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National Oceanic and Atmospheric Administration
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Northern Bering Sea Surface Trawl and Ecosystem Survey Cruise Report, 2019

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ABSTRACT

The northern Bering Sea (NBS) surface trawl and ecosystem survey is a multi-disciplinary research survey that has supported annual sampling of the inner domain (bottom depths generally less than 55 m) of the NBS (60°N–66.5°N). Average sea surface temperature (SST, 11.5°C, upper 10 m) during the 2019 survey was the warmest on record and contributed to significant changes in the NBS ecosystem. Similar to prior years, the jellyfish species, northern sea nettle (*Chrysaora melanaster*), had the largest surface trawl catch biomass with a total catch of 6,989 kg in 2019. Pacific herring (*Clupea pallasii*) were the most abundant species of fish with a total catch of 142,512 fish. Juvenile pink salmon (*Oncorhynchus gorbuscha*) were the most abundant species of salmon with a total catch of 13,507 fish. Annual catch rates of several pelagic fish species increased with temperature, reflecting the influence of temperature on the distribution (e.g. Bristol Bay juvenile sockeye salmon (*O. nerka*), $\rho = 0.9$) and survival (e.g. juvenile coho salmon (*O. kisutch*), $\rho = 0.7$). The abundance and proportion of juvenile Yukon River Chinook salmon (*O. tshawytscha*) in 2019 were the lowest observed in the northern Bering Sea. The abundance of the Canadian-origin stock group (stock proportion of 30%) was estimated at 575,100 juveniles. The abundance of the Total Yukon River stock group (stock proportion of 65%) was estimated at 1,246,000 juveniles. Projected run-sizes for Yukon River Chinook salmon in 2021 and 2022 are 52,300 and 46,300 for the Canadian-origin stock group and 143,800 and 129,000 for the Yukon River stock group, respectively. The abundance of juvenile pink salmon reached a record high abundance in 2019, resulting in an outlook of 6.5 million pink salmon for Yukon River and Norton Sound in 2020. Average lengths of juvenile salmon were typical of past years except for coho salmon, which had the lowest recorded average length in 2019. The proportion of non-target prey consumed by juvenile coho and chum (*O. keta*) salmon has increased in recent years suggesting a decrease in preferred prey. A total of 2,870 km of transects were surveyed. We recorded 3,310 birds on transect, comprised of 38 species plus a few unidentified passerines, with the northern fulmar (*Fulmarus glacialis*) the most abundant seabird species encountered.

CONTENTS

INTRODUCTION

The northern Bering Sea (NBS) surface trawl and ecosystem survey (NBS survey) is a multidisciplinary survey that supports research on pelagic fish species and oceanographic conditions in the eastern Bering Sea. Surface trawl surveys in the NBS were initiated by NOAA's Alaska Fisheries Science Center (AFSC) in 2002 as part of the Bering-Aleutian Salmon International Survey (BASIS). BASIS was a basin-wide research program developed by member nations of the North Pacific Anadromous Fish Commission and designed to improve our understanding of the marine ecology of salmon in the Bering Sea. Surface trawl surveys in the NBS were continued through 2007 as part of the BASIS survey for the eastern Bering Sea shelf. The NBS was not sampled in 2008, but it has been sampled on an annual basis since 2009 to support research objectives on the ecology of salmon in the NBS and to improve our understanding of how the NBS ecosystem is changing in response to warming climate and loss of arctic sea ice.

The NBS survey has supported a range of different survey operations and research objectives in the NBS. Survey operations have included the following: surface and midwater trawl sampling for pelagic nekton, midwater acoustics, seabird and marine mammal observations, bongo net sampling for zooplankton and ichthyoplankton, electronic conductivity, temperature, depth (CTD) data, and water collections for chlorophyll-a, phytoplankton, and nutrients. Survey objectives have supported research objectives on salmon and other pelagic fish resources in the NBS, including: juvenile salmon abundance and run-size forecasts (Murphy et al. 2017, Howard et al. 2019, Howard et al. 2020, Farley et al. 2020), size selective mortality (Murphy et al. 2013, Howard et al. 2016), energy allocation (Andrews et al. 2009, Murphy et al. 2013, Moss et al. 2017), diet (Farley et al. 2009, Andrews et al. 2016, Auburn and Sturdevant 2013, Honeyfield et al. 2016, Garcia and Sewall 2021), and species distribution (Murphy et al. 2009, Murphy et al. 2016, Andrews et al. 2016). An emphasis has been given to Chinook salmon over the last 5 to 10 years due to the decline in their survival (ADF&G 2013) and their importance to subsistence fisheries in the Yukon River. The declining survival of Chinook salmon in the Yukon River has a widespread impact on subsistence fisheries throughout Alaska and the Yukon Territory, and it has had a significant impact on pollock fisheries in the eastern Bering Sea through efforts to reduce Chinook salmon bycatch (Ianelli and Stram 2014,
Stram and Ianelli 2014).

The 2019 NBS survey was a cooperative research survey by AFSC, the Alaska Department of Fish and Game (ADF&G), the Alaska Pacific University (APU), and the U.S. Fish and Wildlife Service (USFWS) to improve our understanding of the marine ecosystem in the NBS. Key funding was provided by the Alaska Sustainable Salmon Fund to help maintain research on juvenile salmon in the NBS. The primary objectives of the 2019 NBS surface trawl survey were to 1) conduct surface trawl operations in support of ecosystem science, with a focus on the marine ecology of juvenile fish species; 2) estimate stock-specific abundance of juvenile Chinook salmon and update run-size forecast models for the Yukon River; 3) collect electronic oceanographic data and water samples for temperature, salinity, chlorophyll-a, nutrients, particulate organic carbon, and harmful algal blooms with a SBE-9-11 CTD and Niskin bottles;

4) collect zooplankton and icthyoplankton samples with a 20 cm (150 µm mesh) and 60 cm (505 µm mesh) bongo array; and 5) assess the distribution and abundance of seabirds and marine mammals on the NBS shelf.

METHODS

The 2019 NBS survey began and ended in Dutch Harbor, AK, with a port call in Nome, AK. The survey occurred over 25 days inclusive of mobilization, demobilization, travel, sampling, and weather days aboard the chartered fishing vessel FV *Northwest Explorer*, August 27 to September 20, 2019. The survey crew consisted of scientists from Alaska Fisheries Science Center, Alaska Department of Fish and Game (ADF&G), U.S. Fish and Wildlife Service (USFWS), and Alaska Pacific University (APU) (Table 1). The survey consisted of 44 stations in the NBS between 60°N–66.5°N and east of 171°W, and three additional stations just north of the Bering Strait (Fig. 1, Table 2). Rough weather conditions at the end of the survey prevented sampling at the distributed biological observatory (DBO) stations in 2019. Each day typically consisted of sampling three stations during daylight hours. The order of operations at each station was 1) a Conductivity Temperature Depth (CTD) instrument system, 2) a Van Veen grab sample to collect benthic organisms and sediment samples for the presence of harmful algal blooms (HABs), 3) an oblique zooplankton net tow with bongo array and a FastCat CTD, and 4) one surface trawl tow. Seabird and marine mammal observations were recorded while travelling between stations.

Oceanographic Conditions

The primary CTD (SeaBird Instruments SBE-9-11+) was outfitted with dual temperature and conductivity (TC) sensors, a Photosynthetically Active Radiation (PAR) spherical sensor (QSP 2300, Biospherical Instruments), chlorophyll-a fluorometer, beam transmissometer (Wet Labs C-star), and two dissolved oxygen sensors (SeaBird Instruments SBE-43). The CTD measured temperature (°C), salinity (psu), and pressure (db) from the surface down to 5 m from the bottom. A SeaBird Instruments SBE-32 carousel water sampler frame with 1.5 liter Niskin bottles was used to collect water samples from the surface down to 5 m from the bottom in 10 m increments. The water samples from the Niskin bottle were filtered following water collection protocols (Appendix A).

The temperature and salinity for each meter of the CTD cast was calculated by averaging the readings from the primary and secondary temperature and salinity sensors. Sea surface temperature (SST) and salinity were estimated by averaging the temperature and salinity measurements from the top 10 m of the water column. Bottom temperature and salinity were equal to the measurements from the deepest cast of the CTD at each station. The average annual SST was estimated for all stations within the NBS (latitudes: 60°N - 65.5°N) and for a restricted spatial range to account for changes in sampling locations over time (longitudes east of 171°W, and latitudes south of 64°N). Norton Sound stations were restricted to three stations along 64°N.

Mixed-layer depth (MLD) was defined as the depth where seawater density (kg/m^3) increased by 0.10 kg/m^3 relative to the density at 5 m (Danielson et al. 2011; Murphy et al. 2017). Seawater density was calculated from temperature and salinity using the oce package (Kelley and Richards 2020) in R (R Core Team 2020). The MLD was set to the maximum depth of the CTD cast when the water column was mixed. The MLD was calculated from the FastCat CTD (SeaBird Instruments SBE-49) when the primary CTD data were not available. Average MLD from adjacent stations was used when both the CTD and FastCat data were not available.

A bongo net array was deployed to sample zooplankton and ichthyoplankton throughout the water column. The bongo array consisted of two 60-cm diameter bongo nets with 505 micron mesh and two 20-cm diameter bongo nets with 153 micron mesh. A FastCat CTD was affixed above the bongo net array to measure depth in real time using a conducting wire. The bongo nets were towed obliquely from the surface down to 5 m off the bottom at a 45° angle. One net from each bongo frame was preserved in 5% buffered formalin, the second bongo net was sorted for on-board Rapid Zooplankton Assessment (RZA) (Appendix A).

RZA was used to provide information on zooplankton abundance and community structure from coarse taxonomic categories of zooplankton during the 2019 NBS survey. Taxonomic categories included small copepods (< 2 mm; example species: *Acartia* spp., *Pseudocalanus* spp., and *Oithona* spp.), large copepods (> 2 mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids (< 15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 µm mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 µm mesh, 60 cm bongo net. Bongo net samples were split with Stemple pipettes to reach a total count of at least 100 individuals per sample. This method was first used in the NBS survey in 2018.

Surface Trawl Data

A Cantrawl 400/601 rope trawl from Cantrawl Pacific Ltd. (Murphy et al. 2003) was used to conduct surface trawl operations. All surface trawl tows were 30 min in duration and trawl dimensions were monitored during each tow with a Simrad FS70 net sounder. A SeaBird Instruments SBE-39 temperature and depth sensor mounted to the center of the footrope measured footrope depth and temperature during each tow. The number of fish (or weight of jellyfish) caught in a single tow was divided by the area swept by the trawl (km^2) to estimate catch-per-unit-effort (CPUE) and was used to describe species distribution and abundance. The area swept by the trawl was calculated using the horizontal opening from the net sonar and the distance sampled from GPS positions at the start and end of the trawl set.

Surface trawl catches were sorted by species and life history stage and up to 50 individuals from each species and life history stage combination were measured for length and weight at each station. Individual specimen weights were not recorded for species with weights less than 10 g due to the limited accuracy of ship-board weights. Mixed-species subsamples were used to estimate the catch of a few small and numerous species (typically ninespine stickleback (*Pungitius pungitius*), age-0 Pacific herring (*Clupea pallasii*), and moon jellyfish (*Aurelia* spp.). Total catch weight and average weight of measured individuals were used to estimate the total number of species when a subsample of the catch was measured. Annual sample requests were used to define specimen collection protocols for juvenile salmon (*Oncorhynchus* spp.), immature/mature salmon, and non-salmon species (Appendix A). Subsample sizes for juvenile salmon species were reduced in 2019 to accommodate specimen requests from the unexpectedly large numbers of juvenile pink (*O. gorbuscha*), chum (*O. keta*), and sockeye (*O. keta*) salmon. Subsample sizes for individual jellyfish widths and weights were also reduced to 10 individuals per species per station in 2019. All biological data were recorded in an electronic catch logging system, known as the Catch Logger for Acoustic and Midwater Surveys (CLAMS). Individual specimens collected in surface trawls were assigned a specimen number (barcode number) and electronically scanned into CLAMS to ensure a consistent record of all specimens collected during the survey. Juvenile chum and pink salmon caudal fins were collected for genetic analysis, frozen, and assigned a station number. All Chinook salmon were scanned for missing adipose fins, coded-wire-tags (CWTs), and Passive Integrated Transponder (PIT) tags.

Correlations between CPUE of the most abundant pelagic fish species and SST were plotted using the ggcorrplot package (Kassambara 2019) in R (R Core Team 2020) to provide insight into how the NBS fish community is responding to warming climate conditions in the eastern Bering Sea. Species-specific CPUE indices were based on log-transformed average CPUE adjusted for MLD as

$$\ln\left(CPUE_y\right) = ln\left(\frac{\sum_i C_{iy} M_{iy}}{\sum_i a_{iy}}\right),$$

where C_{iy}, and a_{iy} are the catch and effort, at station *i*, and year *y*, respectively, and M_{iy} is equal to the ratio of mixed-layer depth to trawl depth when trawl depth is shallower than mixed layer depth at station *i*, and 1.0 when trawl depth is below the mixed-layer depth. The Optimal Interpolation Sea Surface Temperature (OISSTv2.1) dataset (Huang et al. 2021) provided by NOAA’s CoastWatch West Coast Regional Node ERDDAP cite for the eastern Bering Sea shelf (54° to 66°N, and 146° to 176°W) from June through August was used in lieu of *in situ* SST measured by the CTD to enable a broader spatial and temporal scale of temperature. Temperature data at this scale were thought to be more relevant to the overall distribution and abundance of fish species in the NBS; however, *in situ* temperatures were highly correlated with the broader-scale SST data, therefore, the overall conclusions are similar with both temperature datasets.

A multi-year distribution of juvenile Chinook salmon (*O. tshawytscha*) CPUE was created using a simple kriging model with a gaussian semivariogram as part of the geostatistical analyst extension in ArcGIS (ESRI 2019). Juvenile Chinook salmon CPUE was multiplied by average effort (across all years) to scale the distribution to the catch at each station and a first order trend was removed before kriging. The prediction surface was generated with a neighborhood kriging model with a minimum of five and maximum of 20 points within each of four search quadrants. CPUE data from the southern Bering Sea and Chukchi Sea were included to help define the spatial distribution of juvenile Chinook; however, CPUE within Bristol Bay (near the Kuskokwim and Nushagak rivers) were excluded to maintain a focus on the distribution of Chinook salmon within the NBS. The locations of CWT and adipose fin-clipped juveniles from the Whitehorse Rapids Fish Hatchery (WRFH) within the Yukon River were added to the distribution map of juvenile Chinook salmon to highlight the known locations of Yukon River Chinook salmon.

Length-frequency distributions, length-weight relationships, and box plots of lengths were used to describe the size of juvenile salmon and primary non-salmon species captured in the surface trawl. Length-weight relationships were used as a quality control measure to ensure large errors in length or weight were not present. Juvenile salmon lengths (fork length, mm) were standardized to a common capture date using juvenile growth rates calculated from previous NBS surveys (Howard et al. 2019). The common capture date was equal to the average capture date calculated for each species. Growth rates of 1.06 mm/day for Chinook salmon, 1.69 mm/day for chum salmon, and 1.76 mm/day for pink salmon were then used to standardize length (Howard et al. 2019). Growth rates of coho and sockeye salmon in the NBS are not available; therefore, coho salmon were assumed to grow at the same rate as Chinook salmon (1.06 mm/day) and the average growth rate of all juvenile salmon species was used to standardize sockeye salmon lengths (1.50 mm/day). Length frequency distributions of species captured in surface trawls were corrected by the proportion of the catch that was measured at each station to ensure length distributions reflected the total number of fish caught during the survey.

Juvenile Salmon Origin

All juvenile Chinook salmon were scanned for coded-wire-tags (CWTs) and caudal fin clips were collected from all juvenile Chinook and coho salmon and from a subsample of sockeye, pink, and chum salmon captured during the survey. Pectoral fin clips were collected from all immature Chinook and chum salmon. Individual fin clips were placed on Whatman paper cards specific to Chinook, coho, and sockeye salmon and barcode IDs were recorded on the Whatman cards. Caudal fin clips were collected from juvenile chum and pink salmon and were placed on plastic wrap, frozen, and pooled by species for each station. Pelvic fin clips from immature chum salmon were individually labeled and stored in plastic bags. All genetic tissue samples were shipped to the ADF&G Gene Conservation Lab as part of the cooperative NOAA/ADF&G research on salmon stock origin. Genetic mixed stock analysis has not been initiated for sockeye, coho, and pink salmon but samples are being archived to support analyses when funding and specific interest becomes available.

Genetic mixed-stock analysis was completed for juvenile Chinook and chum salmon and immature Chinook salmon, but only stock mixtures of juvenile Chinook salmon are reported here. DNA was extracted from the tissue samples using the NucleoSpin 96 Tissue Kit (Macherey-Nagel, Düren, Germany). Single nucleotide polymorphism (SNP) genotyping of the 80 SNPs common to the AYK baseline of 60 populations (Howard et al. 2019) was performed with standard TaqMan chemistry (Applied Biosystems, Waltham, USA). Quality control analyses included comparison of discrepancy rates between original genotypic data and genotypic data of 8% of individuals that were re-extracted and re-genotyped, removal of individuals missing 20% or more genotypic data, and removal of duplicate individuals. Stock composition was estimated by comparing genotypes of catch samples to reference baseline allele frequencies using the Bayesian statistical approach implemented in the software package BAYES with a flat prior (Pella and Masuda 2001). Contributions of juvenile Chinook salmon from four reporting groups were estimated: Lower Yukon, Middle Yukon, Upper Yukon, and Other Western Alaska. Estimates from the three intra-Yukon River groups (Lower Yukon, Middle Yukon, and Upper Yukon) were summed to estimate the total Yukon River stock contribution.

Juvenile Chinook Salmon Abundance and Run Forecasts

The methods for estimating juvenile Chinook abundance were initially described in Murphy et al. (2017) and revised in Howard et al. (2019) and Howard et al. (2020). Juvenile Chinook salmon catches are scaled to the MLD by dividing the catch of juvenile Chinook salmon by the proportion of the mixed layer sampled at that station. The NBS was divided into four latitude strata: 1) Lower NBS (60 to 62°N), 2) Upper NBS (62° to 64°N), 3) Norton Sound, and 4) the Bering Strait region. The average CPUE within each stratum *n*, was estimated by dividing the total catch by the total effort as

$$CPUE_n = \frac{\sum_{i=1}^{I} C_{ni}}{\sum_{i=1}^{I} a_{ni}},$$

where C_{ni} and a_{ni} are the MLD adjusted catch and area swept, respectively, for station *i* and stratum *n*, and *I* is the total number of stations in stratum *i* (Quinn and Deriso 1999). The variance of *CPUE* by strata was defined as

$$V(CPUE_n) = \frac{I}{I-1} \frac{\sum_i (C_{ni} - CPUE_n \cdot a_{ni})^2}{(\sum_i a_{ni})^2}.$$

The area sampled within each strata (A_n) was calculated from the number of stations in the strata and the average grid area (the average area of the 0.5° latitude by 1° longitude grid, calculated with average latitude). A fixed sample grid area (A_{NS}) was assumed for the Norton Sound stratum as the effective habitat for juvenile Chinook salmon was assumed to be limited by the high turbidity and shallow bottom depths (Murphy et al. 2017). The mean proportion of juvenile Chinook salmon in the Bering Strait (6.7%) and Norton Sound (8.2%) during 2003, 2007, 2009 to 2015, and 2017 were used to adjust abundance estimates in years when these strata were not sampled (2004 to 2006 for Bering Strait and 2016 for Norton Sound). The sum of the individual strata areas was used to estimate the total survey area, *A*. The average *CPUE* for the survey, $CPUE_A$, and variance, $V(CPUE_A)$, were simply the weighted average based on the strata area as

$$CPUE_A = \sum_n \frac{A_n}{A} CPUE_n,$$

$$V(CPUE_A) = \sum_n \frac{A_n}{A} V(CPUE_n).$$

Juvenile abundance ($\widehat{N}$) and variance $V(\widehat{N})$ estimates for the survey were calculated as

$$\widehat{N} = CPUE_A \cdot A,$$

$$V(\widehat{N}) = A^2 \cdot V(CPUE_A).$$

Juvenile Chinook salmon abundance estimates were apportioned by stock composition to Upper Yukon (hereafter Canadian-origin) and total Yukon River groups (combined Canadian-origin, Middle Yukon, and Lower Yukon stock groups). The variance of stock-specific abundance was derived from a Taylor series approximation to the multiplicative variance of 2 random variables (*X* and *Y*) using the Delta method as

$$V(X,Y) = \mu_Y^2\sigma_X^2 + \mu_X^2\sigma_Y^2 + 2\mu_X\mu_Y\sigma_X\sigma_Y\rho,$$

where μ_X and σ_X are the mean and standard deviation of juvenile abundance, μ_Y and σ_Y are the mean and standard deviation of the stock group proportion, and ρ is the correlation between juvenile abundance and stock proportion.

Canadian-origin and Total Yukon Chinook salmon forecasts were generated using juvenile abundance estimates, brood tables, and age at maturity estimates for both Canadian-origin and Total Yukon Chinook salmon. The number of juvenile Chinook salmon predicted to return to the Yukon River was based on the midpoint and 80% prediction interval of the linear regression model between juvenile abundance and adult returns. The majority of Yukon River Chinook salmon spend a full year growing in fresh water after hatching and therefore juvenile abundance is assumed to be offset from spawner abundance by two years (one year is added to account for overwinter egg incubation). The marine ages of returning adults (typically 2 to 4 years) are used to scale juvenile abundance to run year. Projected run sizes were based on recent 3-year average maturity schedules derived from Canadian-origin brood tables (JTC 2020) and the total Yukon River drainage (Howard et al. 2020).

Juvenile Pink Salmon Abundance

Catch and effort, abundance indices, and forecast models for Yukon River and Norton Sound pink salmon were developed and reported in Farley et al (2020). Mixed layer depth corrections were applied to the annual abundance index as

$$\theta_y = \frac{\sum_i M_{iy} C_{iy}}{\sum_i C_{iy}},$$

where C_{iy} is the catch at station i and year y, and M_{iy} is equal to the ratio of mixed-layer depth to trawl depth when trawl depth is shallower than mixed layer depth, and 1.0

when trawl depth is below the mixed-layer depth. The juvenile abundance index for pink salmon was estimated as

$$N_y = \frac{\sum_i ln(CPUE_{iy})}{n_y} \cdot \theta_y,$$

where n_y is the number of trawl stations in year y.

Juvenile Salmon Diet

Stomach contents were examined either at sea or in a laboratory setting between 2004 and 2019. Stomach processing followed standard methods developed by Tikhookeanskiy Nauchno-Issledovatelskiy Institut Rybnogo Khozyaystva I Okeanografiy (Chuchukalo and Volkov 1986, Volkov and Kuznetsova 2007, Moss et al. 2009, Coyle et al. 2011). Typically, the contents of up to 10 stomachs from randomly sampled fish were combined together from each station, and prey composition was recorded as a stomach content index (SCI) and stomach fullness index (SFI). The SCI was calculated as individual prey taxon weight (g) multiplied by 10,000 and divided by predator body weight (g). Multiplying by a factor of 10,000 made these numbers easier to handle, as predator body weight was always much larger than prey taxon weight. The SFI was equal to the sum of all prey SCIs at a given station and gives an indication of fullness as a proportion of prey weight to predator weight. The average SFI was calculated for each year and compared with SST. In some cases, accurate prey weights could not be measured due to movement of the vessel. In these instances, prey taxon weight was estimated based upon percent volume and the assumption of equal body density of all prey items. Laboratory based weights were typically measured at 0.001 g. Prey composition was summarized as %SCI contribution (individual prey category SCI divided by the sum of SCI in a given year). Prey categories occurring in less than 10% of all stomachs within a predator species were combined into broader taxonomic groups. Prey groups were determined by the overall contribution to the diet within a predator species across all years, the proportion of the SFI within years, and in terms of percent frequency of occurrence over all years. Rare prey items that did not fall into a larger category were placed into an “Other” category. *Thysanoessa* was used as a prey category for sockeye salmon diets because they composed 95% or higher of all the euphausiids while euphausiids was used as a broader prey category for pink and chum diets. All stations where stomachs were analyzed, but no prey was present in stomachs or contents were not identified were removed from this analysis. Years with diet data from less than five stations were not included in the diet summaries/figures.

Juvenile Salmon Energetic Condition

Energetic condition (energy density, ED) of juvenile Chinook salmon from the NBS was obtained using bomb calorimetry on dried samples of homogenized whole fish tissues for 2006 - 2019 (Fergusson et al. 2010). From 2006 to 2015, samples were heated at 75°C in a drying oven and manually re-weighed until mass was constant. Starting in 2016, the method of sample drying and moisture determination prior to bombing was changed. Since 2016, samples were heated at 135°C to dryness using a LECO Thermogravimetric Analyzer 601. Moisture values obtained by the two methods were known to differ by less than 1% (Vollenweider et al 2011).

Comparing annual average ED among years required use of weighted least squares in Welch's ANOVA (Welch 1951, Day and Quinn 1989) due to unequal variances among years. Testing for differences in ED among years while controlling for fish size was accomplished using one-way ANCOVA and post-hoc Tukey's pairwise comparisons of adjusted means. Due to unequal variances among years, ANCOVA results were compared to results from a rank-based Kruskal-Wallis test performed on the residuals from a simple linear regression of ED against length, followed by Tukey's pairwise comparisons on the ranked residuals.

Spearman's rank correlation test was used to evaluate the effects of SST on ED and nonlinearity in the relationship was described using generalized additive models (GAMs; Wood 2006) limited to 4 knots to avoid overfitting. Multiple linear regression models of fish length and SST on annual average ED were selected based on Akaike Information Criteria (AICc) (Burnham and Anderson 2004).

Seabird and Marine Mammal Observations

The USFWS conducted seabird surveys during the NBS survey. The USFWS was supported by an Interagency Agreement with the Bureau of Ocean Energy Management (project AK-17-03: Marine Bird Distribution and Abundance in Offshore Waters). This study will combine data collected during the NBS survey with data from other USFWS seabird surveys to examine the distribution of marine birds relative to prey and oceanographic properties. It will also be used to describe seasonal and interannual changes in marine birds and their communities in the Beaufort and Chukchi Planning Areas. Marine birds and mammals were surveyed from 28 August to 19 September, 2019. Survey data will be archived in the North Pacific Pelagic Seabird Database (http://alaska.usgs.gov/science/biology/nppsd).

Marine birds and mammals were surveyed from the port side of the bridge using standard USFWS protocols. Observations were conducted during daylight hours while the vessel was underway. The observer scanned the water ahead of the ship using hand-held 10 x 42 binoculars for identification and recorded all birds and mammals. Bird surveys used a modified strip transect methodology with four distance bins from the center line: 0-50 m, 51-100 m, 101- 200 m, 201-300 m. Rare birds, large flocks, and mammals beyond 300 m or on the starboard side (‘off transect’) were also recorded but will not be included in density calculations. We recorded the species, number of animals, and behavior (on water, in air, foraging). Birds on the water or actively foraging were counted continuously, whereas flying birds were recorded during quick ‘Scans’ of the transect window.

Geometric and laser hand-held rangefinders were used to determine the distance to bird sightings. Observations were directly entered into a GPS-interfaced laptop computer using the DLOG3 program (Ford Ecological Consultants, Inc., Portland, OR). Location data were also automatically written to the program in 20-second intervals, which allowed us to track survey effort and simultaneously record changing weather conditions, Beaufort Sea State, glare, and ice coverage (no ice was encountered during this cruise). Other environmental variables recorded at the beginning of each transect included wind speed and direction, cloud cover, sea surface temperature, and air temperature.

RESULTS AND DISCUSSION

Oceanographic Conditions

The CTD data were collected at each of the 47 stations sampled in 2019 (Table 2). Surface temperatures (upper 10 m) in the NBS in 2019 ranged from 7.9°C to 13.8°C with an average of 11.5°C, which was 2.9°C above average (restricted SST range, 2003 to 2018) (Fig. 2). Surface and bottom temperatures were highest in the shallow nearshore stations and in Norton Sound. Surface temperatures were coldest at stations northeast of St. Lawrence Island; bottom temperatures were much colder due to the presence of the eastern Bering Sea cold pool and were coldest just south of St Lawrence Island (Fig. 3). Surface salinities ranged from 21.7 PSU to 31.9 PSU. The lowest salinities were in Norton Sound and just outside the Yukon River Delta with salinity increasing with distance from shore (Fig. 4). Mixed layer depths ranged from 7 m to 29 m with an average of 19 m (Table 3, Fig. 5). The MLD estimates from the SBE9-11 CTD for stations 2 and 5 were missing data from the top 11 m of the water column; therefore, the MLD estimates for those stations were derived from the FastCat (SBE49) data collected during the bongo tow.

Small copepods (< 2 mm) were abundant across the sampling area, with abundances approaching 10,000 ind/m^3 (Fig. 6). In contrast, large copepod (> 2mm) abundances were low overall, and copepods were largely absent in many stations between 62°N and 64°N. Large copepods abundances would be expected to be higher in an average year, based on the accumulation of *Calanus* spp. C5 stages later in the year (Stabeno and Bell, 2019). Small copepods have faster turnover times, multiple generations per year, and metabolic rates that scale less dramatically with temperature. Warm temperatures in 2018 and 2019 are likely a contributing factor to the elevated abundance of small versus large zooplankton (Kimell et al. 2018, Kimell et al. 2019). The abundance of small and large copepods declined from 2018 and may indicate an overall decline in productivity during 2019. Euphausiid numbers were also low across the NBS, with no euphausiids recorded north of 62°N. Above average temperatures in 2019 may have caused earlier entry into diapause or increased advection of local populations of *Calanus* spp. into the Chukchi Sea. The low euphausiid abundance was expected; bongo tows typically undersample adult euphausiids due to depth distribution.

Surface Trawl Data

Bottom depths at stations sampled during the survey ranged from 14 m to 63 m (Table 2). Footrope setback chains were shortened to collapse the vertical opening of the trawl when sampling locations with bottom depths less than approximately 22 m. The average horizontal and vertical opening of the trawl was 49.8 m and 17.5 m, respectively. The average footrope depth from the SeaBird SBE39 depth sensor was 18.9 m (Table 4), indicating that the average depth of the center of the headrope (where the net sonar is located) was 1.4 m. The average distance towed during each 30 minute trawl set (based on GPS coordinates of the start and end of each tow) was 3.9 km, which results in a calculated average speed of 4.2 knots. MLD expansions were required at 27 of the 47 stations and ranged from 2% to 33% (Table 4).

Similar to previous years, the species with the largest biomass in the surface trawl catches was the northern sea nettle (*Chrysaora melanaster*) at 6,898 kg, and the species with the largest catch in numbers was Pacific herring at 142,512 individuals (Tables 5-7). Juvenile pink salmon was the most abundant species of salmon at 13,507 fish. Ninespine stickleback were the third most abundant species at 9,464 individuals. The catch of age-0 walleye pollock (*Gadus chalcogrammus*, n = 8,798) was above average, but the catch of other forage fish species, including Arctic or Pacific sand lance (*Ammodytes* spp., n = 2) (Orr et al. 2015) and capelin (*Mallotus villosus*, n = 11) were quite low. Sand lance are able to avoid capture with trawl gear, therefore, a low catch does not necessarily reflect low abundance. Capelin are known to be less abundant in the NBS during warm years (Andrews et al. 2016).

The spatial distribution of fish and jellyfish captured in surface trawls varied significantly by species (Appendix B). Surface trawl catch rates of the Juvenile chum and pink salmon were the most widely distributed salmon species with relatively high CPUEs across most of the survey area. Unlike previous years, juvenile Chinook salmon were absent in a number of stations between 60°N and 62°N and their highest catch rates were just west of Norton Sound where surface temperatures tended to be a bit colder. Juvenile coho salmon exhibited high CPUEs south of 62°N, in Norton Sound, and just northwest of the Yukon Delta. Juvenile sockeye salmon catches were concentrated at offshore stations south of St. Lawrence Island. sockeye salmon runs in the Yukon River and Norton Sound are relatively small so we suspect the high catches of sockeye salmon encountered during the 2019 survey were of Southern Bering Sea origin. Except for sockeye salmon, all other salmon species were caught at stations north of 66°N. The northern sea nettle, the most abundant of jellyfish, were caught in all but four stations during the 2019 survey. The moon jellyfish were found throughout the survey except just west of Norton Sound.

Water jellyfish (*Aequorea* spp.) and the whitecross jellyfish (*Staurophora mertensi*) were encountered infrequently. The highest catch rates of Lion's mane jellyfish (*Cyanea capillata*) were in the shallow nearshore stations. Age-0 walleye pollock had high CPUEs west of 167.5°W and south of 63°N, whereas age-1+ walleye pollock catches were sparsely distributed throughout the survey grid. Both age-0 and age-1+ walleye pollock were caught at stations north of the Bering Strait. Pacific herring were captured throughout the NBS, but catches tended to be higher in Norton Sound and nearshore habitats where age-0 herring occur (Appendix B). Rainbow smelt (*Osmerus mordax*) were caught at nearshore stations and in Norton Sound and were absent west of 168°W. Similar to rainbow smelt, ninespine sticklebacks were constrained to nearshore stations east of 168°W and Norton Sound. Documenting species catch and distribution during NBS surface trawl surveys will help identify northward shifts in species's migration and distribution as the Bering Sea continues to increase in temperature over time.

Approximately half of the primary species captured in the NBS were significantly ($\alpha = 0.5$) correlated with SST (Figs. 7 and 8). Average catch rates of juvenile sockeye salmon had the highest positive correlation with SST ($\rho = 0.9$). Increased catch rates of sockeye salmon with temperature stems from the northward dispersal and increased abundance of juveniles from the southeastern Bering Sea (primarily Bristol Bay) as there are only minor spawning populations of sockeye salmon within the Yukon River and Norton Sound (Estensen et al. 2018, Menard et al. 2020). Spawning locations of walleye pollock also are predominantly in the southeast Bering Sea and therefore the positive correlation between age-0 pollock and SST ($\rho = 0.6$) reflects increased northward dispersal of age-0 pollock with temperature. The relationship between age-0 pollock and temperature is non-linear therefore the correlation coefficient underestimates the significance of temperature to the catch rates of age-0 pollock. There are significant spawning stocks of coho salmon in the Yukon River and Norton Sound (Estensen et al. 2018, Menard et al. 2020); therefore the correlation betwenn CPUE and SST ($\rho = 0.7$) most likely reflects an increase in the abundance of juvenile coho salmon stocks within the NBS. Capelin was the only species with a negative correlation ($\rho = - 0.6$) with SST. Capelin are known to have a preference for cooler water in the eastern Bering Sea (Andrews et al. 2016); therefore, this may also reflect a northward shift in their distribution (into the Chukchi Sea) as temperatures increases in the eastern Bering Sea.

Significant positive correlations were present between catch rates of ninespine stickleback and Pacific herring ($\rho = 0.8$), Arctic lamprey (*Lethenteron camtschaticum*) ($\rho = 0.7$), and Chinook salmon ($\rho = 0.6$) (Fig. 8). Ninespine stickleback are an abundant species within the nearshore habitats of the NBS and nearly all ninespine stickleback are captured in the shallowest stations sampled in the NBS (Appendix B). Although age-0 Pacific herring are likely the dominant species within the nearshore fish community, catches of age-0 Pacific herring are not separated from the older age classes, and could reflect a mixture of herring from the NBS and SEBS (Andrews et al 2016). The highly piscivorous diet of juvenile Chinook salmon (Farley et al. 2009, Auburn and Sturdevant 2013, Honeyfield et al. 2016, Miller et al. 2016, Garcia and Sewall 2021) and Arctic lamprey (Shink et al. 2019) would logically support a dependency of these two species on the nearshore fish community. It is possible that the correlations between CPUE of ninespine stickleback and juvenile Chinook salmon and Arctic lamprey could stem from a dependency of Chinook salmon and Arctic lamprey on the nearshore estuarine fish community in the NBS in general, not necessarily a direct association with ninespine stickleback.

Size Distributions

Length-frequency distributions for the primary species captured in surface trawl catches are summarized in Figs. 9 to 11. Juvenile salmon lengths in 2019 were typical of those encountered in past NBS surveys (Fig. 9). Individual lengths and weights of juvenile salmon (Appendix C) confirm that there is limited error in the size data and that juvenile salmon have a relatively stable relationship between length and weight. Juvenile Chinook salmon lengths ranged from 10 to 24 cm, and averaged 20 cm. Most juvenile Chinook salmon caught in the NBS survey spend one year in fresh water (total age 2); however, smaller juvenile Chinook may be indicative of sub-yearlings (Chinook salmon that migrate to sea without spending a year in fresh water). Due to their multi-year residence in fresh water, coho salmon were the largest juvenile salmon species caught in the survey with lengths between 20 and 30 cm and averaging 25 cm. Chum and pink salmon were the smallest species caught with lengths ranging between 12 and 25 cm. The overlap in juvenile chum and pink salmon lengths suggests that their growth rates during the early marine stage may be similar. Except for a few larger individuals, juvenile sockeye salmon lengths ranged between 15 and 22 cm.

There was not a consistent trend in the size of juvenile salmon within or between species across the time series (Fig. 12), which emphasizes the importance of species-specific factors in the growth and size of juvenile salmon. The average lengths of juvenile Chinook salmon from recent warm years (2016-2019) are smaller than those from prior warm years (2004, 2014-2015). The average lengths of juvenile coho salmon has declined in the recent warm years. The recent warm temperatures may be limiting the growth of piscivorous species like juvenile Chinook and coho salmon through changes in prey quality and quantity. The average length of juvenile coho salmon in 2019 was the lowest observed since the survey began in 2003. Due to the multiple fresh water ages of coho salmon (predominantly fresh water ages of 1 and 2), the reduced size of coho salmon could also reflect an earlier age of marine entry. Variation in the average length of juvenile chum and pink salmon did not vary consistently with temperature and above and below average lengths were present in warm and cold years. This highlights the importance of dynamic ecosystem impacts on their size and growth, including prey availability. Growth potential models are in development and will clarify the role of warming temperature on pink and chum salmon in the NBS.

The size and growth of juvenile salmon during the early marine life stage have important implications for future marine survival. Larger juvenile salmon are more likely to survive than smaller individuals because they are able to avoid predators and maintain high energy reserves necessary to survive their first winter at sea (Beamish and Mahnken 2001). Prior research on juvenile Chinook salmon correlated growth and size in the early marine stage with increased adult returns (Tomaro et al. 2012). Additionally, scale pattern analyses have shown that small juvenile Chinook, coho, pink, and sockeye salmon are subject to size-selective mortality during their first summer at sea (Beamish et al. and Mahnken 2001, Moss et al. 2005, Howard et al. 2016), providing further evidence that larger juvenile salmon have higher likelihoods of surviving than their smaller conspecifics. Juvenile salmon caught in the NBS are caught in September, after they have spent their first summer in the ocean, and their size at this critical period may inform whether they are likely to survive their first marine winter.

