Submitted in Support of the U.S. Navy's 2022 Annual Marine Species Monitoring Report for the Pacific

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Fisheries Science Center
2725 Montlake Blvd. E, Seattle, WA 98112
206-637-2514 • Fax: 503-861-2589

Examining the spatial and depth distribution of mixed-aged Chinook salmon in the Northern California Current and within the Northwest Training and Testing Study Area

Citation: Smith, J.M., and D.D. Huff. 2023. Examining the spatial and depth distribution of mixed-aged Chinook salmon in the Northern California Current and within the Northwest Training and Testing Study Area. Prepared for: U.S. Navy, U.S. Pacific Fleet, Pearl Harbor, Hawaii. Prepared by: National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center under MIPR N00070-19-MP-001OJ. June 2023.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
06-2023

2. REPORT TYPE
Monitoring report

3. DATES COVERED *(From - To)*
June 2018 to August 2019

4. TITLE AND SUBTITLE
EXAMINING THE SPATIAL AND DEPTH DISTRIBUTION OF MIXED-AGED CHINOOK SALMON IN THE NORTHERN CALIFORNIA CURRENT AND WITHIN THE NORTHWEST TRAINING AND TESING AREA

5a. CONTRACT NUMBER
N00070-19-MP-001OJ

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Joseph M. Smith
David D. Huff

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NOAA Fisheries, Northwest Fisheries Science Center

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Commander, U.S.Pacific Fleet, 250 Makalapa Dr. Pearl Harbor, HI

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
To improve the understanding of the distribution and abundance of species listed under the Endangered Species Act (ESA) in the northern California current ecosystem, including the endangered Southern Resident Killer Whales (SRKW) and multiple ESA-listed stocks of Chinook salmon, this study conducted depth-specific Chinook salmon sampling and analysis along the coast of Washington in and adjacent to the United Sates (U.S.) Navy's Northwest Training and Testing (NWTT) study area. The objective was to determine the likelihood of capturing Chinook salmon at different locations and times and to identify whether environmental covariates influence distribution, measured as time-to-capture. This study was conducted in the U.S. Navy's NWTT study area, which stretches along the coast from Washington to northern California, where the Navy conducts various training and testing activities. Understanding the occurrence and distribution of potentially impacted species in the NWTT study area is important to minimize potential impacts on wildlife during these activities. Results showed that Chinook salmon had a wide distribution in nearshore marine waters of the Northern California Current, with higher capture rates near estuaries and varied capture rates by water depth. The study also found that the distribution of Chinook salmon was influenced by environmental covariates such as sea surface temperature. These findings have implications for SRKW conservation efforts, as Chinook salmon are a vital prey resource for these whales. By understanding the distribution and abundance of Chinook salmon in the area, actions can be mitigated that could cause harm, supporting their conservation and, by extension, the conservation of SRKW.

Submitted in Support of the U.S. Navy's 2022 Annual Marine Species Monitoring Report for the Pacific

15. SUBJECT TERMS
Monitoring, tagging, Chinook salmon, Southern resident killer whales, endangered species, Northwest Traning Range Complex, Northwest Training and Testing, Washington Coast

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
			UU	15	Department of the Navy
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified			**19b. TELEPONE NUMBER (*Include area code)*** 808-471-6391

Executive Summary

To improve the understanding of the distribution and abundance of species listed under the Endangered Species Act (ESA) in the northern California current ecosystem, including the endangered Southern Resident Killer Whales (SRKW) and multiple ESA-listed stocks of Chinook salmon, this study conducted depth-specific Chinook salmon sampling and analysis along the coast of Washington in and adjacent to the United Sates (U.S.) Navy's Northwest Training and Testing (NWTT) study area. The objective was to determine the likelihood of capturing Chinook salmon at different locations and times and to identify whether environmental covariates influence distribution, measured as time-to-capture. This study was conducted in the U.S. Navy's NWTT study area, which stretches along the coast from Washington to northern California, where the Navy conducts various training and testing activities. Understanding the occurrence and distribution of potentially impacted species in the NWTT study area is important to minimize potential impacts on wildlife during these activities. Results showed that Chinook salmon had a wide distribution in nearshore marine waters of the Northern California Current, with higher capture rates near estuaries and varied capture rates by water depth. The study also found that the distribution of Chinook salmon was influenced by environmental covariates such as sea surface temperature. These findings have implications for SRKW conservation efforts, as Chinook salmon are a vital prey resource for these whales. By understanding the distribution and abundance of Chinook salmon in the area, actions can be mitigated that could cause harm, supporting their conservation and, by extension, the conservation of SRKW.

Background

To effectively protect threatened and endangered species, it is essential to understand their distribution and abundance over time and space. This is particularly important in the Northern California Current Ecosystem, which is home to several species in need of conservation, including the endangered Southern Resident Killer Whales (SRKW; *Orcinus orca*) and multiple listed stocks of Chinook salmon (*Oncorhynchus tshawytscha*). Chinook salmon are a vital prey resource for SRKW and, therefore, it is important to understand their distribution in the ocean to identify areas that may be of particular importance for SRKW conservation efforts (Hanson et al. 2021). By understanding the distribution and abundance of these species, steps can be taken to mitigate actions that could harm them and support their conservation.

Nine Chinook salmon ESU's listed under the ESA have the potential to occur within the NWTT study area (Table 1). However, three of these ESU's originate from California systems. Nicholas and Hankin (1988) found that Chinook salmon from rivers south of Cape Blanco generally rear in the ocean off southern Oregon and northern California. As a result, six of these ESU's are more likely to co-occur with the SRKW that occur most predominantly in southern British Columbia, Washington and northern Oregon waters, particularly in regions where and when returning pre-spawn Chinook salmon may occur.

