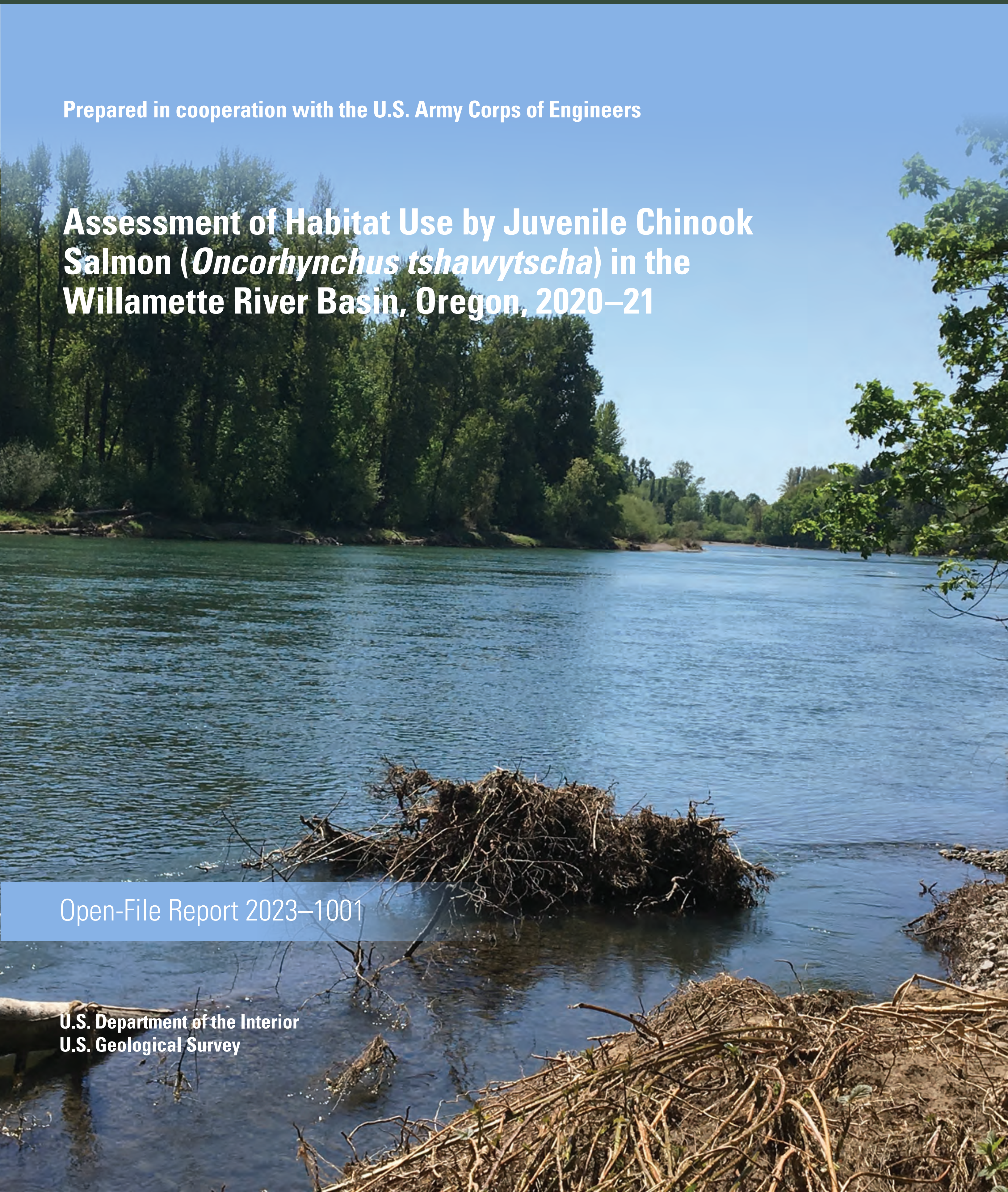

Prepared in cooperation with the U.S. Army Corps of Engineers

Assessment of Habitat Use by Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in the Willamette River Basin, Oregon, 2020–21

Open-File Report 2023–1001

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

Cover. The Willamette River near Harrisburg, Oregon. Photograph taken by Tobias Kock, U.S. Geological Survey, May 7, 2019

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)

Multiply	By	To obtain
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)
	Area	
square meter (m^2)	0.0002471	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

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

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C = (°F – 32) / 1.8.

Abbreviations

AIC_c	Akaike Information Criterion
AUC	area under the curve
RSF	resource selection function
rkm	river kilometer
SWIFT	Science of the Willamette Instream Flow Team
USGS	U.S. Geological Survey

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Abstract

We conducted a field study during 2020–21 to describe habitat use patterns of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the mainstem Willamette, McKenzie, and Santiam Rivers and to evaluate how habitat suitability criteria affected the predictive accuracy of a hydraulic habitat model. Two approaches were used to collect habitat use data: a stratified sampling design was used to ensure that a representative sample of available habitats was included in our sampling; and a targeted sampling design was used to collect additional data in habitat cells where juvenile Chinook salmon were observed. Habitat attributes and fish presence data were collected in habitat cells that were approximately 2 square meters during April, June, and July. A total of 632 cells were sampled during the study and included habitat located in the main channel (373 cells), side channels (228 cells), and in alcoves (31 cells). Juvenile Chinook salmon were observed in 42 percent of the cells located in the main channel, 38 percent of the cells located in side channels, and 7 percent of the cells located in alcoves. We used logistic regression to develop resource selection functions for April, June, and July, which produced probability-based predictions of habitat use for juvenile Chinook salmon based on water velocity and water depth. The resource selection functions revealed a habitat shift by juvenile Chinook salmon to locations with higher water velocities and greater water depths from April to July as juvenile Chinook salmon size increased. The resource selection functions that we developed are an important addition to habitat modeling in the Willamette River basin because they were developed from in-basin data, capture seasonal differences in habitat use, and facilitate probability-based estimates of habitat use for juvenile Chinook salmon. These advancements will improve habitat modeling efforts for juvenile Chinook salmon during spring and summer months within the Willamette River.

Introduction

Flow management is important for the U.S. Army Corps of Engineers which owns and operates the Willamette Project encompassing 13 dams located on large tributaries to the mainstem Willamette River in western Oregon. Resource managers consider multiple factors when making flow management decisions including considerations protecting and enhancing spring Chinook salmon (hereinafter referred to as Chinook salmon; *Oncorhynchus tshawytscha*) and winter steelhead (*Oncorhynchus mykiss*) populations. The species are native to the Willamette River Basin and are listed as threatened under the U.S. Endangered Species Act (National Oceanic and Atmospheric Administration, 2021). Flow management can have important effects on fish populations migrating and rearing downstream of Willamette Project dams by altering available habitat, migration timing and water temperature. Thus, for effective decision-making, it is important to understand how flow releases from Willamette Project dams influence these variables in the Willamette River Basin (R2 Resource Consultant, Inc., 2014; River Design Group, Inc., and HDR, Inc., 2015; Bond and others, 2017; Whitman and others, 2017).

The U.S. Geological Survey (USGS) has provided substantial scientific support to managers tasked with flow management decision-making in the Willamette River Basin (Rounds, 2010; Buccola and others, 2016; Peterson and others, 2021; Stratton Garvin and Rounds, 2022), including a recently completed review of existing datasets and studies and an overview of existing research approaches that could be used to improve the understanding of flow-management effects on salmon and steelhead habitat in the basin (Kock and others, 2021). In this review, the authors identified a lack of in-basin habitat use data as a key data gap to be addressed to improve future river flow and habitat modeling (Kock and others, 2021). Additionally, USGS has developed a hydraulic habitat model that predicts habitat availability for Chinook salmon and steelhead in the mainstem Willamette River and primary tributaries (North Santiam and McKenzie Rivers) across a range of streamflow conditions (White and others, 2022). The hydraulic habitat model used water depth and water velocity data across a range of river flow scenarios and habitat suitability criteria to predict habitat availability for juvenile Chinook salmon and steelhead (Peterson and others, 2021; White and others, 2022). Habitat use data for juvenile Chinook salmon and steelhead in the Willamette River Basin were very limited when the model was developed, so a literature review was conducted to establish a range of water depth and velocity values for these fish, based on data collected in other rivers (Peterson and others, 2021; White and others, 2022). Based on this literature review, White and others (2022) developed three sets of habitat suitability criteria (Narrow, Median, Broad) to classify modeled cells as useable. Individual cells with water velocity or water depth values that fell outside of these criteria ranges were classified as unusable. We conducted a study to advance these modeling efforts and fill a key data gap in the Willamette River Basin by collecting in-basin habitat use data for juvenile Chinook salmon. These data allowed us to assess habitat suitability criteria from White and others' (2022) hydraulic habitat model to predict the presence of juvenile Chinook salmon while also advancing the state-of-knowledge on habitat use in the Willamette River Basin. The data were additionally used to characterize habitat use in three categories based on location in the river: main channel, side channel, and alcove—an area with downstream connection to the main channel that lacks upstream connection to the river as flow decreases. Finally, the data were modeled using logistic regression to create a resource selection function for comparison to the habitat suitability criteria used in the hydraulic habitat model. This comparison allowed us to illustrate differences between habitat definitions derived from literature-based and in-basin suitability criteria. Data collection occurred during spring and early summer 2020 and 2021, and this report summarizes results from those efforts.

Methods

Study Area

Sampling was conducted in the mainstem Willamette River and lower reaches of the North Santiam and McKenzie Rivers. Sampling occurred on the mainstem Willamette River between the mouth of the McKenzie (river kilometer [rkm] 281) and Santiam (rkm 167) Rivers. Data collection on the North Santiam River occurred in the reach between the Jefferson Bridge Float Launch (rkm 6) and the Stayton Bridge County Boat Ramp near Stayton, Oregon (rkm 27). On the McKenzie River, sampling occurred in the reach between the Hendricks Bridge County Park Boat Ramp (rkm 33) and Taylor Landing (rkm 41; fig. 1). Sampling reaches were selected to ensure data were collected in river reaches where hydraulic habitat model (White and others, 2022) predictions were available.