Length measurements were also taken from immature salmon and non-salmon species. Fork lengths were measured for immature chum, sockeye, and Chinook salmon (Fig. 10). Immature sockeye (n = 19) and Chinook salmon (n = 24) are less frequently encountered during the NBS survey compared to immature chum salmon (n = 194). Immature sockeye salmon lengths ranged from 26 cm to 53 cm and averaged 36 cm. Immature Chinook salmon (n = 24) ranged from 31 cm to 79 cm and averaged 43 cm. Immature chum salmon lengths ranged from 29 cm to 79 cm. The bimodal distribution of fork length measurements for immature chum salmon suggest two age classes are encountered during survey operations. Although immature sockeye salmon greater than 45 cm suggest the presence of a separate, older age class, there are not enough samples to categorize age distributions. Bell diameters for moon jellyfish, northern sea nettle, and lion's mane jellyfish were between 10 and 50 cm. Bell diameters were skewed towards smaller sizes between 10 cm and 15 cm for moon jellyfish (mean of 15.3 cm), centered around 23 cm for the Northern Sea Nettle and bimodal at 18 cm and 33 cm for lion's mane jellyfish (Fig. 11, Table 7). Ninespine stickleback were larger than those encountered in the NBS survey in past years, ranging between 4.0 cm and 6.5 cm (Fig. 11, Howard et al. 2020). Pacific herring, rainbow smelt, and walleye pollock length frequencies reflect the multiple age classes of each species encountered during the survey (Fig. 11).

Juvenile Salmon Origin

Juvenile Chinook salmon are distributed within the inner domain (bottom depths less than 55 m) of the NBS and can occur throughout the latitude range of the NBS (Fig. 13). CWT recoveries are particularly useful in characterizing marine distributions of Chinook salmon (Appendix D). All CWTs recovered from juvenile Chinook salmon (including two CWTs in 2019) have been from the Whitehorse Rapids Fish Hatchery (WRFH). All juvenile Chinook salmon released from the WRFH have adipose fin clips and all tagged juveniles exhibit a subyearling migration pattern. Juveniles with an adipose fin clip and not CWT were assumed to be the result of tag shedding and were assumed to be subyearling Chinook salmon from the WRFH. WRFH Chinook salmon had an average length of 151 mm (range: 109 to 207 mm), and an average weight of 43 g. The size of hatchery Chinook salmon were slightly below the average size of pink salmon (164 mm) and chum salmon (177 mm), which migrate to sea during the same year that they hatch. Although hatchery Chinook salmon have been caught throughout the latitude range of the NBS survey, they are most commonly captured in the nearshore stations adjacent to the Yukon River Delta and within Norton Sound (Appendix D).

Although CWTs are useful in identifying the origin of individual Chinook salmon, genetic stock identification is the primary method used to identify the origin of Chinook salmon in the NBS. A total of 125 juvenile Chinook salmon were successfully genotyped for mixed-stock-analysis (MSA) during the 2019 NBS survey. Mean stock composition estimates were: 30% Upper Yukon (hereafter Canadian-origin), 22% Middle Yukon, 14% Lower Yukon, and 35% Other Wester Alaska (non-Yukon River) stocks (Table 8, Fig. 14). The Canadian-origin proportion was lower than the historical average (48%), and the non-Yukon River proportion was higher than the historical average (12%); however, the composition of Lower Yukon and Middle Yukon stocks were similar to historical averages (12% and 27%, respectively). The Canadian-origin stock group had the largest reduction from the historic average (an 18% decrease from average) followed by the Middle Yukon River stock group (6% decrease from average). The proportion of the Lower Yukon River stock group was slightly higher (2%) than the historic average. The increase in non-Yukon stocks (23% increase) may reflect a combination of northward dispersal of Chinook salmon stocks from the southern Bering Sea (e.g., Kuskokwim River Chinook salmon) and possibly an increase in the relative contribution of Norton Sound Chinook salmon.

Juvenile Chinook Salmon Abundance and Run Forecasts

The overall abundance of juvenile Chinook salmon in the NBS during 2019 (2.0 million fish) was significantly below their average abundance during 2003-2018, (3.2 million fish). Abundance estimates of juvenile Chinook salmon were expanded by 10% (MLD adjustment) to account for incomplete sampling of the mixed layer, which was higher than the recent 5-year average of 2%. The abundance of Canadian-origin juvenile Chinook salmon during 2019 was the lowest observed in the NBS at 575,094 fish (sd = 164,126; CV = 29%) (Table 9, Fig. 15), and was less than half of the average abundance (1.57 million) during previous years (2003-2018). Similar to the Canadian-origin stock group, the abundance of Yukon River juvenile salmon was also the lowest observed at 1,246,038 fish (sd = 326,257; CV = 26%), and was less than half of the 2003-2018 average of 2.75 million fish (Table 10, Fig. 15). The juvenile Chinook salmon caught during the 2019 NBS survey will primarily contribute to adult runs in 2021 (as age-4), 2022 (age-5), and 2023 (age-6).

Juvenile abundance is significantly ($\rho < 0.001$) related to adult Chinook salmon returns up to three years into the future (Fig. 16). Both the Canadian-origin and total Yukon runs are expected to decline over the next two years due to the reduction in juvenile abundance during 2017-2019. The projected run sizes for Canadian-origin Chinook salmon are 52,300 (31,200 to 73,400) fish in 2021, and 46,300 (24,800 to 67,900) fish in 2022. The projected run sizes for the total Yukon River run are 143,800 (95,200 to 192,400) fish in 2021, and 129,000 (79,500 to 178,500) fish in 2022. Although the ranges of possible run sizes are very wide, they indicate an expected decline in abundance of Chinook salmon. New forecast models for the Canadian-origin stock group are being developed by the Joint Technical Committee of the Yukon River Panel which will integrate juvenile and other sibling data into a Bayesian model framework. Similar models are also expected to be developed for the total run of Chinook salmon to the Yukon River. Estimates of future run size to the Yukon River have been of particular interest by managers, biologists, and stakeholders within the Yukon River as it helps support fisheries management decisions needed to protect the spawning stock and subsistence fisheries in the Yukon River (JTC 2020).

The number of Chinook salmon juveniles-per-spawner in 2019 was the lowest observed since 2003 for the Canadian-origin stock group (8.4) and the Yukon River stock group (5.3) (Fig. 17, Tables 9 and 10). The number of juveniles-per-spawner has been quite low for the last three years (2017-2019) and indicates a distinct downward shift in the survival of Yukon River Chinook salmon. Although the cause of the reduced survival is unclear, it may be tied to recent losses of arctic Sea ice and warming of the NBS and Yukon River. The number of juveniles-per-spawner does not vary predictably with spawner abundance for either the Canadian-origin or total Yukon River stocks. Similarly, there is no relationship between the number of spawners and the resulting number of juveniles for either the Canadian-origin or Yukon River stock groups. Juveniles-per-spawner and returns-per-spawner are highly correlated ($\rho = 0.76$) for both the Canadian-origin and Yukon River stock groups (Tables 9 and 10) and therefore the survival of Yukon River Chinook salmon during the initial fresh water and/or marine stages of salmon is the key factor in both the decline and variation in abundance over time.

Measurement error in juvenile abundance is a key limitation in the analysis and interpretation of juvenile survival. There are a number of unique features of the NBS survey that help limit the measurement error of surface trawl estimates of the distribution and abundance of juvenile salmon. We are able to restrict abundance of juvenile Chinook salmon to large stock groups such as the Total Yukon (average proportion of 86%) and the Canadian-origin (average proportion of 47%) stock groups, which minimizes the stock identification error in abundance estimates. The shallow depths and presence of the eastern Bering Sea cold pool play a key role in limiting the vertical distribution of juvenile salmon in the NBS. MLD corrections are used to account for changes in the sampling depth of surface trawls relative to juvenile habitat. The relatively limited dispersal rate of juvenile Chinook salmon in the NBS (compared to coastal habitats in the Gulf of Alaska) allows a single survey to sample through the distribution of juveniles and limits the influence of year to year variation in the migration of juveniles on abundance estimates. There has been limited mixing of juvenile Chinook salmon stocks from regions outside of the Yukon River prior to 2019. This has helped clarify the spatial distribution and dispersal patterns of juvenile Chinook salmon stocks from the NBS and has helped establish survey designs for juvenile Chinook salmon in the NBS. However, caution is still needed when interpreting abundance estimates as measurement has not been stationary over time due to changes in sea states, vessel platforms, juvenile distributions, and survey designs over time.

Juvenile Pink Salmon Abundance

The juvenile pink salmon abundance index ranged from 1.0 to 5.4 with an overall average of 2.9 from 2003 to 2019 (Fig. 19). The index is significantly correlated with pink salmon returns to Yukon and Norton Sound rivers and provides an informative tool to forecast adult returns to these regions (Fig. 20). The preliminary index for 2019 was 5.3, which forecasted an adult return of 6.5 million pink salmon to the region in 2020.

Juvenile pink salmon abundance has increased along with the recent warming conditions in the eastern Bering Sea. The NBS is experiencing significant warming and extremes in seasonal ice extent and thickness that may benefit the growth and survival of pink salmon stocks in this region. Increased pink salmon abundance in the NBS and overall warming climate conditions are both thought to play an important role in the expansion of pink salmon into the Arctic (Farley et al. 2020). The critical period (Beamish and Mahnken 2001) in the production dynamics of pink salmon in the NBS appears to be more strongly tied to the initial life-history stages (fresh water and initial marine) than later marine life-history stages and may reflect temperature limitations present in high latitude stocks of salmon. Stock-specific information on juvenile pink salmon abundance would significantly improve our understanding of their movement and production dynamics in the NBS. Farley et al. (2005) identified discontinuous distribution in the size of juvenile pink salmon that may stem from the presence of both North American and Russian stocks in the NBS. Support for this interpretation was provided by the observation that 76% of the juvenile chum salmon in the Bering Strait region were from Russia during the 2007 NBS survey (Kondzela et al. 2009).

Juvenile Salmon Diet

Stomach fullness and species composition of juvenile salmon diets are summarized in Figs. 21 to 27 and in Appendix E. Station numbers and the number of stomachs sampled are also summarized in Appendix E.

Chum salmon fed upon gelatinous plankton, fish, hyperiid amphipods, and euphausiids in most years (Fig. 21). The proportion of hyperiid amphipods, which are rich in fatty acids (Persson and Vrede 2006), increased during cool years (2006-2012) (Appendix E). Feeding on prey high in fatty acids and lipids facilitates the accumulation of energy stores which are needed for overwinter survival (Heintz et al. 2013, Rogers et al. 2020).

Pink and sockeye salmon fed on a combination of fish and zooplankton confirming findings from previous investigations (Cook and Sturdevant 2013). Pink and sockeye salmon demonstrated no preference for a single species of zooplankton prey. Fish prey were most common in pink salmon diets during anomalously warm conditions (2003-2006), a transitional period from warm to cool (2007), and during the anomalously warm year of 2015 (Fig. 22). The composition of prey in sockeye salmon diets varied inter-annually and no pattern or prey preference during cool or warm years was apparent (Fig. 23).

Coho salmon preyed primarily upon sand lance, age-0 walleye pollock, capelin, and other fish (Fig. 24). Capelin increased in coho salmon when ocean conditions were cool (2007-2011) and capelin abundance was elevated in the NBS (Andrews et al. 2016). The proportion of decapods and other prey items not commonly consumed by coho salmon increased during warm years

(2006-2012, 2014-2019), with the exception of 2007 and 2014, which were years when thermal conditions switched from anomalously warm to cool and cool to warm, respectively. Age-0 walleye pollock accounted for a larger proportion of prey in coho salmon diets during warm years, consistent with increased catches and of age-0 walleye pollock in the NBS and northward with warm temperatures (Fig. 7 and 8).

Chinook salmon fed primarily upon fish in the NBS (Fig. 25) which has also been reported by previous investigations (Cook and Sturdevant 2013, Garcia and Sewall 2021). However, piscivory by juvenile Chinook salmon has decreased as SSTs have increased in the NBS (Fig. 26). There has been a clear decline in piscivory in Chinook salmon relative to other species of juvenile salmon in the NBS. Fish composed 88.9% of the diet of Chinook salmon on average during 2004-2017, but decreased to 72.8% on average during 2018-2019. Age-0 walleye pollock were common in Chinook salmon diets when ocean conditions were anomalously warm but were rare when conditions were cool. Capelin was a common prey item composing 16.7-68.4% of the diet during 2004-2013, with the exception of one year (2012), when capelin were not detected. The absence of capelin from the 2012 diet is more likely an artifact of the diet processor than an ecological reflection. No fish were identified to species from the 2012 survey, though a large percent of the diet was still fish. The presence of capelin declined to only 4.7-11.0% during 2014-2018 and were absent from the diet in 2019 (Fig. 25). Concurrent with the decrease and disappearance of capelin from the diet was an increase in the consumption of decapod larvae during 2018-2019, which may reflect a decrease in the availability of fish prey or a reduced ability to capture fish resulting from a concurrent decrease in body size. Our findings highlight key features in the feeding ecology of juvenile Chinook salmon in the NBS and identify areas of potential concern.

The level of piscivory in Chinook salmon and the survey design in 2005 were atypical and the therefore the data from 2005 is treated as an outlier in the time series (Fig. 26). The 2005 survey started later than usual in 2005 and stations were sampled from North to South. Stations at the southern end of the NBS were sampled a month later than most years and juveniles had already begun to disperse into the southern Bering at that point. The unusual distribution of juvenile Chinook salmon in 2005 is believed to be contributing to an atypical pattern in their diet.

The average stomach fullness index (SFI) of all juvenile salmon except for coho salmon has declined as SSTs have increased in the NBS (Fig. 27). The overall average SFI was similar for Chinook (157), pink (156), and coho salmon (153), but lower for chum salmon (126). The average SFI in 2019 for Chinook salmon (67) and chum salmon (49) were the lowest on record and less than half of their overall average. Warmer temperatures increase metabolic rates which would require a higher overall amount of prey consumed or an increase in the energetic quality of prey consumed for a fish to realize the same growth rate under cooler conditions. Therefore, the combination of an increase in thermal experience and a decrease in the amount of food consumed will have a larger effect on growth than an increase in thermal experience alone.

Larger body size requires higher energy prey (Schabetsberger et al. 2003). Years in which piscivory decreased for juvenile Coho and Chinook salmon may signal a lack of energy-rich forage. Sand lance and capelin are energetically rich prey (Litzow 2006). In the absence of high quality prey, lower quality prey may be substituted (Weitcamp and Sturdevant 2008), and an increase in prey diversity may indicate more generalized feeding and a greater reliance on non-preferred prey items (Weitcamp and Sturdevant 2008). If ocean conditions continue to warm and alter lower trophic levels in the Bering Sea (Hunt et al. 2011), these changes are likely to cascade up to higher trophic levels and affect salmon growth and survival. This analysis combined all juvenile salmon diets of a given species without regard to habitat (bottom depth) to provide a synoptic view across the entire NBS survey area. Previous studies have noted that certain prey may be more commonly consumed in certain habitats by juvenile salmon (Cook and Sturdevant 2013) and forage fishes (Andrews et al. 2016).

Juvenile Salmon Energetic Condition

The energetic condition of NBS juvenile Chinook salmon varied across the 12 years of available data, partially driven by differences in fish size (Fig. 28). Average ED (kJ/g dry tissue mass) differed significantly among years (Welch's ANOVA, F = 10.36, R^2 = 17.9%, ρ < 0.001), with 2016 being the highest, 2011 the lowest, and 2019 of intermediate value slightly lower than 2018. Average lengths of analyzed fish also differed among years (Welch's ANOVA, F = 22.12, R^2 = 21.9%, ρ < 0.001), with 2007 the largest, 2011 the smallest, and 2019 of intermediate size slightly larger than 2018. With all data pooled across years, linear regression analysis indicated that the energetic condition of juvenile Chinook salmon increased with fish length (slope = 0.0230; R^2 = 39.7%; ρ < 0.001; Fig. 29). This positive relationship was expected, as energetic condition commonly increases with size in fishes that must store energy prior to winter (Post and Parkinson 2001), and has been previously observed in juvenile Chinook salmon (Murphy et al. 2014). However, this indicated that approximately 60% of the variation in individual ED was due to factors other than fish size. Including year in addition to length increased the explained variation to 50.9%, with a significant effect of year after controlling for length (ANCOVA, $F_{11,562}$ = 11.56, ρ < 0.001). Mean size-adjusted energetic condition overlapped significantly among years but was lowest in 2011 and highest in 2018 (Table 11). Similar results regarding yearly comparisons were obtained using a rank-based test and comparisons of ranked residuals from the regression fit of ED versus length (Kruskal-Wallis Test, H = 103.9, ρ < 0.001; Table 12). Monitoring yearly differences in autumn energetic condition may help understand and project juvenile survival, as cohorts that are able to store more energy prior to their first winter are more likely to survive (Sogard and Olla 2000).

Differences in ED among years also may be driven by annual differences in SST. Annual mean Chinook ED generally increased with mean autumn SST across years (Spearman's rho = 0.583, ρ = 0.047. However, temperature may have a non-linear, dome-shaped relationship to ED, as indicated by a GAM model fit (k = 4, edf = 2.26, adj R^2 = 36.4%, ρ = 0.108) in which ED was highest at intermediate SST and appeared to decline at the highest SST observed in 2019 (< 11 °C; Fig. 30). Temperature effects on ED were evaluated in combination with fish size, given that average length alone accounted for 46.5% of the variation in annual average ED (slope = 0.0237; $F_{1,10}$ = 8.68, ρ = 0.015; Fig. 31) in a simple linear regression model.

Temperature combined with length in a multiple regression model explained 64.0% of the variation in average ED ($slope_{SST}$ = 0.146, $slope_{LEN}$ = 0.0211; $F_{2,9}$ = 7.99, ρ = 0.010). The effect of SST on ED was marginally not significant (ρ = 0.066) in that model and was potentially weakened by collinearity with length due to the non-significant but positive influence of SST on length (slope = 1.72; $F_{1,10}$ = 0.313; R^2 = 3.04%, ρ = 0.588). The 17.5% improvement in fit versus length alone justified the inclusion of the SST term in the model (ΔAICc = - 0.034).

The positive influence of temperature on juvenile Chinook salmon energetic condition across most of the observed temperature range through 2018 may be expected for fish near the northern limit of their distribution, where temperatures are likely below optimal for growth and condition. Warmer temperatures are expected to have a positive effect up to a species-dependent optimal temperature, given the typical dome-shaped responses of fish growth and condition to temperature (Beauchamp et al 2007; Laurel et al 2016). Warmer temperatures in the past have supported higher survival of northern stocks of pink, chum, and sockeye salmon potentially through indirect effects on prey production (Mueter et al. 2002). However, anomalously warm temperatures seen in 2019 may have exceeded the optimum for juvenile Chinook salmon, and thus led to a decline in ED.

The 2019 decline in ED may have been caused by a combination of increased metabolic rates (Gillooly et al. 2001) and negative impacts on prey quality or quantity associated with unusually warm conditions. Higher ED observed in warmer years through 2018 suggests that juvenile Chinook salmon energetic condition during that period generally was not limited by food energy intake. Juvenile Chinook salmon may have adapted to decreased availability of capelin in warm years (Andrews et al. 2016) by eating more sand lance and early-stage decapods. Diet differences in warmer versus colder years make it difficult to strictly distinguish temperature effects from diet effects on energetic condition. However, despite eating fewer fish and less prey overall in warmer years, NBS juvenile Chinook salmon diets were adequate to support higher energetic condition than in cooler years through 2018. The 2019 decline in ED suggests juvenile Chinook salmon were unable to ingest sufficient energy to support optimal energetic condition, though it is difficult to infer mechanisms or trends based on a single anomalous year. If energetic condition consistently declines in response to anomalously warm conditions, continued ocean warming could lead to decreased survival of juveniles, which in 2019 had among the lowest abundances since monitoring began in 2003. These data indicate juvenile Chinook salmon energetic condition is sensitive to temperature-driven changes in ocean conditions that could impact future returns.

Seabird and Marine Mammal Observations

A total of 2,870 km were surveyed during the cruise with 324 km in the Chukchi Sea, 1,734 km in the NBS, and 809 km in the southern Bering Sea during transit to port in Dutch Harbor, AK. We observed a total of 3,310 birds on transect, comprising 38 species plus several unidentified passerines (Table 13).

The northern fulmar (*Fulmarus glacialis*) was the most abundant seabird species (28%) recorded during the survey. Highest concentrations of fulmars were observed in the southern Bering Sea south of 60°N near the shelf-break and the middle domain (Fig. 32). In the northern Bering and Chukchi seas, fulmar observations were generally lower and fulmars were largely absent on transects offshore of Norton Sound. Short-tailed shearwaters (*Ardenna tenuirostris*) and unidentified shearwaters (*Ardenna* spp.) were a predominant bird species (15%) recorded throughout the study area (Table 13). Shearwaters were widely distributed, with higher numbers in the southern Bering Sea, along with larger concentrations of birds near the Bering Strait (Fig. 33). Another *Procellariidae* species, the fork-tailed storm-petrel, was also common in the Bering Sea, with distribution centered in the southern Bering Sea (Fig. 33).

Aethia auklets (Crested, Least, and Parakeet) combined comprised 6% of the total seabird observations during the survey (Table 13). Crested auklets were primarily observed in two areas, southeast of St. Lawrence Island and near King Island in the NBS (Fig. 34). Least and parakeet auklets were more widely dispersed south of St. Lawrence Island, west of Nunivak Island, and in the southern Bering Sea (Fig. 34). Tufted puffins (3%) and common murres (3%) were other commonly detected *Alcid* species.

Phalaropus spp. consisting of red phalaropes (*P. fulicarius*), red-necked phalaropes (*P. lobatus*), and unidentified phalaropes, comprised 8% of total birds recorded during the survey. Phalaropes were mostly found in the NBS near St. Lawrence Island, the Bering Strait, and extending into the Chukchi Sea (Fig. 35). Black-legged kittiwakes (*Rissa tridactyla*) were the prevalent *Laridae* species recorded and comprised 19% of total seabird observations. Kittiwakes were widely distributed, with the highest numbers detected near the Pribilof Islands, east of St. Matthew Island, and Bering Strait (Fig. 36).

We recorded marine mammals during surveys, but because we used seabird survey protocols our observations cannot be used to calculate marine mammal densities. The USFWS observer recorded 65 marine mammals of seven species, including off-transect individuals (Table 14). northern fur seals (*Callorhinus ursinus*) were the most commonly encountered marine mammal, with individuals observed in the Bering Sea within 200 km of Dutch Harbor. The most common cetacean species observed was the humpback whale (*Megaptera novaeangliae*).

Sandhill cranes (*Grus canadensis*) were observed in five flocks near Bering Strait on 14 and 16 September, totaling 604 birds. We recorded three observations of Aleutian terns (*Onychoprion aleuticus)* totaling four birds in early to mid-September, east of St. Paul Island, north of Nunivak Island, and northeast of St. Lawrence Island. Near Nunivak Island we also observed two female Steller's eiders (*Polysticta stelleri*), and one marbled murrelet *(Brachyramphus marmoratus*) in early September.

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TABLES AND FIGURES

Table 1. -- Name and affiliation of scientific crew members during the northern Bering Sea surface trawl survey, 2019. AFSC—Alaska Fisheries Science Center, Auke Bay Laboratories, Juneau, AK; ADFG—Alaska Department of Fish and Game, Commercial Fisheries Division, Anchorage, AK; USFWS—US Fish and Wildlife Service, Office of Migratory Bird Management, Anchorage, AK; APU—Alaska Pacific University, Anchorage, AK.

Name (Last, First)	Title	Date Embark	Date Disembark	Affiliation
Murphy, Jim	Chief Scientist	8/27/2021	9/20/2021	AFSC
Gray, Andrew	Sup. Fish Biologist	8/27/2021	9/8/2021	AFSC
Sewall, Fletcher	Fish Biologist	8/27/2021	9/8/2021	AFSC
Dimond, Andrew	Fish Biologist	8/27/2021	9/8/2021	AFSC
Jallen, Deena	Fish Biologist	8/27/2021	9/8/2021	ADFG
Labunski, Elizabeth	Seabird Observer	8/27/2021	9/8/2021	USFWS
Waters, Charlie	Fish Biologist	9/8/2021	9/20/2021	AFSC
Garcia, Sabrina	Fish Biologist	8/8/2021	9/20/2021	ADFG
Nicols, Dave	Fish Biologist	9/8/2021	9/20/2021	AFSC
Conlon, Ryan	Student	9/8/2021	9/20/2021	APU
Zeller, Tamara	Seabird Observer	9/8/2021	9/20/2021	USFWS

Table 2. -- Dates, locations, and sampling events completed at each station during the northern Bering Sea surface trawl survey, 2019.

Station	Date	Latitude	Longitude	Bottom Depth (m)	CTD Depth (m)	CAT Depth (m)	Benthic Grab
1	8/30/2019	60.01	-167.98	23	17	16	No
2	8/30/2019	59.99	-168.97	38	31	30	No
3	8/31/2019	59.99	-169.97	51	47	41	No
4	8/31/2019	59.99	-170.98	65	47	56	No
5	8/31/2019	60.51	-170.96	59	52	50	No
6	9/1/2019	60.51	-169.98	45	40	NA	No
7	9/1/2019	60.51	-168.97	35	30	26	No
8	9/1/2019	60.51	-167.96	27	21	18	No
9	9/2/2019	60.51	-167.04	24	19	19	No
10	9/2/2019	60.99	-167.04	19	13	12	No
11	9/2/2019	61	-168.02	27	20	21	Yes
12	9/3/2019	60.99	-169.05	34	29	26	No
13	9/3/2019	60.99	-170.02	44	36	37	No
14	9/3/2019	61.03	-170.98	51	47	45	No
15	9/4/2019	61.49	-170.96	48	41	40	No
16	9/4/2019	61.51	-169.98	42	37	34	No
17	9/4/2019	61.5	-169	32	26	26	No
18	9/5/2019	61.49	-168.01	26	21	21	No
19	9/5/2019	61.54	-167.06	19	16	15	No
20	9/5/2019	61.99	-166.98	26	22	21	Yes
21	9/6/2019	61.98	-167.98	25	21	20	No
22	9/6/2019	62	-169.04	34	29	28	No
23	9/6/2019	62.02	-170.07	41	35	35	Yes
24	9/7/2019	62.01	-170.95	47	41	40	Yes
25	9/7/2019	62.5	-166.96	31	26	24	No
26	9/7/2019	63.01	-165.95	18	15	14	Yes
27	9/8/2019	63.51	-165.96	21	18	17	No
28	9/9/2019	63.49	-166.94	23	19	20	Yes
29	9/9/2019	62.99	-167.03	22	19	18	No
30	9/10/2019	62.49	-167.94	26	20	20	Yes
31	9/10/2019	62.5	-169.04	29	25	26	No
32	9/10/2019	62.48	-170.03	33	29	27	Yes
33	9/11/2019	62.49	-170.98	40	37	36	No
34	9/11/2019	63.49	-167.96	30	26	26	No
35	9/11/2019	64	-167.97	34	28	29	No
36	9/12/2019	64.52	-166.99	24	20	19	No
37	9/12/2019	64.01	-166.96	30	27	25	Yes
38	9/13/2019	64.01	-165.96	19	16	16	No
39	9/13/2019	64.1	-162.54	18	15	13	Yes
40	9/13/2019	64.1	-163.56	21	15	18	Yes
41	9/14/2019	64.1	-164.47	19	15	14	Yes
42	9/14/2019	64.53	-168.01	33	30	27	No
43	9/14/2019	65.02	-167.55	22	19	19	Yes
44	9/15/2019	65.42	-168.04	38	29	33	Yes
45	9/15/2019	66.62	-165.8	16	14	13	Yes
46	9/15/2019	66.61	-166.99	28	25	24	Yes
47	9/16/2019	66.12	-167.45	19	16	15	Yes

Table 3. -- Temperature (°C), salinity (PSU), and mixed layer depth (MLD, m) measurements from CTD (SBE-9-11+) and FastCat (SBE-49) casts during the northern Bering Sea surface trawl survey, 2019. Surface values are average values from the top 10 m, and bottom values are values at maximum gear depth.

Station	CTD Surface Temp.	CAT Surface Temp.	CTD Surface Salinity	CAT Surface Salinity	CTD Bottom Temp.	CAT Bottom Temp.	CTD Bottom Salinity	CAT Bottom Salinity	Mixed Layer Depth
1	12.42	12.41	31.15	30.77	12.42	12.41	31.12	30.78	17
2	11.84	11.84	NA	31.82	7.66	7.71	31.91	31.91	22
3	11.99	12.08	31.91	31.91	4.17	4.27	32.05	32.05	21
4	11.99	11.54	31.91	32.05	4.17	2.65	32.05	32.23	21
5	11.68	11.67	--	31.95	2.9	2.90	32.18	32.18	26
6	11.76	--	31.89	--	4.88	--	31.97	--	22
7	10.91	10.94	31.56	31.58	10.09	10.42	31.68	31.65	22
8	12.43	12.44	--	30.97	12.43	12.43	30.97	30.96	21
9	12.87	12.88	30.71	30.72	12.85	12.85	30.73	30.73	19
10	13.77	13.77	29.23	29.21	13.74	13.74	29.3	29.3	13
11	12.59	12.59	30.88	30.88	12.57	12.57	30.88	30.88	20
12	11.03	11.03	31.46	31.46	11.02	11.03	31.46	31.46	29
13	11.27	11.27	31.78	31.77	5.68	5.66	31.86	31.86	24
14	11.41	11.41	31.93	31.92	3.13	3.12	32.09	32.09	27
15	11.37	11.36	31.9	31.89	2.73	2.73	32.04	32.04	23
16	10.95	10.93	31.44	31.44	5.74	5.84	31.69	31.69	20
17	11.23	11.23	31.38	31.37	11.23	11.24	31.38	31.36	26
18	11.93	11.9	30.69	30.68	11.93	11.93	30.69	30.65	21
19	12.96	12.96	30.22	30.04	12.96	12.96	30.22	30.2	16
20	12.87	12.89	30.14	29.86	12.88	12.89	30.19	29.82	22
21	11.02	11.04	--	30.63	11.02	11.07	30.81	30.82	21
22	10.89	10.95	--	30.64	8.02	8.08	31.32	31.33	21
23	11.33	11.33	31.5	31.50	3.44	3.43	31.57	31.57	24
24	11.24	11.26	31.64	31.65	1.77	1.77	31.87	31.88	19
25	12.57	12.56	30.1	30.00	12.07	12.1	30.32	30.31	20
26	12.28	12.32	29.78	29.51	12.03	12.04	29.98	29.99	12
27	11.09	11.18	30.74	30.36	10.31	10.4	31.02	31.01	10
28	9.99	10.02	31.24	31.24	9.53	9.71	31.28	31.01	19
29	11.02	11.18	30.89	30.85	10.95	10.96	30.98	30.96	19
30	11.27	11.39	31.05	30.59	10.47	10.48	31.05	31.35	15
31	11.11	11.1	31.28	31.21	2.96	2.95	31.53	31.57	18
32	11.39	11.39	31.37	31.22	2.02	2.03	31.66	31.67	18
33	11.38	11.39	31.37	31.36	1.72	1.72	31.77	31.77	19
34	10.02	9.88	31.67	31.66	6.42	6.42	31.72	31.73	12
35	10.29	10.3	--	31.71	2.80	2.77	32.11	32.16	20
36	10.62	10.63	30.86	30.88	10.45	10.47	30.96	30.66	19
37	8.45	8.46	31.55	31.55	8.00	8.05	31.72	31.73	27
38	10.36	10.37	31.19	31.13	10.37	10.36	31.19	31.18	16
39	12.93	12.9	21.68	21.75	12.97	12.97	22.06	19.9	14
40	12.93	12.43	21.68	21.08	12.97	12.46	22.06	24.01	14
41	12.07	12.14	29.17	29.18	11.91	11.91	29.47	29.57	8
42	7.91	7.86	31.26	31.43	5.66	5.73	31.93	31.93	17
43	11.38	11.67	--	29.42	11.37	11.35	30.23	30.22	19
44	11.45	11.84	29.3	29.63	10.68	10.68	30.76	30.76	6
45	10.79	10.76	29.59	29.58	10.75	10.74	29.6	29.53	14
46	11.89	11.9	28.5	28.35	11.68	11.78	28.88	28.8	14
47	11.97	11.94	27.36	27.5	11.60	11.63	28.37	28.28	10
Average	11.47	11.46	30.37	30.39	8.70	8.77	30.70	30.64	18.66

Table 4. -- Average surface trawl net dimensions (horizontal and vertical spread), average footrope depth (from the SBE39 temperature-depth recorder) and mixed layer depth (MLD) expansions during the northern Bering Sea surface trawl survey, 2019. MLD expansions are used to scale surface trawl catches to the mixed layer.

Station	Horiz. Net Spread (m)	Vert. Net Spread (m)	SBE39 Footrope Depth (m)	Mixed Layer Depth Expansion
1	38.45	17.15	18.72	1.00
2	49.50	19.00	21.59	1.02
3	51.00	16.40	18.11	1.16
4	51.00	18.50	20.27	1.04
5	51.00	19.00	19.95	1.30
6	50.00	19.00	20.45	1.08
7	48.62	20.87	23.17	1.00
8	49.60	19.20	21.23	1.00
9	51.00	12.00	12.80	1.48
10	51.22	15.39	16.53	1.00
11	52.00	15.00	16.44	1.22
12	50.00	22.00	24.58	1.18
13	48.00	21.00	22.94	1.05
14	52.38	17.12	18.87	1.43
15	49.50	20.00	22.30	1.03
16	50.50	16.00	16.74	1.19
17	50.00	19.24	22.02	1.18
18	50.00	20.19	21.33	1.00
19	50.50	16.50	17.46	1.00
20	51.00	18.00	19.03	1.16
21	49.00	17.00	18.41	1.14
22	49.00	17.00	19.56	1.07
23	52.00	17.00	18.43	1.30
24	49.50	19.50	21.22	1.00
25	51.00	17.50	19.19	1.04
26	51.62	15.00	15.02	1.00
27	53.01	15.34	17.23	1.00
28	44.00	17.00	18.66	1.02
29	48.00	18.00	18.96	1.00
30	49.00	17.00	18.75	1.00
31	51.00	16.00	17.09	1.05
32	45.00	17.00	18.29	1.00
33	47.00	17.75	19.07	1.00
34	51.00	21.00	23.22	1.00
35	47.00	19.50	20.11	1.00
36	48.00	16.00	16.17	1.18
37	47.00	18.50	18.83	1.43
38	51.00	16.50	16.97	1.00
39	52.71	14.29	14.39	1.00
40	51.00	15.50	16.08	1.00
41	51.50	15.00	16.27	1.00
42	50.50	19.00	21.48	1.00
43	51.00	17.00	18.98	1.00
44	53.00	20.00	23.10	1.00
45	53.00	13.00	14.10	1.00
46	51.00	18.50	19.65	1.00
47	49.00	14.50	16.61	1.00
Average	49.81	17.47	18.94	1.08

Table 5. -- Average size (length and weight), total catch, and catch-per-unit-effort (CPUE) of salmon species captured during the northern Bering Sea surface trawl survey, 2019.

Common Name	Scientific Name	Life History Stage	Average Length (cm)	Average Weight (g)	Average CPUE (n/km²)	Total Number Caught
pink salmon	*Oncorhynchus gorbuscha*	Juvenile	15.37	34	1,463	13,507
chum salmon	*O. keta*	Juvenile	16.73	49	397	3,660
sockeye salmon	*O. nerka*	Juvenile	18.56	64	277	2,553
coho salmon	*O. kisutch*	Juvenile	24.82	194	20	182
Chinook salmon	*O. tshawytscha*	Juvenile	19.75	97	14	125
chum salmon	*O. keta*	Immature	42.92	1,187	21	194
Chinook salmon	*O. tshawytscha*	Immature	42.17	1,271	3	26
sockeye salmon	*O. nerka*	Immature	36.62	676	2	19
coho salmon	*O. kisutch*	Immature	65.00	3,870	0.1	1

Table 6. -- Average size (bell width and weight), total weight, and catch-per-unit-effort (CPUE) of common jellyfish species captured during the northern Bering Sea surface trawl survey, 2019.

Common Name	Scientific Name	Average Bell Diameter (cm)	Average Weight (g)	Average CPUE (kg/km²)	Total Weight (kg)
northern sea nettle	*Chrysaora melanaster*	22.91	873	6,898	747,341
lion's mane jellyfish	*Cyanea capillata*	22.60	962	610	66,055
moon jellyfish	*Aurelia labiata*	15.32	302	378	40,906
whitecross jellyfish	*Staurophora mertensi*	--	--	69	7,443
water jellyfish	*Aequorea* spp.	15.40	218	23	2,478
fried egg jellyfish	*Phacellophora camtschatica*	--	--	2	182

Table 7. -- Average size (length and weight), total catch, and catch-per-unit-effort (CPUE) of non-salmon species captured during the northern Bering Sea surface trawl survey, 2019.

Life History Stage	Common Name	Scientific Name	Average Length (cm)	Average CPUE (n/km²)	Total Num. Caught	Total Weight Caught (kg)
--	Pacific herring	*Clupea pallasi*	14	15,401	142,152	1,842
--	salmon shark	*Lamna ditropis*	210	0.2	2	191
--	rainbow smelt	*Osmerus mordax*	13	113	1,040	14
--	ninespine stickleback	*Pungitius pungitius*	5	1,025	9,464	10
--	starry flounder	*Platichthys stellatus*	25	3	27	5
--	Arctic lamprey	*Lethenteron camtschaticum*	38	2	20	2
--	smooth lumpsucker	*Aptocyclus ventricosus*	NA	0	1	2
--	threespine stickleback	*Gasterosteus aculeatus*	4	159	1,464	1
--	Arctic staghorn sculpin	*Gymnocanthus tricuspis*	29	0.3	3	1
--	crested sculpin	*Blepsias bilobus*	12	1	13	1
--	yellowfin sole	*Limanda aspera*	27	0.3	3	1
--	Alaska plaice	*Pleuronectes quadrituberculatus*	19	0.4	4	0.4
--	greenling	*Hexagrammos spp.*	NA	1	7	0.2
--	capelin	*Mallotus villosus*	11	1	11	0.1
--	northern rock sole	*Lepidopsetta polyxystra*	NA	0.1	1	0.1
--	sturgeon poacher	*Podothecus accipenserinus*	26	0.1	1	0.1
--	armhook squid	*Gonatus spp.*	6	1	9	0.1
--	sand lance	*Ammodytes spp.*	15	0.2	2	0.03
--	longhead dab	*Limanda proboscidea*	3	0.2	2	0.002
Age 1+	walleye pollock	*Gadus chalcogrammus*	42	6	51	27
Age 1+	saffron cod	*Eleginus gracilis*	21	4	35	3
Age 0	walleye pollock	*Gadus chalcogrammus*	7	953	8,798	26
Age 0	rainbow smelt	*Osmerus mordax*	7	255	2,350	4
Age 0	saffron cod	*Eleginus gracilis*	10	2	14	0.1
Age 0	Pacific cod	*Gadus macrocephalus*	8	0.3	3	0.02

Table 8. -- Stock composition percentages (mean, standard deviation) for reporting groups (Upper Yukon, Middle Yukon, Lower Yukon, and Other Western Alaska) of juvenile Chinook salmon captured during the northern Bering Sea surface trawl surveys, 2003-2019. Stock composition estimates are not available for 2008 (no survey), 2012 and 2005 (low sample size), and 2013 (genetic samples contaminated during a flooding event aboard the survey vessel).

