Prepared in cooperation with Portland General Electric

Spatial and Temporal Distribution of Bull Trout (*Salvelinus confluentus*)-Size Fish near the Floating Surface Collector in the North Fork Reservoir, Oregon, 2016

Open-File Report 2017–1080

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

Cover: Photograph showing the North Fork Dam and the floating surface collector on the Clackamas River, Oregon, June 24, 2015. Photograph by Portland General Electric. Used with permission.

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RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Acting Director

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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm3)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to Inch/Pound

Multiply	By	To obtain
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
hectare (ha)	2.47105	acre (ac)
meter per second (m/s)	3.281	foot per second (ft/s)
liter (L)	0.2642	gallon (gal)
milligram (mg)	0.000035	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Datum

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

Abbreviations

AIC	Akaike Information Criterion
ANOVA	analysis of variance
ARIS®	adaptive resolution imaging sonar
AUC	area under curve
CSV	comma-separated values
DIDSON	dual-frequency identification sonar
FSC	floating surface collector
IQR	interquartile range
PGE	Portland General Electric
PIT	passive integrated transponder
Project	Clackamas River Hydroelectric Project
ROC	receiver operator characteristic
USGS	U.S. Geological Survey

Spatial and Temporal Distribution of Bull Trout (*Salvelinus confluentus*)-Size Fish near the Floating Surface Collector in the North Fork Reservoir, Oregon, 2016

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Abstract

Acoustic cameras were used to assess the behavior and abundance of bull trout (*Salvelinus confluentus*)-size fish at the entrance to the North Fork Reservoir juvenile fish floating surface collector (FSC). The purpose of the FSC is to collect downriver migrating juvenile salmonids at the North Fork Dam, and safely route them around the hydroelectric projects. The objective of the acoustic camera component of this study was to assess the behaviors of bull trout-size fish observed near the FSC, and to determine if the presence of bull trout-size fish influenced the collection or abundance of juvenile salmonids. Acoustic cameras were deployed near the surface and floor of the entrance to the FSC. The acoustic camera technology was an informative tool for assessing abundance and spatial and temporal behaviors of bull trout-size fish near the entrance of the FSC. Bull trout-size fish were regularly observed near the entrance, with greater abundances on the deep camera than on the shallow camera. Additionally, greater abundances were observed during the hours of sunlight than were observed during the night. Behavioral differences also were observed at the two depths, with surface fish traveling faster and straighter with more directed movement, and fish observed on the deep camera generally showing more milling behavior. Modeling potential predator-prey interactions and influences using collected passive integrated transponder (PIT) -tagged juvenile salmonids proved largely unpredictable, although these fish provided relevant timing and collection information. Overall, the results indicate that bull trout-size fish are present near the entrance of the FSC, concomitant with juvenile salmonids, and their abundances and behaviors indicate that they may be drawn to the entrance of the FSC because of the abundance of prey-sized fish.

Introduction

Portland General Electric (PGE) operates the Clackamas River Hydroelectric Project (Project) in northwestern Oregon, which includes a series of powerhouses, dams, reservoirs, and support facilities (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. In 2008, the National Oceanic and Atmospheric Administration (NOAA) determined that the Project was a limiting factor for upstream and downstream fish passage of anadromous fish stocks in the Clackamas River Basin and mandated a series of Project improvements (National Oceanic and Atmospheric Administration, 2008).

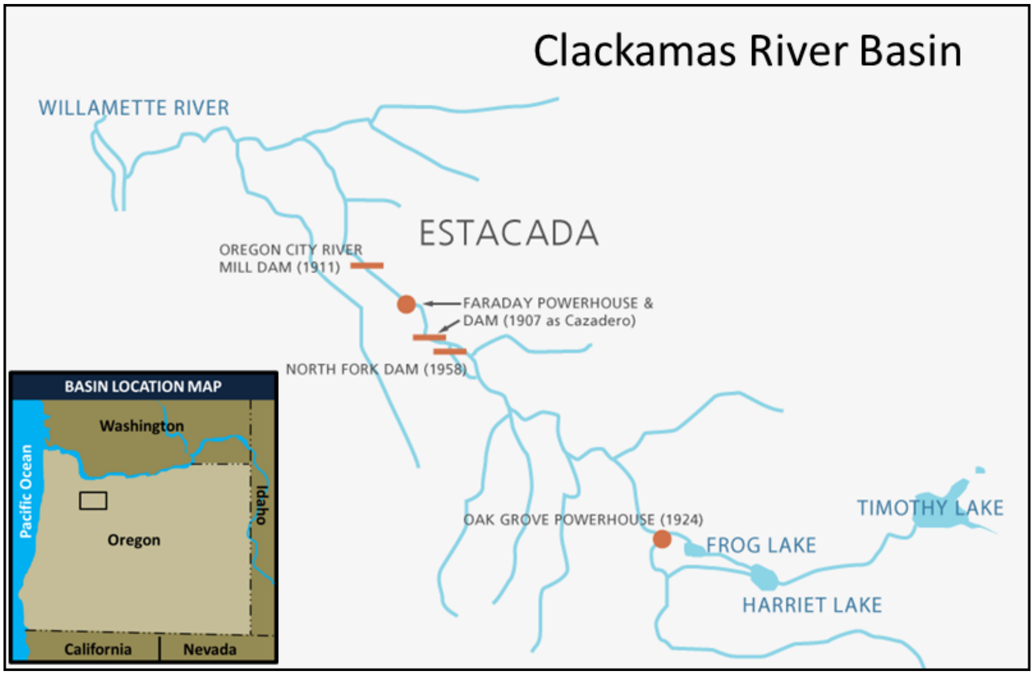

Figure 1. Graphic of Clackamas River Basin showing North Fork Reservoir and Dam, Oregon. Graphic from Portland General Electric.

North Fork Dam is a 63-m-high, thin-shell concrete arch dam on the Clackamas River about 48 km southeast of Portland, Oregon. The dam, completed in 1958, is owned and operated by PGE. It has a hydraulic capacity of 6,000 ft^3/s and two Francis turbine units capable of generating a total of 60 megawatts. During normal operations, all water passing through the dam goes through the powerhouse located in the center of the dam (fig. 2), with the exception of a continuous 43 ft^3/s flow that maintains a 3.1-km-long fishway along the northern side of the dam and along the Clackamas River. A spillway with three Tainter gates is on the northern side of the dam, but is not used during normal dam operations. The 331-acre North Fork Reservoir created by the dam has a storage capacity of 18,630 acre-ft, and a useable storage capacity of 700 acre-ft. The forebay elevation typically fluctuates ±2 ft during normal weather and project operations.

The juvenile bypass facility at North Fork Dam was marginally effective at passing juvenile salmonids migrating downriver (Federal Energy Regulatory Commission, 2006). The 2008 finding by the NOAA spurred the construction of a floating surface collector (FSC) with the goal of improving downstream passage of juvenile salmonids at North Fork Dam by collecting fish near the dam and moving them downstream. Surface collection has been shown to be a viable method of attracting juvenile salmonids (Sweeney and others, 2007), and floating surface collectors have been used at several high-head dams in the Pacific Northwest, including Upper Baker Lake (see http://www.westcoast.fisheries.noaa.gov/stories/2012/2013_01_14_floating_surface_collector.html). As a result of successes at Upper Baker Lake and elsewhere, a FSC was installed in North Fork Reservoir during spring 2015 and evaluated throughout much of the year (Christensen and Grant, 2015).

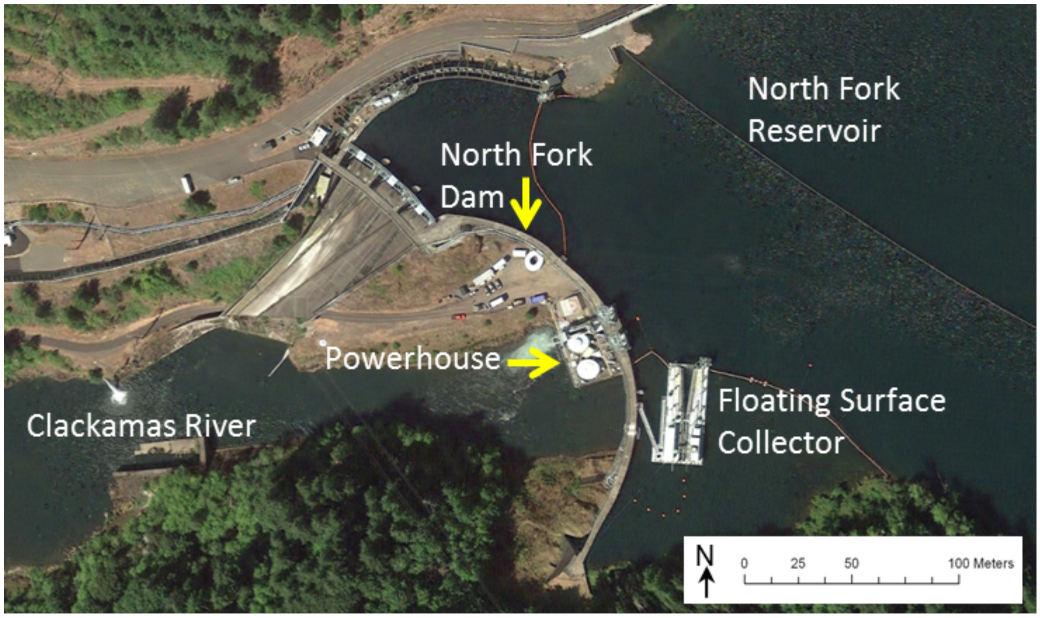

Figure 2. Orthoimage showing floating surface collector at North Fork Dam, Oregon, 2016.

The FSC is about 20 × 45 m in size and uses pumps to draw water from the reservoir with a maximum inflow of 1,000 ft^3/s and a minimum capture velocity of 6.3 ft/s. Fish are guided toward the collector flume (5 m wide × 5.9 m deep) with the use of guidance nets, enter the flume, move past dewatering screens, and then pass directly into a bypass pipe that delivers them into the tailrace of River Mill Dam about 8.2 km downriver. The FSC is placed near the center of the reservoir, as fish tended to congregate along the dam, and the dam could be used to congregate and guide fish toward the flume of the FSC.

As part of the evaluation to determine how well the FSC performs at collecting and passing juvenile salmonids, there is a need to assess the potential effect that predatory fish may have on the efficacy of the structure. Reintroductions of bull trout (*Salvelinus confluentus*) recently have been implemented in the Clackamas River subbasin (U.S. Fish and Wildlife Service and Oregon Department of Fish and Wildlife, 2011; Barry and others, 2014), where they previously had been believed to be extirpated (Shively and others, 2007). Bull trout are known to inhabit the reservoir where the collector is located, and they are known predators of juvenile salmonids. In addition to bull trout, rainbow trout (*Oncorhynchus mykiss*) are the only other known predators of juvenile salmonids present in the reservoir, and also could potentially be observed with the acoustic cameras. We used acoustic cameras to determine if bull trout-size fish are present near the collector and to determine if they are interacting with juvenile fish as they approach the entrance, thereby preventing them from entering and thereby reducing the number of juvenile salmonids passing into the collector.

