Mapping Salmon: Anadromous Waters Prioritization for the Matanuska-Susitna Basin

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A report submitted to the U.S. Fish and Wildlife Service on behalf of the Matanuska-Susitna Basin Salmon Habitat Partnership

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Introduction

Knowing where anadromous fish species are located is essential to conservation of their freshwater habitat. In Alaska, the Anadromous Waters Catalog (*AWC*) is a regulatory geospatial layer that indicates where anadromous fishes carry out at least part of their life cycle. Each year, the AWC is updated and a new regulatory layer is established (5 AAC 95.011). Under the Anadromous Fish Act (*Protection of Waterways for Anadromous Fish* AS 16.05.871-.901), the Alaska Department of Fish and Game must be notified and issue a permit before any alterations of the streamflow or bed surface occur in an anadromous water body. Many organizations across the state invest effort in conducting field surveys to identify anadromous water bodies, because water bodies are not included until two anadromous individuals are located at a sampling site. This fieldwork is often resource-intensive, particularly in remote areas (Cathcart and Giefer 2023). Modeling suitable habitat and likelihood of occurrence of anadromous species is a potential approach to optimize and prioritize efforts to add to the Anadromous Waters Catalog.

Species distribution modeling (also referred to as habitat suitability modeling) uses information about the environment where species are currently found to predict where they are likely to be found in the future. For salmon in particular, topographical variables that affect the in-stream flow environment and fish passage have been found to be strong predictors for species presence/absence. Modeling can predict where in a riverine network fish habitat is likely to be found based on underlying topography and associated flow environments (Bidlack et al. 2014, Romey and Martin 2018, Duda and Hardiman 2023). For example, mean annual flow, gradient, and glacial influence predicted likely habitat for juvenile Chinook salmon in the Copper River watershed (Bidlack et al. 2014). Habitat suitability models can use multiple different statistical approaches, using the same covariates and information on species presence (Guisan and Thuiller 2005). These different techniques can result in very different predictions, with each model having its own strengths and weaknesses (Thuiller et al. 2009). Ensemble modeling can reduce errors and average out those model weaknesses, making ensemble models more reliable and accurate than a single model (Araújo and New 2007, Marmion et al. 2009).

The Matanuska-Susitna basin is the fastest growing area of Alaska (Anderson 2024). Development in the region poses an ongoing threat to salmon populations in these watersheds (Hughes 2013). The Matanuska-Susitna Basin has 7,366 km of anadromous streams and 47,977 km of streams under 1,000 meters. The difference between these two indicates the potential to include additional streams for nomination to the Anadromous Waters Catalog, which provides protections for anadromous fish habitat from construction and other activities. While a portion of the Matanuska-Susitna Borough is accessible via roads, many upper limits of watersheds, protected areas (e.g. the Nelchina Public Use Area), and areas to the west of the Susitna River are more remote. However, there are several proposed projects to expand access with roads and pipelines on the west-side of the Susitna River, potentially resulting in impacts to salmon-bearing streams that are not yet included in the AWC. Thus, being efficient with funding and time means ensuring that any AWC field surveys are targeting streams that have a high likelihood of containing anadromous species. This goal has been highlighted in the Matanuska-Susitna Basin Salmon Habitat Partnership's 2019 Strategic Plan (Objective 1.1. Increase miles of streams in the AWC).

The primary objectives of this work were to: (1) Create a database of topographic attributes for all stream reaches in the NHDPlus for the Matanuska-Susitna basin. (2) Build a suite of species distribution models for juvenile salmonids across the Matanuska-Susitna basin. (3) Map predicted probabilities of suitable habitat for juvenile salmonids using an ensemble of species distribution models and create publicly accessible map products on ArcGIS Online. (4) Validate predicted habitats using a road-based field survey. (5) Document all methods and results in a final report that includes a prioritization of basins for stream surveys to increase nominations to the AWC across the Matanuska-Susitna basin. The data generated by this project provide valuable baseline information on likely habitat supporting important salmon fisheries in the Matanuska-Susitna to help prioritize future Anadromous Waters Catalog nomination efforts.

Methods

Study Area

The Matanuska-Susitna Basin comprises two major watersheds, the Matanuska River and the Susitna River. This work utilized the U.S. Geological Survey's (USGS) National Hydrography Plus (NHDPlus) dataset for the underlying hydrography. Thus, the Yentna River, Chulitna River, Upper Susitna River, Talkeetna River, Lower Susitna River, Matanuska, and Anchorage 8-digit Hydrologic Unit Codes comprise the watershed boundaries for this project (Figure 1).