	Upper Yukon		Middle Yukon		Lower Yukon		Other Western Alaska	
Year	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2003	48.29	3.5	23.44	3.06	16.55	4.34	11.72	4.13
2004	57.37	4.46	26.26	4.03	5.49	3.72	10.88	4.15
2006	48.98	5.34	26.51	4.8	14.99	5.59	9.52	5.14
2007	50.59	3.49	29.88	3.27	13.84	3.09	5.69	2.5
2009	52.43	4.77	28.06	4.42	6.26	4.25	13.25	4.63
2010	48.78	4.59	27.36	4.13	15.27	4.09	8.59	3.54
2011	46.74	2.88	22.46	2.44	17.53	3.52	13.27	3.38
2014	50.62	3.71	36.6	3.62	8.8	2.64	3.98	2.13
2015	44.17	2.93	30.02	2.79	11.87	3.35	13.94	3.37
2016	54.18	3.47	20.84	2.93	9.54	3.27	15.44	3.49
2017	42.3	3.67	19.94	3.04	9.28	4.32	28.47	4.97
2018	34.43	4.03	30.89	4.02	19.18	5.05	15.51	4.82
2019	29.99	4.5	21.17	4.19	13.88	6.04	34.96	6.63
Average	46.84	3.95	26.42	3.6	12.5	4.1	14.25	4.07

Table 9. -- Juvenile abundance, standard deviation (SD) of abundance, and juveniles-per-spawner for Yukon River Canadian-origin Chinook salmon stock group during the northern Bering Sea surface trawl surveys, 2003-2019. Mixed-layer depth expansions, Canadian-origin Chinook salmon spawner abundance, adult returns, and returns-per-spawner are also included.

Juvenile Year	Mixed-Layer Depth Expansion	Juvenile Abundance (000s)	Juvenile Abundance (SD) (000s)	Adult Returns (000s)	Spawner Abundance (000s)	Juveniles-Per-Spawner	Returns-Per-Spawner
2003	1.30	2,691	506	120	53	51.2	2.3
2004	1.23	1,449	298	55	42	34.2	1.3
2005	1.55	1,659	485	98	81	20.6	1.2
2006	1.23	772	161	56	48	15.9	1.2
2007	1.10	1,621	493	78	68	23.8	1.2
2008		--	--	59	63	--	0.9
2009	1.00	984	418	45	35	28.2	1.3
2010	1.08	974	254	42	34	28.7	1.2
2011	1.21	1,843	756	81	65	28.2	1.2
2012	1.19	719	292	55	32	22.4	1.7
2013	1.01	2,924	881	107	46	63.1	2.3
2014	1.01	1,789	412	87	33	54.8	2.7
2015	1.03	2,113	677	70	29	73.7	2.4
2016	1.00	2,126	746	68	63	33.6	1.1
2017	1.03	1,049	219	--	83	12.7	--
2018	1.01	888	224	--	69	12.9	--
2019	1.10	575	164	--	68	8.4	--
Average	1.13	1,511	437	73	54	32	1.6

Table 10. -- Juvenile abundance, standard deviation (SD) of abundance, and juveniles-per-spawner for the Total Yukon River Chinook salmon stock group during the northern Bering Sea surface trawl surveys, 2003-2019. Mixed-layer depth expansions, Total Yukon River Chinook salmon spawner abundance, adult returns, and returns-per-spawner are also included.

Juvenile Year	Mixed-Layer Depth Expansion	Juvenile Abundance (000s)	Juvenile Abundance (SD) (000s)	Adult Returns (000s)	Spawner Abundance (000s)	Juveniles-Per-Spawner	Returns-Per-Spawner
2003	1.30	4,920	878	322	--	--	--
2004	1.23	2,249	435	154	113	19.9	1.4
2005	1.55	2,952	698	263	264	11.2	1
2006	1.23	1426	262	108	150	9.5	0.7
2007	1.10	3,020	884	189	207	14.6	0.9
2008		--	--	178	187	--	0.9
2009	1.00	1629	676	175	128	12.7	1.4
2010	1.08	1824	437	94	147	12.4	0.6
2011	1.21	3,422	1391	200	153	22.3	1.3
2012	1.19	1279	467	101	114	11.2	0.9
2013	1.01	5,204	1285	276	130	40.1	2.1
2014	1.01	3,393	724	238	111	30.6	2.2
2015	1.03	4,115	1294	220	129	31.8	1.7
2016	1.00	3,318	1149	208	173	19.2	1.2
2017	1.03	1,773	361	--	151	11.7	--
2018	1.01	2181	493	--	163	13.4	--
2019	1.10	1246	326	--	236	5.3	--
Average	1.13	2,747	735	195	160	17.7	1.3

Table 11. -- Grouping information from post-hoc Tukey pairwise comparisons of energy density (covariate: length) by year, ordered by mean value, for juvenile Chinook salmon caught during the northern Bering Sea surface trawl surveys, 2006–2019. Years that share a common letter do not significantly differ (95% confidence).

Year	N	Mean Energy Density (kJ/g)	Group				
2018	41	22.359	A				
2017	49	22.213	A	B			
2016	36	22.154	A	B	C		
2010	95	22.152	A	B			
2014	87	21.884		B	C	D	
2019	50	21.733			C	D	
2007	49	21.684			C	D	
2006	10	21.594	A	B	C	D	E
2015	69	21.55				D	E
2012	31	21.55				D	E
2009	17	21.548		B	C	D	E
2011	41	21.076					E

Table 12. -- Grouping information from post-hoc Tukey pairwise comparisons of ranked residuals from simple linear regression of energy density versus length, ordered by mean rank, for juvenile Chinook salmon caught during the northern Bering Sea surface trawl surveys, 2006–2017. Years that share a common letter do not significantly differ (95% confidence).

Year	N	Mean Rank	Group				
2018	41	412.6	A				
2017	49	366.7	A	B			
2016	36	356.3	A	B	C		
2010	95	351.8	A	B			
2014	87	285.2		B	C	D	
2019	50	259.3			C	D	E
2007	49	254.9			C	D	E
2012	31	230				D	E
2006	10	213.9		B	C	D	E
2015	69	211.2				D	E
2009	17	206.1				D	E
2011	41	167.3					E

Table 13. -- Number (N) and percent of total (%) of marine birds recorded on transect during the northern Bering Sea surface trawl survey, 2019.

		S. Bering		N. Bering		Chukchi Sea		Total	
Common Name	Scientific Name	N	%	N	%	N	%	N	%
red-throated loon	*Gavia stellata*					2	0.8	2	0.1
Pacific loon	*Gavia pacifica*	2	0.1	10	0.8	5	2	17	0.5
yellow-billed loon	*Gavia adamsii*			1	0.1			1	< 0.1
unid. loon	*Gavia* spp.			4	0.3	2	0.8	6	0.2
red-necked grebe	*Podiceps grisegena*			2	0.2			2	0.1
black-footed albatross	*Phoebastria nigripes*	7	0.4					7	0.2
Laysan albatross	*Phoebastria immutabilis*	3	0.2					3	0.1
morthern fulmar	*Fulmarus glacialis*	762	40.7	160	13.5	3	1.2	925	27.9
fork-tailed storm-petrel	*Oceanodroma furcata*	97	5.2	3	0.3	1	0.4	101	3.1
short-tailed shearwater	*Ardenna tenuirostris*	281	15	182	15.3	19	7.5	482	14.6
unid. dark shearwater	*Ardenna* spp.	7	0.4					7	0.2
pelagic cormorant	*Phalacrocorax pelagicus*	3	0.2	4	0.3			7	0.2
harlequin duck	*Histrionicus histrionicus*			3	0.3			3	0.1
long-tailed duck	*Clangula hyemalis*			1	0.1			1	< 0.1
Steller's eider	*Polysticta stelleri*			2	0.2			2	0.1
unid. duck	*Anatinae* spp.			1	0.1			1	< 0.1
unid. eider	*Somateria* spp.			3	0.3			3	0.1
sandhill crane	*Grus canadensis*			9	0.8	145	57.5	154	4.7
dunlin	*Calidris alpina*			1	0.1			1	< 0.1
unid. shorebird	*Scolopacidae* spp.			4	0.3			4	0.1
red phalarope	*Phalaropus fulicarius*	14	0.7	170	14.3	20	7.9	204	6.2
red-necked phalarope	*Phalaropus lobatus*	2	0.1	21	1.8			23	0.7
unid. phalarope	*Phalaropus* spp.	2	0.1	21	1.8	15	6	38	1.1
long-tailed jaeger	*Stercorarius longicaudus*	2	0.1					2	0.1
parasitic jaeger	*Stercorarius parasiticus*	5	0.3	2	0.2			7	0.2
pomarine jaeger	*Sterocorarius pomarinus*	4	0.2	5	0.4	3	1.2	12	0.4
unid. jaeger	*Stercocorarius* spp.			1	0.1			1	< 0.1
Aleutian tern	*Onychoprion aleuticus*	1	0.1	1	0.1			2	0.1
Arctic tern	*Sterna paradisaea*	3	0.2	3	0.3			6	0.2
Unid. Tern	*Sterna* spp.	1	0.1					1	< 0.1
black-legged ittiwake	*Rissa tridactyla*	318	17	296	24.9	20	7.9	634	19.2
glaucous gull	*Larus hyperboreus*	2	0.1	16	1.3	10	4	28	0.8
Glacous-winged gull	*Larus glaucescens*	27	1.4	11	0.9			38	1.1
herring gull	*Larus argentatus*	8	0.4	1	0.1			9	0.3
red-legged kittiwake	*Rissa brevirostris*	5	0.3					5	0.2
Sabine's gull	*Xema sabini*	6	0.3	22	1.9			28	0.8
slaty-backed gull	*Larus schistisagus*	2	0.1					2	0.1
unid. gull	*Larid* spp.	6	0.3	7	0.6	3	1.2	16	0.5
common murre	*Uria aalge*	56	3	40	3.4			96	2.9
thick-billed murre	*Uria lomvia*	18	1	13	1.1			31	0.9
unid. murre	*Uria* spp.	14	0.7	17	1.4	1	0.4	32	1.0
ancient murrelet	*Synthliboramphus antiquus*			5	0.4			5	0.2
marbled murrelet	*Brachyramphus marmoratus*			1	0.1			1	< 0.1
crested auklet	*Aethia cristatella*	1	0.1	14	1.2			15	0.5
least auklet	*Aethia pusilla*	30	1.6	52	4.4			82	2.5
parakeet auklet	*Aethia psittacula*	49	2.6	36	3			85	2.6
unid. auklet	*Aethia* spp.	14	0.7	4	0.3			18	0.5
horned puffin	*Fratercula corniculata*	20	1.1	19	1.6	2	0.8	41	1.2
tufted puffin	*Fratercula cirrhata*	97	5.2	15	1.3	1	0.4	113	3.4
unid. alcid	*Alcid* spp.	1	0.1	3	0.3			4	0.1
Passerine spp.	*Passeriformes* spp.			1	0.1			1	< 0.1
unid. bird.	*Aves*spp.	1	0.1					1	< 0.1
Total		1,871		1,187		252		3,310	

Table 14. -- Marine mammals recorded on and off transect during the northern Bering Sea surface trawl survey, 2019.

Common Name	Scientific Name	Southern Bering Sea	Northern Bering Sea	Total
Dall's porpoise	*Phocoenoides dalli*	2	9	11
fin whale	*Balaenoptera physalus*		2	2
harbor seal	*Phoca vitulina*	1		1
humpback whale	*Megaptera novaeangliae*		20	20
killer whale	*Orcinus orca*		3	3
northern fur seal	*Callorhinus ursinus*	2	24	26
unidentified whale	*Cetacea* spp.		2	2
Total		5	60	65

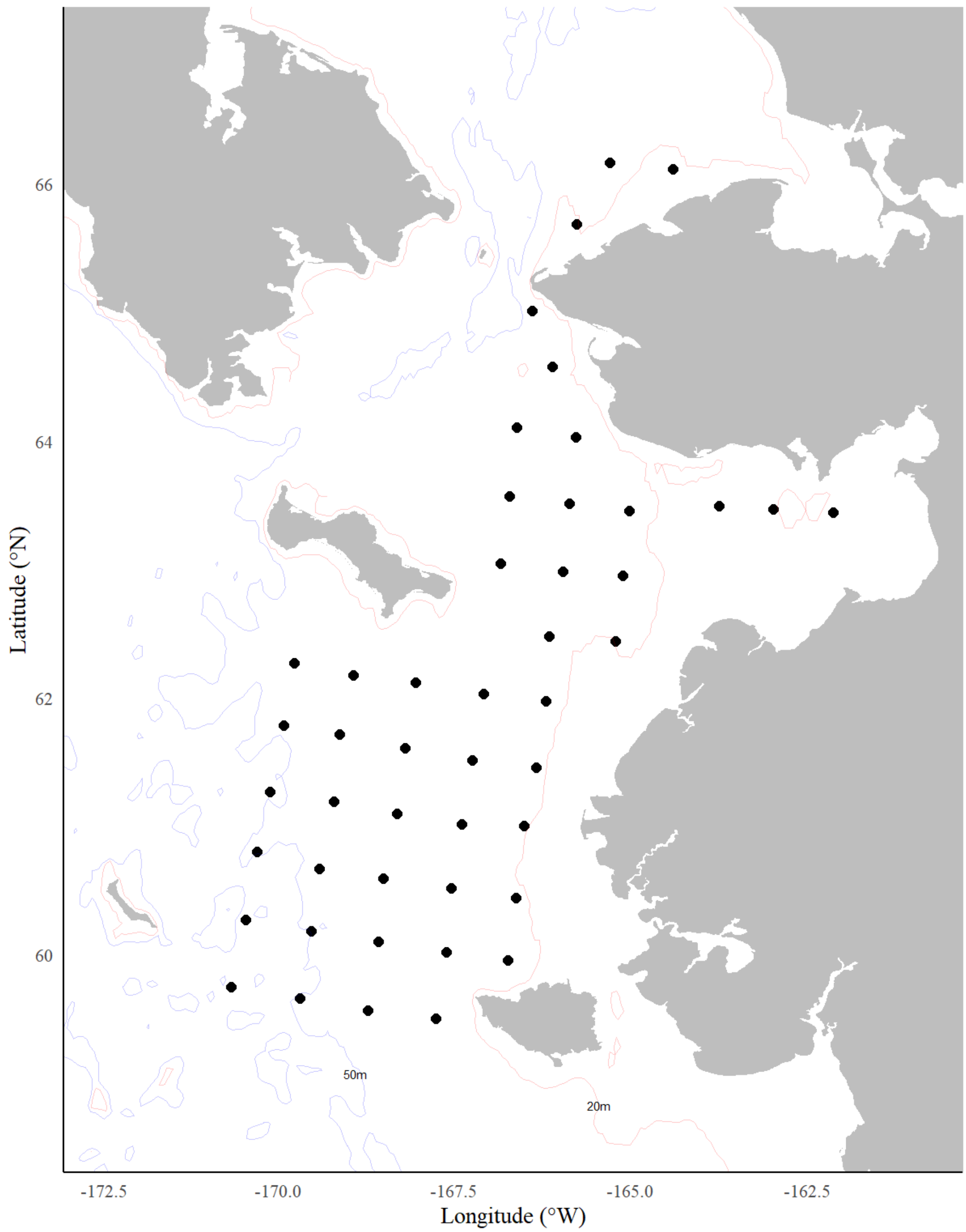

Figure 1. -- Map of stations sampled during the northern Bering Sea surface trawl and ecosystem survey, 2019.

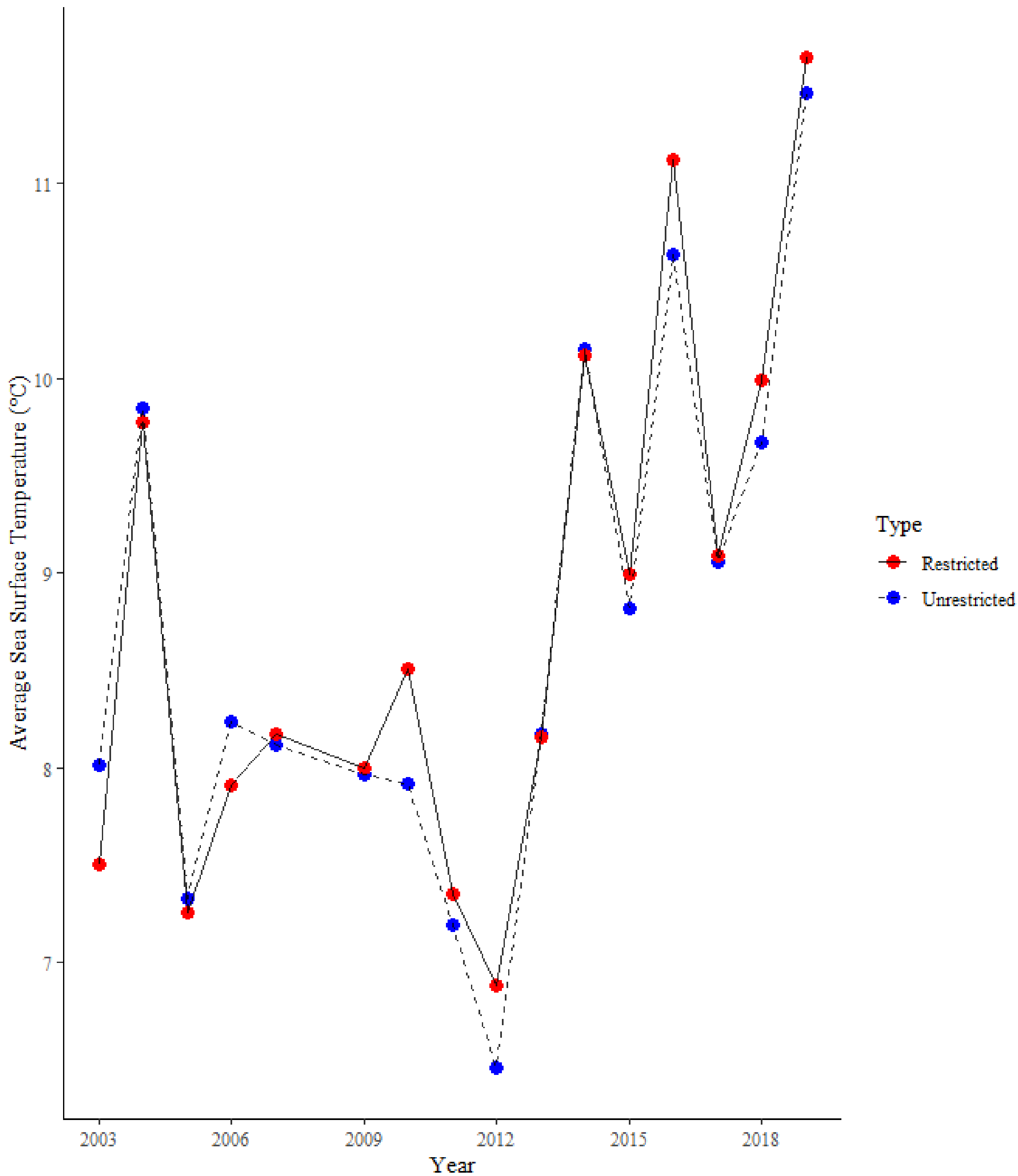

Figure 2. -- Average annual sea surface temperature (top 10 m of the water column) from CTD data collected during the northern Bering Sea surface trawl surveys, 2003-2019.

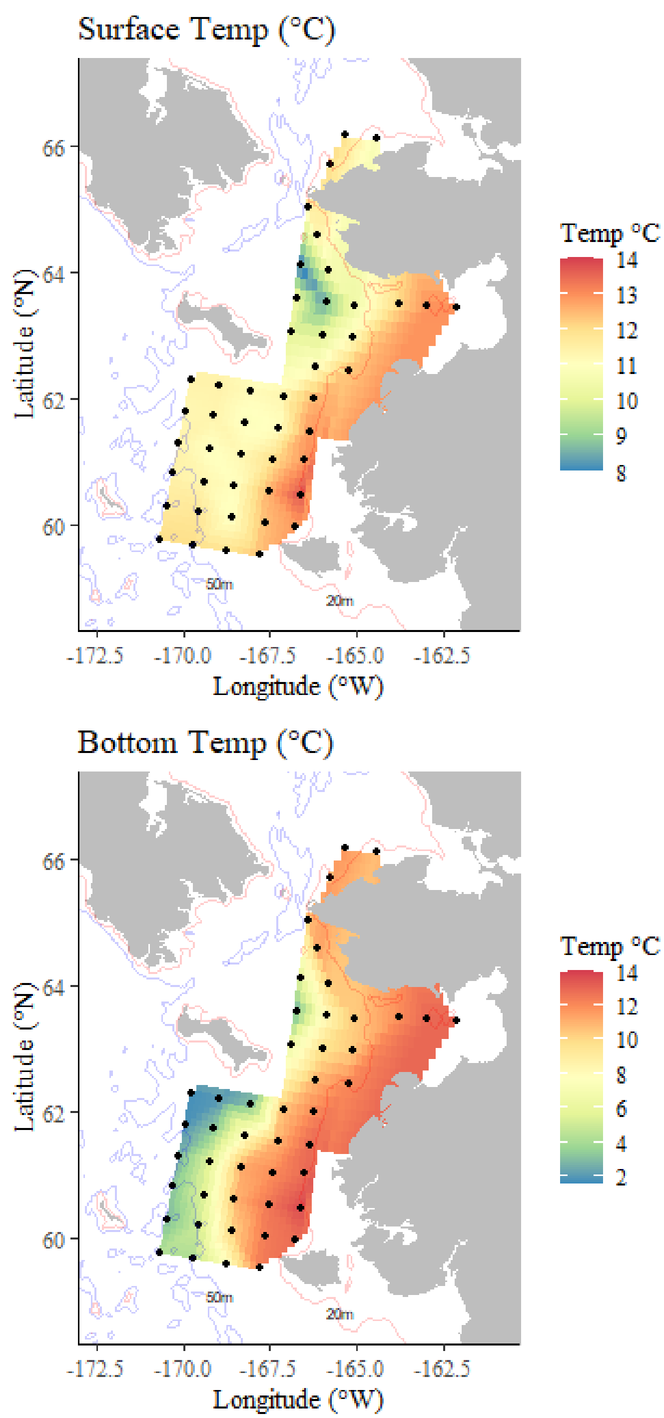

Figure 3. -- Interpolated map of surface (upper 10m) and bottom (deepest depth sampled) temperature (°C) from CTD data collected during the northern Bering Sea surface trawl survey, 2019.

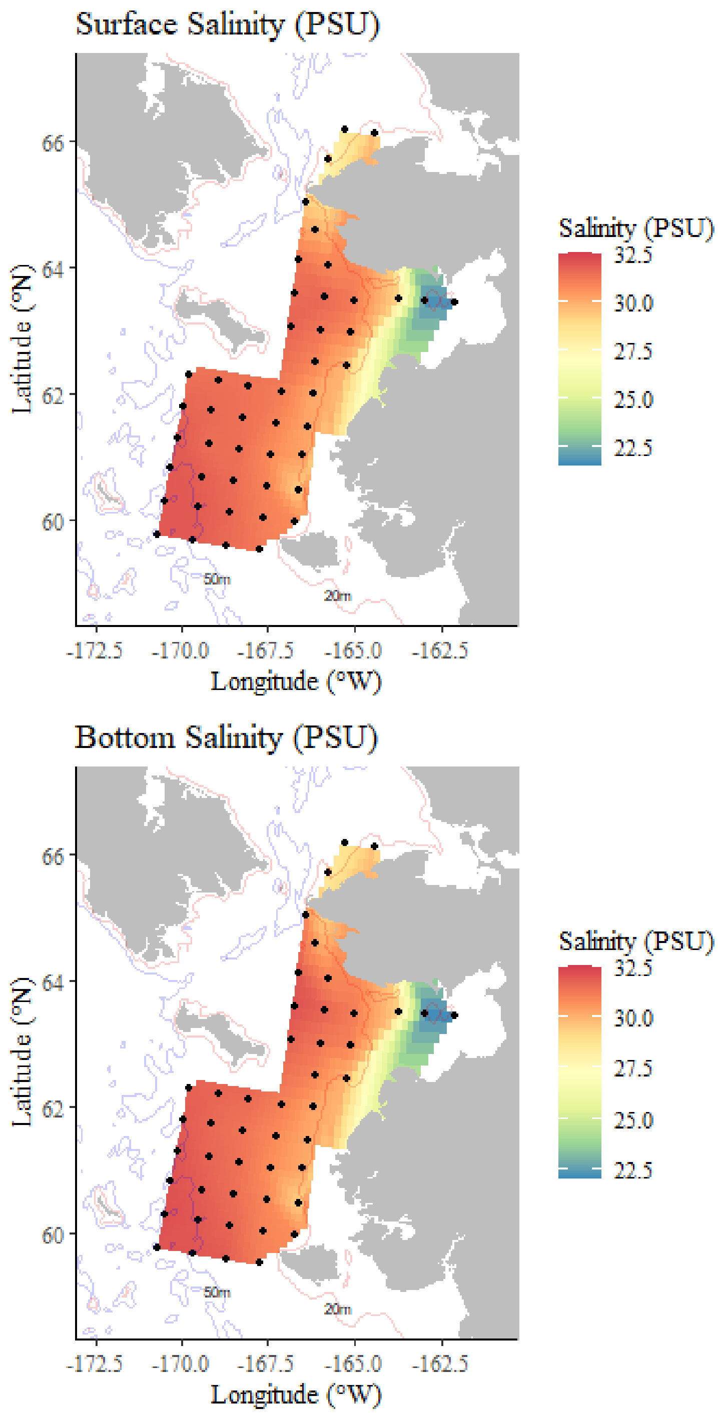

Figure 4. -- Interpolated map of surface (upper 10m) and bottom (deepest depth sampled) salinity (PSU) from CTD data collected during the northern Bering Sea surface trawl survey, 2019.

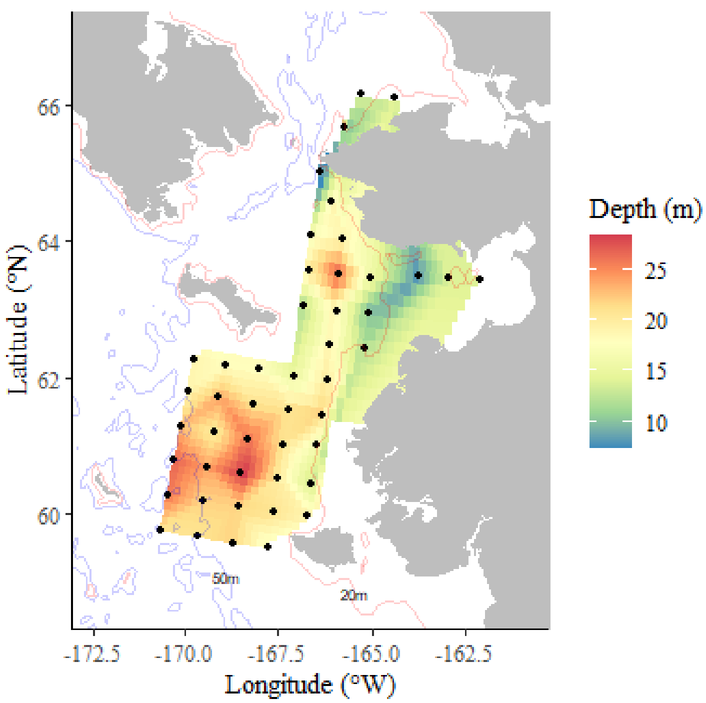

Figure 5. -- Interpolated map of mixed layer depth (m) from CTD data collected during the northern Bering Sea surface trawl survey, 2019.

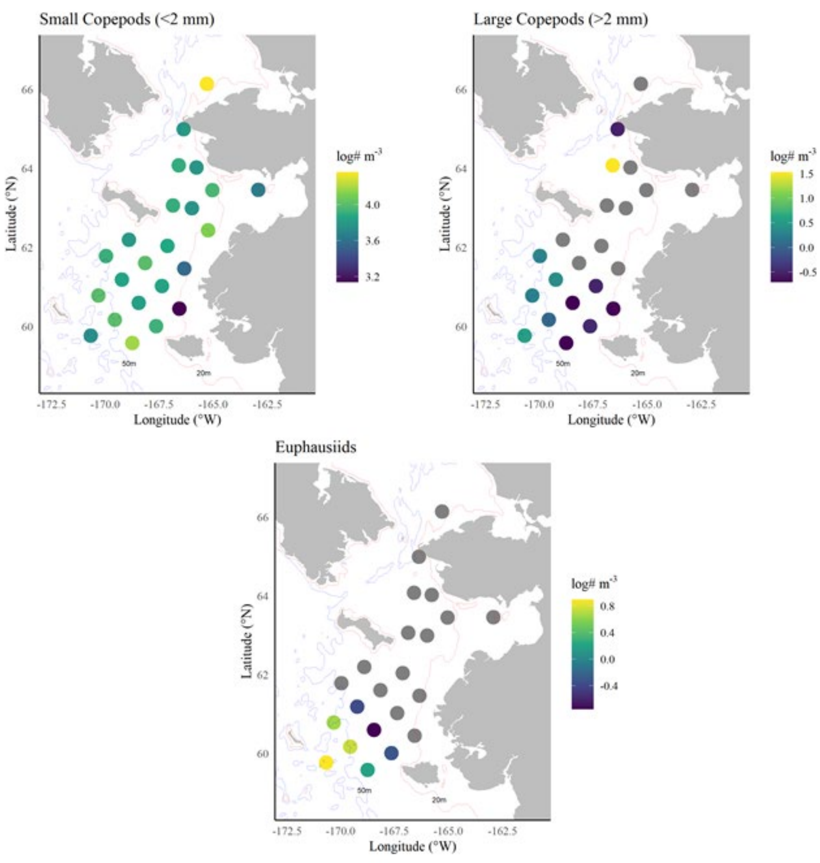

Figure 6. -- Distribution of small copepods, large copepods, and euphausiids determined by rapid zooplankton assessment methods during the northern Bering Sea surface trawl survey, 2019.

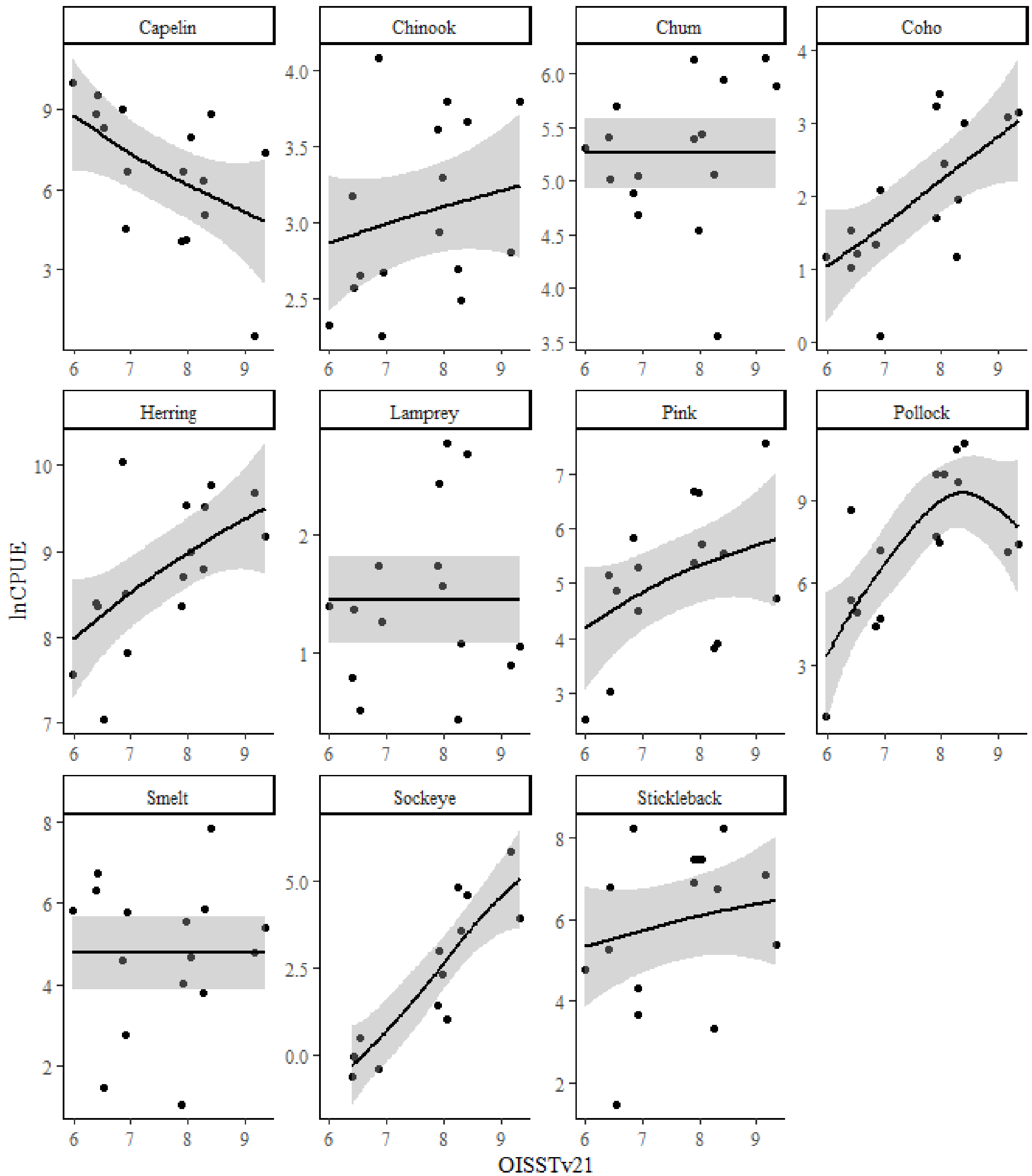

Figure 7. -- General additive model fits (black lines) with 95% confidence intervals (shaded regions) between average summer sea surface temperatures in the northern Bering Sea (OISSTv2.1) and catch rates (lnCPUE) of the primary fish species captured during the northern Bering Sea surface trawl surveys, 2003-2019.

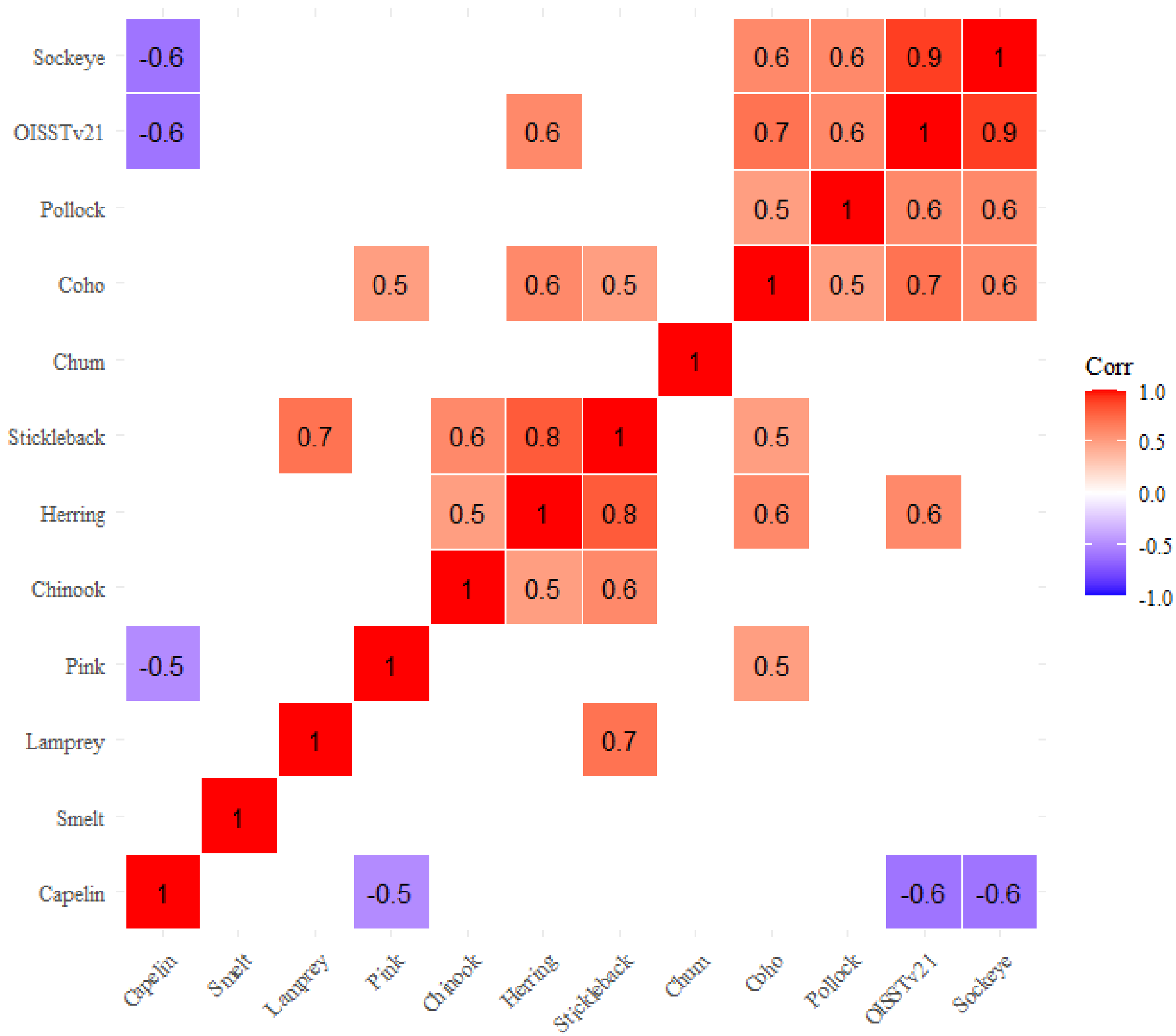

Figure 8. -- Significant correlations (Corr) between average catch rate (ln(CPUE)) of primary species captured during the northern Bering Sea surface trawl surveys and sea surface temperature data (OISSTv2.1), 2003-2019.