The study summarized in this report was designed to provide empirical information about the presence, movement, and behaviors of bull trout-size fish near the entrance to the FSC, as well as their potential interactions with juvenile salmonids at the FSC to help inform decisions about collection and passage solutions. To act as surrogates for run-of-the-river juvenile salmonids, passive integrated transponder (PIT)-tagged fish were used. Measures of the biological performance were based on collection of PIT-tagged fish released in the reservoir, and behaviors of fish near the FSC were quantified using acoustic cameras. The study was designed to provide information for the following objectives:

- To quantify the spatial and temporal distribution of bull trout-size fish near the entrance of the FSC, and
- To assess temporal overlap between bull trout-size fish observed with the acoustic cameras and PIT-tagged juvenile salmonid releases.

It also is important to remember the limitations associated with data collected with acoustic cameras. For instance, (1) there is no way to identify the species of fish, especially if they are of similar size; and (2) individual targets cannot be uniquely identified and tracked continuously throughout the study area, like acoustically tagged fish are, therefore, individuals are likely to be counted more than once as they swim in and out of the area monitored by the cameras. Despite these limitations, the acoustic cameras can be used to collect data that might otherwise be unattainable.

Methods

Dam Operations and Environmental Conditions

Powerhouse discharge, reservoir elevation, and water temperature data were summarized to document the environmental conditions that fish experienced from April 26 to June 15, 2016. Hourly powerhouse discharge and reservoir elevation data were provided by PGE. Water temperature data were collected at the U.S. Geological Survey (USGS) streamgage on the Clackamas River at Estacada, Oregon, and obtained from the USGS Web site, https://waterdata.usgs.gov/usa/nwis/uv?site_no=14210000. Diel periods were assigned using U.S. Naval civil twilight time for Estacada, Oregon, and were obtained at http://aa.usno.navy.mil/data/docs/RS_OneYear.php. Data were summarized using hourly observations, but mean daily values were plotted to increase clarity in the plots. Water elevation data are presented in feet and discharge is presented in cubic feet per second (ft^3/s) according to the local convention.

PIT Interrogation

Following collection in the FSC, fish are transitioned into a pipeline that traverses the downriver face of the dam and routes fish downriver, circumventing the hydroelectric projects. Fish in the pipeline are interrogated using two PIT antenna arrays. The arrays are powered by a KLK5000 (Karltek, Victoria, Australia) fish monitoring system, with decoders and a data logger. The monitoring system records the tag code, time of detection, antenna number, and number of detections for each PIT-tagged fish.

The collection of fish by the FSC was monitored by PGE daily. The PIT tag collection data were provided for the duration of the study. The data provided were electronically entered by USGS and PGE staff and used for analysis after any differences were reconciled.

Procurement, Tagging, and Release of PIT-Tag Fish

PIT-tagged fish used in this study were released as part of other fish passage and survival studies being performed at the North Fork Project (Ackerman and Pyper, 2017), and not solely for this evaluation. Wild origin juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) were used for the test population. Fish were obtained from either the Timber Park or River Mill Dam juvenile fish sampling facilities located about 8 km downriver of the North Fork Project. Fish were held in tanks at the sampling facilities with a continuous supply of river water. During tagging, fish were placed into an anesthetic bath of 50 mg/L of buffered tricane methane sulfonate (MS-222, Argent Chemical Laboratories, Redmond, Washington), and a 1.0 mL/L concentration of Stress Coat Plus® (Aquarium Pharmaceuticals, Inc., Chalfont, Pennsylvania) to reduce handling-related stress to the fish through electrolyte loss. A half-duplex PIT tag (12 mm long and 2 mm in diameter; Destron Fearing, Dallas, Texas) was injected intraperitoneally into the fish using a one-time-use sterilized 12-gauge hypodermic needle. Following tagging, fish were scanned to verify the presence of a PIT tag, their fork length was measured, and they were placed in a perforated 5-gal bucket and supplied with river water for recovery. After recovery, buckets were transferred to a 300-gal transport trailer filled with water and supplemented with oxygen, and fish were allowed a 1-h recovery period. The trailer was then transported to the North Fork Project (about a 14.5-km trip; mean travel time=24 min), and the buckets were removed from the trailer and carried to the release location.

All collection, PIT-tagging, and release were performed by PGE employees. PIT-tagged fish releases began on April 11, 2016, and continued through June 3, 2016. Over this period, 1,593 PIT-tagged coho and steelhead were released at four locations in North Fork Reservoir. Results presented in this report are based on PIT-tag detections of fish passing through the FSC from April 26 to June 15, 2016.

Acoustic Cameras

Surveillance Systems

In this study, we used two adaptive resolution imaging sonar (ARIS®) acoustic cameras deployed at two depths to collect data on fish movements. Both ARIS® acoustic cameras were operated at 1.8 MHz, with a blanking distance of about 3 m from the camera and a maximum range of about 14 m. The cameras were attached to a pole-mounted platform on the western side of the collectors entrance and aimed perpendicular (west to east) to the entrance of the collector (fig. 3). The shallow camera was lowered to a depth of 1.2 m below water surface, and the deep camera was lowered to a depth of 4 m below water surface, about 2 m above the floor of the entrance. In both mounting depths, the acoustic cameras were deployed on rotators to provide precise aiming.

Figure 3. Photograph of North Fork Reservoir floating surface collector and approximate coverage area of the ARIS® acoustic cameras (red cone) in forebay of North Fork Reservoir, Oregon, 2016. Photograph by Landsat, August 11, 2016.

Data Collection

Data were collected nearly continuously at the North Fork Reservoir FSC starting on April 24 and ending on July 7, 2016. We collected about 2,800 h of data over the 74 days that the cameras were recording. Data collection was interrupted only when the cameras were repositioned to maximize fish approach viewing or when equipment malfunctioned. All data collected were stored to hard drives for archival and subsequent processing.

Data Processing

Because of the large volume of data collected with the ARIS® acoustic cameras during the study period, it was not feasible to process and track 100 percent of the data given the budgeted resources. As a result, we randomly subsampled two 15-min blocks of collected camera footage from each camera for every hour for each 24-h period. The duration of each subsampled date was from midnight to midnight.

Signal processing of the raw acoustic signals was analyzed using Echoview® software (version 5.4, Myriax Pty. Ltd., Hobart, Tasmania, Australia). The software is a visualization and analysis program for hydroacoustic data that allows a greater proportion of data to be processed than could be performed with conventional video interpretation. The Echoview® platform allows 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 within individual camera frames and converted to three-dimensional position and time data that can then be applied to target tracking. The conceptual layout of the virtual variable interface for the processing of acoustic camera data is shown in figure 4. Each object in the layout represents operational steps applied to the original data, which allows each individual step to be optimized to maximize efficiency and improve consistency (Boswell and others, 2008).

Analysis included a multi-step process. Initially, geospatial and positional data for each camera were associated with the geographic location of the platform to enable each target to be geospatially referenced (fig. 4, step 1). Next, acoustic camera data files were loaded into Echoview® and converted to volume back-scattering strength (Sv) from raw signal magnitudes (fig. 4, step 2). To remove stationary objects from the data, targets were deemed immobile by calculating the mean results of the four previous pings, which also had targets that did not move. These targets were removed from the dataset (fig. 4, step 3). Next, static noise was removed by implementing a sample statistic subtract operator (fig. 4, step 4). This process implements a synthetic ping into the background signal, and then subsequently subtracts the synthetic ping from each actual ping. This process leads to an increase in the signal-to-noise ratio by the removal of pings returned from inanimate objects and background noise. Following background noise subtraction, the image was enhanced by applying a convolution (median) algorithm filter (fig. 4, step 5). This filter used the median and maximum values of a data point and the eight direct neighboring cells to remove interference and smooth the image without significantly affecting the shape of the image. The next step was to use the multibeam target detection operator to generate multibeam targets from the multibeam data (fig. 4, step 6). These three-dimensional targets were created from groups of adjoining data points (clusters), which then were reduced to point data that include the geometric values of each fish target. The target conversion process was used next (fig. 4, step 7) to transform multibeam targets into single-point targets. Following the operational steps of filtering noise and smoothing the data, all single targets with all associated target properties were exported as comma-separated values (CSV; fig. 4, step 8). These CSV files then were reimported into Echoview® for further tracking and analysis (fig. 4, step 9). The purpose of fish tracking is to obtain counts and movements of individual fish, along with their associated behavioral and morphometric data (Simmonds and MacLennan, 2005).

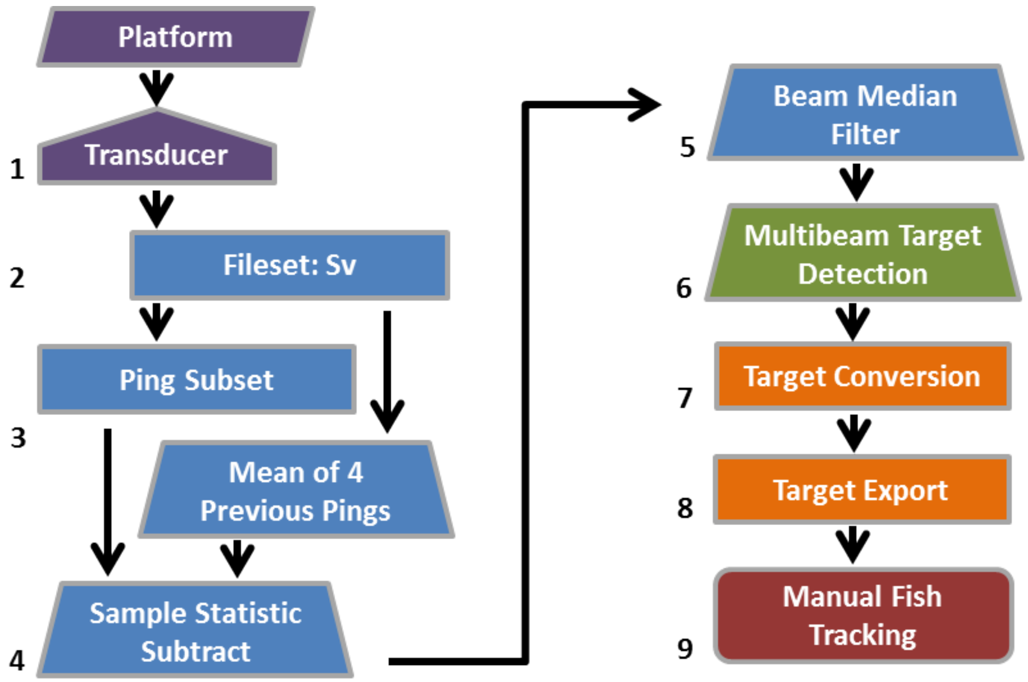

Figure 4. Data flow of the semi-automated Echoview® processing structure used to determine acoustic camera targets near the floating surface collector at North Fork Reservoir, Oregon, 2016. Numbers represent steps in the process.

