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ABSTRACT

Surveys were conducted in the Yukon River estuary during the summers of 2014 and 2015. The primary objectives of this research were to evaluate the community composition and spatial distribution of fish in the distributaries and within the river plume, and to investigate diets and energetic condition of emigrating juvenile Chinook salmon. A shallow, sub-ice platform separates the shoreline of the Yukon Delta plain from the marine environment. This platform extends up to 30 km offshore with water depths between 1 m and 3 m. 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. Sampling for this research was conducted in the three main lower Yukon River distributaries and along the delta front. Sampling in the distributaries occurred from near ice-out in May through the end of July, while sampling along the front was conducted during cruises in June, July, and August of each year. Juvenile Chinook salmon utilized all three lower Yukon River distributaries for emigration; however, higher CPUE was observed at front stations along the north edge of the delta suggesting that the salmon move north after leaving the river mouths. Temporal differences in prey consumption and energy density of juvenile Chinook salmon were observed in both the distributaries and on the front. Juvenile Chinook salmon were a small component of the overall fish catch in each year. Most species captured in the distributaries were juvenile or young of the year (YOY). The most common species captured in the Yukon river distributaries in both sampling years were juvenile and YOY coregonids (whitefish and cisco), juvenile sheefish (*Stenodus leucichthys)*, juvenile Arctic lamprey (*Lethenteron camtschaticum*), and juvenile burbot (*Lota lota*). The most common species on the delta front were Pacific rainbow smelt (*Osmerus dentex*), saffron cod (*Eleginus gracilis*), Pacific herring (*Clupea pallasii*), and ninespine stickleback (*Pungitius pungitius*).

OVERVIEW

The Yukon River is over 3,000 km long, originating in British Columbia, Canada, and ending in the Bering Sea off Alaska. The Yukon-Kuskokwim Delta is the seventh largest delta plain in the world, and its large size and remoteness make it a challenging research environment. On the delta, the Yukon River splits into three main distributaries with numerous secondary tributaries, marshes, lakes, and tidal sloughs within the delta plain. A shallow, sub-ice 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 tributaries 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. 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). 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.

Chinook salmon (*Oncorhynchus tshawytscha)* that spawn in the headwaters of the Yukon River undertake one of the longest fish migrations in the world. The Yukon River region has experienced substantial declines in Chinook salmon production from mid-2000 to the present. Low salmon returns also have resulted in restrictions on commercial and subsistence harvest. The causes of the population declines and fluctuations are not known but research on juvenile Chinook salmon in the northeastern Bering Sea suggests that conditions during fresh water through early marine life stages may strongly influence inter-annual variability of Yukon Chinook returns (Murphy et al. (in press)). It is hypothesized that juvenile salmon that fail to reach a critical size during their first summer in marine waters have higher mortality rates in late fall and winter (Beamish and Mahnken 2001, Farley et al. 2007). Factors affecting juvenile Chinook salmon during the period when they are migrating out of the Yukon River distributaries (emigration) and during the transition to the marine environment in the plume include emigration timing, growth, food availability, predation, and environmental conditions. Emigration timing and growth may be strongly interrelated, and may be tied to environmental conditions affecting the size and availability of prey. The growth-mortality hypothesis posits that larger individuals and/or faster growing individuals can access more prey resources, and more quickly escape predation. To utilize food resources, juvenile salmon need to obtain a sufficient size and gape capacity; hence, size, growth and diet are interconnected. The interplay of growth, emigration timing, size, diet, and condition of juvenile Chinook salmon throughout early marine rearing habitats is, therefore, integral to addressing the role of early marine processes in structuring cohort strength of Yukon River stocks. It is known that emigrating Yukon River Chinook salmon spend late summer and early fall along the eastern Bering shelf (Farley et al. 2005, Murphy et al. 2009, Murphy et al. (in press), Howard et al. (in press)), but information on the period from emigration through the first marine summer is largely unknown and limited to only two studies from the mid-1980's (Martin et al. 1986, Martin et al. 1987).

The objectives of the current study were designed to replicate and expand on the work done by Martin et al. (1987) and to characterize habitat usage, size, diet, marine entry timing, and condition of juvenile

Chinook salmon in the Yukon River Delta. This research is presented in three sections. The first section discusses spatial distribution and habitat use patterns of juvenile Chinook salmon in the distributaries and on the front, and compares these patterns with those of co-occurring species and environmental covariates. The second section examines and compares juvenile Chinook and coho salmon (*O. kisutch*) diets. The third section examines juvenile Chinook salmon energetic status in relation to fish size.

STUDY AREA AND DATA COLLECTION

This research was conducted in the three main lower Yukon River distributaries and on the Yukon Delta front (Fig. 1). Distributary and front habitats are separated by a wide, sub-ice platform that extends up to 30 km offshore. Most of this platform is extremely shallow, with water depths less than 3 m (Martin et al. 1987). The Yukon River estuary includes this platform out to its edge on the delta front where marine waters are first encountered (Thorsteinson et al. 1989). Since our objective was to sample Pacific salmon through their emigration from fresh to marine water, this necessitated two separate data collection efforts: one within the distributaries and one from the delta front within the plume.

Distributary Sampling

Sampling within the lower Yukon River distributaries was designed to replicate and expand on the work of Martin et al. (1987) which sampled stations within the South distributary. Trawls were conducted in a similar manner using the same dimension of net as in the earlier study; however, we did not have the same type of fishing vessels. For this research, distributaries were sampled using 20 ft to 24 ft skiffs which towed a surface net between them. The net was 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. Flow meters were deployed in the net opening to calculate river flow in relation to tow speed. The skiffs were operated by local fishermen and crews from Emmonak and Alakanuk who have knowledge of the river, and field operations were based out of Emmonak.

In 2014, the first year of the research, sampling stations were established early in the season on each of the three lower Yukon River distributaries: South, Middle, and North. Three stations were located on the South distributary: one upriver from Emmonak, one near Alakanuk (i.e., station 17, Martin et al. (1987) study), and one at the distributary mouth. Two stations were established on the Middle distributary, and initially a single station was established on the North distributary. After confirmation that juvenile Chinook salmon were utilizing the North distributary for emigration, an additional station was added to the distributary in late June. In 2015, one additional station was added to each of the mouths of the North and Middle distributaries, resulting in a total of three sampling stations on each distributary.