Table 1. Chinook Salmon ESU's listed under the Endangered Species Act

Chinook Salmon ESU[1]	ESA[2] status
Puget Sound ESU	Threatened
Upper Columbia River Spring-Run ESU	Endangered
Lower Columbia River ESU	Threatened
Upper Willamette River ESU	Threatened
Snake River Spring/Summer-Run ESU	Threatened
Snake River Fall-Run ESU	Threatened
California Coastal ESU	Threatened
Central Valley Spring-Run ESU	Threatened
Sacramento River Winter-Run ESU	Endangered

1 ESU = Evolutionarily Significant Unit;
2 ESA = Endangered Species Act

The NWTT, which stretches along the coast from Washington to northern California, is a designated range where the Navy conducts various training and testing activities. It is important to understand the occurrence and distribution of potentially impacted species in the NWTT study area to minimize potential impacts on wildlife during these activities. Previous studies have shown that SRKW are known to occupy the coast of Washington during the winter and spring months (Hanson et al. 2013). However, their distribution has become less predictable in recent years, potentially due to a lack of food availability (NOAA 2022). As SRKW only feed on fish, and prefer Chinook salmon, understanding the distribution of Chinook salmon in the NWTT study area could be particularly useful in predicting the presence of SRKW and identifying potential areas of overlap with Navy activities.

Most information on Chinook salmon distribution along the coast of Washington State has been examined with fisheries-dependent data (e.g., coded wire tags, Weitkamp 2010, Weitkamp 2011). These studies show that the stocks present along the Washington coast range from British Columbia to California (Weitkamp 2010). Individual Chinook salmon have a relatively variable life cycle compared to other Pacific salmon. They can either migrate to the ocean the same year as a hatching (i.e., sub-yearlings) or stay in the river for another winter and migrate the following year (i.e., yearlings). Once in the ocean, they can return from one to five years later (Quinn 2018) and they can either remain relatively local or migrate long distances. For example, Puget Sound origin Chinook salmon, often referred to as blackmouth, can stay within Puget Sound or migrate farther, whereas Snake River spring-run Chinook salmon tend to migrate to northern waters quickly after entering the ocean. Due to these varied life cycle possibilities, it is difficult to predict what stock and life stage of Chinook salmon are present along the coast for a given time.

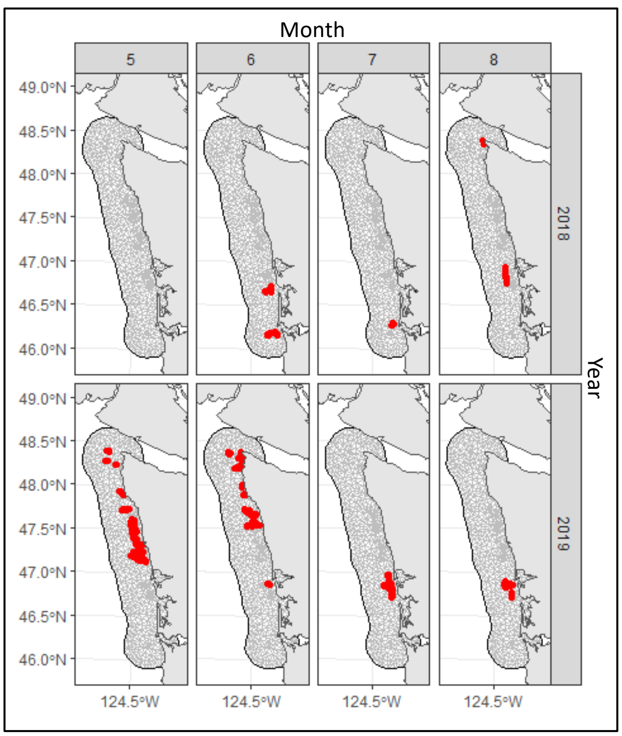

Figure 1. Spatial mesh map used for time-to-capture analysis and sampling locations (red circles) for each year (rows) and month (columns) sampled. Months 5 – 8, refer to May through August

This study conducted depth-specific sampling and analysis to understand the seasonal distribution of Chinook salmon in the coastal waters of Washington State. The objective was to determine the likelihood of capturing Chinook salmon at different locations and times. Specifically, the study was designed to answer the following research questions: 1) What is the spatial and depth distribution of mixed-age Chinook salmon along the Washington coast? 2) Do environmental covariates influence the distribution of Chinook salmon? 3) Do these results have any implications for SRKW, which rely on Chinook salmon as a key prey species? By answering these questions, this study aimed to improve the understanding of the distribution and abundance of Chinook salmon and their potential impacts on SRKW and other species.

Methods

The study area included nearshore marine waters from Neah Bay, Washington to the mouth of the Columbia River between 17 m and 262 m bottom depths and 5 km and 27 km distance from shore (Figure 1). Sampling occurred from 20 June through 26 August 2018 and 2 May through 28 August 2019.

Sampling

Fish were captured using modified microtrolling, a method of sampling developed by Duguid et al. (2017). Multiple leaders were directly attached to a Scotty Depthpower downrigger line using clips spaced 5 m apart and weighted by a 15 lb downrigger ball (Figure 2). The leaders consisted of a terminal clip, 1 m of 150 lb test monofilament, a 5.5" Hot Spot microflasher, 0.5 m of 20 lbs test monofilament, and ending in a size 0 Dick Nite spoon with Gamakatsu #10 Siwash (open eye) hook. Each deployment consisted of a downrigger with up to 7 leaders fishing for 10 to 20 minutes. Depth loggers (Sensus Ultra by ReefNet Inc.) were attached to the downrigger line near the bottom hook and top hook to measure hook depth. Each downrigger deployment was assigned a unique identifier, and each hook of each deployment was assessed for fish capture. Hooks were fished from depths of 1 to 80 m from the surface.