Data Analysis

Summary statistics of fish targets derived from Echoview® (for example, mean length, direction, speed, tortuosity, angle, orientation) were imported into SAS (version 9.3, of the SAS System for Windows, Copyright© 2002–10, SAS Institute Inc., Cary, North Carolina), for subsequent proofing and to merge acoustic camera data with the environmental data. Data were proofed to eliminate non-valid records or records that did not provide measurable morphometric or behavioral data. To consider a fish track as valid, we required that each fish track consisted of at least five pings and had a minimum duration of detection of 0.5 s. The acoustic camera technology cannot distinguish fish that have entered and exited the field of view multiple times; therefore, the detection duration for each individual fish track within a camera beam was determined by the time a fish was first detected by the camera, to the time that the fish exited the camera view. Target datasets were then exported as CSV files for statistical analysis.

Fish Size and Count

Fish targets were grouped into two size classes to distinguish between bull trout-size fish (350–700 mm) and upriver-migrating adult salmonids (>700 mm) including steelhead and coho salmon that entered the reservoir through the fishway. The >700 mm upper threshold was based on measurements of upriver-migrating adult salmonids observed in the fishway (Garth Wyatt, Portland General Electric, oral commun., 2016). Although they were retained, data for fish >700 mm were not included in this analysis.

Direction of Fish Travel

To summarize the directions of fish traveling near the FSC, 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 were shown to conform to a Von Mises distribution (Zar, 1999; Pewsey and others, 2013), the Rayleigh z test was performed. In instances where travel paths had axially bimodal tendencies (modes are 180° apart from each other), angles were doubled (in accordance with Zar, 1999) to transform the bimodal sample into a unimodal sample for further analysis. 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.

Track Characteristics

Fish track characteristics were quantified using travel speed and tortuosity variables exported from Echoview®. Travel speed was calculated as the average travel velocity of each individual target. A tortuosity index (τ) was calculated as adapted from Johnson and Moursund (2000) where:

$$\tau = \left(\frac{\text{Sum of Length of a Track}}{\text{Straight Line Track Distance}} \right) \quad (1)$$

Applying this calculation of tortuosity, a fish traveling in a straight line will have a tortuosity index of 1.0, whereas a fish traveling in a non-linear path will have a tortuosity index of greater than 1.0.

For each of the fish track characteristics, an analysis of variance (ANOVA) was used to determine the significance of the differences for camera location. Statistical analyses were carried out using R software (R Core Team, 2014). A significance level of α=0.05 was used for all tests.

Evaluating the Fish Track Density near the PFFC Entrance

The collected point samples for each individual fish track were used to create three-dimensional density plots of unique fish track locations for the volume sampled. The spatial resolution within the view of each camera was about 1 cm, and interpolation of point data was performed using the akima 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 within each cell. Datasets for each camera depth were used for plotting location data.

Modeling PIT Salmonid/Bull Trout-Size Fish Presence

To determine the potential effects of the presence of bull trout-size fish on the likelihood of collection or rejection of PIT-tagged juvenile salmonids at the FSC, we used several regression methodologies. We used logistic regression to model presence and absence of hourly collection of PIT-tagged juvenile salmonids collected at the FSC as a function of covariates. Hours where PIT-tagged juvenile salmonids were entrained following collection at the FSC were assigned a value of R=1, and hours absent of fish were assigned a value of R=0. The probability of being entrained at the FSC was modeled using generalized linear models in R (R Core Team, 2014). We selected covariates that were available at the Project and were consistent with variables that potentially influenced collection and passage of juvenile salmonids at other fish collection and guidance structures (Adams and others, 2015; Smith and Adams, 2015; Beeman and others, 2016). The covariates considered in the modeling included bull trout-size fish presence (Present=1, Absen =0), bull trout-size fish count (count per hour), photoperiod (Light=1, Dark=0), powerhouse discharge (in cubic feet per second), temperature in degrees Celsius (USGS streamgage 14210000), and hour of day. Interaction terms that were biologically or physically sensible also were evaluated. Turbidity and reservoir elevation are other factors that could affect passage at the FSC; however, in this system at the time of our study, both turbidity and reservoir elevation were essentially stable. Thus, following initial investigations of influence, we did not include either of these covariates in further analysis. Conversely, we also modeled the presence and absence of hourly observations of bull trout-size fish near the entrance to the FSC to identify if the presence of PIT-tagged salmonids influenced the likelihood of presence. Identical covariates used in the previous model were available for selection. Model selection was based on Akaike Information Criterion (AIC, Akaike, 1973; Burnham and Anderson, 2002), and model goodness of fit was evaluated using the Hosmer-Lemeshow goodness of fit test (Hosmer and Lemeshow, 2000). Additionally, the area under the receiver operator characteristic (ROC) curve (AUC) was estimated to determine model predictive accuracy (Hosmer and Lemeshow, 2000).

In addition to logistic regression, we also explored using a zero-inflated Poisson regression and a zero-inflated negative binomial regression (because of a high count of zero observation values) to model the hourly counts of bull trout-size fish observed with the acoustic cameras and PIT-tagged juvenile salmonids collected at the FSC. Both regressions are useful for modeling count variables that contain excessive zeros, and a zero-inflated negative binomial regression is used when there are overdispersed count outcome variables. Hourly counts of PIT-tagged fish and bull trout-size fish were used as response variables. All aforementioned covariates were available for use in these zero-inflated regressions.

Results

Definition of Study Periods

The acoustic camera study period was from April 25 to July 7, 2016. Data collection was interrupted only when cameras were repositioned or underwent general maintenance, or when equipment malfunctioned. Because few PIT-tagged juvenile salmonids were available for collection and detection after about mid-June, the period for acoustic camera data analysis was further shortened to include dates between April 26 and June 15, 2016. During this time period, 17 dates were included in the analysis for the shallow acoustic camera, and 24 dates were included for the deep acoustic camera. Dates were randomly selected for analysis, and only dates with complete data files for each 24-h period were included.

Dam Operations and Environmental Conditions

Dam operations and environmental conditions followed typical seasonal patterns. Powerhouse discharge decreased throughout the study period, coinciding with river flows (fig. 5). Mean hourly powerhouse discharge was 1,367.2 ft^3/s (range 283.6–3,105.1 ft^3/s; table 1). The reservoir elevation was maintained at a constant daily elevation of nearly 665 feet above National Geodetic Vertical Datum of 1929 (NGVD 29) for the entirety of the study, with a 0.3-ft fluctuation. Water temperature generally increased through the study period, with a peak at 16.5 °C on June 10, 2016, whereas the minimum water temperature of 8.4 °C occurred on April 27, 2016. The FSC and the migrant channel operated uninterrupted during the entirety of this study, and the spillway remained closed.

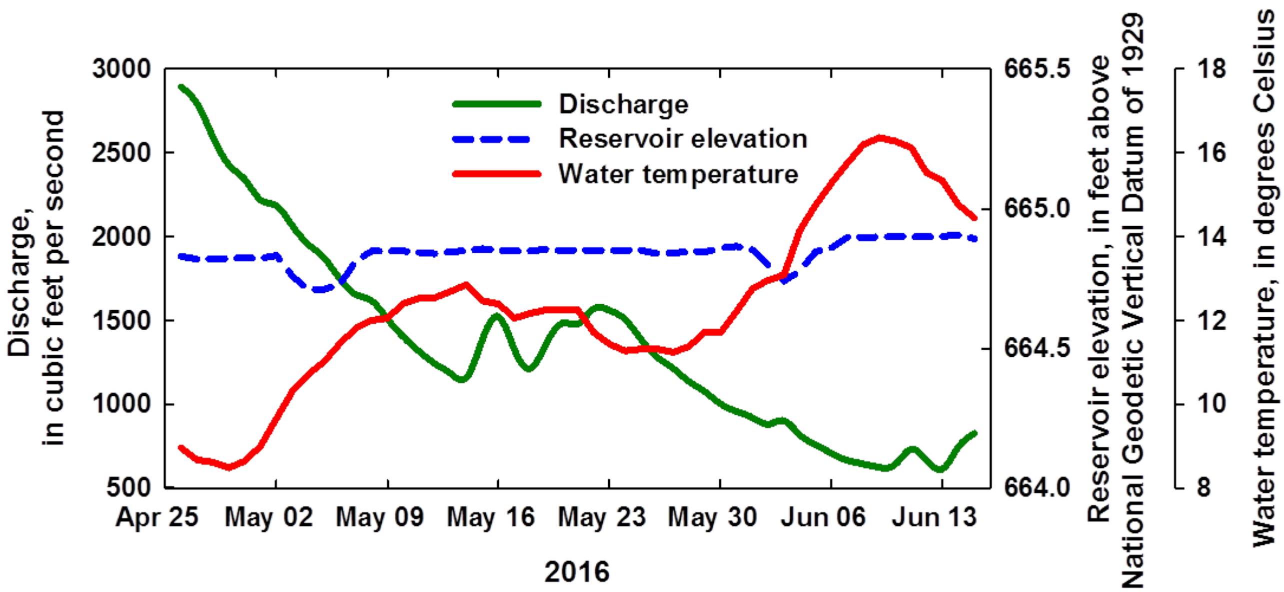

Figure 5. Graph of project discharge, reservoir elevation, and water temperature at North Fork Dam, Oregon, April 26–June 15, 2016.

Table 1. Summary statistics of hourly dam operations and environmental conditions at North Fork Dam, Oregon, April 26–June 15, 2016.

[SD, standard deviation; ft^3/s, cubic foot per second]

Dam operating conditions	Mean	Median	Range	SD
Powerhouse discharge (ft^3/s)	1,367.2	1,295.1	283.6–3,105.1	591.4
Forebay elevation (feet)	664.8	664.8	664.7–664.9	0.05
Water temperature (degrees Celsius)	12.3	12.2	8.4–16.5	2.1

PIT-Tag Detections Following FSC Collection

The collection and subsequent detection of PIT-tagged juvenile coho salmon and steelhead that passed through the FSC was composed of wild-origin fish that were released into the reservoir in 2016. These juvenile salmonids were collected from April 11 through June 26, 2016 (fig. 6). A total of 923 PIT-tagged juvenile salmonids were collected. Over the study period, the daily collection of PIT-tagged salmonids ranged from 1 to 61. A thorough description and findings of all PIT-tag studies conducted at the North Fork Project in 2016 is available in Ackerman and Pyper (2017).