All stations were selected for depth and hydrographic characteristics similar to the Martin station. Stations were located adjacent to cut banks in fast moving water with eddies or other turbulence. Sampling began shortly after ice-out in May and continued until the end of July, and stations were sampled three times per week. Three 15-minute trawls were made in an upriver direction at each station. Station location, temperature, and depth were recorded at the beginning of each three tow set. The ending location of the set was recorded at the end of the final trawl. Martin et al. (1987) estimated the average area swept by the net during a 10 minute tow to be 2.92 km^2. Area swept includes distance the vessels and net are carried downstream due to river current.

Front Sampling

Along the delta front, five transects were established perpendicular to the delta (Fig. 2) with the inner-most located near the steepest gradient of depth change on the delta front in approximately 8 m of water. Additional stations were placed on 11 m and 14 m depth contours. Transect and station locations were selected to maximize spatial coverage around the delta while maintaining a reasonable project cost. Station locations were also selected to sample across the freshwater/marine transition of the Yukon River plume. An additional transect was established adjacent to Stuart Island to be used as an alternative sampling location in adverse weather. Front stations were sampled aboard a 40 ft charter fishing vessel. Front field sampling commenced and ended in Nome, Alaska.

Gear for sampling the front was selected for its ability to be fished in shallow waters by a single vessel. Martin et al. (1987) used the same two-boat tow net to sample both distributary and front habitats during day excursions. The spatial extent of front sampling during that study was more limited than in the present research. The addition of transects around the entire perimeter of the front, and with stations extending into deeper water, necessitated the use of a larger vessel capable of handling offshore weather conditions over a deployment of several days. In 2014, all stations were sampled with an Aluette mid-water trawl from Innovative Nets (10 m foot-head ropes, 20 m length, 1.6 cm nylon mesh at the headrope decreasing to 0.4 cm at the codend) equipped with temperature and depth sensors on the foot and head ropes. At all stations, the trawl was fished near the surface with the head rope 0 to 1.5 m deep. At the two deepest stations on each transect, the trawl was also fished below the surface with the headrope 2 to 5 m deep. The deeper tows were made to ensure that the entire plume depth was sampled given that the depth of the freshwater plume layer was unknown. In 2015, the midwater trawl was fished below the surface (2 to 5 m deep) at the two deepest stations, and a Mamou surface trawl from Innovative Nets (12 m foot-head ropes, 15 m length, 1.6 cm nylon mesh at the headrope decreasing to 0.4 cm at the codend) was fished at each station. The average area swept by these trawls was estimated at 0.012 km^2 per station.

Stations were sampled in June, July, and August of each year. 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 the transect.

Sample Processing

Captured fish from distributary and front sampling were identified to species, and a minimum of 30 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. Chinook and coho salmon specimens were each assigned a unique identifying number, fin clipped for genetic samples, and either frozen or fixed in 10% formalin for laboratory analysis. Chum salmon (*O. keta*) were bagged in groups of five, and either frozen or fixed in

10% formalin for laboratory analysis. Fish that could not be identified to species in the field were photographed, vouchered, and returned to the laboratory for identification.

SECTION 1: SPATIAL DISTRIBUTION AND HABITAT USE

INTRODUCTION

Little is known about the estuarine and nearshore dependence of juvenile Chinook salmon on the Yukon River Delta. Juvenile Chinook salmon leave the Yukon River in late spring and early summer when river discharge is highest. High river discharge prevents the influx of marine water into the river mouth, creating an offshore estuary during the summer (Thorsteinson et al. 1989). During this period, Yukon River water spreads in a shallow, low salinity layer up to 30 km offshore into Norton Sound and the northern Bering Sea. The interface between low salinity river water and higher salinity marine water creates an estuarine transition zone or plume front. The importance of plume fronts has been documented on other large western rivers (St. John et al. 1992, Wong et al. 2013, De Robertis et al. 2005). Juvenile salmon are often more abundant in plume fronts than more saline surrounding waters (De Robertis et al. 2005, Burla et al. 2010). They likely exploit these habitats for feeding and for undergoing physiological changes needed to transition from the freshwater to the marine environment (Gregory and Levings 1998). This transitional period has high selective pressures, and there is substantial evidence that juvenile salmon that fail to reach a critical size during their first summer in marine waters have higher mortality rates in late fall and winter (Beamish and Mahnken 2001, Farley et al. 2007). Spatial and temporal variability in environmental conditions, abundance of prey, and the composition of the fish community in the offshore estuary of the Yukon River plume may be important factors in juvenile Chinook salmon condition and survival. This section examines the spatial distribution and habitat use of juvenile salmon in the lower Yukon River distributaries and Yukon River plume.

METHODS

Temporal catch of common species was visualized spatially by computing standardized monthly catch-per-unit-of-effort (CPUE) for each station. Monthly CPUE was calculated as the number of individuals divided by the tow time (15 minutes for river stations and 20 minutes for front stations) and the number of tows at each station per month. CPUE for both river and front stations were entered into a GIS to produce monthly relative abundance maps. The maps are useful tools for recognizing temporal and spatial patterns, but because the river and front sampling used different gear, CPUE from river and front are not directly comparable.

Community composition was calculated separately for river and front stations due to differences in species observed in each location. Fish abundances from individual trawls were fourth-root transformed to reduce the influence of species with high abundances, and Bray-Curtis similarity matrices were computed to examine differences in assemblage structure among river and front stations and among front transects. Multidimensional scaling (MDS) was used to visualize similarities between front stations and transects. The SIMPER routine from Primer 6™ was used to decompose dissimilarities between groups identified in the MDS to obtain the percent contribution of species to the dissimilarities observed. The results of the MDS were also used to compare differences in community composition with environmental data.