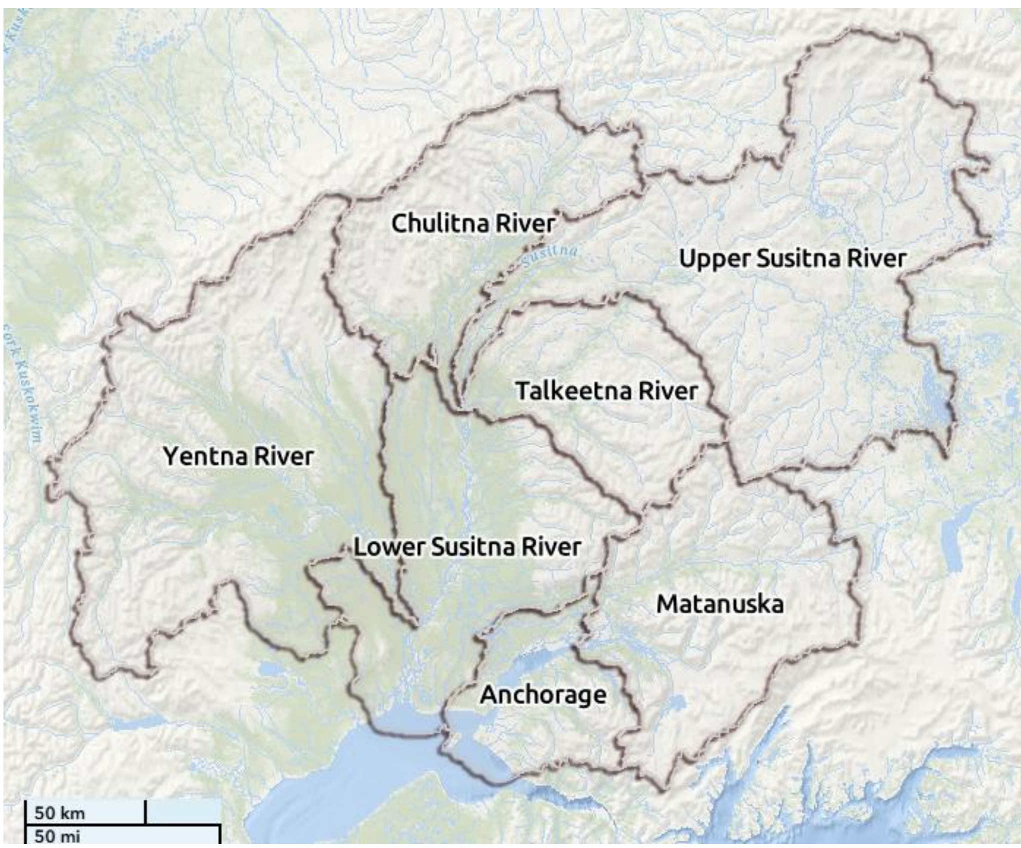

Figure 1 Map of study area with 8-digit Hydrologic Unit Codes from the U.S. Geological Survey's National Hydrography Plus HR dataset outlined and named.

Habitat Suitability Modeling

Covariate Extraction and Geospatial Processing

The USGS's NHD Plus dataset includes the digital elevation model (DEM) used to generate the vector stream network, along with catchments linked to each stream reach, and "value-added attributes" to help navigate the stream network. All covariates were derived from the associated digital elevation model, the elevation-based catchments, and the value-added attributes (Table 1). All covariate extraction took place in ArcGIS Pro, using the Alaska Albers projection. Valley confinement was calculated using the Valley Bottom Extraction Tool, which uses a stream shapefile, DEM, drainage area, and user-defined thresholds to produce estimated valley widths.

Table 1 Covariates used in habitat suitability modeling.

Covariate Name	Description	Rationale
Latitude	Latitude of the centroid of the catchment polygon on the NHDPlus flowline	Proxy for air and water temperature.
Longitude	Longitude of the centroid of the catchment polygon on the NHDPlus flowline	Proxy for migration distance.
Elevation	Mean elevation of the NHDPlus flowline catchment	Proxy for water temperature and hydrologic regime.
Stream Order	Strahler stream order of the NHDPlus flowline segment from value-added attributes	Representative of stream size and proximity to ocean habitat.
Watershed Area	Upstream drainage area from NHDPlus value-added attributes	Representative of stream size and proximity to ocean habitat.
Valley Confinement	Mean valley bottom width in the NHDPlus flowline catchment	Measure of habitat diversity (diverse, high quality habitat in unconfined valleys).
Maximum Slope	Maximum slope of the NHD Plus flowline catchment	Representative of fish barriers for spawners and juveniles.
Mean Slope	Mean slope of the NHD Plus flowline catchment	Representative of overall steepness and challenges for spawners and juveniles to access.

Because the AWC is built on a different base hydrography from the NHD Plus, attributing the NHD Plus flowline segments with their AWC status required more geoprocessing. Briefly, a trace network was created from the NHD Plus flowline and HydroNet junctions. The AWC presence was extracted, and converted to "dangle" type points and then the points were attached to the network using "snap to trace". The points then were visually inspected to ensure that they were snapped to an appropriate flowline and adjusted manually where necessary. Those snapped points were traced downstream, and that trace output was used to identify NHD Plus catchments with AWC records.

Covariates and AWC status for each NHD Plus flowline segment was exported as a .csv for habitat suitability modeling in R version 4.3.2 (R Core Team 2023).

Modeling Process

An initial, simple habitat suitability model was built using the 2024 AWC as a species presence layer, with a binomial logit model structure. This model was built using the base 'glm' (generalized linear model) function, with the covariates as described (Table 1) predicting presence of anadromous species along NHD Plus flowline segments, then using the terra package (Hijmans et al. 2025) to export model output as a raster.

Following field validation (described below) a more complex ensemble model was constructed, using the 2025 AWC as the species presence layer, and keeping the same covariates as the earlier model.

The ensemble modeling process used the biomod2 package (Wilfried et al. 2012), with some post-processing in ArcGIS Pro. First, areas not included in the AWC were converted into pseudo-absences, because they do not represent true absence data (i.e. areas that have been sampled thoroughly without finding any evidence for anadromous fish presence). Then pseudo-absences were randomly generated from these points, with 4 reps of 1000 each, generating four pseudo-absence datasets for modeling.

Single models were then constructed, using all available models (Table 2) for each pseudo-absence dataset. Biomod2 acts as a "wrapper" and brings in these single models from other R packages, referenced in Table 2. We elected to use two replicates of random cross-validation for model evaluation, which can result in better predictive performance (Huang et al. 2025), but lower transferability. However, we were not extrapolating our model in space or time, so that trade-off was preferable to ensure accuracy in the study area. 80% of the data were reserved for calibration, and we used the biomod2 packages 'bigboss' pre-defined parameter values for model tuning. Three permutations were performed on each variable to estimate variable importance in the model. The true skill statistic (TSS) and area under the receiver operating curve (ROC) were used as evaluation metrics for model performance, both of which are independent of prevalence of presences in the model study area (Allouche et al. 2006).