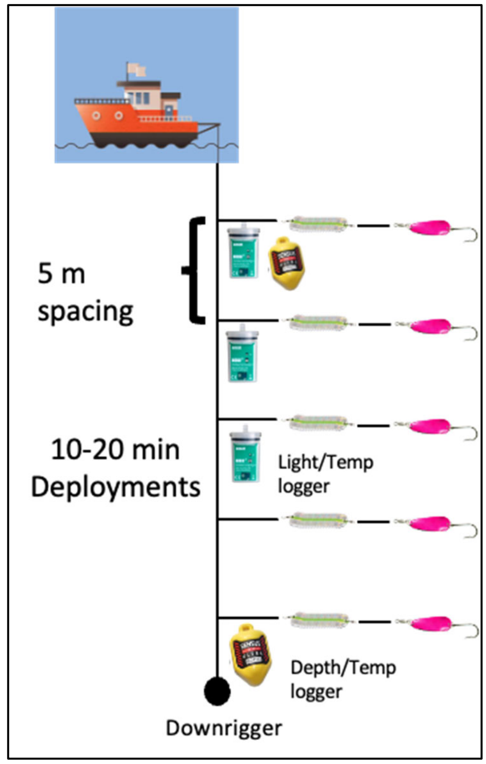

Figure 2. Microtrolling setup showing 5 m spacing between leaders with depth and temperature sensors.

The study identified and collected detailed data on each captured Chinook salmon. This included measures of fork length (mm), weight (g), and scale samples for estimating life history (sub-yearling or yearling) and total age. To determine the genetic origin, Evolutionarily Significant Units (ESUs), and sex of each fish, fin clips were taken from the dorsal or anal fin and stored them in 70% ethanol. For Chinook salmon with a fork length greater than 300 mm, fish were anesthetized and surgically inserted an acoustic tag into the peritoneal cavity as part of a related study. After tagging, the fish were released back into the water near the capture location. In addition, locations tracks and boat speed were recorded for each deployment using a Garmin GPSMAP 64st. Overall, these data were used to provide a comprehensive understanding of the characteristics and behavior of Chinook salmon in the study area.

Data analyses

To understand how environmental variables may influence the probability of capturing Chinook salmon, data was extracted from from LiveOcean, a regional ocean modeling system (ROMS) at the median latitude and longitude of each deployment (https://faculty.washington.edu/pmacc/LO/LiveOcean.html). LiveOcean provided a range of variables at each specific hook depth including temperature, oxygen, ocean bottom depth, east-west waterflow velocity (u-momentum), vertical waterflow velocity (w-momentum), and phytoplankton. Two independent variables sea surface temperature (OISST) and sea surface chlorophyll were calculated using satellite data (https://coastwatch.pfeg.noaa.gov/erddap/index.html). Other independent variables included boat speed, time of day, day of the year, relative depth (proportion of water depth from the surface). We used linear interpolation to estimate the depth of each hook between the bottom and top hooks where depth loggers were deployed. These data were used to examine how environmental variables may affect the probability of capturing Chinook salmon.

To understand how environmental variables may influence the time it takes to capture a Chinook salmon, we tested different forms of a right-censored survival model with random equilibrium effects for the relative depth and spatial location and random deviations from the equilibrium conditions by the relative depth and spatial location.

Random effects

Random effects for the depth, location, and the interaction between depth and location, were included in the model of Chinook salmon capture rate to account for heterogeneity not explained by the fixed covariates, and to allow for hooks on the same line at different depths to be treated as statistically independent observations. The vector of random effects are considered to be the equilibrium conditions across depth and location, respectively.

The depth effects are categorical; that is, they are stratified into increments so that only one hook per line is at a particular stratum. The likelihood for the deviates for depth strata is assumed to be normally distributed with a mean of zero. The vector of equilibrium spatial effects across all locations is described by a multivariate normal distribution with a vector of mean zero, a correlation matrix using a Matérn function with smoothness equal to one.

Model estimation

To estimate the fixed and random effects of the model, we use the non-linear optimization libraries in the Template Model Builder package built for R. To create an Integrated Nest Laplace Approximation (INLA (; INLA package R) mesh that accurately represented the distribution of the data across the Washington coast, the approach first reduced the number of observed spatial locations from around 6,000 to 150 knots using a nearest neighbor algorithm (RANN package). The spatial field is estimated using Gaussian Markov Random Fields (GMRF) and is summarized in Thorson et al. (2015). Using the nonconvex hull mesh algorithm in INLA, the approach then used these knots to create a boundary around the entire sampling region, with a high resolution in areas that were intensively sampled and a more uniform resolution in areas with fewer observations. A minimum edge distance of 10 nautical miles was set based on an estimated decorrelation range of 20 nautical miles (the distance at which the correlation between observations decreases to 10%). The response variable for this model was the time-to-capture of a Chinook salmon on each hook, and we included relative depth bins in increments of 0.1 from the surface to the bottom of the ocean. The variable importance of all independent variables was examined using Akaike information criterion (AIC) and plotted response curve marginal plots for variables with importance values greater than 0.2. The approach only considered combinations of up to four non-correlated independent variables to avoid including correlated variables in the same model.