Sampling Designs

Fish use and habitat data were collected using two approaches. A stratified sampling design was used to ensure that the distribution of available habitat was adequately represented in our sampling and to provide data suitable for validating the performance of the White and others (2022) hydraulic habitat model. Additionally, a targeted sampling design was used to ensure that we collected sufficient habitat data at locations where juvenile Chinook salmon were observed. For both approaches, we collected fish use and habitat data in individual 2 square meters (m^2) sites (hereinafter referred to as "cells").

Stratified Sampling Design

To implement the stratified sampling design, we used outputs from the hydraulic model of White and Wallick (2022) to identify and characterize habitat conditions for sampling locations. Prior to each sampling period, we input predicted streamflow into the hydraulic model to predict water depths and velocities predicted at the sampling location (an approximately 1.6 kilometer [km] section of river). We then proportionally distributed 40 cells into 9 water depth and water velocity groups constrained by expected sampling limitations (fig. 2). Cells were assigned equally (20 each) to 2 categories using classifications aligned with the Science of the Willamette Instream Flow Team (SWIFT; DeWeber and Peterson, 2020; Peterson and others, 2022) median criteria for pre-smolt (>60 millimeters [mm]) juvenile Chinook salmon to represent habitat suitability: habitat and non-habitat (table 1). Habitat and non-habitat categories were used to balance data collection of fish use in habitat conditions where fish were expected to be observed and fish use in habitat conditions where fish were not expected to be observed.

Targeted Sampling Design

A targeted sampling design was used to collect habitat data at cells where juvenile Chinook salmon were observed. For this design, the snorkeler(s) moved slowly downstream while continuously scanning for juvenile Chinook salmon. Shorelines were observed at random where conditions allowed for snorkeler safety, and area was observed to the extent limited by visibility. To increase the potential for observing juvenile Chinook salmon, snorkelers attempted to observe various conditions (for example, depth, velocity, cover) present on the selected section of river. Once juvenile Chinook salmon were observed, downstream movement was discontinued, an approximately 2 m^2 cell was visually established, and the fish were observed for approximately (~) 60 seconds to determine number of fish in the cell. Once the number of fish at the cell was recorded, the sampling crew collected the full suite of habitat data for the cell and then resumed a downstream search for more juvenile Chinook salmon—repeating this process for the remainder of the sampling day.

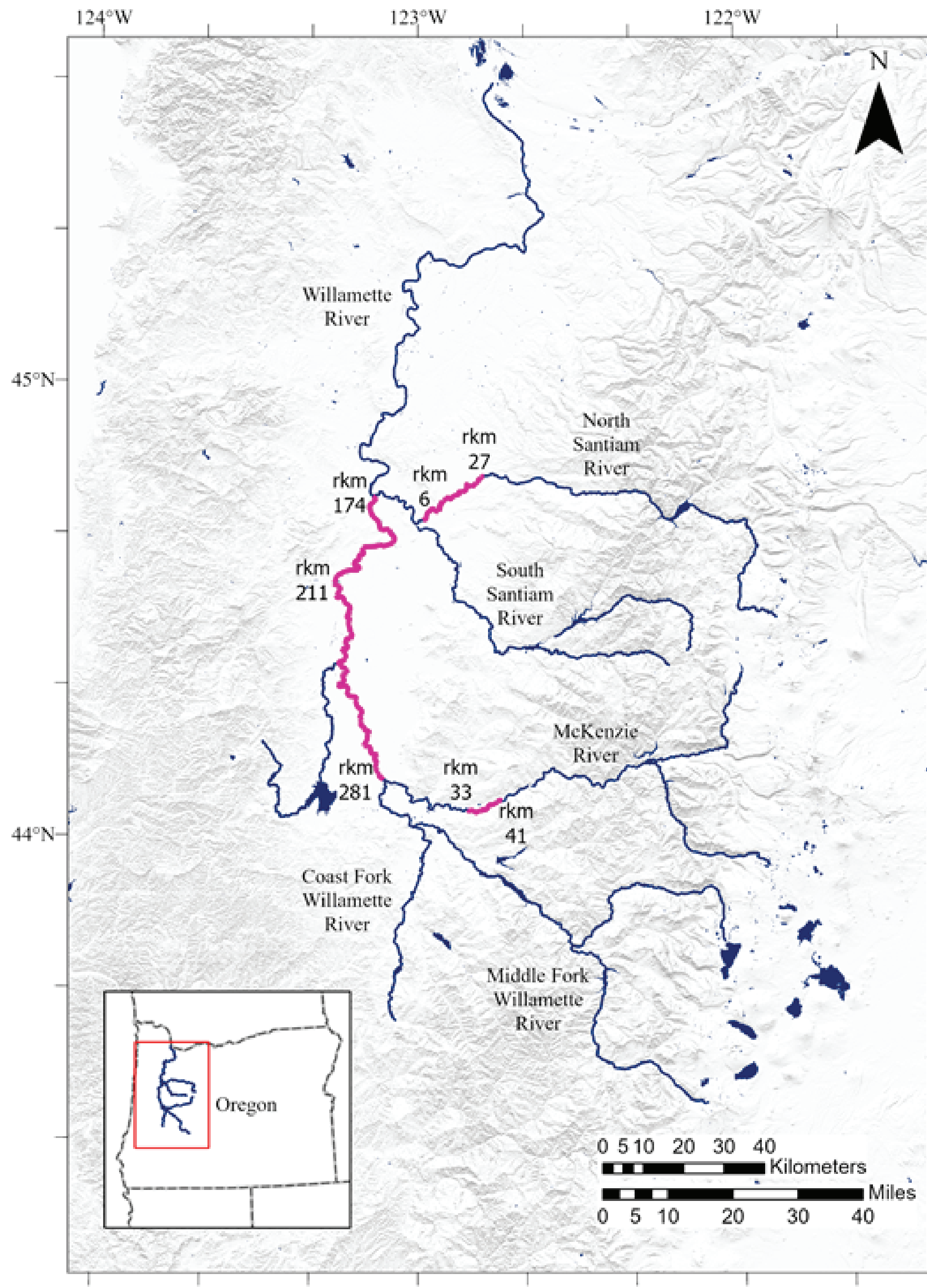

Figure 1. Map showing reaches (pink shading) where habitat sampling occurred during April–July 2020 and 2021 on the mainstem Willamette, Santiam, and McKenzie Rivers.

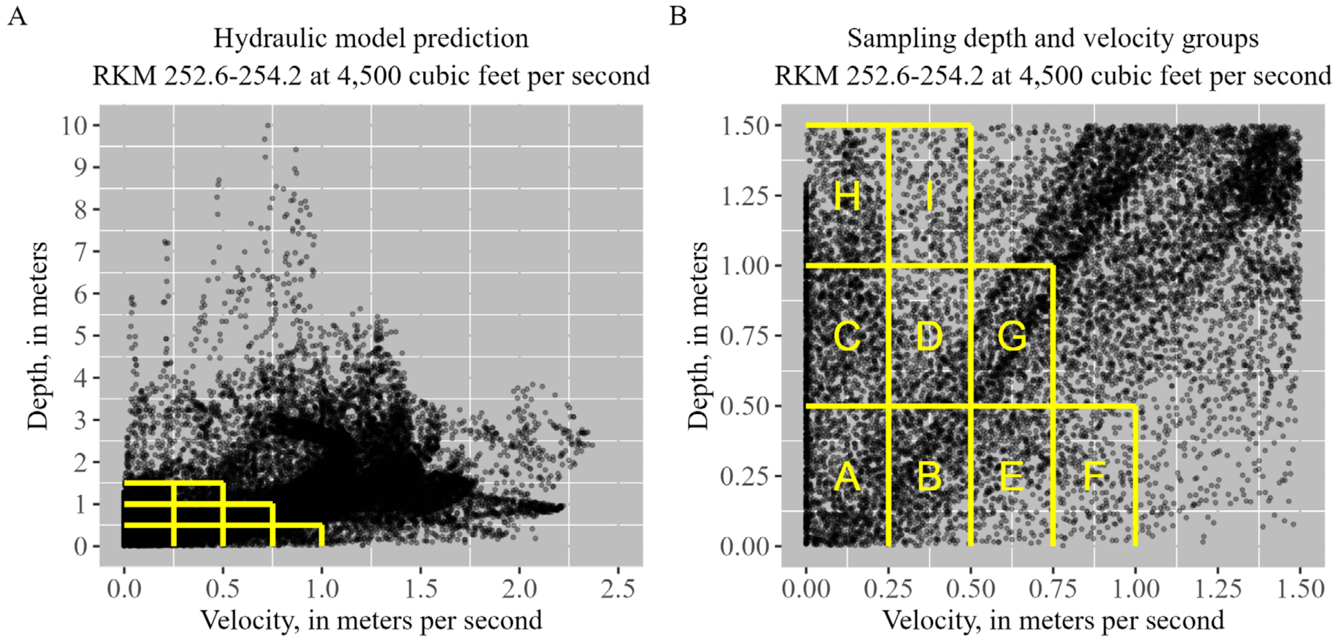

Figure 2. Representative hydraulic model prediction (*A*) and detailed sampling water depth and velocity groups (*B*) used to proportionally distribute cells for a sampling location at a specific streamflow.

Table 1. Depth and velocity groups used to stratify habitat suitability categories.