Table 2 Models used in ensemble modeling process, with corresponding acronyms and R packages, cited.

Model Name	Acronym	R Package and Citation
Artificial Neural Network	ANN	nnet (Ripley and Venables 2025)
Classification Tree Analysis	CTA	rpart (Therneau et al. 2025)
Flexible Discriminant Analysis	FDA	fda (Ramsay et al. 2025)
Generalized Additive Model	GAM	gam (Hastie and Narasimhan 2025) and mgcv (Wood 2025)
Generalized Boosting Model (or Boosted Regression Trees)	GBM	gbm (Ridgeway et al. 2024)
Generalized Linear Model	GLM	stats (base R package)
Multiple Adaptive Regression Splines	MARS	earth (Milborrow et al. 2024)
Maximum Entropy (Java)	MAXENT	dismo (Hijmans et al. 2024) to access Java-based Maxent software
Maximum Entropy (R)	MAXNET	maxnet (Phillips 2021)
Random Forest	RF	randomForest (Leo Breiman et al. 2024)
Random Forest downsampled	RFd	randomForest (Leo Breiman et al. 2024)

Surface Range Envelope	SRE	biomod2 (Wilfried et al. 2012)
Extreme Gradient Boosting Training	XGBOOST	xgboost (Chen et al. 2025)

All models were used in the ensemble modelling process, with a threshold value of 0.7 for the TSS used to evaluate single models for exclusion from the final ensemble model. The weighted mean was used to create the ensemble model predictions with weights attributed proportionally to the models' evaluation scores. The model was then projected onto the NHD Plus for the upper Cook Inlet HUC 8 watersheds (Figure 1; Upper Susitna River, Chulitna River, Talkeetna River, Matanuska, Anchorage, Lower Susitna River, and Yentna River). The model output is accessible both as a shapefile on the ACCS data catalog and through an ArcGIS Online Dashboard. The Dashboard includes the model output, along with layers useful for planning fieldwork or informing optimization of future AWC work. These layers include the current version of the AWC, brought in as a feature layer; 8, 10, and 12 digit HUC watershed boundaries; Alaska Department of Transportation roads feature layer; Matanuska-Susitna Borough E911 Roads web feature layer; the trails feature layer from the 2022 Statewide Comprehensive Outdoor Recreation Plan; the merged trails feature layer from the Municipality of Anchorage; the BLM Landownership feature layer; and the Cook Inlet wetlands layer from the Matanuska-Susitna Borough (Table 3).

Table 3 Layers included in ArcGIS Dashboard with a description of information in the layer and a link to access the feature layer.

Layer Name in ArcGIS Dashboard	Description and Hyperlink
Anadromous Streams	Current Anadromous Waters Catalog
NHD layers > Flowlines with Habitat Score	Model output
NHD layers > HUCs	USGS Hydrologic Unit Code watershed boundaries
Infrastructure and Ownership > Roads > Roads_AKDOT	Statewide road centerlines
Infrastructure and Ownership > Roads > PublicSafety_E911Roads	Matanuska Susitna Borough road centerlines
Infrastructure and Ownership > Trails > SCORP_Trails	Statewide inventory of trails
Infrastructure and Ownership > Trails > ParksRec_Trails_Merged	Anchorage Municipality Parks and Recreation trails
Infrastructure and Ownership > Land_Ownership > Landownership_BLMSMA	Surface management agency land ownership (federal, state, private)
Infrastructure and Ownership > Additional Planning Layers > Environment_Wetlands_CookInlet	Cook Inlet lowlands wetland map

Field Survey Validation

Sampling sites were selected based on output from the first "rough draft" model to represent a range of modeled probabilities for field validation. Sites for field validation were then filtered based on their accessibility (e.g. located on public lands, within a 0.5 mile distance of a road or trail). Only sites not in the 2024 version of the AWC were considered for field sampling.

Fish sampling used the Alaska Freshwater Fish Inventory methodology (Cathcart and Giefer 2023). In brief, fish were collected using a Smith-Root LR-20B backpack electrofisher, shocking for 10 minutes, or until at least two anadromous fish were collected at each site. Shock times ranged from 111 seconds to over 600 seconds. Conductivity measurements were taken at each site before sampling to ensure that voltage settings were set as low as possible to be effective. Specific conductance ranged from 13.5-295 µS/cm across sampled sites. The frequency was always set to 30 Hz, the duty cycle to 15%, and the voltages used ranged from 150-700, depending on conductivity at the site. After netting, fish were held in buckets of stream water with bubblers until they could be enumerated and measured. All collected fish were anesthetized (MS-222), identified, and counted. Fork length and weight were recorded for all species. After processing, fish were placed in an aerated recovery bucket prior to their release back into the water. Photo vouchers were taken of all collected fish species at each sampling location.

All fish methodologies were approved through the UAA Institutional Animal Care and Use Committee (protocols 2314063-2 and 2312110-2) and were permitted by an ADFG Aquatic Resource Permit (No. SF2025-114).

Results

Habitat Suitability Model

Overall, all model combinations, runs, and pseudoabsence datasets performed well (Figure 2), giving relatively high confidence in the ensemble model output. Catchment elevation and stream order were the strongest determinants of the probability of anadromous presence (Figure 3). Generally, smaller, higher elevation streams were modeled as being less likely to have anadromous species present (Figure 4).

Model performance varied across algorithms but was consistently high overall (Figure 2). Most models achieved strong discrimination ability, with Area Under the Curve values exceeding 0.94 and True Skill Statistic values generally above 0.80. Ensemble-eligible models such as Random Forest, Generalized Boosted Model, and MaxEnt performed particularly well, clustering at the upper end of both ROC and TSS metrics. In contrast, simpler envelope-based approaches (e.g., SRE) showed substantially lower performance, indicating limited predictive capacity in this context. Variability among model runs was relatively low for top-performing algorithms, suggesting stable model behavior across cross-validation folds.

