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Diets and Prey Items of Juvenile Chinook (*Oncorhynchus tshawytscha*) and Coho Salmon (*O. kisutch*) on the Yukon Delta

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ABSTRACT

Juvenile Chinook salmon on the Yukon River undertake one of the longest fish migrations in the world, travelling over 3,000 km from spawning grounds in Canada to the marine waters of the Bering Sea. Evidence suggests that much of the variability in Yukon River Chinook salmon production occurs prior to the end of the first summer at sea, either during freshwater rearing, downstream migration, or entry into the marine environment. Prey availability and prey quality are important factors in juvenile Chinook salmon growth and condition. This research investigated spatial and temporal patterns in juvenile Chinook and coho prey consumption and availability on the Yukon River Delta. Results suggest that while there are limited spatial differences in prey availability, prey varies seasonally. Juvenile Chinook and coho exhibit similar selectivity for invertebrate prey. Comparisons of the results of this study with data from prior sampling years indicates that juvenile Chinook salmon in 2016 had lower stomach fullness and lower energy densities than Chinook from prior years. Additional years of prey sampling are needed to identify factors that affect prey availability.

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INTRODUCTION

After spending their first full year rearing in the Yukon River, juvenile Chinook salmon undertake one of the longest known fish migrations travelling over 3,000 km from the headwaters in Northwest Canada to the Bering Sea in Alaska. The long downstream migration differentiates Yukon River Chinook salmon from other Chinook salmon stocks in the United States and Canada and may have a disproportionate influence on production than is typical for other Chinook populations. Size-selective mortality during early life history stages has been identified in Yukon River Chinook salmon (Murphy et al., 2013). Evidence suggests that much of the variability in Chinook salmon production may occur prior to the first summer at sea (Howard et al. 2016, Murphy et al. 2017) and that larger fish with higher energy content at the end of their first marine summer had a greater chance of surviving to adulthood (Howard et al. 2016).

Outmigration timing and early marine processes are thought to be important in structuring productivity patterns in Arctic-Yukon-Kuskokwim Chinook salmon stocks. Chinook salmon production patterns have been correlated to the timing of ice breakup on the Yukon River (Ohlberger et al. 2016), suggesting that the timing of marine entry and potential mismatch with available prey resources in fresh water and in the first months of marine residency may be key contributors to cohort survival. It is generally accepted that fish that grow larger and faster during their first marine summer have a survival advantage over slower-growing fish (Beamish et al. 2006, Farley et al. 2007, Tomaro et al. 2012). Additionally, research suggests that the quality and quantity of prey resources available during outmigration and early marine residence are crucial factors for juvenile salmon growth and survival (Beauchamp 2009, Moss et al. 2009, Duffy et al. 2010).

The limited information available on the diets of juvenile Chinook salmon in the Yukon River comes from the Chena River near Fairbanks (Gutierrez 2011, Wipfli et al. 2014). There are no studies evaluating changes in diet quality of smolts during outmigration or as they move from freshwater to offshore habitats. The relationship between particular habitat conditions and juvenile salmon prey, growth and energetics is also largely unknown. Recent research suggests that the diets of juvenile salmon in the upper Yukon consist mainly of drifting terrestrial and aquatic invertebrates (Gutierrez 2011, Wipfli et al. 2014). Diet data from 2014 and 2015 field seasons in the lower Yukon River indicates that juvenile Chinook begin transition to piscivory prior to ocean entry (Miller et al. 2016), and as the fish mature and move downstream and offshore their diet diversifies.

Prey quality, measured as energy density, is an important determinant of juvenile salmon growth (Trudel et al. 2002, Cross et al. 2005), with small differences in prey quality having large effects on growth and condition. Energy density for invertebrate and vertebrate prey varies with taxa and life stage, as well as varying temporally and spatially (Whitman 2010, James et al. 2012). There is no published information on prey energy densities for juvenile Chinook salmon in the Yukon River system, leaving researchers to rely on values from a few published literature sources from work done elsewhere (Hillgruber et al. 2007). This is especially true of the terrestrial and aquatic invertebrates that are important components in the diets of juvenile Chinook salmon captured in summer 2014 on the Yukon Delta. Understanding the factors that affect growth and energetic condition of juvenile salmon during outmigration could identify limitations to production that may affect survival and recruitment.

The objectives of this research were to examine spatial and temporal variation in prey composition for juvenile Chinook salmon during outmigration, and to investigate differences in energy content of prey items in 2016. This research continued investigation into factors affecting juvenile Chinook salmon habitat use, outmigration timing, size, feeding and growth during their first months of marine residency that was begun in 2014 (AYKSSI #1330) and reported in Miller et al. (2016) and Howard et al. (2017).

MATERIALS AND METHODS

Study Area

The Yukon River is over 3,000 km long, originating in British Columbia, Canada, and ending in the Bering Sea off Alaska. Eight major rivers flow into the Yukon, which drains an area of more than 330,000 square miles (Brabets et al. 2000). The Yukon-Kuskokwim Delta is a plain of sediment deposited by the Yukon and Kuskokwim rivers. It emerges into the southern coast of Norton Sound and extends westward into the northern Bering Sea. It is the second largest delta plain in the United States, and its large size and remoteness make it a challenging research environment.

On the delta plain, the Yukon River splits into three main distributaries with numerous secondary channels, marshes, lakes, and tidal sloughs within the delta plain. Chinook salmon utilize each of these distributaries for juvenile outmigration and adult spawner returns (Miller et al. 2016, Howard et al. 2017). The distributaries are seasonally ice-covered from late October to mid-May. Spring breakup is accompanied by a large increase in discharge and sediment from snow and ice melt. Peak discharge tends to occur immediately following breakup and into June, but large interannual variations in the timing and size of discharge are common (Thorsteinson

et al. 1989). Prior research has shown that juvenile Chinook salmon begin their outmigration shortly after ice leaves the lower river (Martin et al. 1987, Miller et al. 2016, Howard et al. 2017).

A shallow, seasonally ice-covered platform separates the shoreline of the delta plain from the marine environment. This platform extends up to 30 km offshore with water depths between 1 m and 3 m. Extensions of the main river distributaries run through the platform in incised channels between 5 m and 15 m deep, which may act as migration corridors for juvenile fish transiting from the river to the marine environment (Thorsteinson et al. 1989). At the seaward edge of this platform, the bathymetry increases sharply along an area known as the delta front, which marks the transition between fresh and marine waters (Martin et al. 1987, Miller et al. 2016). Fresh water from the Yukon River stretches offshore of the delta front as a buoyant surface layer that defines the estuary of the Yukon River, with the offshore extent of the estuary determined by river discharge and winds.

This research was conducted on the three main distributaries of the lower Yukon River and in the estuarine waters from the delta front offshore to the 15 m isobath. This study was conducted in 2016, the third year of sampling along permanent transects established in the study area.

Field Work

Sampling within the lower Yukon River distributaries followed the method described in Howard et al. (2017) and Miller et al. (2016). In 2014 and 2015, six permanent sampling stations were established on the three lower Yukon River distributaries (Fig. 1). These distributaries are locally referred to as South Mouth (SM), Middle Mouth (MM), and North Mouth (NM), a naming scheme also used for this project. Stations were sampled three times per week by teams of fishermen and biologists using a surface net towed between two small (20 ft to 24 ft) skiffs. The skiffs were operated by local fishermen and crews from Emmonak and Alakanuk who have knowledge of the river, with field operations based out of Emmonak. The nets used for this research were 6.8 m wide and 1.8 m depth at the mouth tapering to a 0.3 m by 0.3 m bag at the codend with the mouth held open by metal poles that also provided weight to the net. A set of three 15-minute tows was performed at each station. River temperature was recorded using a probe thermometer at the start of sampling at each station. Barring occasional mishaps with boat engines or gear, all sampling was conducted between 0800h and 1800 h.

Drift samples were collected in the distributaries to investigate prey availability. Drift invertebrates were sampled at each station using a neuston net with 500 μm mesh. The net was secured to the side of one of the tow boats with the top of the frame above the water. The

net was towed for 30 minutes. The net was rinsed with buckets of water during retrieval to concentrate samples in the codend, the codend was detached, and the contents of the codend were poured directly into a Nalgene bottle filled with 70% ethanol. Twelve drift samples collected between 29 June and 2 July across all three distributaries were poured into plastic bags and frozen to be later analyzed for lipid content. Seventy-six of the drift samples collected from 25 May to 27 July were used to investigate prey availability across nine stations.

Sampling of the delta front in 2016 used a different set of transects than were used in prior study years. (Miller et al. 2016, Howard et al. 2017). Strong and persistent westerly winds made it impossible to sample transects on the western side of the Yukon Delta. As a result, sampling was confined to the northern portion of the front (Fig. 2). Transects and stations along the delta front were sampled using a 40 ft charter vessel that originated out of Nome, AK. A surface and a midwater trawl were made at each of the two outermost stations on each transect. At the inner-most station, only a surface trawl was made due to shallow depths. The midwater trawl had 10 m foot-head ropes, 20 m in length, and with 1.6 cm nylon mesh at the head rope decreasing to 0.4 cm at the codend. The surface trawl had 12 m foot-head ropes, 15 m in length, and with 1.6 cm nylon mesh at the head rope decreasing to 0.4 cm at the codend. Both trawls were equipped with temperature and depth sensors on the foot and head ropes. Stations were sampled in June. All tows were 20-minutes in length and trawl location was recorded as the starting and ending position of each tow. For each tow, water temperature, water depth, boat speed, and wind speed and direction were recorded. Conductivity, temperature, and depth (CTD) profiles were collected with a SeaBird SBE 19 profiling CTD at each mile along a transect.

Captured fish from distributary and front sampling were identified to species or lowest taxonomic level achievable. A minimum of 40 fish (distributary) and 50 fish (front) of each species were measured to the nearest 1 mm fork length (FL) or total length (TL), depending on the species, and released. When there were more than one size class of a species, 20 individuals (distributary) and 30 individuals (front) from each size class were measured at each station. The remaining individuals that were not measured were enumerated by size class. All juvenile Chinook and coho salmon specimens were retained. Each was assigned a unique identifying number, fin-clipped for genetic samples, and either frozen or fixed in 10% formalin for laboratory analysis. Five individuals of each potential fish prey type were collected from each distributary. Primary fish prey species were chum salmon (*Oncorhynchus keta*), pink salmon (*O. gorbuscha*), cisco (*Coregonus sardinella* and *C. laurettae*), whitefish (*Coregonus nasus*, and *C. pidschian*), and burbot (*Lota lota*). Fish prey were bagged and frozen for energetic analysis. Fish that could not be identified to species in the field were photographed, vouchered, and returned to the laboratory for identification.

Juvenile Salmon and Fish Prey Laboratory Methods

Chinook salmon captured in the distributaries and frozen for energetic analyses (272 individuals) were subsampled in the laboratory by selecting the three largest and smallest salmon collected in each sampling week and then randomly sampling from the intermediate sizes. This subsampling provided energy density results for 223 Chinook (Table 1). This method was selected based on analysis in 2015 which suggested that juvenile Chinook less than 85 mm in length had different energy densities relative to larger size groups (Miller et al. 2016).

Chinook and coho samples were weighed to the nearest 0.001 g. For Chinook, the sagittal otoliths were removed for later analysis of age and microchemistry, stomachs were removed, the entire bolus of prey was weighed to obtain an estimate of stomach fullness, and the empty stomach was returned to the body cavity. All fish were homogenized and a subsample was dried using a thermogravimetric analyzer to measure percent moisture content. Each subsample was pressed into a 0.15 g pellet and run through a semi-microbomb calorimeter (PARR 1425) to measure caloric content (cal/g).

Chinook and coho salmon captured in the distributaries and preserved in formalin for diet analyses (319 and 174 individuals, respectively) were subsampled in the same manner used for salmon retained for measuring energy content. Coho salmon diets were investigated to evaluate prey overlap and competition with Chinook salmon. This subsampling resulted in diet analysis of 211 Chinook and 110 coho salmon. Samples were removed from formalin and stomachs were excised. Stomachs were weighed full and then the contents were removed. The stomachs were re-weighed, and content weight was determined by subtracting the content weight from the full stomach weight.

Identification of Prey Taxa in Drift and Stomach Samples

Drift samples and juvenile salmon stomach contents were processed and identified at the Alaska Center for Conservation Science Aquatic Ecology Laboratory (University of Alaska Anchorage, UAA). Drift samples were subsampled to 300 organisms. Samples varied greatly in total number of organisms, with most samples having fewer than 300 total organisms. These samples were subsampled for 4 hours, or until at least one-quarter of the sample had been processed. Drift taxa were identified to the lowest practical taxonomic level, often family, and counted. Counts were divided by the volume sampled to obtain densities (number/m^3). UAA

composited organisms across drift samples from 38 different taxa groups for lipid analysis. Lipid was extracted from samples following the methods of Vollenweider et al. (2011).

For stomach content analysis of juvenile Chinook and coho, invertebrate prey items were identified to the lowest practical taxonomic level, often family, counted, and measured. Invertebrate lengths were converted to biomass using length-mass coefficients obtained from Bob Wisseman with Aquatic Biologic Associates, Inc. Fish prey wet weights were converted to dry mass using calculated percent dry mass values, which varied from 20% to 22%.

Diets were also evaluated separately for 35 juvenile Chinook caught on the delta front.

Analysis

Juvenile salmon abundance and size distributions

Catch per unit effort (CPUE) for both delta front and distributary sampling was calculated as catch per minute of trawling time. Although CPUE measured as the total volume of water flow through the net is a more accurate determination of catch in river systems, attempts to calculate volume of water flowing through the nets using flow meters mounted in the mouth of the net was hampered by the cavitation from the outboard engines of the sampling boats disrupting the flow. Alternative methods are being investigated to methods to calculate volume sampled in future years. CPUE was calculated on daily and weekly catches by summing the total catch for the period of interest by the total time spent towing during that period. To investigate spatial differences in catch, CPUE for each sampling week and year were also calculated by distributary. A t-test was used to compare data from 2016 with each of the other sampling years. To examine size-related variation in species abundance over time, Chinook and major prey species were grouped into 10 mm length bins. Chinook, coho, and major prey item lengths were summarized by sampling week, distributary, and year. Stomach fullness was calculated for both Chinook retained for diet and energetic analyses as the stomach content weight relative to the Chinook body weight (%BW):

$$\%BW = \frac{CW_P}{(BW - CW_P)} \times 100 \,,$$

where BW is the wet weight of the juvenile salmon and CW_p is the weight of the stomach contents.

Drift composition

To examine differences in prey availability across the delta and over the summer season, differences in composition of drift samples were examined using non-metric multidimensional scaling (NMS) ordination (Clarke 1993). Drift samples were not collected in 2014 and 2015, so differences in prey availability could not be compared across years. Taxa were grouped by family or higher and rare taxa were removed (frequency < 5% across all 76 drift samples), which reduced the number of unique taxa from 93 to 46. Densities for the remaining taxa were log-transformed to lessen the effect of small abundant taxa on the results. We also ran a permutational multivariate analysis of variance (MANOVA) on the drift taxa composition by time period, station, and distributary (Anderson 2001) using R (R Development Core Team, 2008). Sample dates were grouped into three time periods of approximately three weeks in duration (21 May – 11 June, 13 June – 2 July, and 4 July – 27 July). The number of drift samples in each distributary and time period varied from 3 to 15.

Patterns in drift densities over the summer and differences in drift quality were assessed by grouping drift taxa into orders except where the lowest practical level of identification was higher. All fish were grouped into teleosts. Drift densities were plotted over time and modeled as a function of date and date squared to examine non-linear patterns in availability. Quality of organisms found in the drift was assessed by comparing average percent lipid content for the different macroinvertebrate orders.

Prey composition and selection

Important invertebrate prey groups were identified based on percent dry mass in the juvenile salmon stomachs. Prey items were grouped by order except where the lowest practical level of identification was higher and all fish were grouped into teleosts. Dry masses were summed for each fish stomach and plotted by distributary and time period.

Juvenile salmon prey preferences were examined using Ivlev's Electivity Index:

$$E_i = \frac{(r_i - p_i)}{(r_i + p_i)},$$

where r_i is fractional composition of each item (i) in the stomach contents and p_i is fractional composition in the drift. Values range from -1 to +1 indicating avoidance of prey items to

preference for prey items. Values close to zero indicate prey items were selected in equal proportion to their presence in the drift samples.

The size of fish prey consumed and available to juvenile Chinook was examined using a length-weight regression for each prey species calculated from the lengths and weights from prey samples collected for energetic analysis. Where a whole diet prey item could be identified to species, the individual length-weight regression was used to convert diet content weight to prey fish length. If a whole prey item could not be identified to species, a generic length-weight regression using all prey species was applied to the weight from the stomach. Only whole diet prey were used for length-weight analysis. Predator-prey length ratios were calculated by dividing the estimated length of the fish prey by the Chinook salmon length.

Prey available to juvenile Chinook salmon in each sampling week and year was investigated by plotting the length distributions of major fish prey with length distributions for Chinook salmon during the same time period. Plotted Chinook lengths were 41% of the measured fork length of sampled Chinook and represent the upper range of prey sizes available to Chinook salmon during the period. The 41% predator-prey ratio was selected by using the average maximum predator-prey ratio from this study with average ratios from the literature (Chamberlin et al. 2017).

