavior, or can be used at night without a supplemental light source to investigate diurnal effects, which are an important behavioral factor for migrating salmonids

(Dunbar, 2008; Pavlov and others, 2009). Data collected with the imaging sonar provide information on fish size, movement direction, habitat use, and fish travel speed.

In conjunction with observing smolt behaviors near the SWW, there is a need to assess if the presence of predatory fish negatively affects the number of smolts entering the collection system. Although surface collection systems provide a downstream route of passage, Petersen (1994) confirmed that concentrating and confining juvenile fish in a relatively simplified habitat potentially increases interactions with predatory fish relative to fluvial reaches (Petersen, 1994). Increased interactions could cause smolts to avoid predators near the entrance to surface collectors, potentially hindering the passage efficacy of these devices. Beauchamp and Van Tassell (2001) found that out-migrating smolts experienced a significant predation risk by the abundant resident bull trout population in Lake Billy Chinook. Further, recent dam passage studies near surface collectors have identified avoidance behaviors of smolts in the presence of predators such as bull trout (Adams and Smith, 2017; Smith and others, 2020). Uncertainty regarding these factors creates the need to better understand how predation risk impacts the effectiveness of surface collectors. We used the imaging sonar observations to determine if bull trout-size fish were present near the collector and to determine if they were interacting with smolt-size fish as they approach the entrance. These interactions could deter smolts from entering the SWW and subsequently reduce overall collection efficiency.

The study was designed to provide information for the following objectives:

1. to quantify the spatial and temporal distribution of untagged smolt and bull trout-size fish near the entrances of the SWW,
2. to assess the potential locations of flume rejection (if observed) of smolts under different operating flows in the SWW flume, and
3. to determine the influence of bull trout-size fish on smolt behavior near the entrances of the SWW.

Methods

Study Area

Round Butte Dam is a 134-meter (m) high and 402-m wide, rockfill embankment dam. At the base of the dam is a powerhouse containing three Francis turbine units capable of generating a total of 338 megawatts (fig. 2). During normal operations, all water passing the dam goes through the powerhouse intake located approximately 200 m upstream of the dam. An emergency spillway with a single radial gate is located to the west of the dam but is not used during normal dam operations. The 1,619-hectare (ha) Lake Billy Chinook has a storage capacity of 65,991 hectare-meters (ha-m), and a

Figure 2. Selective Water Withdrawal structure at Round Butte Dam, Oregon. [Photograph by Landsat, U.S. Geological Survey, April 25, 2019.]

useable storage capacity of 33,797 ha-m. The forebay elevation typically fluctuates ±1 m during normal weather and project operations.

The above-water fish collection structure of the SWW (fig. 3) measures approximately 27 × 46 × 18 m and uses water drawn from the surface of the reservoir that is directed to the power intake via a vertical flow conduit with a maximum inflow of 6,992 cubic feet per second (ft^3/s). Discharge herein is presented in ft^3/s according to the local reporting conventions of both the U.S. Geological Survey (USGS) and PGE. In total, the SWW structures is 83 m tall. Fish enter either collector flume (9.6 m wide × 12.2 m deep), subsequently move past dewatering screens, and then pass directly into a pipe that delivers them into the fish transfer facility located alongside the SWW. At the fish transfer facility, fish are sorted by species, and smolts are trucked and released into the Deschutes River downriver of the Project. The SWW collector is near the north shore of the reservoir and over the turbine intake. From March 15 to June 15, 2020, the SWW operates following a nighttime generation protocol whereby operations attempt to maintain a minimum flow of 4,500 ft^3/s from approximately 9 p.m. to 4 a.m. to increase attraction flow during times of active smolt migration. Additional information on SWW operations and performance is available in Pyper and others (2017) and Portland General Electric Company and The Confederated Tribes of the Warm Springs Reservation of Oregon (2015, 2018).

Dam Operations and Environmental Conditions

Project discharge, turbidity, and water temperature data were summarized to document the environmental conditions that fish experienced from March 14 to May 31, 2020. Hourly data were collected and provided by PGE. Water temperature data were collected at a water-quality monitoring station in the forebay, and turbidity measurements were collected from the tailrace. Tributary inflow data were collected at the USGS streamgages on the Deschutes and Crooked rivers near Culver, Oregon, (U.S. Geological Survey, 2020a, 2020b) and the Metolius River near Grandview, Oregon (U.S. Geological Survey, 2020c). Data were summarized using hourly observations, but mean daily values were plotted to increase clarity in the plots.

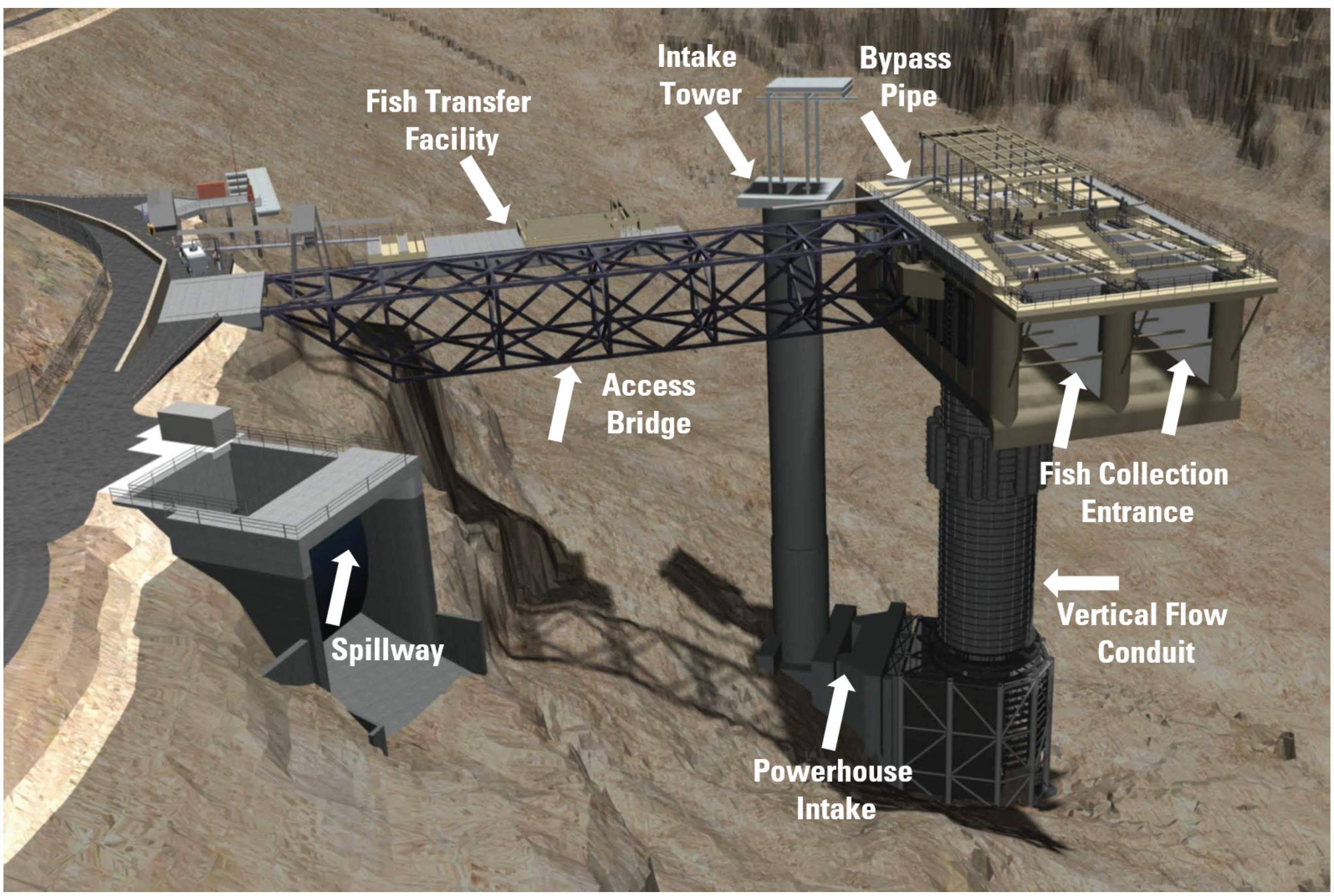

Figure 3. Selective Water Withdrawal tower and surface collector at Round Butte Dam, Lake Billy Chinook, Oregon. [Image courtesy of Portland General Electric; used with permission.]

Imaging Sonar Deployment and Data Processing

Adaptive resolution imaging sonar systems were used to collect data on fish movements upstream and in the north flume of the SWW. The sonars were operated at 1.8 Megahertz, with an operating range of 3–14 m. The sonars were attached to pole-mounted platforms on either of the collector entrances and in the north collection flume. The entrance sonar was deployed 3.5 m below the water surface at the center of the collector and aimed perpendicular (south to north) to monitor the north entrance from March 14 to April 29, 2020 and then north to south to monitor the south entrance from April 30 to May 31, 2020 (fig. 4). The flume sonar was deployed 0.3 m below the water surface at the center of the north flume and aimed toward the entrance to monitor the area between the primary and secondary screens from March 14 to April 29, 2020 and then moved toward the entrance approximately 4.5 m from April 30 to May 31, 2020 (fig. 4).

The imaging sonars collected data continuously at the SWW between March 14 and May 31, 2020, to coincide with the peak outmigration timing of salmonid smolts. Data collection was interrupted only when the sonar was repositioned to maximize fish approach viewing or when equipment malfunctioned. All data collected were stored in hard drives for archival and subsequent processing. Over the duration of the study, 74 dates with complete 24-hour sampling periods were included in the analysis.

Signal processing of the raw acoustic signals collected with the imaging sonar deployed in the flume was done using Echoview software (Echoview, 2014), and the footage of fish observed at the entrance was analyzed using an image recognition and tracking program developed specifically for analyzing sonar images (described below). The Echoview software is a visualization and analysis program for hydroacoustic data. The platform enables the operator to use successive filters to manipulate data to enhance the acoustic signal and remove static objects and noise from acoustic returns (Kang, 2011). Non-stationary acoustic returns are identified as targets in individual video frames and converted to three-dimensional

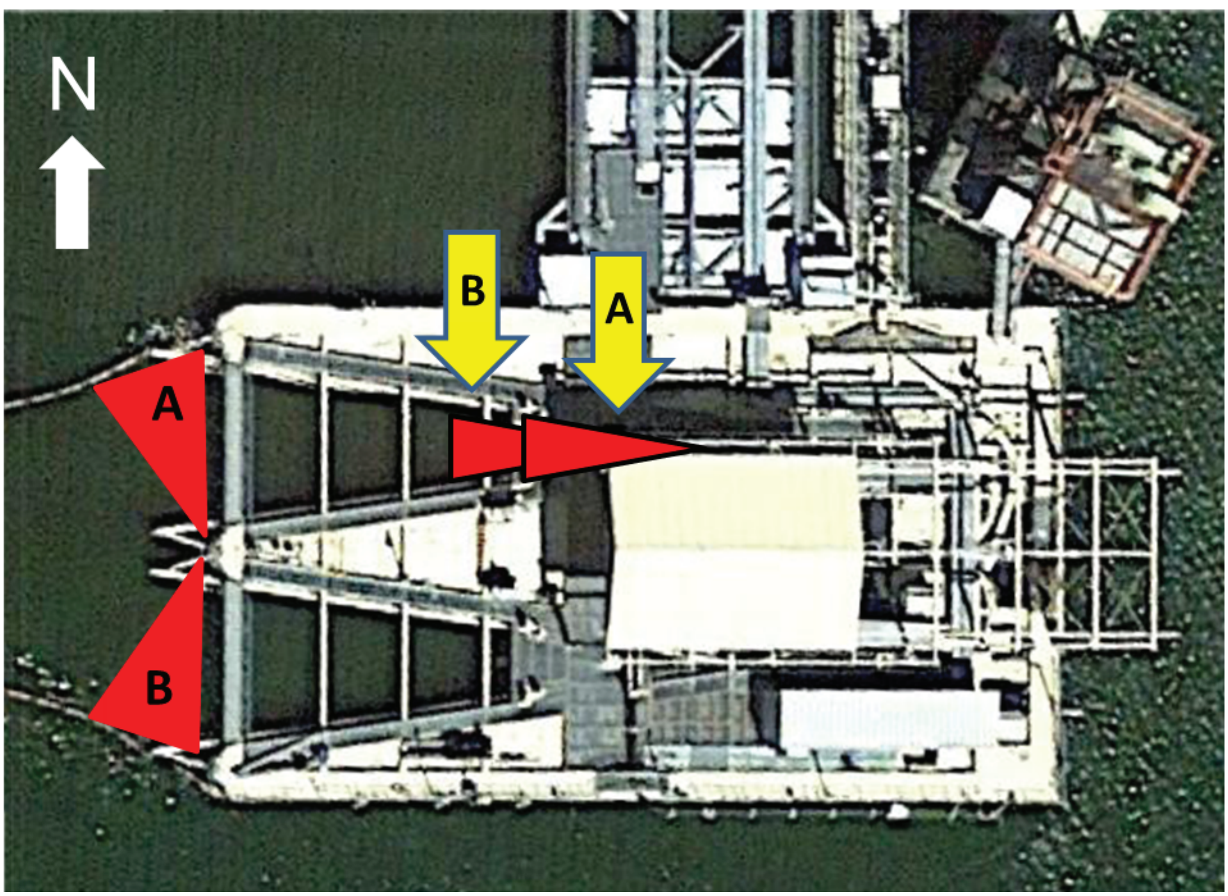

Figure 4. Lake Billy Chinook Selective Water Withdrawal surface collector and approximate coverage areas of the adaptive resolution imaging sonar units (red triangles) in the forebay at Round Butte Dam, Oregon, 2020. Letter "A" denotes deployment locations from March 13 to April 30, and letter "B" denotes deployment locations from May 1 to May 31. Flume deployment locations are identified by arrows. [Photograph by Landsat, U.S. Geological Survey, April 25, 2019.]

position and time data that can then be applied to target tracking, which is used to obtain counts and movements of individual fish along with their associated behavioral and morphometric data (Simmonds and MacLennan, 2005). Unfiltered video footage was observed congruently with tracking of the processed acoustic signals during target tracking to ensure that only fish targets were included in the dataset and target morphometric data was concomitant with target data observed in the video footage. A step-by-step description of the operational procedures used for processing acoustic signals using the Echoview software may be found in Adams and Smith (2017).