Densities of juvenile Chinook salmon, *D*, were estimated with catch per km^2 to allow comparisons between the different trawl gear types used in the distributaries, front, and marine environments. Distributary densities were calculated for each station as

$$D = CPUE_{10}\ x\ CF,$$

where $CPUE_{10}$ is the CPUE standardized to a 10-minute trawl, and *CF* is the 2-boat tow net conversion factor from Martin et al. (1987). Although the net used in this research was identical to the net used in the earlier study, vessel differences may introduce variation in distances covered during trawls and results should be viewed with that in mind.

Delta front densities were calculated as $D = \frac{C}{E}$,

where *C* is the number of juvenile Chinook salmon captured at station during each cruise, and *E* is the area swept in $km^{2.}$. Area swept was calculated as

$$E\ =\ D\ \times\ H\ \times\ CF,$$

where D is the distance towed during the trawl, *H* is length of the net head rope, and *CF* is the fraction of the headrope length which is equal to the path swept by the trawl. CF values were obtained from the net manufacturer. This method for calculating densities was chosen to allow for comparison of juvenile Chinook salmon captured on the Yukon delta front and during the cooperative Alaska Department of Fish and Game (ADF&G)/NOAA trawl surveys in the northeastern Bering Sea and Norton Sound as part of the ADF&G Chinook Initiative Research (ADF&G 2013). This comparison does not account for differences in gear used or gear efficiencies and should be interpreted conservatively.

RESULTS

Physical Variability

Weekly distributary water temperatures were on average 1.2 °C higher in 2015 than in 2014 (Fig. 3). In 2015, water temperatures increased abruptly from 14.42 °C in week 25 to 18.15 °C in week 26 and remained above 18 °C until the third week of July. The highest recorded average weekly temperature for 2014 was 16.8 °C during the week of 6 July through 12 July. River discharge volume also differed between years. In 2014, discharge peaked at close to 530,000 cfs near 21 May and stayed close to 500,000 cfs through the third week of August (Howard et al. (in prep)). In 2015, discharge peaked at 619,000 cfs on 5 June at the USGS Pilot Station gauge, but declined to about 350,000 cfs by June 29; this lower level remained through the end of August.

Salinity and temperature on the Yukon Delta front varied between transects and seasonally within each year. Sampling on the front did occur a week later in each month of 2014 than in 2015 due to issues with charter vessel contracting. Temperature and salinity profiles for transects off the west (Taku) and north sides of the delta (Apoon) are presented for each sample month and year in Appendix A. When these transects were not sampled due to weather or gear malfunction, CTD data from Kwiguk and Uwik transects are shown for the west and north sides of the delta.

Yukon River water occurs as a very shallow surface layer during June. In June of both 2014 and 2015, water column stratification off the west and north sides of the delta was deeper and extended farther offshore than in the other sampling months. In 2014, the water column above 6 m water depth was characterized by low salinity (≤ 15 PSU) Yukon River water over colder (≤ 7 °C) and more saline marine water on the west transect (Appendix A, Fig. 1). A distinct front of very low salinity river water is evident over the shallow stations. The 2015 pattern at the western transect shows a much shallower stratified layer that extends less than 5 m deep (Appendix A, Fig. 2). Outflowing river water temperatures in June 2015 were much colder than June 2014, likely reflecting the later start of sampling in 2014. Differences in the depth of stratification is also evident off the north side of the delta. In June 2014, the water column is dominated by warm (> 9 °C), low salinity water. In 2015, temperatures were much lower and salinities much higher.

Stratification is lower on the north side of the delta than on the west side. A lens of fresh Yukon River water is evident in the surface layer at the western transects throughout the summer, gradually decreasing in depth as the summer progresses. The salinity of this layer is much lower in all periods of 2014 than in 2015, while bottom salinities are higher in July and August 2014 than the same months in 2015. Greater water column mixing is apparent on the north side of the delta front. The lens of fresh Yukon River water is much thinner on the northern transect in both sampling years, and bottom salinities are lower.

Temperature differences between years were most evident on the northern transects in June and July. Water column temperatures were much lower in June 2015 than in 2014, reflecting differences in sample timing and ice retreat. West transect stations were ice free by 21 May, 2014 and north transects were ice free by 23 May, 2014. In 2015, ice free conditions occurred on 24 May at west transects and 27 May at north transects (Alaska Ocean Observing System 2016). Earlier ice retreat and later sampling in 2014 provided approximately two additional weeks for nearshore waters to warm. July water column temperatures tended to be higher at both north and west transects in 2015, while the range of August temperatures was similar between the two years.

Spatial Distribution

Twelve species or species groups were encountered in the Yukon River distributaries during the 2-year study, with 26,482 individuals captured in 2014 and 87,815 individuals captured in 2015 (Howard et al. 2016; Table 1). On the Yukon Delta front, catch was spread across 10 primary species, with 23,021 individuals captured in 2014 and 11,709 individuals captured in 2015 (Table 2). Most individuals captured in the distributaries and on the front were juveniles or young-of-the-year (YOY). For the distributaries it was not always possible to determine the life stage of fish that were tallied but not measured, so the in-river spatial analysis includes all juvenile and YOY age classes together. Greater distinction in life stage was possible for the Yukon Delta front catch. Where sufficient sample sizes were available, spatial analysis of fish from the front was broken out by size class. Maps showing the spatial distribution of selected species are in Appendix B.

Four species of juvenile salmon (Chinook, coho, chum, and pink (*O. gorbuscha)*) were captured in 2014 and 2015 in all three distributaries and on the Yukon Delta front. Only chum and Chinook salmon were captured in sufficient numbers on the front to make comparisons with the river catch.

Juvenile chum salmon were captured in all distributaries and on all transects. Chum salmon were caught from May through July in the distributaries and June through August on the front. In both areas, the highest CPUE occurred in June of both sampling years (Howard et al. (in prep)). Chum salmon catch was higher at both the distributary and front stations in 2015 compared with 2014. Catch varied temporally and spatially among distributaries and along front stations. The spatial and temporal trends in catch size at front stations does not follow the trends in catch size at the distributary stations (Appendix B, Fig. 1).