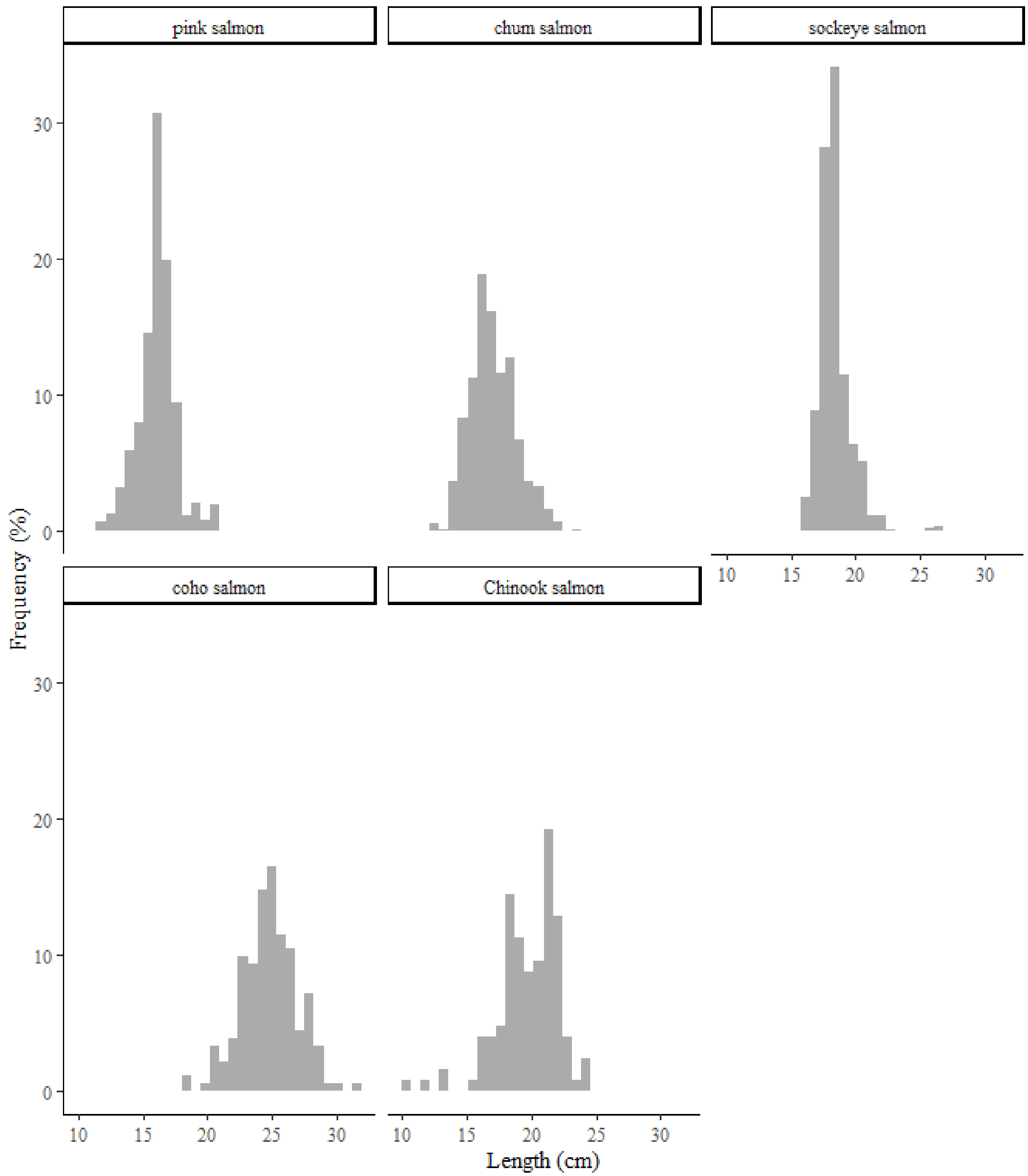

Figure 9. -- Length frequency distributions of juvenile salmon species captured during the northern Bering Sea surface trawl survey, 2019.

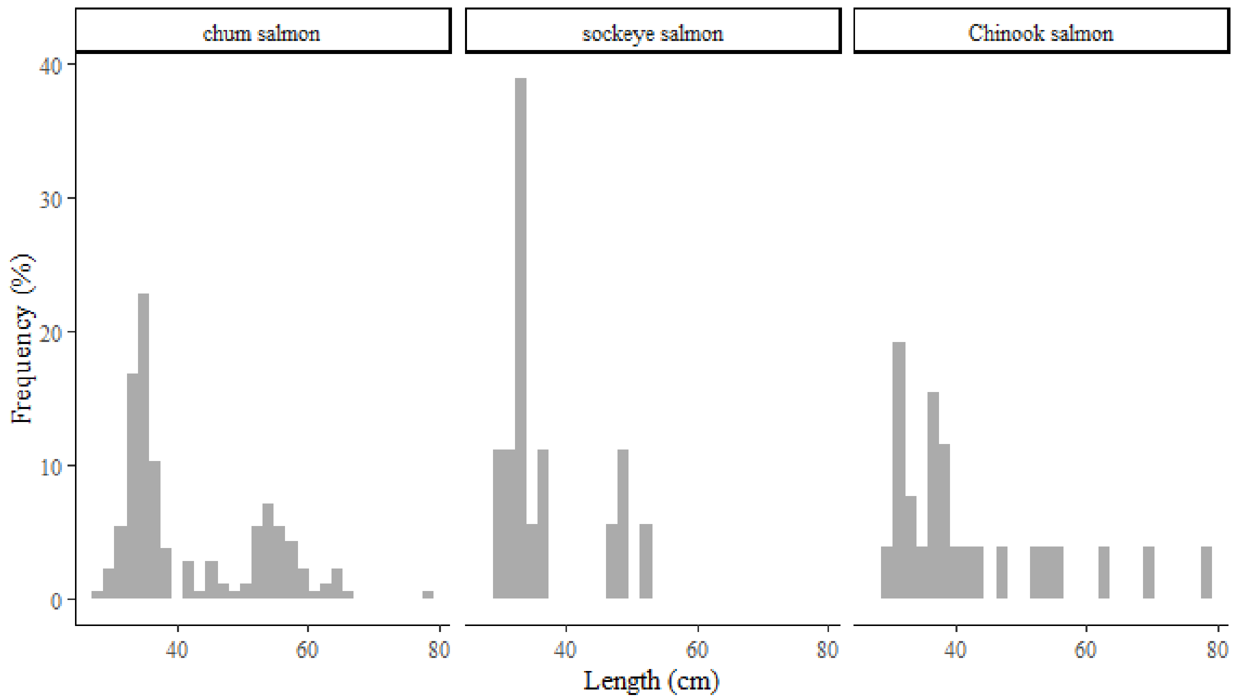

Figure 10. -- Length frequency distributions of immature salmon species captured during the northern Bering Sea surface trawl survey, 2019.

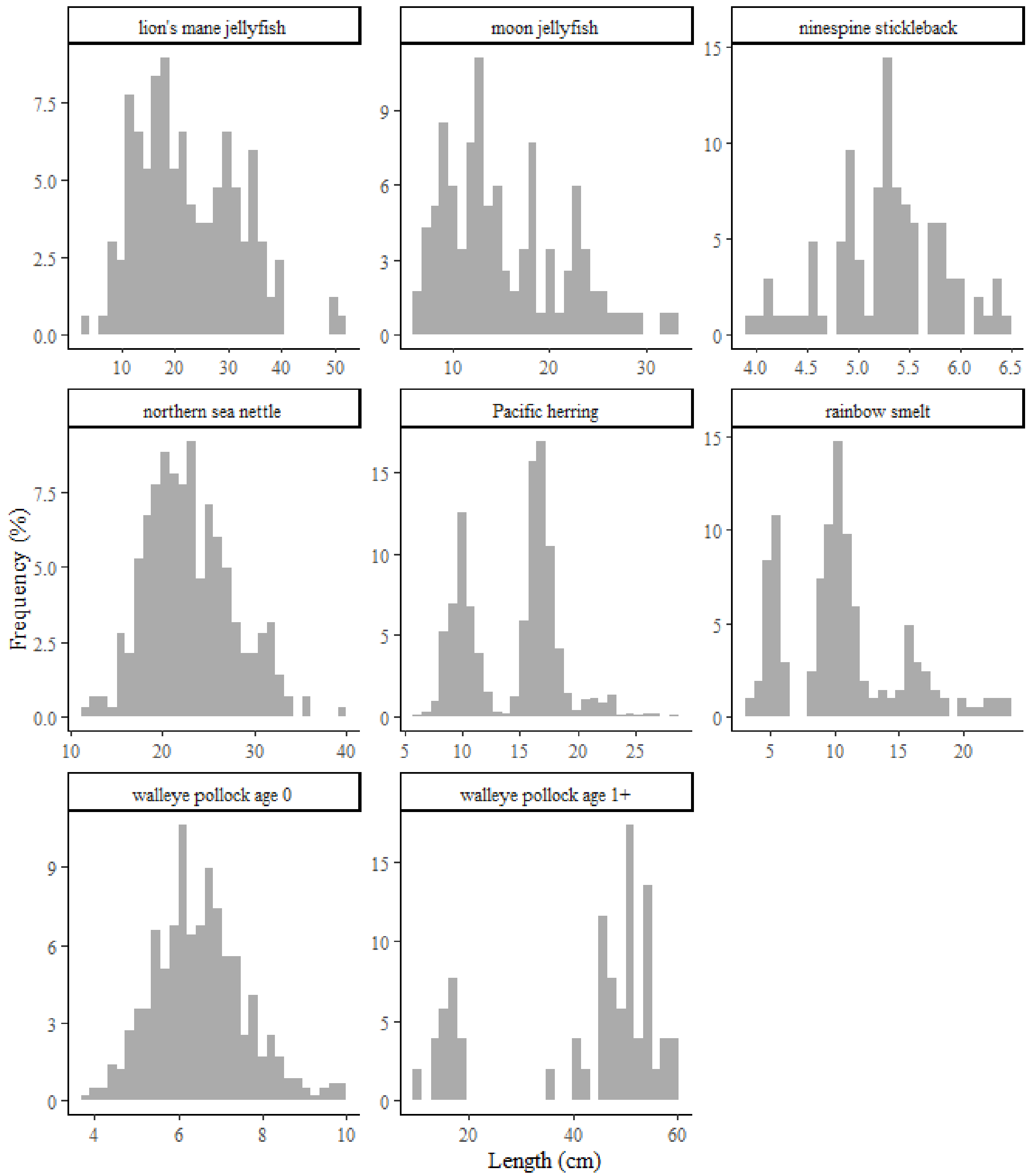

Figure 11. -- Length frequency distributions of the most abundant non-salmon species captured during the northern Bering Sea surface trawl survey, 2019.

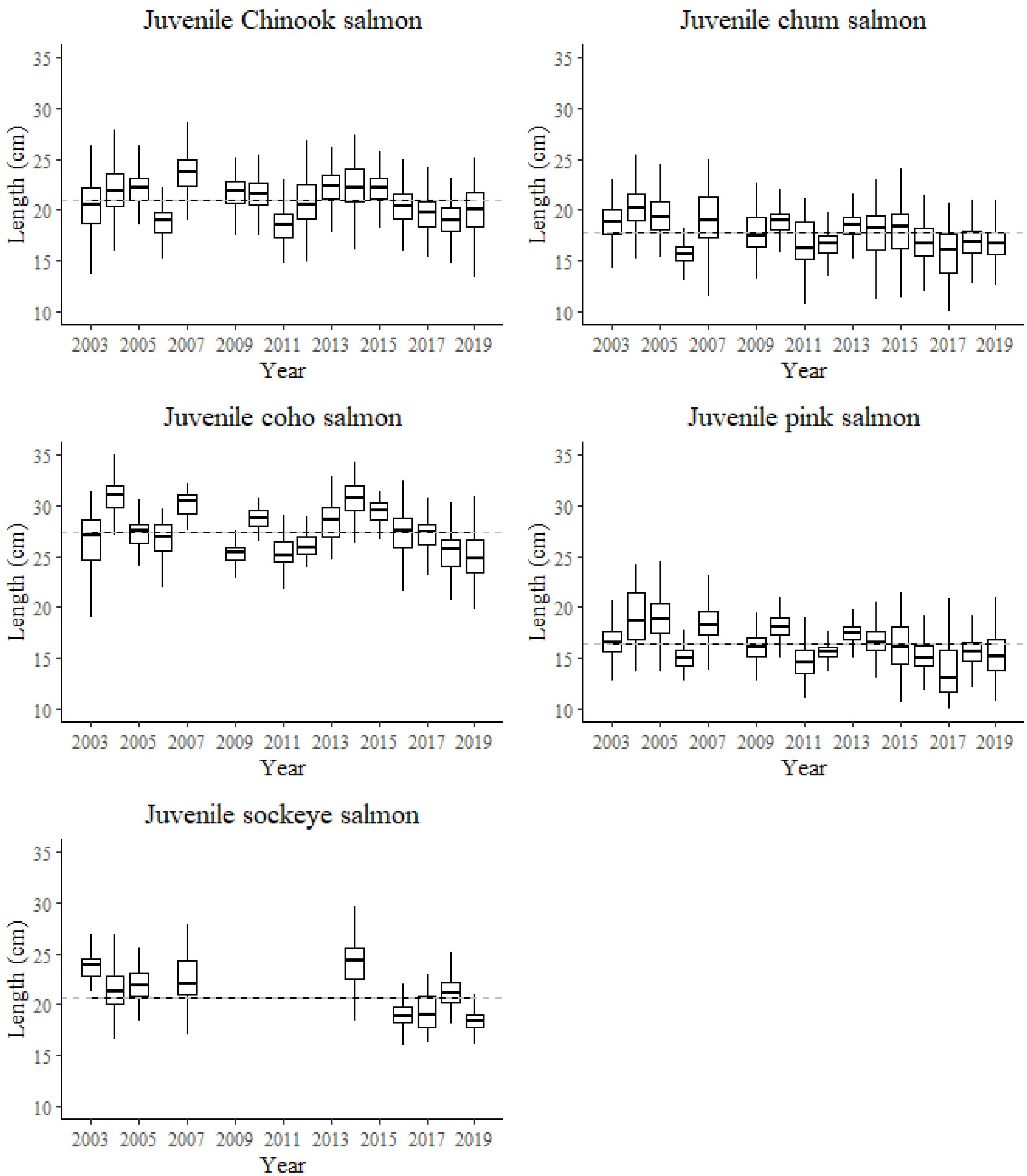

Figure 12. -- Box plots of juvenile salmon fork lengths (cm) sampled during the northern Bering Sea surveys, 2003-2019. The dashed line is the mean length across all years. Sockeye salmon lengths were limited to years where at least 20 lengths were measured.

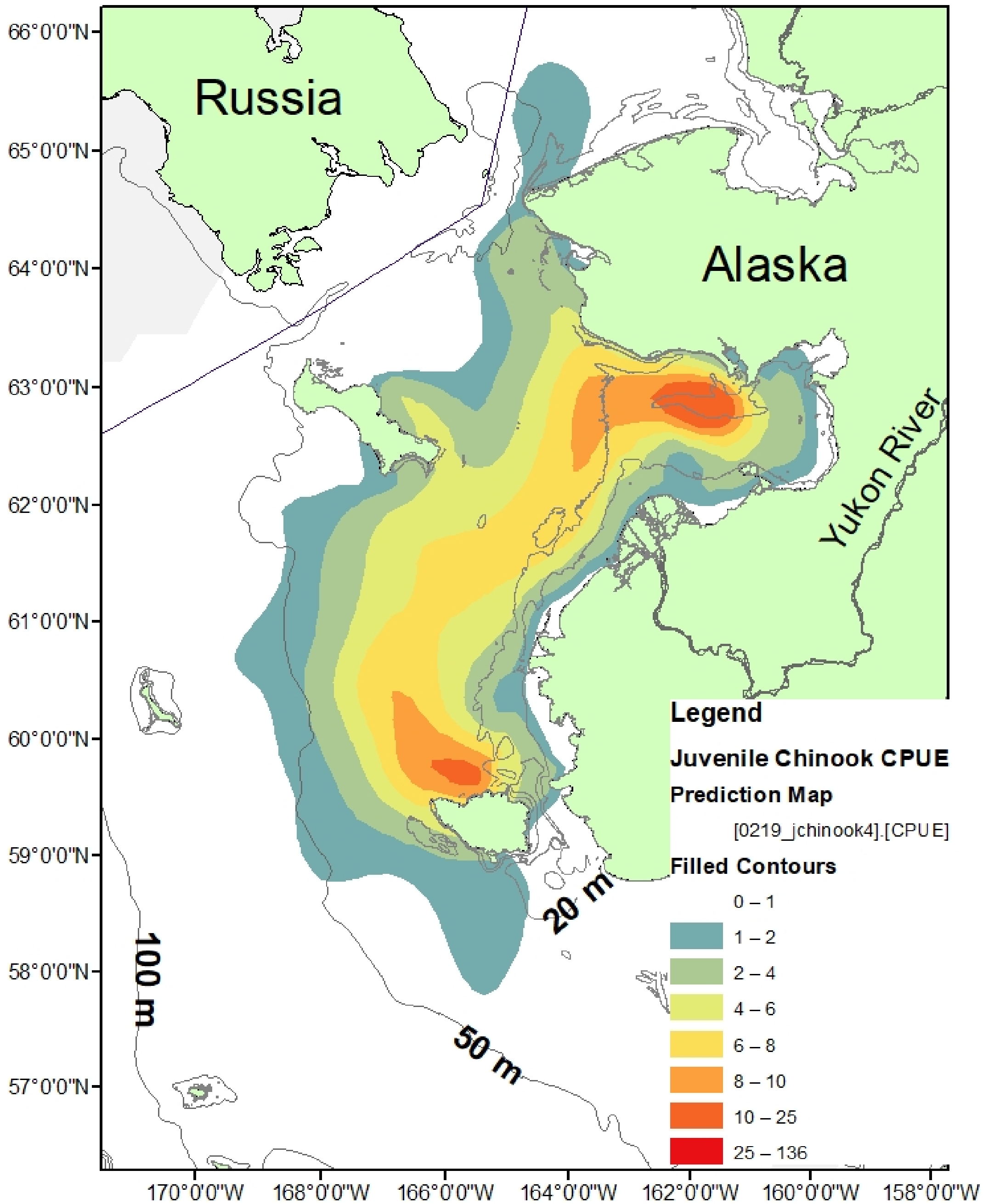

Figure 13. -- A kriging predicted surface of juvenile Chinook salmon catch rates during the northern Bering Sea surface trawl survey, 2003-2019.

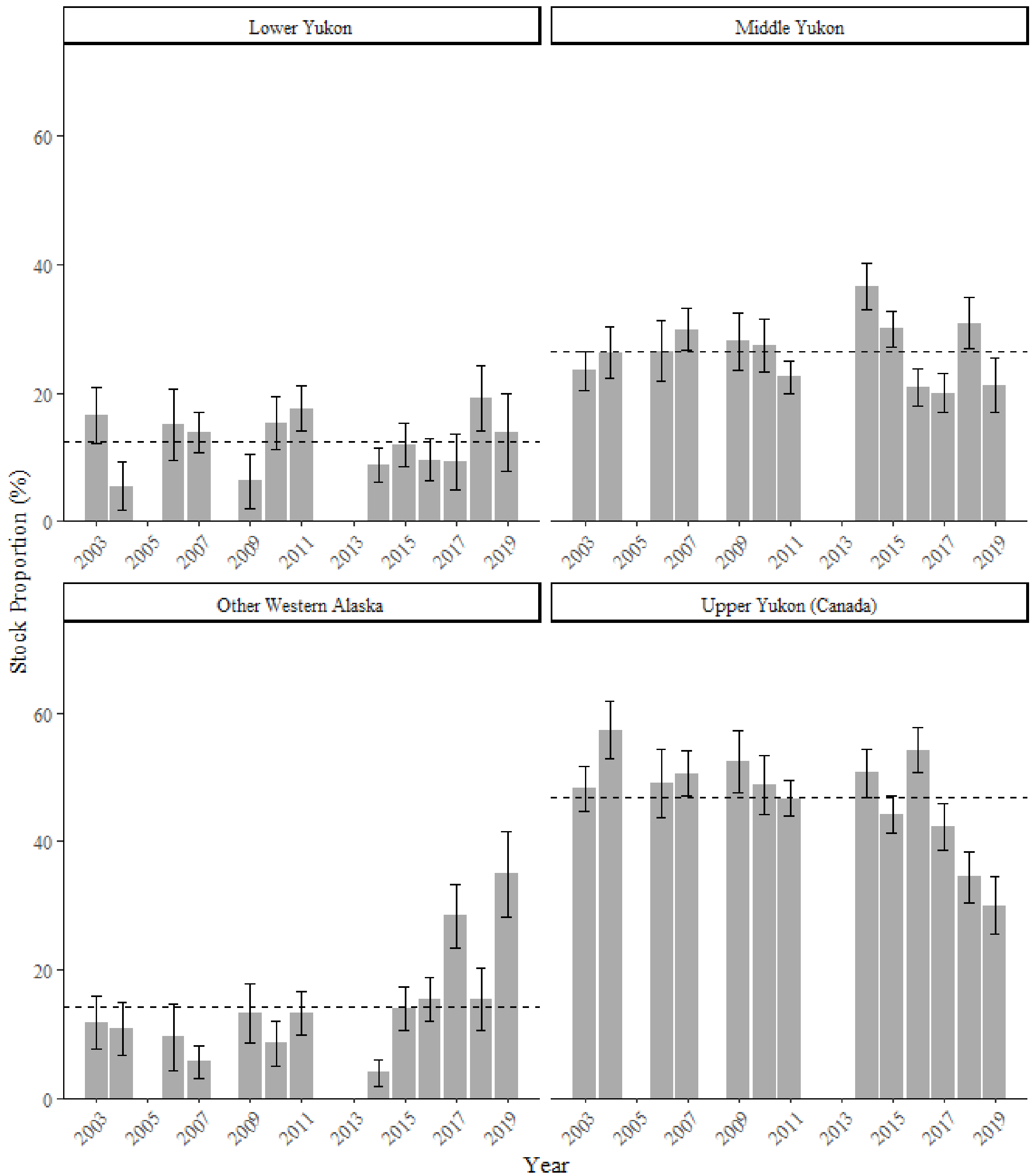

Figure 14. -- Genetic stock proportions of juvenile Chinook salmon captured during the northern Bering Sea surface trawl surveys, 2003-2019. Average stock proportions (dashed line) are included for each stock group.

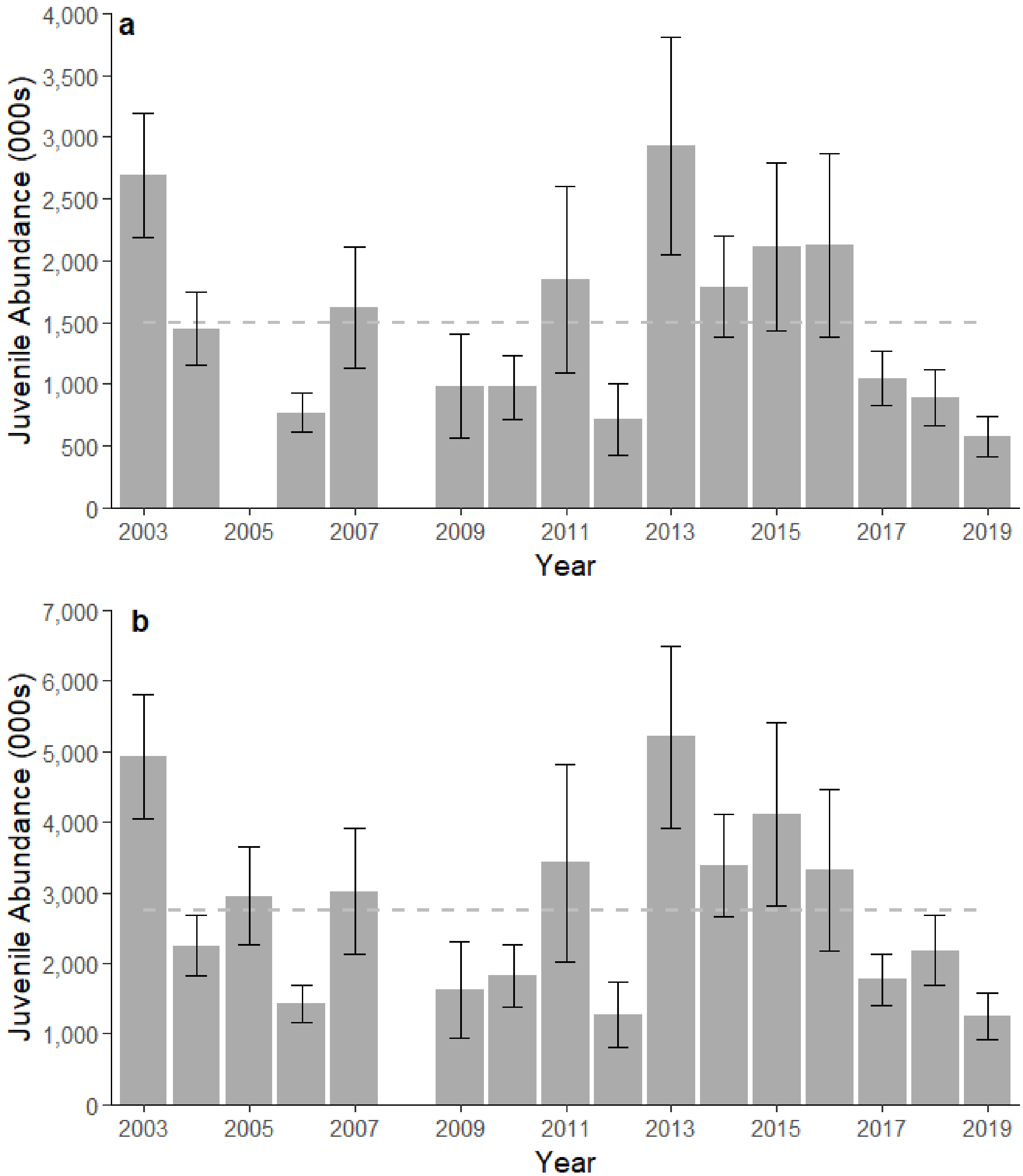

Figure 15. -- Stock-specific abundance estimates of Yukon River Canadian-origin (a) and Total Yukon (b) stock groups of Chinook salmon during the northern Bering Sea surface trawl surveys, 2003-2019. Average abundance for each stock group (solid line) is included.

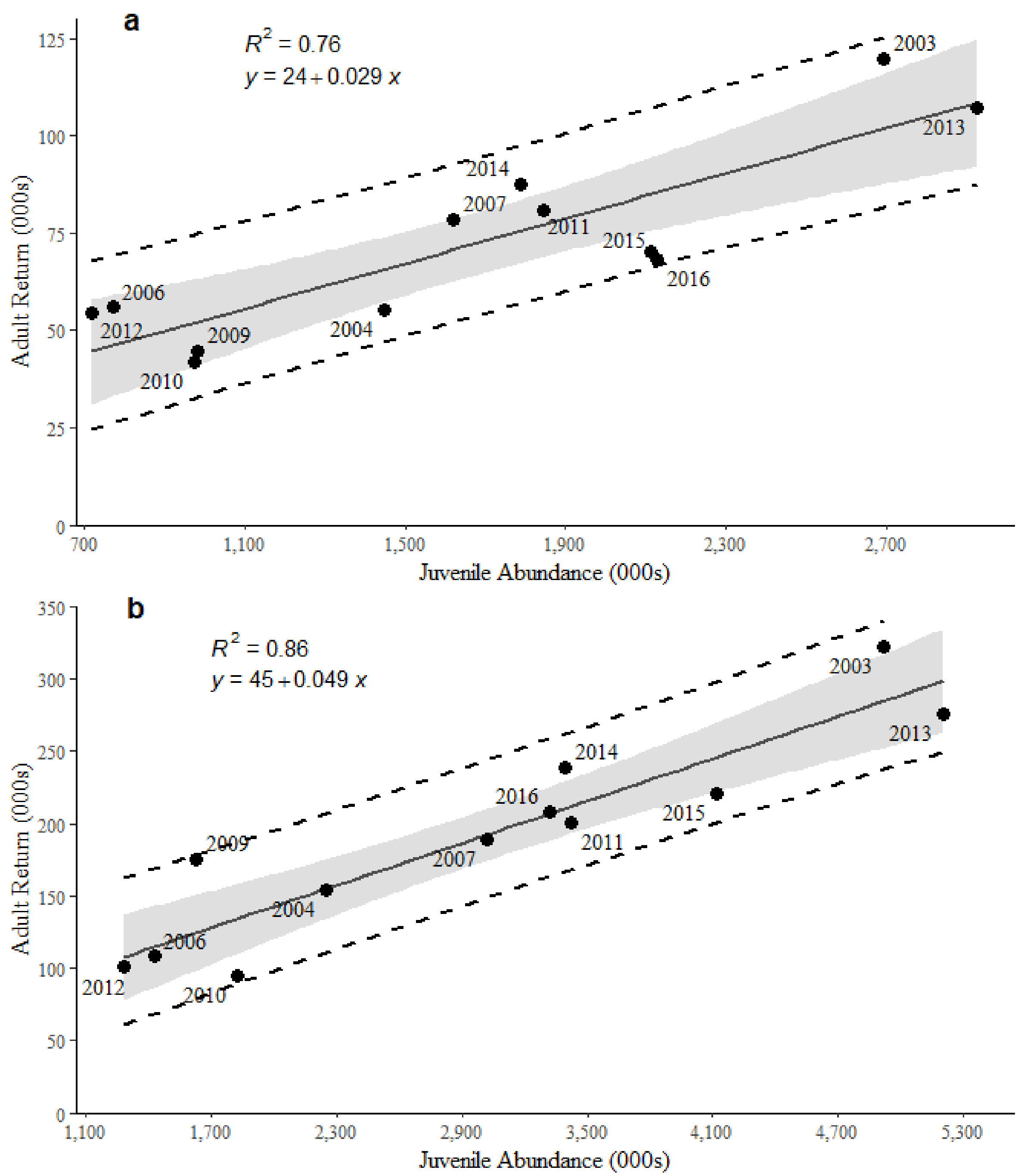

Figure 16. -- Relationships between juvenile abundance and resulting adult returns of Yukon River Canadian-origin (a) and Total Yukon (b) stock groups of Chinook salmon, 2003-2016. The fitted relationship (solid line), 80% prediction interval (dashed lines), 80% confidence interval (shaded region), and survey years (labels) are included.

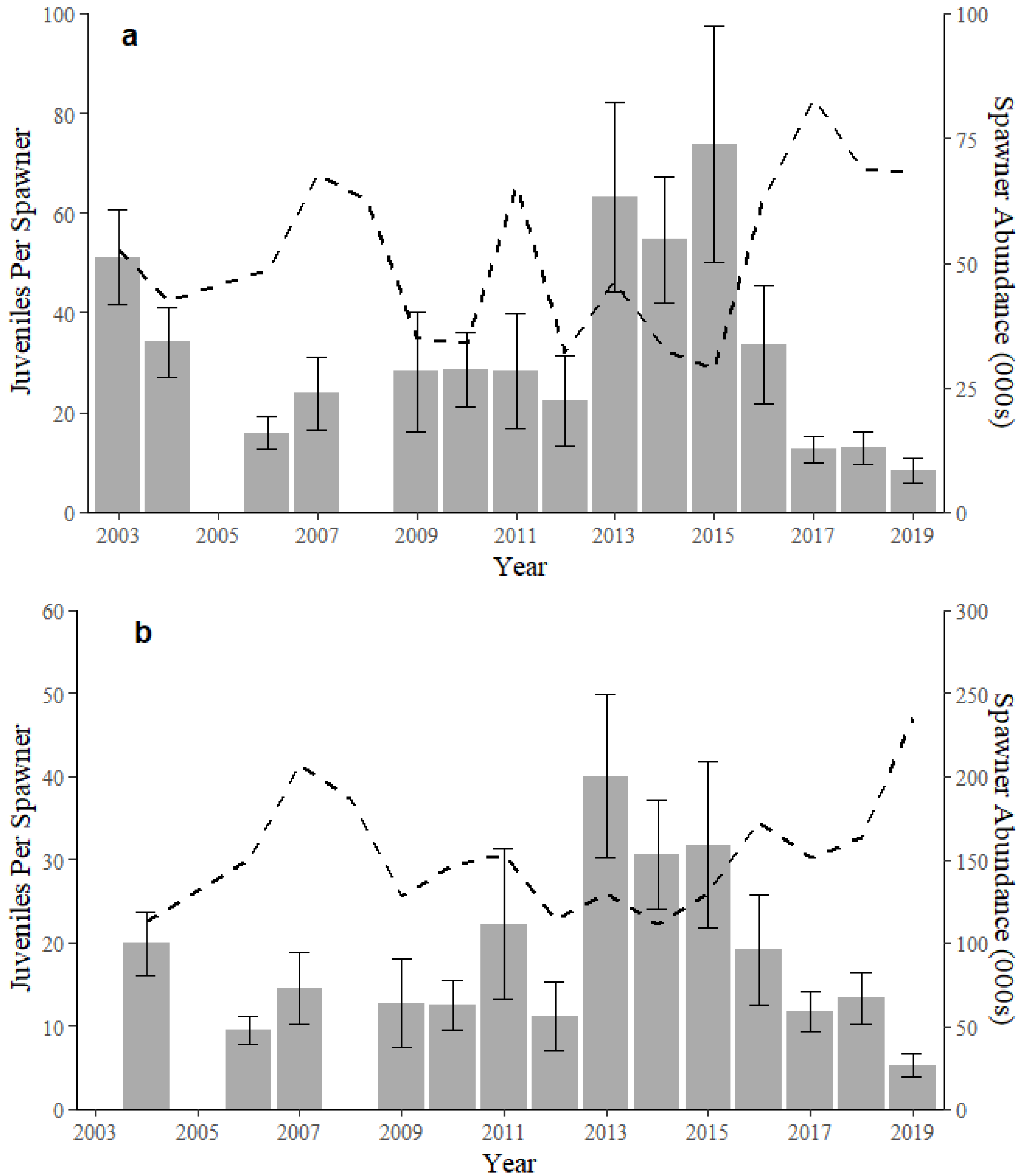

Figure 17. -- The number of juveniles-per-spawner (gray bars) and spawner abundance (dashed line) for the Yukon River Canadian-origin (a) and Total Yukon (b) stock groups of Chinook salmon, 2003-2019.

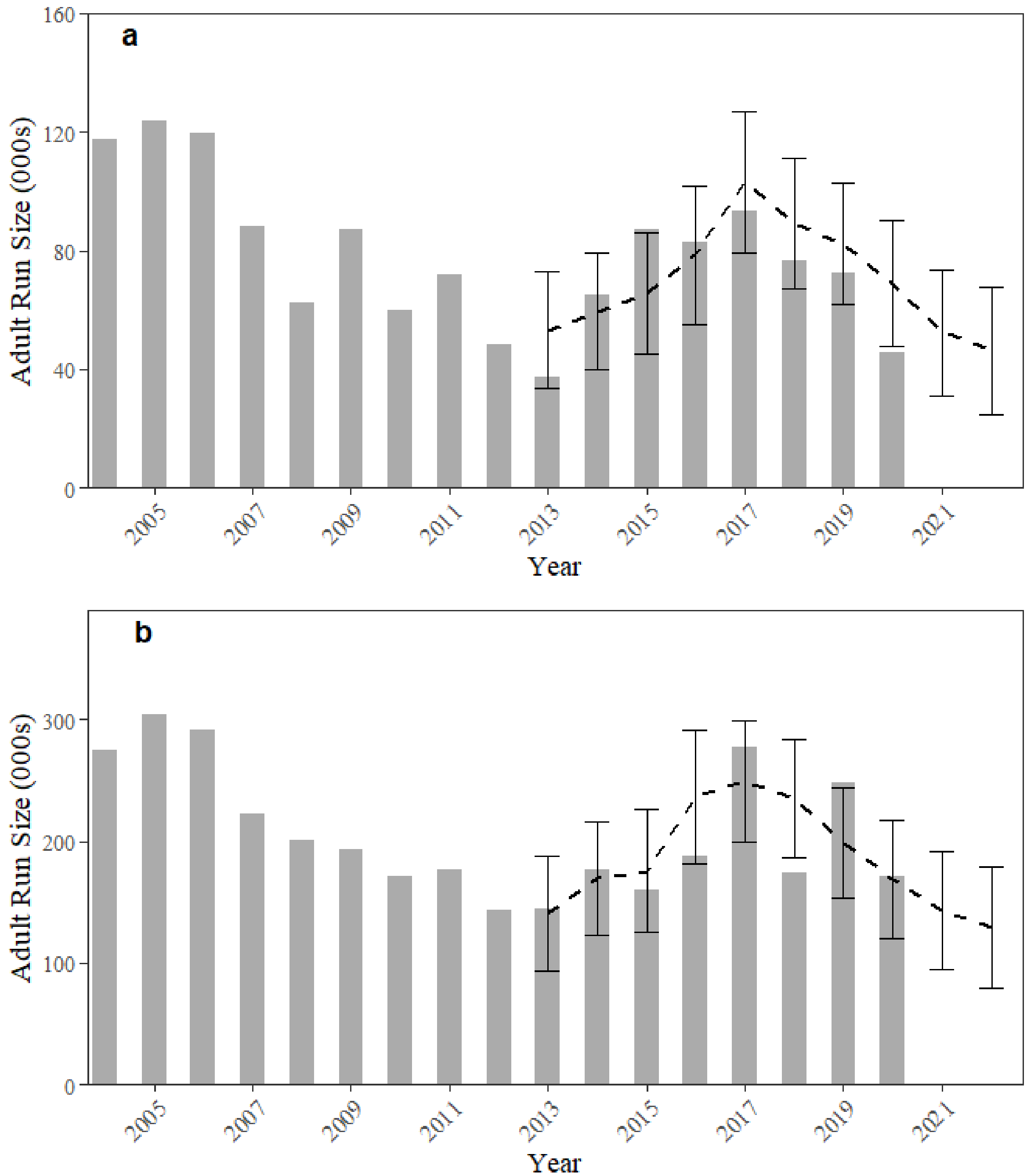

Figure 18. -- Observed (gray bars) and 80% predicted intervals of projected run sizes (black error bars) for the Yukon River Canadian-origin (a) and Total Yukon (b) stock groups of Chinook salmon, 2003-2022.