The image recognition and tracking programs used for identifying fish targets at the entrances used four types of software to prepare and process the collected acoustic signals. Initially, ARISFish software (Sound Metrics, 2018) removed acoustic noise from the collected files. Files were then parsed to time sequential images using MATLAB software (The Math Works, 2019). Computer vision software, OpenCV (2020) was next used to locate fish target positions in the sequential images. Finally, target tracking algorithms developed in Python (Python Core Team, 2020) were applied to the located targets to determine individual fish behavioral and morphometric data.

Imaging sonar technology cannot distinguish individual fish that have entered and exited the field of view multiple times; therefore, the following analysis assumes that each fish track, not the fish, are independent observations. Additionally, it is not possible to definitively identify the species of fish observed; however, if discrete group sizes are present and identifiable through other methods (in other words, collection), informed inferences of species can be made. Despite these limitations, imaging sonar can be used to collect data that would otherwise be unattainable.

Summary statistics of fish targets derived from signal processing (mean length, direction, speed, and location in beams) were imported into SAS (SAS Institute, 2012), for subsequent proofing and to merge imaging sonar data with the environmental data. Data were proofed to eliminate non-valid records or records that did not provide measurable morphometric or behavioral data. Target datasets were then exported as comma-separated value files for further statistical analysis using R software (R Core Team, 2014).

Fish Size and Count

Fish targets were grouped into three size classes to distinguish between Chinook and sockeye smolt-size fish (95–190 millimeters [mm]), kokanee (lacustrine sockeye salmon *O. nerka,* 190–300 mm), steelhead smolt-size fish (190–300 mm), and adult bull trout (>350 mm). Kokanee, which are “landlocked,” non-migrating sockeye salmon are returned to Lake Billy Chinook, rather than collected and passed downstream below the Project. Observations of kokanee are included in analysis with the smolts hereafter. In addition to fish size, run timing facilitated the approximate species differentiation between kokanee and steelhead with 10 percent overlap in the two species occurring before and after May 1, 2020. Therefore, 190–300-mm fish observed before May 1, 2020 were classified as kokanee, whereas fish of the same size class observed after May 1, 2020 were classified as steelhead. Size classes were determined by observations of fish collected at SWW collection facility. Data for fish 300–350 mm were not included in the analyses, as there is overlap between both large kokanee and steelhead and small bull trout, though observations were rare. Additionally, although salmonid fry (<95 mm) were occasionally observed, data from those observations were not included in this analysis.

Direction of Fish Travel

To summarize the directions of fish traveling near the entrances to the SWW under low discharge (<4,500 ft^3/s) and the target high (>4,500 ft^3/s) discharge conditions, we implemented circular statistics to calculate modes and measures of variability (Mardia and Jupp, 2000) using the `circular` package for R software (R Core Team, 2014). Tests for randomness were performed to determine if the sample population presented either uniform (random) or directed travel paths. If the data conformed to a Von Mises distribution (Zar, 1999; Pewsey and others, 2013), the Rayleigh z test was performed. Data that were multi-modal or did not follow a Von Mises distribution were subjected to the Rao’s spacing test (Batschelet, 1981). If the P-value was significant (at the α = 0.05 level), then it was assumed that the direction of fish travel was non-random.

The influence of discharge rates on the general direction of travel (toward or away from the SWW) of smolt size groups was examined. Discharge rates were binned in 1,000 ft^3/s increments and were based on discharge values recorded at the time of fish observation. A chi-square goodness-of-fit test was performed to determine if the directions of travel were statistically different across discharge rates (Zar, 1999; Agresti, 1996). To determine a measure of effect size for tests of association for nominal variables, a variant of the Cramér's V for goodness-of-fit tests was calculated (Mangiafico, 2016). Cramér's V will vary from 0 to 1, where a value of 0 indicates no variation in category proportions (no effect) and a value of 1 indicates pronounced variation in category proportions (strong effect). Additionally, we used a Chi-square test to determine if the presence of bull trout-size fish significantly influenced the general direction of travel (toward or away from the SWW) of smolts. The presence of bull trout-size fish was defined as the observation of a bull trout-size fish within one minute of an observation of a smolt-size individual. Statistical analyses were done using R software (R Core Team, 2014) with package `rcompanion` for Cramér’s V, and stats used for chi-square tests, with a significance level α = 0.05.

Track Characteristics

Fish-track characteristics were quantified using the travel speed variable obtained from individual fish tracks. Travel speed was calculated as the average travel velocity of each individual target. An analysis of variance (ANOVA) was used to determine the significance of the differences for fish sizes for observations at both the north and south entrances and in the flume. If significant differences were found using ANOVA, an F-test by fish size groups and Tukey's Honestly Significant Difference (HSD) test (Sokal and Rohlf, 1969) were used to locate the pairwise differences in concentrations between groups. Statistical analyses were done using R software (R Core Team, 2014) with a significance level $\alpha = 0.05$.

Evaluating the Fish Track Density near the SWW Entrances

The collected point samples for each individual fish track were used to create two-dimensional density plots of unique fish track locations for the volume sampled. Individual data points were centered using a smooth kernel function at each observation point then summed to get a density estimate using the MASS package for R software (R Core Team, 2014). The magnitude of the point count is defined as the count of unique observations of each individual fish location in each cell. Datasets for each fish size group were used for plotting point location data.

Results

Dam Operations and Environmental Conditions

A combination of upper basin reservoir water storage for irrigation and lower than average rainfall and snowmelt resulted in reduced instream flows on the Deschutes, Crooked, and Metolius rivers during March and early April than are normally experienced during the typical spring seasonal pattern (fig. 5). However, by about mid-April, instream flows returned to near-median flows for the remainder of the observation period. The mean hourly SWW discharge was 2,906 ft^3/s (range 70.4–5,823.6 ft^3/s; fig. 6; table 1). The spillway was not opened during the study and all water passed through the SWW with a peak daily discharge of 3,738.3 ft^3/s occurring on April 9, 2020. The reservoir elevation was maintained at a constant daily elevation of nearly 1,944.5 feet above National Geodetic Vertical Datum of 1929 (NGVD 29) for the entirety of the study with a 1.9-foot fluctuation. During the study, the mean turbidity was 66.4 Nephelometric turbidity units (range 7.3–260.0 Nephelometric turbidity units; table 1; fig. 7). Water temperature generally increased through the study period, peaking at 15.3 degrees Celsius on May 29, 2020, whereas the minimum water temperature of 7.0 degrees Celsius occurred on March 15, 2020 (fig. 7). The SWW operated uninterrupted during the entirety of this study.

Fish Abundance

Data from the imaging sonar indicate that abundances of smolt and bull trout-size fish near the entrance and in the flume of the SWW varied as the migration season progressed (figs. 8–9). Abundance of fish observed on both imaging sonars generally were lowest during early March 2020, then trended upward to a peak abundance of 1,210 fish on May 6, 2020, on the entrance sonar and 381 fish on May 3, 2020, on the flume sonar before decreasing on both sonar units again in late May. Observations were mostly smolt-size fish; however, the daily abundance trends of bull trout-size fish generally corresponded with that of the smolt-size fish.

Flume Rejection Observations

Observations of flume rejection by all three smolt-size fish groups were rare and indicated no clear rejection location. Sixteen Chinook and sockeye smolt-size fish and 3 steelhead smolt-size fish observed reversing direction in the flume sonar view, totaling less than 1 percent of all observations for those size groups. A larger percentage of kokanee-size fish were observed reversing direction (1.8 percent), but only included 22 individuals. Locations for reversal and heading back toward the entrance were spread throughout the entirety of the sonar view.

Direction of Travel

The predominant directions of travel for fish in the acoustic beams differed by entrance and discharge but were generally similar between the fish-size groups (table 2). All fish-size groups observed with the imaging sonar at both the north and south entrances had travel paths that were generally circular (figs. 10–13) with significant (Rao P <0.05) primary directions of travel that were somewhat directed toward the center of the SWW under low discharge conditions (<4,500 ft^3/s). However, when discharge was under the >4,500 ft^3/s condition, the primary vector of travel of all fish size groups were directed more toward either the north or south entrance. Low concentration parameter (κ) values (range 0.99–1.52) for all criteria indicate a reduced concentration of the distribution toward a mean direction.

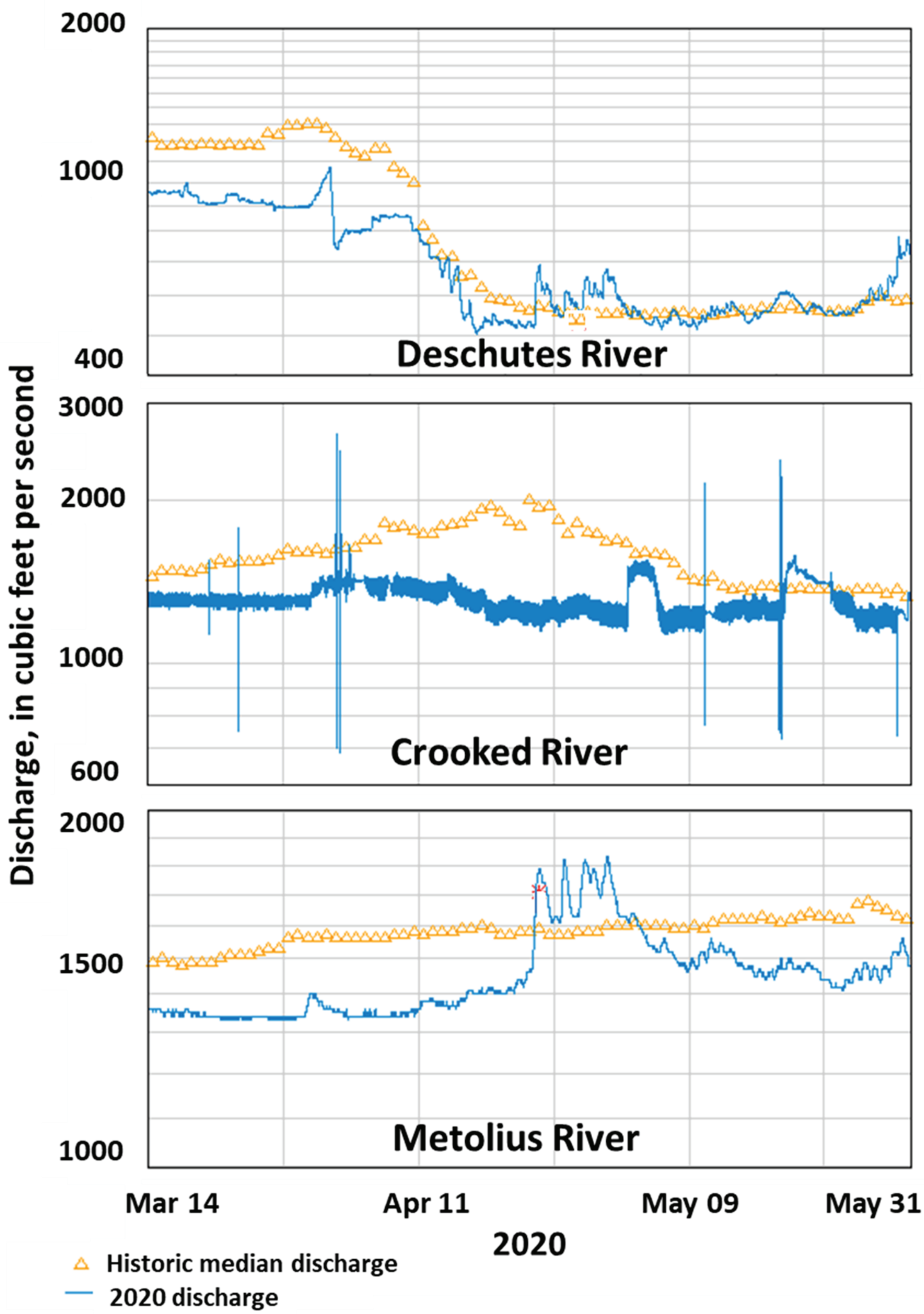

Figure 5. Discharges of Deschutes, Crooked, and Metolius Rivers from U.S. Geological Survey hydrological sites near Lake Billy Chinook, Oregon, March 14–May 31, 2020. Graphs produced from data in U.S. Geological Survey (2020a, 2020b, 2020c).

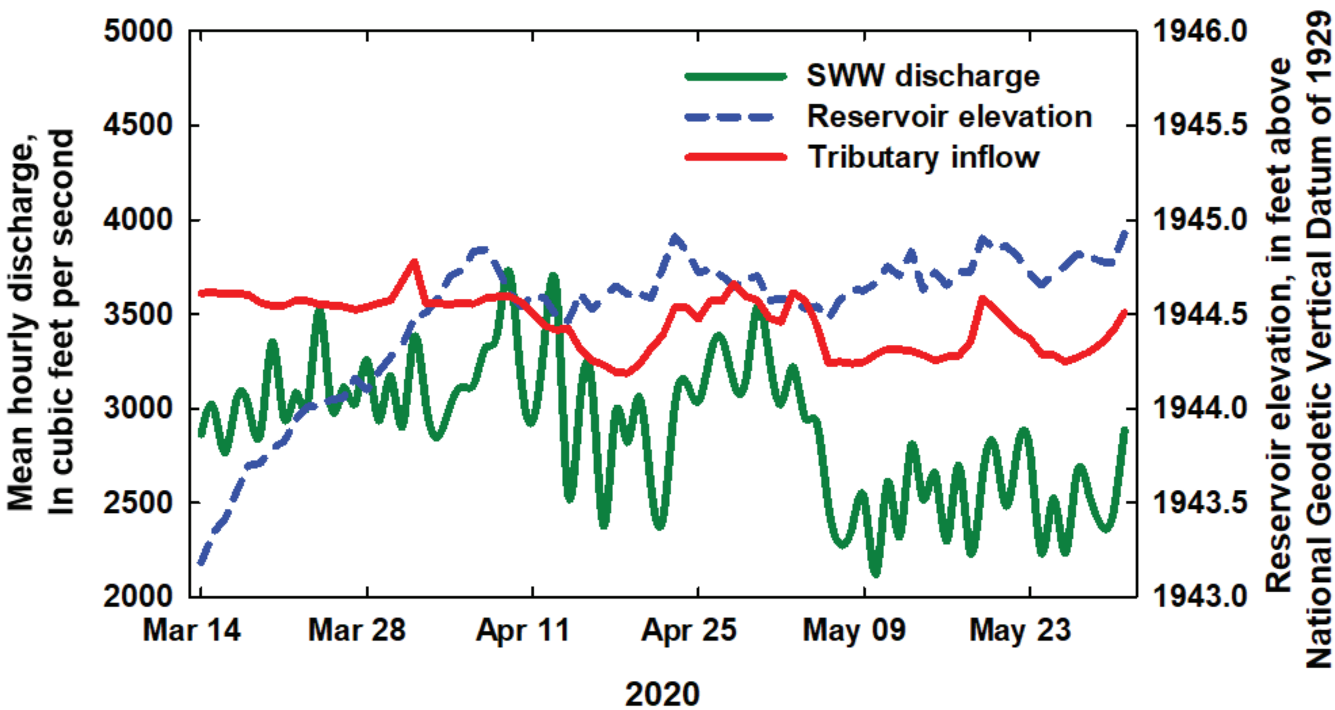

Figure 6. Selective Water Withdrawal (SWW) mean hourly discharge, tributary inflow, and reservoir elevation at Lake Billy Chinook, Oregon, March 14–May 31, 2020.