Energetic composition

Energy density for Chinook salmon caught in 2016 was compared with the two prior sampling years. Analysis for 2014 and 2015 indicated that energy density varied seasonally and suggested that there may be seasonal differences in the energy densities of small and large juvenile Chinook (Miller et al. 2016). To investigate seasonal differences in energy density, median energy densities (kilojoules per gram dry mass) were plotted by sampling week. Energy densities for fish prey were compared to seasonal patterns of abundance and to energy density trends of juvenile Chinook salmon.

RESULTS

Environmental

Breakup occurred on the upper Yukon at Dawson City on 23 April 2016. This was the earliest breakup since the start of record keeping in 1896 (Fig. 3). Breakup in 2014 and 2015 occurred at Dawson City on 2 May and 4 May, respectively. Ice left the lower river outside Emmonak (approximately 1,250 km downstream) on 26 May 2014; 25 May 2015 and 6 May 2016. River discharge generally peaks shortly after ice-out. Discharge measured at the USGS gauge at Pilot station show different patterns in discharge among years. Average daily discharge was higher than the long-term median in the early portion of the sampling period in all years, but dropped below the long-term median during June in 2014 and 2016 (Fig. 4). July discharge was higher than the median in 2014 but below median values in 2015 and 2016.

River water temperatures were obtained from the Arctic-Yukon-Kuskokwim Database Management System for the Lower Yukon Test Fishery station at Big Eddy near Emmonak (ADF&G 2018) for the period from 1986 to 2016. The average value of these years was used to develop a long-term average for comparison purposes. In 2015 and 2016 temperatures stayed above the long-term average for the lower Yukon River for most of the sampling period (Fig. 5), with temperatures exceeding average values 84% and 94% of the time, respectively. In both years, daily water temperatures also exceeded long-term maximum values 16% of the time. In 2014, mean June and July temperatures were just below the long-term averages of 13.0° C and 16.4° C, respectively. In 2015 and 2016, both mean June and mean July temperatures exceeded the long-term average by up to 2.0° C. In contrast, water temperatures in 2014 showed less fluctuation and were similar to the long-term average.

Juvenile Salmon Abundance and Size Distributions

Catch varied substantially between sampling years and distributaries (Fig. 6) with an overall higher CPUE in 2015. A similar peak in CPUE was evident in NM in late May and early June, but peak outmigration occurred at different times in the other two tributaries. Timing of outmigration was not correlated to either river water temperatures (r = -0.21) or discharge (r = 0.26). Juvenile Chinook salmon size varied by year and sampling week (Fig. 7). The average size of 2016 juvenile Chinook was significantly smaller than from 2014 (p = 0.006) but larger than from 2015 (p = 0.005). Small juvenile Chinook salmon (≤ 80 mm) appeared toward the end of the sampling periods in both 2016 and 2015, but not in 2014. Evaluation of Chinook size by

distributary does not suggest any bias in outmigration strategy by fish size: all size classes were observed in all three distributaries.

A total of 78 juvenile Chinook salmon were captured on the delta front. The highest CPUE was at the Kawanak transect on the northwest side of the Yukon Delta. CPUE decreased at each station progressing into Norton Sound.

Salmon Diets, Stomach Fullness, and Energetic Content

Chinook salmon from the Yukon River tributaries used in diet analyses in 2016 ranged in length from 70 to 131 mm FL (Table 1). The proportion of Chinook with empty stomachs was lower in 2016 than in the other two sampling years while the number of Chinook that had consumed fish was similar to the number in 2014. Both the number of empty stomachs and number of Chinook consuming fish were highest in 2015. The proportion of fish prey in Chinook diets varied by year and sampling period (Fig. 8). The average amount of prey consumed as a percent of juvenile Chinook body weight was approximately 0.82% (s = 1.09%) in 2016 compared with 1.7% (s = 1.4%) in 2014 and 1.9 % (s = 1.5%) in 2015. Stomach fullness was lower in most sampling weeks than in either 2014 or 2015, and was an order of magnitude lower in May and the early part of June (Fig. 9). Stomach fullness had no relation to water temperature (r = 0.12) or river discharge (r = 0.056) and did not vary by distributary.

Chinook from the delta front ranged in length from 82 to 131 mm. Over half of the Chinook had empty stomachs. Of the Chinook that had prey in their stomachs, 95% of the diets by weight were fish, with the remainder composed of gammarid amphipods (1.57%), insects (1.35%), crab zoea (1.04%), and other (0.95%). The average percent body weight of prey varied by transect with fish at the Okshok transect north of the Yukon Delta having the highest percent body weight (Fig. 10).

Energy densities in all years varied by sampling week. Energy density for juvenile Chinook in 2016 was significantly lower than either 2014 or 2015 (p < 0.001, p < 0.001, respectively) with median energy density diverging strongly from prior year values beginning in late June (week 26, Fig. 11). In 2016, energy densities declined slightly but significantly (p = 0.0007) with fork length over the entire sampling period. Energy densities did not vary by distributary.

Average energy density for juvenile Chinook from the front was lower than average energy density from the river during this same time period (19.8kJ/g vs. 20.24 kJ/g). Energy densities were also lower than juvenile Chinook salmon from prior sampling years.

Drift Composition

The drift sample ordination based on invertebrate families had three dimensions and a stress of 0.13. Drift samples collected at different stations and in different distributaries overlapped in the ordination (Fig. 12) and MANOVA results showed no differences by station or distributary (p-value = 0.12 and p-value = 0.26, respectively). There were significant differences in samples collected across the three time periods (p-value = 0.001) and samples from the middle time period had high Axis 2 scores in the ordination. Total drift densities (all organisms summed) were not significantly different by time period (p-value = 0.74) so differences between drift samples collected in the second half of June and those collected earlier or later were driven by composition. Taxa with significant differences (p ≤ 0.5) in their abundance between the middle and either early or late time periods included Auchenorrhyncha (a suborder of true bugs, Hemiptera), Heteroptera (also a suborder of true bugs), Polycentropodidae (a family of caddisflies, Trichoptera), and Sciaridae (a family of true flies, Diptera).

Densities of prey groups in the drift spanned four orders of magnitude and several groups showed a peak in availability during the summer season (Fig. 13). The most abundant prey groups were mites (Acari), spiders (Araneae), true flies (Diptera) and bees and wasps (Hymenoptera). Mites, stoneflies (Plecoptera), and caddisflies (Trichoptera) had the most pronounced peaks during the summer season, but models of taxa densities based on date and date squared had poor fits to the data (R^2 ranged from 0.003 for Araneae to 0.11 for Plecoptera).

Prey Composition and Selection

Important prey groups for both Chinook and coho included fish (teleost), stoneflies (Plecoptera), true flies (Diptera), beetles (Coleoptera), and mayflies (Ephemeroptera, Fig. 14). Caddisflies (Trichoptera) and true bugs (Hemiptera) comprised more biomass in the diets of Chinook salmon than coho salmon (Fig. 15). Large variation in lipid content for the different groups reflect differences across the summer season and/or differences across taxa within a group.

Chinook preferentially selected caddisflies, mayflies, fish, stoneflies, beetles, and true bugs in proportions greater than their availability in the drift for some time periods and river channels (Fig. 15). True flies were selected in proportions equal to their availability across distributaries

and time periods ($E_i \sim 0$). The only obvious seasonal pattern was the selection of beetles during the latest time period in all distributaries. There were no patterns in selection by distributary.

Coho salmon had similar preferences as Chinook, with positive electivity indices across most time periods and distributaries for mayflies, caddisflies, fish, and stoneflies (Fig. 16). Seed shrimp (Ostracoda) were important in early summer in the NM and nematodes were strongly selected for in the SM and both time periods. True flies were again selected in proportions equal to their availability in the drift ($E_i \sim 0$).

Fish were considered as potential prey for juvenile Chinook salmon if they were listed as prey in the literature, or were identified as a diet item in this study. The major fish prey items examined in this study were juveniles of chum and pink salmon, burbot, cisco, and whitefish. Other species, including juvenile smelts (Osmeridae) and sheefish (*Stenodus leucichthys*), were captured during the study; however, these species were not directly identified in the stomach contents of juvenile Chinook. Additionally, both smelt and sheefish were sampled in limited numbers and occurred at sizes greater than the maximum size at which they are vulnerable to predation by Chinook. Fish in diets of juvenile Chinook captured on the front were tentatively identified as larval Pacific sand lance (*Ammodytes hexapterus* Pallas); however, sand lance were not captured in the sampling gear. Studies have suggested that juvenile salmon can consume prey that are 41% to 50% of their body length (Weitkamp 2005); however, field measurements of predator-prey ratios are generally much smaller (Pearsons and Fritts 1999, Weitkamp 2005, Chamberlin et al. 2017). In this research predator-prey ratios averaged between 0.38 and 0.31.

Fish prey varied spatially and temporally. Pink salmon were very abundant in catches in 2015 but less abundant in 2014 and 2016 reflecting the alternate year run strength for this species in the Yukon River (Howard et al. 2017). All prey species were more abundant and CPUE was higher in 2015 than in the other two sampling years (Fig. 17). Chum salmon and whitefish species catches were lower in 2016. With the exception of pink salmon, succession of prey species was similar in all three sampling years. Chum were most abundant in the early part of the summer, cisco appeared in catches near the end of June, and burbot showed up near the middle of July. Prey availability was lowest in all sampling weeks in 2016.

Differences in size and abundance by distributary were observed for some prey species in 2016 (Appendix 1: Figs. 1A – 1E). Juvenile burbot had a higher frequency of occurrence in NM and MM than in SM. Chum salmon appear to use all three tributaries relatively equally during the first part of the summer, but are observed more frequently in SM and MM after the end of June. Both cisco and whitefish had similar abundances and composition of size classes between distributaries.

All fish prey species rapidly outgrew their susceptibility to predation by Chinook salmon (Appendix 2: Figs. 2A – 2E). For chum salmon, the majority had outgrown most Chinook salmon predation potential within the first couple of weeks of sampling in each year. During the early part of the 2016 sampling period, fish prey was a substantial component of Chinook diets only during the first week of sampling. Fish were absent from the diets until the end of June (week 25) when juvenile burbot and cisco became available. Fish prey consumption in 2015 dropped in July despite extremely high abundances of this prey group. Juvenile Chinook salmon size in 2015 remained relatively constant during the sampling period, in contrast to 2016 and especially 2014 where Chinook size increased. As a result, it appears that juvenile Chinook captured in July were too small to take advantage of the amply available prey.

Prey Quality

The highest quality prey items included leeches, amphipods, mayflies, and roundworms (lipid content greater than 5%, Fig. 18). Beetles, caddisflies, and true flies were the next highest quality prey items with values ranging from 2 to 5%. Large variation in lipid content for the different groups reflected differences between taxa within a group as samples were collected in a short time window of less than a week in late June-early July.

Energy content of fish prey was examined to evaluate the quality of prey as food. Only fish prey within the predation size of juvenile Chinook salmon was included in the analysis. Unfortunately, the small size of the fish prey items resulted in dried homogenates that were insufficient to constitute an individual bomb calorimetry sample for each sampling week. As a result, homogenates were composited from all weeks of sampling with the ability to evaluate changes in energy density over time being lost. Prey energy content differed by fish species, with young-of-the-year burbot having the lowest energy content and young-of-the-year cisco having the highest energy content (Fig. 19).

DISCUSSION

This study provided insight into spatial and temporal distributions of juvenile Chinook salmon prey resources on the Yukon Delta during salmon outmigration. Juvenile Chinook consumed a variety of drift and fish prey which were widely available in all three Yukon River distributaries.

The composition of drift samples varied temporally with large differences between samples collected at the beginning, middle and end of the summer, but the total amount of drift remained relatively constant. Fish prey resources were strongly time-dependent. Young of the year of individual fish species had defined occurrences with juvenile salmonids (pink and chum) occurring in the early summer, and coregonids (whitefish and cisco) and burbot occurring near the end of June or beginning of July. Both the abundance and the timing of juvenile fish prey varied between sampling years, and all species of fish prey were more abundant in 2015 than in other years. Higher pink salmon abundance was likely the result of alternate year class cycles for this species, but the high occurrence of coregonid and burbot juveniles does not have a ready explanation. Little is known about the patterns of abundance of these relatively understudied species, and it is not known whether they have alternate year abundances similar to pink salmon.

The proportion of piscivorous juvenile Chinook salmon was similar in all three sampling years. Comparison of size distributions of fish prey and Chinook salmon during sampling weeks from 2014 through 2016 show that fish prey rapidly outgrew their susceptibility to Chinook predation. Although patterns in prey overlap with Chinook size generally explain patterns when Chinook were consuming fish, they are not able to explain differences in the quantity of fish consumed. For example, in sampling weeks 25 and 26 of 2016, when prey size was low relative to Chinook salmon size, fish consumption was only moderate. In comparison, fish prey consumption was highest during sampling week 22 when prey and Chinook size overlap was only modest. Fish prey consumption was more continuous throughout the summer in 2014, consistent with the relative overlap between fish prey size and juvenile Chinook size. In 2015 and to a lesser extent 2016, small-sized Chinook appeared in the samples late in the summer after most fish prey had outgrown their susceptibility to predation.

Several orders of aquatic and terrestrial insects and fish were important prey items found in the stomachs of juvenile salmonids. Chinook and coho salmon showed similar patterns in their diets across time periods and river channels, although Chinook appeared to rely more on caddisflies and coho on fish. The importance of caddisflies, mayflies, stoneflies, and true flies aligns with other diet studies, especially those from freshwater habitats (Rine et al. 2016). The highest quality drift taxa were not necessarily the most preferred drift taxa. Mayflies were preferentially eaten while leeches were avoided by both Chinook and coho juveniles, despite the fact that both had high lipid content. Since leeches lack hard body parts, they may not have been identifiable in the stomach contents. Alternatively, Piscicolid leeches (all identified leeches belonged to this family) are parasitic on fish, which may make them less vulnerable to predation. Amphipods were selected by both species early in the season and roundworms were selected by both species in the south distributary, but not in other distributaries.

Low stomach fullness and energy content of 2016 Chinook suggest potential challenges in accessing prey resources during certain periods of the summer compared to Chinook in 2014 and 2015. Average stomach fullness in 2016 was 34% lower than in 2014, and 29% lower than in 2015 with some weekly fullness values less than half those of the prior years. There is limited information on feeding intensity of age-1 Chinook during outmigration, making comparison of our results to other research challenging. Several studies have found that Chinook feeding intensity varies throughout the day (Schabetsberger et al. 2003, Duffy et al. 2010), but it is unlikely that this would explain the differences between sampling years as all sampling was conducted within a similar timeframe. Both discharge and temperature may decrease feeding intensity. High discharge has been hypothesized to decrease prey encounter rates (Neuswanger et al. 2015), while increased temperature can increase gastric evacuation (Benkwitt et al. 2009). However, no relationship between stomach fullness and temperature or discharge was observed.

Combined with low stomach fullness, the decreasing pattern of energy density throughout the summer is suggestive of energetic stress possibly related to low density of prey resources. Drift sample densities indicated that some prey groups peaked in their availability during the middle of the summer season, which may impact growth for juveniles entering the delta later in the summer. Decreases in drift prey densities coincided with low fullness and energy density in late June and through July. Catch of chum salmon and whitefish in size ranges susceptible to Chinook predation were lower in 2016 than the other sampling years. Young of the year coregonids (whitefish and cisco) are morphologically similar and are difficult to distinguish in stomach samples. The high proportion of fish in the diets in early July 2014 and 2015 correspond to high densities of small whitefish in these years. If Chinook preferentially consume whitefish over cisco, low densities of whitefish might be a factor in the lower proportion of fish in Chinook diets in July 2016. Lower prey densities, combined with the natural turbidity of Yukon River water, may reduce encounters between predators and prey. Turbidity was not directly measured in this study and was assumed to be a factor of river discharge. Although discharge patterns differed between sampling years, late summer discharge in 2016 was below the long-term median.

The energetic quality of prey resources is an important factor in juvenile Chinook salmon condition. Drift and fish prey sample sizes were too small to evaluate changes in prey quality through the summer. For fish prey in particular, it would be beneficial to evaluate changes in fish prey quality with respect to Chinook energetic condition, since fish species may respond to environmental conditions in similar ways. Prior research has suggested that fish prey may be a higher quality diet than drift organisms (Daly et al. 2009, Duffy et al. 2010, Litz et al. 2016). Due to the small sample sizes of drift prey available for analysis, we were not able to directly compare the energy content of drift and fish prey. However, comparison of Chinook diets to

median energy densities between sampling weeks did not indicate a strong relationship between Chinook energetic condition and diet components. Chinook energetic condition in 2016 was low throughout the sampling period, and did not vary with variations in diet. Similarly, energetic condition of juvenile Chinook in July of 2015 was similar to that observed in 2014 despite the fact that as much as 80% of the Chinook diet in 2014 was fish compared to less than 20% in 2015. Because juvenile Chinook salmon collected for diet analyses were preserved in formalin to reduce digestion, they could not be used in bomb calorimetry for measuring energy content. Therefore, we were not able to directly compare diets with energetic condition using the same samples. To enhance comparability between energy content and diets of juvenile Chinook, future research should investigate alternative methods for diet sample collection (e.g., gastric lavage) and incorporate additional laboratory analyses, such as fatty acids and stable isotopes, to evaluate diets integrated over a longer period of time (Litz et al. 2016).