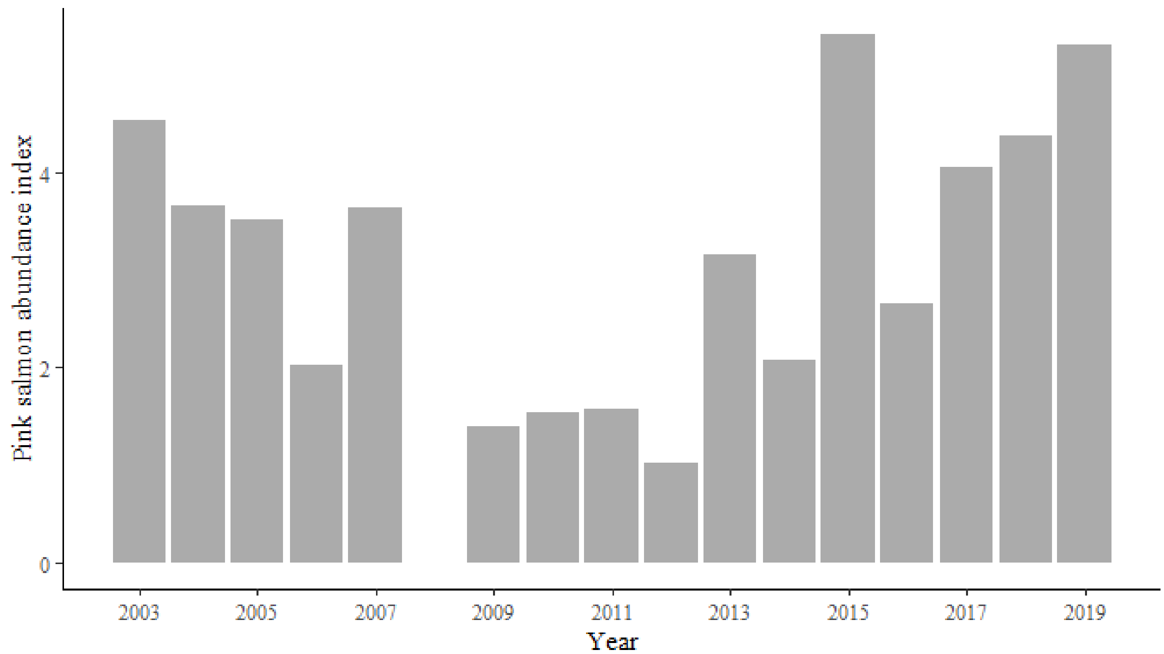

Figure 19. -- The juvenile pink salmon abundance index from the northern Bering Sea surface trawl surveys, 2003-2019.

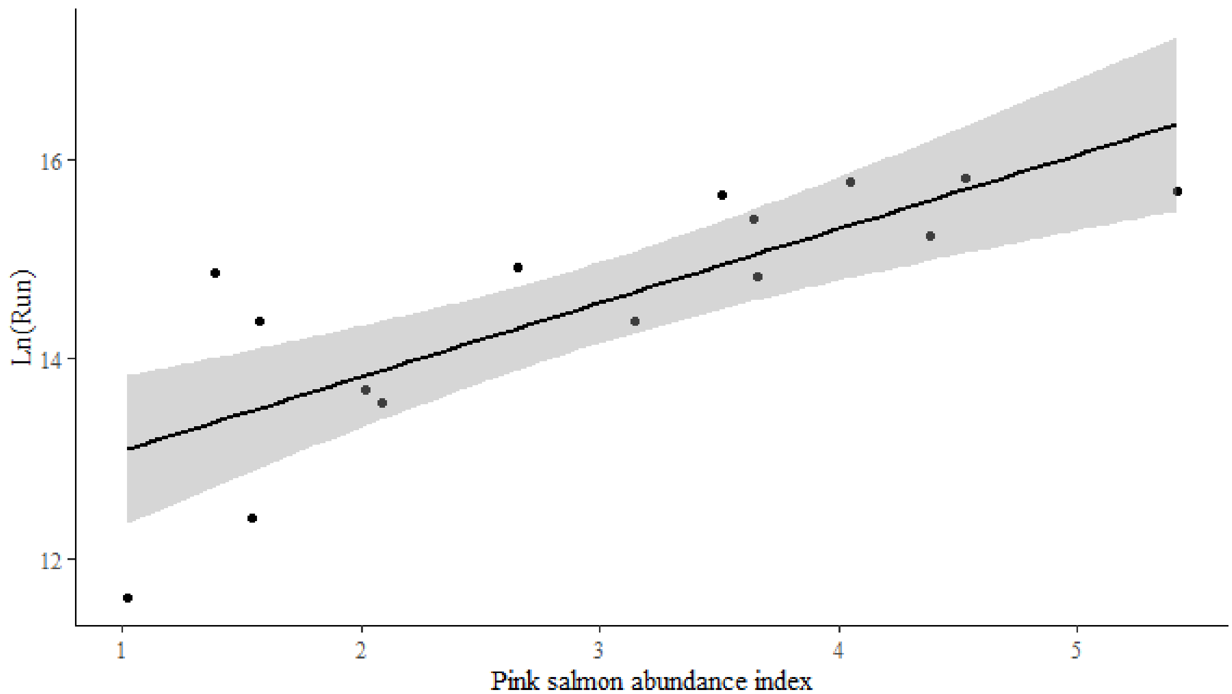

Figure 20. -- A linear regression model fit (black line) with 95% confidence interval (shaded region) between the juvenile pink salmon abundance index from the northern Bering Sea surface trawl surveys (black dots; 2003-2018) and the natural log of the adult pink salmon run index (Yukon River and Norton Sound; 2004-2019).

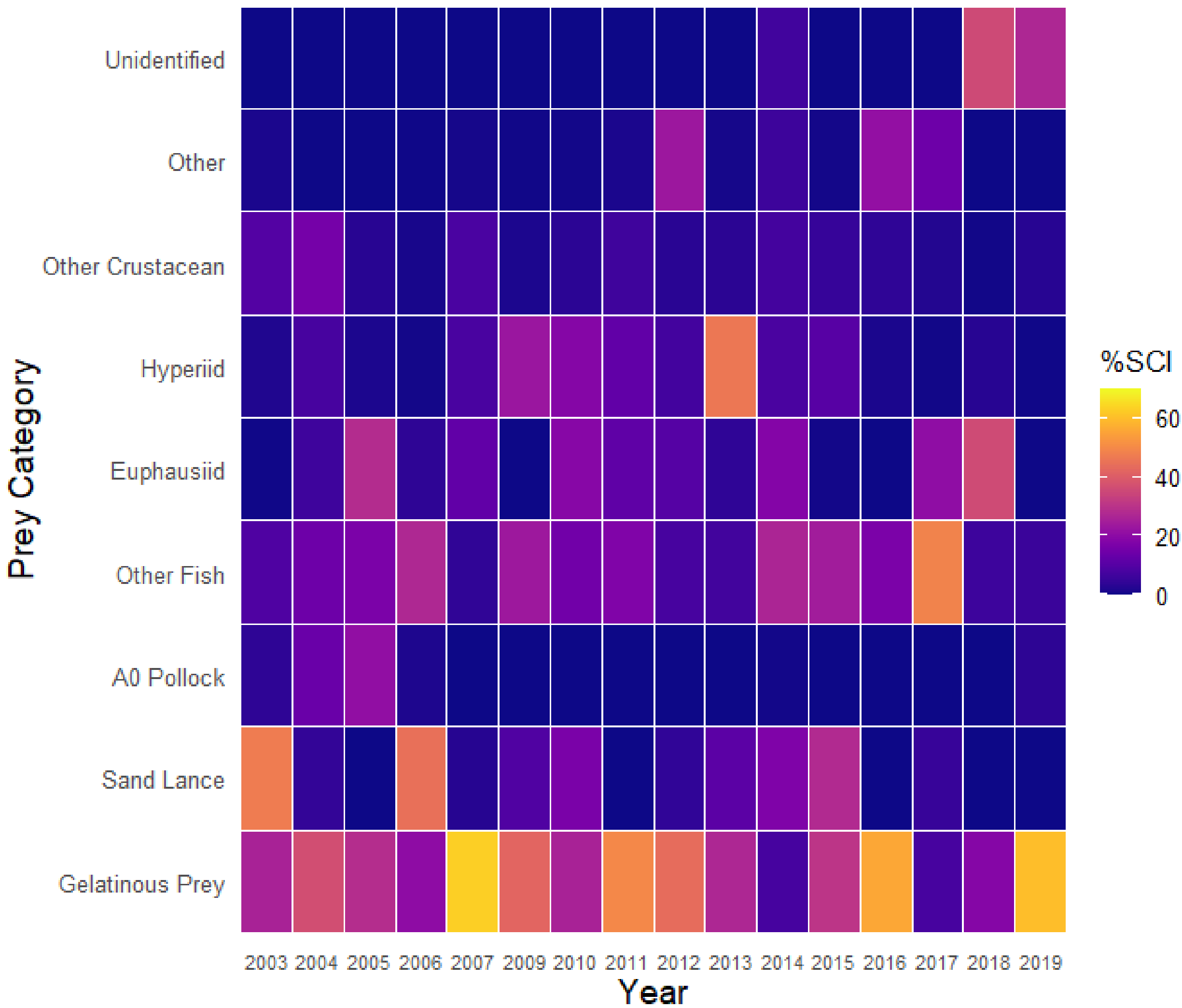

Figure 21. -- The percent of taxonomic prey groups by stomach content index in the stomachs of juvenile chum salmon sampled from the northern Bering Sea surface trawl surveys, 2003-2019.

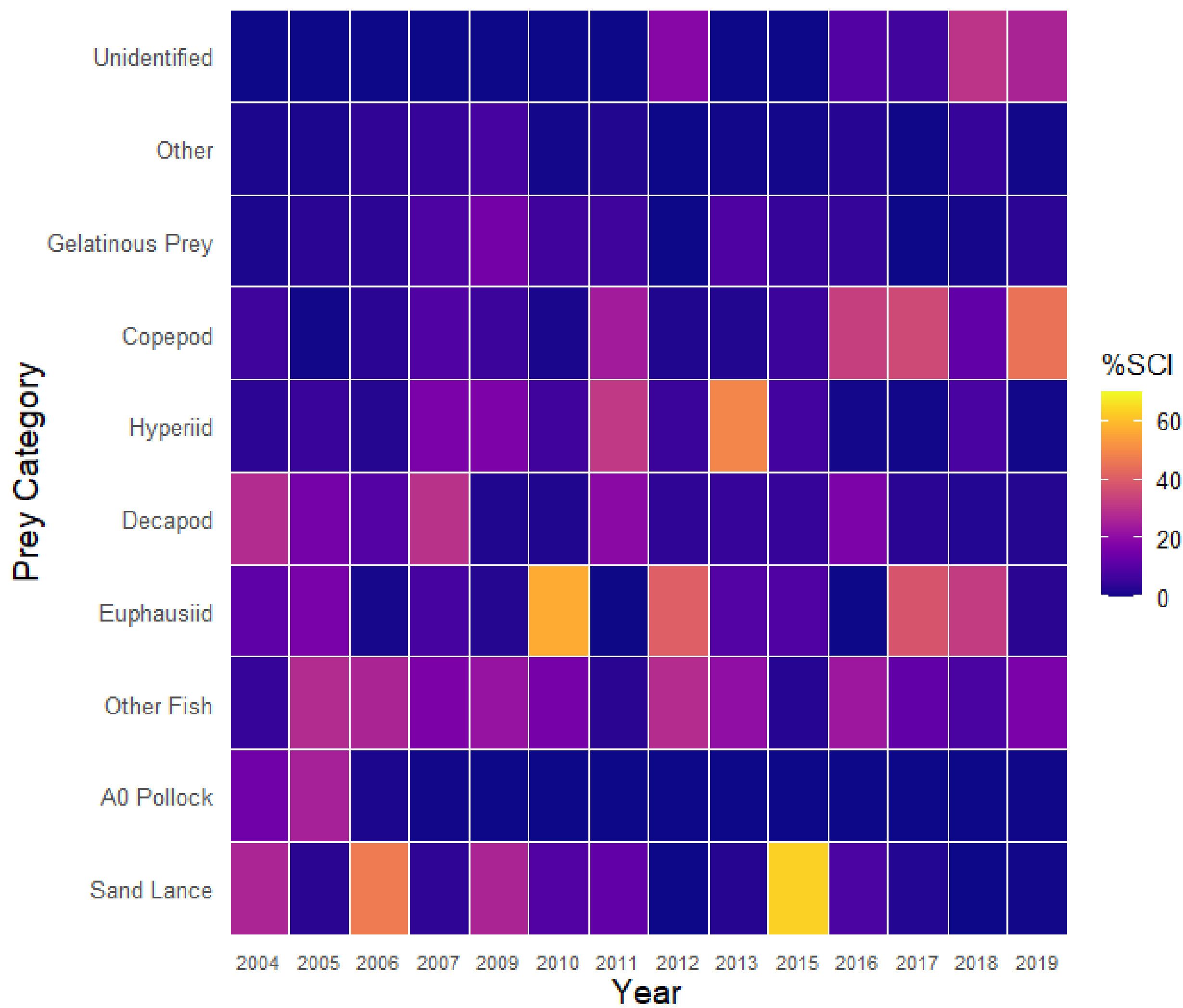

Figure 22. -- The percent of taxonomic prey groups by stomach content index in the stomachs of juvenile pink salmon sampled from the northern Bering Sea surface trawl surveys, 2003-2019.

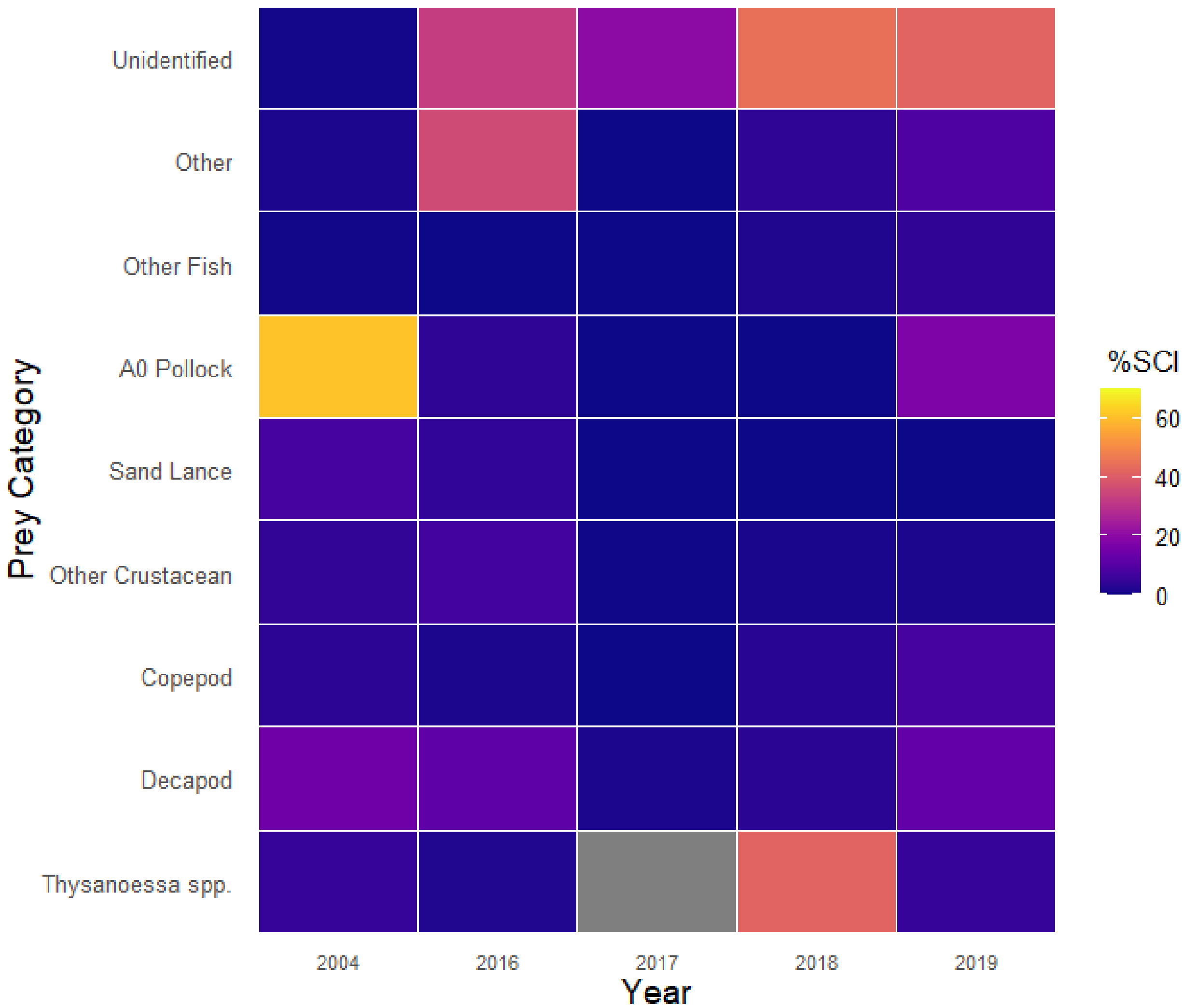

Figure 23. -- The percent of taxonomic prey groups by stomach content index in the stomachs of juvenile sockeye salmon sampled from the northern Bering Sea surface trawl surveys, 2003-2019.

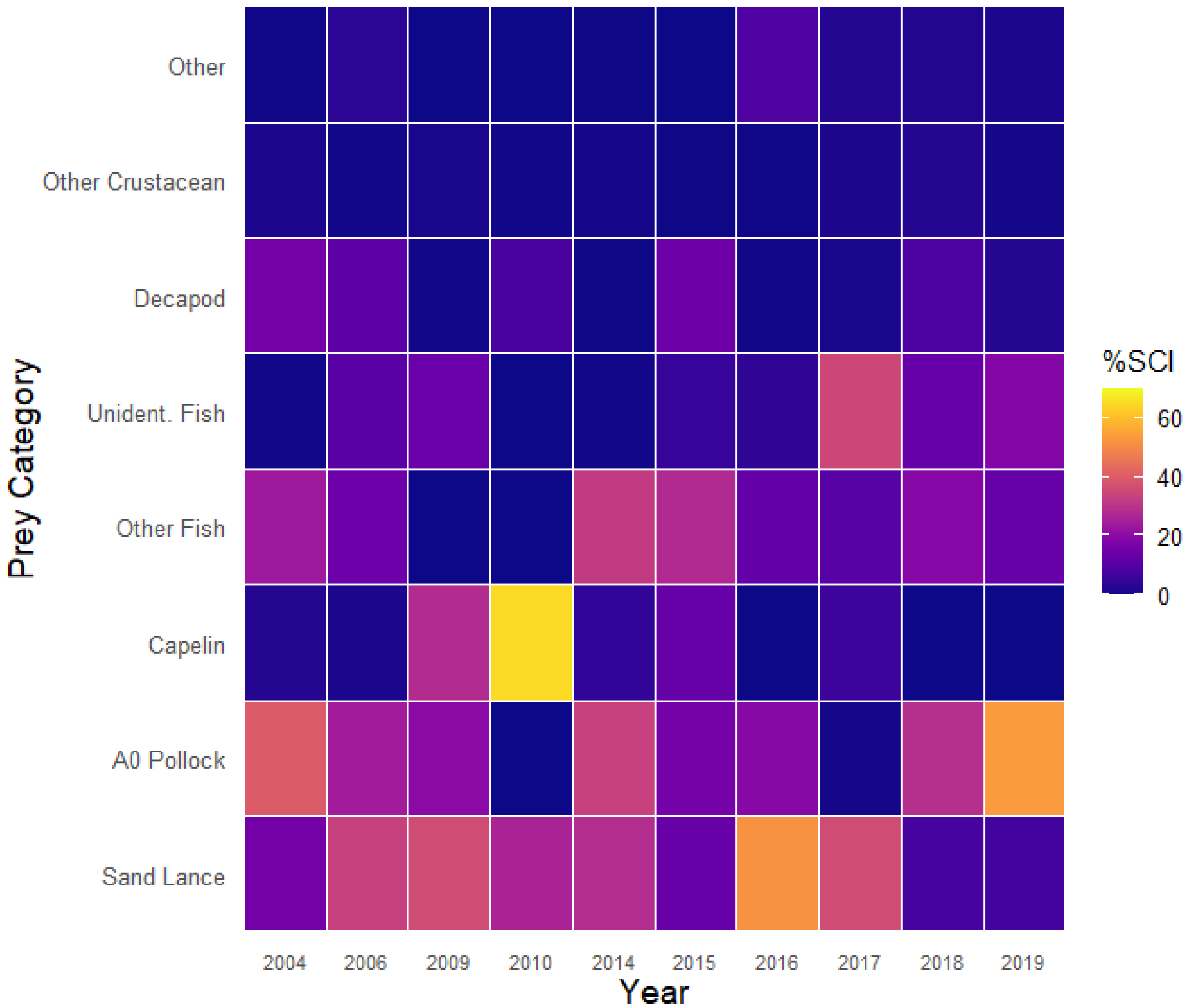

Figure 24. -- The percent of taxonomic prey groups by stomach content index in the stomachs of juvenile coho salmon sampled from the northern Bering Sea surface trawl surveys, 2003-2019.

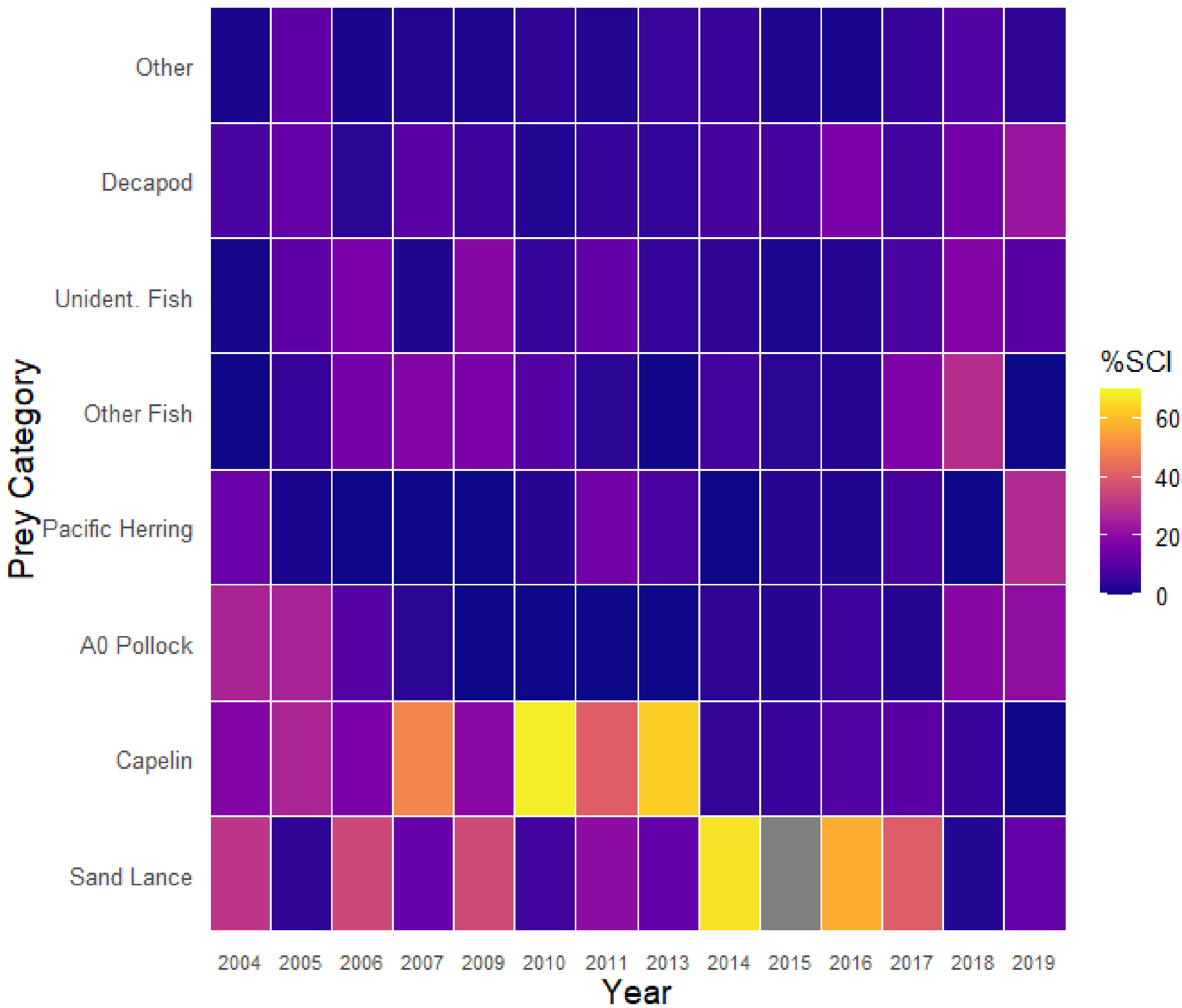

Figure 25. -- The percent of taxonomic prey groups by stomach content index in the stomachs of juvenile Chinook salmon sampled from the northern Bering Sea surface trawl surveys, 2003-2019.

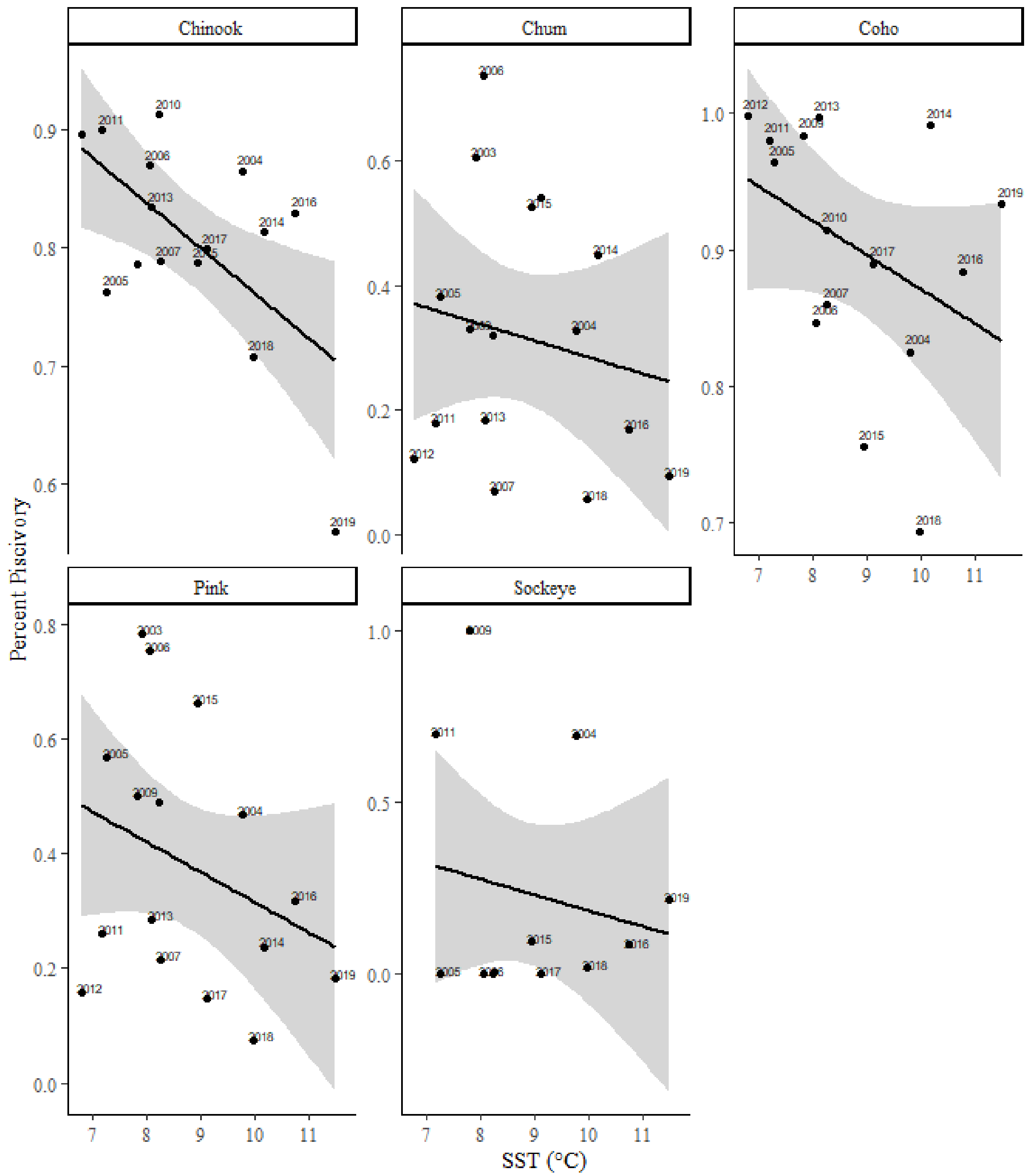

Figure 26. -- Linear regression model fits (black lines) with 95% confidence intervals (shaded regions) between the average percentage of fish in the stomachs of juvenile salmon (piscivory) and sea surface temperature (SST) sampled during the northern Bering Sea surface trawl surveys, 2004-2019. Each point is labeled with the sample year.

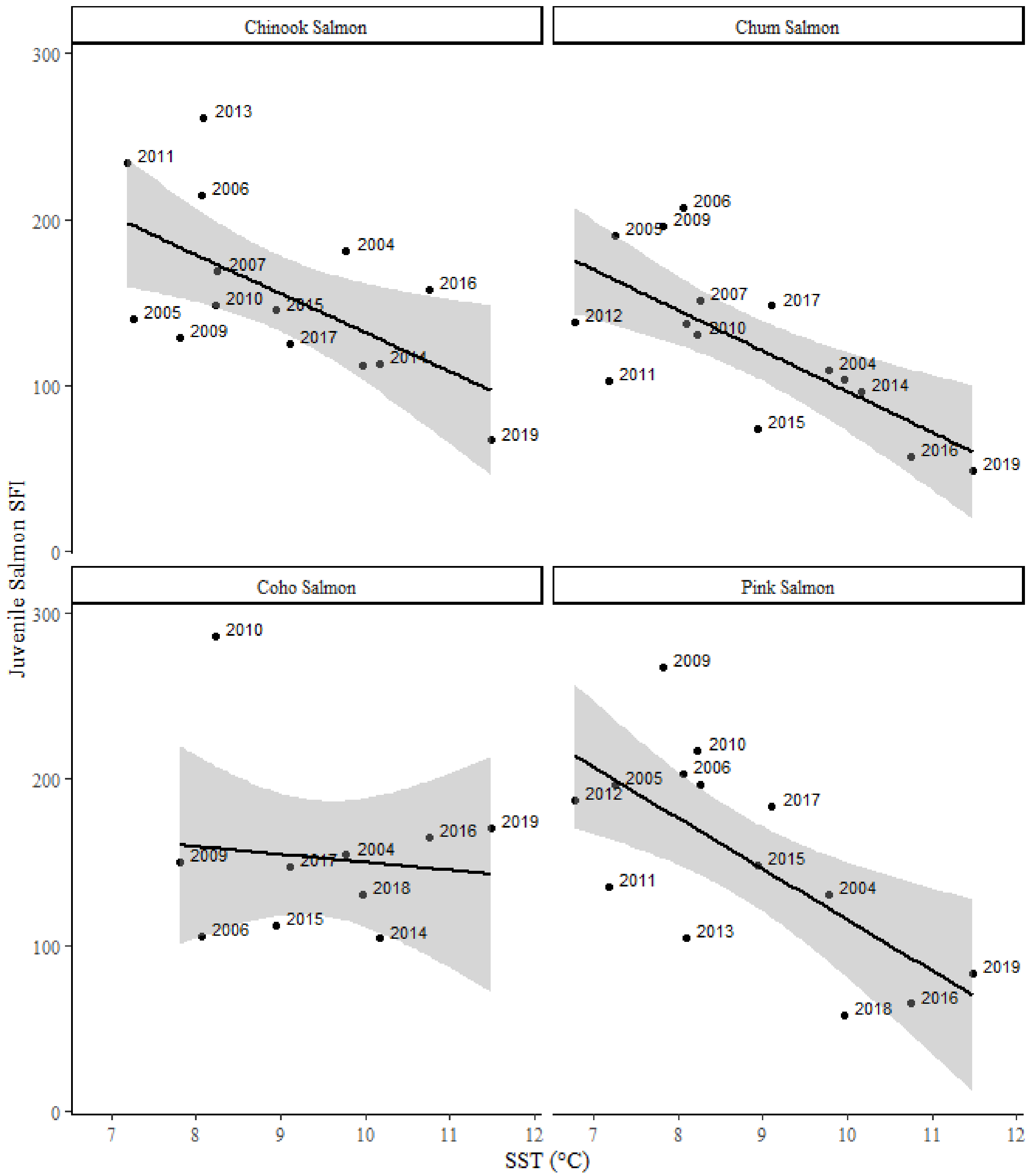

Figure 27. -- Linear regression model fits (black lines) with 95% confidence intervals (shaded regions) between the average stomach fullness index (SFI) of juvenile salmon and sea surface temperature (SST) sampled during the northern Bering Sea surface trawl surveys, 2004-2019. Each point is labeled with the sample year.

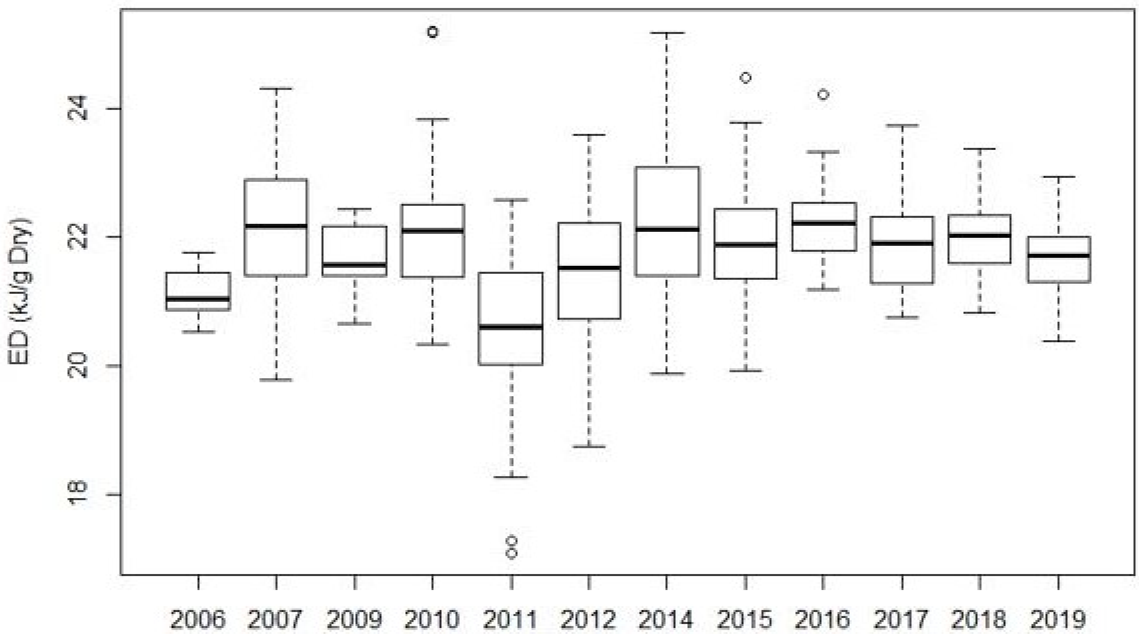

Figure 28. -- Boxplots of juvenile Chinook salmon sampled for energy density (kJ/dry tissue mass, n=575) sampled during northern Bering Sea surface trawl surveys, 2006-2019. Data unavailable for 2008 and 2013. Medians, interquartile ranges (IQR), whiskers (1.5 IQR), and outliers (empty circles, >1.5 IQR) are shown.

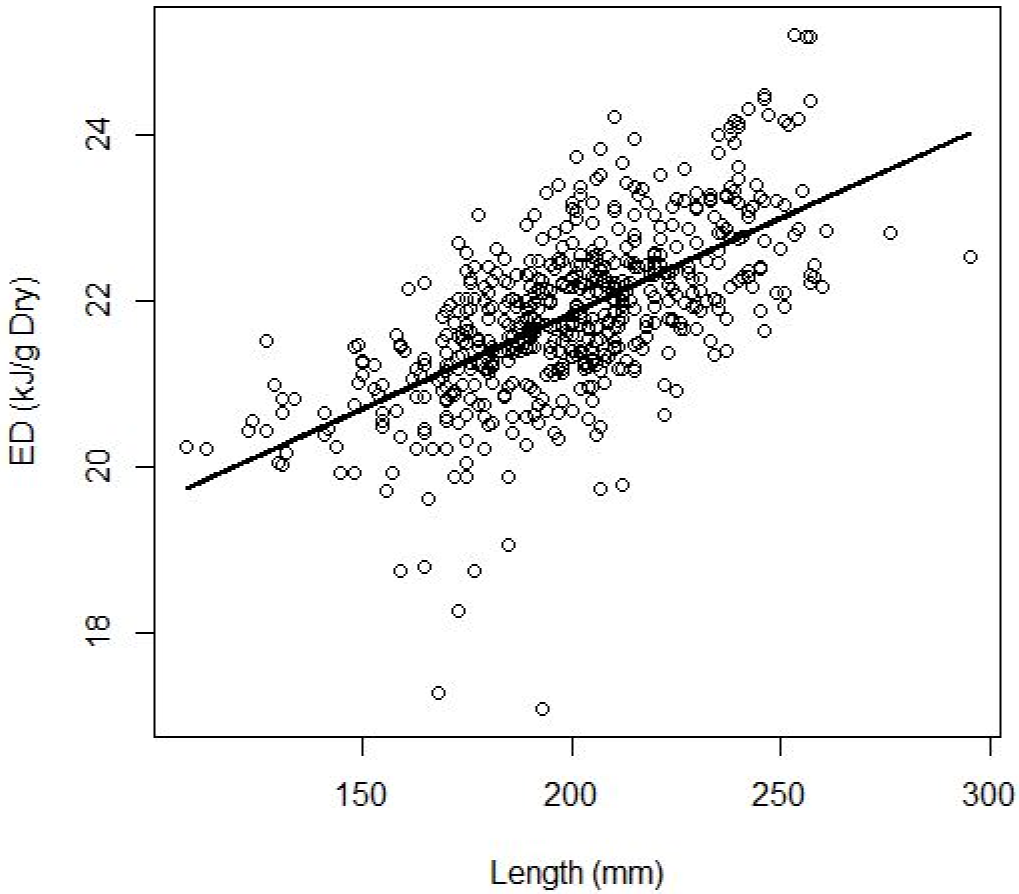

Figure 29. -- Energy density (kJ/g) of dry tissue mass by fork length (mm) of juvenile Chinook salmon caught during the northern Bering Sea surface trawl surveys, 2006-2019. Simple linear regression model fit shown by line (n = 575).