Table 1. Summary statistics of hourly dam operations and environmental conditions at Round Butte Dam, Oregon, March 14–May 31, 2020.

[**Abbreviations**: SD, standard deviation; ft^3/s, cubic foot per second; NTU, Nephelometric turbidity unit]

Dam operating conditions	Mean	Median	Range	SD
Project discharge (ft^3/s)	2,906.4	2,850.2	70.4–5,823.6	1,295.8
River inflow (ft^3/s)	3,452.4	3,504.4	3,057.9–3,845.0	156.8
Forebay elevation (feet)	1,944.5	1,944.6	1,943.1–1,945.0	0.4
Turbidity (NTU)	66.4	50.5	7.3–260.0	48.6
Water temperature (degrees Celsius)	11.7	12.4	7.0–15.3	2.2

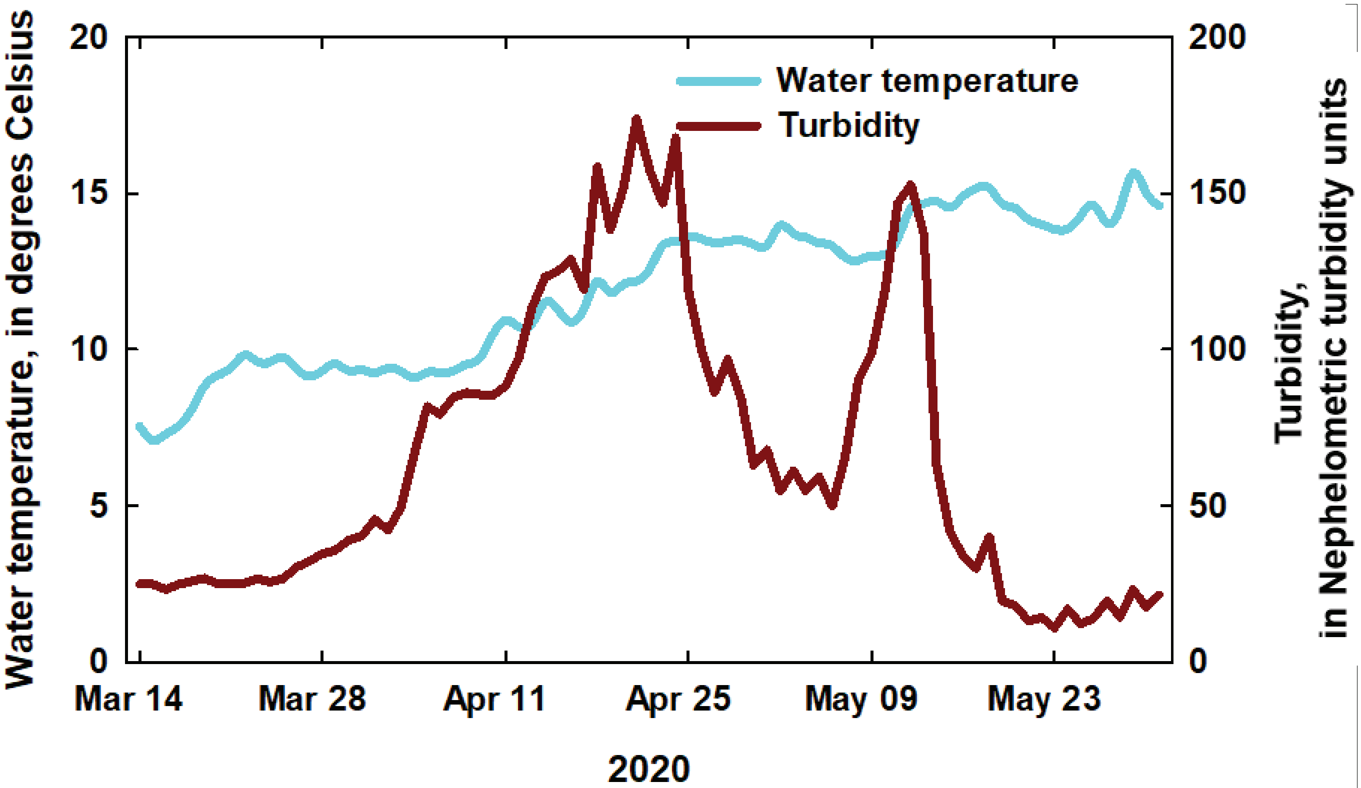

Figure 7. Water temperature and daily turbidity plotted from mean hourly measurements at Round Butte Dam, Oregon, March 14–May 31, 2020.

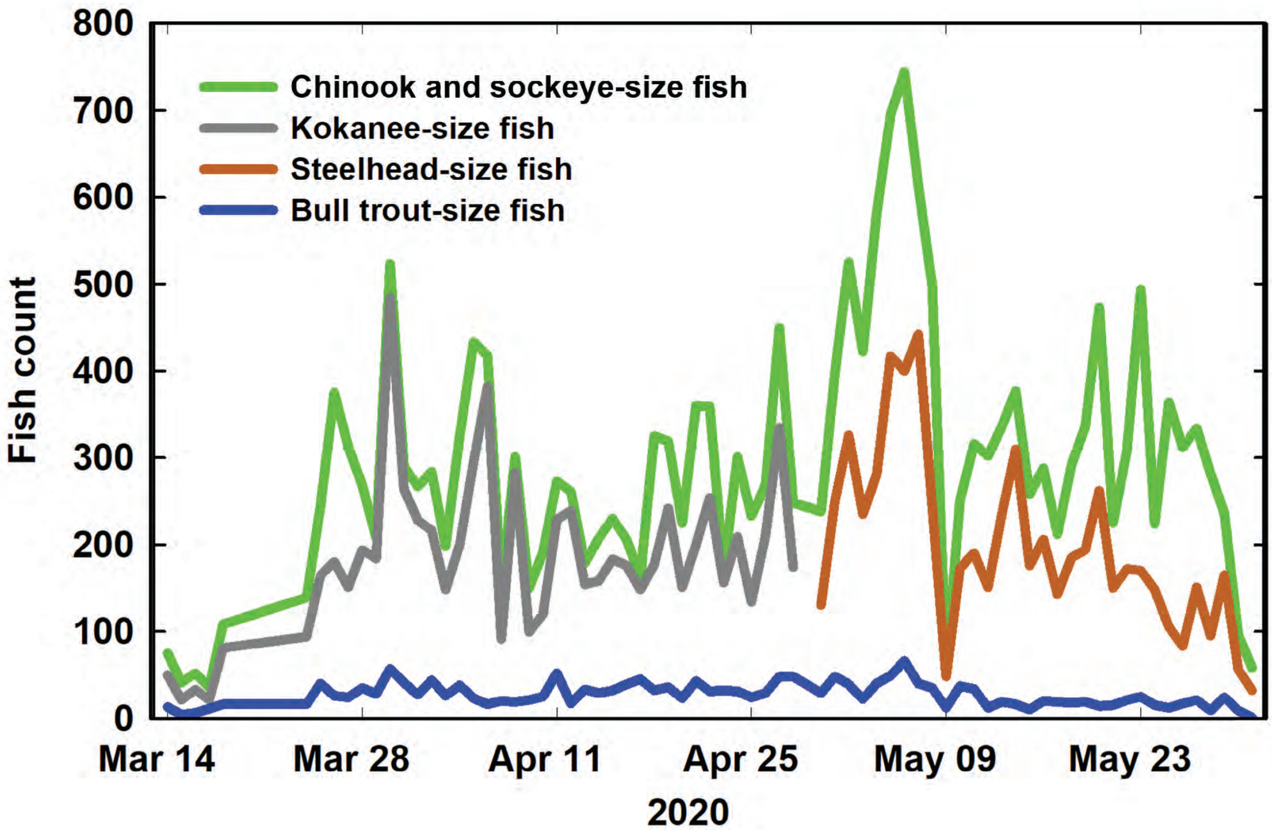

Figure 8. Daily count (on the date of detection) of smolt and bull trout-size fish at the collector entrances using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

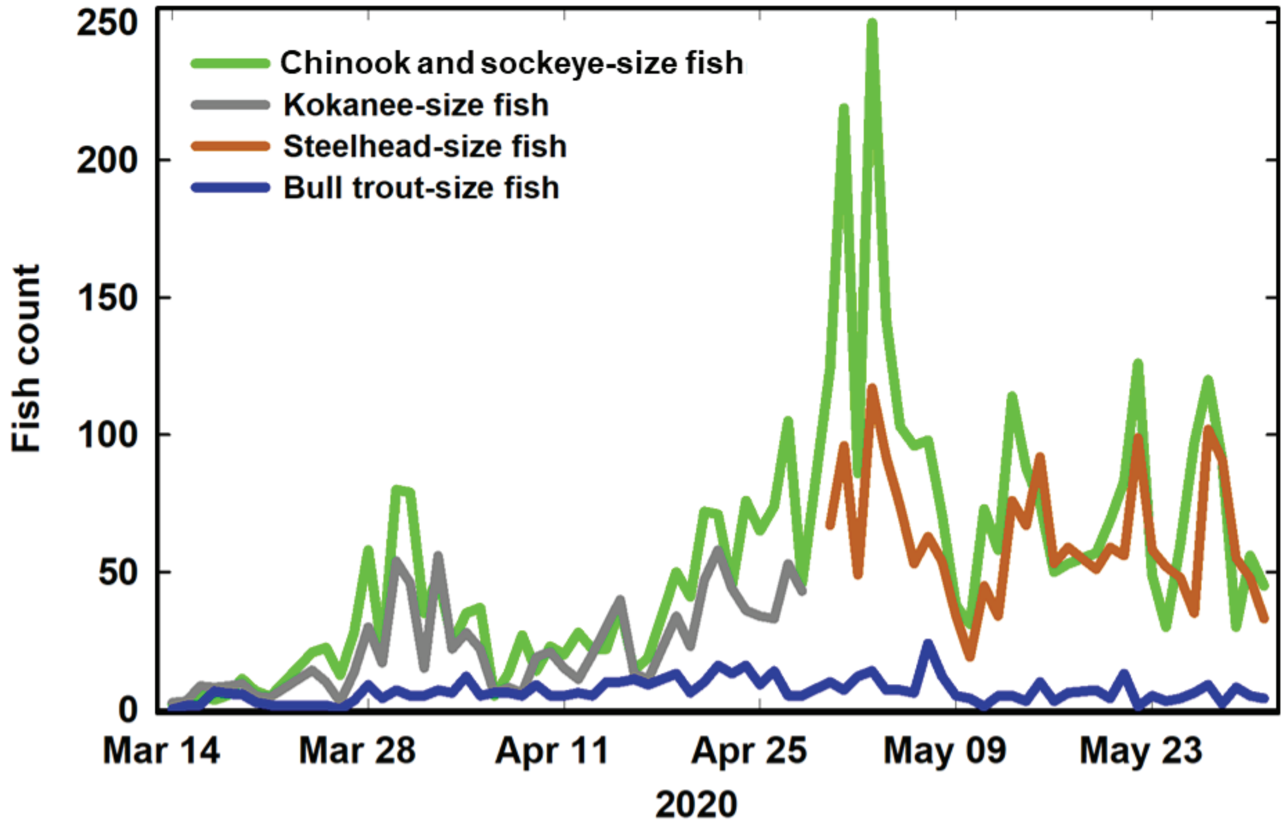

Figure 9. Daily count (on the date of detection) of smolt and bull trout-size fish in the collection flume using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

Table 2. Mean travel directions and concentration parameter for smolt and bull trout-size fish observed using the adaptive resolution imaging sonar at the entrance of the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

[Heading of the imaging sonar is normalized to 0 degrees, with a value of 270 degrees indicating a heading directly toward the SWW. Sample size is the number of fish observation events with the imaging sonar, not necessarily the number of individual fish, because a given fish could be observed more than once. **Abbreviations and symbols**: mm, millimeters; ft³/s, cubic feet per second; *N*, sample size; μ, mean travel direction (in degrees) of the fish; SE, standard error; κ, concentration parameter; <, less than; >, greater than]

Fish group (mm)	Discharge (ft³/s)	*N*	μ (SE)	κ (SE)
North entrance				
Chinook and sockeye (95–190)	<4,500	9,225	235.6 (0.8)	1.08 (0.02)
	>4,500	936	256.1 (2.3)	1.25 (0.06)
Kokanee (190–300)	<4,500	6,861	224.3 (0.8)	1.33 (0.02)
	>4,500	652	248.0 (3.0)	1.16 (0.07)
Bull trout (> 350)	<4,500	1,128	224.2 (2.0)	1.31 (0.06)
	>4,500	72	248.6 (7.1)	1.52 (0.24)
South entrance				
Chinook and sockeye (95–190)	<4,500	8,121	328.6 (1.0)	0.99 (0.02)
	>4,500	3,022	311.4 (1.2)	1.36 (0.04)
Steelhead (190–300)	<4,500	4,769	321.3 (1.2)	1.01 (0.02)
	>4,500	1,556	303.4 (1.5)	1.52 (0.05)
Bull trout (> 350)	<4,500	662	330.4 (3.3)	1.03 (0.07)
	>4,500	105	305.3 (7.9)	1.06 (0.17)