The patterns in prey consumption, diet, and energetic content were very different for juvenile Chinook salmon in the river compared to those on the front. Chinook from the front had a much higher incidence of empty stomachs than Chinook in the river. High incidence of empty stomachs may be a factor of the need to adapt to a new feeding environment and prey spectrum (Brodeur and Morgan 2016). The percent of empty stomachs was much higher than in other nearshore studies (Weitkamp and Sturdevant 2008, Daly et al. 2009), suggesting that factors, such as condition on marine entry, may also play a role in foraging ability. Additional data on past prey consumption and energy density of fish with empty stomachs could potentially shed light on the condition of Chinook upon entering marine waters. The higher average stomach fullness of feeding front Chinook compared with those from the river, suggests that, once found, prey resources appear to be plentiful.

Future research should continue sampling both juvenile Chinook and their prey to investigate the inter-annual variability in available food and juvenile use of those food resources. Additionally, prey item quality should be examined across different time periods and for additional taxa to investigate the importance of quality on food selection. The sampling years evaluated in this report contain only a single year (2015) of high pink salmon outmigration. This year also had much higher catches of other Chinook fish prey species, raising the question of whether variability in these other species is also along a predictable, alternating schedule. The higher stomach fullness of Chinook in 2014 and 2015 suggests that densities of drift prey resources may also have been higher than in 2016. Patterns in drift densities were not strongly correlated to seasonal development, indicating that other factors, such as river temperatures and discharge, may be playing important roles controlling prey availability (Brittain and Eikeland

1988). Continued sampling of drift abundance and composition could provide insight into the influence of climactic changes on prey availability. Future research should also include more intensive sampling of juvenile Chinook and prey resources on the delta front. In particular, it is important to evaluate diets with energetic condition and investigations of prior prey consumption through the use of fatty acids and isotopes. This could help assess whether condition of Chinook as they leave the river is a factor in feeding success once in the marine environment.

The general patterns investigated in this research provide insight into factors that may affect juvenile Chinook salmon growth and condition prior to their first marine summer. However, additional tools are needed to tease out factors contributing to variation in diets and energetic content. This survey samples several migrating populations of Chinook, some of which have travelled up to 3,000 km and some that originated from tributaries in the Lower Yukon. It is reasonable to expect that there may be differences in growth and condition based on distance traveled and habitats encountered. New tools, such as advanced genomic methods or otolith chemistry, need to be evaluated for their potential to identify groups or clusters within the outmigration that can provide insight into factors affecting juvenile Chinook salmon health.