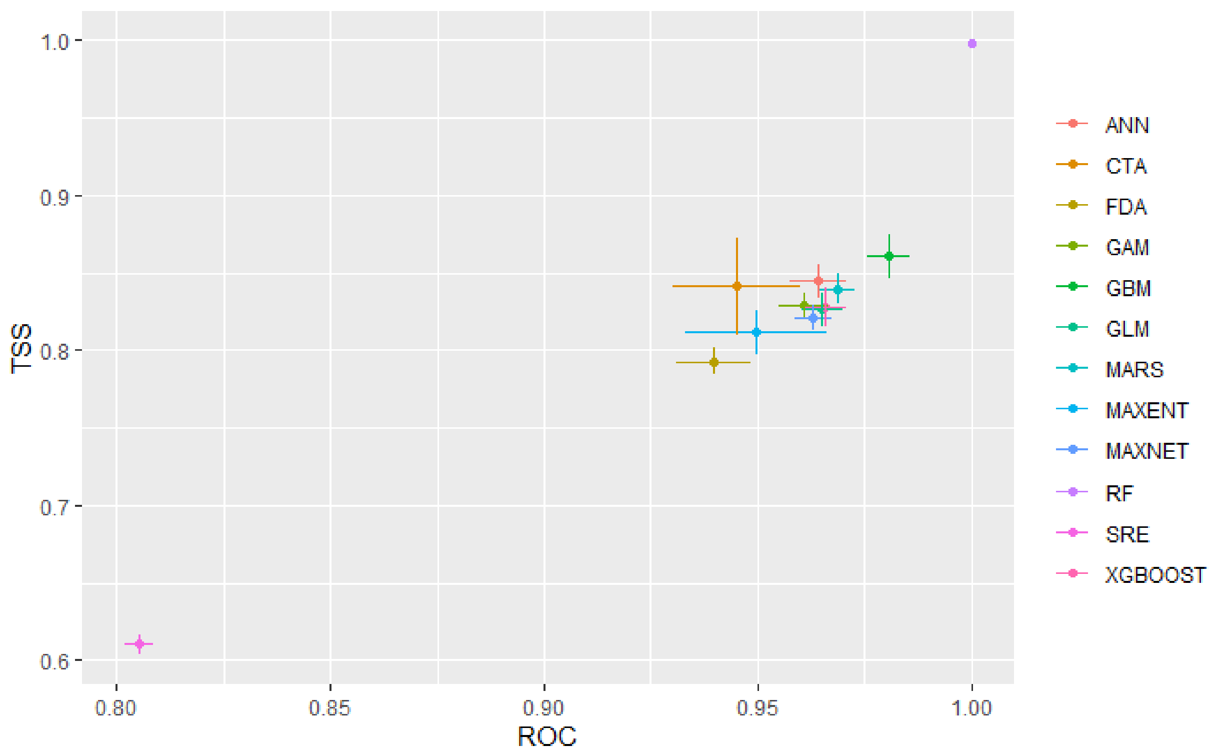

Figure 2 Receiving Operator Curve vs True Skill Statistic plot for all combinations of models, pseudoabsence datasets, and model runs.

Response curves from the ensemble revealed consistent relationships between environmental predictors and anadromous habitat suitability (Figure 3). Elevation showed a strong negative effect, with anadromous habitat suitability declining sharply above ~1,000 m, indicating a preference for lower-elevation systems. In contrast, watershed area and stream order were positively associated with suitability, with probabilities increasing steadily and leveling off at higher values. These patterns suggest that larger, higher-order stream systems are more likely to support anadromous species. Topographic variables such as mean and maximum slope exhibited relatively weak or slightly negative relationships with suitability, implying that slope may play a secondary role compared to network size and position. Geographic gradients were also evident: latitude showed a slight decline in suitability toward the northern extent of the study area, while longitude suggested modest spatial structure, potentially reflecting regional environmental differences not fully captured by other predictors. Channel morphology had a generally positive but shallow relationship with suitability, indicating a preference for wider valley bottoms, though this effect was less pronounced than for drainage area or stream order. Importantly, response curves were largely consistent across ensemble bounds (e.g., mean, upper, and lower TSS-filtered models), indicating low uncertainty in the direction of predictor effects even where effect size varied.

Overall, the ensemble model indicates that stream size and network position are primary drivers of predicted anadromous habitat suitability, with elevation acting as a strong limiting factor. Other variables contribute more modestly but help refine spatial predictions. The agreement among high-performing models and consistency in response curves suggest that these relationships are robust, though some spatial and environmental gradients remain less certain.