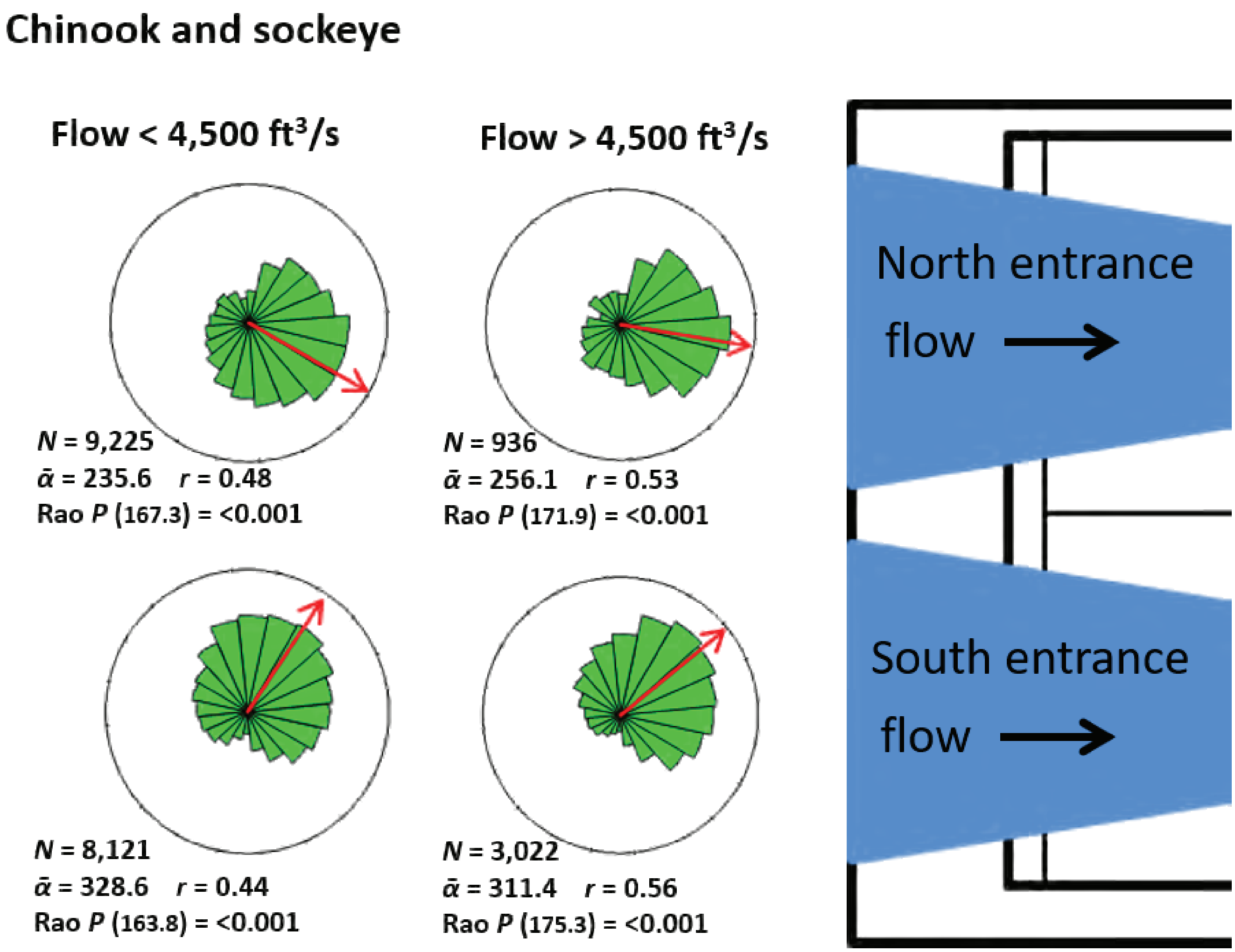

Figure 10. Mean travel directions (in degrees) for Chinook and sockeye smolt-size fish detected using the adaptive resolution imaging sonar at the entrance of the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020. Heading of the imaging sonar is normalized to 0 degrees (top), with a value of 270 degrees signifying a heading directly toward the Selective Water Withdrawal collector. [Sample sizes represent the number of fish (*N*) observed. Mean vectors (ᾱ) are described by arrows. Rao *P* indicates significance level according to the Rao spacing test statistic (in parenthesis). ft^3/s, cubic feet per second; <, less than; >, greater than.]

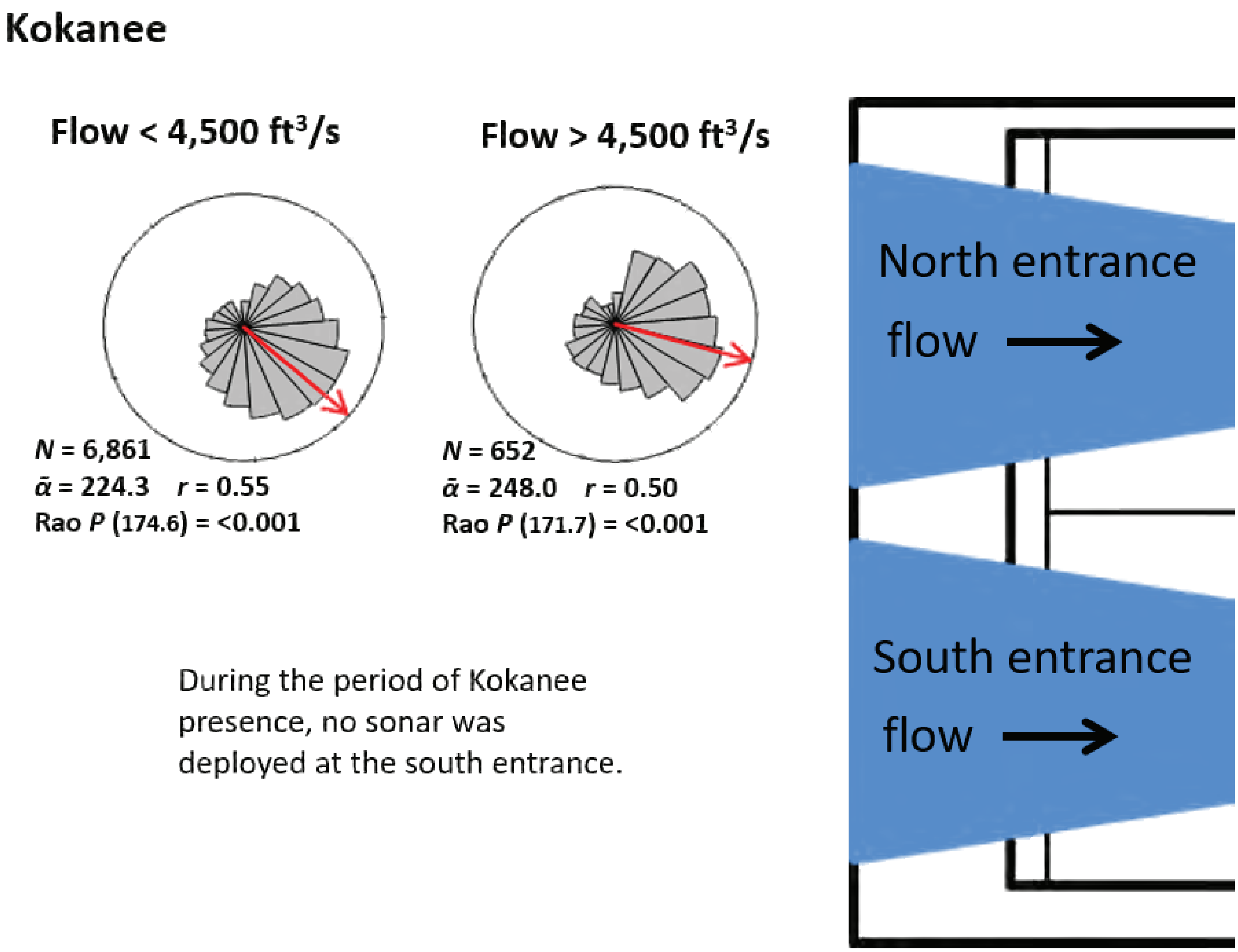

Figure 11. Mean travel directions (in degrees) for kokanee-size fish detected using the adaptive resolution imaging sonar at the entrance of the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020. Heading of the imaging sonar is normalized to 0 degrees (top), with a value of 270 degrees signifying a heading directly toward the Selective Water Withdrawal collector. [Sample sizes represent the number of fish (*N*) observed. Mean vectors ($\bar{\alpha}$) are described by arrows. Rao *P* indicates significance level according to the Rao spacing test statistic (in parenthesis). ft^3/s, cubic feet per second; <, less than; >, greater than.]

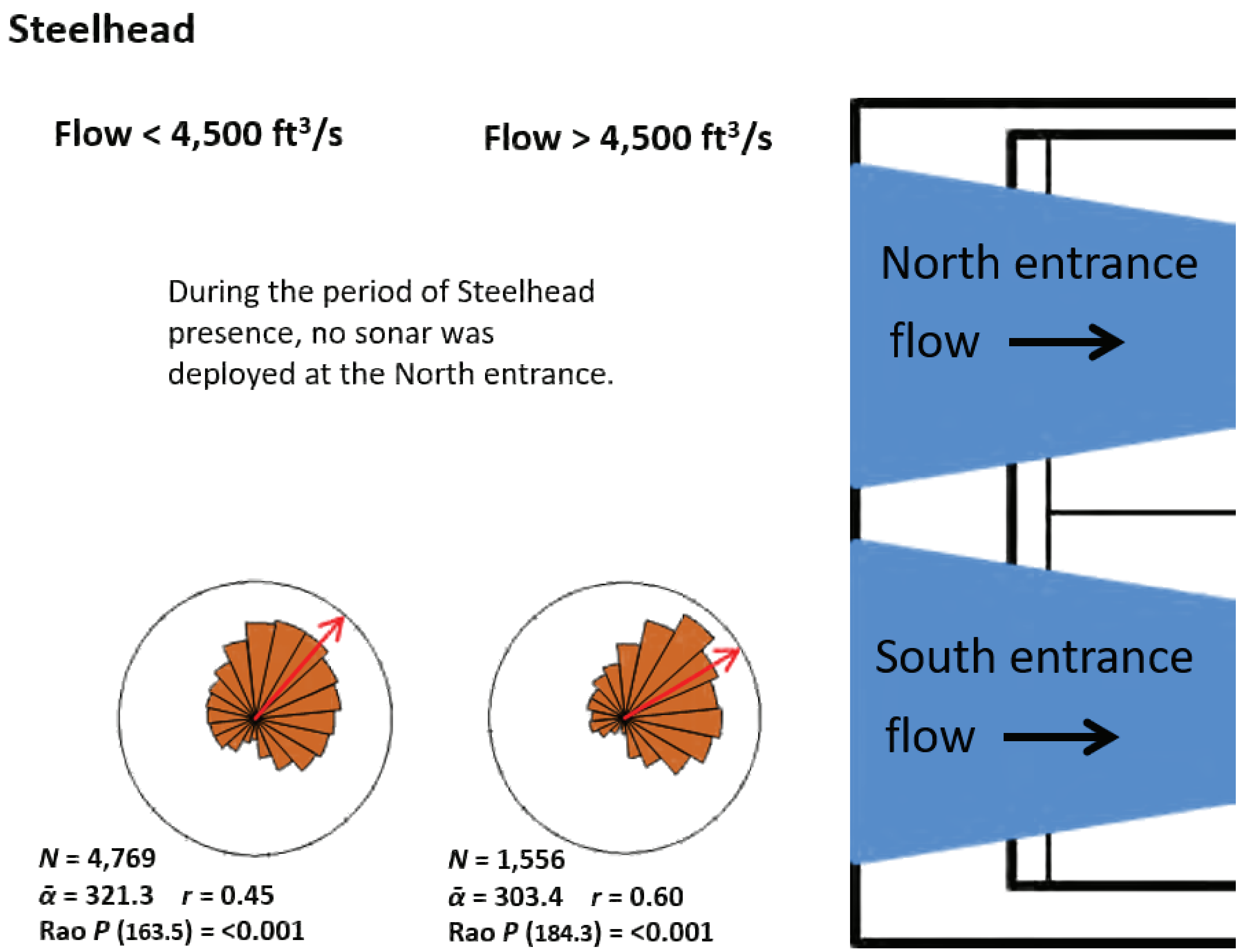

Figure 12. Mean travel directions (in degrees) for steelhead smolt-size fish detected using the adaptive resolution imaging sonar at the entrance of the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020. Heading of the imaging sonar is normalized to 0 degrees (top), with a value of 270 degrees signifying a heading directly toward the Selective Water Withdrawal collector. [Sample sizes represent the number of fish (*N*) observed. Mean vectors ($\bar{\alpha}$) are described by arrows. Rao *P* indicates significance level according to the Rao spacing test statistic (in parenthesis). ft^3/s, cubic feet per second; <, less than; >, greater than.]