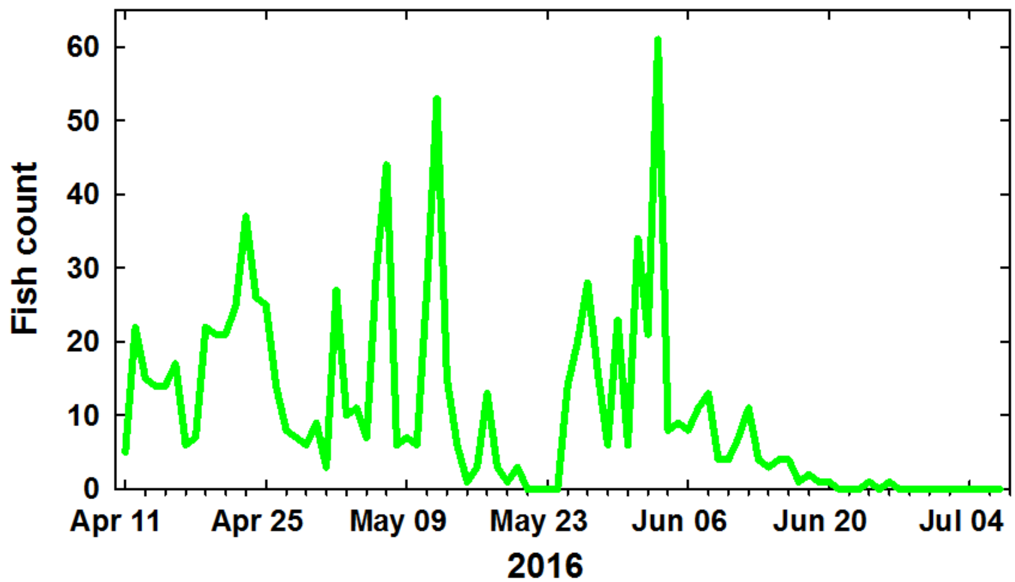

Figure 6. Graph showing daily counts of passive integrated transponder-tagged juvenile salmonids detected following collection by the floating surface collector at North Fork Reservoir, Oregon, 2016.

Fish Abundance

Data from the acoustic cameras indicate that bull trout-size fish abundance near the entrance of the FSC varied with depth and as the season progressed (fig. 7). Abundances of fish observed on the deep camera generally were lowest during late-April and early-May, and trended upward to a peak abundance of 754 fish on May 30, before decreasing again through mid-June. Fewer fish were observed on the shallow camera; however, the daily abundance trends of fish observed with the shallow camera generally mimicked that of the deep camera through mid-May, then remained at less than 100 fish per day for the rest of the season. Observations of PIT-tagged salmonids collected by the FSC during this time generally were stable, with a mean daily collection of nearly 13 fish. Abundances between bull trout-size fish observed with the acoustic cameras and PIT-tagged salmonids collected by the FSC are not directly relatable, as fish observed with the acoustic cameras have the opportunity to be sampled multiple times, whereas PIT-tagged salmonids are only detected once they have become fully entrained and are not available for resampling.

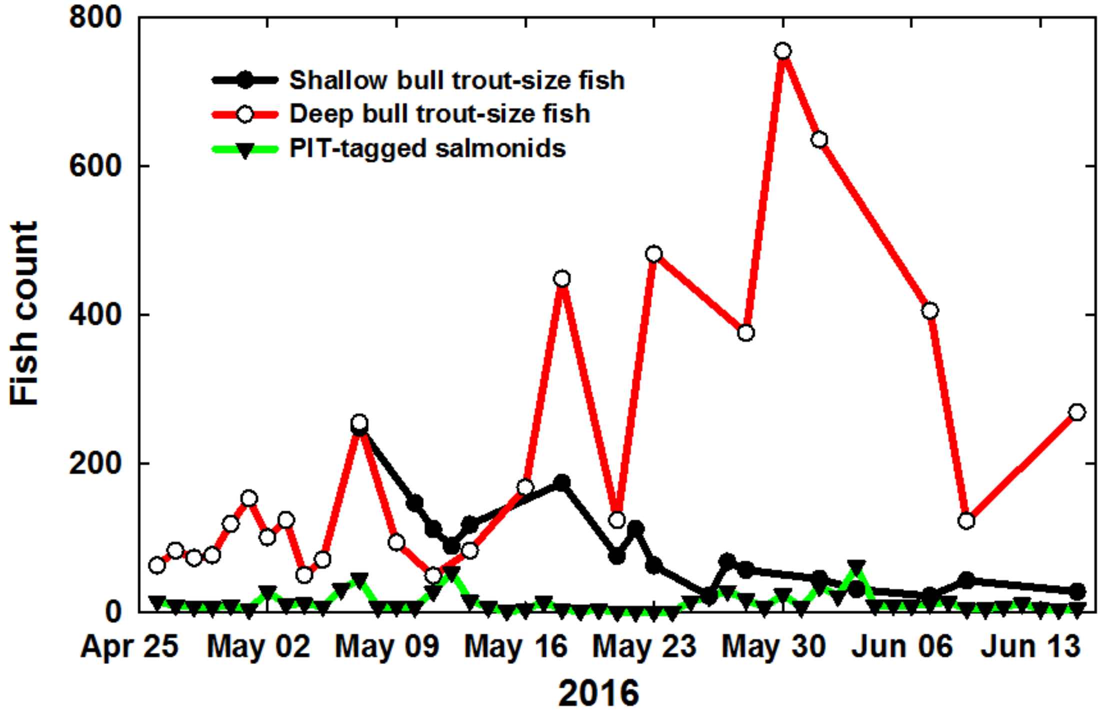

Figure 7. Graph showing daily count of bull trout-size fish on the date of detection using the acoustic cameras and count of passive integrated transponder (PIT)-tagged juvenile salmonids following collection at the floating surface collector at North Fork Reservoir, Oregon, 2016.

Direction of Travel for Bull Trout-Size Fish

The predominant direction of travel for bull trout-size fish in the acoustic beams generally was similar between the cameras mounted at the two depths (table 2). For fish observed on the shallow camera, the direction of fish movement had a diametrically bimodal distribution, with movement significantly (Rayleigh $P<0.001$) directed lateral to the entrance to the FSC (fig. 8). Bull trout-size fish observed with the deep acoustic camera had travel paths that were more circular than those observed on the shallow-mounted camera (fig. 9), and with a significant (Rayleigh $P<0.001$) primary direction of travel that was lateral to the entrance of the FSC and toward the dam.

Table 2. Mean travel directions and concentration parameters for bull trout-size fish observed using the acoustic cameras outside of the floating surface collector at North Fork Reservoir, Oregon, 2016.

[Headings of the acoustic cameras are normalized to 0 degrees. Sample size is the number of fish observation events with the acoustic camera, not necessarily the number of individual fish, because a given fish could be observed more than once. m, meters; *N*, sample size; μ, mean travel direction (in degrees) of the fish; SE, standard error; κ, concentration parameter.]

Camera location	Camera depth (m)	Days processed	*N*	μ (SE)	κ (SE)
Shallow	1.2	17	1,438	19.9/199.9 (2.03)[1]	1.13(0.05)
Deep	4	24	5,159	182.6 (1.76)	0.66 (0.02)

[1]Because of bimodal distribution, data were transformed (not shown) in accordance with Zar (1999), with μ resulting in an axial distribution.

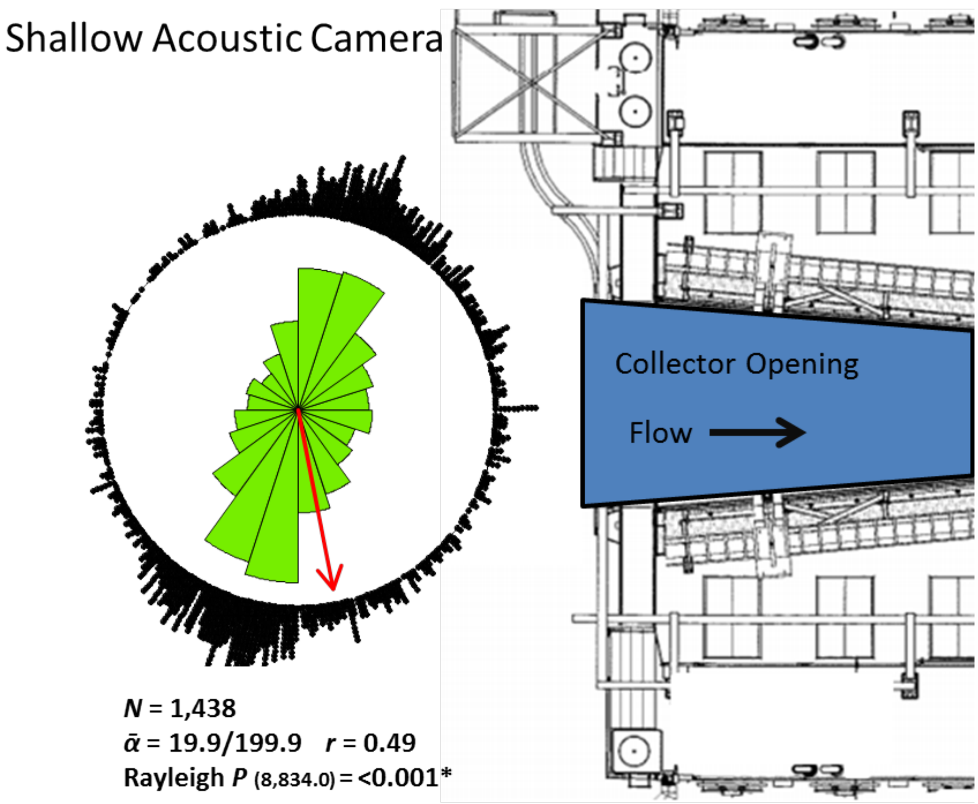

Figure 8. Rose diagram of mean travel directions (in degrees) for bull trout-size fish detected using the shallow acoustic camera outside the floating surface collector at North Fork Reservoir, Oregon, 2016. Heading of the acoustic camera is normalized to 0 degrees (top). Sample sizes represent the number of fish (*N*) observed. Mean vector (ᾱ) and mean vector resultant length (*r*) are described by arrows. Rayleigh *P* indicates significance level according to Rayleigh *z* test statistic (in parenthesis). *Because of a bimodal distribution, data were transformed (not shown) in accordance with Zar (1999).