Catch of juvenile Chinook salmon was higher in both the distributaries and on the front in 2015 than in 2014. CPUE was highest in June of both sampling years (Appendix B, Fig. 2, and Howard et al. 2016). On the river, overall CPUE did not differ between distributaries, and spatial differences between stations were relatively small. On the front, juvenile Chinook salmon were only captured on the northern transects in 2014. Northern transect catch was highest in 2015, but juvenile Chinook were also caught at western transects in June. High CPUE occurred along the Kawanak transect at the interface between the north and west delta in June 2015, and this was the only station where juvenile Chinook were caught in July 2014. The magnitude of Chinook catch at northern transects was not in proportion to the magnitude of catch on the adjacent north distributary in both years. Densities of juvenile Chinook salmon varied spatially and temporally (Table 3) often with substantial variation between adjacent stations during the same sampling period. In June 2014, densities were highest at middle and inner stations on north transects. The June 2015 pattern is similar to 2014 for the northern transects, but on the western transects the highest densities of juvenile Chinook salmon occurred on the middle and outer stations.

Densities of juvenile Chinook salmon were calculated for distributary and front habitats. Differences in the way these densities were calculated make direct comparisons challenging, and they are provided here only to facilitate discussion of overall patterns. Juvenile Chinook salmon densities at distributary stations ranged from 0 to 507 in 2014 and 0 to 1234 in 2015 (Table 3). Front densities ranged from 0 to 559 in 2014 and 0 to 396 in 2015 (Table 4). The highest distributary densities occurred in June of both years, but densities were also high at selected stations in July. On the front, densities were highly variable between stations, months, and years. The highest densities occurred in June; however, low densities and zero catches were also observed during this period.

Juvenile coho and pink salmon were infrequently captured on the front but were abundant in distributary samples. Juvenile coho salmon were most abundant in June of each sample year (Howard et al., 2016 and Appendix B, Fig. 3). Variations in juvenile coho CPUE between sample months and years in the individual distributaries was small. Pink salmon were more abundant in 2015 with peak abundance occurring in May (Howard et al. (in prep)). Spatial analysis of CPUE by distributary station shows higher CPUE at stations on the North and Middle distributaries in May 2015, with a dampening of the spatial distributions in June and July (Appendix B, Fig. 4). In 2014, juvenile pink CPUE was evenly distributed across distributaries in all months.

The most common species captured in the Yukon River distributaries in both sampling years were juvenile and YOY coregonids (whitefish and cisco), juvenile sheefish (*Stenodus leucichthys)*, juvenile Arctic lamprey (*Lethenteron camtschaticum*), and juvenile burbot (*Lota lota*) (Howard et al. (in prep)). These species were captured in all distributaries and at all stations. Overall catch of these species was higher in 2015 compared with 2014, but the spatial distribution patterns between years are similar for most of the species (Appendix B, Figs. 5 through 8); the exception is burbot, with much higher CPUE at North distributary stations in June 2015 than at either South or Middle distributary stations.

Spatial variation between sampling years was much more evident in catch from the Yukon Delta front than from the river distributaries. The most common species on the delta front were Pacific rainbow smelt (*Osmerus dentex*), saffron cod (*Eleginus gracilis*), Pacific herring (*Clupea pallasii*), and ninespine stickleback (*Pungitius pungitius*) (Howard et al. (in prep)). A length frequency analysis indicates a multimodal size distribution for saffron cod and rainbow smelt that varied by month over the study period (Figs. 2 and 3). The smallest size classes of saffron cod and rainbow smelt, which we refer to as YOY, were the most abundant component of catch in July and August 2014. These species were broadly distributed, occurring on all transects and at all station depths (Appendix B: Figs. 9 through 19). Larger saffron cod juveniles were caught in June and July 2014; spatial distribution of these fish in July was similar to the distribution of YOY. Two size modes of juvenile rainbow smelt were observed in July of both sampling years. Pacific herring length frequencies indicate a bimodal size distribution (Fig. 4). July catch was dominated by herring from 70 mm to 126 mm FL, while herring < 70 mm FL were the largest portion of the catch in August. Although spawn timing between Norton Sound and Prince William Sound are different, size at age data from Prince William Sound (Norcross et al. 2001) suggests that Pacific herring captured in July are overwintered fish from the previous spring spawn (i.e., second-year fish), while the smaller fish in August were spawned in the current year (i.e., first-year fish or YOY). The larger size mode in August is likely composed of the same cohort as the July herring that have grown. The spatial distribution of second year herring was similar between sampling years, but CPUE was highest in July 2014 and August 2015 (Appendix B, Fig. 15). The spatial distribution of YOY fish differed between years, with higher CPUE along the north transects in 2014 and along the west transects in 2015 (Appendix B, Fig. 16).

Invertebrates are an important component of the biomass on the Yukon Delta front. The most abundant invertebrates were mysids and several species of jellyfish. The CPUE of these invertebrates was higher in 2014 than in 2015. Mysids were extremely common in trawls from most stations and transects in 2014 but were captured in very small numbers in samples from 2015 (Appendix B, Fig. 18). In both years, mysids were captured at all stations and depths, but CPUE was generally greater at stations closer to shore. There was similarity in the spatial distribution of jellyfish between the same months in each year (Appendix B, Fig. 19). Jellyfish CPUE was much higher in August than other months, and catch was generally higher at the deeper stations.

Community Analyses

MDS ordinations of catch from stations in the Yukon River distributaries show evidence of strong seasonal influence on fish community composition (Figs. 5a and b). This is especially true for 2015 samples, where there is a strong division between fish communities from weeks 22 through 25 (Period A) compared with weeks 27 through 31 (Period B). In 2014, the community composition shows a gradual shift from Period A to Period B. Community similarity between stations in each of these periods is lower than in 2015, as evidenced by the greater spread between stations in the MDS plot and the results of the SIMPER analysis (Table 4). Species contributing most of within group similarity in Period A are similar in both years with the exception of juvenile pink salmon which were a major contributor only in 2015. The MDS for 2015 shows lower overall similarity between sampling stations in weeks 30 and 31. Within group similarity for these samples is 61%, with 15% of the similarity contributed by the juvenile Chinook salmon.