ACKNOWLEDGMENTS

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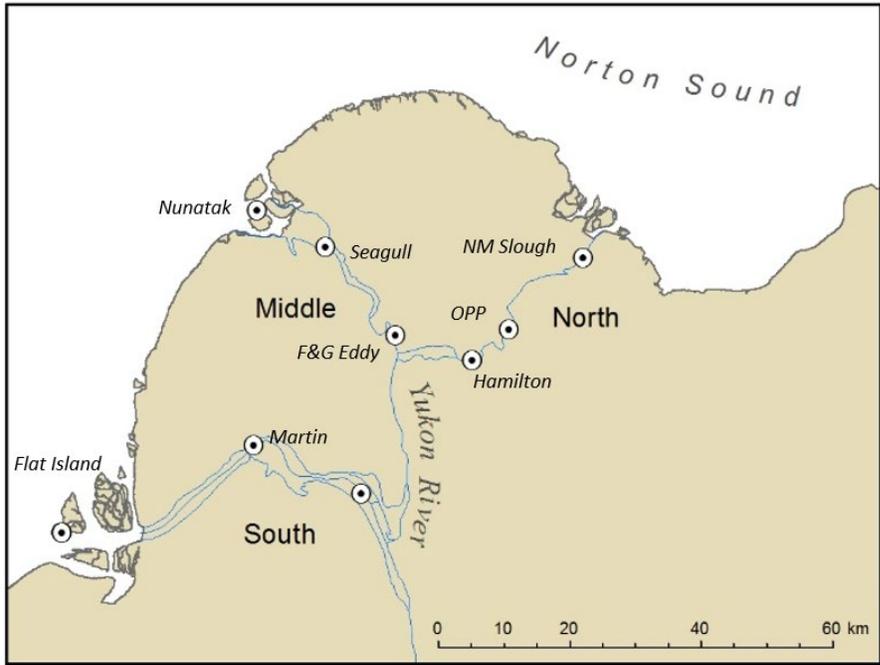
Figure 1 -- Permanent sampling stations (circled dots) on the three main lower Yukon River tributaries
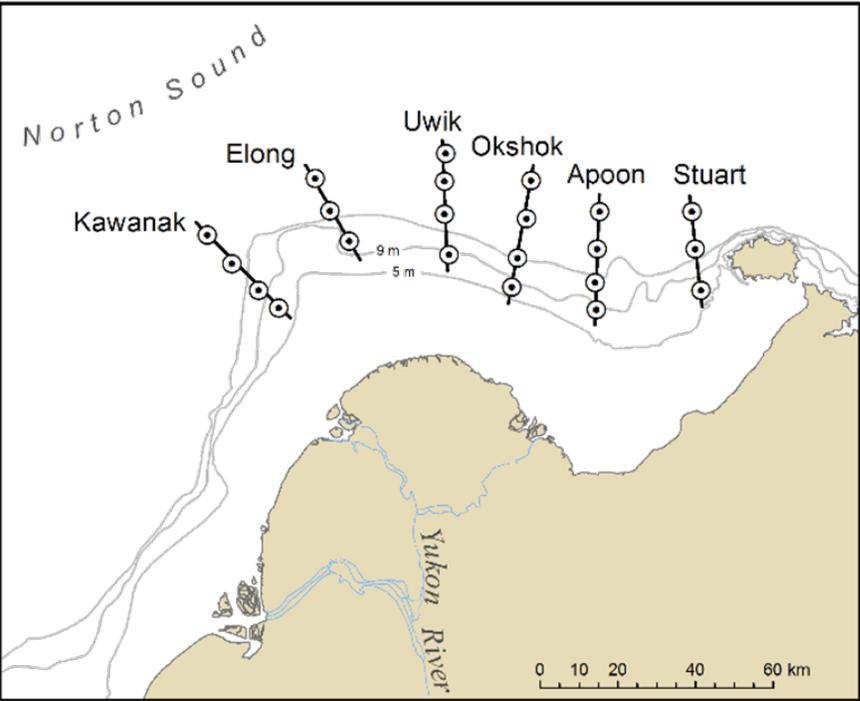
Figure 2 -- Permanent sampling transects and stations (circled dots) on the Yukon Delta front.
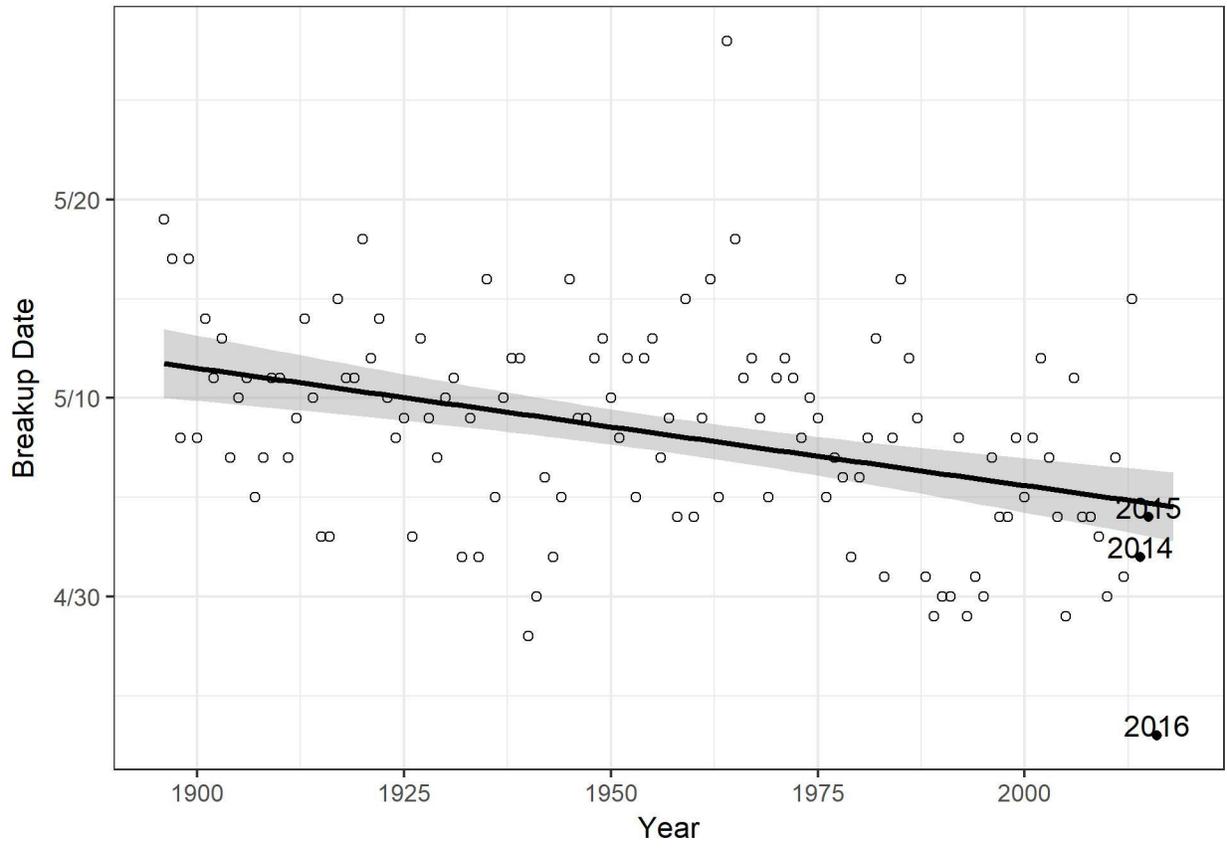
Figure 3. -- Ice break-up dates by year for the Yukon River at Dawson City, Canada. Black line shows the average breakup date with the gray band denoting the 95% confidence interval. Sampling years are identified in black.
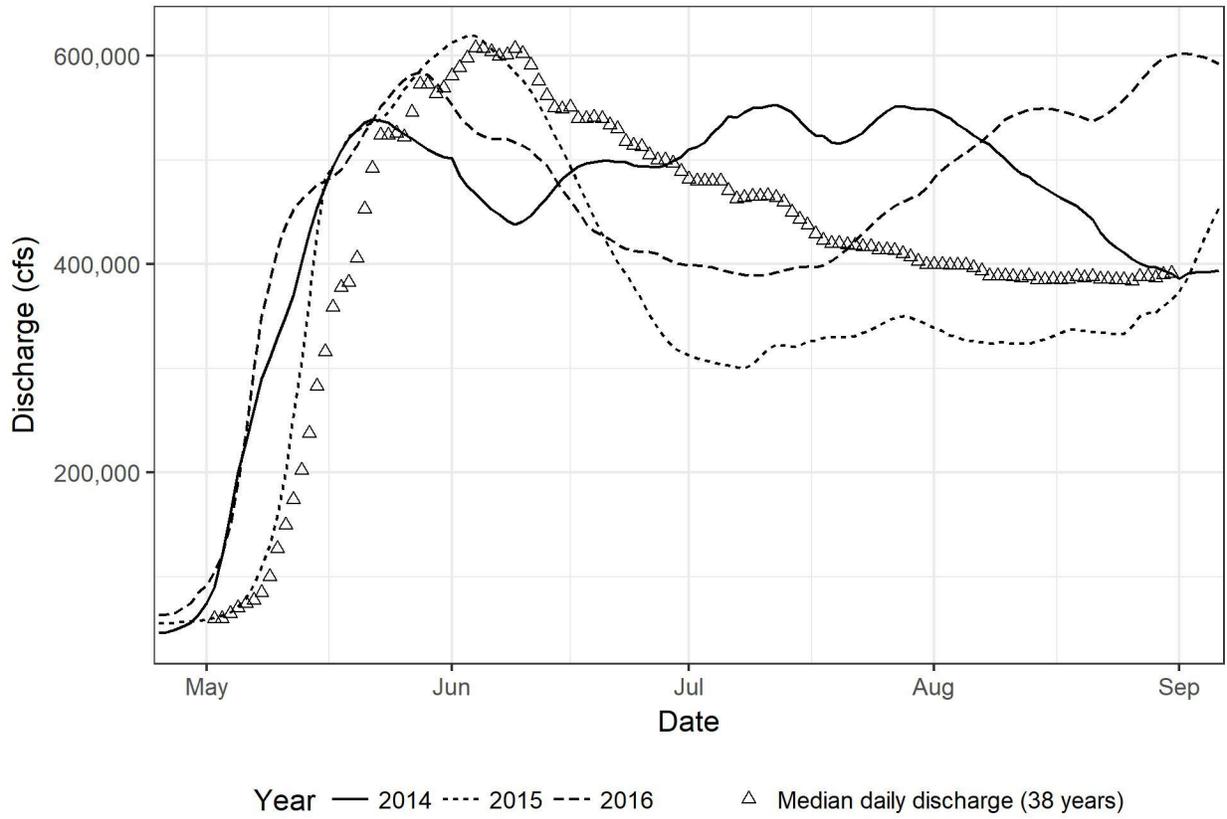
Figure 4 -- Yukon River discharge at the USGS Pilot Station gauge in cubic feet per second (cfs). Discharge for each study year are shown with the 38-year median discharge from 1978 to 2016.
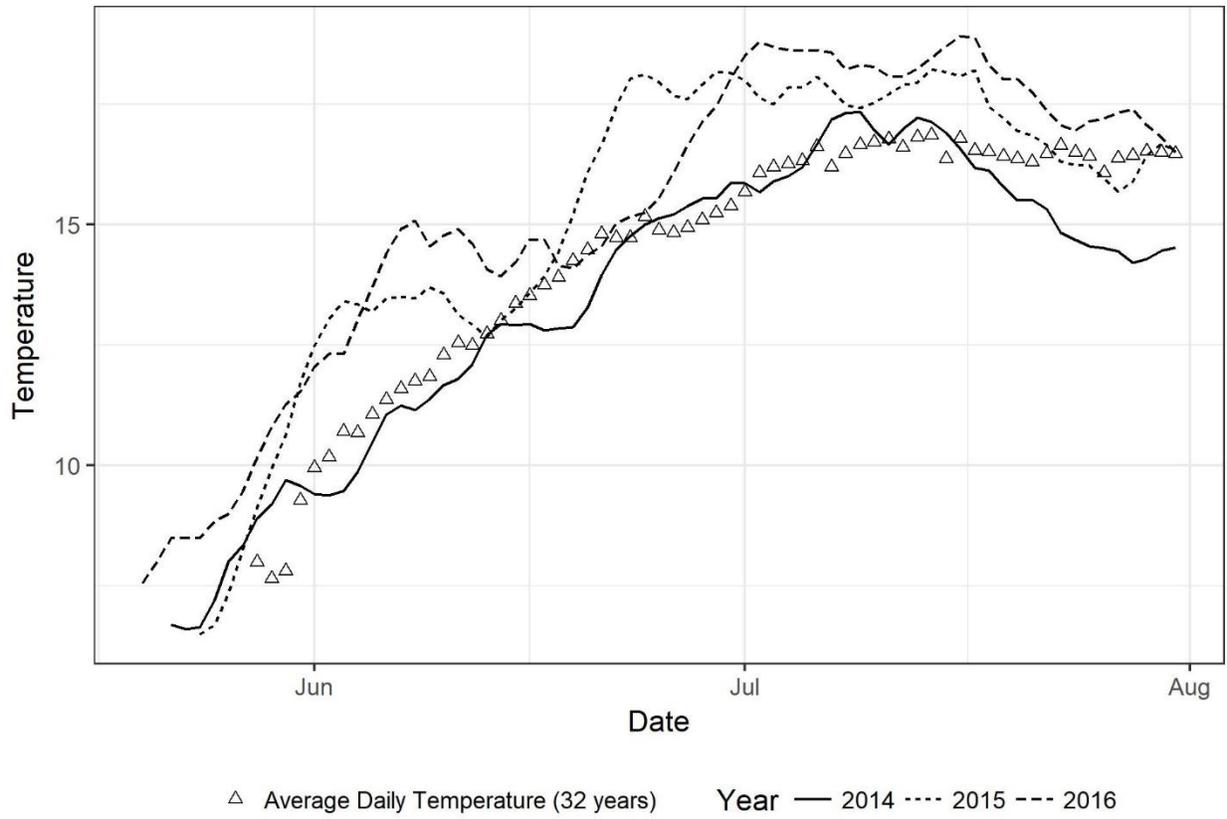
Figure 5 --In situ water temperatures (°C) in the lower Yukon River compiled from data collected by the Alaska Department of Fish and Game lower Yukon River test fishery.
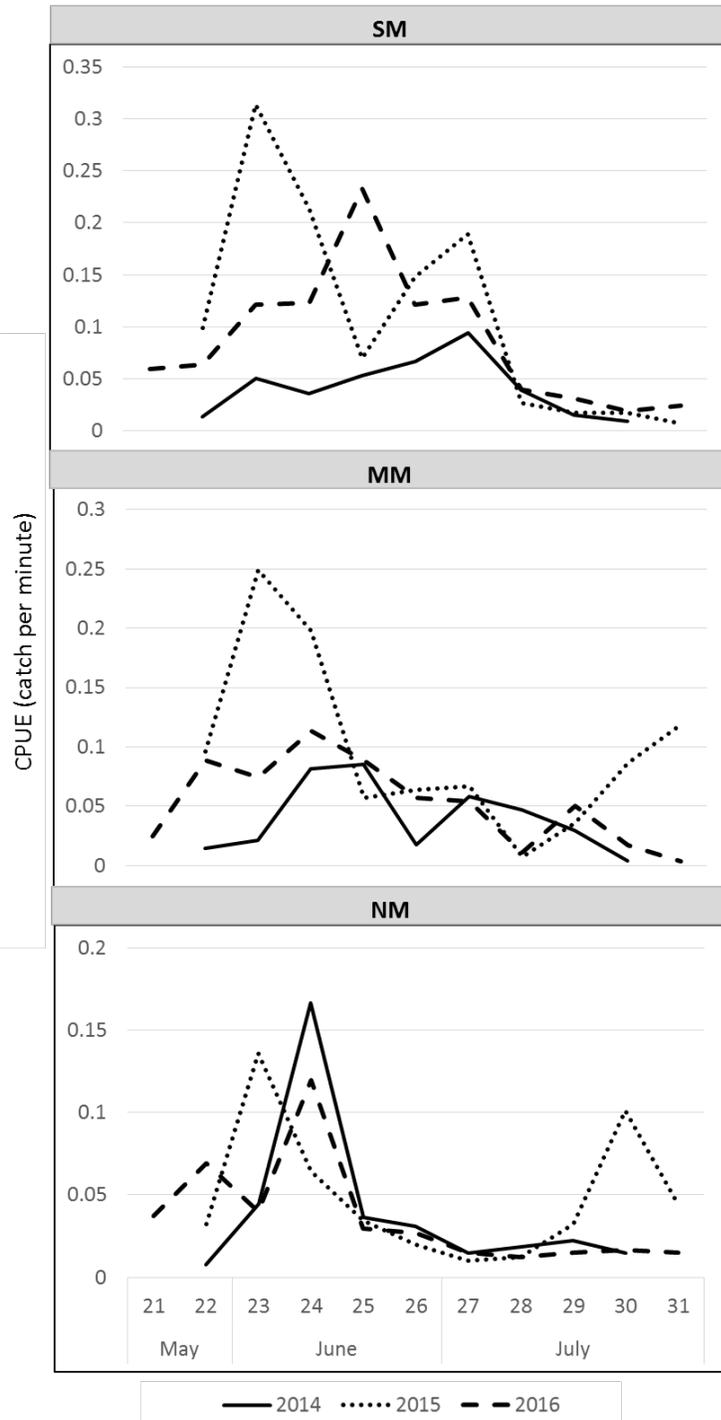
Figure 6 -- Variation in CPUE of juvenile Chinook by distributary. SM = South Mouth, MM = Middle Mouth, NM = North Mouth.
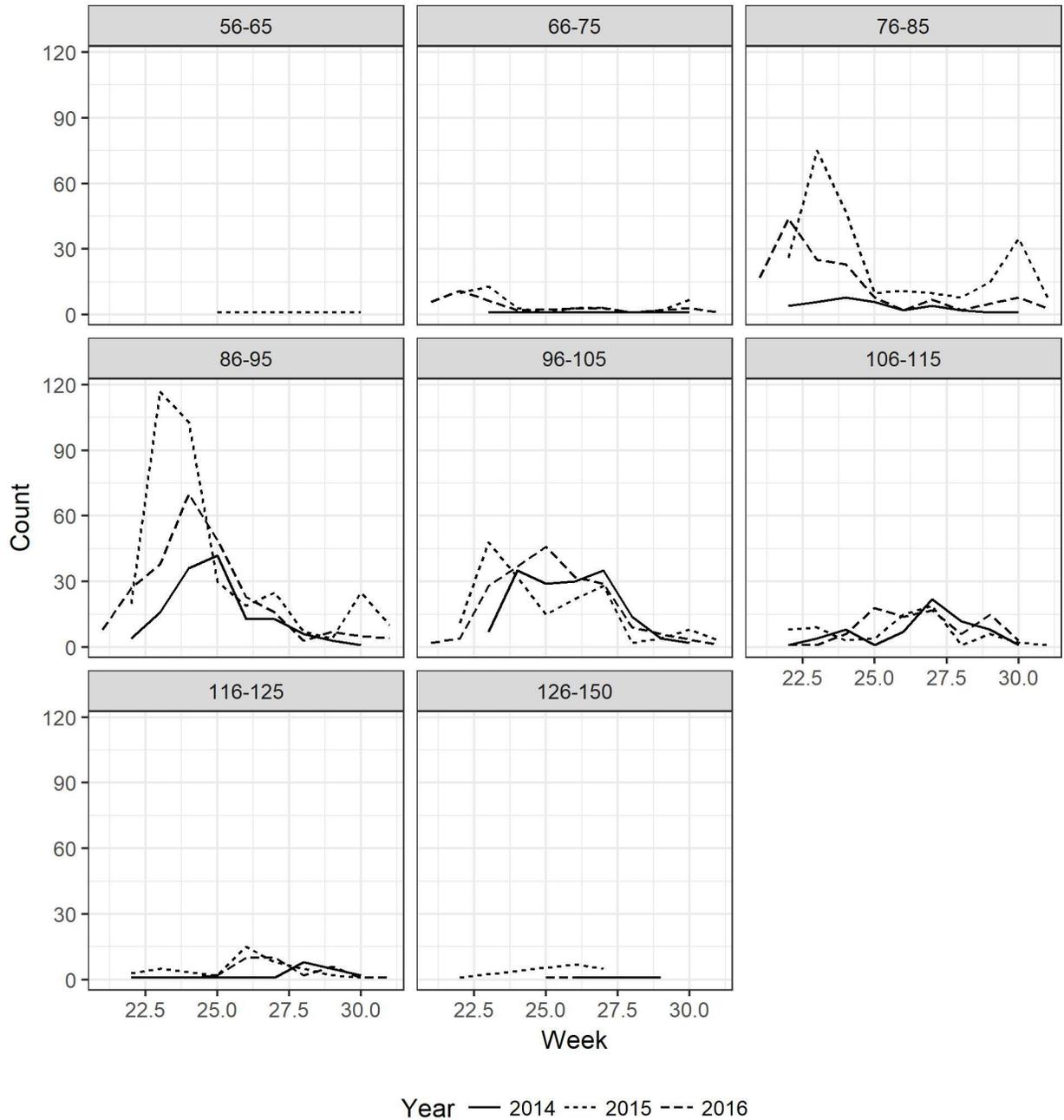
Figure 7. -- Juvenile Chinook salmon length in 10 mm bins by year and sampling week.
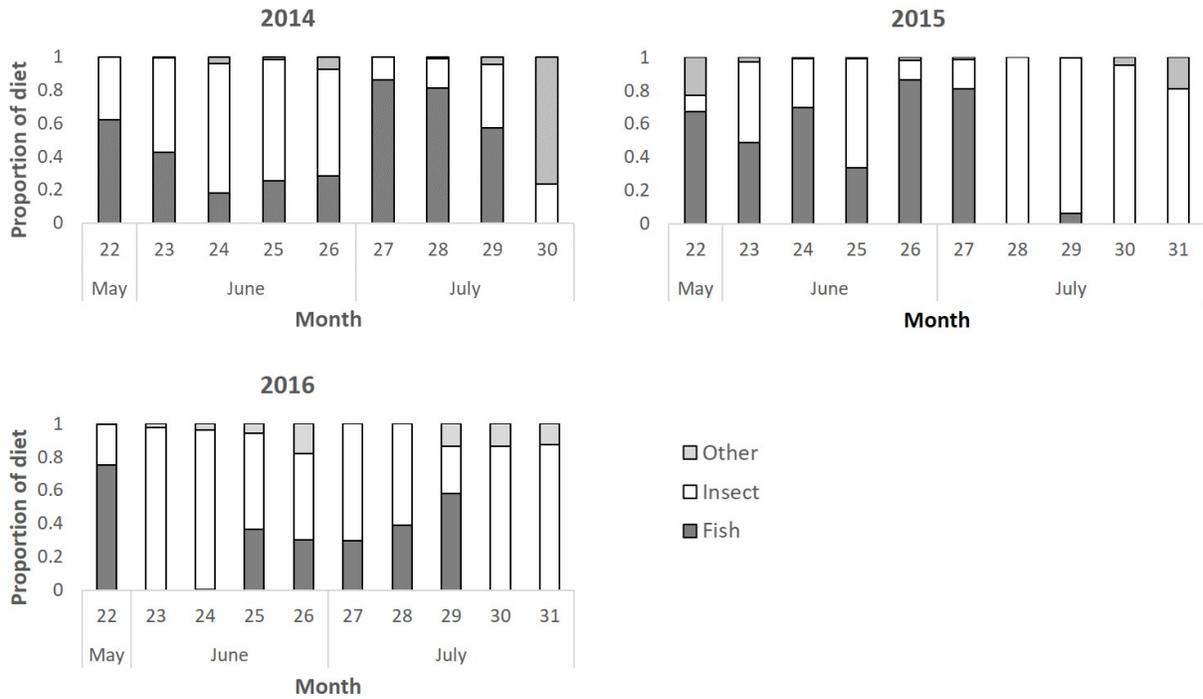
Figure 8. -- Proportion of fish, invertebrates and other items in the diets of juvenile Chinook
salmon on the lower Yukon River 2014-2016.
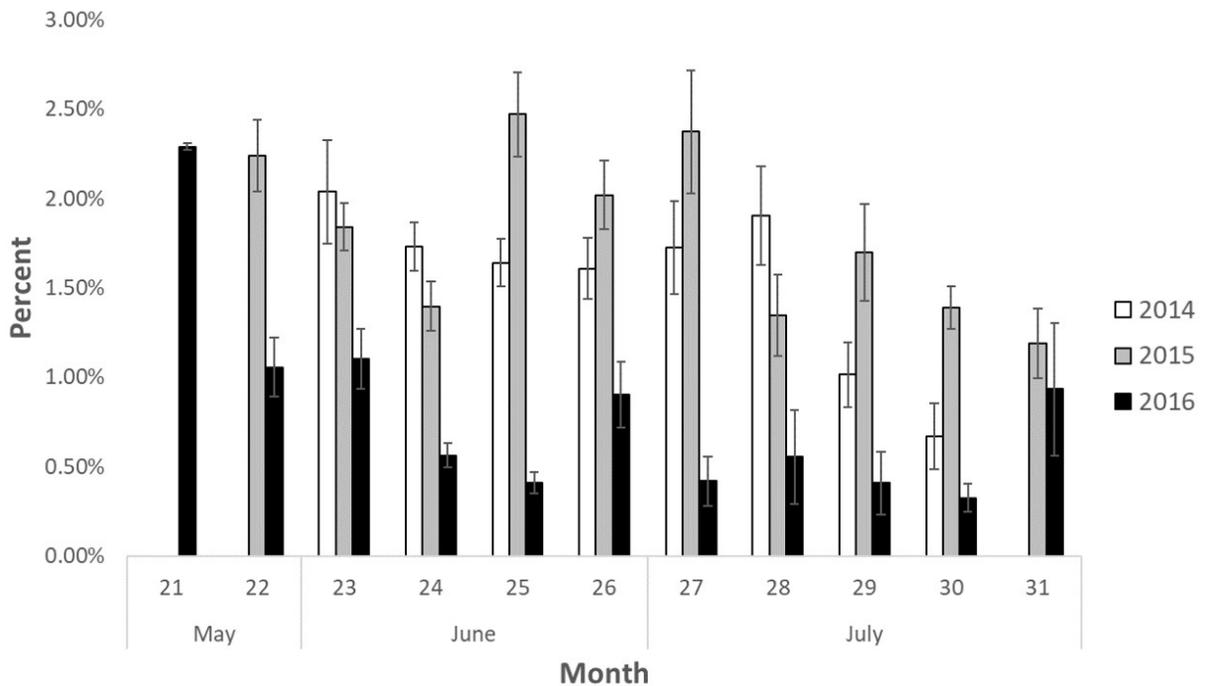
Figure 9. -- Average Chinook stomach fullness as percent body weight by sampling week and
year. Lines represent standard errors.
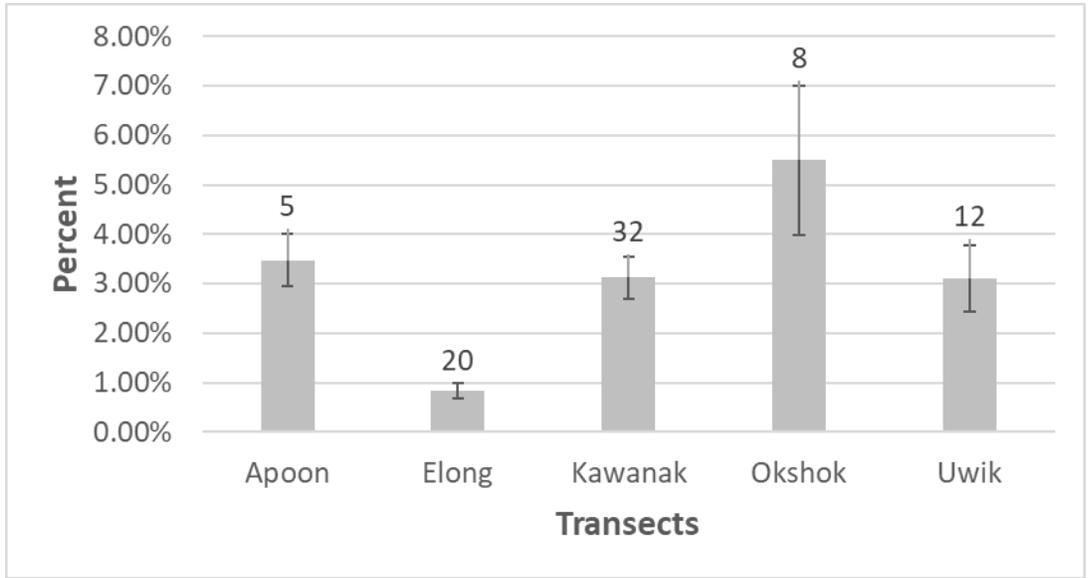
Figure 10. --Stomach fullness as a percent of body weight for juvenile Chinook salmon captured on the Yukon Delta front in 2016. Lines are standard errors. Numbers over the bars are the sample size.
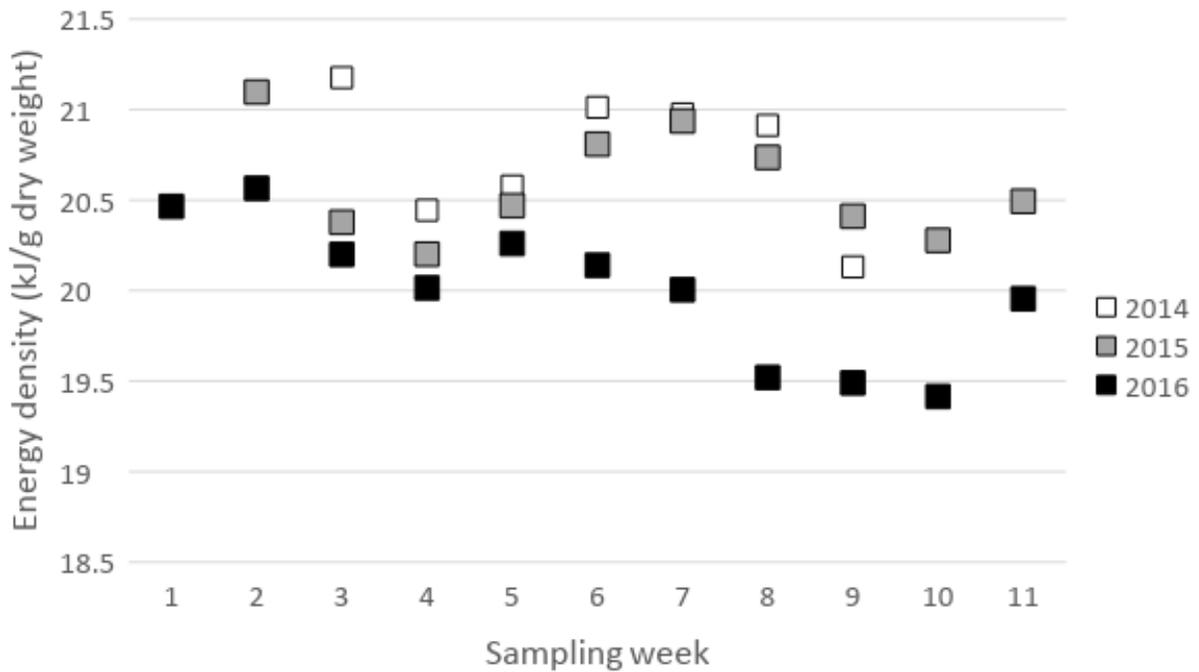
Figure 11. -- Median energy densities of juvenile Chinook salmon on the lower Yukon by sampling week and year.
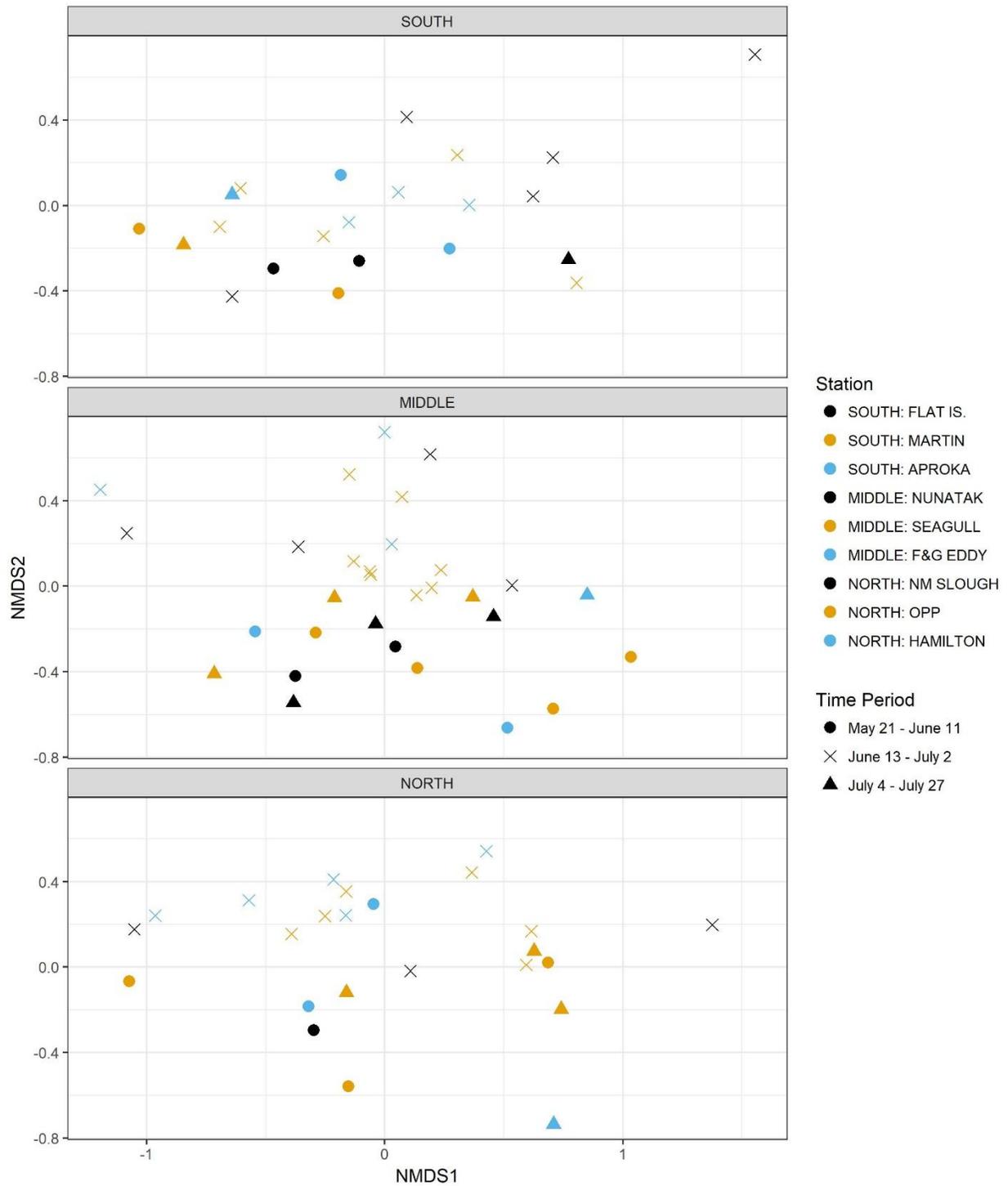
Figure 12. -- NMS ordination of drift samples by distributary (top to bottom), station (colors), and time period (shape). Samples from the middle time period had variable axis 1 scores and high axis 2 scores.
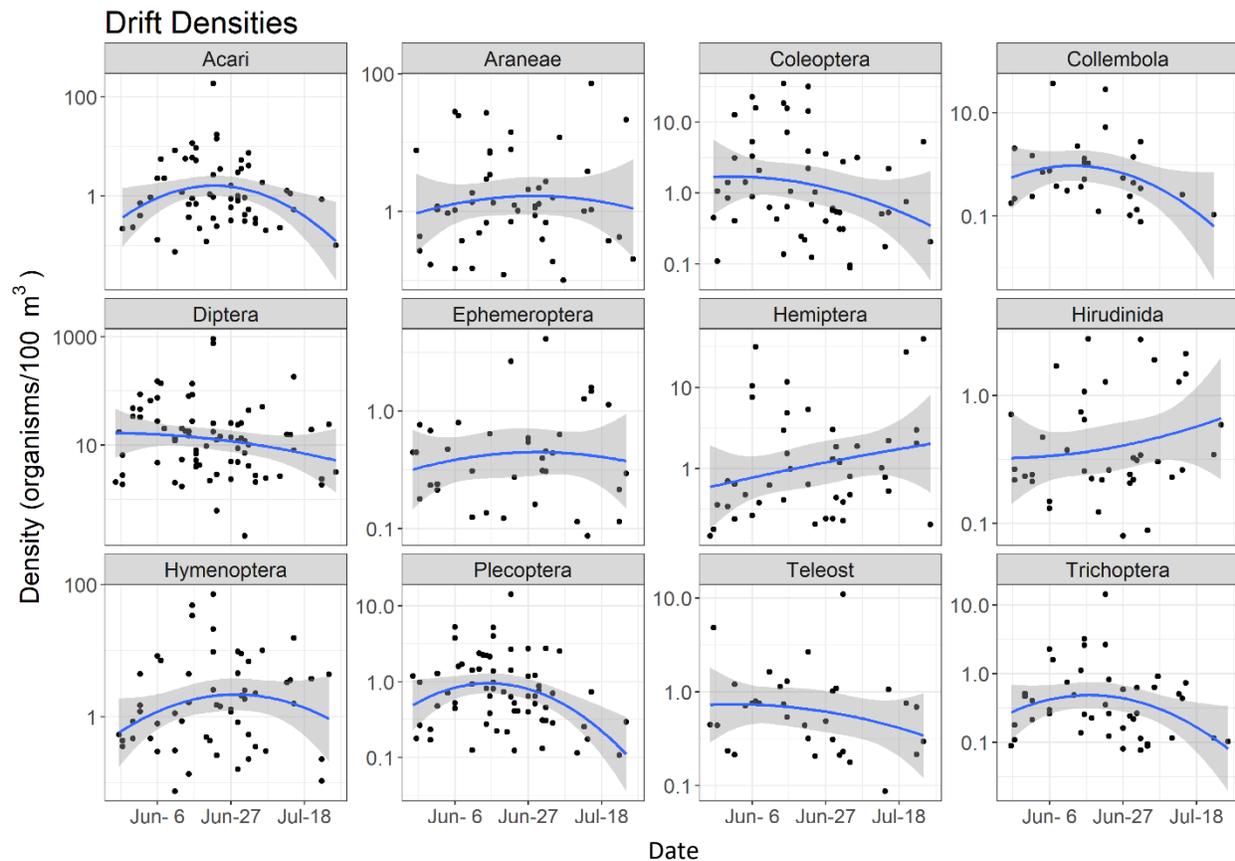
Figure 13. -- Patterns in drift densities for groups that occurred in 30% or more of the 76 drift samples processed. Blue lines are modeled densities using data and date squared as predictors to allow for non-linearities over time and gray bands are 95% confidence intervals. Note: Y-axes are different across taxa.