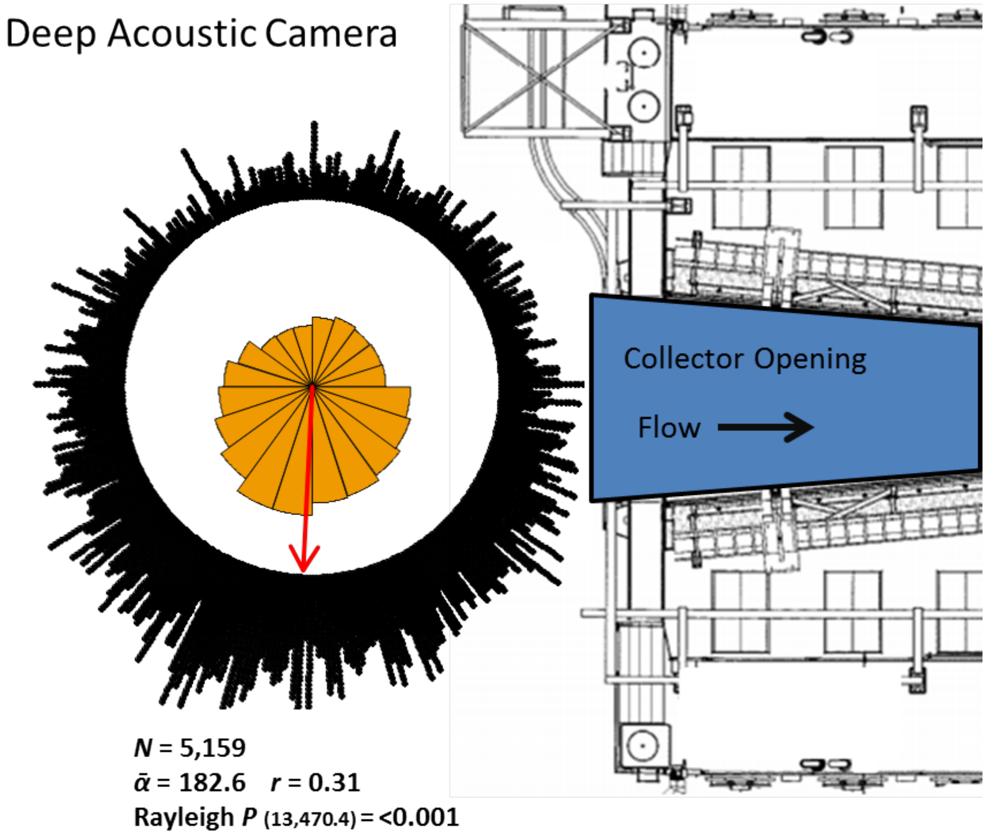

Figure 9. Rose diagram of mean travel directions (in degrees) for bull trout-size fish detected using the deep acoustic camera outside the floating surface collector at North Fork Reservoir, Oregon, 2016. Heading of acoustic camera is normalized to 0 degrees (top). Sample sizes represent the number of fish (*N*) observed. Mean vector (ᾱ) and mean vector resultant length (*r*) are described by arrows. Rayleigh *P* indicates significance level according to Rayleigh *z* test statistic (in parenthesis).

Fish Velocity and Tortuosity

The speed at which bull trout-size fish traveled in the area upstream of the FSC differed between fish observed at the two camera depths (table 3; fig.10). For example, the mean swimming velocity of fish was 0.25 ft/s (interquartile range [IQR]=0.17) for fish observed on the shallow camera, and 0.08 ft/s (IQR=0.06) for fish observed on the deep camera (table 3). These differences in fish swimming speed were significant between camera depths (ANOVA; $F_{1,\,6{,}595}$=4,332.0, P<0.001).

The tortuosity index indicated that the tracks of bull trout-size fish near the FSC entrance differed depending on observation depth (table 3; fig.10). Tracks of fish observed with the shallow camera were more linear, with a mean tortuosity index of 3.23 (IQR=1.39), whereas the tracks of fish observed on the deep camera had a mean tortuosity index that was about twice as much (6.44, IQR=4.68). These differences were significant between camera depths (ANOVA; $F_{1,\,6{,}595}$=48.2, P<0.001). These results indicate that fish observed with the shallow camera traveled faster and with straighter tracks than those fish observed with the deep camera, indicating that deeper fish were showing greater milling behavior whereas shallow fish had faster and more directed movement.

Table 3. Summary statistics for the swimming velocity and tortuosity of detection of bull trout-size fish observed using ARIS® acoustic cameras outside the floating surface collector at North Fork Reservoir, Oregon, 2016.

[Sample size is the number of fish observation events with the acoustic cameras, not necessarily the number of individual fish, because a given fish could be observed more than once. *N*, sample size; SD, standard deviation; IQR, interquartile range; m/s, meter per second; s, second; <, less than]

Camera	*N*	Mean	SD	IQR	Minimum	25th percentile	50th percentile	75th percentile	Maximum
Swimming velocity (m/s)									
Shallow	1,438	0.25	0.13	0.17	0.03	0.15	0.23	0.32	0.88
Deep	5,159	0.08	0.07	0.06	<0.01	0.03	0.05	0.09	0.86
Tortuosity index									
Shallow	1,438	3.23	10.47	1.39	1.00	1.20	1.53	2.59	348.13
Deep	5,159	6.44	16.59	4.68	1.00	1.56	2.85	6.23	564.40

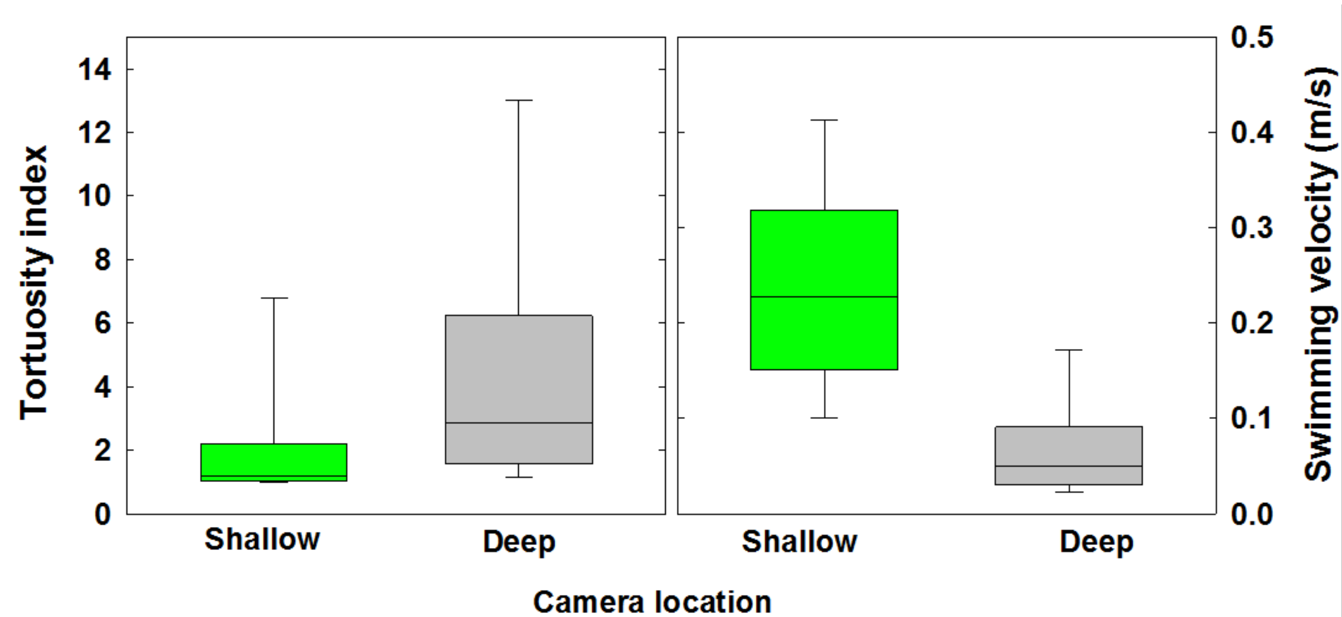

Figure 10. Boxplots of the tortuosity index and swimming velocity by camera depth of bull trout-size fish observed with ARIS® acoustic cameras near the entrance to the floating surface collector in the North Fork Reservoir, 2016. Boxes range from the 25th to the 75th percentiles, with lines indicating the medians and whiskers representing 10th and 90th percentiles.

Timing of Detection

The counts of bull trout-size fish observed with the acoustic cameras near the entrance to the FSC differed by time and camera depth (fig. 11). For fish observed on the deep camera, counts were lowest during periods of darkness, and increased beginning with the morning crepuscular period (5:00 a.m.) through midday. Following midday, fish counts decrease, and increase again at about 5:00 p.m., which is about when the entrance to the FSC begins receiving shade from the sun provided by the FSC structure. Following 5:00 p.m., fish counts gradually decrease along with decreasing light down to nighttime levels.

Similar to counts of fish observed with the deep camera, counts of fish observed with the shallow camera generally were low during the night, and began increasing with the morning crepuscular period. Throughout the remainder of the daylight hours, counts of fish viewed on the shallow camera remained relatively stable whereas counts of fish on the deep camera were elevated, possibly indicating that fish moved deeper in the water column with increasing daylight.

The counts of PIT-tagged juvenile salmonids detected following collection by the FSC did not show as much timing variability as the fish observed by the acoustic cameras (fig. 11). Detections for PIT-tagged juvenile salmonids were at their lowest during the 7:00–8:00 a.m. time period, before rising and then remaining stable throughout the day. In the early evening (5:00–7:00 p.m.) detections again decreased, coinciding with the time period when bull trout-size fish incidence was elevated.

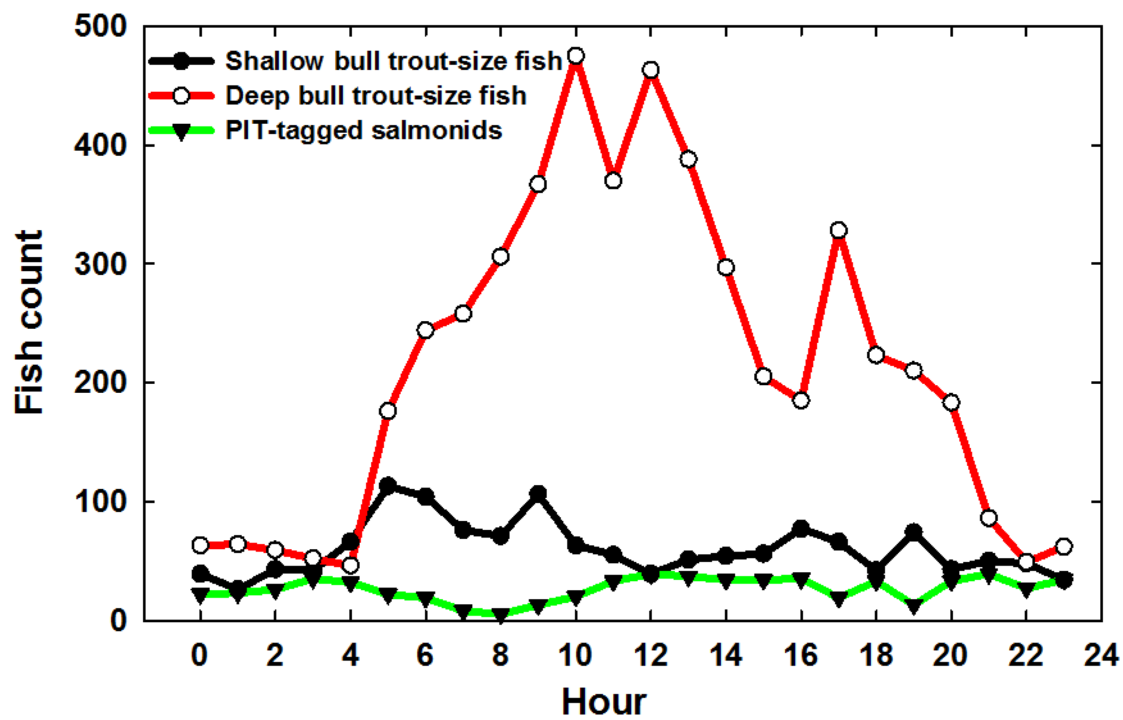

Figure 11. Graph showing count of bull trout-size fish by hour of detection using the ARIS® acoustic camera and count of passive integrated transponder (PIT)-tagged juvenile salmonids detected immediately following collection at the floating surface collector at North Fork Reservoir, Oregon, April 26–June 15, 2016.