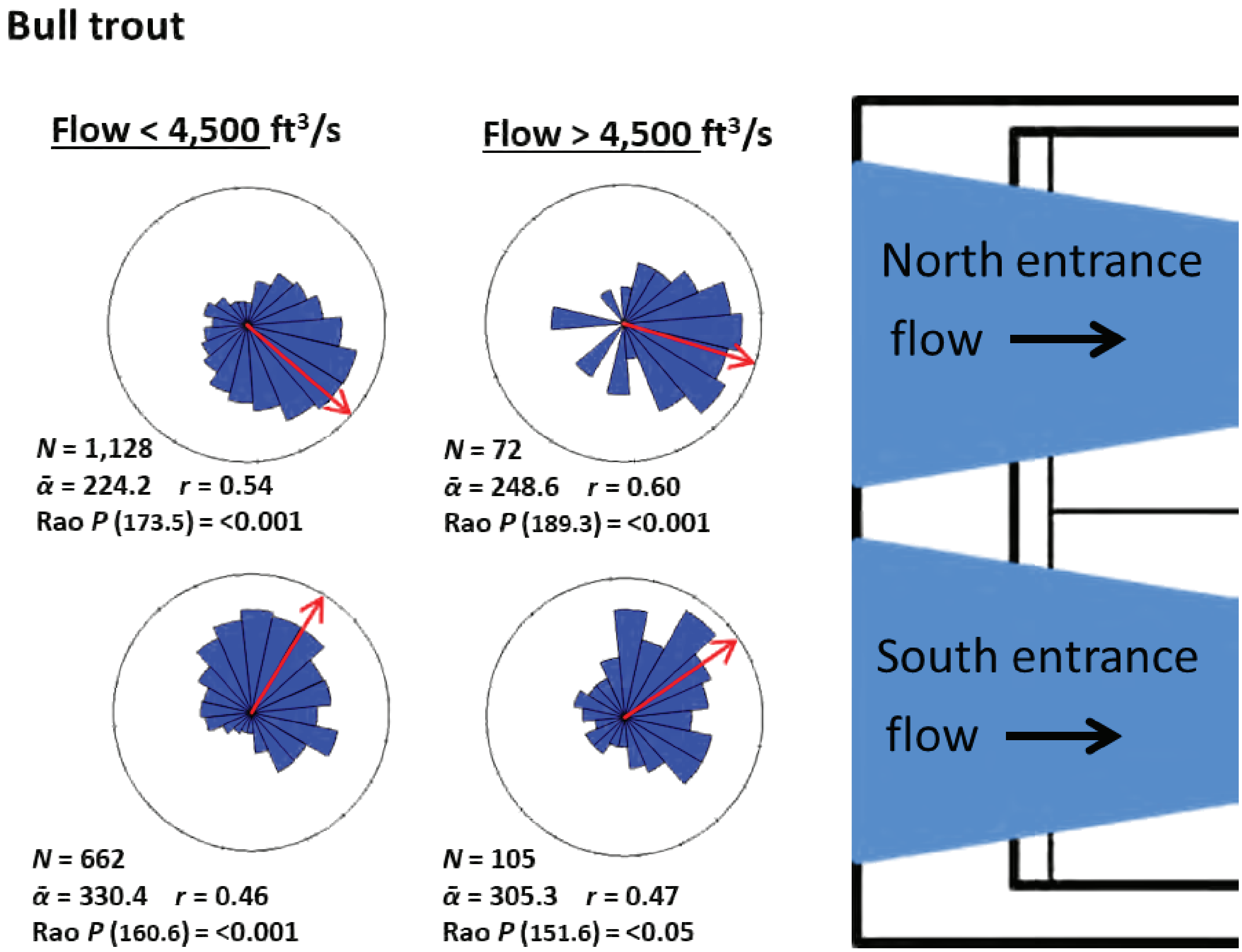

Figure 13. Mean travel directions (in degrees) for bull trout-size fish detected using the adaptive resolution imaging sonar at the entrance of the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020. Heading of the imaging sonar is normalized to 0 degrees (top), with a value of 270 degrees signifying a heading directly toward the Selective Water Withdrawal collector. [Sample sizes represent the number of fish (*N*) observed. Mean vectors ($\bar{\alpha}$) are described by arrows. Rao *P* indicates significance level according to the Rao spacing test statistic (in parenthesis). ft^3/s, cubic feet per second; <, less than; >, greater than.]

The amount of discharge through the SWW influenced the general direction of travel of the three smolt-size fish groups near the entrance to the SWW and in the flume (figs. 14–15). Near the entrances, the general directions of travel (either toward or away) of the Chinook and sockeye smolt-size fish group were near 50 percent when discharge through the SWW was less than 4,000 ft^3/s with no strong effect indicated by Cramér's V (table 3). However, when discharge was greater than 4,000 ft^3/s, the general direction of travel became predominantly toward the entrance, with a moderate effect indicated by Cramér's V. The general directions for kokanee-size fish were similar, however, at discharges between 2,000 and 3,000 ft^3/s a Cramér's V of 0.74 indicate that there was strong effect for travel away from the SWW entrance, and these directional differences were statistically significant (X^2 [1] = 4545.10, P <0.001; table 3). For steelhead smolt-size fish, the general directions of travel at the various discharge rates were like the other two fish size groups, although at the 4,000–5,000 ft^3/s discharge rate, the direction of travel was statistically significantly (X^2 [1] = 37.34, P <0.001) toward the SWW (compared to other discharge rates), but the effect remained low (Cramér's V = 0.12; table 3).

In the flume, the general directions of travel for all fish size groups were significantly toward collection (same direction as flow) under all discharge rates (P <0.05; fig. 15; table 3). The percentage of the Chinook and sockeye smolt-size group directed toward collection was 74 to 91 percent, with the highest rates observed at discharges greater than 4,000 ft^3/s and strong effects indicated by Cramér's V (table 3). The direction of travel for the kokanee-size group was least affected by discharge rates with at least 85 percent of fish traveling toward collection under all discharge rates and strong effects indicated by Cramér's V scores (table 3). The steelhead smolt-size group had the greatest variability for effects of discharge rates on direction with increasing percentages of fish heading toward collection with increasing discharge rates and more moderate Cramér's V scores compared to the other fish size groups (table 3).

The presence of bull trout-size fish also influenced the general direction of travel of the three smolt-size groups near the entrance to the SWW (fig. 16). When bull trout-size fish were absent, 43 percent of the Chinook and sockeye smolt-size fish were traveling away from the entrance of the SWW, whereas 57 percent were traveling toward the SWW. When bull trout-size fish were present, a higher percentage of Chinook and sockeye smolt-size fish were traveling away from the SWW (52 percent) than toward the SWW (48 percent), and the differences were significant (X^2 [1] = 44.0, P <0.0001). For kokanee-size fish, 51 percent of the fish were traveling away from the entrance of the SWW, whereas 49 percent were traveling toward the SWW when bull trout-size fish were absent. When bull trout -size fish were present, a significantly (X^2 [1] = 9.8, P = 0.002) larger percentage of kokanee-size fish were traveling away from the SWW (57 percent) than toward the SWW (43 percent). Similarly, when bull trout-size fish were absent, 48 percent of the steelhead smolt-size fish were traveling away from the entrance of the SWW, whereas 52 percent were traveling toward the SWW. When bull trout-size fish were present, a larger percentage of steelhead smolt-size fish were traveling away from the SWW (57 percent) than toward the SWW (43 percent), with significant (X^2 [1] = 19.6, P <0.0001) differences.

Fish Swimming Velocity

The speed at which fish traveled at the entrances of the SWW differed between the fish-size classes but were similar between the two entrances (table 4; fig. 17). For example, at the north entrance the mean swimming velocity of Chinook and sockeye smolt-size fish was 0.35 meters per second (m/s) (interquartile range [IQR] = 0.11); it was 0.36 m/s (IQR = 0.25) for kokanee-size fish and 0.42 m/s (IQR = 0.27) for bull trout-size fish. These differences in fish swimming speed were significant between fish sizes (ANOVA; $F_{2, 18,874}$ = 70.89, P <0.001) with incremental increases in swimming speed with increasing fish size groups. Results of a post hoc Tukey HSD test indicated that all fish size groups had significantly different swimming speeds from each other (P <0.001). These results are not surprising as larger fish generally exhibit greater swimming abilities (Webb, 1995; Mesa and others, 2004). At the south entrance, the mean swimming velocity of Chinook and sockeye smolt-size fish was 0.34 m/s (IQR = 0.20); it was 0.39 m/s (IQR = 0.26) for steelhead smolt-size fish and 0.42 m/s (IQR = 0.31) for bull trout-size fish. These differences in fish swimming speed also were significant between fish sizes (ANOVA; $F_{2, 18,235}$ = 120.60, P <0.001), with speeds increasing with fish size groups. Results of the post hoc Tukey HSD test indicated that all fish size groups had significantly different swimming speeds from each other (P <0.001).

Fish observed in the flume had greater variability in swimming speeds than fish observed at the entrances with the mean swimming velocity of Chinook and sockeye smolt-size fish at 0.35 m/s (IQR = 0.34), 0.44 m/s (IQR = 0.33) for kokanee-size fish, 0.30 m/s (IQR = 0.25) for steelhead smolt-size fish, and 0.35 m/s (IQR = 0.34) for bull trout-size fish (table 4; fig. 17). These differences in fish swimming speed were significant between fish sizes (ANOVA; $F_{2, 8,136}$ = 68.26, P <0.001) with mean swimming speeds varying irrespective of size groups. Results of the post hoc Tukey HSD test indicated that the swimming speeds of the Chinook and sockeye smolt-size group and the bull trout-size group were not significantly distinguishable from each other (P = 0.99), whereas all other fish size groups had significantly different swimming speeds (P <0.01).

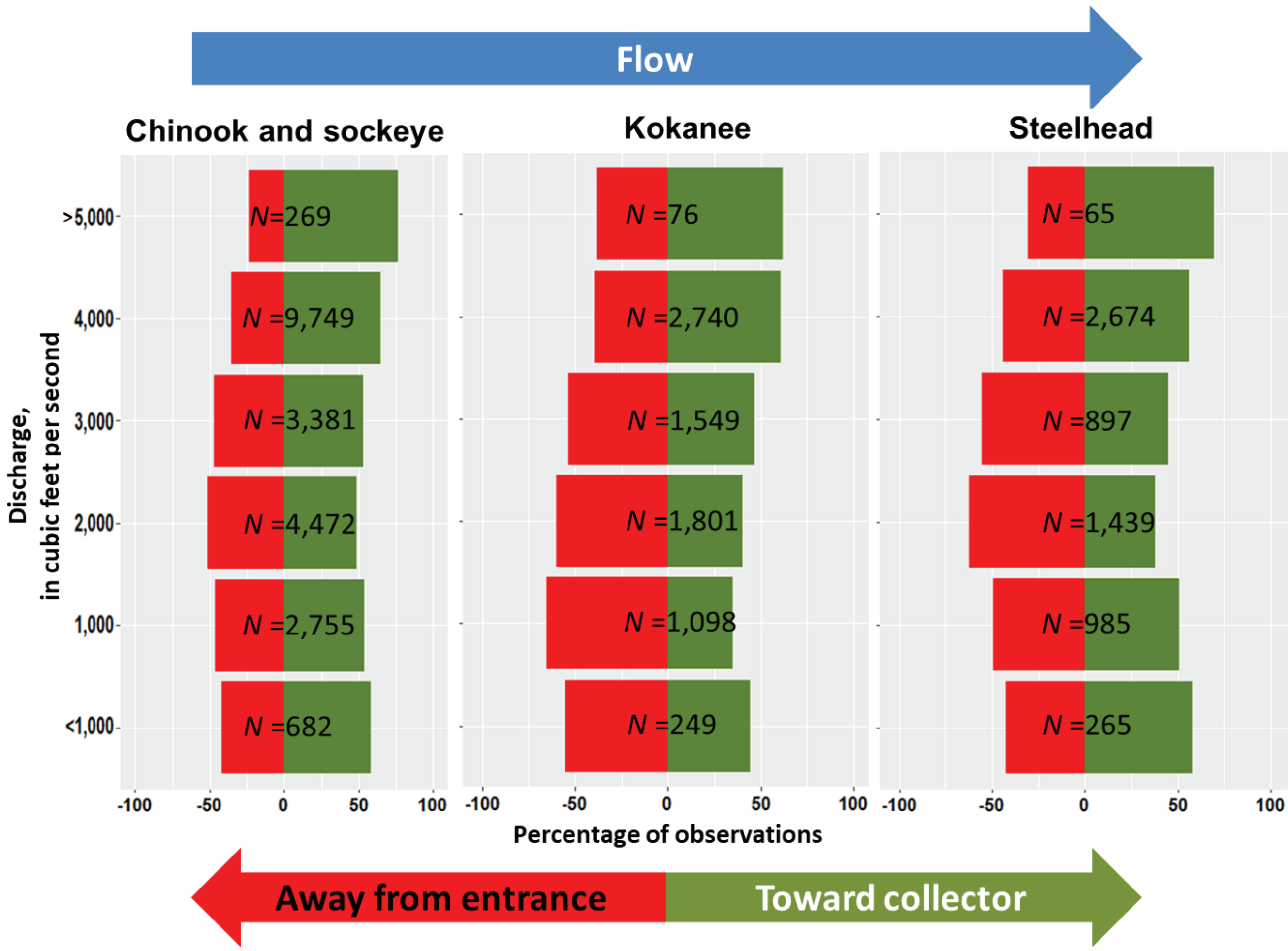

Figure 14. Directional travel for smolt-size fish observed at the collector entrances under different discharge levels using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020. Sample sizes represent the number of smolt-size fish (*N*) observed.