Results

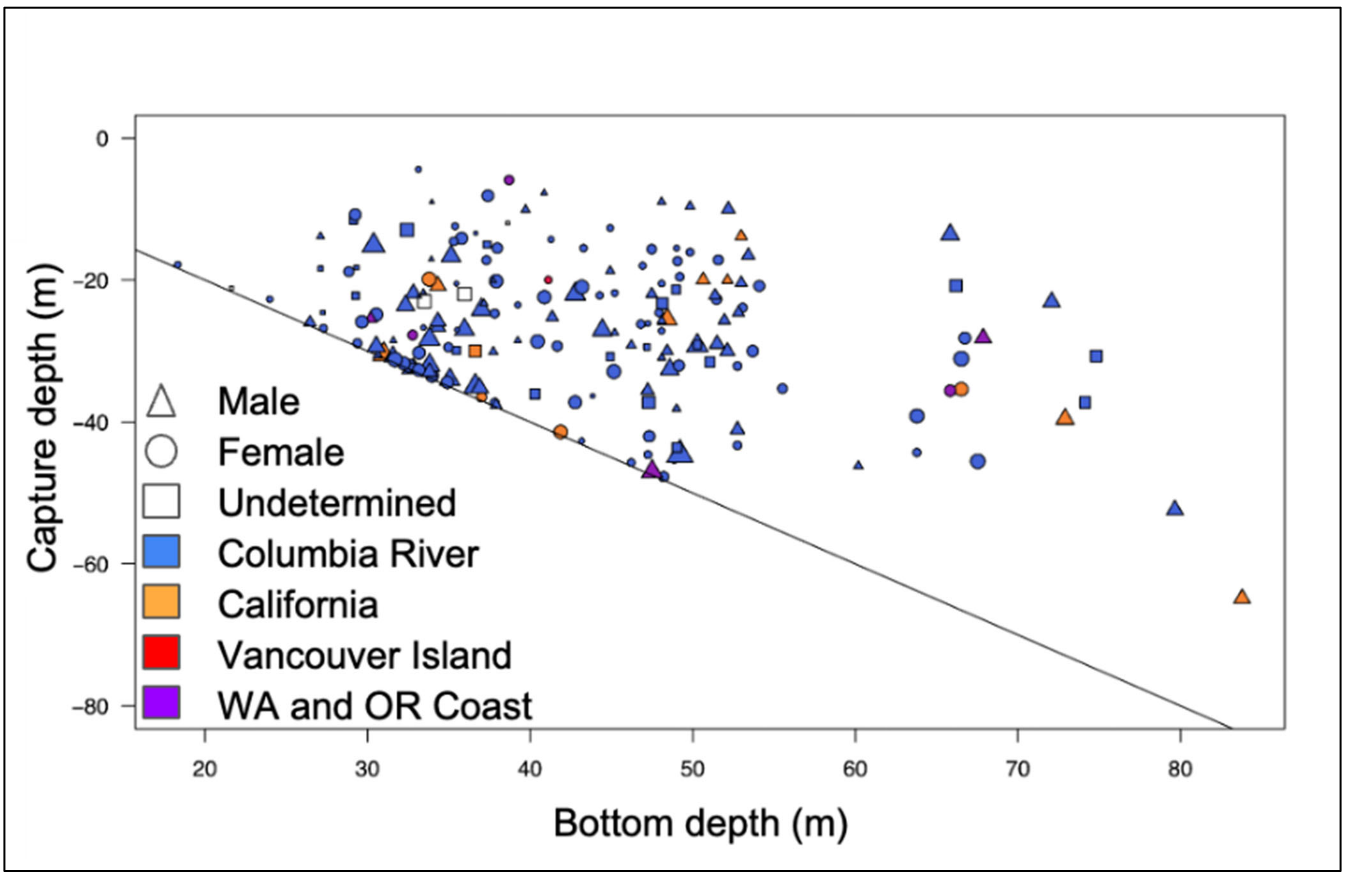

Figure 3. Depth distribution of Chinook salmon by sex and stock location. Males are represented by triangles, females are represented by circles, and undetermined sex is represented by squares. The size of the symbol is proportional to the fish fork length. Blue symbols represent Columbia River stocks, orange symbols represent California stocks, red symbols represent Vancouver Island stocks, and purple symbols represent Washington or Oregon coast stocks. The capture depth (m) is plotted against the bottom depth (m) of each fish.