Spatial Fish Distribution

The spatial distributions of bull trout-size fish tracks near the entrance of the FSC varied by depth of observation. The fish density data includes 6,597 individual tracks that were recorded by the acoustic cameras. Observations recorded by the shallow camera showed fish tracks that primarily were spread across the entire width of the FSC entrance, with a concentration nearer to the dam-side of the entrance (fig. 12). These observations primarily were on the right one-half of the camera view. The comparative spatial density of fish that were observed with the deep acoustic camera differed from observations from the shallow camera in both concentration and location (fig. 13). Fish tracks recorded by the deep camera were concentrated on the reservoir side of the collector entrance and centered on the middle of the view of the acoustic camera, thereby at a slightly farther distance from the entrance of the FSC.

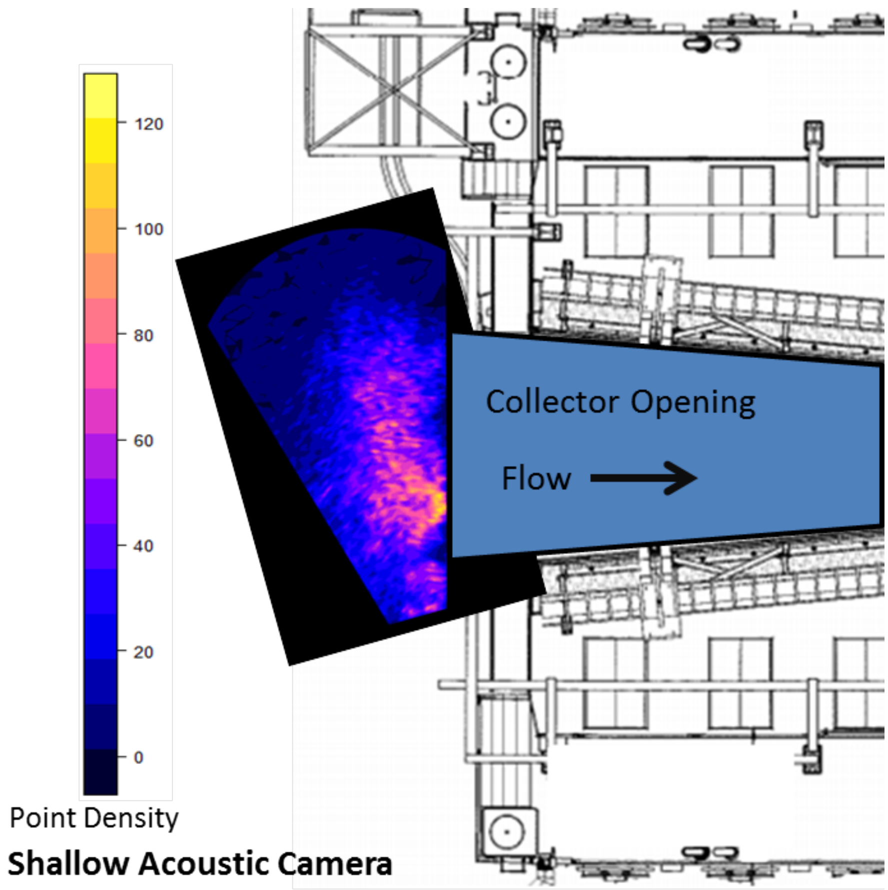

Figure 12. Graph showing relative point density for bull trout-size fish detected using the shallow acoustic camera outside of the entrance to the floating surface collector at North Fork Reservoir, Oregon, 2016.

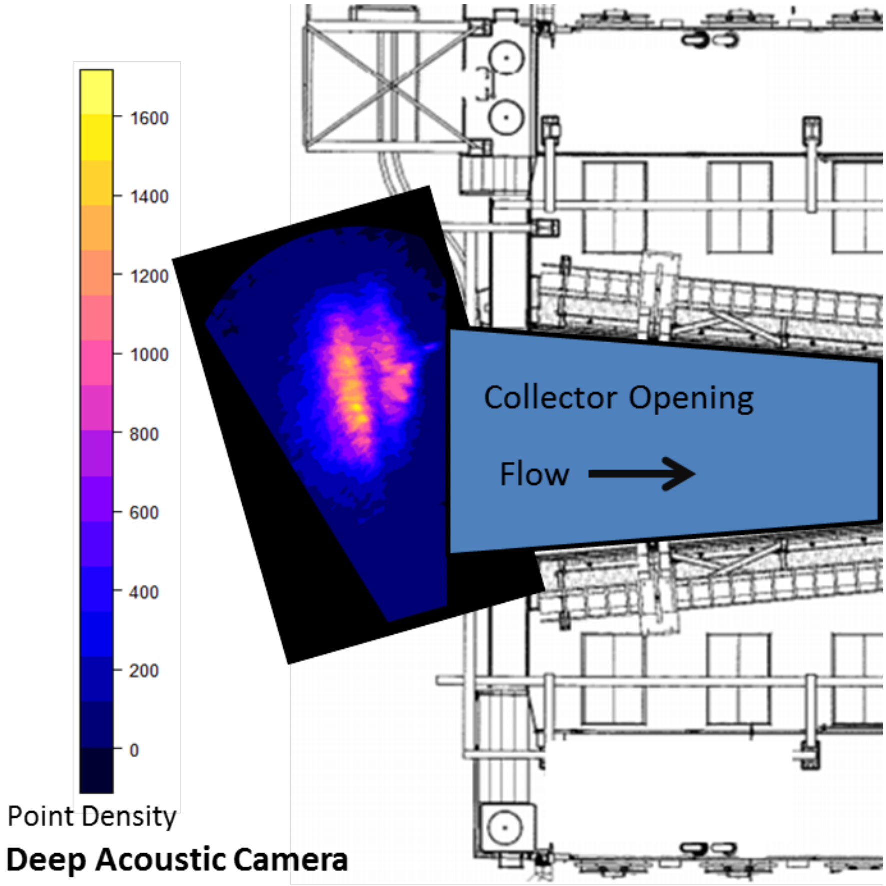

Figure 13. Graph showing relative point density for bull trout-size fish detected using the deep acoustic camera outside of the entrance to the floating surface collector at North Fork Reservoir, Oregon, 2016.

Modeling PIT-Tagged Salmonids/Bull Trout-Size Fish Presence

Modeling the potential effects of the presence of bull trout-size fish on the likelihood of collection or rejection of PIT-tagged juvenile salmonids at the FSC proved inconclusive, as were models identifying the effects of PIT-tag fish presence on bull trout-size fish observations. All logistic regression models had poor to virtually no predictive power. Although Hosmer-Lemeshow goodness of fit tests were not significant (P=0.06 -0.12), the area under the receiver operator characteristic (ROC) curves was never better than 0.64, indicating poor predictive power of all models. Zero-inflated regression models predicting hourly counts of PIT-tagged salmonids and bull trout-size fish were equally poor, with lack of significance of covariates and little predictive power. Because of the inconclusiveness of model results, model selection and diagnostics will not be further described. Although the models themselves were inconclusive, effects plots generated from these covariates provide some indication as to why these results occurred (figs. 13 and 14).

Effects plots of the presence of PIT-tagged juvenile salmonids (fig. 14) indicate that presence of bull trout-size fish positively influenced the collection of PIT-tagged salmonids when counts of bull trout-size fish were less than about 50 observations per hour, then negatively influenced collection when counts were greater than about 50 observations per hour. However, these high counts of bull trout-size fish were rare, representing less than 3 percent of the total hourly observations. As was seen in the hourly abundance (fig. 11), presence generally was less during hours of daylight, and slightly greater during hours of darkness. Water temperature did show some influence on the presence of PIT-tagged fish, with positive effects occurring at temperatures between about 9 and 14 °C. This is not surprising, as these temperatures were present during most of the study period (see fig. 5). Finally, powerhouse discharge had very little influence on the collection of PIT-tagged salmonids at the FSC.

Effects plots of the presence of bull trout-size fish (fig. 15) indicate that the hourly counts or presence of PIT-tagged juvenile salmonids had little influence on bull trout-size fish presence. As was observed for hourly abundance (fig. 11), a positive effect was observed during hours of daylight, but a negative effect was observed during hours of darkness. Effects of water temperature and powerhouse discharge on the presence of bull trout-size fish were similar to their effects on the presence of for PIT-tagged salmonids, for the same reasons.

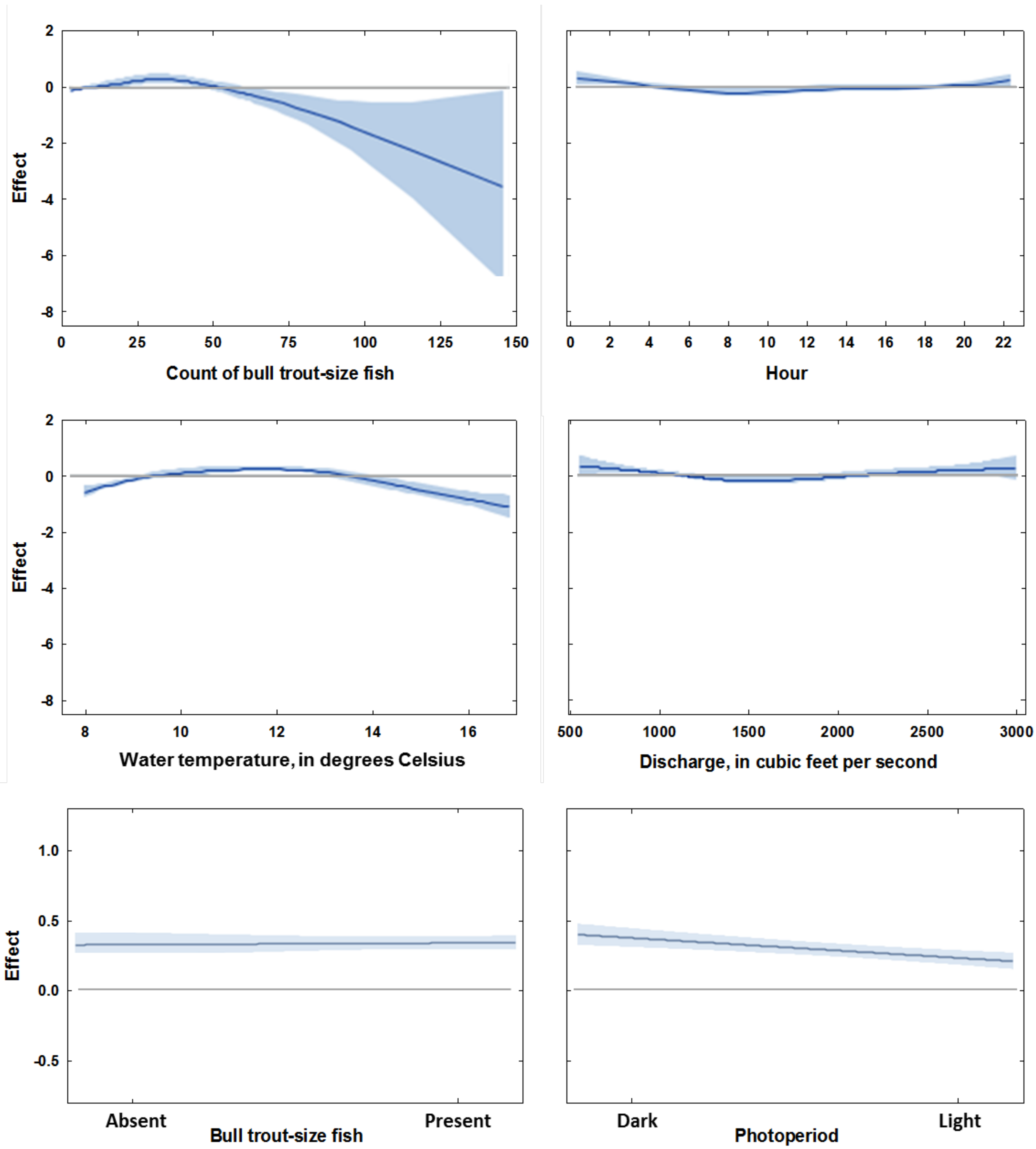

Figure 14. Effects plots of covariates used for modeling the presence of passive integrated transponder (PIT)-tagged juvenile salmonids at the floating surface collector at North Fork Reservoir, Oregon, 2016. Shaded bands indicate the 95-percent confidence intervals.