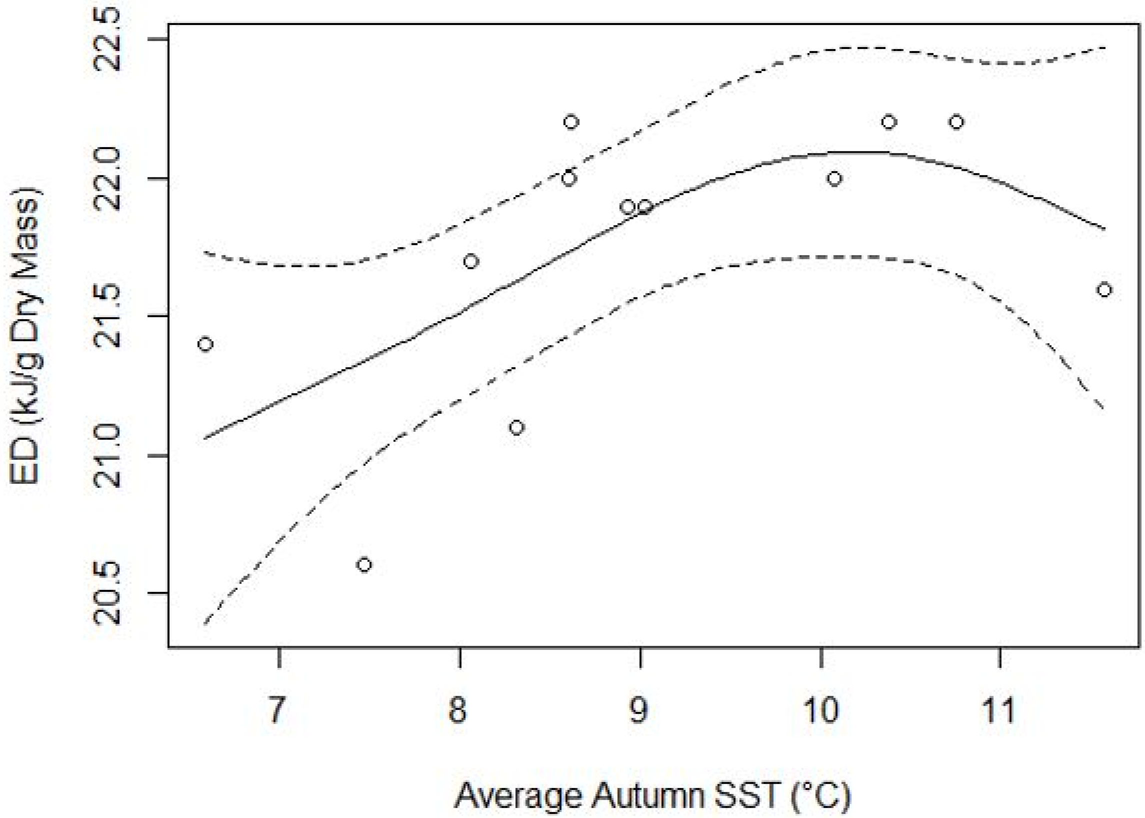

Figure 30. -- Annual mean energy density (kJ/g) of dry tissue mass by average autumn sea surface temperature (°C) for juvenile Chinook salmon caught during the northern Bering Sea surface trawl surveys, 2006-2019. Generalized additive model fit shown by solid line, dashed lines represent ±1 SE. Data unavailable for 2008 and 2013.

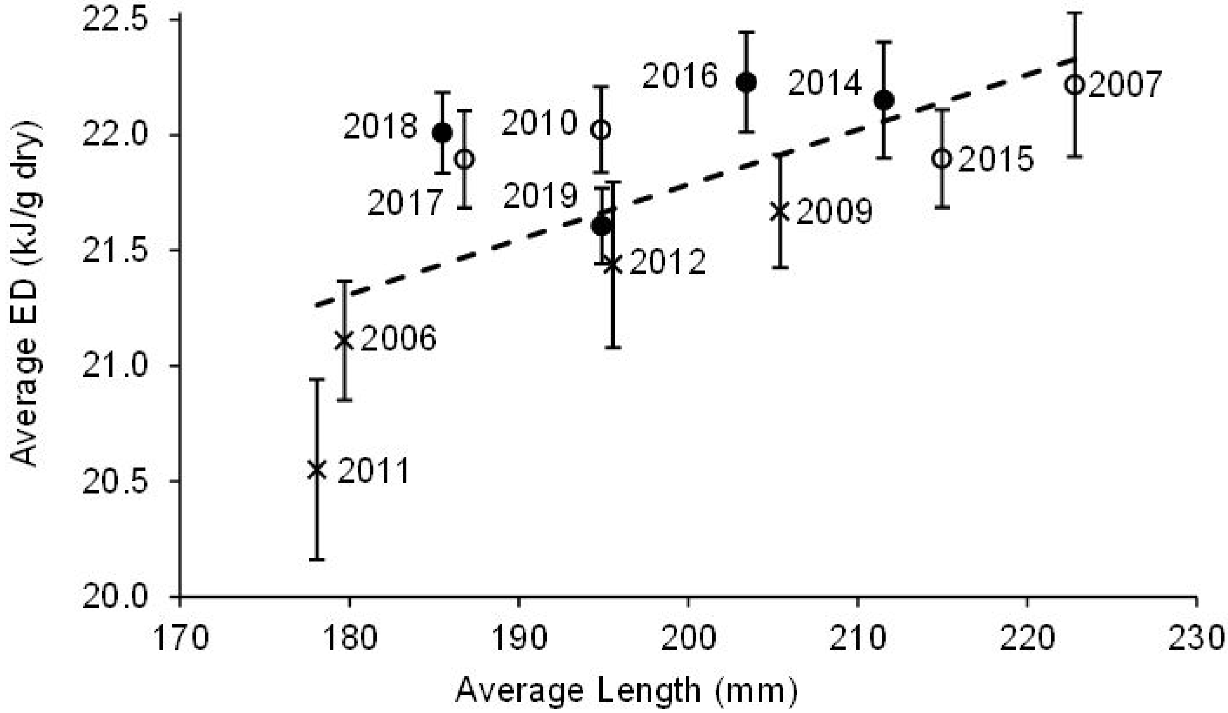

Figure 31. -- Annual mean energy density (kJ/g) of dry tissue mass by fork length (mm) of juvenile Chinook salmon caught during the northern Bering Sea surface trawl surveys, 2006-2019. Simple linear regression model fit shown by dashed line (n = 12 years). Error bars represent 95% confidence intervals. Data unavailable for 2008 and 2013. Symbols indicate four warmest years (filled circles; autumn SST > 9.5 °C), four coldest years (X; autumn SST < 8.5 °C), and four intermediate years (empty circles).

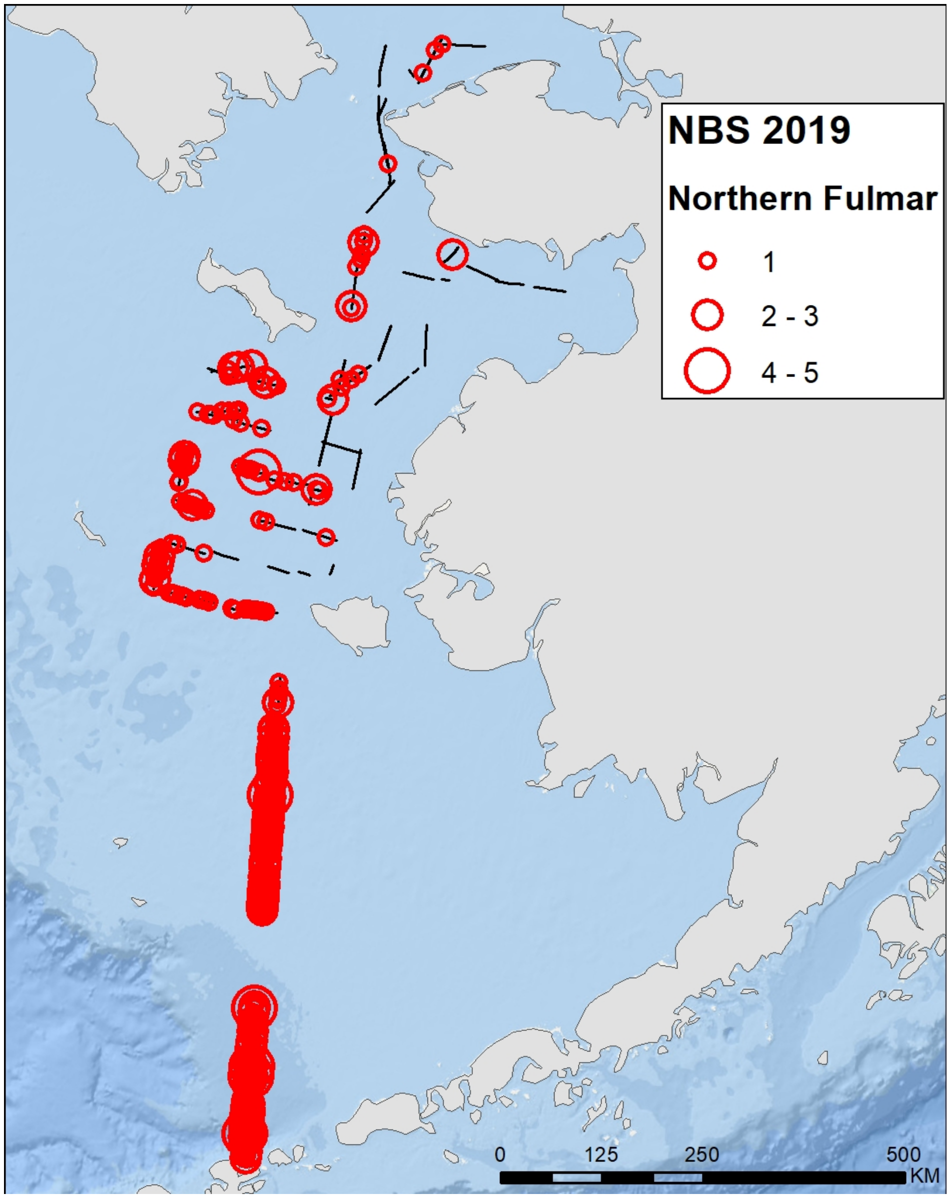

Figure 32. -- Distribution of northern fulmars observed during the northern Bering Sea surface trawl survey, 2019.

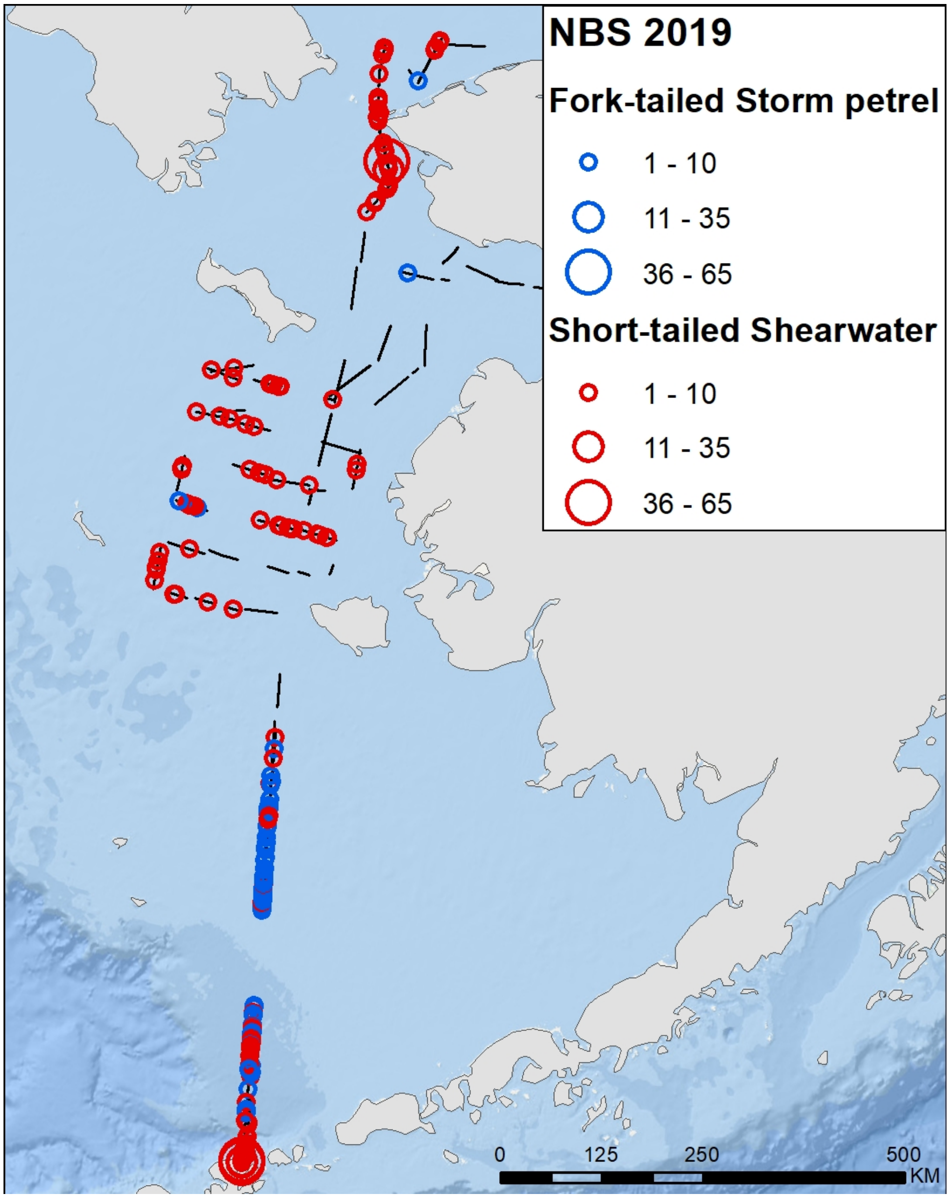

Figure 33. -- Distribution of shearwaters and fork-tailed storm-petrels during the northern Bering Sea surface trawl survey, 2019.

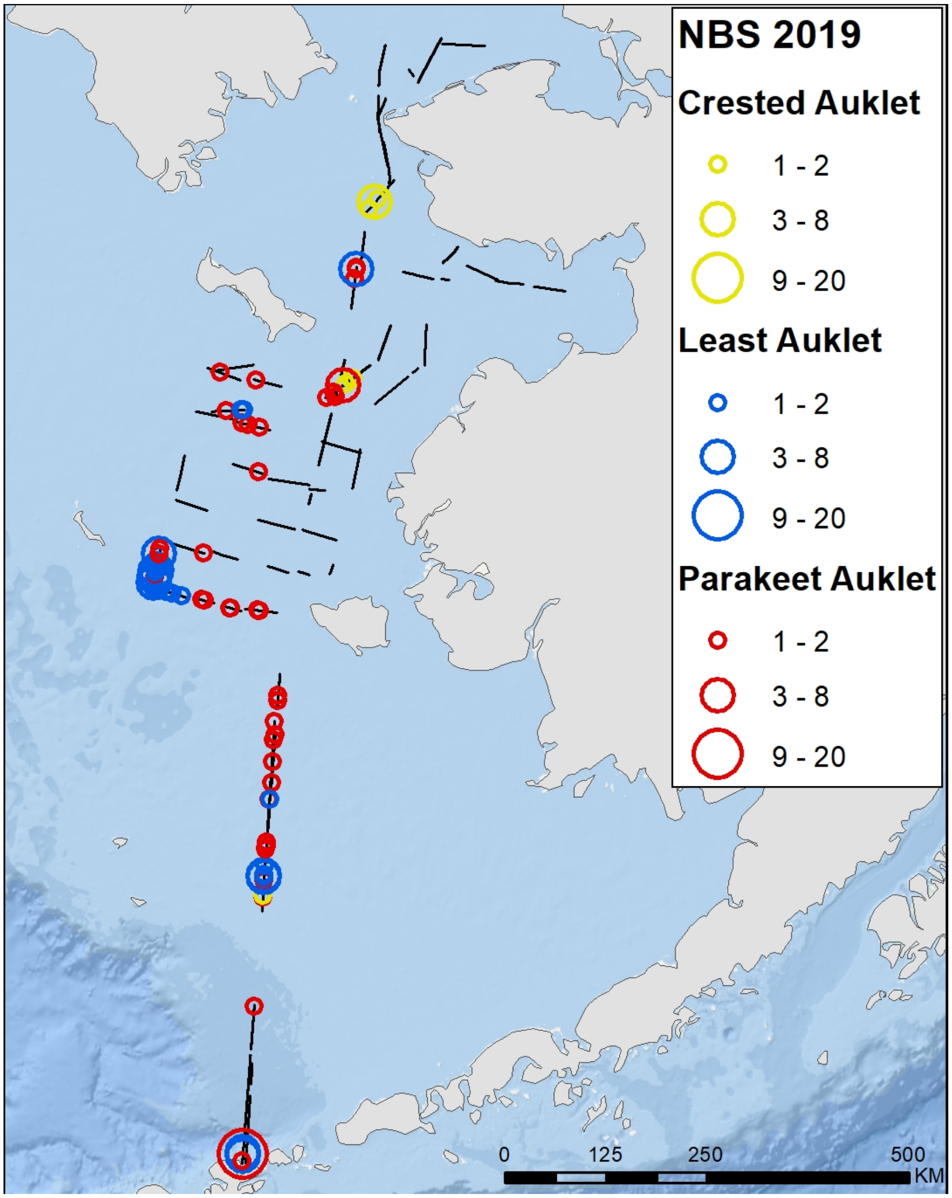

Figure 34. -- Distribution of auklet species during the northern Bering Sea surface trawl survey, 2019.

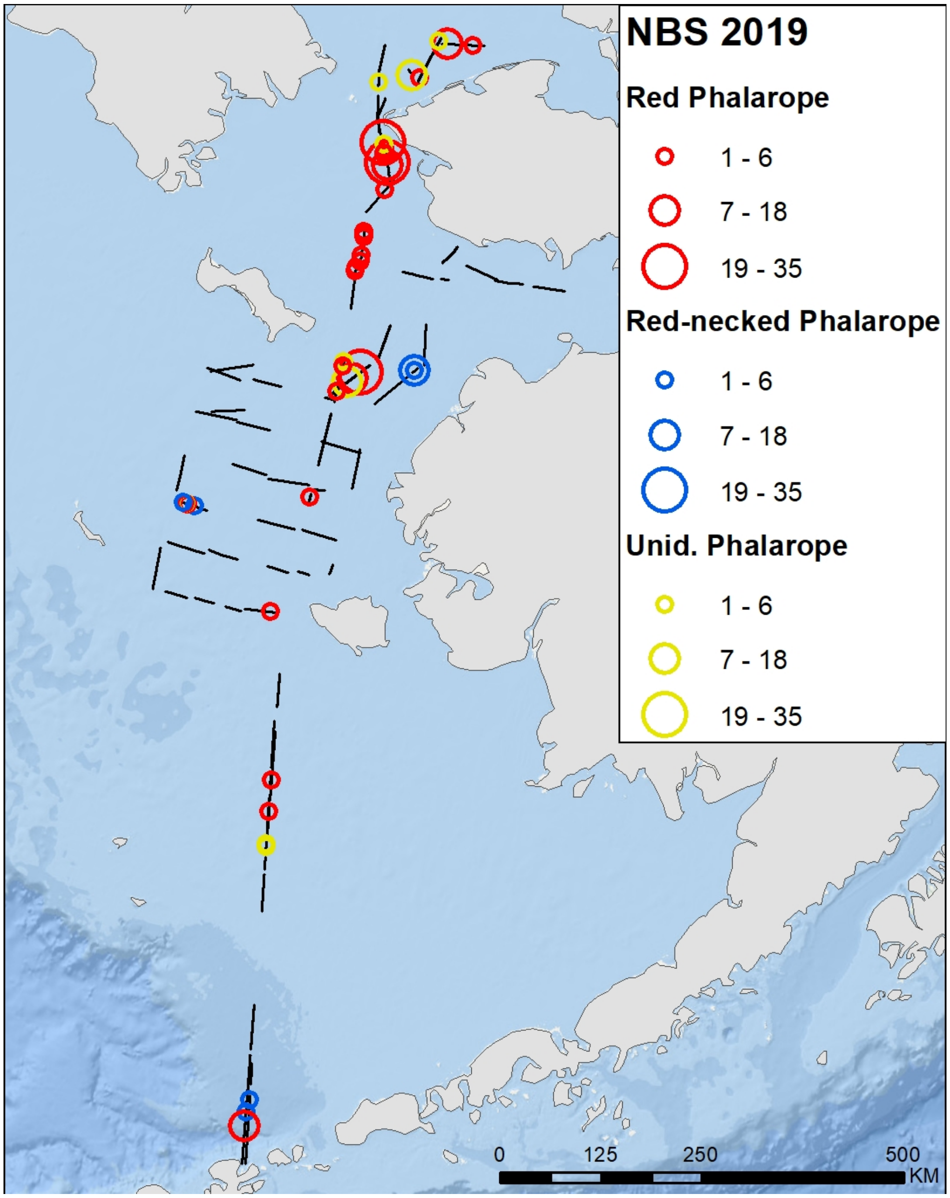

Figure 35. -- Distribution of phalarope species observed during the northern Bering Sea surface trawl survey, 2019.

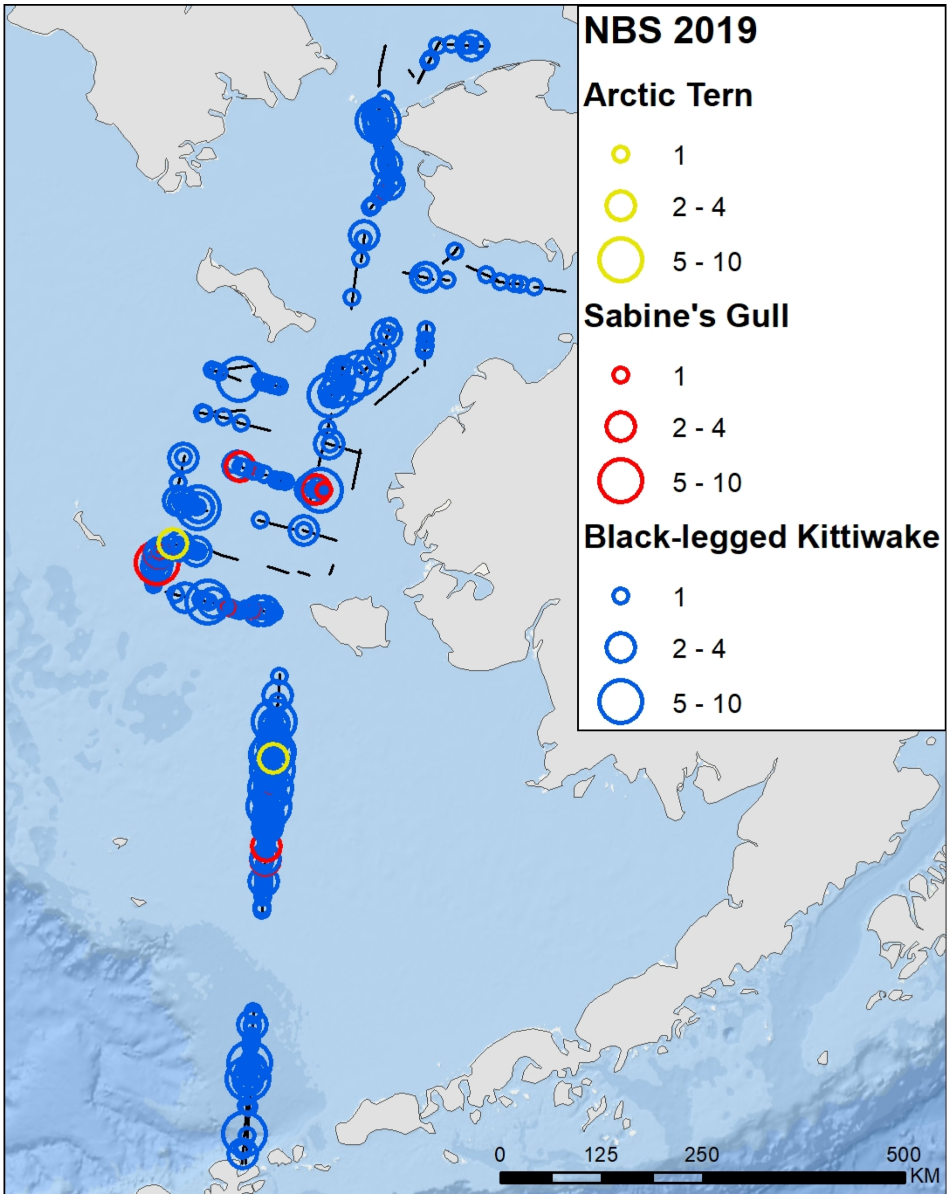

Figure 36. -- Distribution of Arctic tern, Sabine's gull, and black-legged kittiwakes observed during the northern Bering Sea surface trawl survey, 2019.

APPENDIX A. -- Collection protocols

Water Collection Protocol

Depth	GFF	>10 Large Diameter	GFF and >10 Duplicates	Blanks	Nutrients	Salinity	Phyto preservation	Genomics samples (phyto)	HABs samples
	Every station	Every Station	1/day	Every other day	Every station	(1/day, alternate surface/deep)	Every station	Every Station	Every station
0	X				X	X (OR) ↓			X
10	X	X			X		X	X	
20	X				X				
30	X				X				
40	X (OR) ↓				X (OR) ↓				
50	X (OR) ↑								
60									
75									
100					X (OR) ↑	X (OR) ↑			
X (OR) ↑ (Sample either here or at shallower depth depending on criteria)									
X (OR) ↓ (sample either here or at deepest depth available)									

Zooplankton Collection Protocol

MasterCod project Code (BF). Target Wire 45° Good range is 35° - 55°. Wire out 40 m/min and wire up 20 m/min. Target depth: 5-10m off bottom or 200m if water is deeper than 200m.

Zooplankton Distribution and Abundance (ECO-FOCI) (20BON and 60BON).

Preserve plankton from net 1 from the 20cm bongo (153 micron, 20BON) and 60cm (505 micron, 60BON) bongo jars with 50 ml of formaldehyde and sodium borate. Use 2 jars if a single jar is more than 1/2 full of plankton. Mark number of jars on label and COD forms. Freeze net 2 20BON for stable isotopes. Sort net 2 60BON for Rapid Zooplankton Assessment (RZA).

Zooplankton Lipids (*Miller*) (60BON-RZA samples)

Collect at least 3 large Calanus copepods and 2 adult euphausiids per event, more is better. Take photo and annotate in the lipid logbook. Use a kimwipe to wick the samples dry. Place each group of zooplankton in separate glass vials. Store in coldest available freezer

Zooplankton stable isotopes (*Miller*) (20BON & 60BON-RZA samples)

Collect adult euphausiids from 60BON-RZA samples and collect bulk zooplankton from net 2 20BON samples from 5-10 stations. Collect from the first 5 stations observing euphausiids, then spread the other 5 collections to other stations. Store in coldest available freezer

Juveniles (0-320 mm) Take lengths and weights of 50 of each species and life-history stage at each station. Note any fin clips, scarring, parasites, or skeletal deformities. Photograph unusual features with notation in CLAMS. Collect specimens from pink salmon (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), sockeye salmon (*O nerka*), coho salmon (*O. kisutch*), and Chinook salmon (*O. tshawytscha*). Scan Chinook salmon for adipose fin clips and CWT. Use pre-assigned barcode numbers for Chinook salmon (1-600), coho salmon (601-900), and sockeye salmon (901-1200).

Salmon Genetics

Juvenile Chinook, coho, and sockeye salmon, and immature Chinook salmon (*Garcia/Dann/Habicht/Liller*): Remove a caudal fin clips from juveniles and pectoral fin clips from immature salmon and staple onto separate Whatman paper sheets for each species and station. Place Whatman sheets in a desiccant container to dry. Record barcode number range for the specimens collected on each Whatman sheet.

Juvenile chum salmon (*Kondzela*) and juvenile pink salmon (*Garcia/Dann/Habicht/Liller*):

Collect and freeze caudal fin clips from measured juveniles not saved whole for energetics, wrap fin clips in plastic wrap, bag by station, and freeze at -40. Collect additional fin clips if time permits.

Immature chum salmon (*Kondzela*):

Remove pectoral fin clips from immature chum, wrap in plastic wrap, bag by station, and freeze at -40.

Salmon Diets (*Cieciel*)

Collect up to 10 stomachs by species and life-history stage at each station. Place stomachs in a soil bag, label with station number and species. Preserve in 5-gallon bucket of 10% formalin and Flag Stomach in CLAMS.

Salmon otoliths (*Murphy*)

Save whole or heads of Chinook, sockeye, and coho salmon. Wrap heads in plastic wrap with barcode tag, freeze at -20, and flag Head collection in CLAMS.

Salmon Energetics (*Sewall*)

Wrap 2-5 average sized whole juvenile fish in plastic wrap with barcodes and freeze at each station. Flag whole fish in CLAMS. Stomachs will be removed from frozen whole fish and provided to Cieciel, otoliths will be removed from frozen whole fish and provided to Murphy.

Non-Salmon Collection Protocol

Collect length or lengths and weights of up to 50 individuals per pre-assigned life-history stages at each station. Collect specimens from saffron cod (*Eleginus gracilis*), Pacific cod (*Gadus macrocephalus),* walleye pollock (*Gadus chalcogrammus*), Pacific herring (*Clupea pallasii*), Arctic cod (*Boreogadus saida*), capelin (*Mallotus villosus*), sand lance (*Ammodytes* spp.), rainbow smelt (*Osmerus mordax*), Arctic lamprey (*Lethenteron camtschaticum*), and salmon shark (*Lamna ditropis*). Do not collect individual weights for fish (e.g. Age-0) that are too small to accurately measure individual weights. Average weight for these fish will be based on the subsample weight. Freeze all unidentified and rare species with station or barcode data for species verification.

Non-salmon Diet (*Cieciel*)

Save 10 whole age-0 fish in formalin (soil bag), flag diet in CLAMS for: saffron cod, Pacific cod, walleye pollock, and Pacific herring. Save 10 whole age 1+ fish or stomachs in formalin in a single soil bag, flag diet in CLAMS for: Pacific cod, walleye pollock, Arctic cod, capelin, Arctic sand lance, and rainbow smelt.

Energetics (*Sewall*)

Collect 3-5 age-0 fish and freeze with barcode, flag nutrition in CLAMS for: saffron cod, Pacific cod, walleye pollock, and Pacific herring. Collect 3-5 age-1+ fish and freeze with barcode, flag nutrition in CLAMS for: Arctic cod, capelin, and Arctic sand lance.

HABs (*Lefebvre*)

Collect and freeze whole 4 fish at each station for the following species: saffron cod, Pacific cod, walleye pollock, Pacific herring, and capelin.

Arctic lamprey (*Sutton*) Freeze all specimens individually with barcode tags.

Salmon shark (*Garcia*)

Record length, sex, and collect muscle biopsy plug and fin clip for genetic analysis. Tag salmon shark with dorsal fin mounted geolocation data tag and pop-up geolocation tags anchored to muscle tissue following protocols for each type of tag. Murphy/Sewall coordinates tagging on leg 1, Garcia coordinates tagging during on Leg 2.

APPENDIX B. -- Spatial distribution surface trawl catch

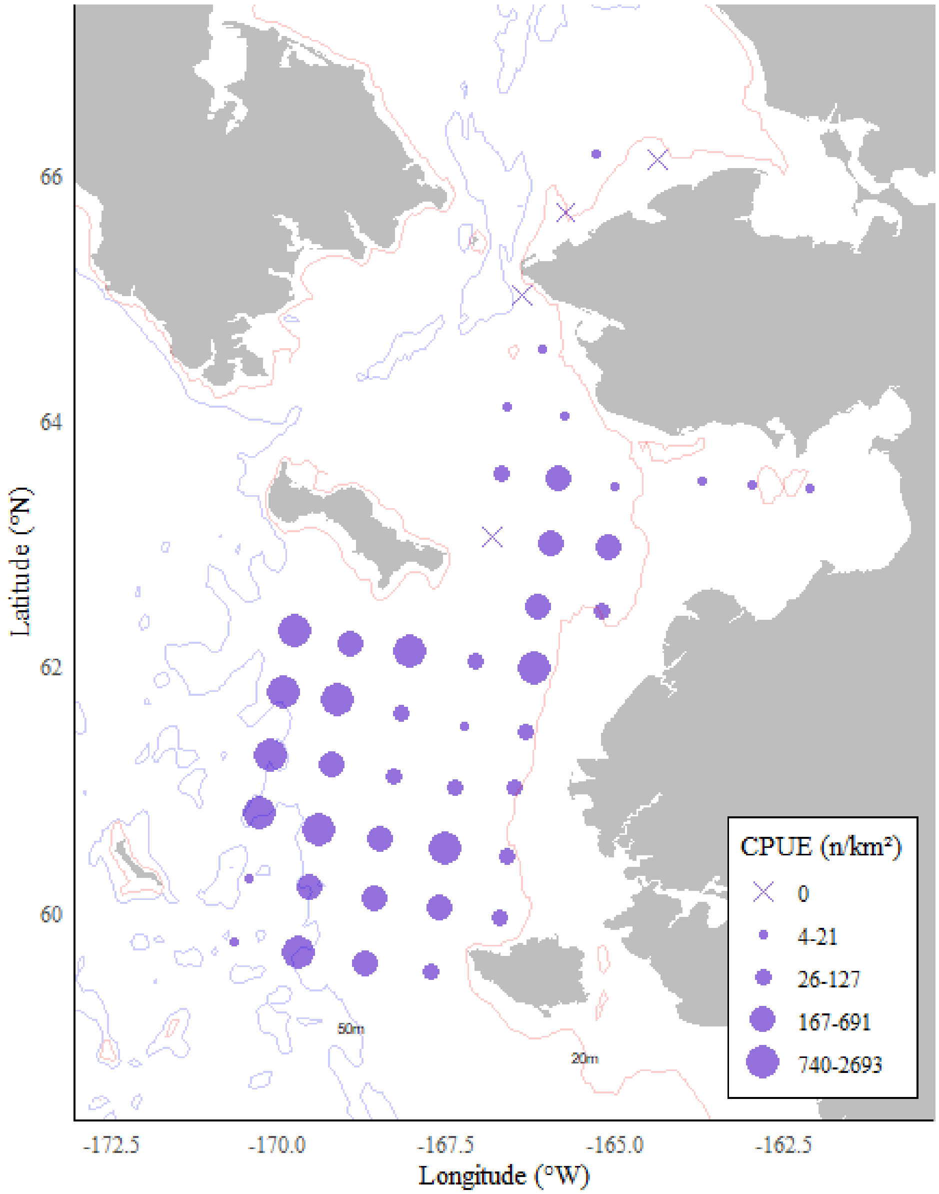

Figure B1. -- Surface trawl catch rates of juvenile chum salmon (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

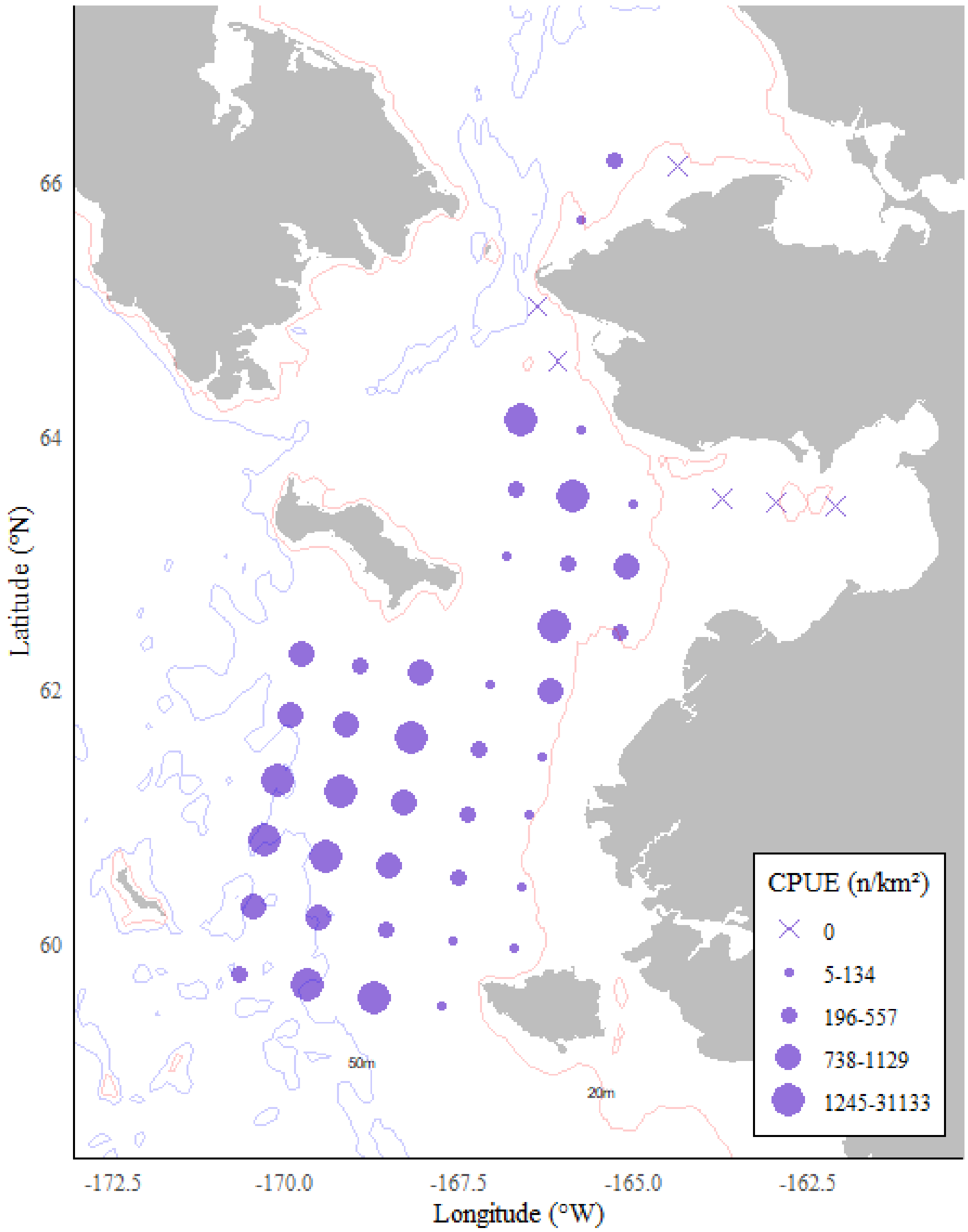

Figure B2. -- Surface trawl catch rates of juvenile pink salmon (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