[Proportion and cell numbers are provided for a sampling location at a specified streamflow to illustrate the distribution of cells by group using the hydraulic model prediction. Water depth in meters, water velocity in meters per second. **Abbreviations:** >, greater than; rkm, river kilometer; ft³/s, cubic feet per second]

Group	Water depth	Water velocity	Habitat suitability	rkm 252.6–254.2 at 4,500 ft³/s	
				Proportion by habitat group	Number of cells
A	0.0–0.5	0.00–0.25	Yes	0.300	6
B	0.0–0.5	>0.25–0.50	Yes	0.240	5
C	>0.5–1.0	0.00–0.25	Yes	0.306	6
D	>0.5–1.0	>0.25–0.50	Yes	0.154	3
E	0.0–0.5	>0.50–0.75	No	0.176	4
F	0.0–0.5	>0.75–1.00	No	0.093	2
G	>0.5–1.0	>0.50–0.75	No	0.358	7
H	>1.0–1.5	0.00–0.25	No	0.258	5
I	>1.0–1.5	>0.25–0.50	No	0.115	2

River Conditions

We compared river flow and water temperature conditions during our study to similar periods during 2015–19 using daily mean streamflow and river temperature data from USGS streamgage 14166000 Willamette River at Harrisburg, Oregon, from April 01 to July 31. To characterize seasonal sampling streamflow and river temperature conditions in a river segment, we used the nearest upstream gage to the sampling locations. Daily mean streamflow and river temperature data were obtained from existing USGS stream gages accessed on the National Water Information System website (USGS, 2021) for the following stream gages: 14166000 Willamette River at Harrisburg, Oregon; 14171600 Willamette River at Corvallis, Oregon (records streamflow only); 14174000 Willamette River at Albany, Oregon; 14183000 North Santiam River at

Mehama, Oregon (records streamflow only); 14183020 North Santiam River below Stout Creek, near Mehama, Oregon (records river temperature only); 14163900 McKenzie River near Walterville, Oregon.

Data Collection

We collected information about fish presence and habitat attributes in each cell that was sampled using both the stratified and targeted sampling designs. Fish presence data included the identification and enumeration of all fish species observed in a cell. Juvenile salmonids were categorized into two size classes based on visual estimation by each snorkeler: less than or equal to (≤) 60 mm and greater than (>) 60 mm. To describe habitat conditions, we collected data on several habitat attributes in each cell. The latitude and longitude (measured at the center of the cell) of each cell location was recorded using a global positioning system (Trimble TDC600 handheld with a Trimble Catalyst DA1 antenna). Water depth (in meters) was also measured at the center of the cell using a 1.5 m topset wading rod. Water velocity was measured using a Sontek Flowtracker handheld acoustic doppler velocimeter. Each water velocity measurement consisted of a 40-second (s) average for two velocity components (the x- and y-planes) from which we calculated a magnitude for the total velocity vector, referred to hereinafter as velocity. Cells that were 0.46 m or shallower were sampled at a single depth (approximately 60 percent of the total depth); cells that were deeper than 0.46 m were sampled at 20 percent and 80 percent of the total depth. Multiple velocity measurements for a cell (depths greater than 0.46 m) were averaged to create a single depth averaged velocity for those cells. The Sontek Flowtracker also recorded water temperature (in degrees Celsius [°C]) in each cell. Substrate was characterized as the diameter in millimeters of the dominant substrate material present within the cell. Bed slope (in degrees) was measured perpendicular to the shoreline using a manual slope inclinometer. Distance-to-shore and distance-to-cover measurements were obtained using a laser rangefinder (Bushnell Scout 1000 ARC, Bushnell Outdoor Products)—distance-to-cover measurements were only recorded if cover was located within 10 m of the cell boundary (we assumed that fish could not effectively use cover located more than 10 m away). Cover type was visually estimated and categorically assigned to one of 7 variables: small woody debris (100 mm diameter or less), large woody debris (greater than 100 mm diameter), aquatic vegetation, terrestrial vegetation, boulder, undercut bank, or not available based on the nearest cover available for the cell. All data collection and sampling occurred during daytime hours.

For a selected stratified sampling location, sampling occurred over a 2-day period using methods adapted from Pinnix and others (2019). On the first day, we marked the boundaries of approximately 40 cells with large (76 mm diameter) metal washers and measured habitat conditions in each cell. The sites were left undisturbed overnight to allow fish to reoccupy the cells. Fish use was recorded on day two, when two snorkelers slowly approached opposite sides of the cell boundaries to observe fish that were present within a cell. Snorkelers remained near the cell boundaries ~60-seconds to observe if fish were moving in or out of the cells. Once the observation period was concluded, data collection in that cell was determined to be complete. The boundary markers were retrieved, and observations from the snorkelers were recorded.

Evaluating Prediction by the Habitat Suitability Criteria

To assess the performance of the habitat suitability criteria used in the hydraulic habitat model, we compared fish presence at cells predicted as habitat or non-habitat using the SWIFT habitat criteria. All sampled cells were assigned as habitat or non-habitat based on water depth and velocity measured in the cell using the SWIFT Median habitat criteria for juvenile (pre-smolt) Chinook salmon—water velocity from 0 to 0.38 meters/second (m/s) and water depth from 0.05 to 1.07 m. The cells were then visualized using water depth and velocity bivariate plots by month to illustrate patterns of fish habitat use.

Data Analysis and Modeling

Data collected using the stratified sampling design and the targeted sampling design were merged and analyzed as a single dataset for analysis. Data from multiple sources (GPS receiver, acoustic doppler velocimeter, and field datasheets) were merged, examined for discrepancies, and reconciled to create a final dataset. Data compilation, proofing, visualization, and analysis were performed using R statistical software (R Core Team, 2021) and additional packages (ggplot2, pROC) were run in RStudio (Robin and others, 2011; Wickham, 2016; RStudio Team, 2021).

General Observations on Habitat Use

Habitat cells were assigned to one of three general categories, based on their location in the river, to allow for comparison of fish use between categories. The three geomorphic unit categories were: main channel, which was defined as the river segment containing the primary streamflow; side channel, which were segments of branching streamflow that maintained connection on both the upstream and downstream end of the segment (and could contain multiple braided sections); and alcoves, where areas were disconnected from upstream flow with connection to the main channel or a side channel on the downstream end (fig. 3). Once cells were assigned to the geomorphic units, we created presence/absence tables for each group by sampling month to provide a general overview of habitat use.

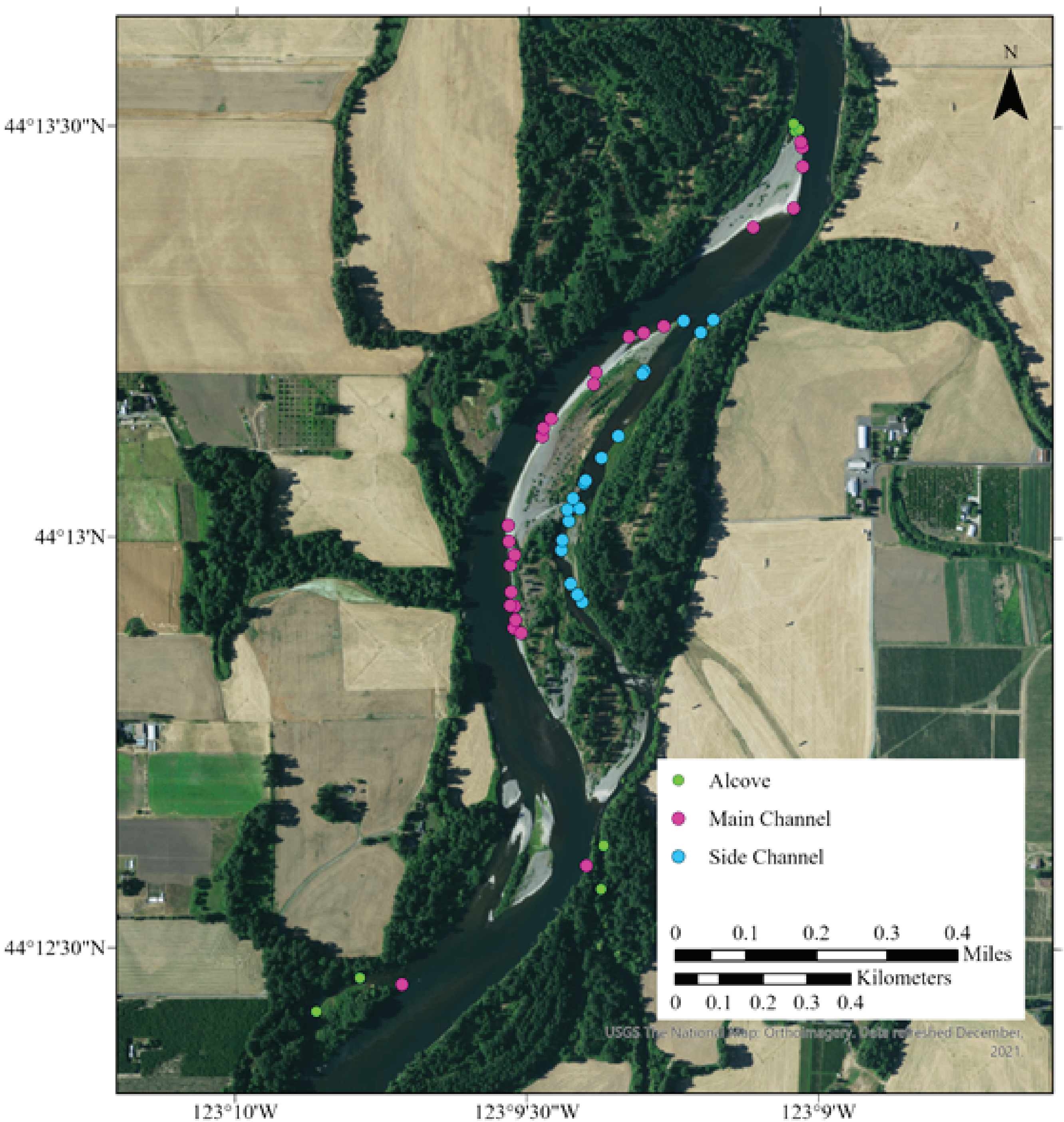

Figure 3. Example of general habitat designation: main channel (pink dots), side channel (blue dots), and alcove (green dots).