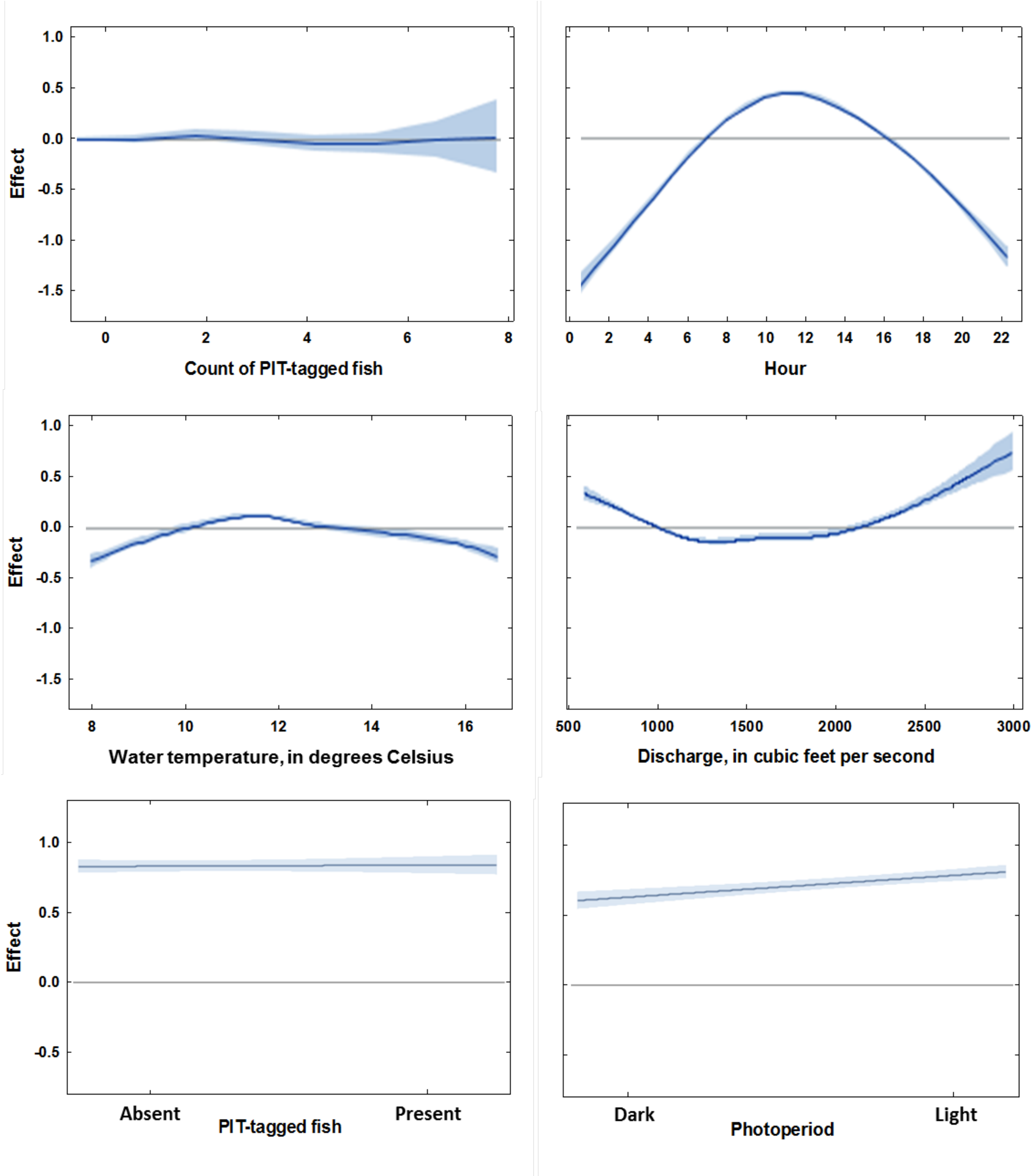

Figure 15. Effects plots of covariates used for modeling the presence of bull trout-size fish near the entrance to the floating surface collector at North Fork Reservoir, Oregon, 2016. Shaded bands indicate the 95-percent confidence intervals.

Discussion

Historically, acoustic camera technology has been used to obtain primarily qualitative data for summarizing trends in fish movement, along with estimating abundance. In this study, we used acoustic cameras and numerous analytical methods to provide quantitative assessments of predatory-size fish movements near the entrance to a FSC that was designed to capture downriver migrating salmonids. We were interested in determining how these fish were influenced by the FSC and environmental factors such as photoperiod, discharge, water temperature and depth, and the presence of potential prey items. Results of this study indicate that the acoustic camera technology was capable of monitoring bull trout-size fish near the FSC. This analysis enabled us to characterize fish behaviors, abundance, and movements near the FSC, and provided useful insights for enhancing future deployments of acoustic camera technology around fish collection structures.

The FSC at North Fork Reservoir is one of several surface collectors in use at storage dams in the Pacific Northwest. 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); Round Butte Dam at Lake Billy Chinook, Oregon (Portland General Electric); Cougar Dam on the McKenzie River, Oregon (U.S. Army Corps of Engineers); and Cushman Dam No.1 on the North Fork of the Skokomish River, Washington (Tacoma Power). Of these collectors, the facilities at North Fork Reservoir, Lake Billy Chinook, and Cougar Dam are known to have bull trout in close proximity to the surface collectors (McIlvaine, 2015; Beeman and others, 2016). However, bull trout typically are bottom dwellers (Scott and Crossman, 1973) and are highly substrate-oriented (Pratt, 1984), neither of which are available near the entrances to these surface collectors, possibly indicating that these structures may provide increased feeding opportunities for predators.

An advantage of using acoustic cameras is the ability to observe untagged fish 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 acoustic cameras include the lack of species specificity, the possibility of counting individuals multiple times, difficulty in observing small targets (less than about 30 mm in length), acoustic noise or attenuation produced in some environments, and difficulty in positively identifying predation attempts or success. Additionally, the time required to process the large volume of acoustic camera data into meaningful results also can be burdensome, but much of the process was automated to reduce the time required and to increase the volume of data used for analysis. In the case of this FSC study, we assume that most fish that were 350–700 mm long were bull trout, and those greater than 700 mm long likely were upriver-migrating adult salmonids. Given that this uncertainty may exist, we determined that camera depth was an important factor in abundance and behavioral differences for bull trout-size fish observed near the entrance to the FSC.

Data from the ARIS® acoustic cameras indicated that the daily number of observations of bull trout-size fish near the entrance to the FSC was greater on the deep camera than on the shallow camera. During peak abundances observed in early June, daily abundances were as much as eight times greater for the deep camera than for the shallow camera. Additionally, there were differences in the diel abundance of bull trout-size fish near the entrance to the FSC. For both camera depths, counts were lowest during periods of darkness, followed by increases during the morning crepuscular periods, with the greatest abundances observed on the deep camera during midday. Fluctuating intensities of sunlight and darkness contribute to changes in the underwater photic environment and may be coupled with modifications in fish behavior and habitat use (Hobson and others, 1981). Diel shifts in habitat use, and especially water depth, have been observed for bull trout (Sexauer and James, 1997; Thurow, 1997; Muhlfeld and others, 2003). Bull trout also have been shown to avoid high light intensities (Goetz, 1994, 1997; Swanberg, 1997), and our observations of greater abundances of bull trout-size fish on the deep camera during the daytime indicate that these fish are using the shade provided by the FSC structure as cover in conjunction with using depth to evade sunlight. Reduced abundances of bull trout-size fish during hours of low light suggest that the FSC is being used as a prey ambush location during the daytime.

Additional behavioral differences were observed for fish at the two camera depths. Bull trout-size fish observed with the shallow camera predominantly moved in directions lateral to the entrance of the FSC, whereas movements of fish observed with the deep camera were more circular, but primarily directed lateral to the entrance of the FSC and toward the dam. The swim speed and tortuosity of fish observed on the shallow camera were faster and straighter than those of fish observed on the deep camera. A reduced uniform direction of travel, slow swim speed, and increased tortuosity of fish observed on the deep camera indicate that fish may be showing greater milling behavior, which has been observed at other fish passage structures (Beeman and others, 2014, 2016; Adams and others, 2015). We also observed differences in the spatial use of the habitat near the entrance to the FSC. Shallow fish primarily were located along the edge of the entrance and spread across its entirety, whereas deep fish were farther from the entrance (1–4 m) and congregated at the side of the entrance farthest from the dam. It is unknown if differences in the flow field, current velocities, or increased prey ambush opportunities contributed to these differences.

PIT-tagged fish released in the reservoir provided collection information as a surrogate for run-of-the-river juvenile salmonids. Releasing PIT-tagged fish of a size commensurate with wild fish at the time of release enabled timing of collection to be estimated. Detections for PIT-tagged juvenile salmonids decreased immediately following the morning crepuscular period, as abundances of bull trout-size fish were rapidly increasing. Predation likely is increased during the daytime because prey fish are more readily noticed by piscivorous predators (Olla and Davis, 1990). Thus, factors such as predation risk can alter the diel activity patterns of juvenile salmonids (Sundström and others, 2003; Beeman and Maule, 2006; Adams and others, 2015), and we show that collection of PIT-tagged juvenile salmonids potentially was influenced by time of day and the number of bull trout-size fish observed in the acoustic beams. Khan and others (2012) found that predator abundance increased near a fish passage structure when juvenile salmonid abundances increased, and correspondingly decreased with decreased juvenile salmonid abundances. It is difficult to discern if the collection of PIT-tagged salmonids at the FSC increased irrespective of bull trout presence, or if bull trout-size fish abundances increased corresponding to the increased abundance of potential prey items. It is not known if PIT-tagged salmonid passage would have been greater in the absence of bull trout-size fish, as that rarely occurred during this study.