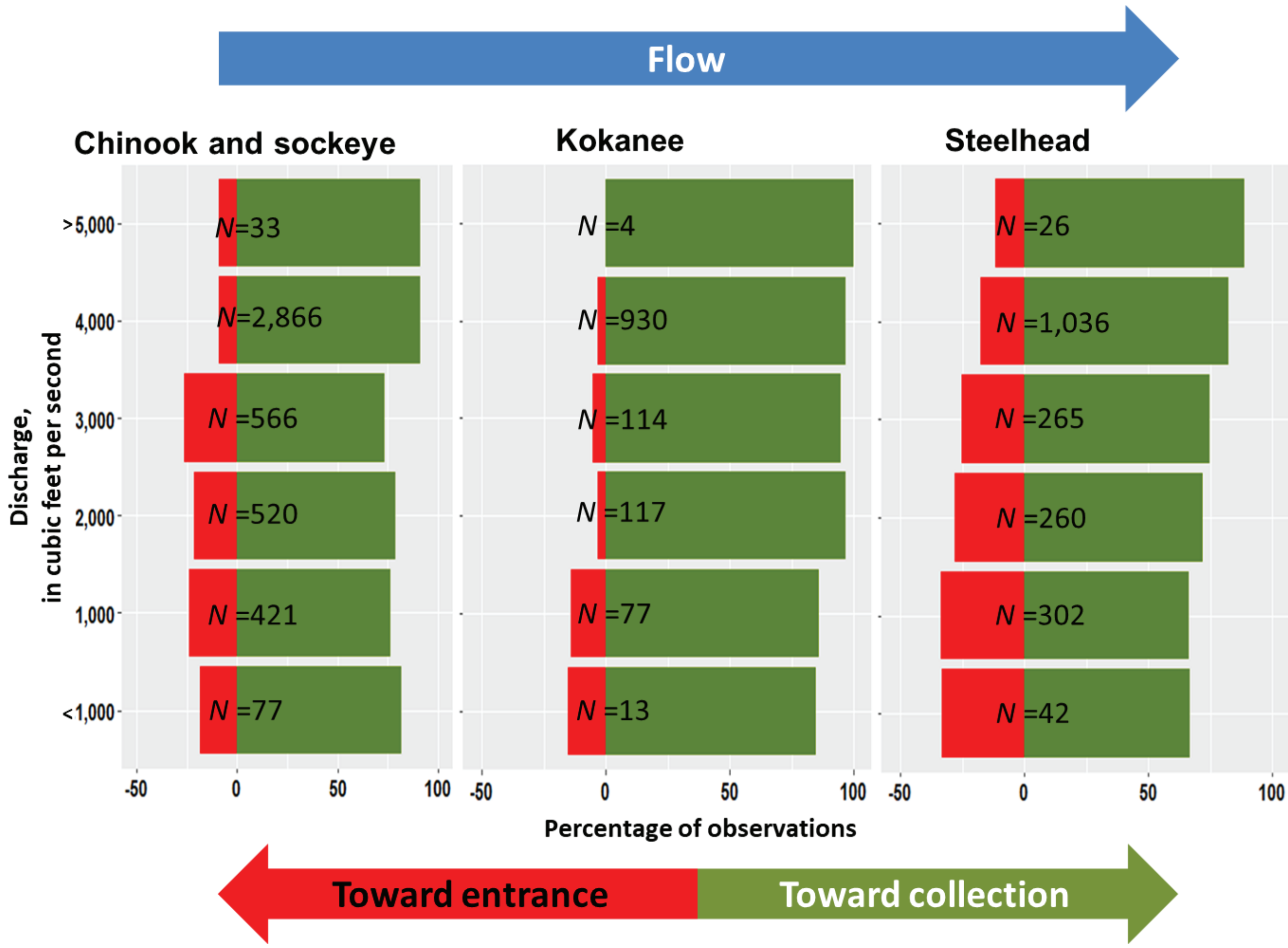

Figure 15. Directional travel for smolt-size fish observed in the collector flume under different discharge levels using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020. Sample sizes represent the number of smolt-size fish (*N*) observed.

Table 3. General direction of travel for smolt-size fish observed at binned flow increments using the adaptive resolution imaging sonar at the entrances and flume of the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

[Direction is either toward or away from the collector. Sample size is the number of fish observation events with the imaging sonar, not necessarily the number of individual fish, because a given fish could be observed more than once. **Abbreviations and symbols**: mm, millimeters; ft³/s, cubic feet per second; *N*, sample size; %, percentage; χ2, Chi-square test; <, less than; >, greater than]

Fish group (mm)	Discharge (ft³/s)	*N* Away (%)	*N* Toward (%)	χ2	*p*-value	Cramér's V
		Entrances				
Chinook and sockeye	<1,000	287 (42.1)	395 (57.9)	17.10	<0.001	0.16
(95–190)	1,000–2000	1271 (46.1)	1484 (53.9)	16.47	<0.001	0.08
	2,000–3,000	2306 (51.6)	2166 (48.4)	4.38	0.033	0.03
	3,000–4,000	1594 (47.1)	1787 (52.9)	11.02	<0.001	0.06
	4,000–5,000	3470 (35.6)	6279 (64.4)	809.36	<0.001	0.29
	>5,000	63 (23.4)	206 (76.6)	76.02	<0.001	0.53
Kokanee	<1,000	138 (55.4)	111 (44.6)	2.93	0.087	0.11
(190–300)	1,000–2,000	717 (65.3)	381 (34.7)	102.82	<0.001	0.31
	2,000–3,000	1079 (59.9)	722 (40.1)	4545.10	<0.001	0.74
	3,000–4,000	831 (53.6)	718 (46.4)	8.24	0.004	0.07
	4,000–5,000	1082 (39.5)	1658 (60.5)	121.09	<0.001	0.21
	>5,000	29 (38.2)	47 (61.8)	4.26	0.039	0.24
Steelhead	<1,000	112 (42.3)	153 (57.7)	6.34	0.012	0.16
(190–300)	1,000–2,000	488 (49.5)	497 (50.5)	0.08	0.777	0.01
	2,000–3,000	895 (62.2)	544 (37.8)	85.62	<0.001	0.24
	3,000–4,000	495 (55.2)	402 (44.8)	9.64	0.002	0.10
	4,000–5,000	1179 (44.1)	1495 (55.9)	37.34	<0.001	0.12
	>5,000	20 (30.8)	45 (69.2)	9.62	0.002	0.38
		Flume				
Chinook and sockeye	<1,000	14 (18.2)	63 (81.8)	31.18	<0.001	0.64
(95–190)	1,000–2,000	100 (23.8)	321 (76.2)	116.01	<0.001	0.52
	2,000–3,000	110 (21.2)	410 (78.8)	173.08	<0.001	0.58
	3,000–4,000	150 (26.5)	416 (73.5)	125.01	<0.001	0.47
	4,000–5,000	260 (9.1)	2606 (90.9)	1920.30	<0.001	0.82
	>5,000	3 (9.1)	30 (90.9)	22.09	<0.001	0.82
Kokanee	<1,000	2 (15.4)	11 (84.6)	6.23	0.013	0.69
(190–300)	1,000–2,000	11 (14.3)	66 (85.7)	39.29	<0.001	0.71
	2,000–3,000	4 (3.4)	113 (96.6)	101.55	<0.001	0.93
	3,000–4,000	6 (5.3)	108 (94.7)	91.26	<0.001	0.90
	4,000–5,000	32 (3.4)	898 (96.6)	806.40	<0.001	0.93
	>5,000	0 (0)	4 (100.0)	4.00	0.5	0
Steelhead	<1,000	14 (33.3)	28 (66.7)	4.67	0.031	0.33
(190–300)	1,000–2,000	102 (33.8)	200 (66.2)	31.80	<0.001	0.32
	2,000–3,000	73 (28.1)	187 (71.9)	49.99	<0.001	0.44
	3,000–4,000	67 (25.3)	198 (74.7)	64.76	<0.001	0.49
	4,000–5,000	184 (17.8)	852 (82.2)	430.72	<0.001	0.65
	>5,000	3 (11.5)	23 (88.5)	15.39	<0.001	0.77

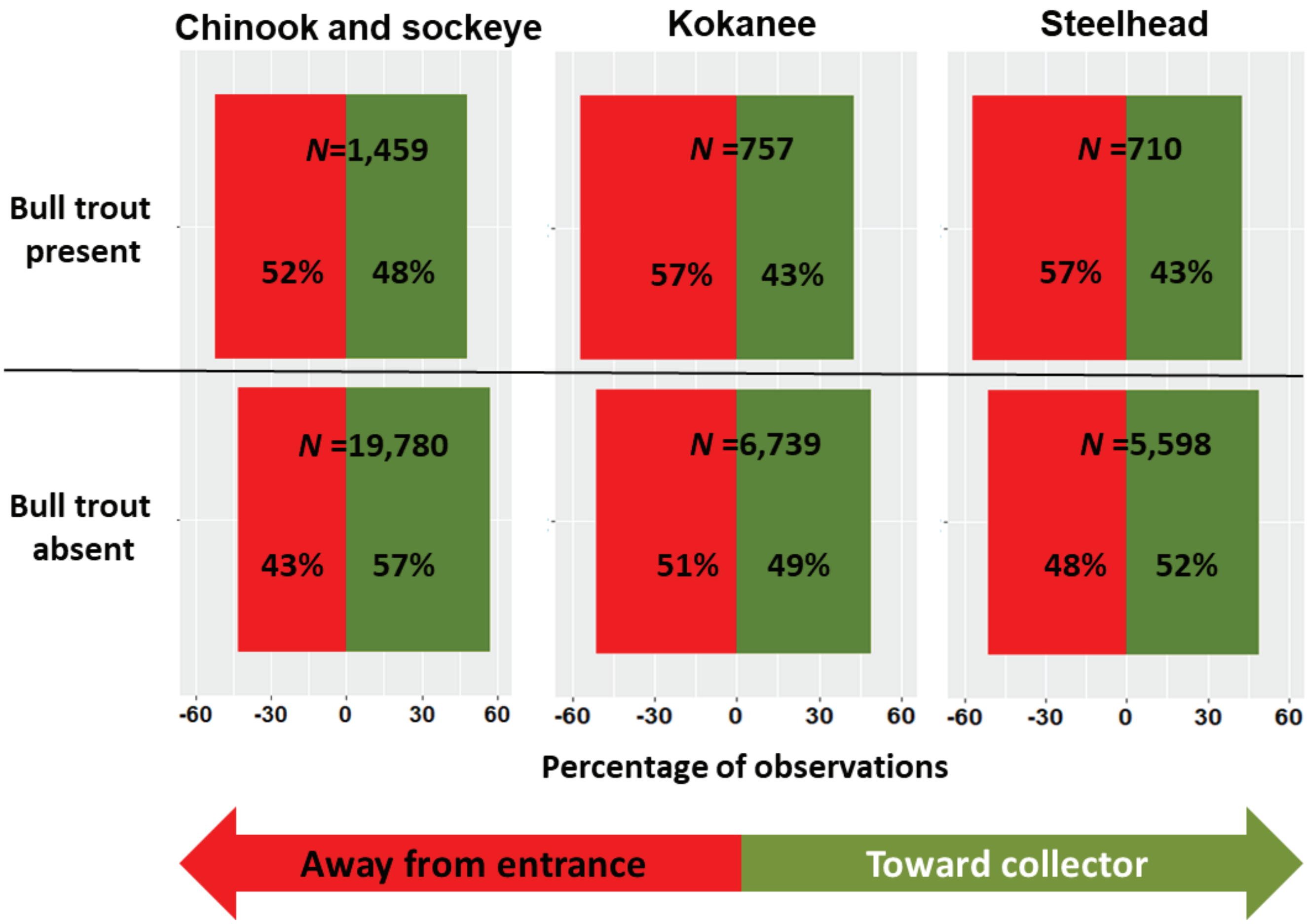

Figure 16. Directional travel for smolt-size fish detected in the presence or absence of bull trout-size fish using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020. Sample sizes represent the number of fish (*N*) observed in each group.

Table 4. Summary statistics for the swimming velocity of fish observed using the adaptive resolution imaging sonars at the entrance and in the flume at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

[All numbers in the table, except in the fish group, are in meters per second. Sample size is the number of fish observation events with the imaging sonars, not necessarily the number of individual fish, because a given fish could be observed more than once. **Abbreviations and symbol:** *N*, sample size; SD, standard deviation; IQR, interquartile range; <, less than]

Fish group (millimeters)	*N*	Mean	SD	IQR	Minimum	Maximum
North entrance						
Chinook and sockeye (95–190)	10,161	0.35	0.19	0.11	<0.01	2.04
Kokanee (190–300)	7,513	0.36	0.19	0.25	0.01	2.02
Bull trout (> 350)	1,200	0.42	0.20	0.27	0.03	1.75
South entrance						
Chinook and sockeye (95–190)	11,143	0.34	0.22	0.20	<0.01	2.70
Steelhead (190–300)	6,325	0.39	0.20	0.26	<0.01	1.72
Bull trout (> 350)	767	0.42	0.21	0.31	0.02	1.10
Flume						
Chinook and sockeye (95–190)	4,403	0.35	0.29	0.34	<0.01	2.44
Kokanee (190–300)	1,226	0.44	0.25	0.33	0.02	2.48
Steelhead (190–300)	1,929	0.30	0.18	0.25	<0.01	1.11
Bull trout (> 350)	578	0.35	0.25	0.34	<0.01	1.71

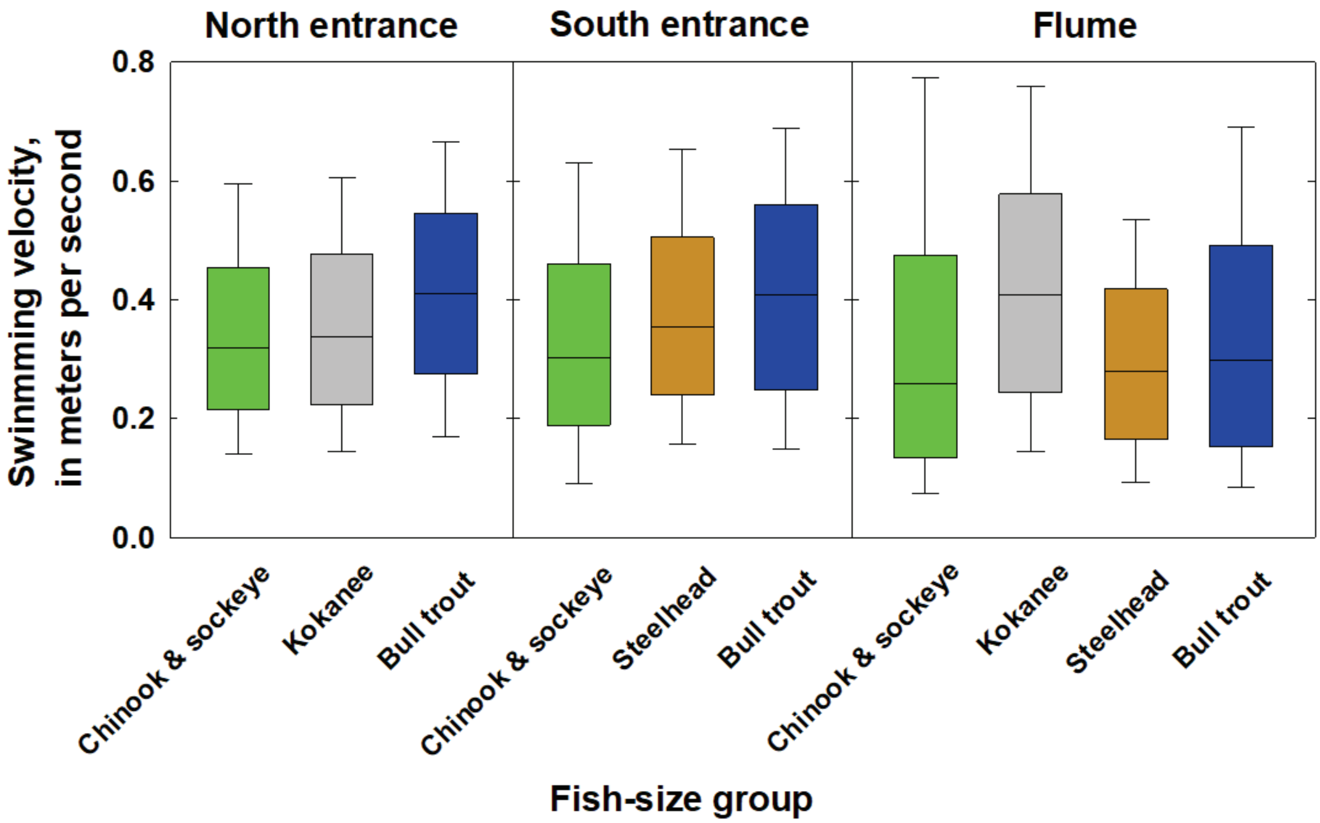

Figure 17. Swimming velocity of fish observed using the adaptive resolution imaging sonars at the north and south entrances and in the flume at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020. Boxes range from the 25th to the 75th percentiles, with lines indicating the medians and whiskers representing the 10th and 90th percentiles.