Resource Selection Functions

We used logistic regression models to develop resource selection functions (RSF) that estimated the probability of fish presence in a given habitat cell for juvenile Chinook salmon in the Willamette River Basin. Logistic regression was performed using generalized linear models and logit link functions with the form of:

$$logit(P) = b + bX + bY + \ldots \text{bn} \quad (1)$$

where

- P is the probability of observing Chinook salmon;
- b are fitted parameters;
- X is a variable/interaction of interest;
- Y is an additional variable/interaction of interest; and
- n is the *n*th variable/interaction of interest.

To parameterize our models, we used depth and velocity with their associated quadratic and interaction terms. Quadratic terms were included to represent the expected biological response displaying an optimal value with asymmetrical tails. The interaction of depth and velocity was included under the assumption the response of fish to a given velocity may depend on depth. We established an a priori candidate set of models (including a null model) to compare relative model performance. The logistic regression models were fit to a binary variable indicating whether Chinook salmon were seen (1) or not seen (0). Finally, a separate set of models were fitted for each month (April, June, July) when data collection occurred to account for observed increases in fish size due to growth of a given year-class of juveniles.

Developed logistic regression models were evaluated for fit and compared for performance to select the best-fitting model. Model fit was evaluated by estimating c-hat as a measure of overdispersion and performing a Hosmer-Lemeshow Goodness of Fit test using the R package vcdExtra (Friendly, 2021). To compare models, we used second-order Akaike Information Criterion (AIC_c) and for the receiver operating characteristic curve, area under the curve (AUC). Models were ranked by lowest AIC_c value, and we selected the most complex model among the set of models that were within 2.0 AIC_c points of the lowest-AIC_c model, since models within 2.0 AIC_c points are considered competing models. This approach ensured that selected models included quadratic or interaction terms over simpler, less biologically plausible models as long as the more complex model was within 2.0 AIC_c of the lowest AIC_c model. The mean accuracy of selected models was estimated using k-fold cross validation from 100 iterations.

To illustrate the response of the model to depth and velocity, we created combinations of water depth and velocity as inputs to the resource selection function. For each sampling month we sequentially increased either water depth (0–1.5 m, by 0.01 m) or velocity (0–1.5 m/s, by 0.01 m/s), while setting the alternate parameter constant at the mean value observed during that period. Secondarily, we created a set of possible combinations for water depths (0–1.5 m, by 0.01 m) and velocity (0–1.5 m/s, by 0.01 m/s) for application of the resource selection functions.

Characterizing Differences in Habitat Assessment Methodology

To illustrate the difference between the habitat assessment methodologies of the SWIFT habitat suitability criteria and the resource selection function produced in this study, we used receiver operating characteristic curves to select thresholds to produce Narrow, Median, and Broad categories. For example, one could select 0.5 as the threshold for the probability of presence above which a cell would be classified as habitat and below which it would not be considered as suitable habitat. As the probability threshold increases, the error in false classification of habitat is reduced but not all true habitat classification is incorporated. Thus, a higher probability threshold results in a narrow range of values classified as habitat with reduced errors in false classification. A lower probability threshold incorporates a wider range of values classified as habitat but increases the potential for classifying habitat falsely. The Median category probability thresholds were determined as the point on the curve with the greatest distance from the random chance line. Narrow and Broad category thresholds were calculated as the median of either side of the remaining curve bisected by the Median category threshold. We used the Median threshold probabilities to illustrate how the probability threshold selection corresponds to the true positive and true negative classification. These thresholds represent the minimum probability from which to obtain depth and velocity criteria from the resource selection function. The range of the criteria is determined by the minimum and maximum values of depth and velocities for all probabilities in the resource selection function greater than the threshold value.

Results

River Conditions

Streamflow and water temperature conditions on the mainstem Willamette River during the study were similar to those observed during previous years in April, June, and July (fig. 4). April streamflow ranged from 5,350 to 15,000 cubic feet per second (ft^3/s), June streamflow ranged from 5,000 to 9,000 ft^3/s, and July streamflow ranged from 4,000 to 5,250 during both 2020 and 2021. During the last half of July, streamflow was relatively high in 2020, and relatively low in 2021 compared to late-July flow during 2015–19 (fig. 4). Water temperatures were also within normal ranges, compared to 2015–19, and increased from approximately 8–12 °C during April to 16–20 °C in July during both years (fig. 4). For river

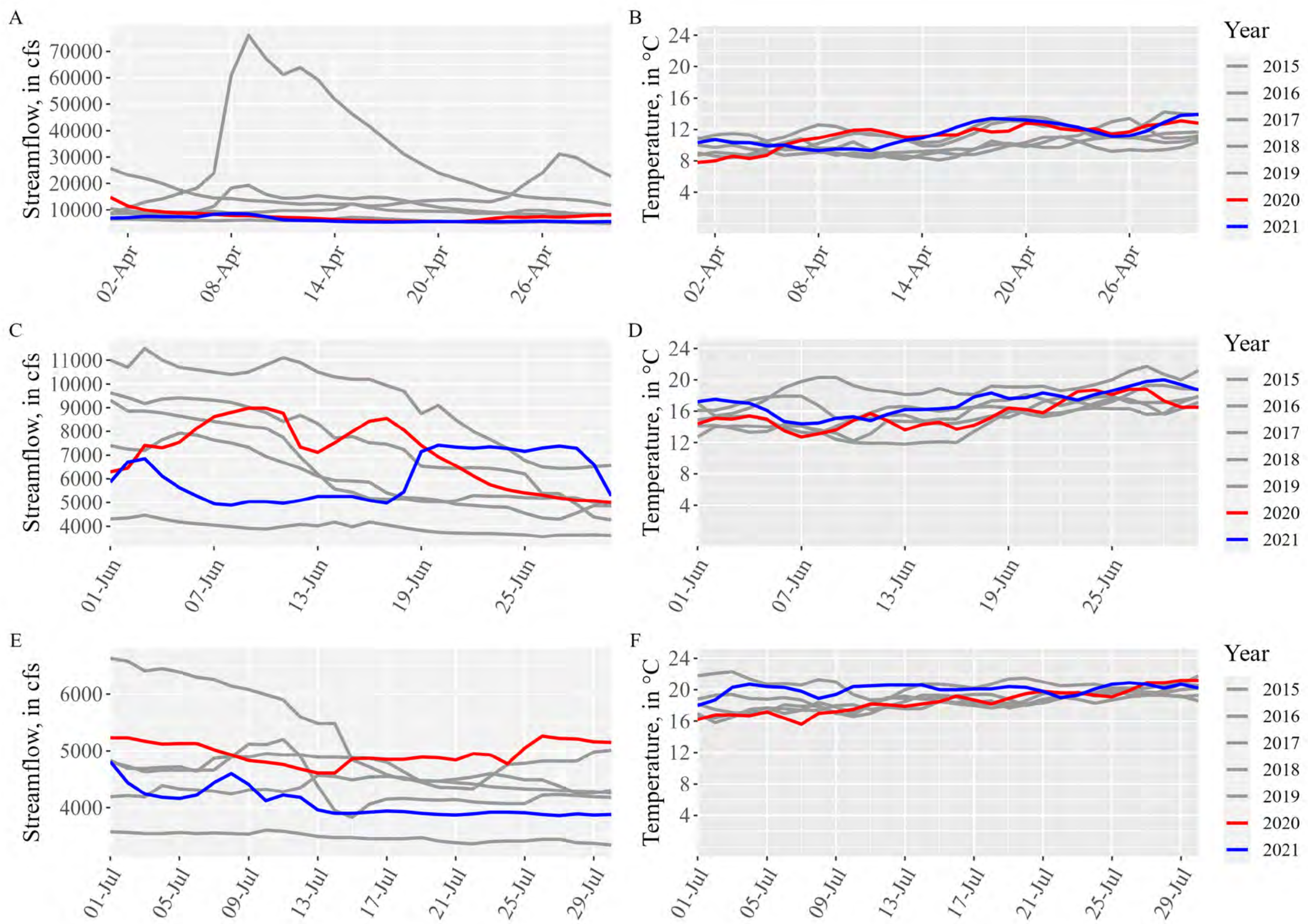

Figure 4. Mainstem Willamette River streamflow and water temperature for April (*A, B*), June (*C, D*), and July (*E, F*) at Harrisburg, Oregon, 2015–21.

segments where sampling was conducted, mean streamflow ranged from 1,120 ft^3/s on the McKenzie to 8,550 ft^3/s on the mainstem Willamette River and mean river temperature ranged from 10.4 °C on the McKenzie to 19.1 °C on the mainstem Willamette River on dates when sampling occurred (table 2).

Sampling Locations

A total of 634 cells were sampled during 2020–21 with 362 cells sampled using the stratified sampling design and 272 cells sampled using the targeted sampling design (table 2). Most cells (473 cells) were located in the mainstem Willamette River and the remaining cells were located in the McKenzie (78 cells) and North Santiam (83 cells) Rivers (table 2; figs. 5, 6). Data collected in these cells provided a broad range of habitat conditions within the three river sections where sampling occurred (fig. 7).

Assessment of the Habitat Suitability Criteria

We found that SWIFT habitat criteria provided a reasonable representation of juvenile Chinook salmon habitat use in the Willamette River during April while there were substantial differences between habitat criteria and observed fish use during June and July (fig. 8; table 3). In April, when fish were smallest (predominantly <60 mm), 92 percent of the cells where juvenile Chinook salmon were observed occurred in habitat defined as suitable by SWIFT criteria (table 3). This declined to 66 percent in June and 27 percent in July (fig. 8; table 3), when observed fish size was larger (generally >60 mm). Data in figure 8 show that juvenile Chinook salmon moved into locations with higher water velocities as the study progressed from April to July, whereas water depth was fairly constant in cells occupied by Chinook salmon juveniles throughout the study period.

Table 2. Sampling dates, river, mean streamflow, mean river temperature and number of habitat cells by sampling design.