Figure 14. -- Proportion dry mass of prey items in Chinook and coho salmon stomachs by time period and distributary. Early time period = 21 May – 11 June, middle time period = 13 June – 2 July, and late time period = 4 July – 27 July. Coho salmon were only caught in the early and middle time periods. Prey items with > 2% mass during one or more time periods are shown.
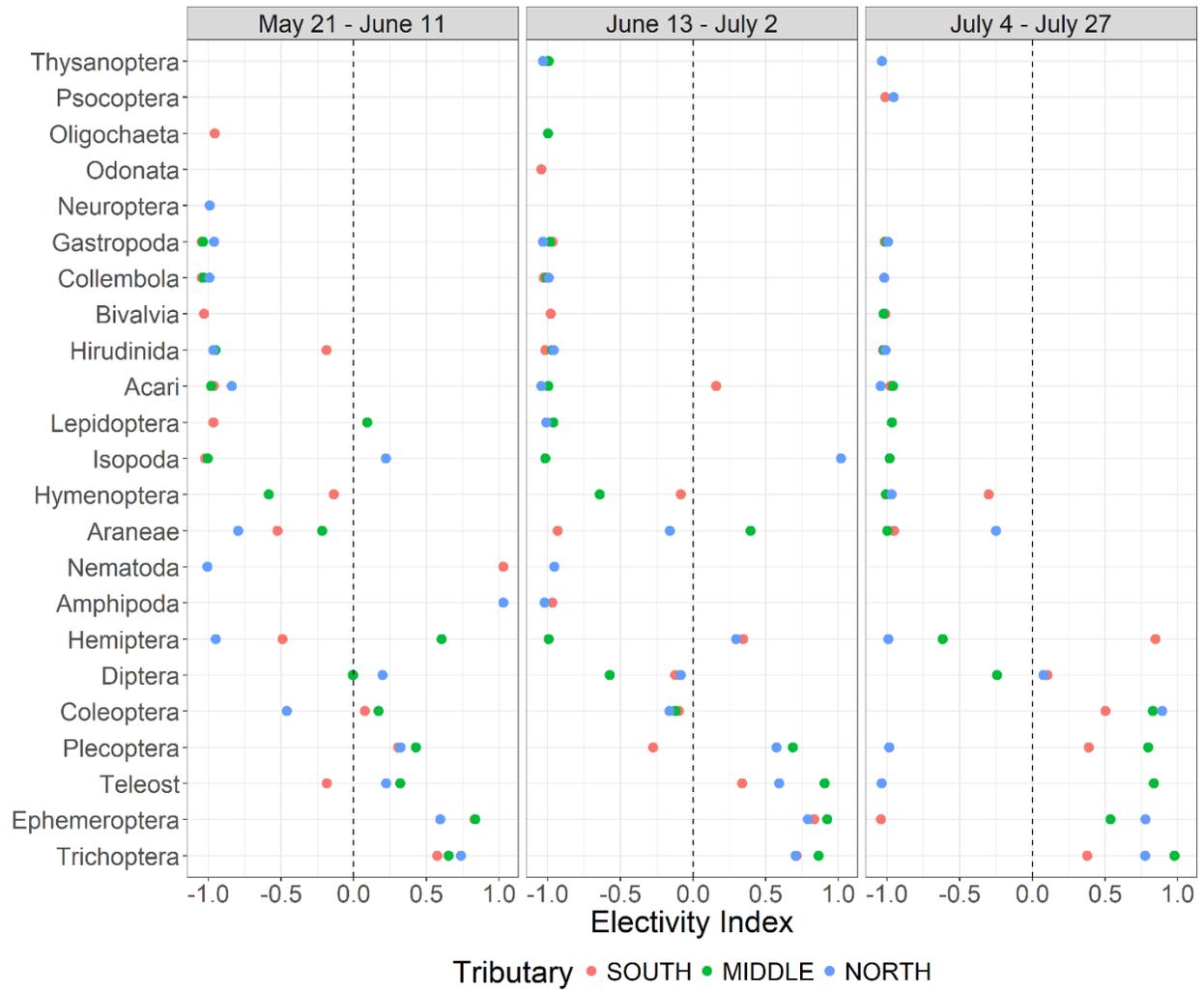
Figure 15. -- Selection of prey by juvenile Chinook salmon across distributary and time period using Ivlev's Electivity Index. Values close to zero (dashed line) indicate prey items selected in equal proportion to their presence in the drift samples.
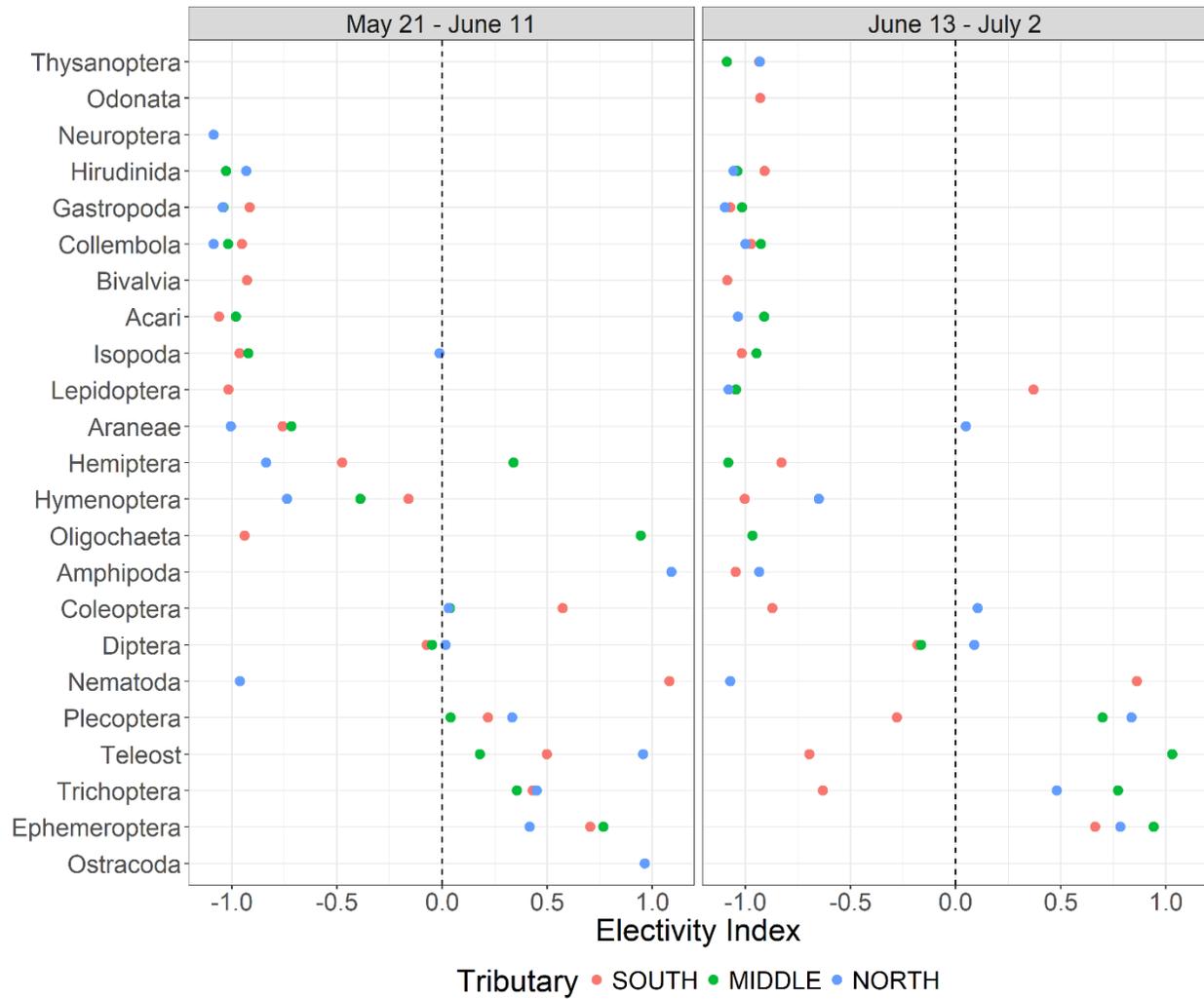
Figure 16. --Selection of prey by juvenile coho salmon across distributary and time period using Ivlev's Electivity Index. Dotted lines indicate point where prey items were selected in equal proportion to their presence in the drift samples.
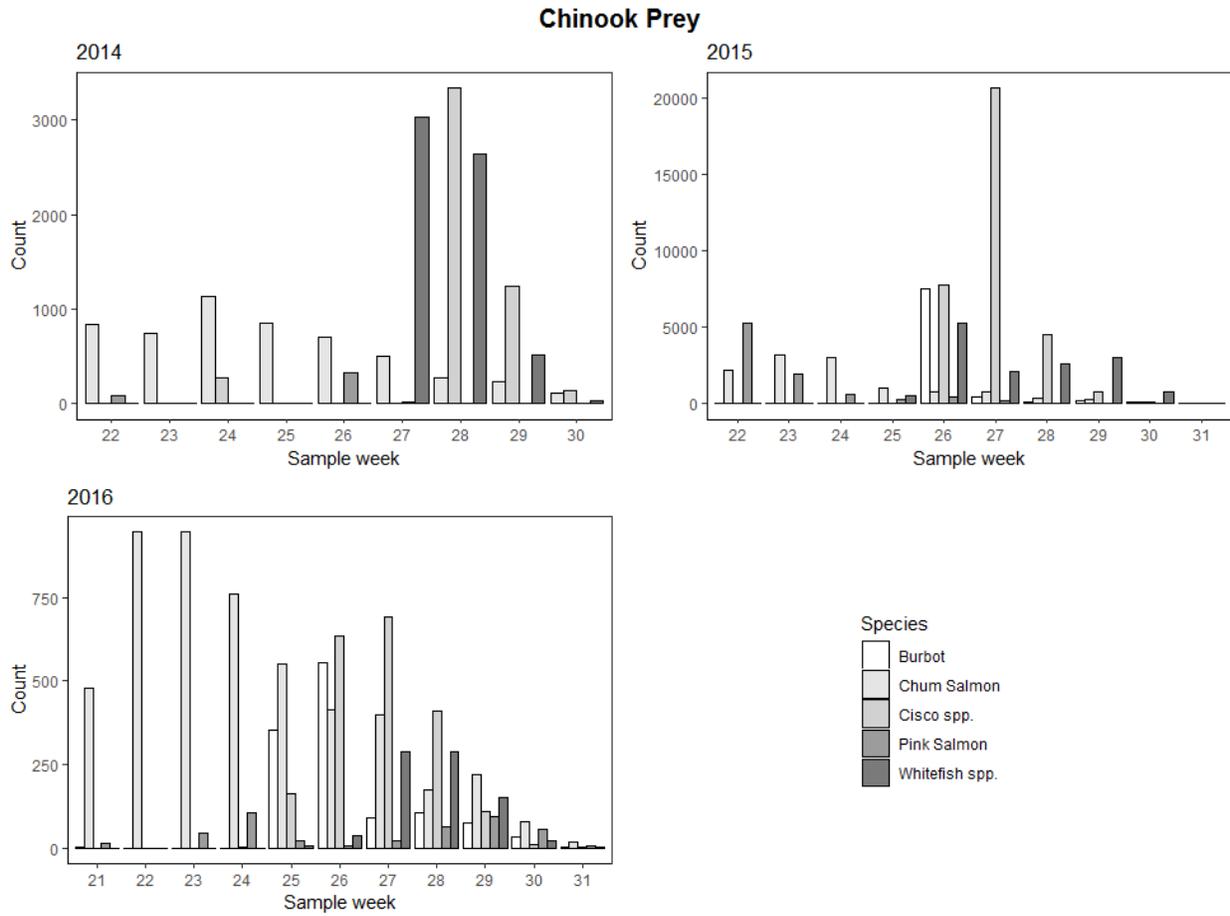
Chinook Prey