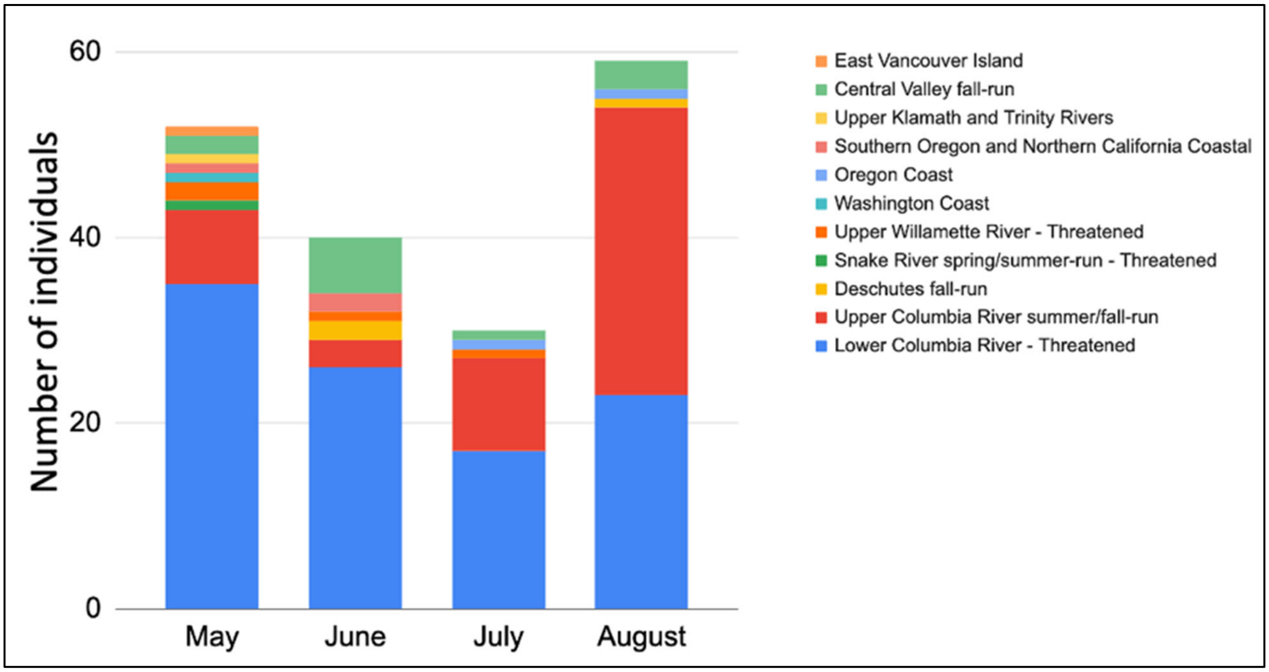

Figure 4. The number of Chinook salmon individuals caught per month grouped by the Evolutionarily Significant Unit (ESU) determined from genetics stock identification.

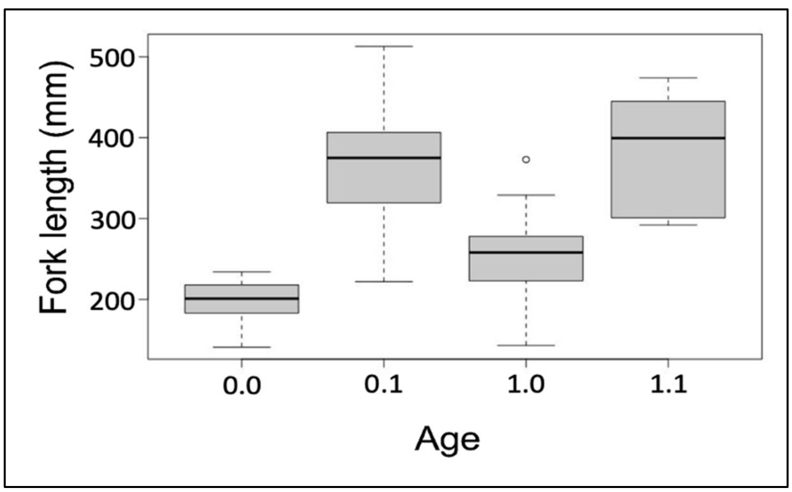

Figure 5. Fork length distribution of Chinook salmon by age. Boxplots show the range, median, and interquartile range of fork length for each age group, determined by aging scales. Age is indicated in years, with ages before the period representing years spent in freshwater and ages after the period representing years spent in the ocean.

During the study, 1,299 deployments were conducted, deploying 6,616 hooks. As a result, 223 Chinook salmon were captured, which ranged in size from 111 mm to 560 mm in fork length. The capture depth varied from 5 m to 60 m (Figure 3). Of the samples that were able to be identified 11 different Evolutionarily Significant Units (ESUs) of Chinook salmon were found, with the Lower Columbia River and Upper Columbia River