[Mean streamflow units are in cubic feet per second, mean temperature is in degrees Celsius]

Sampling date	River	Mean streamflow	Mean temperature	Stratified cells	Targeted cells
June 02–03, 2020	Willamette	8,200	15.8	39	0
June 15–17, 2020	Willamette	8,270	13.7	87	0
June 29–July 01, 2020	Willamette	5,255	15.7	88	0
July 13–15, 2020	Willamette	4,770	16.9	88	0
July 21–23, 2020	Willamette	4,950	19.1	0	53
April 18–20, 2021	North Santiam	2,300	11.5	30	23
April 21–22, 2021	McKenzie	1,120	10.4	30	29
April 28–29, 2021	Willamette	5,565	11.8	0	28
June 01, 2021	Willamette	5,740	15.7	0	23
June 02, 2021	McKenzie	3,320	13.3	0	19
June 03, 2021	North Santiam	1,370	18.1	0	30
June 07–10, 2021	Willamette	5,095	14.4	0	67

General Observations on Habitat Use

Juvenile Chinook salmon were frequently observed in habitat cells located on the main channel and side channels during our sampling but were rarely observed in habitat cells located in alcoves. Juvenile Chinook salmon were observed in 39 percent (246 cells) of the habitat cells which were surveyed (table 4). Nearly all fish observed were in habitat cells located on the main channel or side channels: 99 percent of the habitat cells where juvenile Chinook salmon were observed were located in these habitats. Forty-two percent of the 373 habitat cells located in the main channel, 38 percent of the habitat cells (228) located in side channels, and 7 percent of the 31 habitat cells located in alcoves had Chinook salmon present during sampling (table 4).

Logistic Regression Model Results

Model selection criteria resulted in models of similar complexity, containing multiple common parameters, and increasing model accuracy from April to July, as measured by AUC. The selected models for April, June, and July each included parameters for depth, velocity, and quadratic terms for depth and velocity. Additionally, the June and July models also included an interaction between depth and velocity. For April, a total of five candidate models had delta AIC_c values less than 2.0 (table 5). Based on selection criteria previously described, we selected the model with parameters for velocity, depth, and quadratic terms for velocity and depth. This model had a model accuracy estimate of 0.781 and an AUC value of 0.635. For June, two candidate models had delta AIC_c values less than 2.0 (table 5). We selected the model that had the same parameters as the April model and included an interaction between velocity and depth. This model had a model accuracy estimate of 0.790 and an AUC value of 0.726 (table 5). For July, the only model that met our criteria had the same parameters as the June model and this model had a model accuracy estimate of 0.854 and an AUC value of 0.837 (table 5).

We plotted resource selection functions separately for depth and velocity to illustrate the predicted response to changes in these variables (fig. 9). The maximum predicted probability in April was 0.776 at a velocity of 0.07 m/s and 0.748 at a depth of 0.60 m (fig. 9). In June, the maximum probability was 0.654 when water velocity was at 0.46 m/s velocity and 0.628 when water depth was 0.76 m. Maximum probabilities in July were 0.392 at 0.73 m depth and 0.686 at 0.87 m/s velocity (fig. 9).

Because of the higher order terms in the model (for example, interactions), we also plot the resource selection functions for water velocity and water depth to illustrate how the probability of presence depends jointly on both variables (fig. 10). The highest probability of presence in April was predicted to be in habitat cells with water depths of 0.60 m and water velocities of 0.07 m/s. During June, peak presence was predicted in cells where water depth was 0.80 m and water velocity was 0.40 m/s. Finally, in July, peak presence was predicted for habitat cells where water depth was 0.93 m and water velocity was 1.02 m/s (fig. 10).

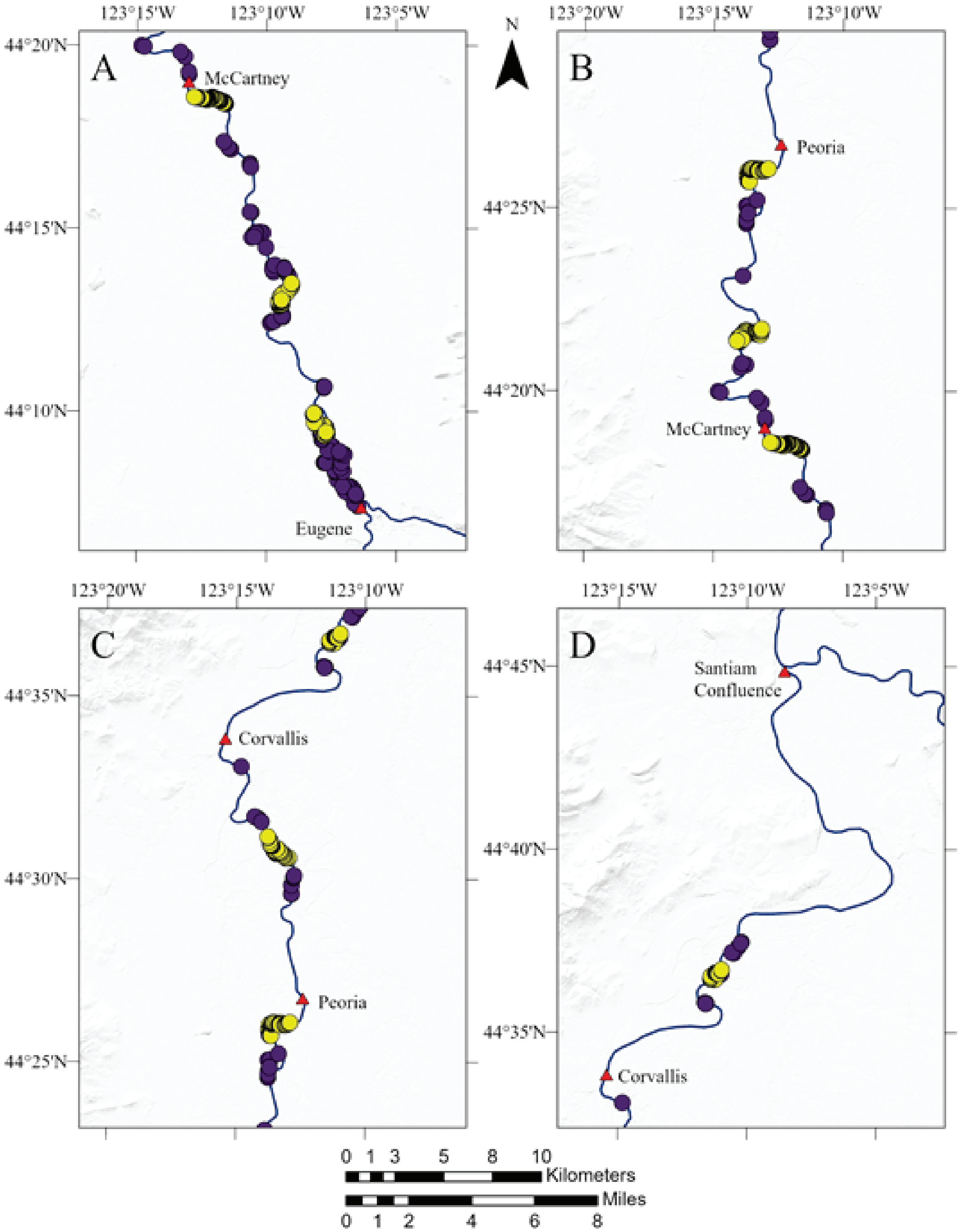

Figure 5. Sampling locations for reaches on the mainstem Willamette River from Eugene to McCartney (*A*), McCartney to Peoria (*B*), Peoria to Corvallis (*C*), and Corvallis to the Santiam (River) Confluence (*D*), 2020 and 2021. Yellow circles represent cells collected using a stratified sampling design and purple circles represent cells collected during a targeted sampling design.