Fish community composition on the Yukon Delta front was not related to station depth, salinity, or temperature. Composition at transects and stations was best explained in each sampling year by the month in which sampling occurred (Figs. 6a and b). Nonetheless, average similarity between stations within each month was relatively low, reflecting differences in catch between transects and stations. Community composition at stations did not show strong similarity in catch with other stations in the same transect or between trawls at a given station. Juvenile Chinook and chum salmon contributed to the within group similarity in June of both years. Juvenile Chinook salmon contribution was similar in 2014 and 2015, but juvenile chum salmon contribution was larger in 2015. Mysids as wells as juvenile and YOY rainbow smelt were important contributors to assemblage similarity in 2014, while ninespine stickleback and jellyfish were larger contributors to community composition in 2015 (Table 5). The average dissimilarity was highest between June and the other two months in both years.

DISCUSSION

Spatial differences in CPUE were much more evident for most species at front stations than at distributary stations. Selection of distributary stations was biased towards hydrological conditions favorable to juvenile Chinook salmon (see Sample Design) with the objective of maximizing catch. As a result, there is little physical variation in conditions between stations within a distributary, and between distributaries. Front stations were selected to provide spatial coverage around the Yukon Delta from the steepest gradient of depth change out to the 45 ft depth contour. The objective for the front sampling was to investigate spatial patterns in habitat use around the front. Temperature and salinity profiles from transects along the west and north sides of the delta suggest that these two areas have different physical environments. Coastal circulation data, albeit limited, indicates that currents on the west and north side of the delta respond differently to wind stress (Thorsteinson et al. 1989). Wind driven currents along the west side of the delta tend to be predominantly along shore, while wind driven currents on the north side of the delta tend to be toward or away from shore. Depending on the direction of the wind, alongshore currents along the western delta result in either upwelling or downwelling conditions (Thorsteinson et al. 1989). Yukon River discharge creates a mean northerly density driven flow of water along the delta front. This northward current is enhanced by the flow of Alaska Coastal Water (ACW) which splits at the northwest edge of the delta with the major branch continuing north and a smaller branch entering into Norton Sound (Moser and Hein 1984). The combination of ACW, density flow, and prevailing southeast winds results in a general movement of water from transects along the west side of the delta to those in the north.

Stations on the north side of the front generally had higher CPUE of juvenile Chinook salmon than stations on the west side. This finding corroborates previous work that showed a trend of increasing fish density from south to north at stations on the front (Martin et al. 1987) and suggests that juvenile Chinook move through the delta with the prevailing currents. Research on the distribution and migration of juvenile Chinook salmon in the Bering Sea hypothesized that juvenile Chinook salmon initially migrate northward into Norton Sound before eventually moving southwest along the western Alaska coastline (Farley et al. 2005).

Densities of juvenile Chinook salmon were highly variable throughout the sampling period in both the distributaries and on the delta front. In the distributaries, the variation in densities may be attributable to the pattern of emigration describe in Howard et al. (2016). Densities were generally higher at all stations in June, compared with May and July. This corresponds to a period of peak emigration in both years. The densities observed in the distributaries may also be associated with pulses of emigration occurring throughout the summer (Howard et al. 2016). As the juvenile salmon move out of the confines of the distributaries, the factors affecting their distribution and density change. Physical properties of the river plume, including prevailing currents and temperature and salinity gradients, may influence juvenile Chinook salmon distribution around the delta. Front densities were highly variable both between adjacent transects and between stations within a transect. Although the densities were generally higher at stations on the north side of the front, there is no consistent pattern showing a relationship between density and depth or station location.

The use of plume habitats by juvenile salmon has been evaluated for other large river systems (De Robertis et al. 2005, St. John et al. 1992, Emmett et al. 2004) where salmon densities are generally higher within the plume than in adjacent marine waters. There is only a single study evaluating juvenile Chinook salmon distribution in marine waters adjacent to the Yukon Delta. Surface trawl surveys have been conducted in the northern Bering Sea (NBS) and Norton Sound (NS) since 2002. The net used in the NBS/NS survey samples an average area of 0.21 km^2 per station (J. Murphy, pers. comm.), which is considerably larger than the 0.012 km^2 estimated area swept per delta front station. Despite the many differences between the delta front and NBS/NS surveys (e.g., habitat, season, and net), the latter offers the only available dataset from marine waters near the delta front sampling area during 2014 and 2015 which can be used to place the current research in a larger context. In 2014 and 2015, standardized, per-km^2 densities of juvenile Chinook salmon ranged from 0 to 559 on the delta front and 0 to 321 in NBS and NS (J. Murphy, pers. comm.). While this may suggest that some delta front stations have higher peak densities of juvenile Chinook salmon than adjacent marine waters; the front densities may also reflect physical variations in the plume habitats that juvenile Chinook salmon encounter during their initial marine life-history period.

The limited physical data collected during this research suggests that the Yukon River plume front may be more similar to the horizontally diffuse plume front of the Mackenzie River (Wong et al. 2013, Carmack and Macdonald 2002) than the steeper plume front of the Columbia River (Morgan et al. 2005). Spatial variation in Chinook salmon CPUE was not strongly related to differences in temperature and salinity at locations where they were caught. While temperature and salinity varied between transects, variation between stations on a given transect were generally small and did not explain differences in CPUE. In large river systems it is not uncommon for fronts to occur at small temporal and spatial scales as a result of density differences between river discharge and marine water, or in response to wind turbulence (Morgan et al. 2005, Carmack and Macdonald 2002). Within the plume, interactions between currents, tides, and wind create complex and variable environments that change rapidly and may occur at scales too small to be easily detected during sampling. Juvenile Chinook salmon distributions may be related to mesoscale features within the plume that are differentiated by prey availability or physical variables and this could explain some of the high variability in densities between stations.