Figure 17. --Abundance of Chinook fish prey by sampling week and year. Note different y-axes on the individual plots.
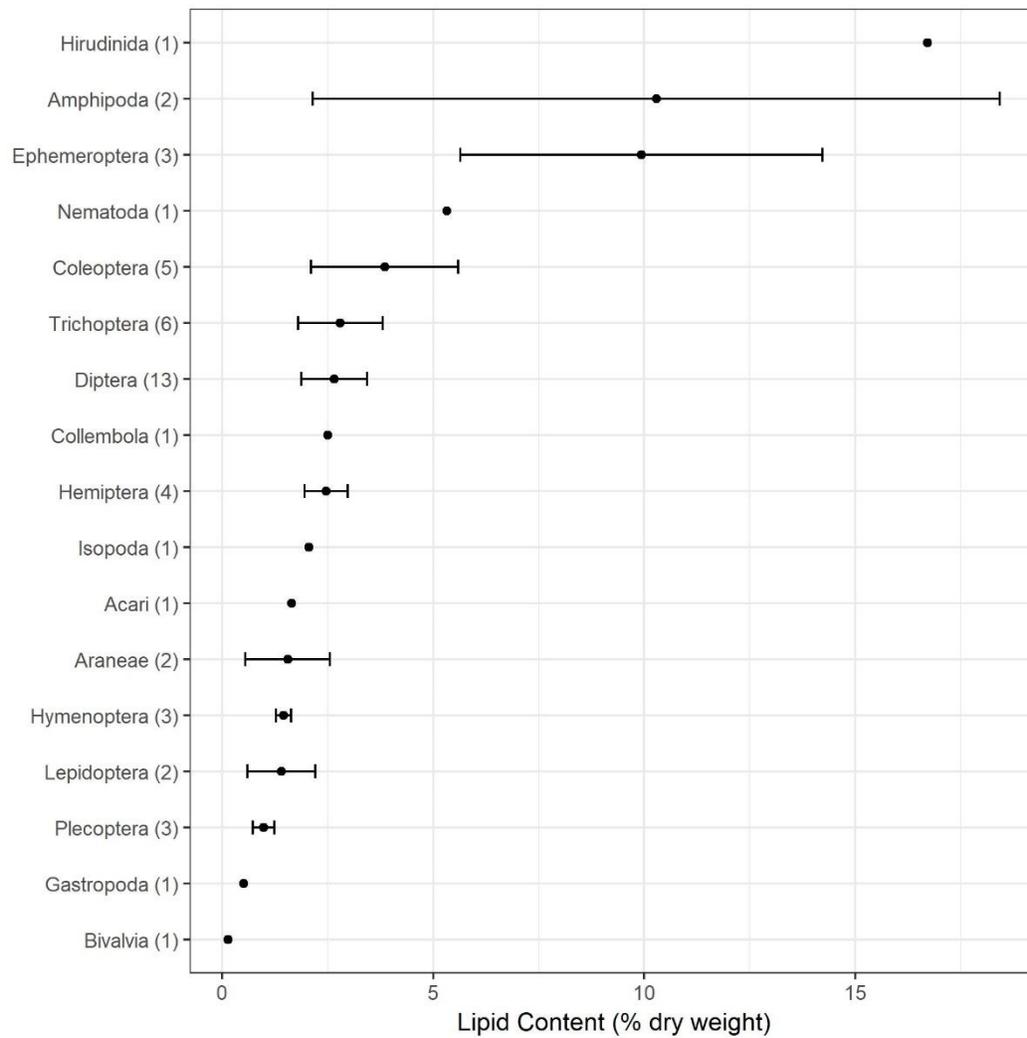
Figure 18. -- Mean (± 1 SE) lipid content for different macroinvertebrate groups composited across drift samples. Number of taxa in each group are shown in parentheses.
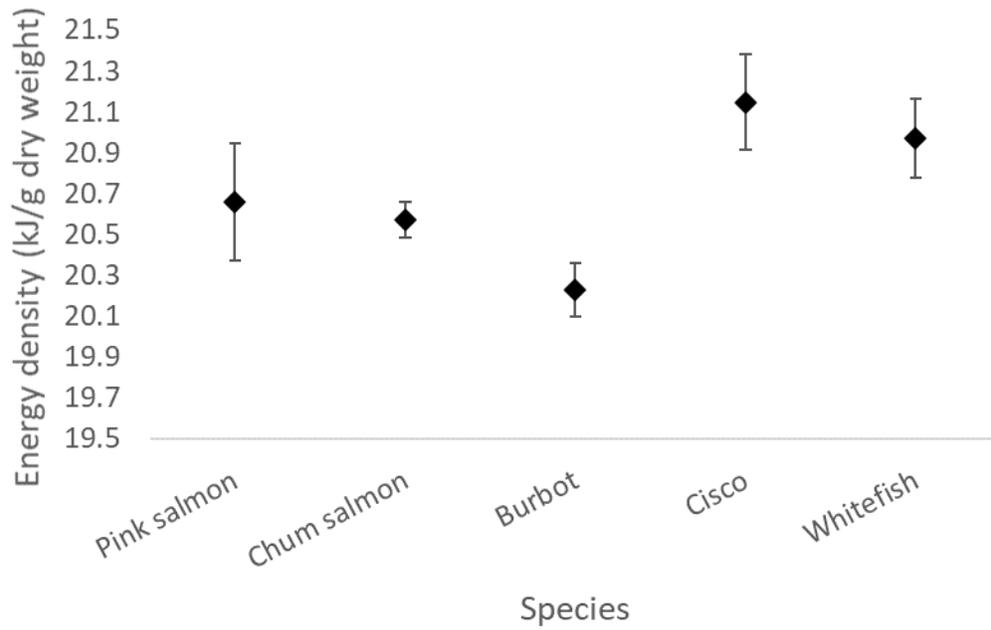
Figure 19. -- Energy content of major prey items of juvenile Chinook salmon in the lower Yukon River.

Table 1. -- Juvenile Chinook salmon processed for diet and energetic analysis from Yukon River: 2014-2016.

	2014	2015	2016
Number processed			
Diets	182	351	194
Energy density	135	204	223
Stomach fullness	371	575	435
Number empty	28	79	20
Min. length (mm)	67	56	70
Max. length (mm)	130	130	131
% BW	1.17	1.92	0.07
Proportion empty	14	22	10
Percent with fish	16	24	16
Min length with fish (mm)	86	70	84
Avg. length with fish (mm)	106	100	102

Table 2. -- Total catch and catch per unit effort (CPUE: calculated as catch per minute towed) for juvenile Chinook salmon and prey species within the predation size of juvenile Chinook in the lower Yukon River: 2014-2016.

Species	2014		2015		2016	
	Count	CPUE	Count	CPUE	Count	CPUE
Chinook	416	0.04	951	0.09	737	0.06
Burbot			8354	0.76	1212	0.10
Chum	5407	0.54	11656	1.06	4984	0.41
Cisco	4995	0.50	33847	3.07	2022	0.17
Pink	444	0.04	8764	0.79	426	0.04
White	6216	0.63	14378	1.30	795	0.07

APPENDIX 1

Figures showing the number and distribution of different size classes of fish prey items by sampling week and tributary in 2016. SM = South Mouth, NM = North Mouth, MM = Middle Mouth. Fork length is in millimeters.
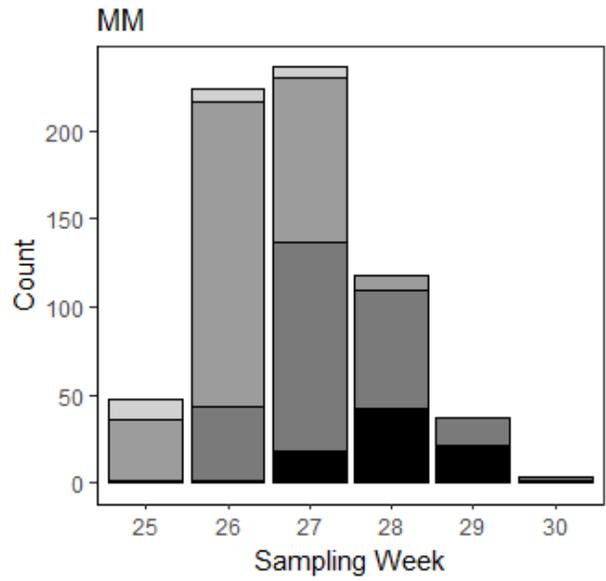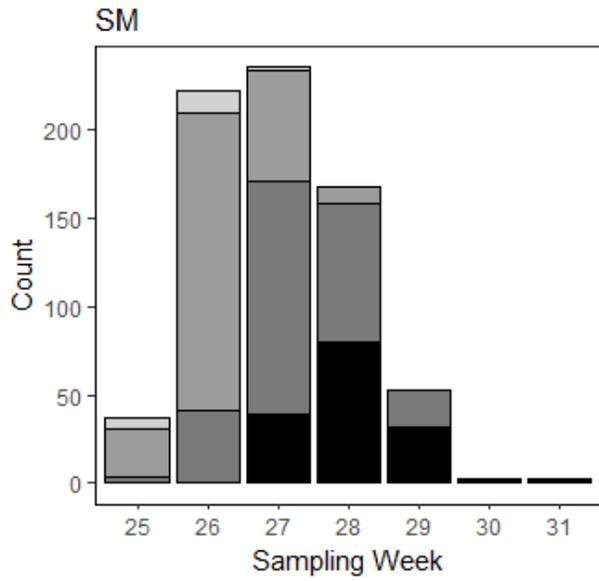
Chum