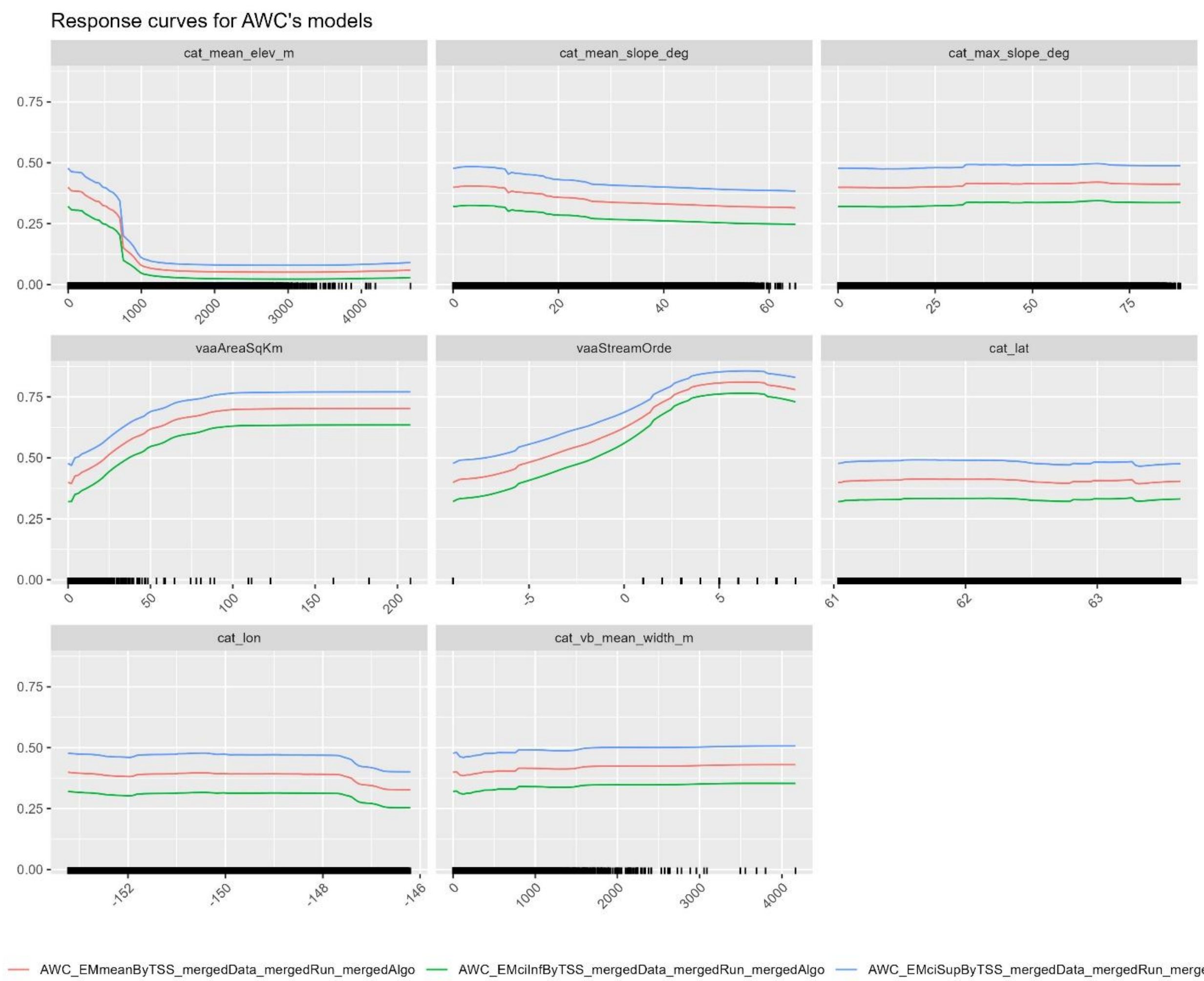

Figure 3 Ensemble model response curves by covariate. The red line indicates the mean of ensemble model responses to covariate values, while the blue line indicates the upper bound confidence interval and the green line indicates the lower bound confidence interval.

Field Validation

25 sites were sampled, reflecting a range of anadromous fish presence probabilities in the initial model (0.004-0.674) and geographic spread across the study area. Salmon were found at sites ranging in probability from 0.175 to 0.269 (Figure 5). Dolly Varden were found across a wide range of sites and probabilities, although they were likely all residents.