Timing of Detection

The counts of fish observed with the imaging sonar at the SWW differed by location, time, and discharge. For all fish size groups observed at the entrances, counts were lowest during the daytime periods when discharge rates were reduced (fig. 18). After about 5:00 p.m., counts of all fish size groups increased along with the corresponding increase in discharge. Following a decrease in flow at about 3:00 a.m., fish counts continued to increase until about 6:00 a.m., before quickly decreasing at 7:00 a.m.

The trends of counts for fish observed in the flume were like those observed at the entrances (fig. 19). Counts of fish from all size groups were lowest during the daylight hours and highest during the night. Counts began rapidly increasing after about 6:00 p.m., following an increase in discharge, and increased through the night. Counts of fish from the kokanee, steelhead, and bull trout-size groups began decreasing with the concomitant decrease in discharge at 3:00 a.m. Counts of Chinook and sockeye smolt-size fish also began decreasing at about 3:00 a.m. but remained elevated until 5:00 a.m., before rapidly decreasing to reduced observations during periods of daytime and low discharge rates.

Fish Track Density

The spatial distributions of fish positions near the entrances of the SWW were distributed differently depending on the fish size group. The fish location point density data includes over 500,000 location points from 37,109 individual tracks that were recorded by the imaging sonar. Positions for Chinook and sockeye smolt-size fish were primarily observed near the area between the SWW entrances with lesser concentrations of positions on the outsides of the SWW structure (fig. 20). Positions for kokanee and steelhead smolt-size groups were similar at the north and south entrances with both fish groups nearly spread across the entirety of both entrances, with fewer detections on the far north and far south ends of the SWW (fig. 21). The bull trout-size group was primarily observed near the area between the SWW entrances, like detections of the Chinook and sockeye smolt-size group (fig. 22).

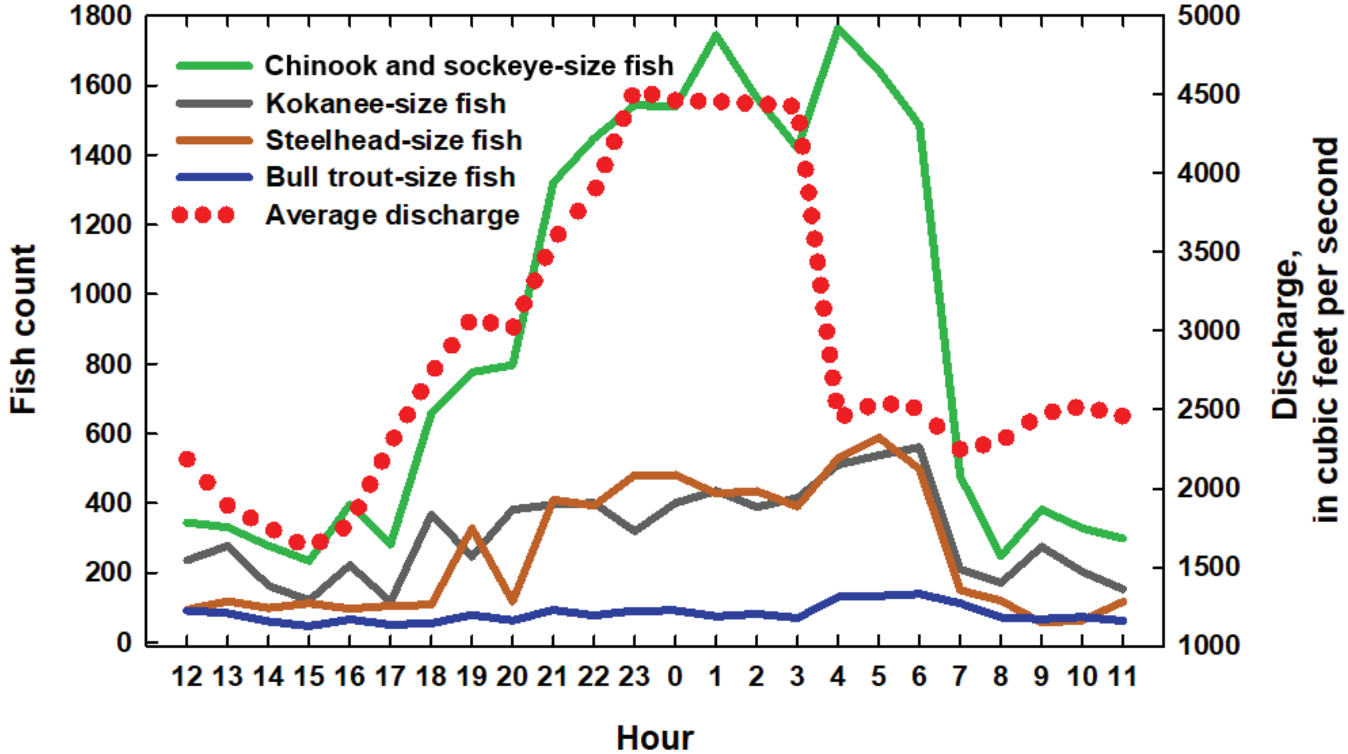

Figure 18. Counts of fish-size groups by hour of detection at the collector entrances using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

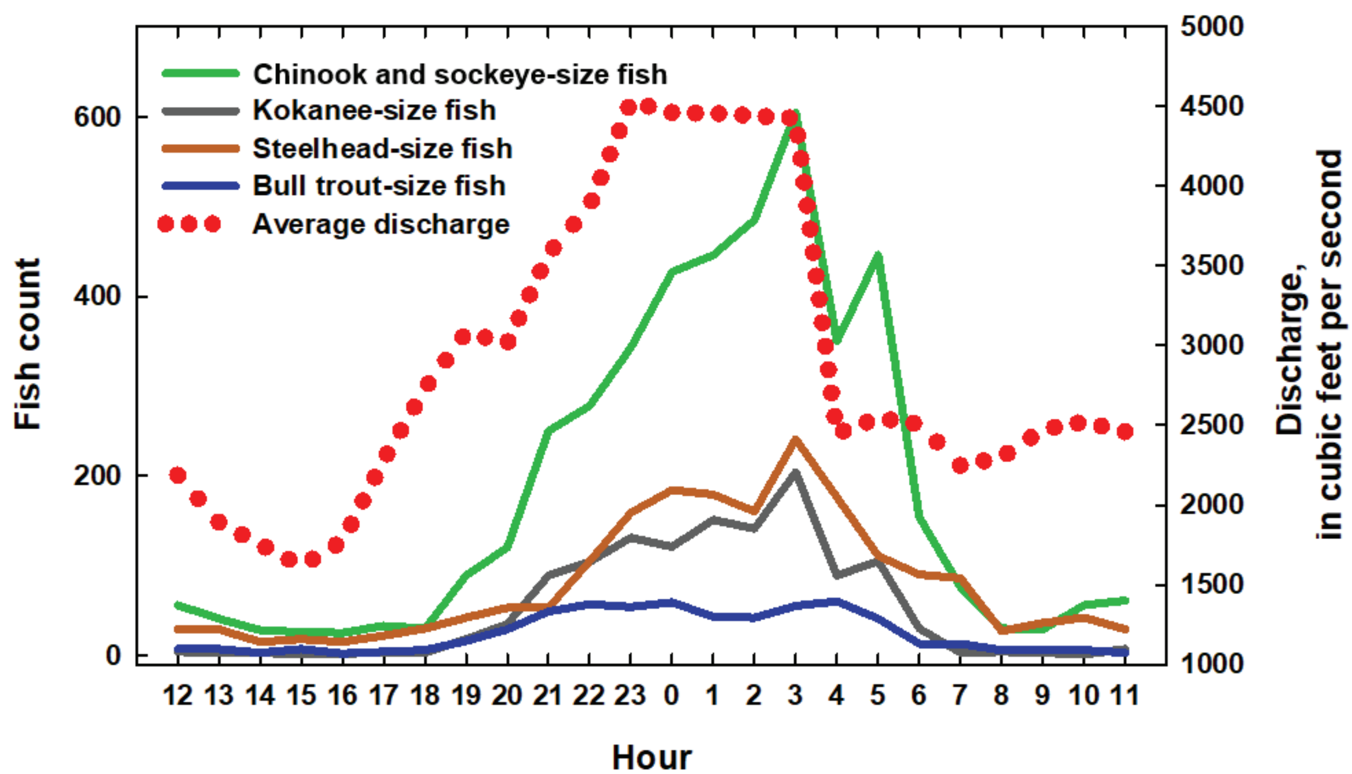

Figure 19. Counts of fish-size groups by hour of detection in the collection flume using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

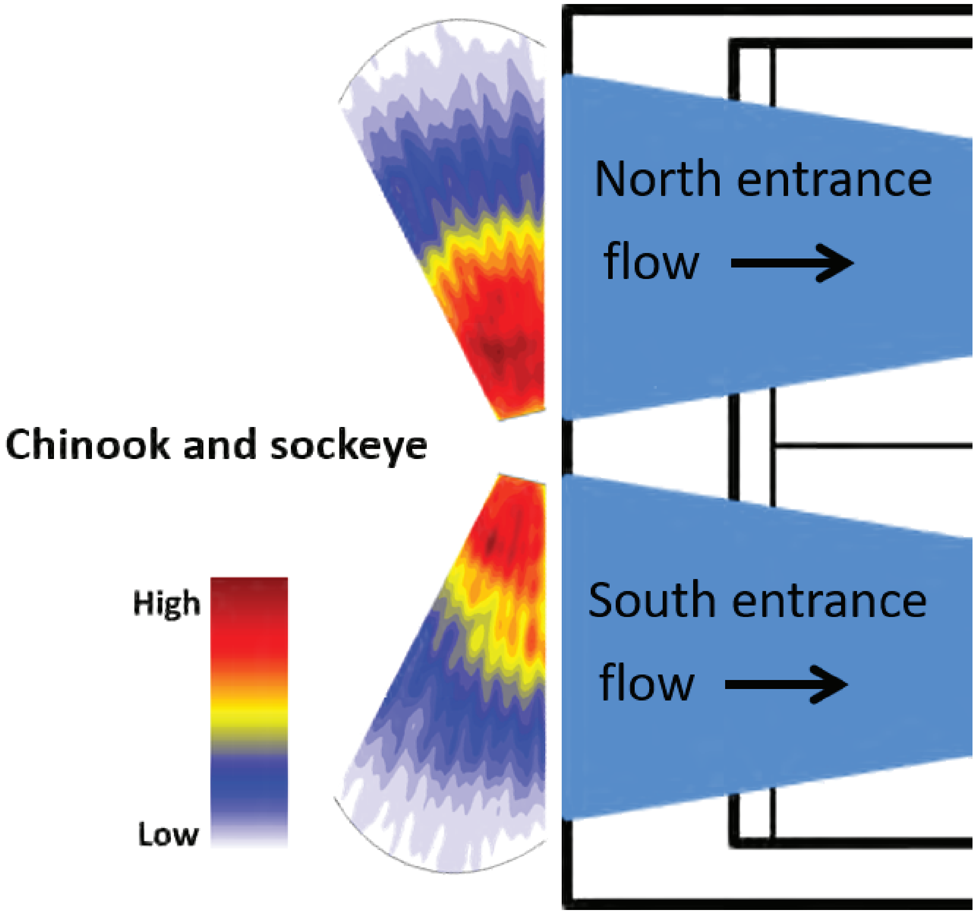

Figure 20. Chinook and sockeye smolt-size fish detected at the collector entrances using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