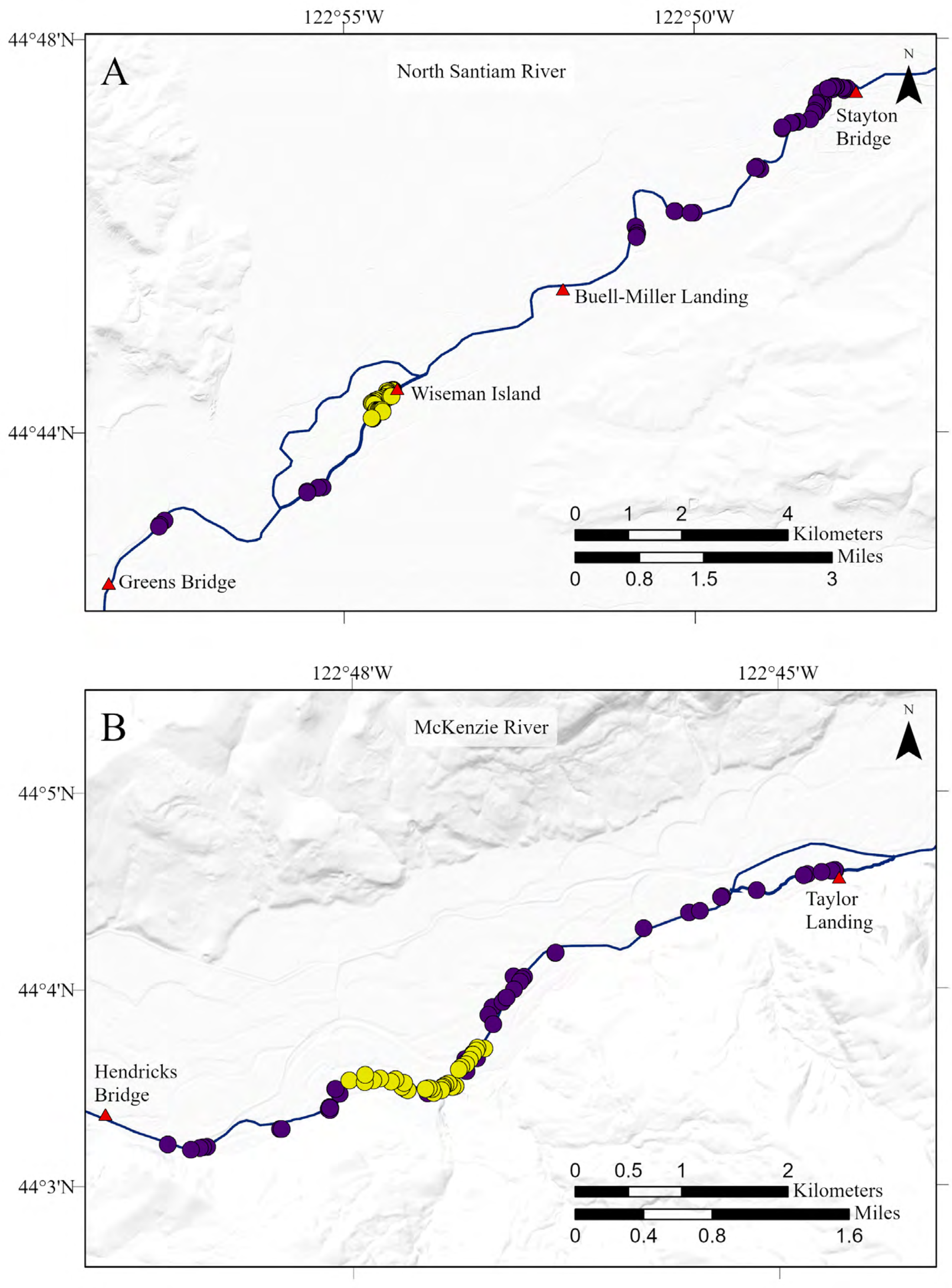

Figure 6. Sampling locations on the North Santiam River (*A*) and McKenzie River (*B*) in 2021. Yellow circles represent cells collected using a stratified sampling design and purple circles represent cells collected during a targeted sampling design.

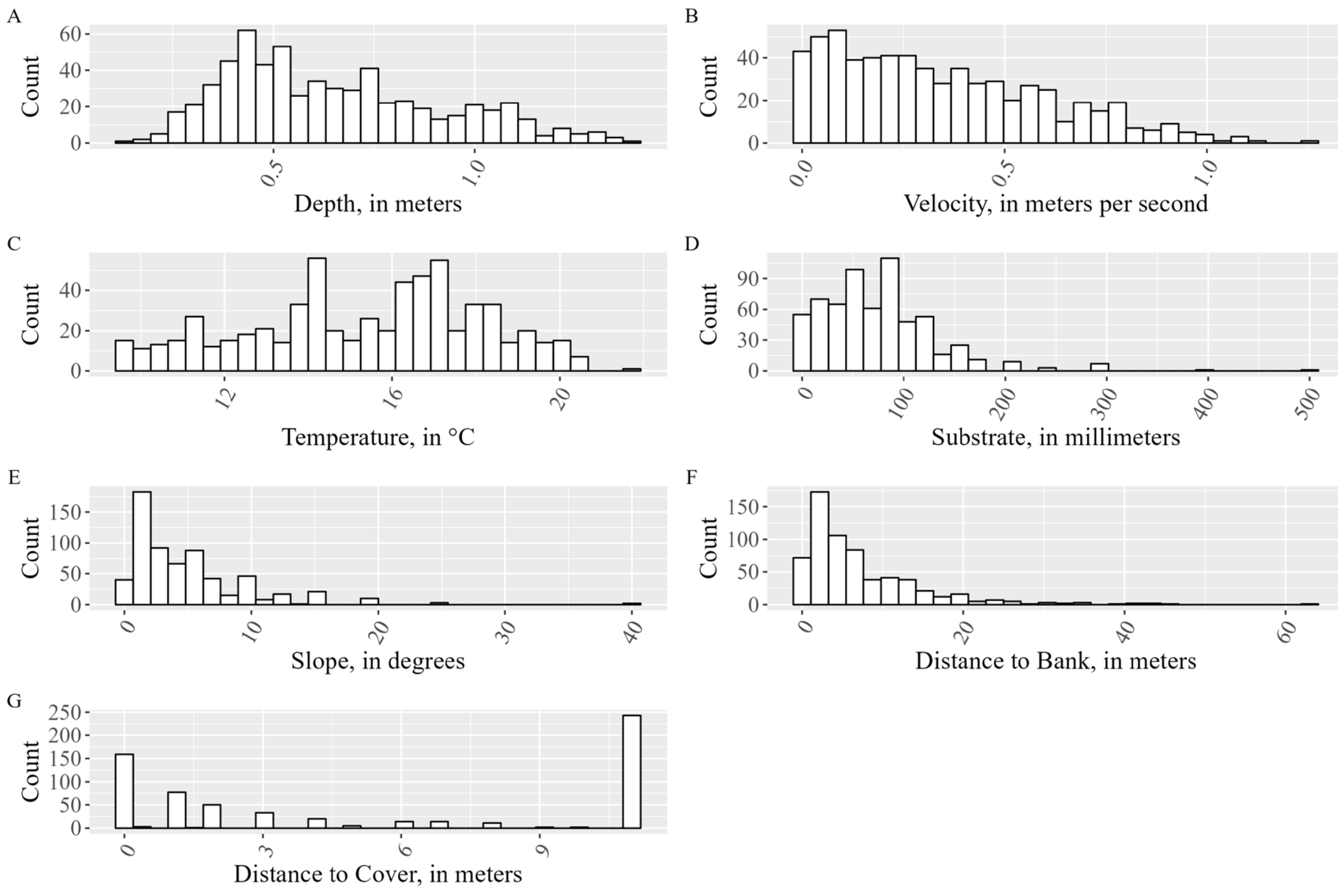

Figure 7. Histograms showing distribution of data collected for individual habitat variables. Distance-to-cover data does not include 243 cells where cover was not available within 10 meters of the habitat cell.

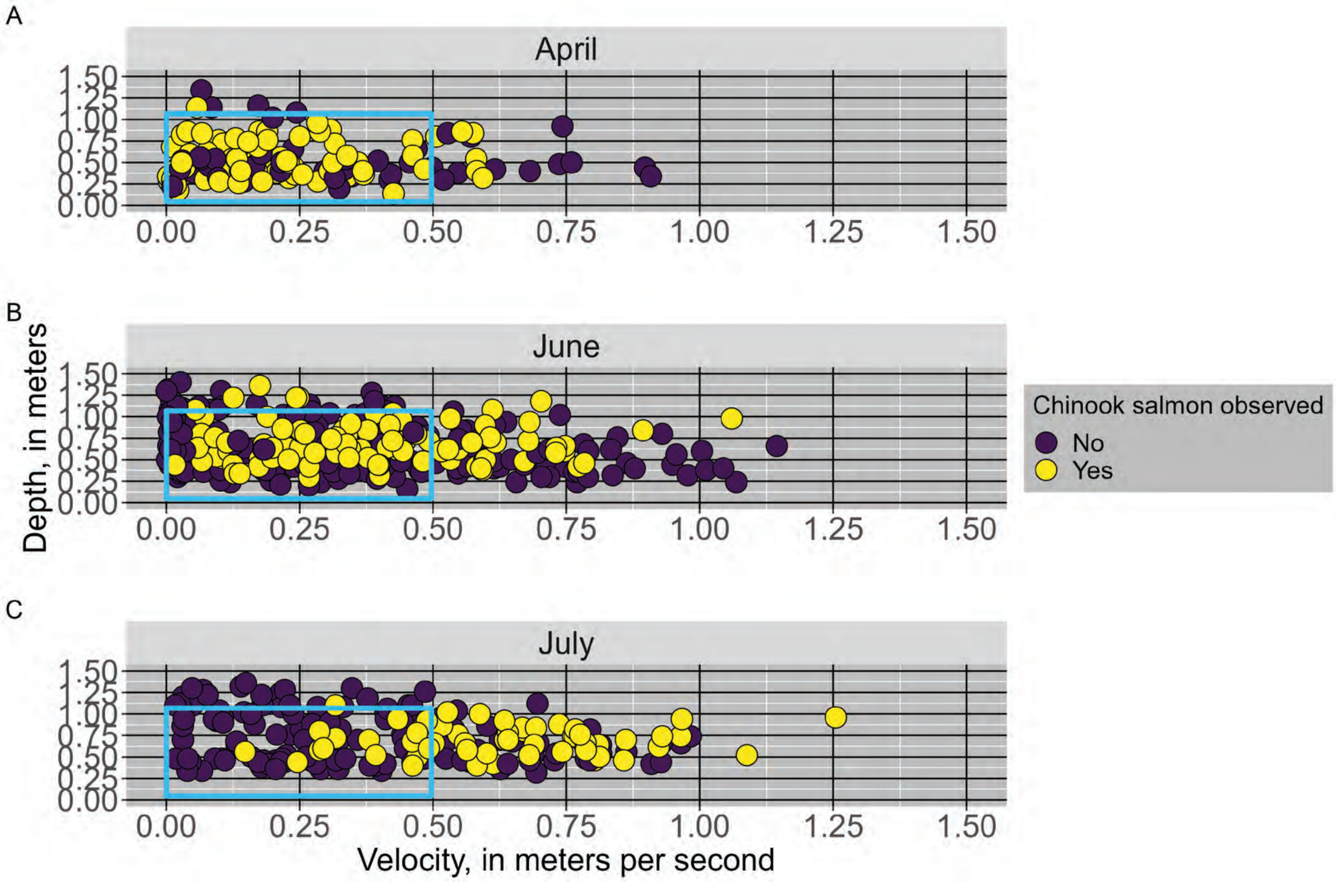

Figure 8. Monthly plots showing water depth and water velocity measured at each habitat cell during the study. Yellow circles are habitat cells where juvenile Chinook salmon (*Oncorhynchus tshawytscha*) were observed and purple circles are habitat cells where juvenile Chinook salmon were not observed. The blue box outlines the zone defined as suitable habitat by the Science of the Willamette Instream Flow Team Median criteria.