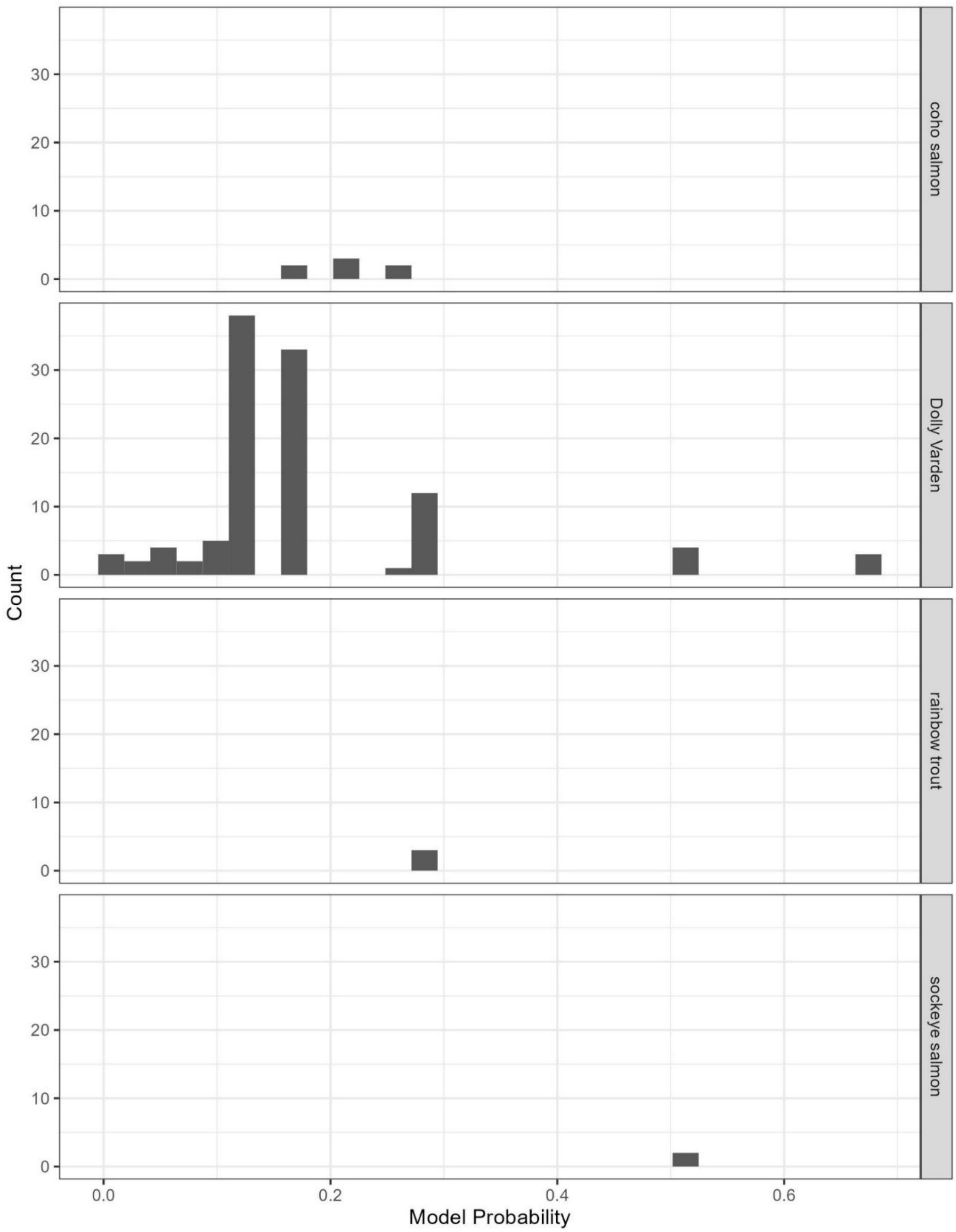

Figure 4. Count of species by modeled probability (0-1) of anadromous occurrence.

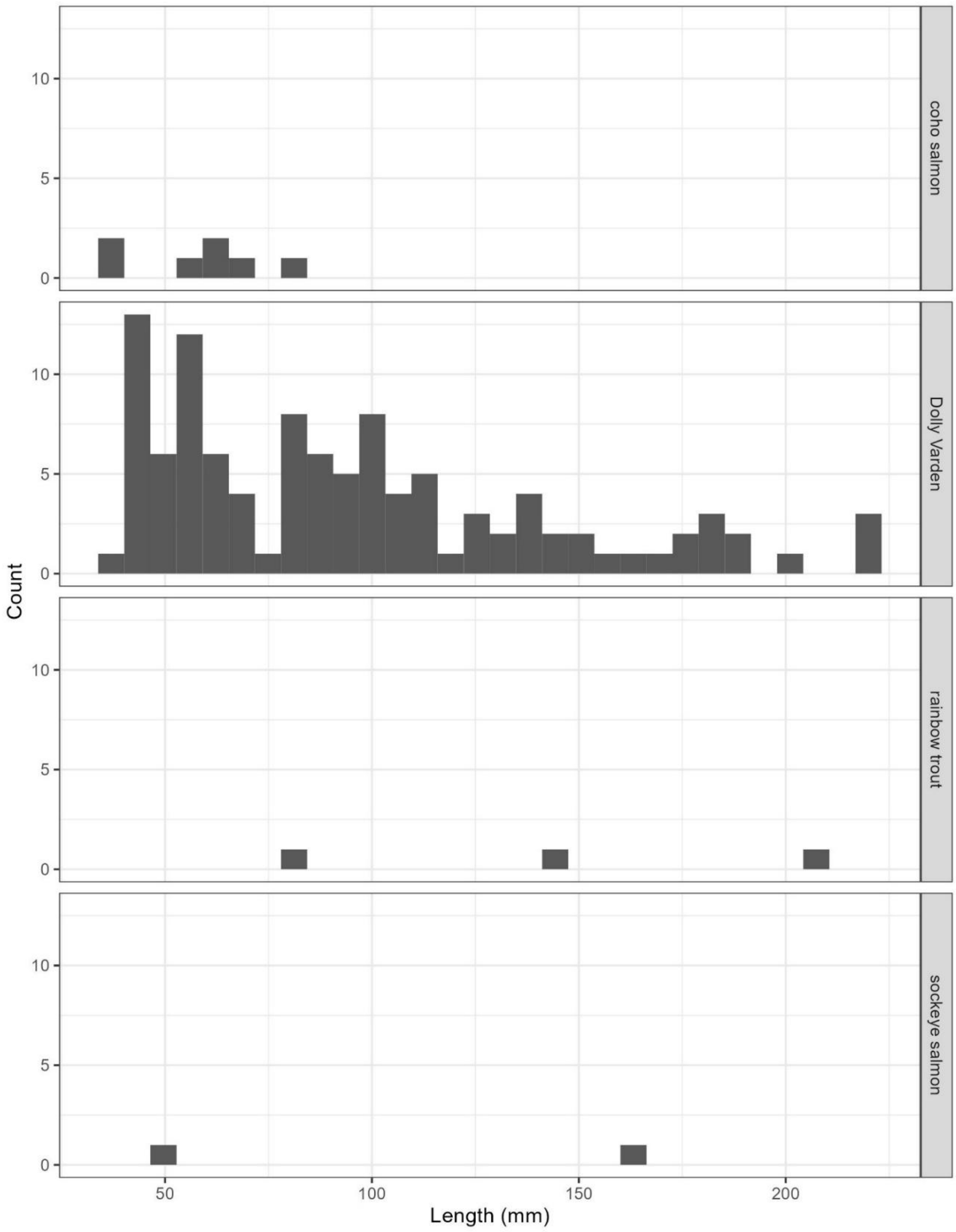

Figure 5 Distribution of individual lengths by species at all sites.

Prioritization of Future AWC Work

All seven HUC 8 watersheds in the region have suitable anadromous habitat (Figs. 6 and 7), according to ensemble model output. In terms of both total mileage and percentage mileage, the Yentna and the Lower Susitna drainages (Figs. 6 and 7) are likely candidates to prioritize for future AWC work. However, it is worth noting, that AWC nominations were made during the field validation for this project in easily road accessed stream segments in the Anchorage municipality.