The sampling methodology employed on the front was focused on evaluating juvenile Chinook salmon use of front habitats spanning the entire delta. Martin et al. (1987) hypothesized that river outflow in the sub-ice channels of the platform carried juvenile salmon into front and offshore habitats. Since this prior study was limited to stations in the South distributary, and front sampling was limited, there was a paucity of information with which to evaluate juvenile Chinook salmon emigration through the offshore estuary of the Yukon River. The results of the present study suggest that juvenile Chinook salmon move northward upon leaving the distributaries, perhaps transiting over the platform, and do not necessarily end up in marine waters adjacent to the distributary through which they outmigrated. Testing this hypothesis is challenging given the difficulty of catching juvenile Chinook salmon outside the river. Juvenile Chinook salmon comprised less than 1% of the total catch in the delta front sampling, and only 1.5% of the total catch in the tributaries. Similar low catches were observed in prior surveys of the Yukon-Kuskokwim area where juvenile Chinook salmon regularly comprised less than 1% of the total species caught (Hillgruber and Zimmerman 2009). The relative scarcity of juvenile Chinook salmon requires more effort to increase overall catch. Although comparison with larger surveys should be made with caution, catch of juvenile Chinook salmon in the NBS and NS survey during 2014 and 2015 ranged from 0 to 73 using a net that samples average area of 0.21 km^2 at each station. In the present research, the area swept by the small net used to access the shallow waters of the Yukon Delta front sampled an average area of 0.012 km^2 at each station and catch of juvenile Chinook ranged from 0 – 7 over both years. This suggests that the capture efficiency of the gear used on the front is effective at sampling juvenile Chinook salmon and that added effort, either through longer tows or additional transects, is required to increase overall catch. River plume environments, and the fronts that form at the interface of marine and freshwater, may concentrate prey (St. John et al. 1992, Wong et al. 2013, Fukuwaka and Suzuki 1998), resulting in distinct prey assemblages in plume and non-plume habitats (Wong et al. 2013). Potential juvenile Chinook salmon prey items from the Yukon River plume includes YOY Pacific herring, larval and YOY rainbow smelt, and mysids. Pacific herring YOY (20 to 30 mm) have been observed in diets of juvenile Chinook salmon captured in northern Norton Sound in Fall surveys (Cook and Sturdevant 2013) and were noted in the stomach contents of juvenile Chinook salmon from north transects in June and July 2015 (Chapter 2). However, Pacific herring were only abundant in catches in August. Rainbow smelt YOY and larvae have also been identified as prey for juvenile Chinook salmon in Norton Sound (Cook and Sturdevant 2013, Murphy et al. 2014), but were not specifically identified in the diets of salmon in this study; most fish diet items were identified only as larval fish. In 2014, larval rainbow smelt were most abundant in June off the mouth of the South distributary, while YOY were more abundant in July on the north front transects. Highest catch of these life stages is not coincident with the period and location of highest juvenile Chinook CPUE. Catches of rainbow smelt were higher in 2014 than in 2015. Mysids are a common component of the benthic zooplankton community in Norton Sound (Dragoo 2006) and are an important component in fish diets, including chum and Chinook salmon (Hillgruber and Zimmerman 2009). Mysid CPUE was extremely high during all sampling months in 2014 and occurred at all stations where juvenile Chinook salmon were caught. Mysids were observed in the diets of Chinook salmon caught in June 2014 (Chapter 2).

The high interannual variability in the CPUE of potential Chinook salmon prey makes it difficult to connect prey availability to spatial differences in juvenile Chinook salmon CPUE. Differences in CPUE between years may be partially attributable to the difficulty in accurately enumerating larval species in the samples. Both larval herring and larval rainbow smelt are within the capture size range of the sampling gear, they are not as efficiently retrieved with this gear as they would be with a plankton tow. Larval Pacific herring in particular are extremely small and translucent and can adhere to the net or become lost in a sample with numerous larger species, which could lead to underreporting of this species. The size of the CPUE difference between years argues against enumeration issues as being the sole cause of the disparity. Several studies have observed high variability in the catch of pre-adult rainbow smelt and Pacific herring near the Yukon River (Martin et al. 1987, Martin et al. 1986, Hillgruber and Zimmerman 2009). During the 2 years of this research, the period with highest juvenile Chinook salmon catch in both the distributaries and on the front corresponds to the period with the lowest catch of potential prey in the plume. Multi-year studies on the factors affecting variation in prey species are sparse, and with only 2 years of data from the present research it is not possible to identify the factors contributing to this apparent mismatch in prey availability.

Fish community composition in the Yukon River distributaries is primarily attributable to seasonal changes from species migrating into and out of the distributaries, forming two distinct temporal communities: Period A and Period B. The gradient between these two communities differs between years. The strong gradient in 2015 results from a high, short-term catch of juvenile pink salmon in the early sampling period and a surge in the catch of juvenile coregonids, sheefish, and burbot in the later sampling period. The sharp gradient between the two assemblages is coincident with a period of rapid temperature increase. Very little is known about the seasonal spatial dynamics of these juvenile species or the effects of temperature on their distribution within the river. Community composition in late July 2015 was influenced by an increase in juvenile Chinook salmon catch; this was not observed in 2014. These late arriving Chinook in 2015 were more abundant in the Middle and North distributaries than in the South distributary, causing a decrease in similarity across stations for the last 2 weeks of the sampling period. Many late arriving Chinook were small (≤ 85 mm), and their arrival following the peak CPUE of other fish species may have implications in terms of prey availability and condition (see Chapter 2).

Community composition on the front was best described by the month in which sampling occurred each year, but within group similarity was low. Differences in assemblages within years resulted primarily from changes in abundance of juvenile age classes rather than changes in species occurrence, while assemblage differences between years result from high catch of several species in 2014 that were nearly absent in 2015. In each year, community similarity between transects and stations within the same sampling period was relatively low, reflecting the complex and dynamic environment of the Yukon River plume and its effect on species distributions around the Delta front.

SECTION 2: JUVENILE CHINOOK SALMON DIET

INTRODUCTION

The Yukon River estuary provides important foraging habitat for juvenile Chinook salmon as they transition to marine residency. It is generally accepted that fish that grow faster and larger 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). Research also suggests that the quality and quantity of prey resources available during emigration and early marine residence are crucial factors for juvenile salmon growth and survival (Duffy et al. 2010, Beauchamp 2009, Moss et al. 2009). Information on the diets of emigrating Chinook salmon in the Yukon River is scarce, and there are no studies evaluating changes in diet quality of emigrating smolts as they move from river to offshore habitats.