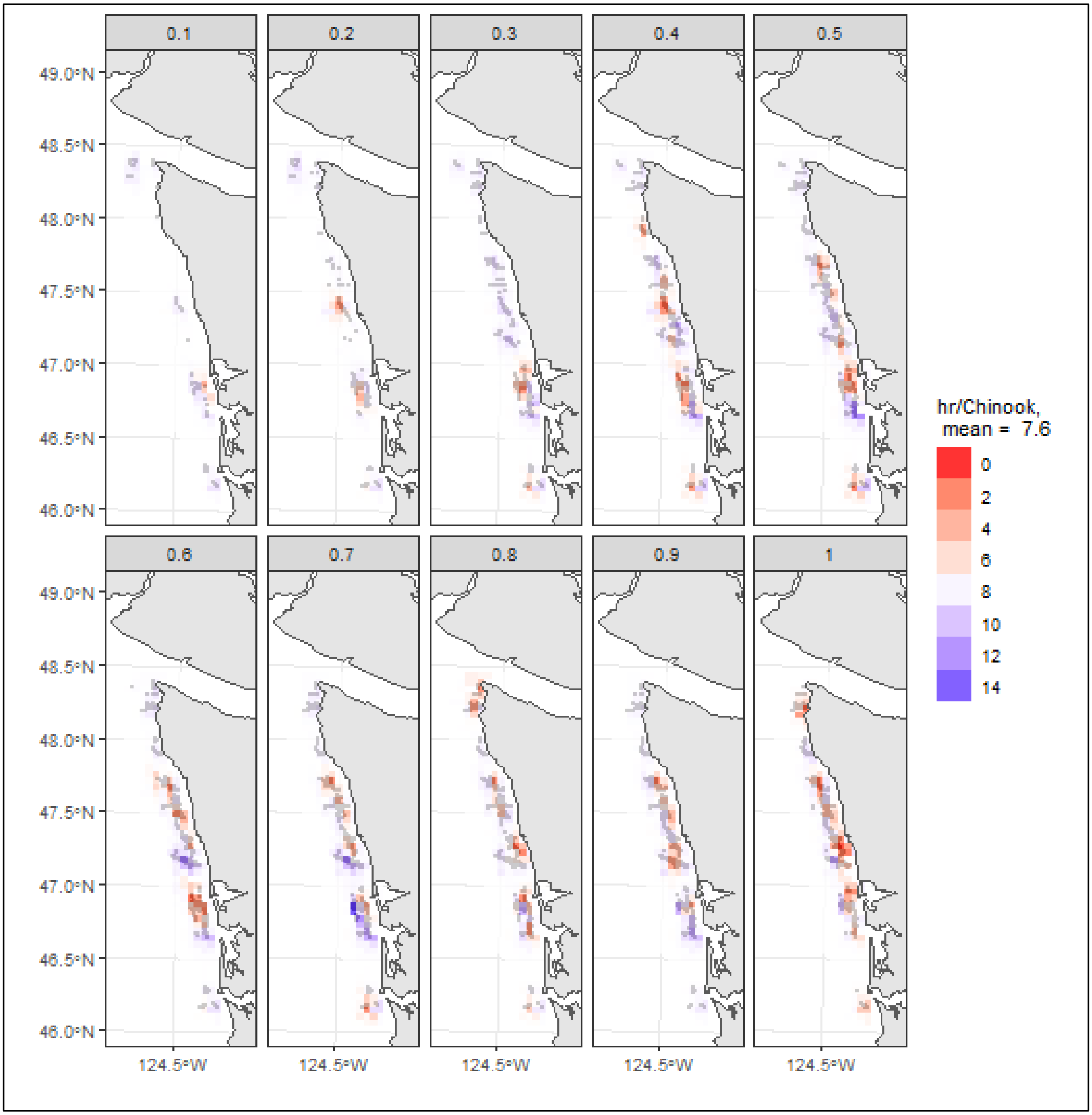

Figure 6. Predicted values of time-to-capture (hours to catch a Chinook salmon) by relative depth bin of 0.1 intervals. The 0.1 depth bin indicates depth sampled near the surface, 0.5 indicates the middle of the water column and 1.0 indicates near the ocean bottom. Time-to-capture values closer to zero (red) indicate less effort to catch a Chinook salmon. Time-to-capture values far from zero (blue) indicate more effort to capture a Chinook salmon.

(age 0.0 or 0.1) and yearling (age 1.0 and 1.1) Chinook salmon were caught (Figure 5). Three of eleven ESUs that were caught were ESA-listed as threatened.

The analysis of time-to-capture data for Chinook salmon showed that the likelihood of capture varied spatially, with shorter capture times (indicated by red areas in Figure 6) varying by depth. When the influence of environmental variables on time-to-capture was examined, it was found that found that sea surface temperature and boat speed had the greatest impact, with variable importance values greater than 0.2 (Figure 7). Specifically, we found that Chinook salmon were more likely to be caught quickly in areas with warmer sea surface temperatures and faster boat speeds (Figure 8).