Table 3. Number of habitat cells where juvenile Chinook salmon (*Oncorhynchus tshawytscha*) were observed, and not observed in relation to the Median habitat suitability criteria used by the hydraulic habitat model.

Median criteria	Chinook observed	
	No	Yes
	April	
Suitable	34	83
Unsuitable	16	7
	June	
Suitable	134	67
Unsuitable	74	34
	July	
Suitable	70	15
Unsuitable	60	40

Table 4. Number of habitat cells by habitat category, month, and juvenile Chinook salmon (*Oncorhynchus tshawytscha*) observation.

Habitat category	Habitat cells with juvenile Chinook observation					
	April		June		July	
	No	Yes	No	Yes	No	Yes
Alcove	**0**	**1**	**29**	**1**	**0**	**0**
Main channel	31	42	75	69	110	46
Side channel	19	47	104	31	18	9

Table 5. Candidate models characteristics: modeling structure, parameters, AIC_c, delta AIC_c, and AUC values and model accuracy for selected models.

[**Abbreviations:** V, velocity; D, depth; AIC_c, second-order Akaike Information Criterion; AUC, area under the receiver operating characteristic curve; --, no data]

Modeling structure	Parameters	AIC_c	Delta AIC_c	AUC	Model accuracy
April					
V	2	176.06	0.00	--	--
V+D+D^2	4	176.63	0.57	--	--
V+D+V^2+D^2	5	177.00	0.94	0.635	0.781
V+D+V^2	4	177.72	1.65	--	--
V+D	3	177.80	1.74	--	--
V+D+V^2+D^2+VD	6	178.43	2.37	--	--
null	1	184.52	8.46	--	--
D	2	186.21	10.14	--	--
June					
V+D+V^2+D^2	5	318.72	0.00	--	--
V+D+V^2+D^2+VD	6	318.95	0.23	0.726	0.790
V+D+V^2	4	330.03	11.31	--	--
V+D+D^2	4	338.24	19.52	--	--
V	2	350.02	31.31	--	--
null	1	351.32	32.60	--	--
V+D	3	351.48	32.76	--	--
D	2	353.26	34.54	--	--
July					
V+D+V^2+D^2+VD	6	201.05	0.00	0.837	0.854
V+D+V^2+D^2	5	203.08	2.03	--	
V+D+D^2	4	206.08	5.03	--	--
V+D+V^2	4	215.29	14.24	--	--
V	2	220.00	18.95	--	--
V+D	3	221.42	20.37	--	--
null	1	259.59	58.54	--	--
D	2	261.35	60.30	--	--

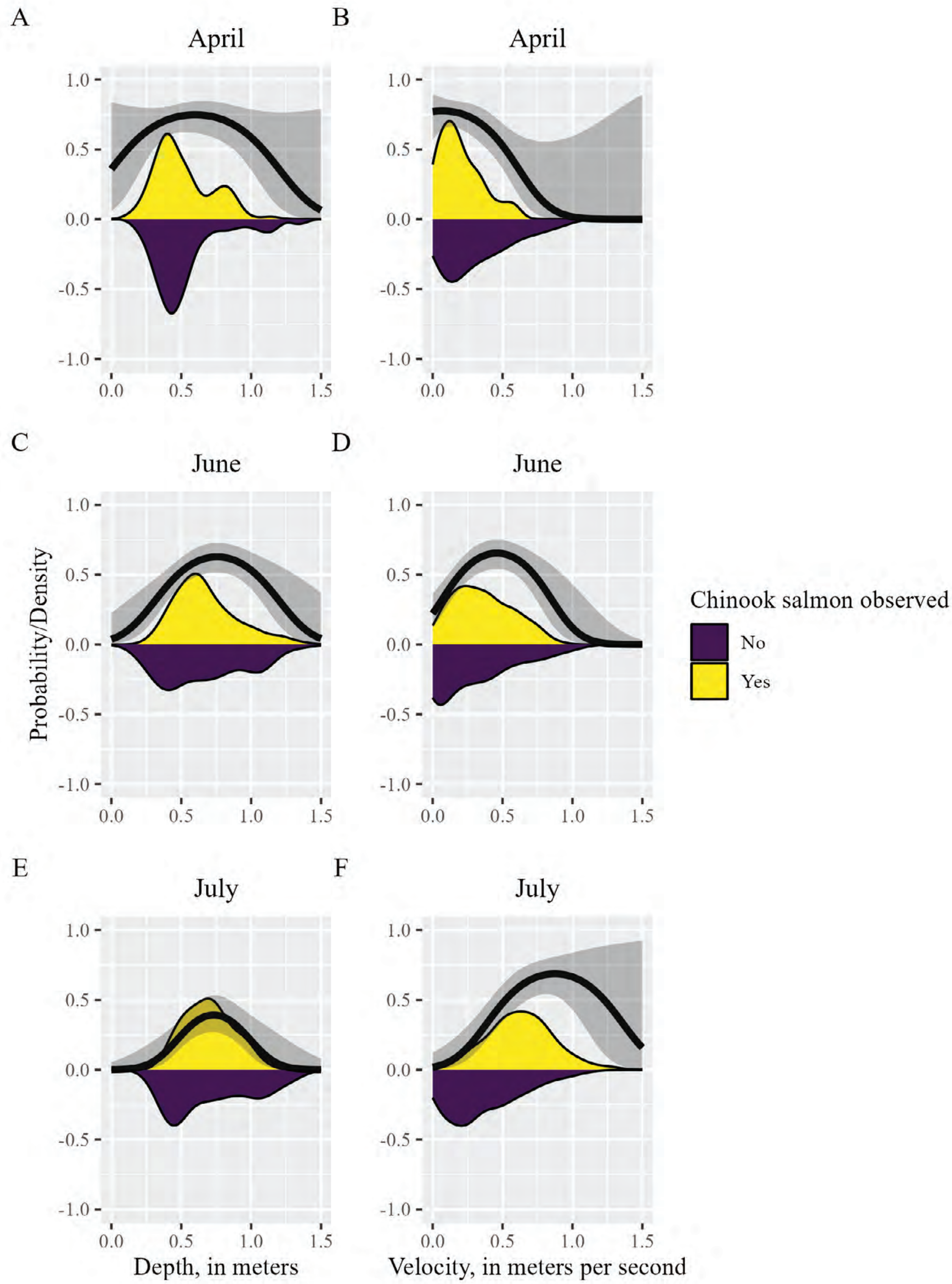

Figure 9. Model predicted probabilities of observing juvenile Chinook salmon (*Oncorhynchus tshawytscha*; heavy curved lines) for velocity at mean depth and depth at mean velocity with confidence intervals (grey shaded areas) by month. Filled areas represent kernel density estimates of juvenile Chinook salmon observations.

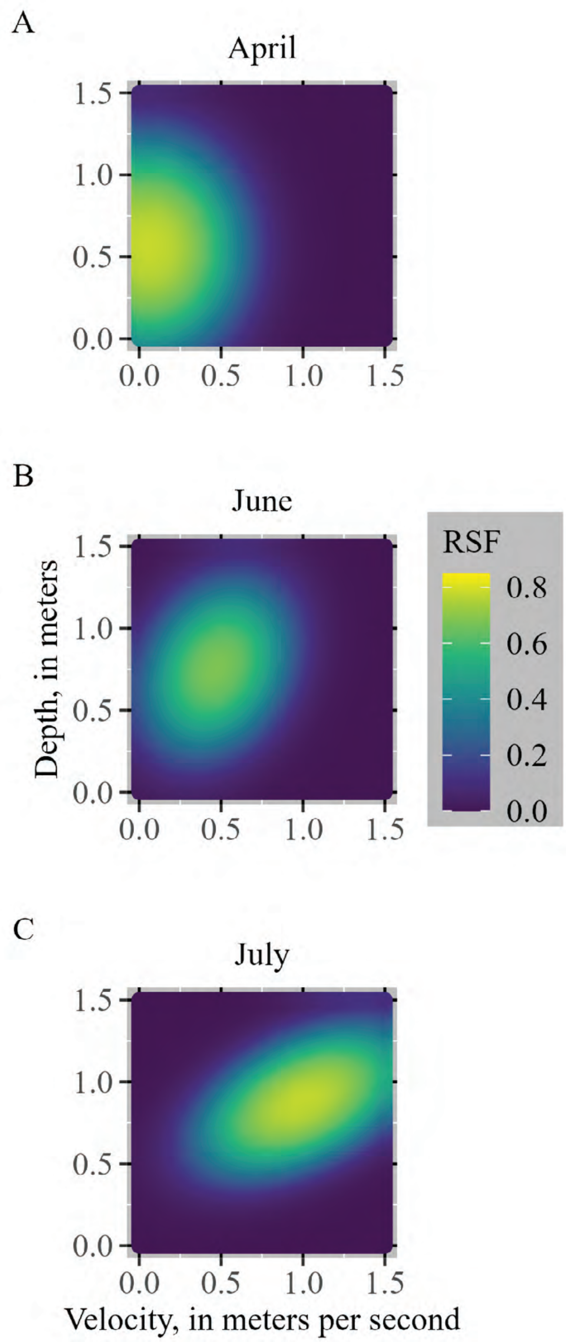

Figure 10. Estimated presence probability from the resource selection function (RSF) for juvenile Chinook (*Oncorhynchus tshawytscha*) salmon based on water velocity and water depth.

Habitat Suitability Criteria and Resource Selection Function Comparison

Thresholds were established for the resource selection function to compare with the SWIFT habitat suitability criteria categories (Narrow, Median, and Broad) using receiver operating characteristic curves. The probability thresholds above which cells were classified as habitat were 0.73, 0.59, and 0.42 for Narrow, Median, and Broad categories, respectively, for April. At the Median category threshold for April the true positive rate was 0.88 and true negative rate 0.44 (fig. 11). This reflects a high proportion of positive observations correctly classified as positive and slightly less than half of the negative observations correctly classified as negative. The June Narrow, Median, and Broad categories probability thresholds were 0.55, 0.40, and 0.23. The Median threshold in June displayed a lower true positive rate (0.69), but a higher true negative rate (0.68) resulting in slightly better predictive classification as compared with the April model (fig. 11). The July probability thresholds for the Narrow, Median, and Broad categories were 0.44, 0.17, and 0.04. The true positive rate (0.93) and true negative rate (0.65) for the July Median threshold resulted in the best predictive classification observed for the 3 months, further represented by July having the highest AUC (fig. 11).