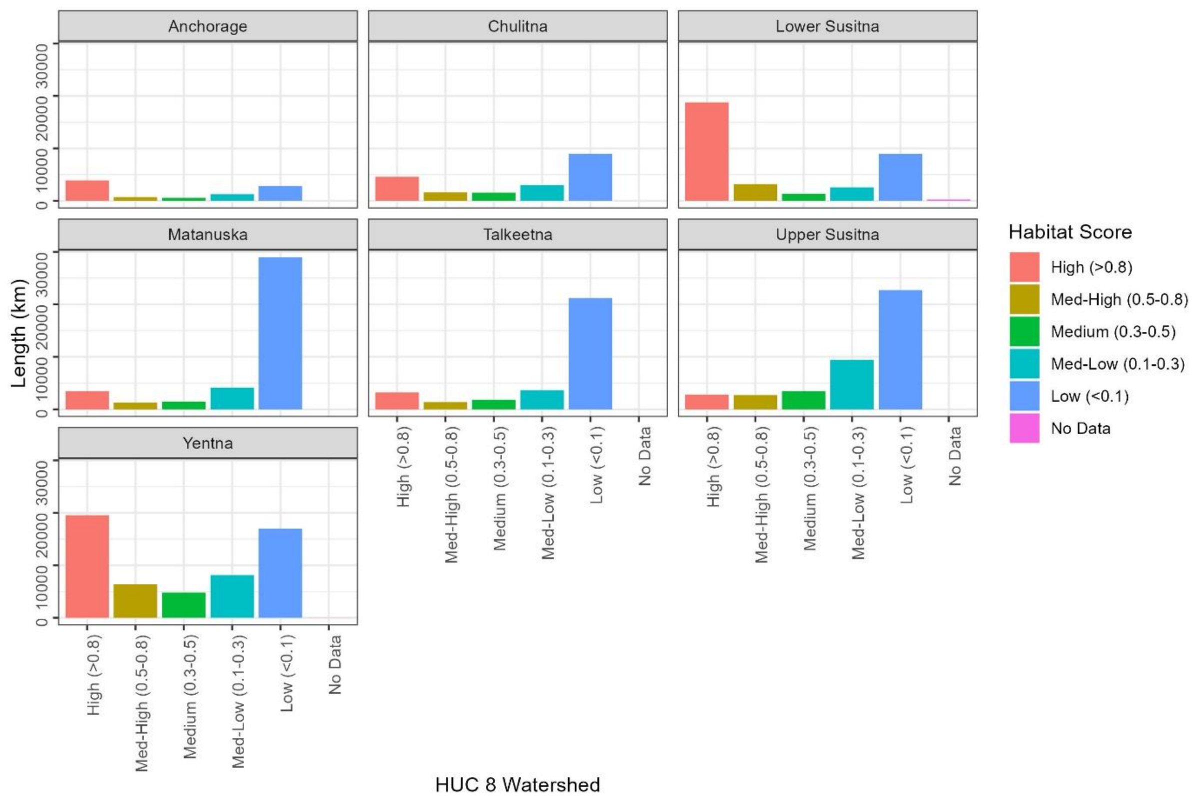

Figure 6 Kilometers of stream length in NHDPlus by habitat score, shown for each HUC 8 watershed.