In summary, although there were challenges involved in collecting, processing and analyzing the large volume (6 terabytes) of continuous data obtained by the acoustic cameras, this technology was an informative tool for assessing the spatial and temporal behaviors of bull trout-size fish near the entrance of the FSC. Results of modeling potential predator-prey interactions and influences proved largely unpredictable at such fine space and time scales. The area ensonified by the beams of the acoustic cameras was limited relative to the size of the near-FSC area. Additionally, the quantity of PIT-tagged juvenile salmonids available for collection may have been inadequate to provide a sufficient sample size for modeling for the duration of the study. Nonetheless, PIT-tagged salmonids did provide relevant information on collection timing and abundance. Despite these limitations, we were able to provide empirical information about the presence, movement, and behaviors of bull trout-size fish near the entrance to the FSC. We were able to identify the presence of bull trout-size fish at the entrance to the FSC in conjunction with the presence of PIT-tagged juvenile salmonids. These results can be used to help inform decisions about collection and passage solutions for juvenile salmonids at the FSC, as well as to identify the potential for predation by bull trout near the FSC entrance.

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References Cited

Ackerman, N.K., and Pyper, B., 2017, Evaluation of juvenile salmonid passage through the North Fork hydroelectric development, 2016 Progress Report, Clackamas River Project (FERC No. 2195) Appendix D, Article 32(b), and Appendix E, Article 32(a): Prepared by Portland General Electric, 54 p.

Adams, N.S., Smith, C.D., Plumb, J.M., Hansen, G.S., and Beeman, J.W., 2015, An evaluation of fish behavior upstream of the water temperature control tower at Cougar Dam, Oregon, using acoustic cameras, 2013: U.S. Geological Survey Open-File Report 2015-1124, 62 p., accessed February 22, 2017, at https://pubs.er.usgs.gov/publication/ofr20151124.

Akaike, H., 1973, Information theory as an extension of the maximum likelihood principle, *in* Petrov, B.N., and Csaki, F., eds., Second International Symposium on Information Theory: Budapest, Akademiai Kiado, p. 267–281.

Barry, P.M., Hudson, J.M., Williamson, J.D., Koski, M.L., and Clements, S.P., 2014, Clackamas River bull trout reintroduction project, 2013 Annual Report: Oregon Department of Fish and Wildlife and U.S. Fish and Wildlife Service, 46 p.

Beeman, J.W., Evans, S.D., Haner, P.V., Hansel, H.C., Hansen, A.C., Hansen, G.S., Hatton, T.W., Sprando, J.M., Smith, C.D., and Adams, N.S., 2016, Evaluation of the biological and hydraulic performance of the portable floating fish collector at Cougar Reservoir and Dam, Oregon, 2014: U.S. Geological Survey Open-File Report 2016-1003, 127 p., accessed February 22, 2017, at https://pubs.er.usgs.gov/publication/ofr20161003.

Beeman, J.W., Hansel, H.C., Hansen, A.C., Evans, S.D., Haner, P.V., Hatton, T.W., Kofoot, E.E., Sprando, J.M., and Smith, C.D., 2014, Behavior and dam passage of juvenile Chinook salmon at Cougar Reservoir and Dam, Oregon, March 2012–February 2013: U.S. Geological Survey Open-File Report 2014-1177, 52 p., accessed February 22, 2017, at https://pubs.usgs.gov/of/2014/1177/.

Beeman, J.W., and Maule, A.G., 2006, Migration depths of juvenile Chinook salmon and steelhead relative to total dissolved gas supersaturation in a Columbia River Reservoir: Transactions of the American Fisheries Society, v. 135, no. 3, p. 584–594.

Boswell, K.M., Wilson, M.P., and Cowan, J.H., Jr., 2008, A semiautomated approach to estimating fish size, abundance, and behavior from dual-frequency identification sonar (DIDSON) data: North American Journal of Fisheries Management, v. 28, p. 799–807.

Burnham, K.P., and Anderson, D.R., 2002, Model selection and multimodel inference—A practical information-theoretic approach: New York, Springer-Verlag, 488 p.

Christensen, P., and Grant, P., 2015, North Fork Dam floating surface collector hydraulic evaluation report, Clackamas River Project (FERC No. 2195): Prepared for Portland General Electric, Portland, Oregon, by R2 Resource Consultants, Inc. and Alden Research Laboratory, Inc.

Federal Energy Regulatory Commission, 2006, Final environmental impact statement for the Clackamas River Hydroelectric Project, Clackamas County, Oregon (FERC Project No. 2195): Federal Energy Regulatory Commission, 216 p.

Goetz, F.A., 1997, Diel behavior of juvenile bull trout and its influences on selection of appropriate sampling techniques, *in* Mackay, W.C., Brewin, M.K., and Monita, M., eds., Friends of the bull trout conference proceedings, Trout Unlimited Canada, Bull Trout Task Force, Calgary, Alberta, Canada, p. 387–402.

Goetz, F.A., 1994, Distribution and juvenile ecology of bull trout (*Salvelinus confluentus*) in the Cascade Mountains: Corvallis, Oregon State University, Master's thesis , xv + 173 p.

Hobson, E.S., McFarland, W.N., and Chess, J.R., 1981, Crepuscular and nocturnal activities of Californian nearshore fishes, with consideration of their scotopic visual pigments and the photic environment: Fishery Bulletin, v. 79, p. 1–30.

Hosmer, D.W., and Lemeshow, S., 2000, Applied logistic regression: New York, Wiley, 375 p.

Johnson, R.L., and Moursund, R.A., 2000, Evaluation of juvenile salmon behavior at Bonneville Dam, Columbia River, using a multibeam technique: Aquatic Living Resources, v. 13, no. 5, p. 313–318.

Kang, M., 2011, Semiautomated analysis of data from an imaging sonar for fish counting, sizing, and tracking in a post-processing application: Fisheries and Aquatic Sciences, v. 14, no. 3, p. 218–225.

Khan, F., Johnson, G.E., Royer, I.M., Phillips, N.R., Hughes, J.S., Fischer, E.S., Ham, K.D., and Ploskey, G.R., 2012, Acoustic imaging evaluation of juvenile salmonid behavior in the immediate forebay of the water temperature control tower at Cougar Dam, 2010: Pacific Northwest National Laboratory report PNNL-20625, 50 p.

McIlvaine, P., 2015, Application review for low impact hydropower institute re-certification of the Pelton-Round Butte Project No. 2030: Wright-Pierce, 27 p., accessed February 21, 2017, at http://lowimpacthydro.org/wp-content/uploads/2007/03/Pelton-Round-Butte-Final-Report-Sept-2015.pdf.

Mardia, K.V., and Jupp, P.E., 2000, Directional statistics: Chichester, United Kingdom, Wiley, 492 p.

Muhlfeld, C.C., Glutting, S., Hunt, R., Daniels, D., and Marotz, B., 2003, Winter diel habitat use and movement by subadult bull trout in the Upper Flathead River, Montana: North American Journal of Fisheries Management, v. 23, no. 1, p. 163–171.

National Oceanic and Atmospheric Administration, 2008, Endangered Species Act section 7(a)(2) consultation biological opinion and Magnuson-Stevens Fishery Conservation and Management Act essential fish habitat consultation—Consultation on the Willamette River Basin Flood Control Project: National Oceanic and Atmospheric Administration Fisheries Log Number FINWRl2000/02117, June 11, 2008, 227 p., accessed February 22, 2017, at https://www.nwcouncil.org/media/15608/willamette_biop_final_part1_july_2008.pdf.

Olla, B.L., and Davis, M.W., 1990, Effects of physical factors on the vertical distribution of larval walleye pollock (*Theragra chalcogramma*) under controlled laboratory conditions: Marine Ecology Progress Series, v. 63, p. 105–112.

Pewsey, A., Neuhauser, M., and Ruxton G.D., 2013, Circular statistics in R (1st ed.): Oxford, United Kingdom, Oxford University Press, 208 p.

Pratt, K.P., 1984, Habitat use and species interactions of juvenile cutthroat and bull trout in the Upper Flathead River Basin: Moscow, University of Idaho, Master's thesis, xi + 95 p.

R Core Team, 2014, R—A language and environment for statistical computing: Vienna, Austria, Foundation for Statistical Computing, accessed 2014, at http:// www.R-project.org/.

Scott, W.B., and Crossman, E.J., 1973, Freshwater fishes of Canada, Bulletin 184: Fisheries Research Board of Canada, Ottawa, 966 p.

Sexauer, H.M., and James, P.W., 1997, A comparison of the microhabitat use by juvenile bull trout in four streams located in the eastern Cascades, Washington, *in* Mackay, W.C., Brewin, M.K., and Monita, M., eds., Friends of the Bull Trout Conference Proceedings: Bull Trout Task Force, Trout Unlimited Canada, Calgary, Alberta, p. 361–370.

Shively, D., Allen, C., Alsbury, T., Bergamini, B., Goehring, B., Horning, T., and Strobel, B., 2007, Clackamas River bull trout reintroduction feasibility assessment: U.S. Forest Service, Mount Hood National Forest for the Clackamas River Bull Trout Working Group, Sandy, Oregon, 253 p.

Simmonds, J. and MacLennan, D., 2005, Fisheries acoustics—Theory and practice (2d ed.): Oxford, United Kingdom, Blackwell Scientific Publications, 456 p.

Smith, C.D., and Adams, N.S., 2015, Re-Analysis of DIDSON camera data to assess fish behavior near the 2014 Georgiana Slough floating fish guidance structure: Data summary report to the California Department of Water Resources, 53 p.

Sundström, L.F., Devlin, R.H., Johnsson, J.I., and Biagi, C.A., 2003, Vertical position reflects increased feeding motivation in growth hormone transgenic coho salmon (*Oncorhynchus kisutch*): Ethology, v. 109, p. 701–712.

Swanberg, T., 1997, Movements and habitat use by fluvial bull trout in the Blackfoot River, Montana: Transactions of the American Fisheries Society, v. 126, p. 735–746.

Sweeney, C.E., Giorgi, A.E., Johnson, G.E., Hall, R., and Miller, M., 2007, Surface bypass program comprehensive review report: ENSR Corporation document number 09000-399-0409, 494 p.

Thurow, R.F., 1997, Habitat utilization and diel behavior of juvenile bull trout (*Salvelinus confluentus*) at the onset of winter: Ecology of Freshwater Fish, v. 6, p. 1–7.

U.S. Fish and Wildlife Service and Oregon Department of Fish and Wildlife, 2011, Clackamas River bull trout reintroduction implementation, monitoring, and evaluation plan, Portland, Oregon, 63 p.

Zar, J. H., 1999, Biostatistical analysis (4th ed.): Upper Saddle River, New Jersey, Prentice Hall, 663 p.

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