During spring when juvenile Chinook salmon migrate out of the river, Yukon River water spreads in a shallow plume well into Norton Sound and the Bering Sea, and there is evidence to suggest that the transition to the marine environment occurs along the plume front (Martin et al. 1987). Recent research suggests that the diets of juvenile salmon in the upper Yukon consist mainly of drifting terrestrial and aquatic invertebrates (Wipfli et al. 2014, Gutierrez 2011). As the fish move downstream and offshore their diet diversifies with an increasing contribution of fish prey. Size-specific competition may affect juvenile Chinook salmon spatial distribution, growth, condition and recruitment. A number of studies have documented diet overlap between juvenile Chinook and coho salmon (Bollens et al. 2010, Brodeur and Pearcy 1990, Cook and Sturdevant 2013); however, the relationship between particular habitats and juvenile salmon prey and growth is largely unknown. This section examines the diets of juvenile Chinook and coho salmon in distributary and front habitats in 2014 and 2015.

Laboratory Methods

Juvenile Chinook and coho salmon collected for diet analysis were measured to the nearest 1 mm fork length (FL) in the field and preserved in a 10% formalin solution. In the laboratory, each fish was weighed to the nearest 0.001 g. Stomachs were removed from the fish and weighed. Stomach contents were removed and the stomachs were re-weighed empty. The stomach content weight was determined by subtracting the stomach full weight from the stomach empty weight. Stomach contents were examined microscopically to identify prey items by taxa, species, life stage, and level of digestion. Prey items were identified to the lowest taxonomic level achievable. Each prey group was weighed, and the percent composition of major prey categories was summarized. Feeding intensity (i.e., stomach fullness) was calculated as percent of the fish body weight (%BW):

%BW = prey weight /(fish weight – prey weight) * 100

for all non-empty stomachs. Feeding incidence was calculated as the ratio of empty stomachs to total stomachs.

Prey consumption was described by the percent weight (%W) and percent frequency of occurrence (%FO) of prey categories from all non-empty stomachs. Percent weight was calculated as the total weight of an individual prey taxa divided by the total weight of all prey taxa combined for each stomach. Percent weight was averaged by prey type to obtain a mean proportion by prey type for all sampled fish. Percent frequency of occurrence was calculated as the percent of stomachs containing a given prey and is used as a measure of diet composition (Bowen 1996).

RESULTS

Diet analyses were conducted in the laboratory on a total of 949 juvenile Chinook salmon. Chinook used in the diet analyses ranged in size from 56 mm to 126 mm FL in distributary samples and 79 mm to 170 mm FL for the front samples. Stomach content analysis was conducted on a total of 568 Chinook (Tables 7 and 8). In 2014, stomach content analysis was conducted on all 192 juvenile Chinook retained for diet analyses; 10 were from the front. In 2015, large numbers of Chinook were retained from the tributaries for diet analyses, but stomach content analysis was restricted to a subsample of 351 tributary-caught fish randomly selected from each station per week. All 25 Chinook retained in 2015 from the front for diet analyses had there stomach contents analyzed. In 2015, higher numbers of Chinook were retained for diet analysis from the distributaries and the front, and stomach content analysis of distributary-caught fish was limited to a randomly drawn subset of specimens from each station per week. Stomach fullness analysis was conducted on all Chinook salmon analyzed for stomach contents, as well as fish retained for energetics. A total of 949 juvenile Chinook salmon were evaluated for stomach fullness; 337 tributary and 17 front specimens from 2014, and 555 and 40 from 2015.

Diet analyses were conducted on a total of 388 juvenile coho salmon captured in the tributaries (Table 9). Juvenile coho salmon were rarely caught on the front and were not evaluated for diet. Juvenile coho used in diet analyses ranged in size from 71 mm to 141 mm FL. Stomach content analysis was conducted on a subsample of 37 coho from 2014 and 108 from 2015 (Table 3); evaluated specimens were randomly drawn from each station and week. Stomach fullness analysis was conducted on 388 juvenile coho salmon; 178 from 2014 and 210 from 2015.

Chinook Diets – Yukon River Distributaries

During the two years of the study, 16 prey categories were identified in the stomachs of juvenile Chinook salmon captured in the distributaries (Table 7). The most important prey categories by weight over the two years of the study were fish (59.3%) and unidentified insects (20.9%). Other important diet components were Perlodidae (stoneflies), Trichoptera (caddisflies), and Chironomids. Larval and pupal stages of aquatic invertebrates were more common in the diets than adult stages. Larval fish and fish remains were observed in the stomachs of juvenile Chinook < 70 mm in May 2015 and were relatively common in Chinook > 80 mm in both sample years. The smallest Chinook containing fish remains was 65 mm in length.

Diet composition varied by sample year and month. Within distributaries, fish comprised a substantially larger percentage of diets by weight in July 2014 (82.0%) than in July 2015 (27.4%). Additionally, 2015 fish consumption was high in May and remained strong into June comprising 62.0% of the diets compared with 28.3% of the diets in June 2014. Perlodidae and Chironomids frequently occurred in diets throughout the sampling months in both years. Non-food items, such as plant debris and sediment, occurred in all months but were more frequent in diets from July.

Diet composition was similar across distributaries within a sampling year (Fig. 1). In 2014, invertebrate consumption was higher in June than in July in all distributaries, while fish consumption was much higher in July. Fish consumption, measured both as %W and %FO, was higher in juvenile Chinook salmon captured in the North distributary in June 2014 than in either the South or Middle distributaries. Diets in general were more diverse in June than in July 2014, with juvenile Chinook in the South distributary consuming a slightly larger variety of prey than those in the other two distributaries.

Diets in May of 2015 were the least diverse of all sampling periods. In the Middle and North distributaries, fish comprised over 90% of the diets by %W and over 70% by %FO during this period. Fish was a smaller diet component in juvenile Chinook salmon captured in the South distributary in May 2015. Invertebrates were a much larger component of diets in the North and Middle distributaries in July 2015 than they were in the South distributary diets. Fish comprised a little over half the diets by %W for juvenile salmon captured in the South distributary in July 2015, but were less than 10% of the diets for fish from the North distributary. None of the juvenile Chinook salmon from the Middle distributary had fish in their diets during this period.