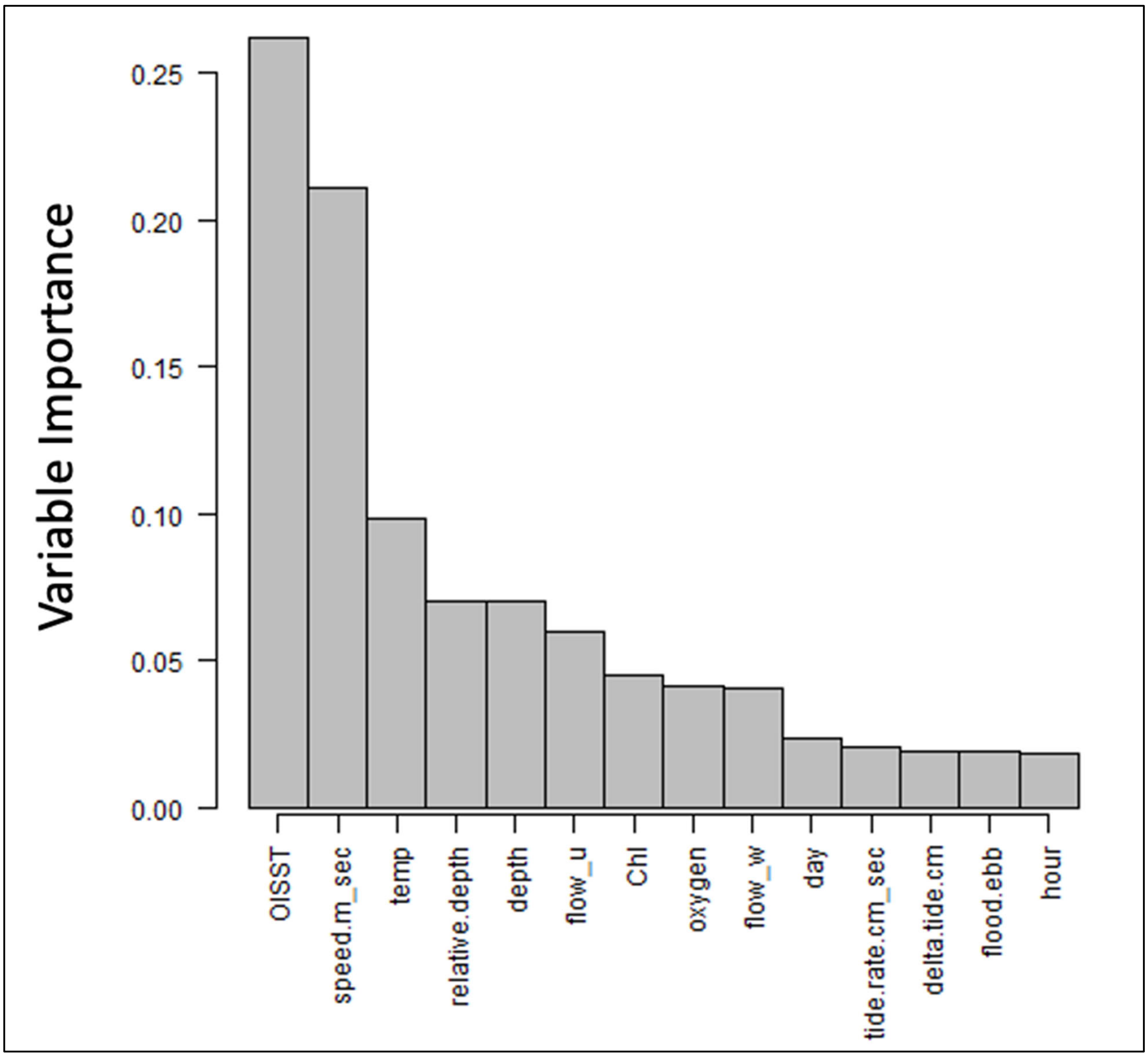

Figure 7. Variable importance of each independent variable used in the time-to-capture INLA model.

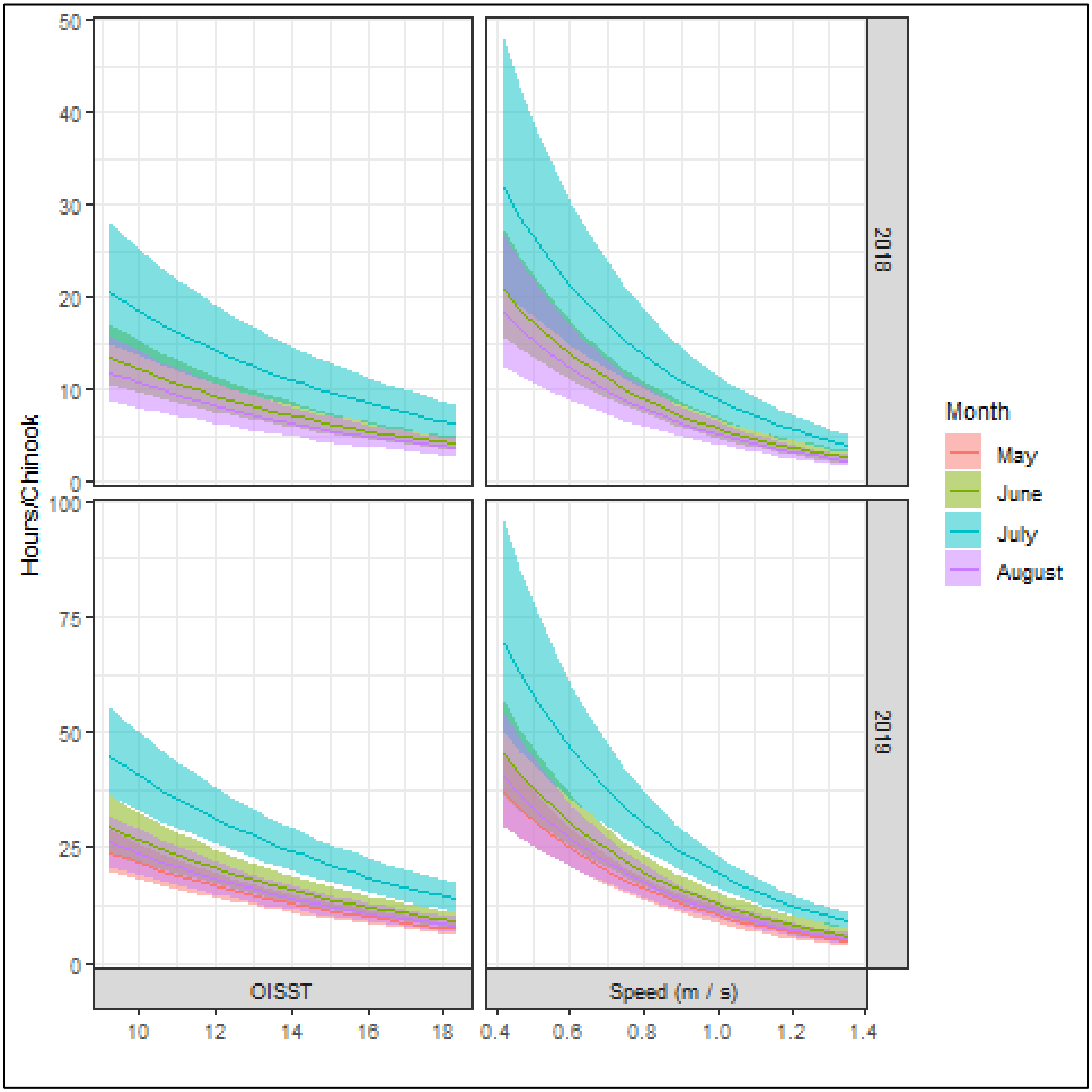

Figure 8. Response curves for the variables with variable importance greater than 0.2 for each month and year sampled.

Discussion

This research found that the occurrence of Chinook salmon varied spatially, with hotspots often occurring near estuaries and was variable by water depth, but higher closer to ocean bottom. These findings are consistent with previous studies, which have demonstrated that Chinook salmon frequently were found near the bottom where depths <50m. Beyond that bathy line, Chinook were captured most frequently at mid-water depths. Specifically, we observed that time-to-capture was lower near estuaries such as the mouth of the Chehalis River and the Columbia River and varied by depth (as shown in Figure 3, 6). Overall, these results highlight the importance of considering spatial variation in the distribution of Chinook salmon, particularly in areas near estuaries and the ocean bottom.