SM

MM

NM

Fork Length
30
40
50
60
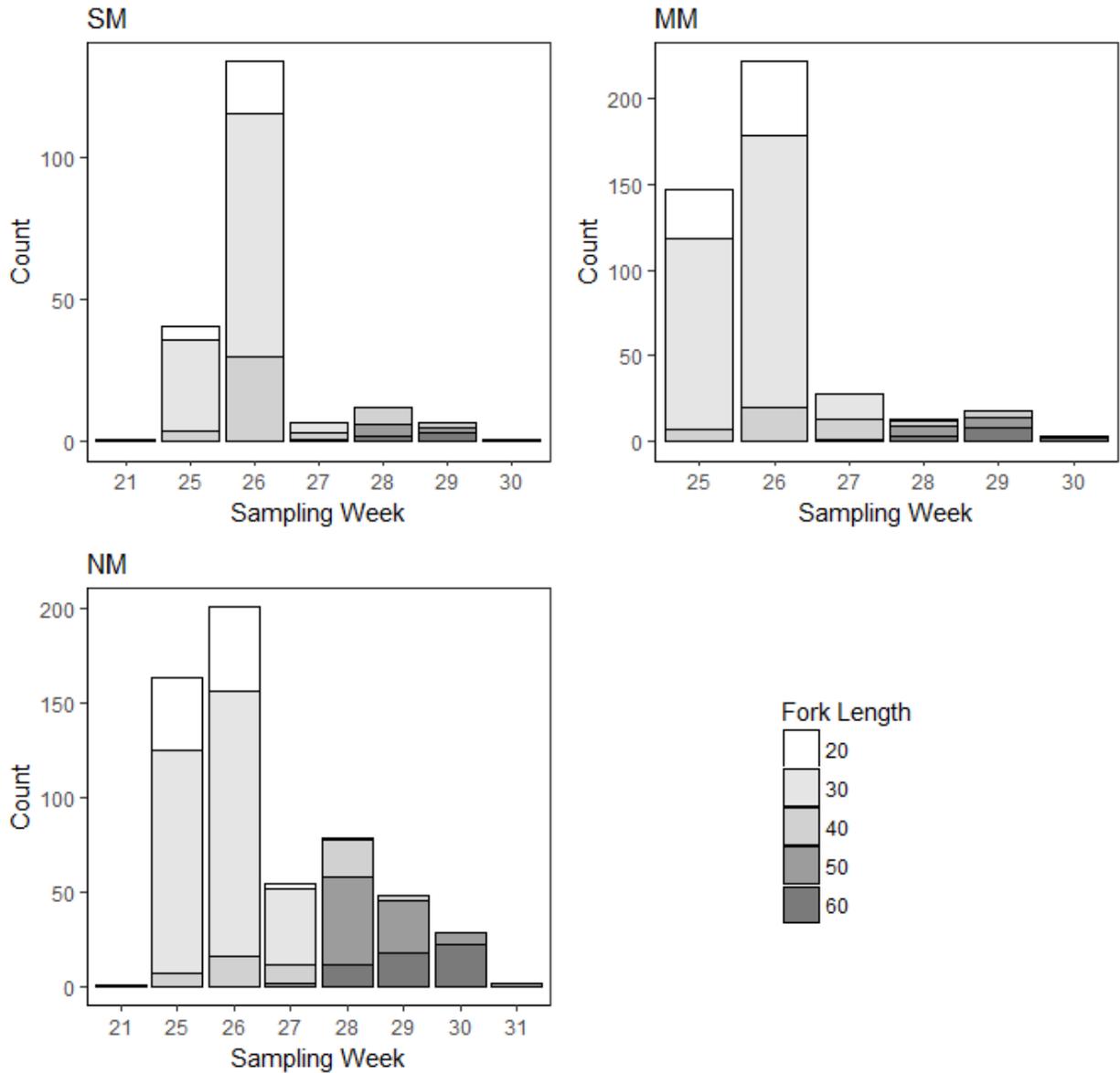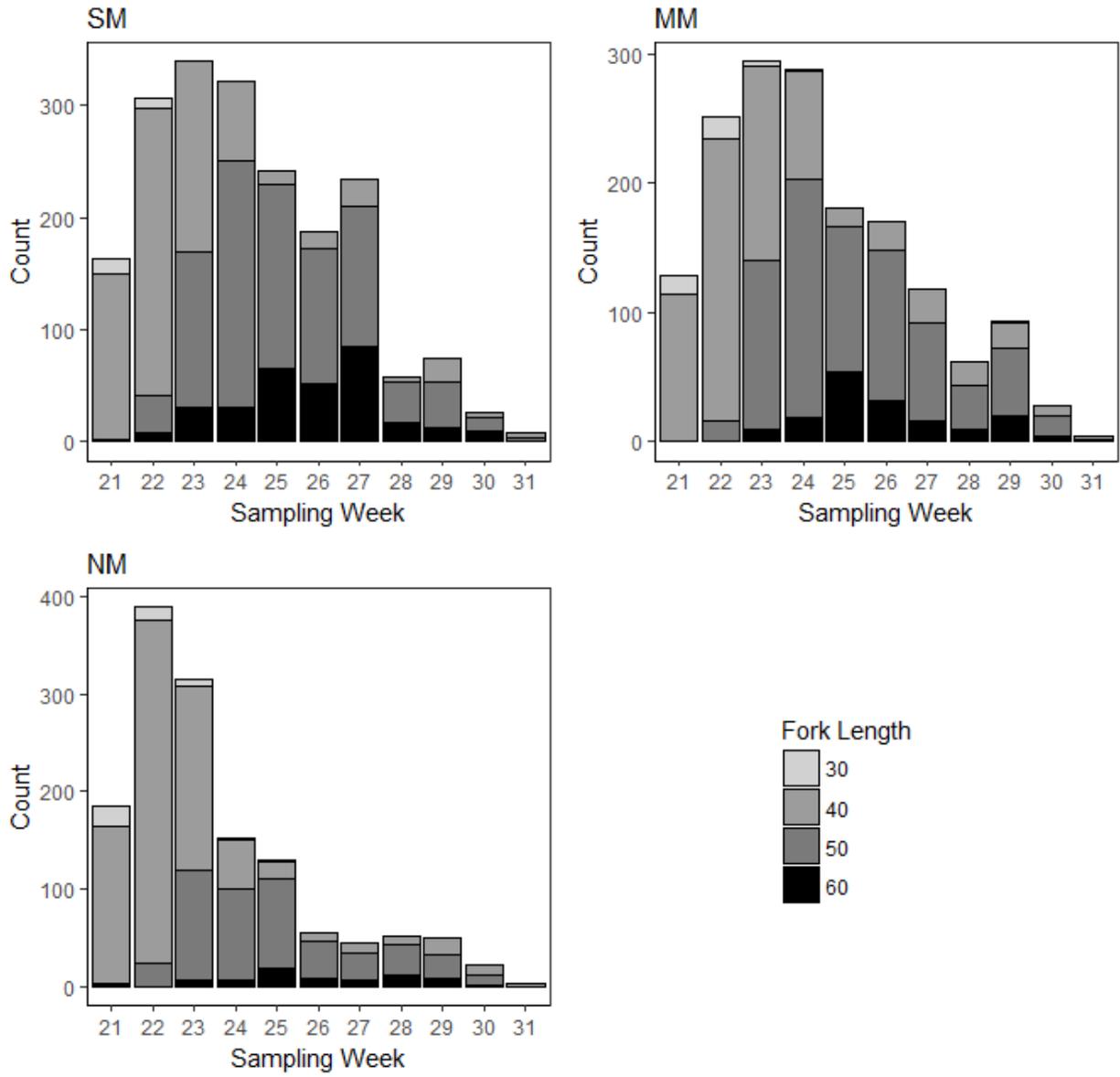
Cisco
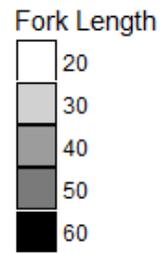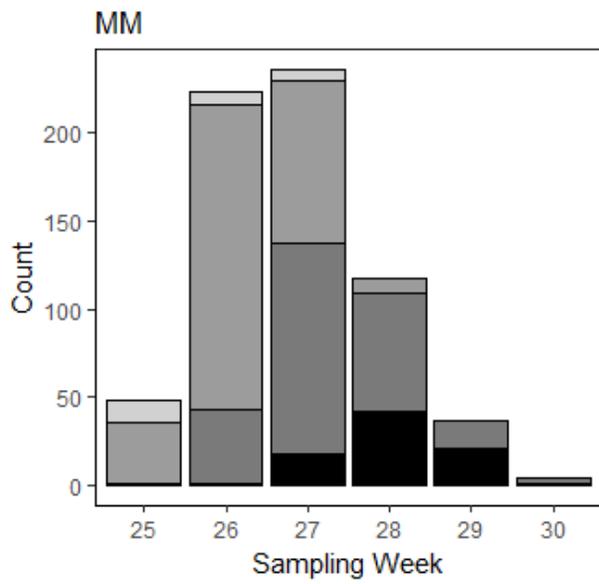
Pink salmon
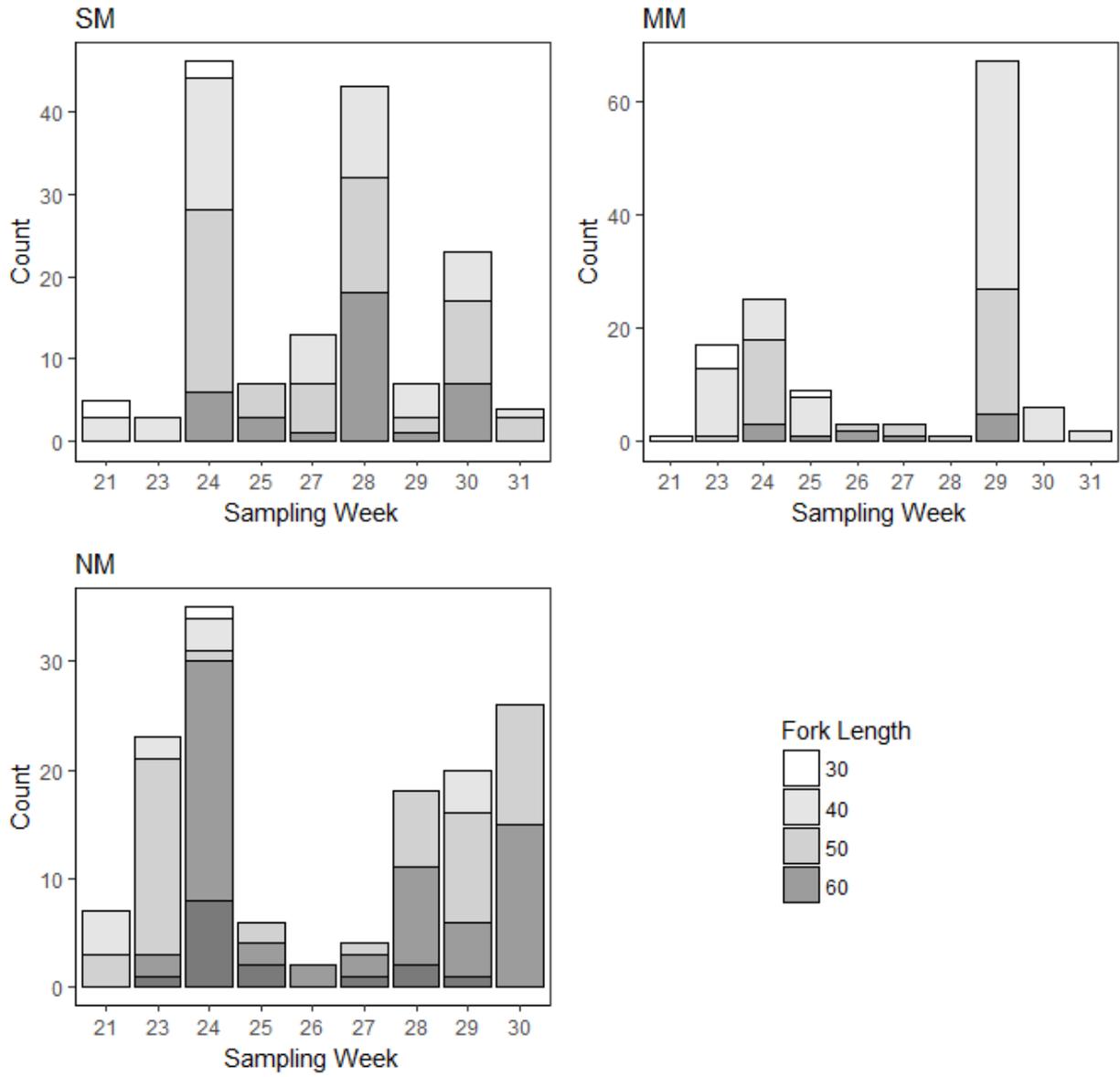
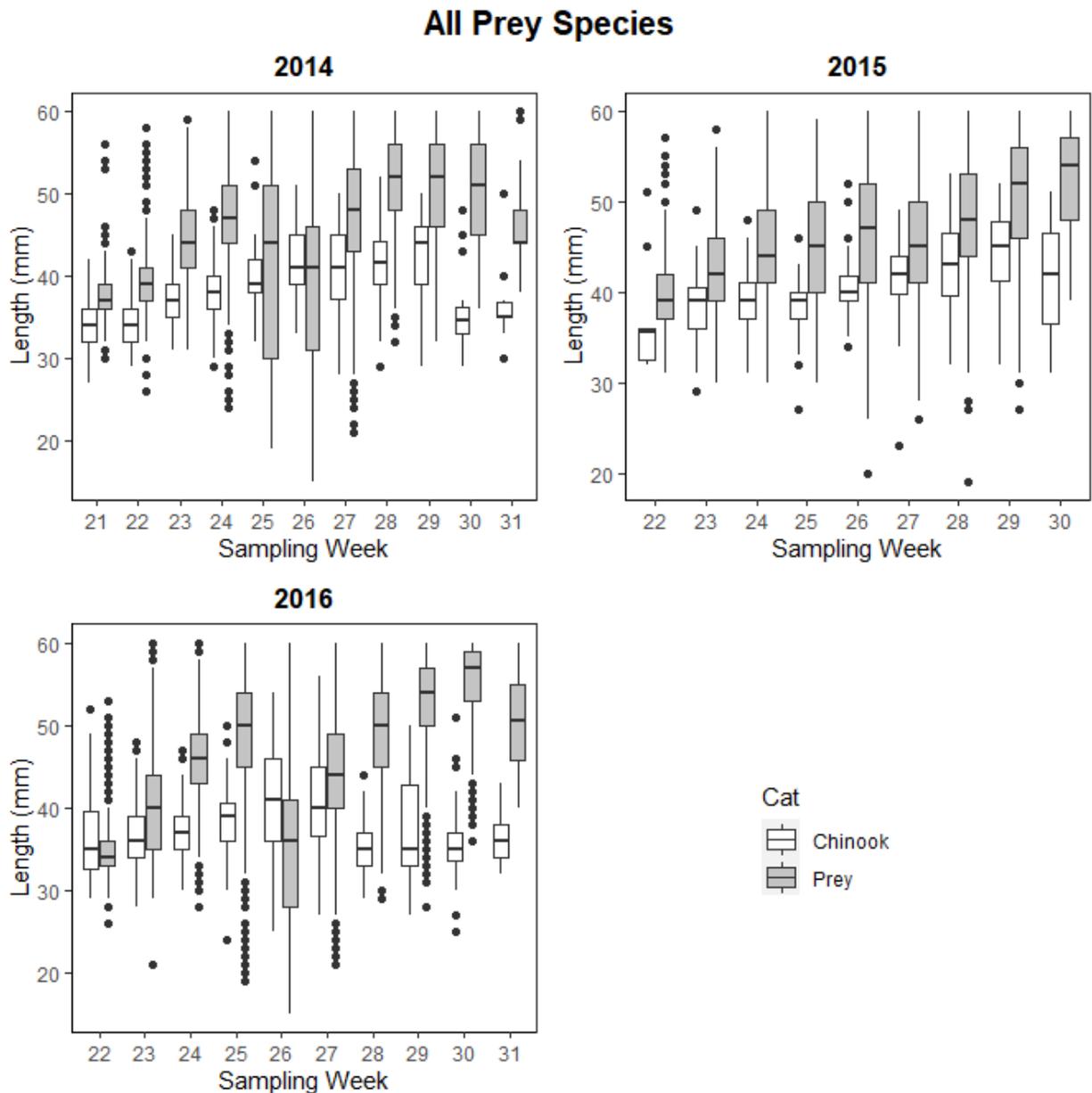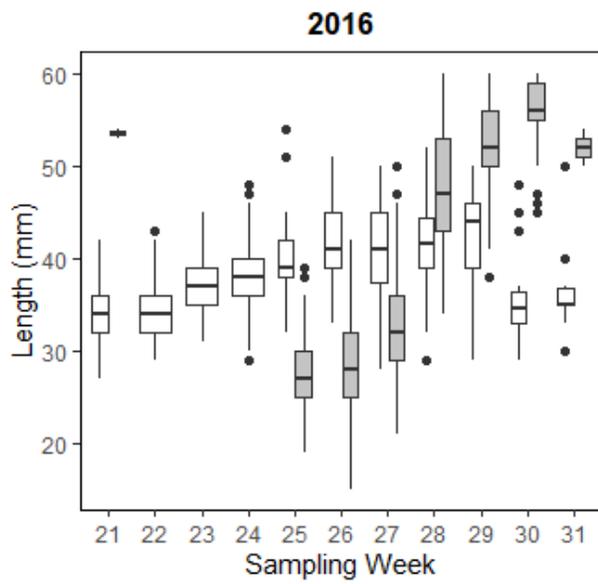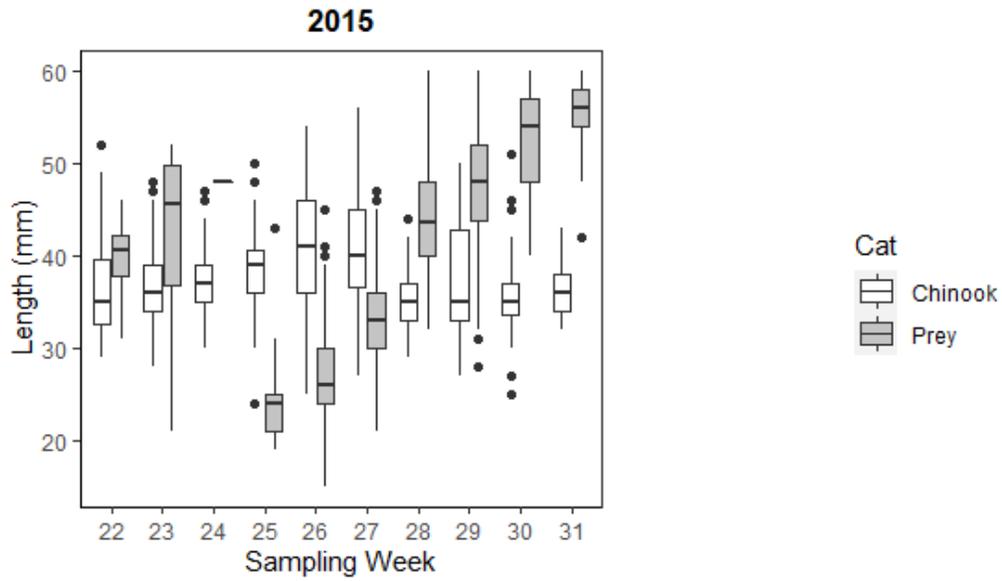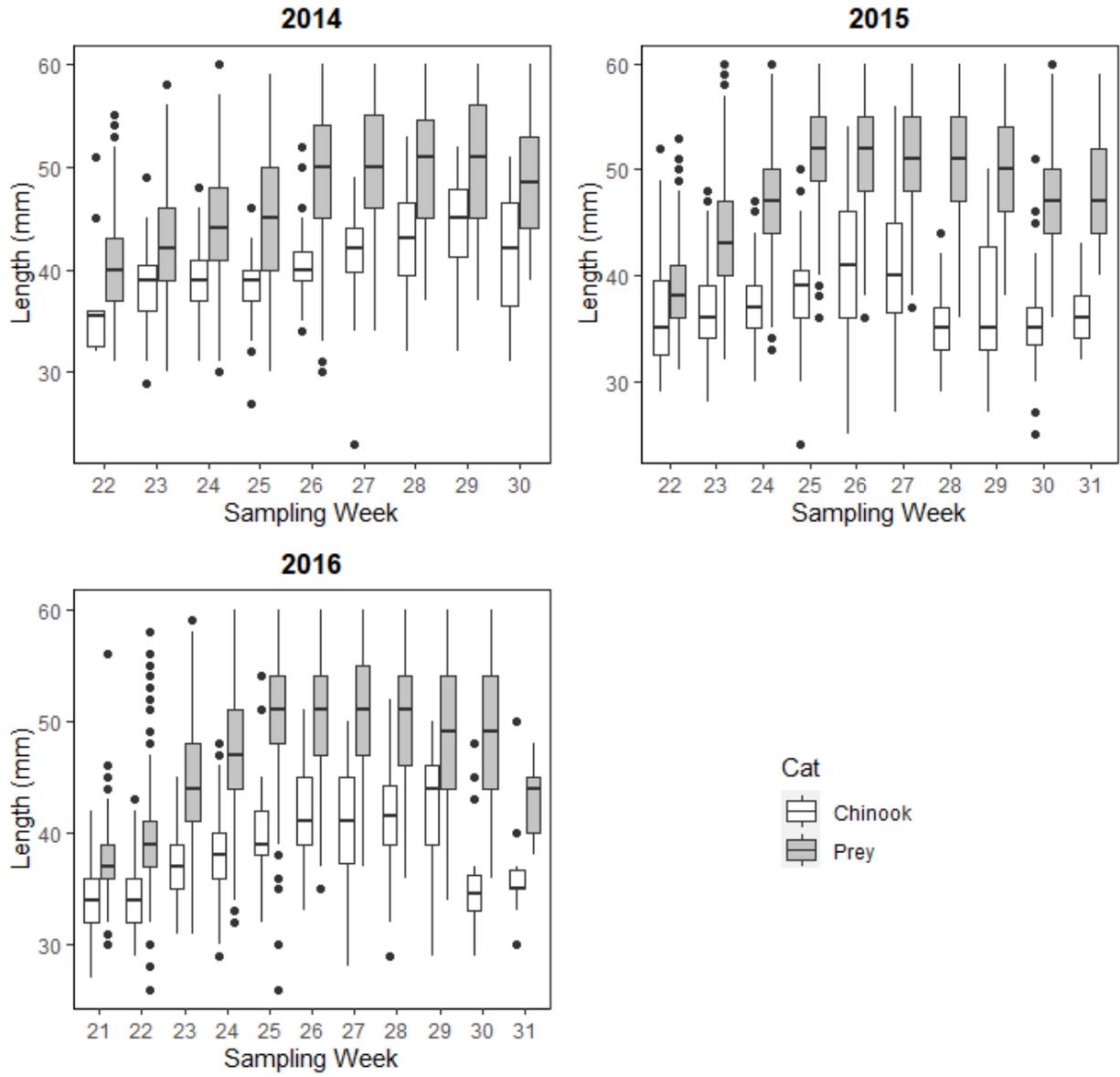# Whitefish
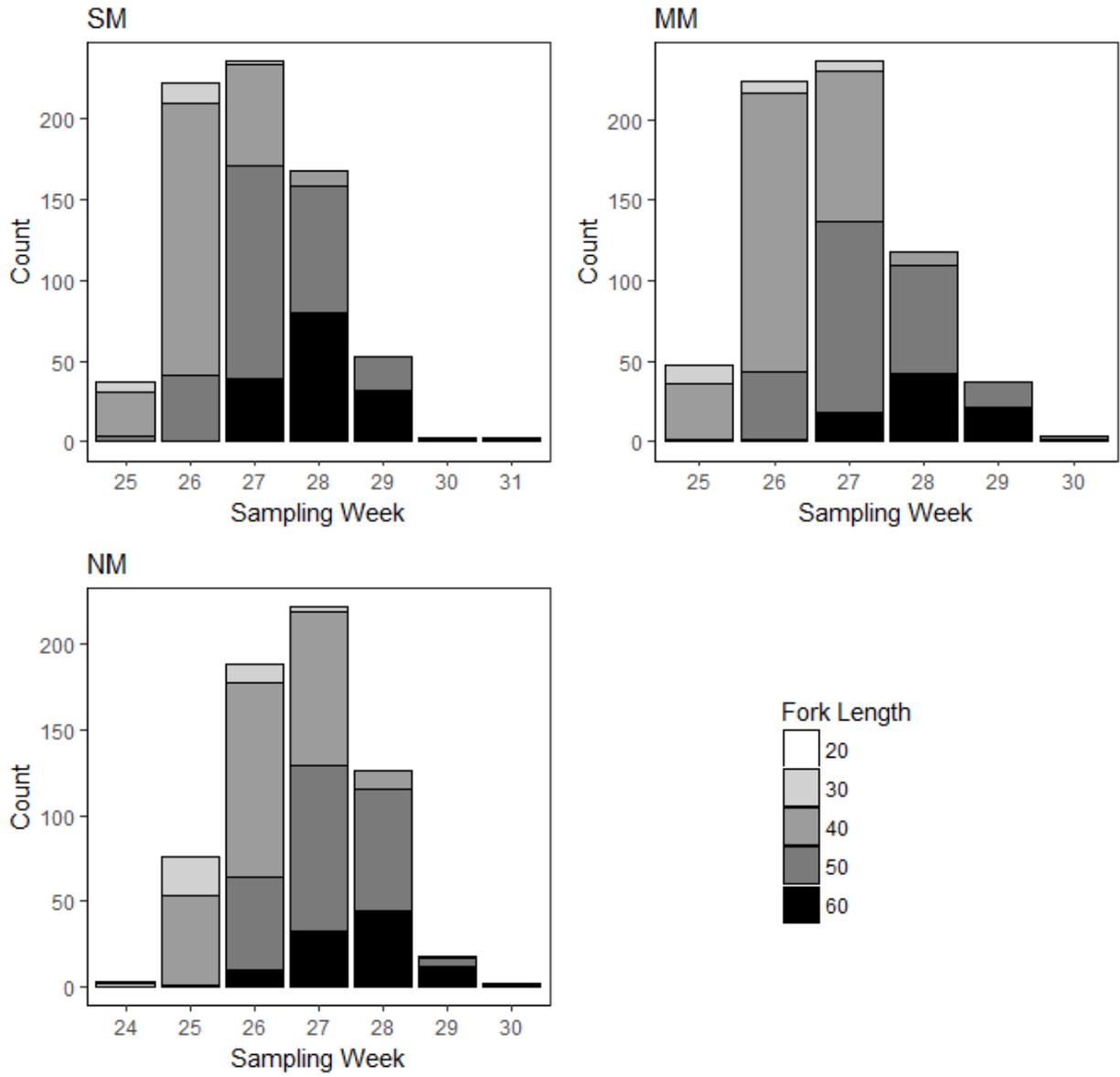
Figures showing prey and juvenile Chinook salmon lengths and density by sampling week and year. Field measured juvenile Chinook salmon lengths were converted to maximum prey size equivalents by multiplying by 0.41. The white bars show the densities of Chinook salmon and the maximum size of prey they can consume. Gray bars show the densities and actual size of prey available. Sampling years were not included where the species sampled abundance was very low or absent.
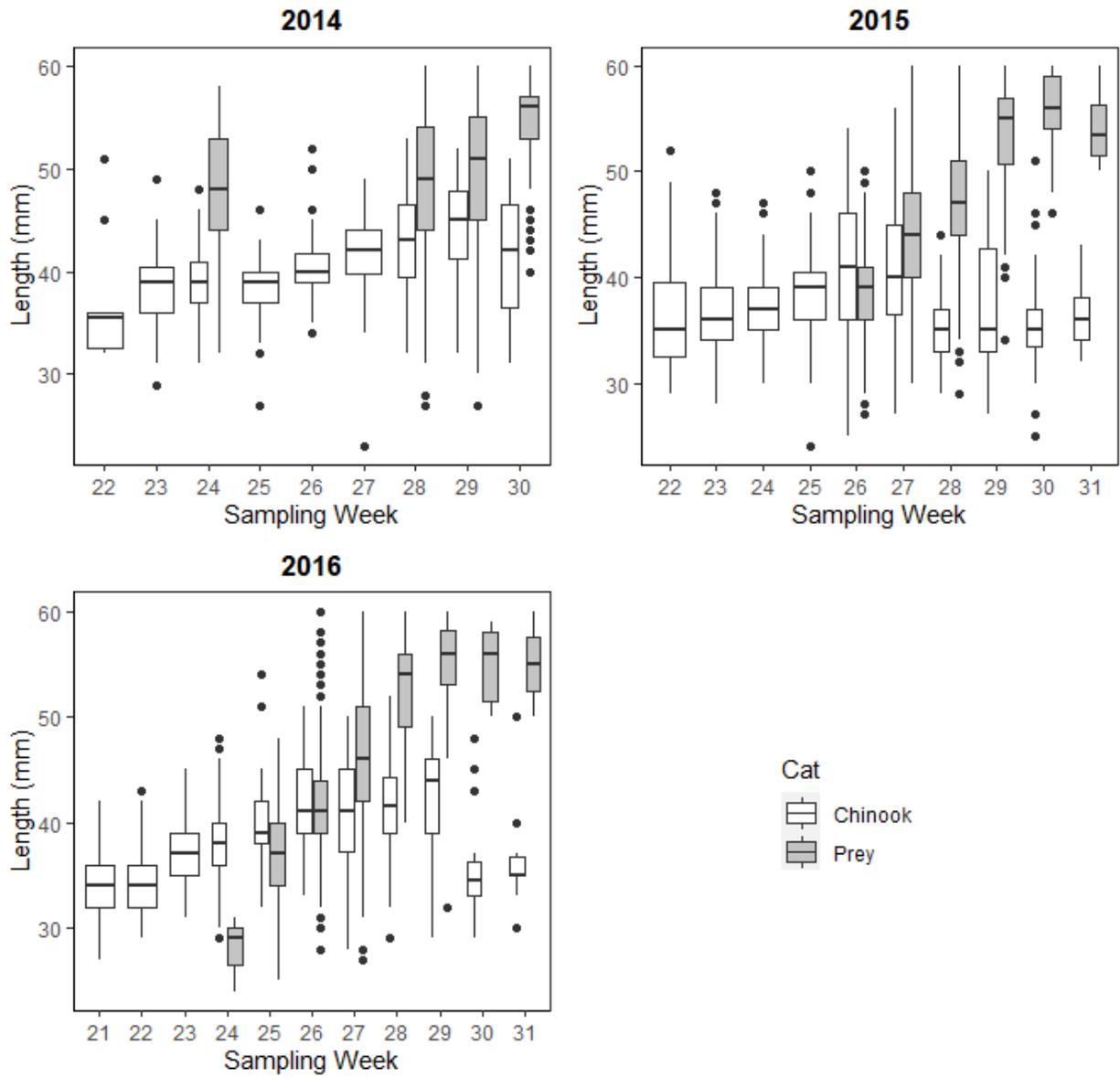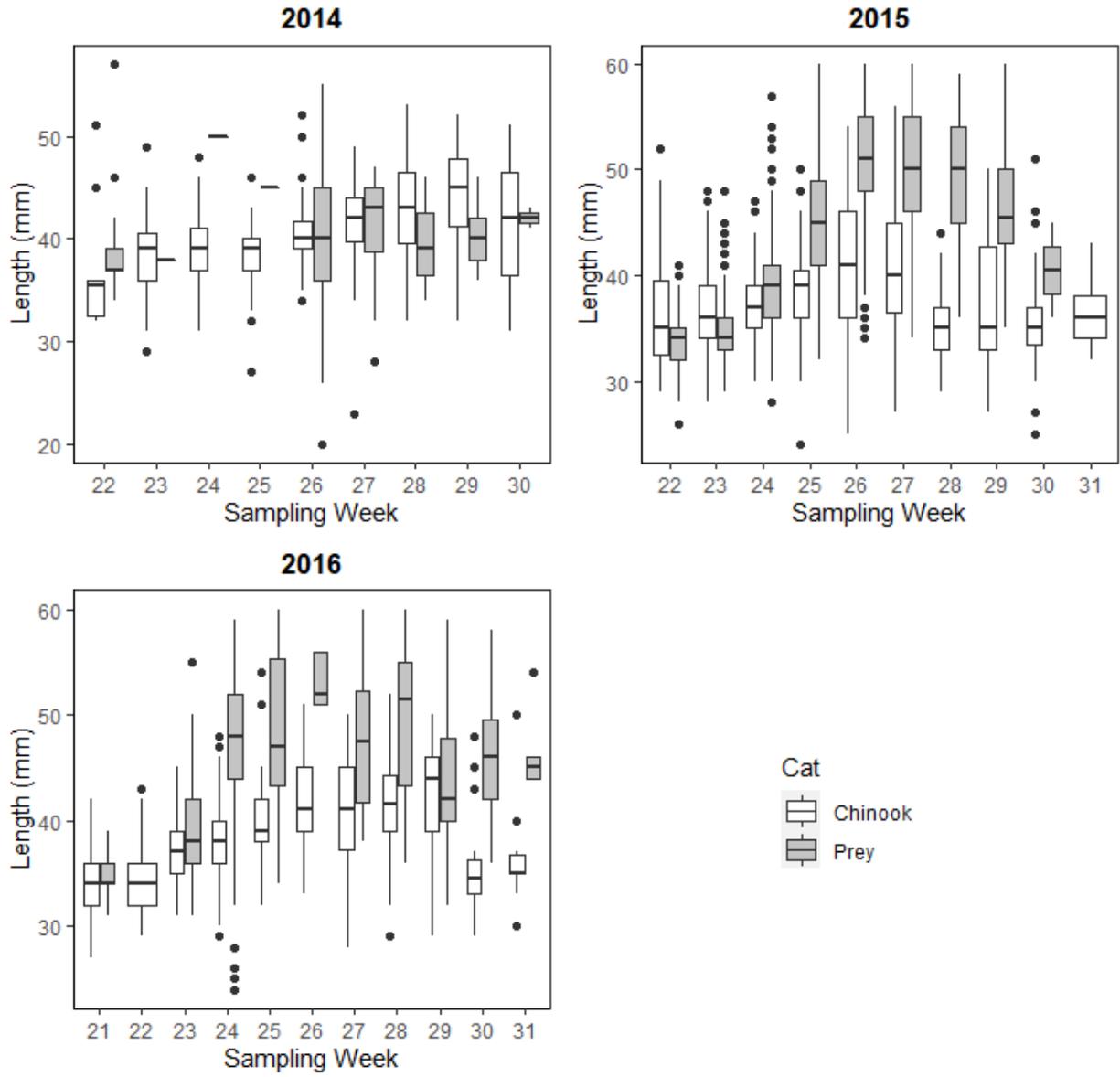