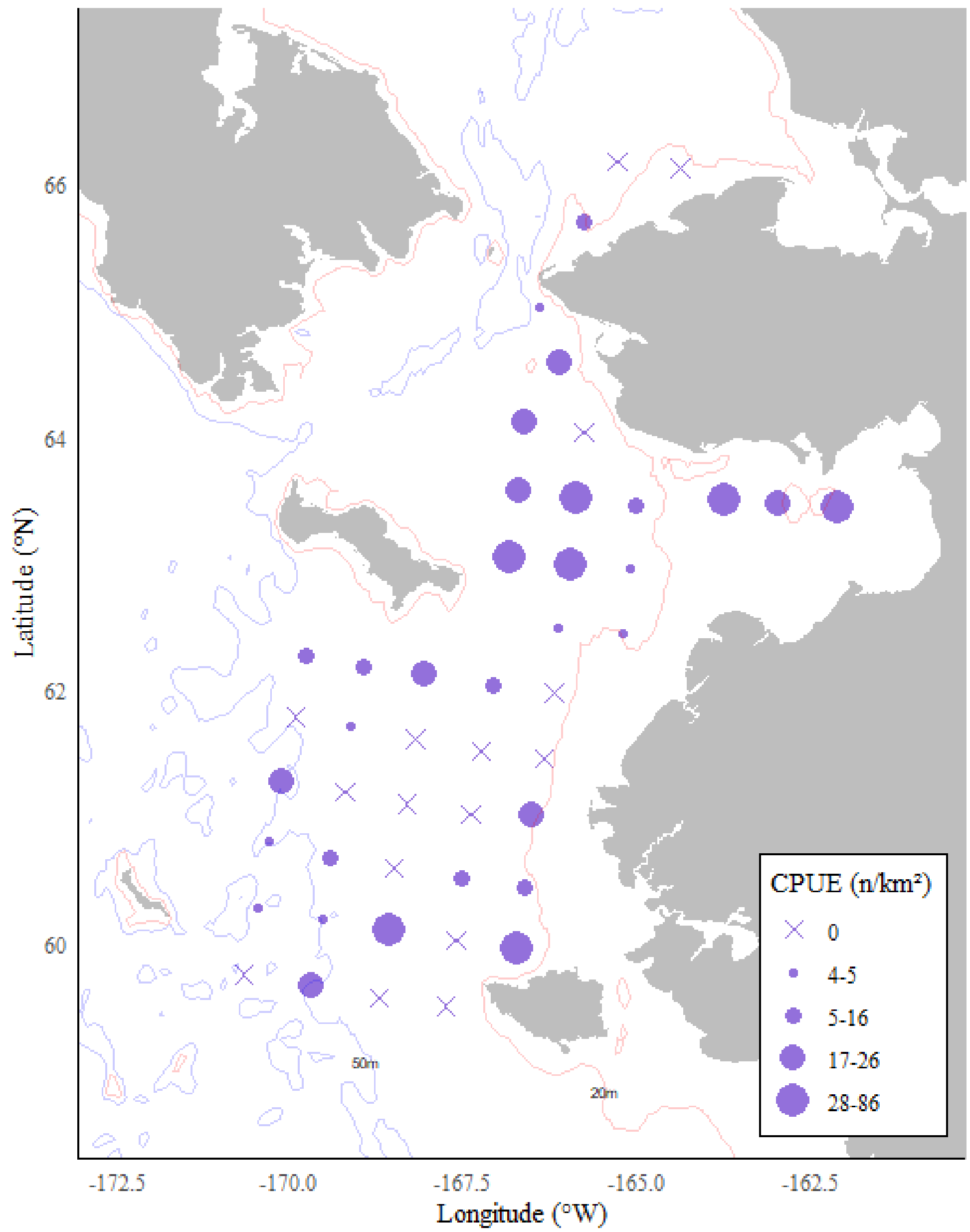

Figure B3. -- Surface trawl catch rates of juvenile Chinook salmon (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

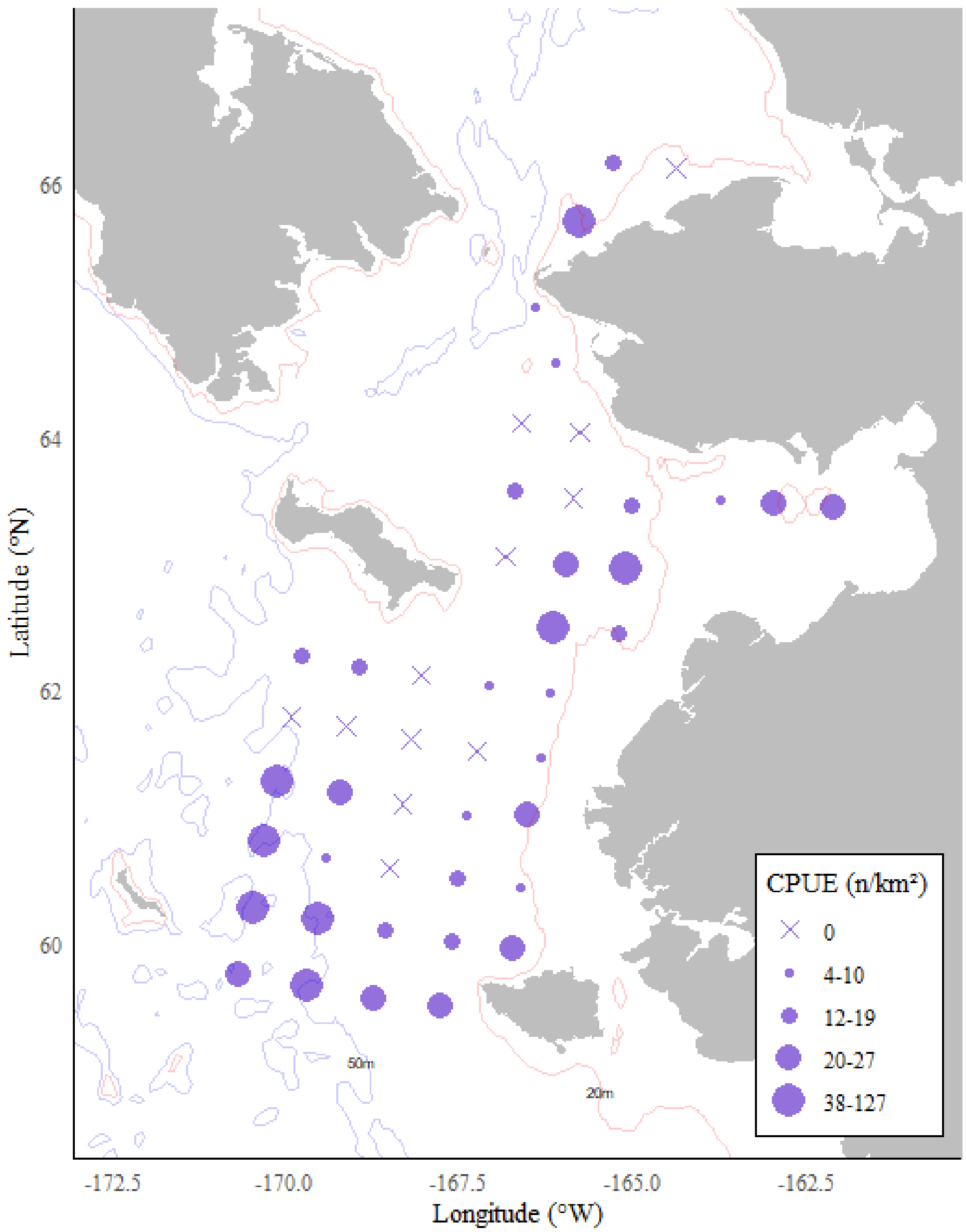

Figure B4. -- Surface trawl catch rates of juvenile coho salmon (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

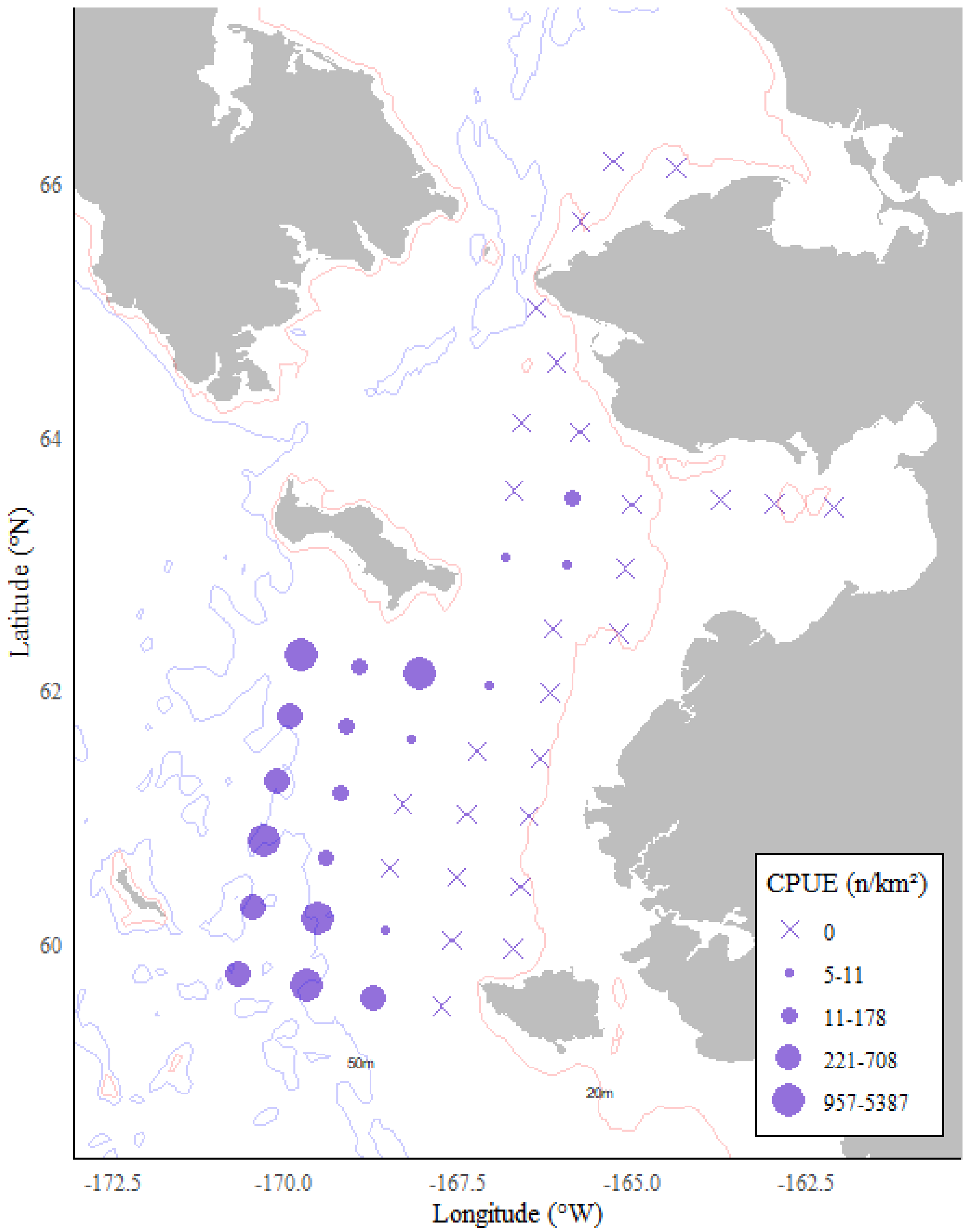

Figure B5. -- Surface trawl catch rates of juvenile sockeye salmon (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

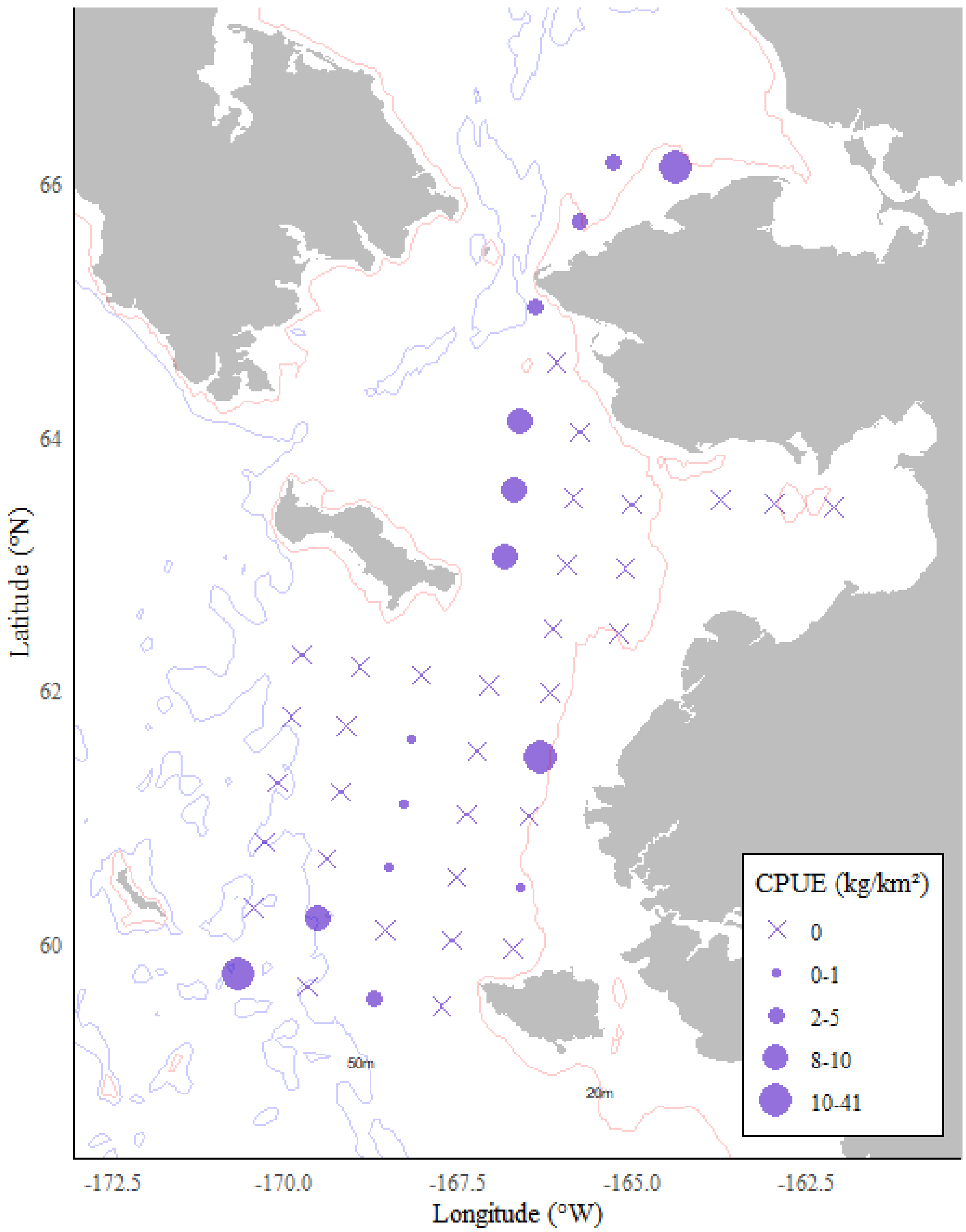

Figure B6. -- Surface trawl catch rates of water jellyfish (*Aequorea* sp.) (CPUE, kg/km^2) during the northern Bering Sea surface trawl survey, 2019.

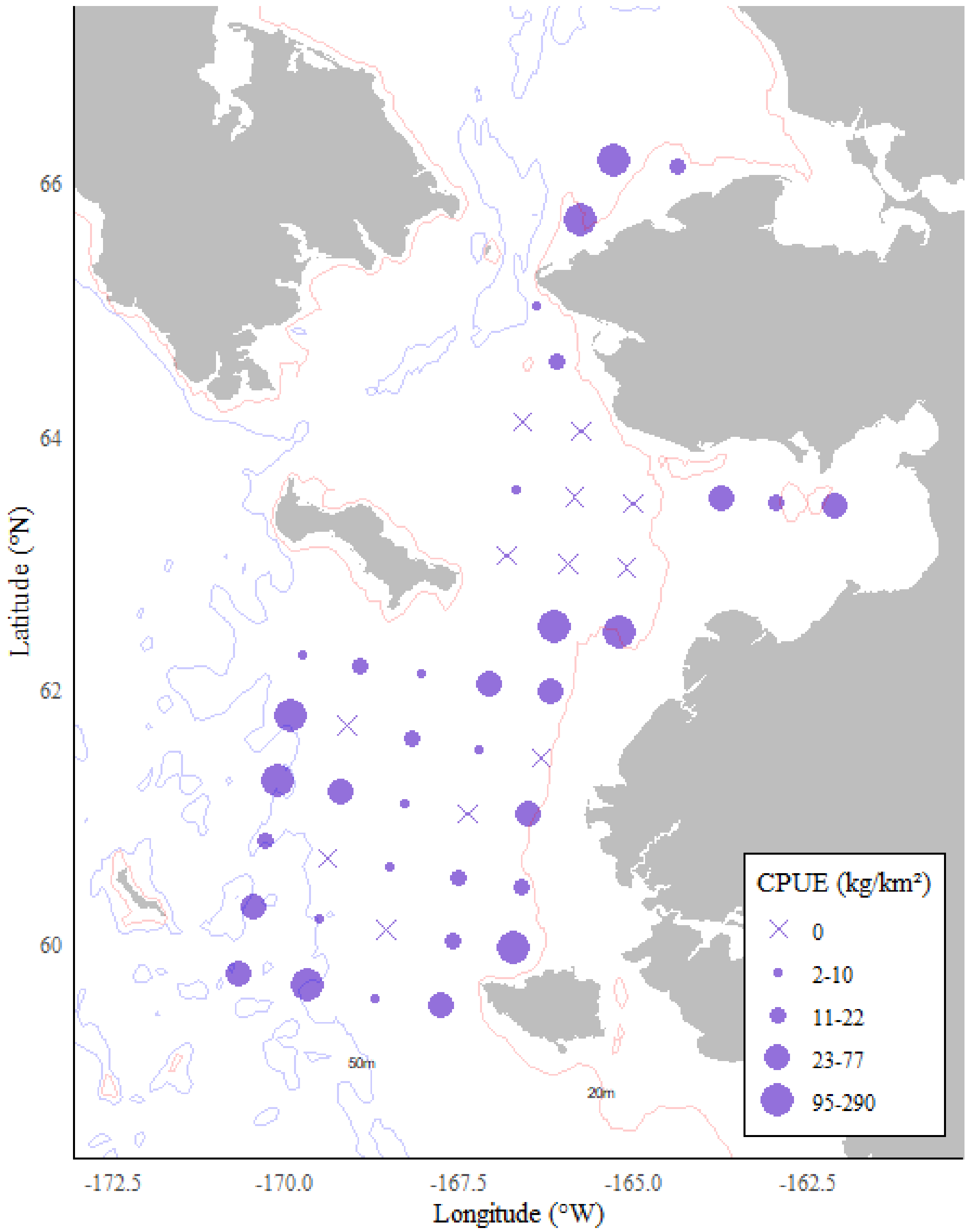

Figure B7. -- Surface trawl catch rates of moon jellyfish (*Aurelia labiata*) (CPUE, kg/km^2) during the northern Bering Sea surface trawl survey, 2019.

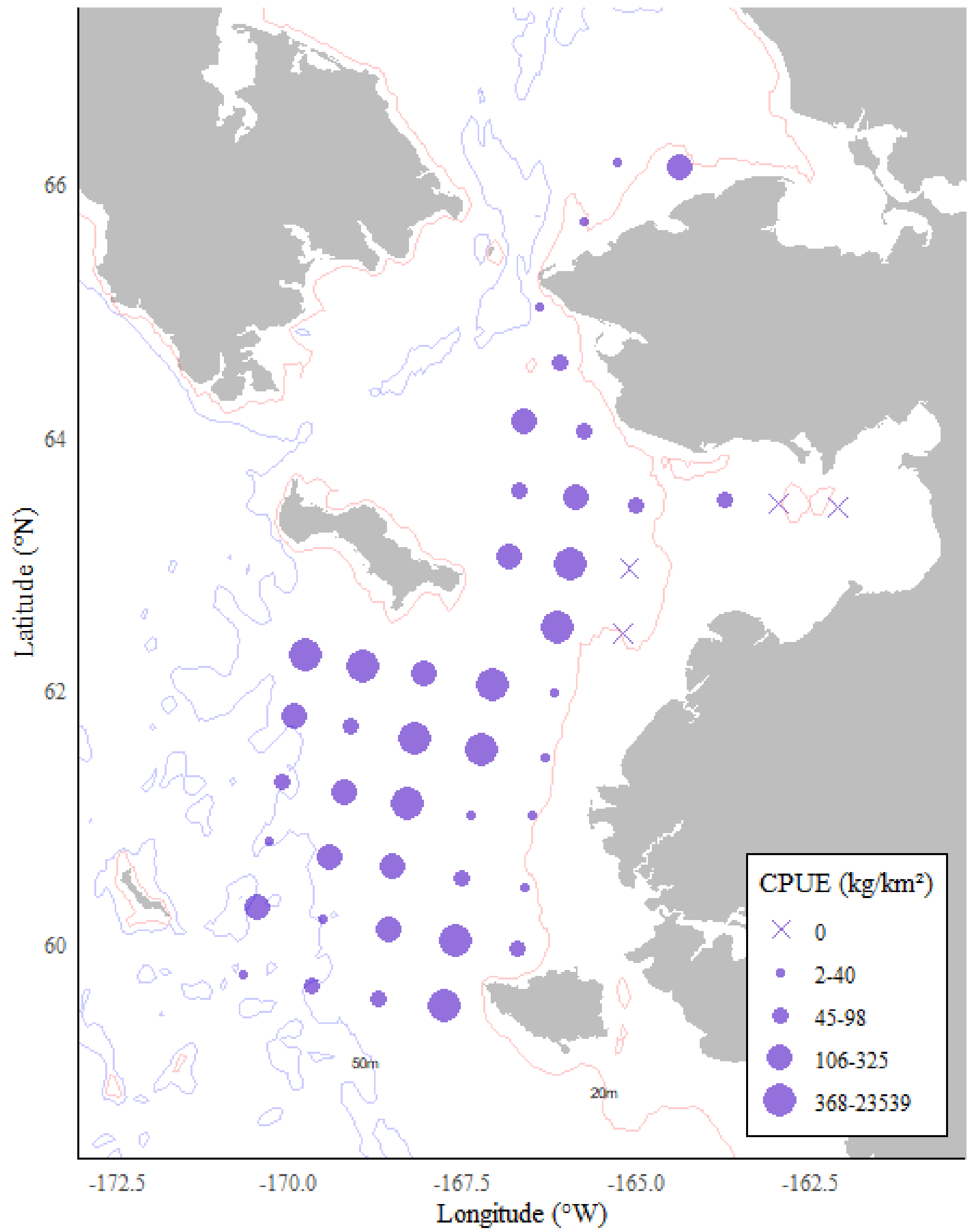

Figure B8. -- Surface trawl catch rates of northern sea nettle (*Chrysaora melanaster*) (CPUE, kg/km^2) during the northern Bering Sea surface trawl survey, 2019.

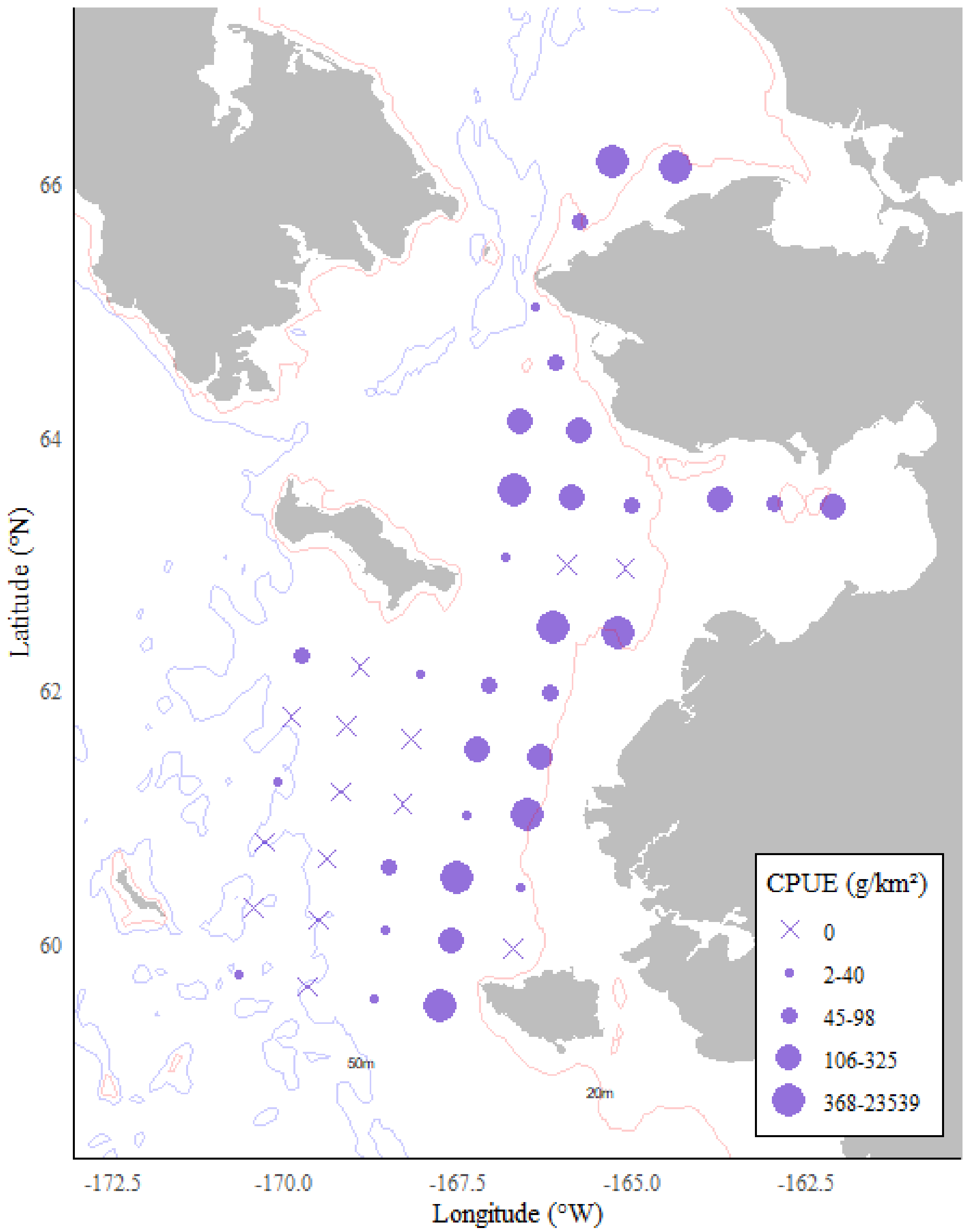

Figure B9. -- Surface trawl catch rates of lion's mane jellyfish (*Cyanea capillata*) (CPUE, g/km^2) during the northern Bering Sea surface trawl survey, 2019.

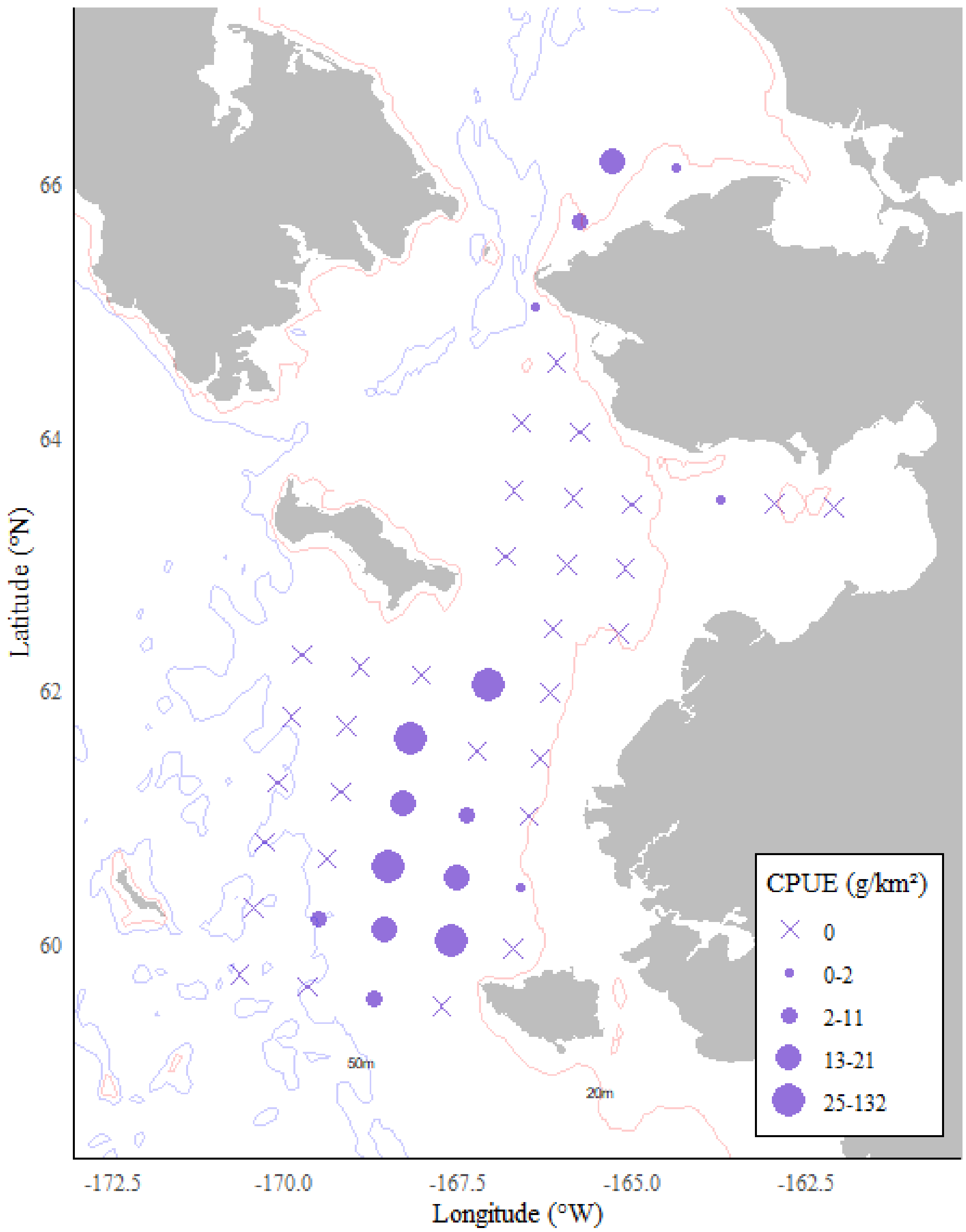

Figure B10. -- Surface trawl catch rates of whitecross jellyfish (*Staurophora mertensi*) (CPUE, g/km^2) during the northern Bering Sea surface trawl survey, 2019.

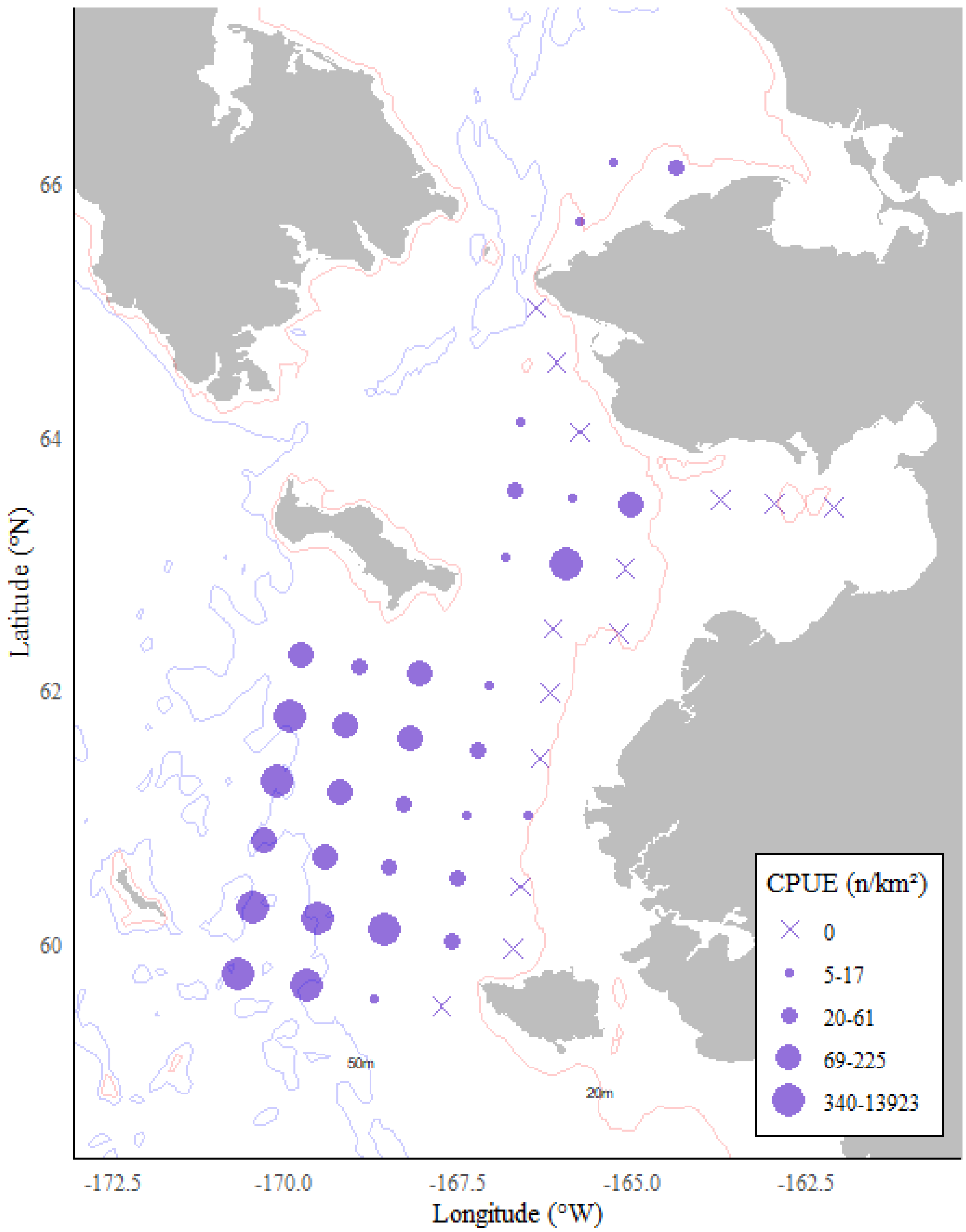

Figure B11. -- Surface trawl catch rates of age-0 walleye pollock (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

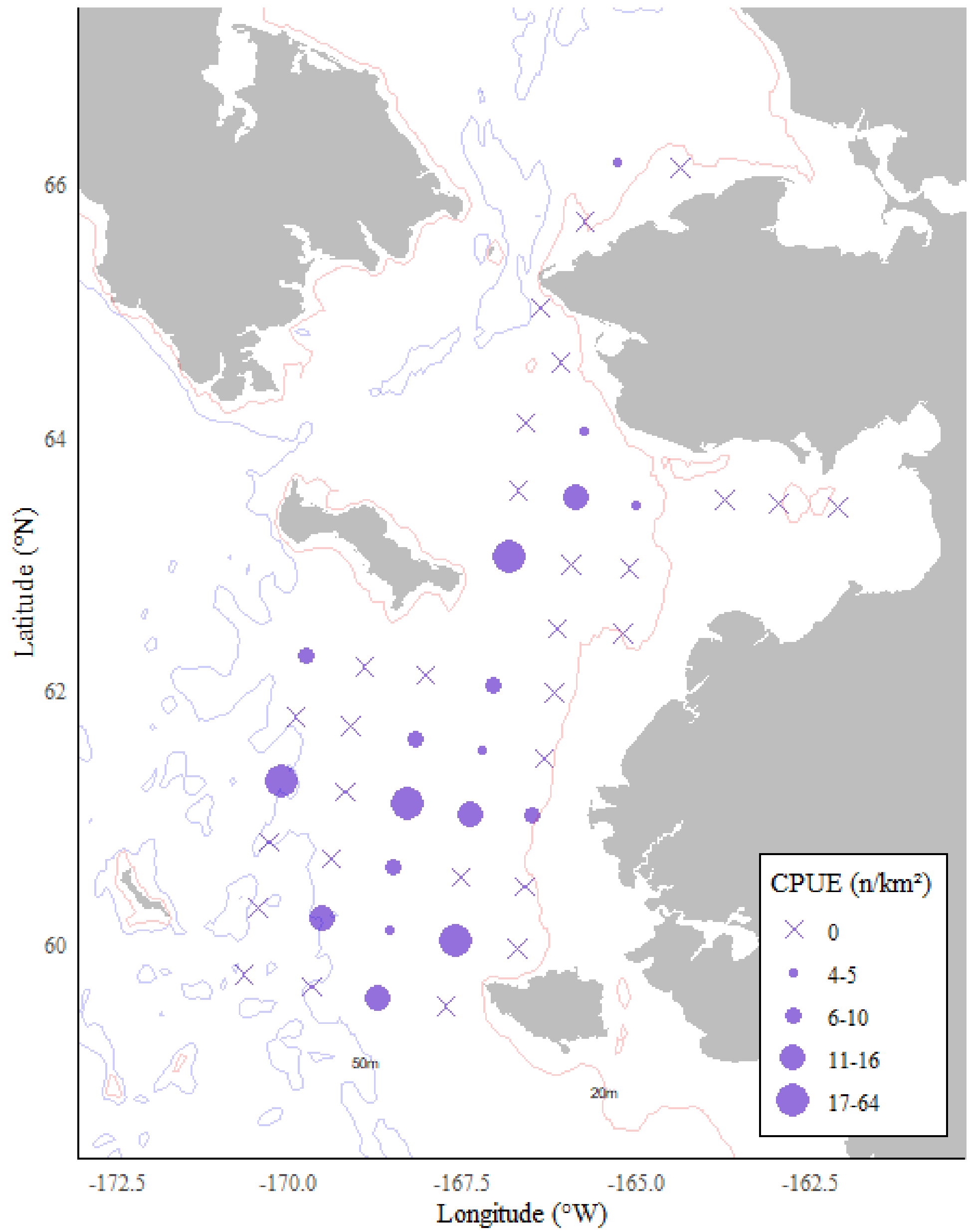

Figure B12. -- Surface trawl catch rates of age-1+ walleye pollock (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