Our analysis of time-to-event data for Chinook salmon catch showed that sea surface temperature was the most significant predictor of catch rates. Specifically, we found that Chinook salmon were caught more quickly in areas with relatively warmer sea surface temperatures regardless of the capture location's bottom depth (Figure 8). This may be because localized areas with higher sea surface temperatures are often more productive and may support higher concentrations of Chinook salmon prey. The second most important predictor was boat speed, with slower boat speeds resulting in slower catch rates, likely because the fishing gear was less effective at those slow speeds. While this finding may not have significant ecological implications, it is important to consider when sampling Chinook salmon, as excessively slow or fast boat speeds may result in lower catches. Overall, these results highlight the importance of considering sea surface temperature and boat speed when studying the distribution and abundance of Chinook salmon.

This study found that a mix of Chinook salmon ESUs were present in each month of sampling. This suggests that some individuals from these ESUs do not migrate long distances from their river of origin during at least the first two years at sea. The most abundant ESU detected was the Lower Columbia River Chinook salmon, which is listed as threatened under the Endangered Species Act (ESA). The second most abundant ESU was the Upper Columbia Summer and Fall ESU (not listed under the ESA), which became the most frequently caught ESU in August. These ESUs may be particularly important for SRKW that feed on Chinook salmon along the coast of Washington, as they may provide a reliable source of prey when other stocks are not actively returning to rivers. Overall, these findings highlight the importance of considering the distribution and abundance of different Chinook salmon ESUs to understand their potential impacts on SRKW and other species that rely on them for food.

The study found that Chinook salmon tended to concentrate near the bottom of the ocean, particularly in depths between 30 and 50 m (as shown in Figure 3). Previous research has shown that SRKW spend more time in similar habitats. These findings support the hypothesis that

SRKW may spend time in these depth ranges because Chinook salmon are more likely to be present in these locations. This suggests that understanding the distribution of Chinook salmon in relation to ocean depth may be useful for predicting the presence and behavior of SRKW in certain areas.

One limitation of the study was spatial gaps in sampling coverage along the coast (as shown in Figure 1). This means that additional hotspots of Chinook salmon occurrence that were present outside the areas we sampled may have been missed. Additionally, spring-run Chinook salmon were rarely captured in our study which could be a result of the time of sampling. Despite this limitation, we could identify areas and environmental covariates (such as sea surface temperature) where it took less time to capture Chinook salmon. This information can be used to target future sampling efforts and improve our understanding of the distribution and abundance of Chinook salmon along the coast. Overall, our results provide valuable insights into the occurrence of Chinook salmon and can be used to inform conservation and management efforts for this important species.

Acknowledgments

The authors thank Wayne Haimes, Steve Corbett, Brian Wells, Brian Burke and William Matsubu for help field sampling. We thank Brian Burke, Brandon Chasco, and Doug Jackson for assistance with statical modelling. This study was partially funded by an NWFSC cooperative grant. The authors thank Andrea Balla-Holden from the U.S. Navy, U.S. Pacific Fleet, Environmental Readiness Division for providing funding to complete this study, and thank Chris Hunt, Stephanie Sleeman, Brittany Bartlett, and Jessica Chen from Naval Facilities Engineering Systems Command for comments on the report and logistics support.

References

Duguid, W. D. P., and F. Juanes. 2017. Microtrolling: an Economical Method to Nonlethally Sample and Tag Juvenile Pacific Salmon at Sea. Transactions of the American Fisheries Society 146(2):359–369.

Hanson, M. B., C. K. Emmons, E. J. Ward, J. A. Nystuen, and M. O. Lammers. 2013. Assessing the coastal occurrence of endangered killer whales using autonomous passive acoustic recorders. The Journal of the Acoustical Society of America 134(5):3486–3495.

Hanson, M. B., C. K. Emmons, M. J. Ford, M. Everett, K. Parsons, L. K. Park, J. Hempelmann, D. M. Van Doornik, G. S. Schorr, J. K. Jacobsen, M. F. Sears, M. S. Sears, J. G. Sneva, R. W. Baird, and L. Barre. 2021. Endangered predators and endangered prey: Seasonal diet of Southern Resident killer whales. PLoS ONE 16(3 March):1–27.

Nicholas, J. W., and D. G. Hankin. 1988. Chinook salmon populations in Oregon coastal river basins: description of life histories and assessment of recent trends in run strengths. Oregon Dept. Fish Wildl. Infi. Rep.No.88-1.

NOAA. 2022. Southern Resident Killer Whale Recovery Planning and Implementation. https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/southern-resident-killer-whale-recovery-planning-and

Quinn, T. P. 2018. The Behavior and Ecology of Pacific Salmon and Trout Second Edition. University of Washington Press.

Thorson, J. T., A. O. Shelton, E. J. Ward, H. Skaug. 2015. Geostatistical-delta generalized linear mixed models improve precision for estimated abundance indices for West Coast ground fishes. ICES Journal of Marine Science 72:1297-1310.

Weitkamp, L. A. 2010. Marine Distributions of Chinook Salmon from the West Coast of North America Determined by Coded Wire Tag Recoveries. Transactions of the American Fisheries Society 139(1):147–170.

Weitkamp, L. A. 2011. Marine Distributions of Coho and Chinook Salmon Inferred from Coded Wire Tag Recoveries. Pages 191–214 in J. R. McKenzie, B. Parsons, A. C. Seitz, R. K. Kopf, M. Mesa, and Q. Phelps, editors. Advances in Fish Tagging and Marking Technology. American Fisheries Society Symposium 76. Bethesda, Maryland.