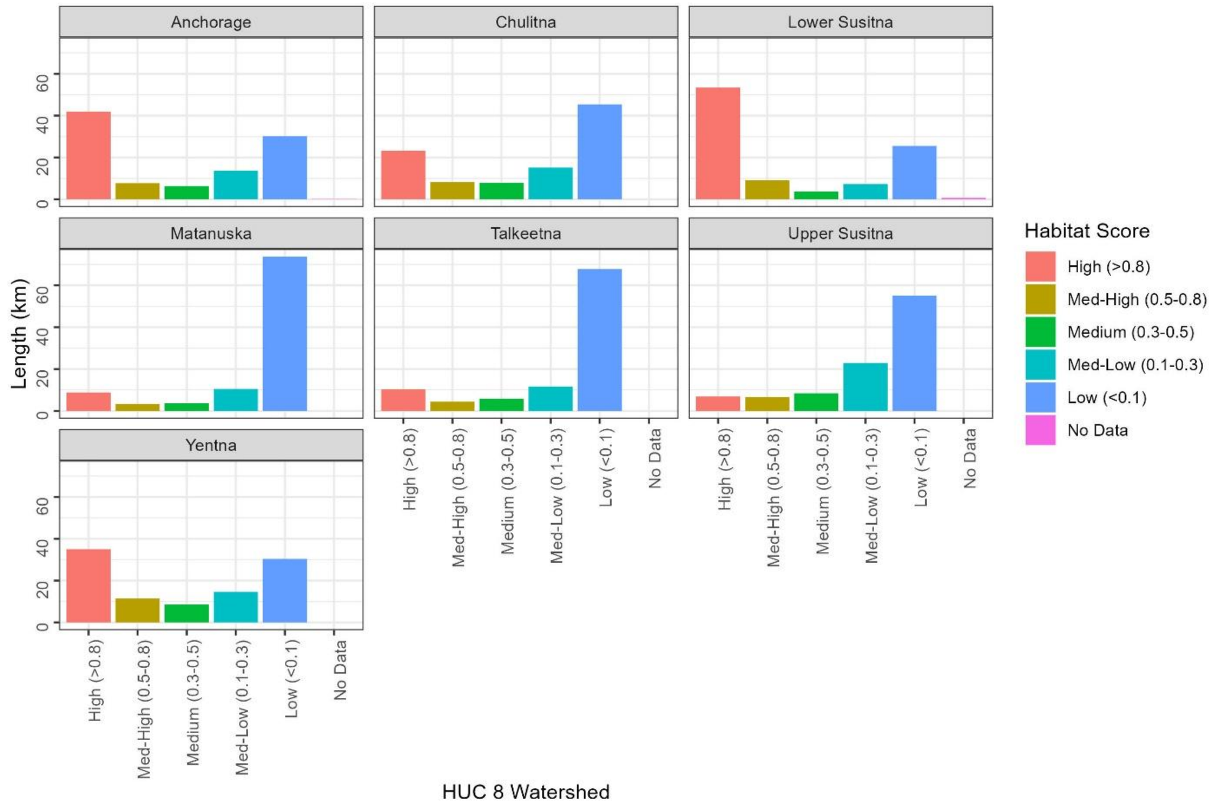

Figure 7 Percentage of stream length in NHDPlus by habitat score, shown for each HUC 8 watershed.

In addition to prioritization at the HUC 8 level, an ArcGIS dashboard was developed to help decision makers and data collectors making more finely resolved prioritization of sampling areas and selection of potential sampling sites. The ArcGIS Online Dashboard includes layers to help plan fieldwork logistics (Table 3).

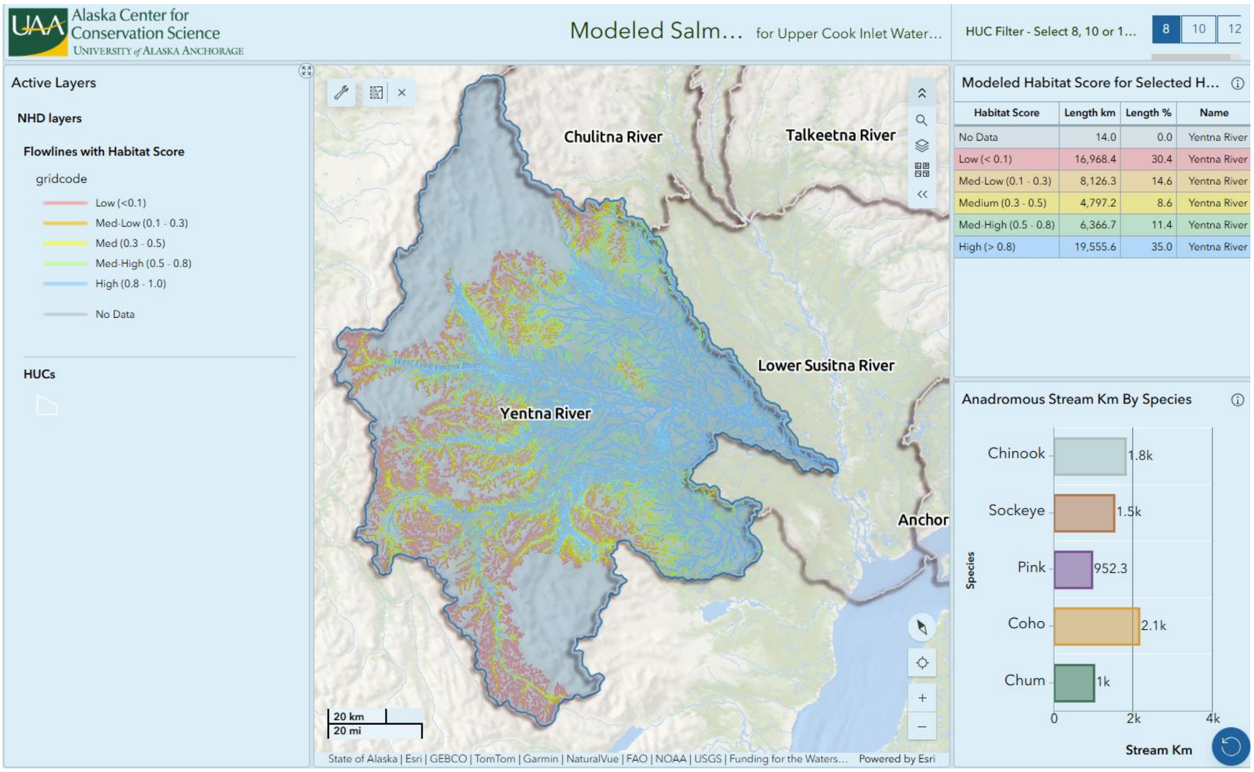

Figure 8 Screenshot of the ArcGIS Online Dashboard, zoomed in on the Yentna River drainage. Cooler colors indicate higher probability of anadromous species' occurrence, while warmer colors indicate lower probabilities.

Discussion

This project aimed to help with prioritizing efforts to add waterbodies to the Anadromous Waters Catalog in the Matanuska-Susitna Basin. Overall, an ensemble model was developed that had sensible relationships between environmental covariates and likelihood of anadromous presence, with elevation and stream order strongly predicting anadromous occurrence. Model output can be used to decide on prioritization of future AWC fieldwork, and an ArcGIS Online Dashboard developed as part of this work helps with navigating and contextualizing model output.

There are important caveats to consider when using the dashboard and model output. First, the Anadromous Waters Catalog and National Hydrography Plus Dataset do not always align. This mismatch can cause challenges with extrapolating this approach to other areas, because aligning these layers requires considerable heads-up GIS work. Low order, particularly 1st order, systems in NHDPlus often do not have flowing surface water. Field testing for this work was limited to road accessed areas, and model testing might have resulted in a different final model if more remote areas had been used in the field validation. Habitat suitability models are not infallible, and users of the dashboard and the model output should use their own contextual knowledge to make decisions about future AWC work.

Future work could be done to better align the Anadromous Waters Catalog with standard hydrography, and to ensure that hydrographic products for the state are consistent statewide.

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