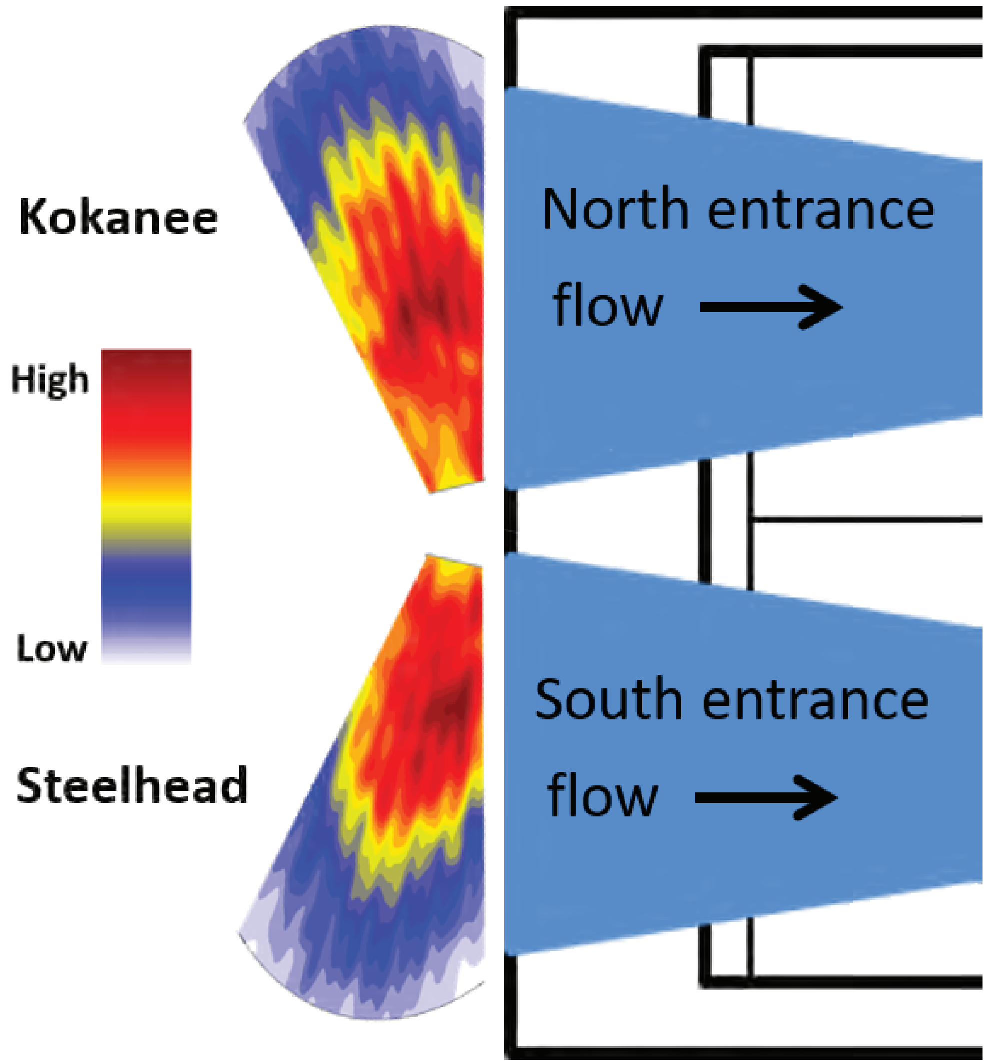

Figure 21. Kokanee-size fish (top) and steelhead smolt-size fish (bottom) detected at the collector entrances using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

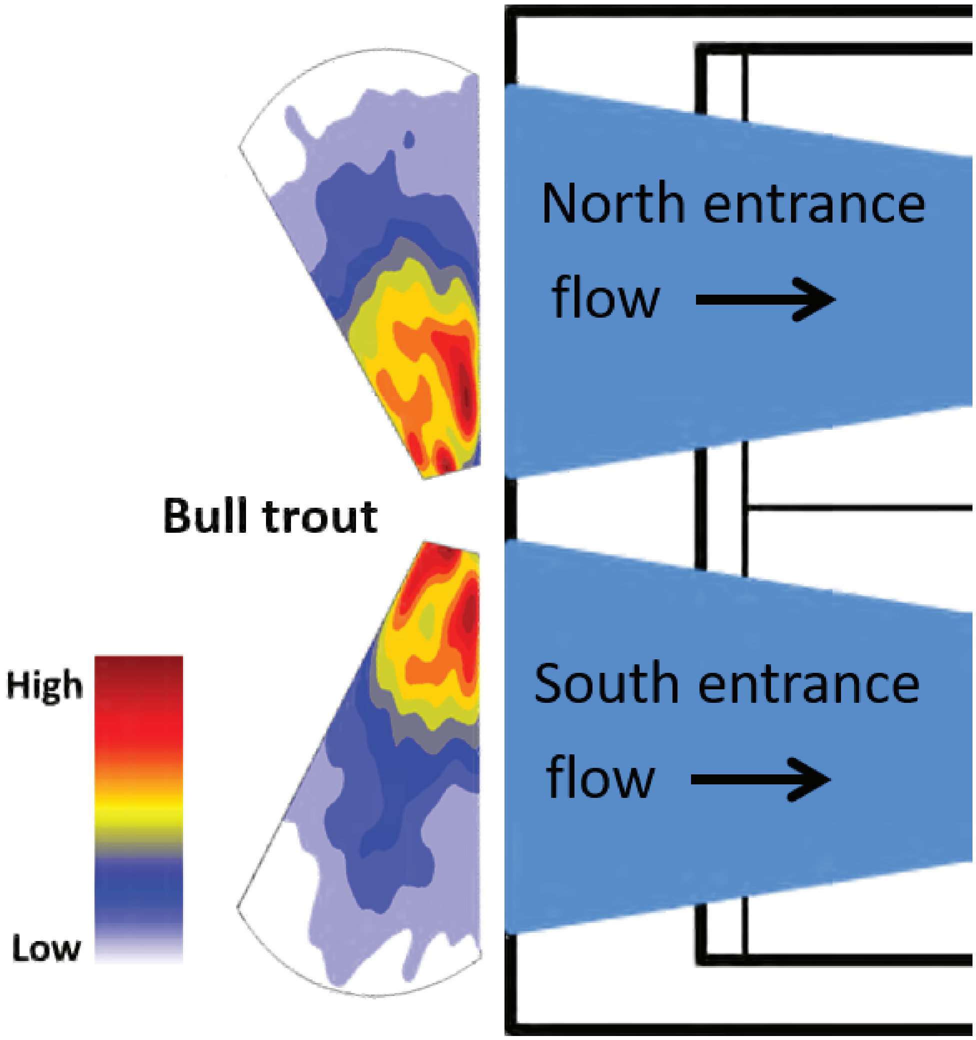

Figure 22. Bull trout-size fish detected at the collector entrances using the adaptive resolution imaging sonar at the Selective Water Withdrawal collector at Lake Billy Chinook, Oregon, 2020.

Discussion

In this study, we used imaging sonar and statistical analysis to provide quantitative assessments of the abundance and movements of smolt and bull trout-size fish at a SWW surface collector that is operated to entrain and capture downriver migrating salmonids. We established a baseline understanding of fish movements around and in the SWW collector, determined the potential effect of discharge rates on smolt-size fish at the SWW, and determined how potential predator-prey interactions at the SWW may affect smolt-size fish behaviors. Results of this study indicate that the imaging sonar technology was capable of monitoring both smolt and bull trout-size fish near the SWW and enabled us to characterize fish behaviors, abundance, and movements at the SWW, providing useful insights into how different discharge rates influence fish behaviors.

Imaging sonars have the advantage of enabling observation of untagged fish in situ without affecting their behavior. Therefore, this technology is well suited for evaluating the activities of fish near collection and guidance structures. However, the limitations of imaging sonars include the lack of species specificity for fish of similar size, the possibility of counting individual fish multiple times, and the difficulty in positively identifying successful predation. Additionally, the time required to process the large volume of imaging sonar data into meaningful results can be labor-intensive. In this study, much of this process was automated, reducing the time required and increasing the volume of data used for analysis. In this SWW collector study, we used run-timing and size metrics from fish directly collected at the SWW fish transfer facility to classify fish size groups. Using these observations, we assume that fish 95–190 mm long were either Chinook or sockeye smolts, that fish 190–300-mm long prior to May 1 were kokanee, fish that were 190–300-mm long after May 1 were steelhead smolts, and that those greater than 350-mm long were bull trout.

The SWW at Lake Billy Chinook is one of several surface-oriented collectors in use at storage and power generating dams in the Pacific Northwest (Adams and Smith, 2017). Other collectors are at Upper and Lower Baker Lake on the Baker River, Washington (Puget Sound Energy); Swift Reservoir on the Lewis River, Washington (PacifiCorp); Cowlitz Falls Dam at Lake Scanewa, Washington (Tacoma Power); North Fork Dam on the Clackamas River, Oregon (Portland General Electric); and Cushman Dam No.1 on the North Fork of the Skykomish River, Washington (Tacoma Power). The inflows at these collectors vary between 250 ft^3/s at Cushman to about 5,000 ft^3/s at the SWW (Kock and others, 2019). Additionally, all facilities except the SWW use some form of nets or positioning along landforms to help guide fish to their entrances. Kock and others (2019) found that increased smolt catch rates were generally experienced at facilities using both nets and higher flow rates. The SWW collector relies on a target flow of 4,500 ft^3/s to attract and collect juvenile salmonids, which is five times greater than that used at some of the other facilities. The SWW currently uses no nets to provide physical directional guidance toward the collector entrance, however, future net installation is under investigation (Gonzalo Mendez, PGE, oral commun., October 15, 2020). The addition of guidance nets in the forebay of Round Butte Dam, coupled with target attraction flow, might increase fish collection based on the abundance of fish observed at the entrances at the SWW and the increased collection experienced at other facilities.

Data from the imaging sonar indicated that increases in the hourly number of observations of smolt-size fish near the entrances and the flume of the SWW generally coincided with the target operational discharge of >4,500 ft^3/s. For all fish-size groups observed at the entrances, counts were lowest during the daytime periods when discharge rates were reduced, then increased with the corresponding increase in discharge at night. Following a decrease in discharge in the early morning, fish counts near the entrances to the SWW remained elevated for an additional 3–4 hours before quickly decreasing. However, it should be noted that smolt collection rates at the SWW have been historically low during the day, indicating a propensity for greater overall activity during nighttime hours (Pyper, 2015). In the flume, these observations were similar, except for a rapid decrease in fish abundance immediately following the decrease in discharge. Discharge rates are generally recognized as one of the primary drivers of forebay collector performance because the distance from the entrance of detectable flow created for migrating salmonids is dictated by the amount of discharge (Johnson and Dauble, 2006; Kock and others, 2019). The disparity between abundances of smolts observed (1) in the flume and (2) at the entrances, immediately following the rapid decrease in target discharge, supports the need to focus on improving the operational timing of flow decrease. It may be possible to increase flume entry rate by augmenting operations to maintain target flow for a longer duration. To determine how this operational change might impact abundance and arrival timing, a block design of early (approximately 3 a.m., control) and late (dawn, treatment) target flow decrease timing based on alternative day blocks could be used to test this hypothesis.

We observed behavioral differences for fish near the entrance to the SWW. Fish of all four size groups generally did not travel in a preferred direction under low flow conditions (<4,500 ft^3/s), but the fish moved more toward the entrance to the SWW once flows increased to the target operational flow of >4,500 ft^3/s. In the flume, the direction of travel for all smolt-size groups was toward collection (same direction as flow) under all discharge rates with increased movement toward collection observed at target operational flows. However, that tendency was more moderate for the steelhead smolt-size group compared to the other size groups. In the flume, few fish were observed rejecting collection in the area covered with the imaging sonar. However, it is possible that rejection occurred in locations not monitored. Additionally, there may be differences in the rate of flume rejection by the different species at the SWW as observed by Pyper (2015).

The swimming velocity of fish at the entrances of the SWW were similar at the two entrances but differed between the fish-size classes because swimming speed increased with fish size. However, in the flume, swimming speed was more variable between size groups and did not have a pattern of increased swimming speed with fish size. We also observed differences in the spatial use of the habitat of both smolt and bull trout-size fish near the entrance to the SWW. Kokanee and steelhead smolt-size fish were observed across the entirety of the collector entrances, whereas the Chinook and sockeye smolt and bull trout-size groups were oriented more toward the center of the collector with fewer observations on the outside halves of the collector entrances. These spatial differences in patterns of use suggest that kokanee and steelhead smolt-size fish may be holding in the attraction flow field at the SWW entrances prior to entering, whereas Chinook and sockeye smolt and bull trout-size fish may be using the lower velocity flow area located between the entrances.

When bull trout-size fish were present, larger percentages of all three smolt-size fish groups traveled away from the SWW than when bull trout-size fish were absent, which has been observed at other surface collectors (Smith and others, 2020). In the flume, bull trout-size fish were observed but were infrequently captured (Gonzalo Mendez, PGE, oral commun., October 15, 2020). A non-uniform direction of travel at the entrance and observations from a previous acoustic telemetry study performed at the SWW (Hill and others, 2013) indicate that bull trout-size fish may be milling at the SWW, thereby increasing the risk of predation of smolt-size fish. Similar milling behavior and attempted predation has been observed at other fish-passage structures, although the collection or passage of predator-size fish at these structures is rare (Beeman and others, 2014, 2016; Adams and others, 2015). Counts of bull trout-size fish at the entrances were generally stable during all hours with the greatest abundance occurring in conjunction with that of smolt-size fish, which is like findings by Khan and others (2012) near a similar surface-oriented fish collector. In the flume, increased counts of bull trout-size fish coincided with the increased abundances of smolt-size fish and were low during all daylight hours. Increased abundances of bull trout-size fish during periods of increased smolt-size fish presence suggest that the SWW is being used as a prey ambush location when potential prey densities are elevated. The facilities at Round Butte Dam (and other surface collectors) are known to have bull trout near the entrance of the collector (McIlvaine, 2015; Beeman and others, 2016; Smith and others, 2018). However, bull trout typically are bottom dwellers (Scott and Crossman, 1973) and are highly substrate-oriented (Pratt, 1984); neither of these habitats are available near the entrances to these surface collectors. The presence of these fish near the entrances of the SWW indicate that this structure is a habitat that may be increasing opportunities for bull trout to feed on migrating salmonid smolts, which is an important factor to consider if guidance nets are used in the future. With the implementation of guidance nets, this information supports the need to further assess the level of predator interactions at the SWW with imaging sonar technology. Additionally, the direct removal and relocation of bull trout from the SWW has been considered (Terry Shrader, PGE, oral commun., October 15, 2020), and imaging sonar technology could be used to evaluate the value of a predator removal program by determining predator abundances at the SWW before and after removal.

Recently, forebay collectors have been deployed to increase passage rates and survival of juvenile salmonids at dams. The imaging sonar technology used in this study proved to be an informative tool for assessing the abundance, movements, and behaviors of both smolt and bull trout-size fish at the entrance and in the flume of the SWW. Observations of smolt-size fish confirmed that the abundance and direction of travel were primarily dictated by the operational flows of the SWW. Additionally, we observed that the presence of bull trout-size fish negatively influenced the directional swimming behavior of smolt-size fish at the entrance to the SWW. Although surface collection systems provide a downstream route of passage, they concentrate and confine fish into a relatively simplified habitat that may lead to increased predator-prey interactions. These results can be used to help inform resource managers how discharge can influence abundance and behaviors of smolts at the SWW as well as the potential impact that predation or behavioral effects caused by an abundant population of bull trout-size fish may have on smolt collection.

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