All Prey Species

Burbot

2015

2016

Chum Salmon

2014

2015

2016

Cat
- Chinook
- Prey

Cisco
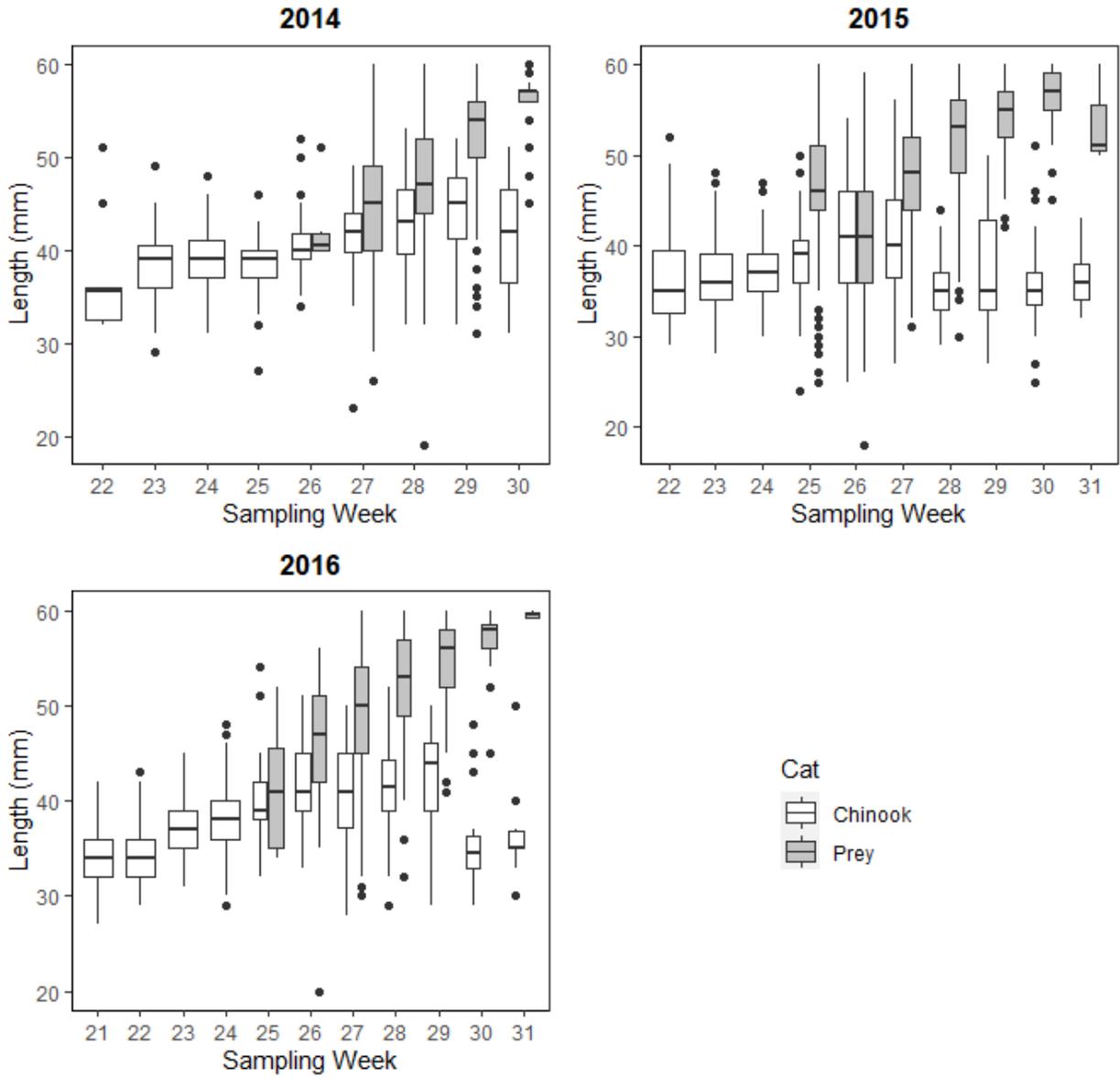
Pink Salmon

2014

2015

2016

Cat
- Chinook
- Prey

Whitefish

U.S. Secretary of Commerce
Wilbur L. Ross, Jr.

Acting Under Secretary of
Commerce for Oceans and
Atmosphere
Dr. Neil Jacobs

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October 2020

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