Habitat use limits from the habitat suitability criteria for fry sized salmonids was compared to the April resource selection function values (table 6). For velocity, the resource selection function predicts a 120–180 percent increase in the maximum value for the three classification categories, while minimum velocity criteria values for both the resource selection function and the habitat suitability index was 0.00 m/s. Minimum depth values for the habitat suitability criteria remains constant at 0.05 m while the resource selection function varies from 0.02 to 0.37 m from the Broad to Narrow classification. Maximum depth criteria vary from 0.61 to 1.52 m for the habitat suitability criteria (from the Narrow to Broad classification), but only ranges from 0.83 to 1.18 m for the resource selection function.

A greater difference was observed comparing the presmolt values from the habitat suitability criteria with the resource selection function limits for July (table 6). Velocity criteria minimum (0.08–0.47 m/s) and maximum (1.50 m/s) values were greater for all classification groups produced from the resource selection function compared to the habitat suitability index minimum (0 m/s) and maximum (0.91–0.38 m/s) values. Similarly, minimum (0.27–0.54 m) and maximum (1.31–1.50 m) depth criteria values were greater for all classification groups from the resource selection function compared to the habitat suitability criteria minimum (0.05 m) and maximum values (0.69–1.07 m), except the Broad category which puts no upper limit on depth.

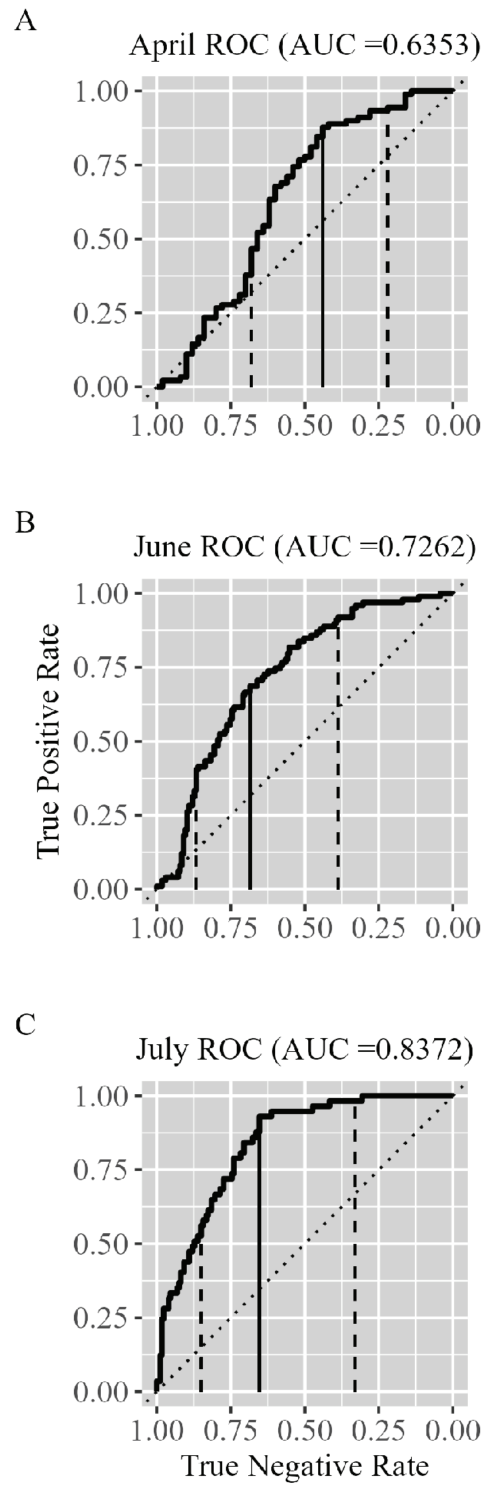

Figure 11. Receiver operating characteristic (ROC) curve (bold solid line) with Narrow (left vertical dashed line), Median (vertical solid line), and Broad (right vertical dashed line) category thresholds for selected models. Area under the curve (AUC) is an indication of model performance. For comparison perfect chance (the diagonal dotted line) representing a random flip of a coin has an AUC = 0.5.

Table 6. Comparison of habitat suitability criteria and resource selection function classification categories used to estimate habitat suitability for juvenile Chinook salmon (*Oncorhynchus tshawytscha*), Willamette River Basin, 2020–21.

[**Abbreviations:** m, meters; m/s, meters per second; HSC, habitat suitability criteria; RSF, resource selection function; ≥, greater than equal to]

Habitat metric	HSC			RSF		
	Broad	Median	Narrow	Broad	Median	Narrow
	Fry			April		
Velocity (m/s)	0–0.46	0–0.38	0–0.15	0–0.57	0–0.45	0–0.27
Depth (m)	0.05–1.52	0.05–1.07	0.05–0.61	0.02–1.18	0.16–1.04	0.37–0.83
	Pre-smolt			July		
Velocity (m/s)	0–0.91	0–0.50	0–0.38	0.08–1.50	0.27–1.50	0.47–1.50
Depth (m)	≥0.05	0.05–1.07	0.05–0.69	0.27–1.50	0.40–1.45	0.54–1.31

Discussion

This study used empirical observations of habitat use by juvenile Chinook salmon in the Willamette River Basin to develop resource selection functions useful for hydraulic habitat modeling efforts in the future. Previous studies provided data on habitat use by juvenile Chinook salmon in the Willamette River Basin (Friesen, 2005; Friesen and others, 2007; Whitman and others, 2017), but these studies had limited usefulness for assessing the current hydraulic habitat model. The Friesen (2005) and Friesen and others (2007) study was a rigorous, multi-year effort that focused on the Lower Willamette River, downstream of Willamette Falls, which is not a reach of primary interest for flow management actions in support of juvenile salmonid habitat in the basin. Whitman and others (2017) collected habitat information primarily at gravel bars where seining crews focused collection efforts to tag juvenile Chinook salmon using passive-integrated-transponders to study migration timing. Our study expanded on these efforts by focusing on river reaches that are of primary interest for flow management to improve habitat for rearing juvenile salmonids, and included sampling a range of habitats within these reaches to better understand the importance of the various habitat types. There are limitations with the data collection methods. Field staff collected habitat data while wading and made fish observations while snorkeling. As a result, we were limited by depth (depths greater than 1.5 were not assessed), water velocity (data primarily collected in areas where velocities were 1 m/s or slower), and water visibility (2 m or less). The presence of snorkelers may also have affected fish behavior, which is a factor that we were unable to assess. Additionally, all data were collected during daylight hours, so the data do not account for diel differences in juvenile Chinook behavior and habitat use. Finally, our sampling occurred on a portion of the mainstem Willamette River and in lower reaches of two tributaries. Habitat conditions differ in areas located outside of sampling reaches, so results from this study may not apply to those areas. Our results represent an addition to the foundation of knowledge for juvenile Chinook salmon habitat use, while identifying possibilities for additional refinement of habitat relationships to flow within the Willamette River basin.

Our sampling included sites located in the main river channel, side channels, and in alcoves, and we found that juvenile Chinook salmon were routinely present in main channel and side channel habitats but were seldom observed in alcoves. Off-channel habitat has been shown to be important for juvenile Chinook salmon (Limm and Marchetti, 2009; Huntsman and Falke, 2019). During our study, we found that juvenile Chinook salmon were only observed in 7 percent of the alcove habitats that we sampled compared to approximately 40 percent of the main channel and side channel habitats. However, alcove sampling comprised a relatively small proportion of our overall effort, and our sampling was limited to April, June, and July. Friesen and others (2007) used radio-telemetry to monitor habitat use by tagged juvenile Chinook salmon in the Lower Willamette River and reported that most of the fish they relocated were present in mainstem, rather than off-channel habitat. Collectively, these results indicate that off-channel habitat usage may be limited for juvenile Chinook salmon in reaches of Willamette River we studied, but additional research will be needed to fully assess this factor and to understand if the use of off-channel habitat varies throughout the year or as flows change.

We found that habitat use by juvenile Chinook salmon underwent a seasonal shift that was likely driven by the increasing size of fish over time. The resource selection functions developed from data collected during our study showed that optimum water velocity for juvenile Chinook salmon in April was near 0.1 m/s and increased to nearly 0.9 m/s in July, while optimum depth increased from approximately 0.6 m to 0.7 m during the same period. The resource selection functions also showed that the probability of juvenile Chinook salmon occupying a given habit decreased substantially as velocity and depth departed from these optimum values. These findings are supported by other studies that have shown that juvenile Chinook salmon move farther offshore and into deeper water as they grow during spring and early summer (Everest and Chapman, 1972; Tabor and others, 2011).

These resource selection functions can be used to improve hydraulic habitat models, particularly in comparison to coarser approaches such as the SWIFT habitat suitability criteria. For example, the hydraulic habitat model classified habitat as suitable, using the SWIFT criteria, if habitat cells had water depth as shallow as 0.05 m. We found that juvenile Chinook salmon were rarely observed in water depth less than 0.25 m, which means that the SWIFT criteria resulted in an overestimation of habitat availability relative to our observations. Additionally, all habitat cells with water velocity and depth attributes that met the SWIFT criteria were designated as suitable habitat, so this approach did not allow for proportional predictions of habitat use based on various water depth and velocity combinations. These observations illustrate the value of using in-basin data to develop resource selection functions with proportional probabilities to optimize predictive hydraulic habitat models.

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For information about the research in this report, contact
Director, Western Fisheries Research Center
U.S. Geological Survey
6505 NE 65th Street
Seattle, Washington 98115-5016
https://www.usgs.gov/centers/western-fisheries-research-center

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