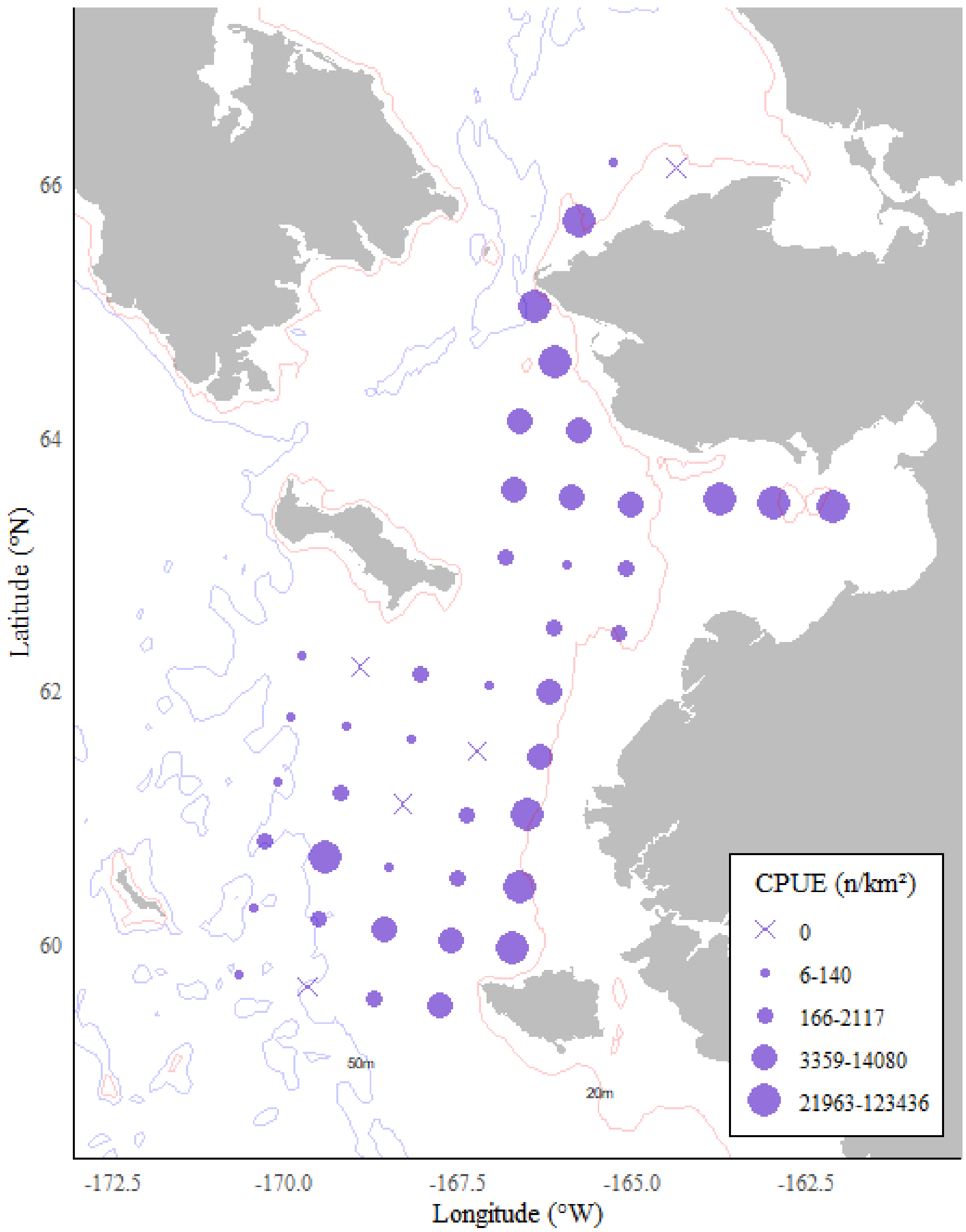

Figure B13. -- Surface trawl catch rates of Pacific herring (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

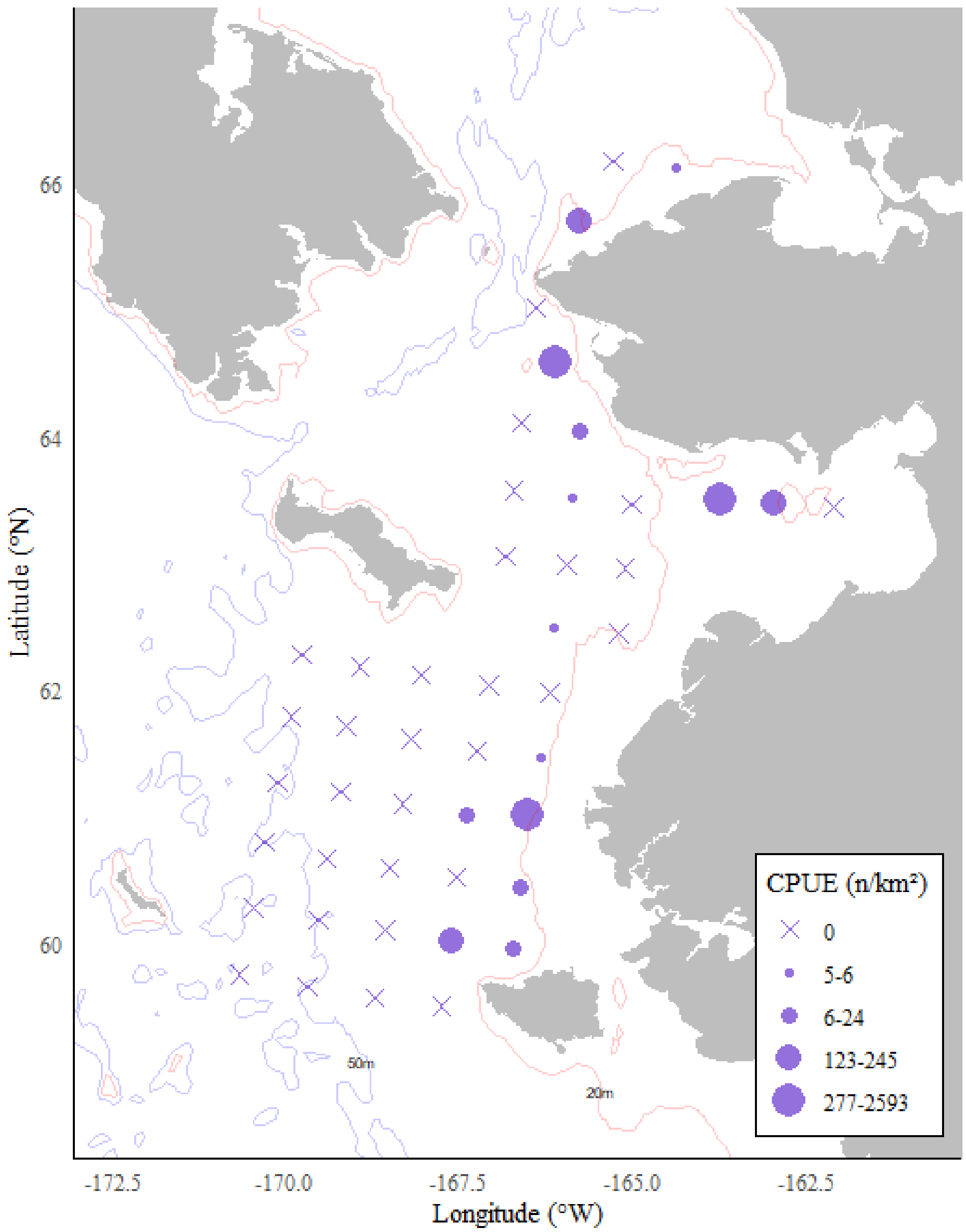

Figure B14. -- Surface trawl catch rates of rainbow smelt (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

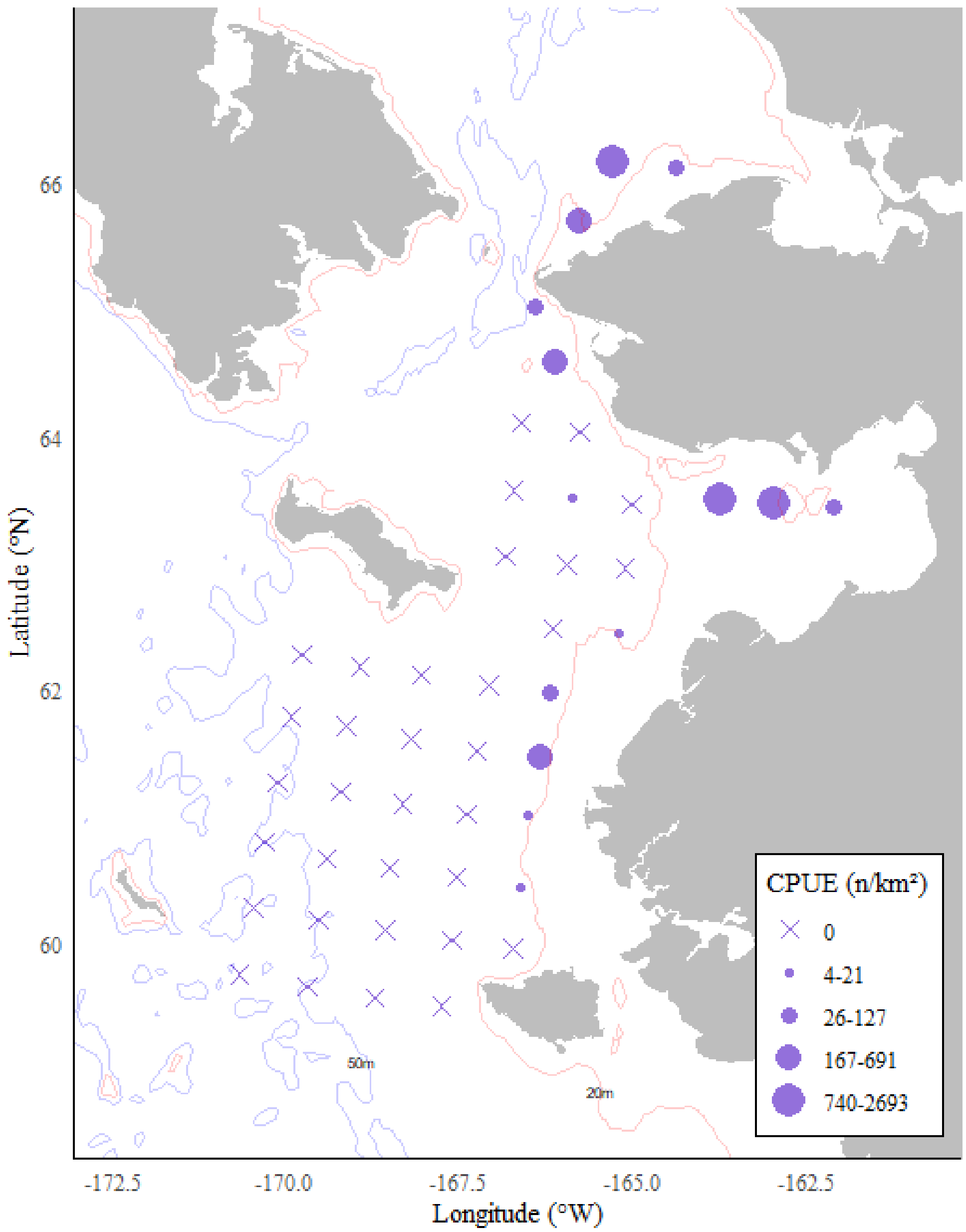

Figure B15. -- Surface trawl catch rates of ninespine stickleback (CPUE, n/km^2) during the northern Bering Sea surface trawl survey, 2019.

APPENDIX C. -- Length-weight relationships

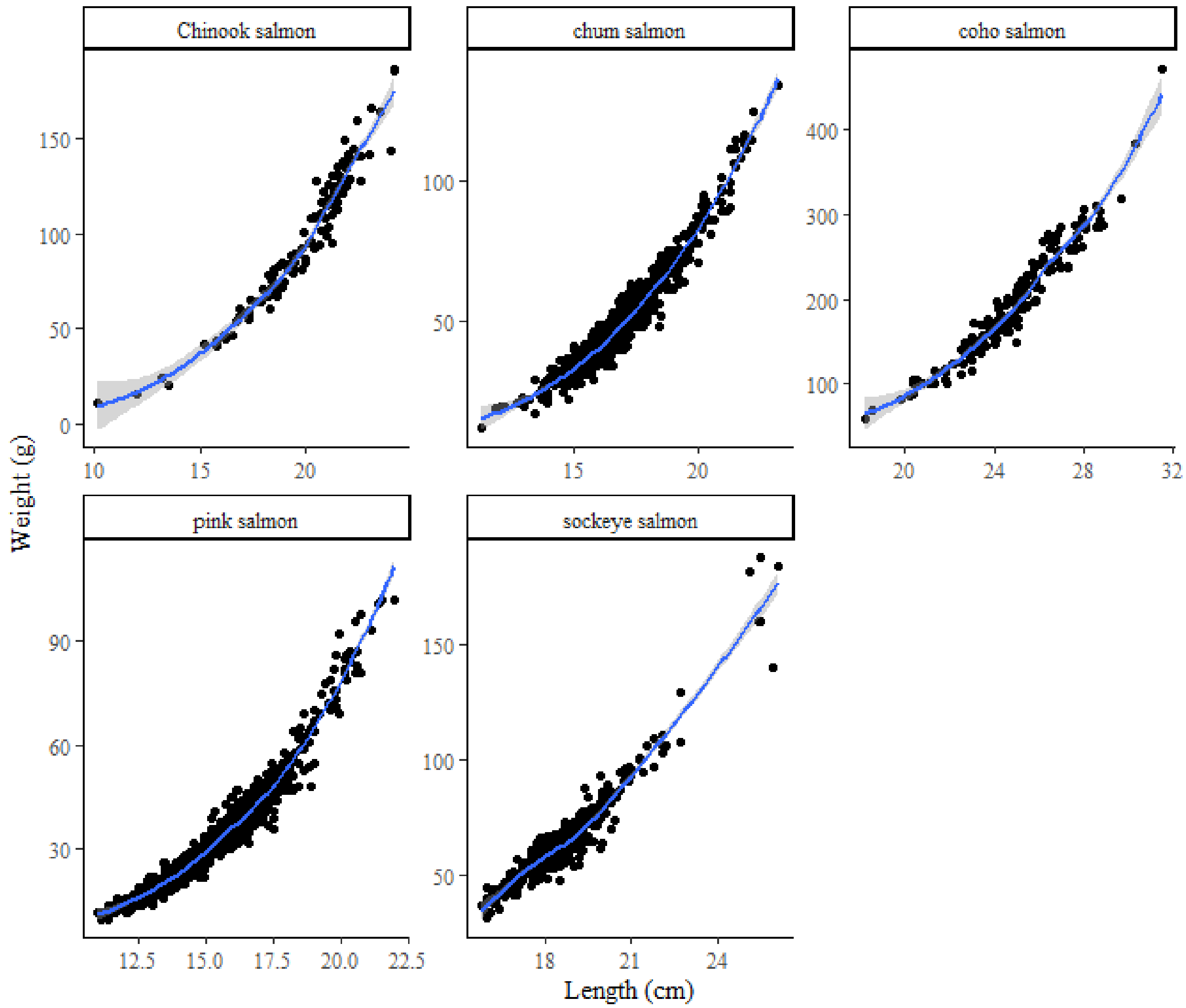

Figure C1. -- Length weight relationships of juvenile salmon species sampled during the northern Bering Sea surface trawl survey, 2019. Lines and shaded regions are from a local regression model (loess) fit and standard error.

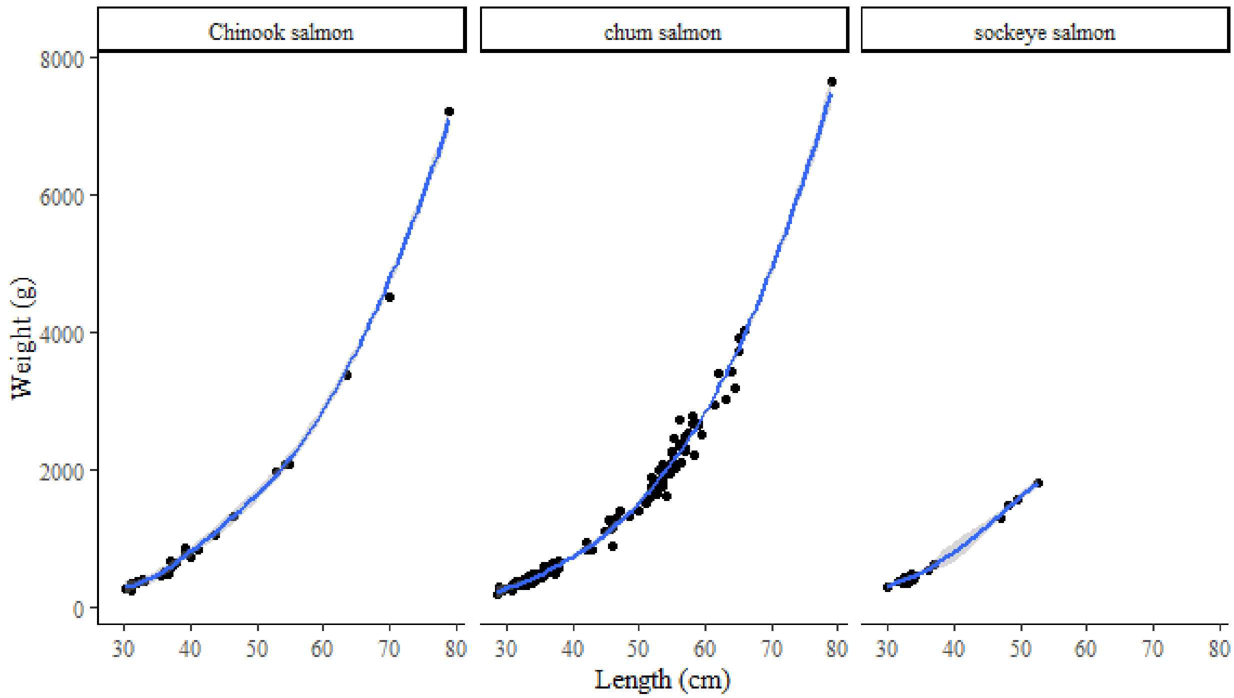

Figure C2. -- Length weight relationships of immature salmon species sampled during the northern Bering Sea surface trawl survey, 2019. Lines and shaded regions are from a local regression model (loess) fit and standard error.

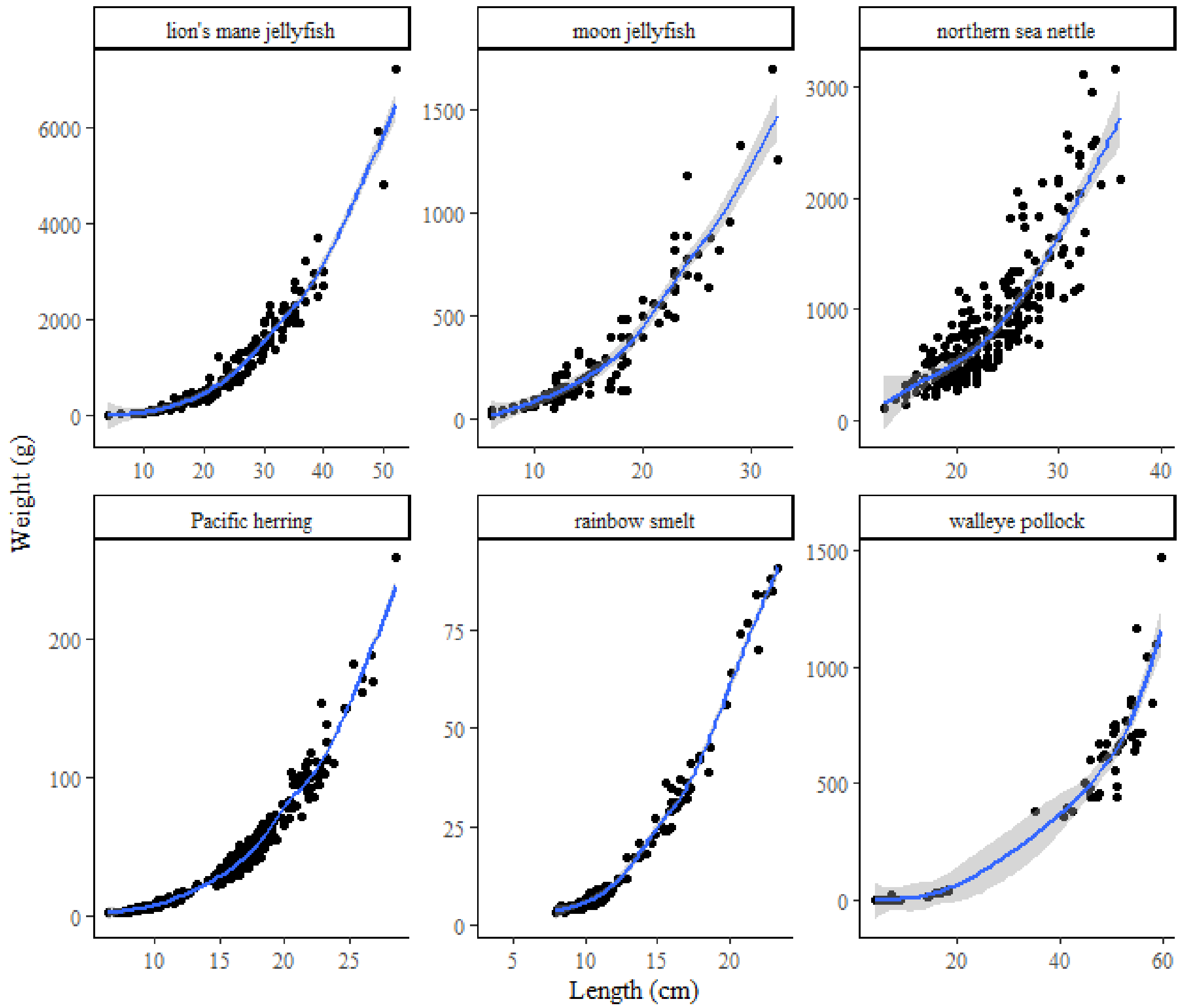

Figure C3. -- Length weight relationships of other key non-salmon species sampled during the northern Bering Sea surface trawl survey, 2019. Lines and shaded regions are from a local regression model (loess) fit and standard error.

APPENDIX D. -- Coded-wire-tag recoveries

Table D1. -- Coded-wire-tag (CWT) recovery information from Whitehorse Rapids Fish Hatchery Chinook salmon captured during the northern Bering Sea surface trawl surveys, 2003-2019.

CWT or Ad-Clip	Brood Year	Release Date	Recovery Date	Latitude (N)	Longitude (W)	Length (mm)	Weight (g)
185106	2001	6/10/2002	10/4/2002	64.1	-164.52	193	79
185102	2001	6/2/2002	10/4/2002	64.1	-164.52	155	46
185061	2001	6/10/2002	10/4/2002	63	-165.97	161	49
18	2006		9/13/2007	65.2	-168.1	125	18
18	2006		9/13/2007	65.2	-168.1	176	58
18	2006		9/13/2007	65.2	-168.1	179	58
18	2009		9/25/2010	64.07	-162.72	164	50
181374	2011	6/6/2012	9/22/2012	61.48	-167	138	28
181779	2011	6/6/2012	9/24/2012	64.1	-163.55	160	45
181779	2011	6/6/2012	9/24/2012	60.98	-168	138	25
182874	2013	6/6/2014	9/5/2014	63.85	-165.97	126	18
183184	2013	6/1/2014	9/6/2014	63.02	-166.05	120	15
183185	2013	6/6/2014	9/14/2014	62.5	-167.08	192	75
183187	2013	6/6/2014	9/14/2014	62.5	-167.08	177	60
183186	2014	6/8/2015	9/8/2015	62.98	-165.97	109	13
183186	2014	6/8/2015	9/14/2015	64	-166.02	120	18
183186	2014	6/8/2015	9/14/2015	64	-166.02	124	21
184064	2014	6/3/2015	9/9/2015	63.02	-167.07	112	13
184065	2014	6/3/2015	9/14/2015	64	-166.02	129	24
184593	2016	6/7/2017	9/3/2017	62	-168	110	12
185573	2018	6/12/2019	9/13/2019	64.12	-162.52	152	42
185587	2018	6/12/2019	9/13/2019	64.12	-162.52	132	24
ad-clip			10/5/2002	63	-167.48	134	23
ad-clip			9/25/2010	63.82	-162.78	190	87
ad-clip			9/12/2012	64.4	-166.07	185	75
ad-clip			9/24/2013	60.52	-167.05	207	108
ad-clip			9/16/2013	63.77	-164.57	183	70
ad-clip			9/19/2013	62.52	-167.03	202	94
ad-clip			9/13/2015	64.02	-167	113	15
ad-clip			9/10/2018	63.5	-166	127	22

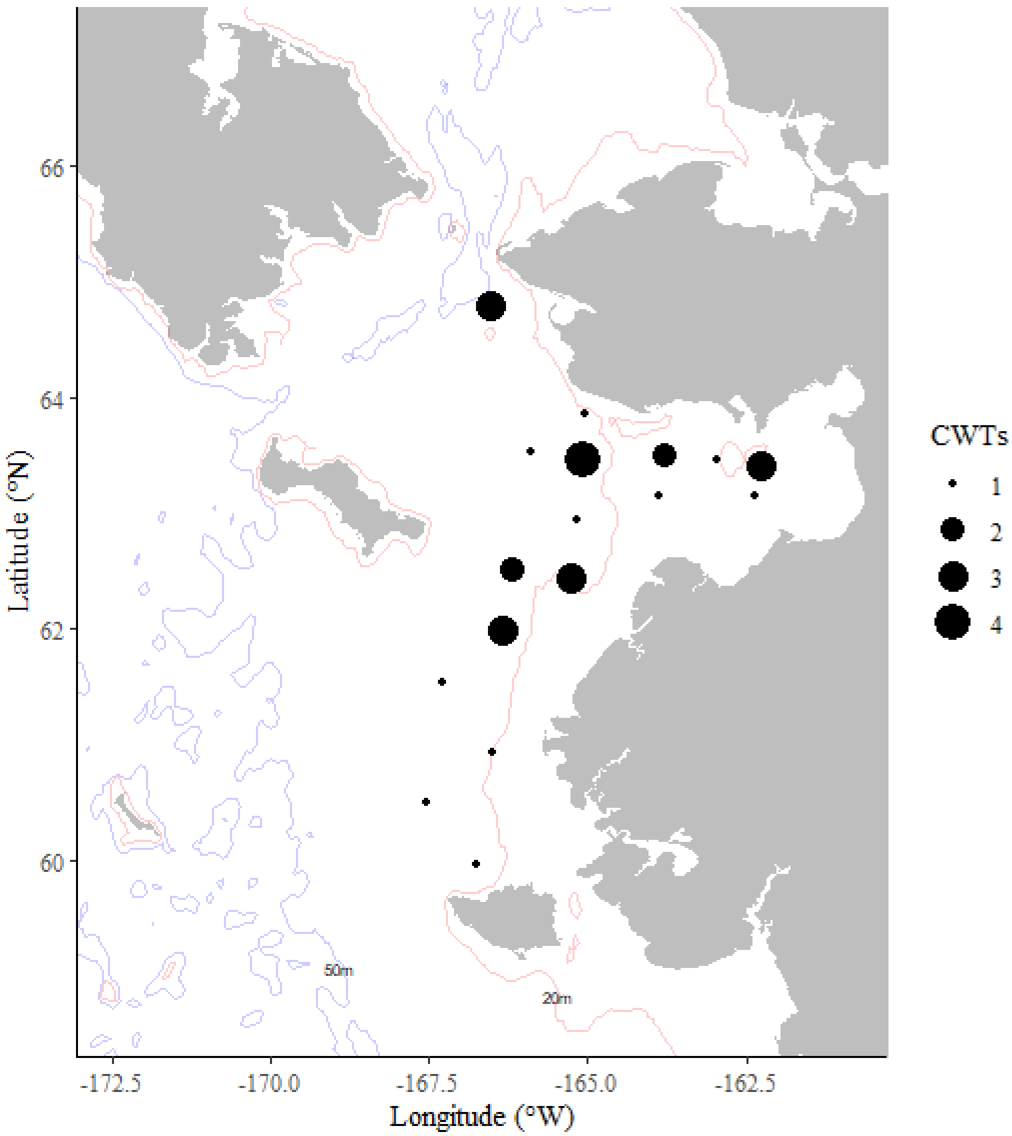

Figure D1. -- Location of CWTs recovered from Whitehorse Rapids Fish Hatchery Chinook salmon during the northern Bering Sea surface trawl surveys, 2003-2019.

APPENDIX E. -- Juvenile salmon diet

Table E1. --Juvenile Chinook, coho, chum, pink, and sockeye salmon sample size by number of stations (N), total number of stomachs (n), and the mean fullness index (SFI) sampled during the northern Bering Sea surface trawl surveys, 2004-2019.

	Chinook Salmon			Coho Salmon			Chum Salmon		
Year	Stations (n)	Stomachs (n)	Mean SFI	Stations (n)	Stomachs (n)	Mean SFI	Stations (n)	Stomachs (n)	Mean SFI
2004	37	138	180.85	27	96	154.39	42	261	109.43
2005	16	75	140.42	2	3	280.45	31	142	190.21
2006	28	87	215.00	21	78	105.36	32	213	207.08
2007	18	98	169.02	4	5	183.60	44	294	151.71
2009	11	50	129.02	5	13	150.35	18	138	196.09
2010	16	69	148.55	6	30	286.58	29	229	130.55
2011	15	111	234.26	4	13	151.29	20	177	103.09
2012	6	42	96.55	1	10	170.69	13	126	137.95
2013	20	174	261.07	3	16	292.98	17	148	136.99
2014	29	204	113.43	11	65	104.08	34	332	96.65
2015	27	180	145.26	7	43	111.65	27	215	74.29
2016	22	91	157.60	5	17	164.86	17	165	57.38
2017	28	148	125.21	19	117	147.19	18	167	148.12
2018	24	109	145.36	24	132	117.73	24	227	102.89
2019	10	44	70.47	17	84	173.49	29	252	48.21

	Pink Salmon			Sockeye Salmon		
Year	Stations (n)	Stomachs (n)	Mean SFI	Stations (n)	Stomachs (n)	Mean SFI
2004	48	323	130.29	23	173	95.35
2005	39	171	197.13	1	1	31.30
2006	24	131	203.30	2	2	172.20
2007	47	325	196.95	4	34	157.50
2009	14	121	267.38	1	10	100.90
2010	15	116	217.68	1	6	89.40
2011	14	114	135.51	1	2	105.26
2012	5	43	187.53	0	0	
2013	21	188	104.33	0	0	
2014	0	0		0	0	
2015	24	222	148.23	3	12	54.86
2016	12	97	64.95	11	78	106.75
2017	20	194	183.73	7	42	41.45
2018	31	277	56.43	7	30	37.90
2019	32	320	86.72	13	126	42.84

Table E2. --Juvenile Chinook salmon diet expressed as percent stomach content index (SCI) during the northern Bering Sea surface trawl survey, 2004-2019.

Year	Sand Lance	Capelin	A0 Pollock	Pacific Herring	Other Fish	Decapod	Other	Unident. Fish
2004	30.75	18.52	26.29	14.01	0.16	8.21	1.11	0.94
2005	3.97	26.63	25.84	1.27	5.14	12.99	12.05	12.11
2006	35.24	16.69	10.22	0	15.95	3.58	1.37	16.95
2007	13.33	49.60	3.62	0	18.03	10.81	2.52	2.11
2009	35.76	19.79	0	0	16.78	6.14	2.03	19.50
2010	6.89	68.39	0	3.24	10.16	2.35	4.02	4.95
2011	20.52	40.65	0	15.38	3.71	5.03	2.50	12.22
2012	0	0	0	0.00	0	4.22	1.00	94.78
2013	12.93	63.05	0	8.33	0.57	4.31	5.86	4.95
2014	66.46	4.68	4.10	0	7.35	7.97	5.52	3.92
2015	73.43	5.44	3.07	3.04	3.37	7.93	1.91	1.82
2016	57.29	9.90	6.06	2.31	2.95	17.01	1.29	3.19
2017	40.37	11.00	2.67	7.95	17.61	6.81	5.30	8.29
2018	2.39	5.59	19.50	0	28.70	15.46	9.79	18.56
2019	12.98	0	21.00	28.08	0	22.78	4.18	10.99

Table E3. --Juvenile coho salmon diet expressed as percent stomach content index (SCI) during the northern Bering Sea surface trawl surveys, 2004-2019.

Year	A0 Pollock	Capelin	Decapod	Other	Other Crustacean	Other Fish	Sand Lance	Unident. Fish
2004	40.07	2.43	15.71	0.3	1.5	23.75	15.69	0.55
2005	0	0	0.23	3.35	0	95.22	0	1.19
2006	24.35	1.35	11.56	3.44	0.36	14.46	33.36	11.13
2007	0	23.88	14.04	0	0	34.35	22.19	5.53
2009	20.1	28.35	0.42	0	1.21	0	36.18	13.75
2010	0	65.06	8.07	0	0.45	0	26.41	0
2011	0.23	44.41	1.95	0	0	9.35	43.47	0.59
2012	0	0	0	0	0.2	0	0	99.8
2013	0	0	0.17	0.16	0	11.18	88.35	0.14
2014	33.47	4.38	0.09	0.05	0.73	32.09	28.65	0.5
2015	15.92	13.28	14.58	0	0.11	27.66	13.56	5.09
2016	19.48	0	0.36	9.27	0.27	12.75	51.99	4.17
2017	0.59	6.22	1.23	2.46	1.65	10.68	36.36	35.13
2018	29.2	0	8.89	2.21	2.56	19	7.69	13.38
2019	53.93	0	2.51	1.37	0.62	13.28	7.22	18.86

Table E4. --Juvenile chum salmon diet expressed as percent stomach content index (SCI) during the northern Bering Sea surface trawl surveys, 2004-2019.

Year	Gelatinous Prey	Sand Lance	A0 Pollock	Other Fish	Euphausiid	Hyperiid	Other Crustacean	Other	Unident.
2003	26.07	47.43	3.87	9.25	0.26	1.95	9.83	1.34	0
2004	36.91	4.64	13.72	14.47	6.38	7.84	15.97	0.08	0
2005	28.74	0	21.1	17.04	28.51	1.56	3.05	0	0
2006	20.49	44.64	1.76	27.34	3.88	0.67	1	0.22	0
2007	63.29	2.72	0	4.23	12.31	8.26	8.4	0.79	0
2009	42.23	9.44	0	23.5	0	22.97	1.54	0.33	0
2010	26.07	16.87	0	15.07	19.08	18.86	3.46	0.59	0
2011	49.91	0	0	17.87	11.97	12.37	6.56	1.33	0
2012	43.81	4.32	0	7.8	10.29	7.27	3.2	23.31	0
2013	27.13	11.29	0	6.95	4.03	46.42	3.38	0.8	0
2014	7.73	17.7	0.51	26.7	18.59	8.36	7.42	6.11	6.88
2015	30.65	27.9	0	24.56	0.55	10.61	5.09	0.64	0
2016	56.1	0	0	16.96	0	1.37	4.02	21.55	0
2017	7.86	5.2	0	48.89	20.88	0.41	2.27	14.48	0
2018	18.86	0	0	6.22	35.88	2.92	0.41	0.03	35.67
2019	60.28	0	3.65	5.7	0.06	0.32	2.92	0.01	27.08

Table E5. --Juvenile pink salmon diet expressed as percent stomach content index (SCI) during the northern Bering Sea surface trawl surveys, 2004-2019.

Year	A0 Pollock	Copepod	Decapod	Other	Gelatinous Prey	Other Fish	Sand Lance	Euphausiid	Hyperiid	Unident.
2003	29.18	0.96	4.75	0	0	40.46	8.66	14.19	1.8	0
2004	14.98	6.55	28.36	1.47	1.4	5.07	26.75	11.83	3.59	0
2005	25.46	0.4	15.86	1.58	3.36	28.19	3.15	16.65	5.35	0
2006	1.48	3.28	10.16	4.21	3.59	26.53	47.26	0.89	2.59	0
2007	0.37	9.5	29.96	5.24	8.97	17.11	3.96	7.86	17.05	0
2008	0	0	30	0	0	0	50	0	20	0
2009	0	6.03	1.92	7.64	15.72	22.27	26.64	2.47	17.32	0
2010	0	1.16	1.96	0.62	6.75	16.3	9.7	56.78	6.72	0
2011	0	24.38	19.73	2.14	6.39	3.14	12.55	0.12	31.55	0
2012	0	1.96	3.95	0	0	28.43	0	40.91	5.72	19.01
2013	0	2.16	5.09	0.56	9.04	21.01	2.69	9.88	49.57	0
2015	0	6.21	5.21	0.73	5.02	2.65	63.49	9.44	7.24	0
2016	0	33.11	17.2	2.62	4.92	23.34	8.47	0	0.61	9.71
2017	0	35.78	3.31	0.25	0	12.24	2.35	38.56	0.59	6.93
2018	0	12.54	2.34	5.08	0.79	8.34	0	32.32	8.24	30.35
2019	0.27	45.45	2.52	0.56	3.73	16.88	0.52	3.15	0.47	26.46

Table E6. --Juvenile sockeye salmon diet expressed as percent stomach content index (SCI) during the northern Bering Sea surface trawl surveys, 2004-2019.

Year	Copepod	Sand Lance	A0 Pollock	Other Fish	*Thysanoessa* spp.	Decapod	Other Crustacean	Other	Unident.
2004	3.68	7.87	61.15	0.44	5.17	14.78	4.63	1.55	0.74
2005	0	0	0	0	0	0	0.96	30.03	69.01
2006	0	0	0	0	33.04	47.5	4.73	14.72	0
2007	26.97	0	0	0.49	4.83	0.65	12.08	55.03	0
2009	0	100	0	0	0	0	0	0	0
2010	0	0	0	0	95	0	0	5	0
2011	0	0	0	70	0	30	0	0	0
2015	5.91	0	9.44	0	0.2	73.57	9.45	0.24	1.19
2016	1.42	4.33	4.17	0	2.12	11.85	7.26	36.05	32.8
2017	0	0	0	0	77.67	1.68	0.27	0	20.38
2018	2.98	0	0	1.92	41.9	3.34	1.14	4.05	44.67
2019	7.86	0	17.71	4.19	5.2	12.67	1.49	9.01	41.86

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