Diet analysis identified a difference in the proportion of fish in the diets of small (≤ 85 mm FL) and large (≤ 85 mm FL) juvenile Chinook salmon in 2015. The ratio of fish to insects in the diets of both size classes were similar in June of 2014, but the species composition of prey items differed (Fig. 2). There were too few samples in smaller size class captured in July 2014 to make comparisons of diet by size. In 2015, juvenile Chinook salmon diets varied by fish length across the three sampling months (Fig. 3). Diets of both size classes were comprised primarily of fish in May 2015 with a slightly higher consumption of insects by small Chinook salmon. In June and July 2015, diets of the small juvenile Chinook salmon contained a much higher proportion of insects than large Chinook.

Stomach fullness (%BW) was not significantly different ($p > 0.05$) between sample years for fish captured in the distributaries; however, there were variations in %BW by sample month and distributary both within and between sample years (Fig. 4). Stomach fullness was lowest in juvenile Chinook from the North distributary in July of both years. Chinook salmon from the North and Middle distributaries in May 2015 had the highest stomach fullness. The total average weight of prey consumed was not significantly different between study years, but did vary by distributary with juvenile Chinook salmon from the Middle and South distributaries having a larger average stomach content weight than fish from the North distributary.

Chinook Diets – Yukon Delta Front

Diets on the front were classified into eight prey categories (Table 2). Across the study period, 75% of the juvenile Chinook salmon diets were composed of fish. Other important diet items included mysids, adult Chironomids, Diptera (true flies), insects, and other crustaceans. Fish were the primary component of juvenile Chinook salmon diets by %W in June of both 2014 and 2015. In fish analyzed from July 2015, fish prey comprised only 53% of the diet by %W, with the remainder of the diets composed of drift insects. There were no juvenile Chinook salmon captured in July 2014 and only a single small individual of 85 mm FL was captured in August 2014. Mysids were an important diet component in June 2014 and were also a major component of the total trawl catch during that period. In contrast, in June 2015 there were very few mysids in the trawl catch or in the diets of juvenile Chinook salmon.

Front transects were divided into regions corresponding to areas of similar circulation and wind patterns on the Yukon Delta (See Chapter 1). Adult chironomids, flies, and unidentified drift insects comprised 10% or more of the diets of salmon from all regions (Fig. 5). Diet composition differed by year and station depth where fish were captured (Fig. 6). Somewhat surprisingly, diets from fish captured at the deepest stations were the most diverse, with the highest proportion of Diptera, Trichoptera, and Chironomids, as well as crustaceans. Mysids made up 78% of the diets from fish captured at the shallowest stations in 2014, but are virtually absent from diets of Chinook caught at nearshore stations in 2015.

Diet Comparison

There was substantial overlap between the diets of juvenile coho and juvenile Chinook salmon captured in the Yukon River distributaries (Table 1 and 3). In 2014, juvenile coho salmon consumed a higher proportion of fish both by %W and %FO than Chinook salmon. In May 2015, fish was the largest proportion of both Chinook and coho diets by %W, but %FO of fish was lower for coho than Chinook salmon. In June 2015, coho salmon diets contained similar proportions of fish and insects compared with Chinook salmon whose diets were composed primarily of fish.

Juvenile Chinook salmon consumed a larger variety of prey than juvenile coho salmon, including larval stoneflies (Plecoptera), true flies (Diptera), and adult Chironomids. Both species consumed non-food items, such as plant material, in similar proportions during May and June. Chinook salmon consumed non-food items at higher proportions of their diet in July of both years compared with other months; however, too few coho salmon were caught in July to be able to compare diets. A higher proportion of coho salmon had empty stomachs in May of 2015 than Chinook in that same period, but otherwise the proportion of empty stomachs was similar between months and years. Average stomach fullness for juvenile Chinook salmon was substantially lower than for juvenile coho salmon in June 2014, but was higher in May and June of 2015. Stomach fullness was highest in May 2015 for both species.

DISCUSSION

Juvenile Chinook salmon diet composition varied by year and month for fish captured in the Yukon River distributaries and on the Yukon Delta front during 2014 and 2015. Variations in diet reflect annual and seasonal variations in the availability of fish and invertebrate prey. Juvenile Chinook salmon showed evidence of piscivory in distributary habitats from the start of sampling in each sample year. Juvenile Chinook salmon from the delta front were predominantly piscivorous with a relatively small contribution from marine invertebrates (e.g. copepods and mysids) and terrestrial and aquatic drift insects from the Yukon River. All of the fish from the delta front were 80 mm FL or greater. Piscivorous juvenile Chinook salmon on the Yukon Delta front were similar in size to piscivorous juvenile Chinook from nearshore waters in Southeast Alaska (Weitkamp and Sturdevant 2008) and Puget Sound (Duffy et al. 2010).

Most information on the relative contribution of fish to juvenile Chinook salmon diets comes from studies in river plumes (Schabetsberger et al. 2003, De Robertis et al. 2005) and nearshore environments (Duffy et al. 2010, Weitkamp and Sturdevant 2008) following emigration. In these locations, juvenile Chinook salmon predation on pink and chum salmon has been documented (Duffy et al. 2010). There is a paucity of data on juvenile Chinook salmon piscivory within river habitats during emigration.

Interannual variation in fish consumption by juvenile Chinook salmon appears to be related to differences in the prey species composition in May and June as well as differences in the relative size of juvenile Chinook salmon and potential prey in both years. The high proportion of fish prey in the diets of distributary caught juvenile Chinook salmon in May and June 2015 is coincident with a high abundance of pink salmon in trawl catches during this period. Pink salmon emigration peaked in May 2015 but continued through June (Howard et al. (in prep)). During this period, fish constituted nearly 90% of juvenile salmon diets by weight in May, and 60% by weight in June. In 2014, juvenile pink salmon were only 2% of the total fish catch and fish was a much smaller component of juvenile Chinook salmon diets. Juvenile chum salmon were the second most abundant species in both sampling years with high CPUE into early June in 2014 and mid-June in 2015 (Howard et al. (in prep)). Chum salmon could be the primary component of fish in juvenile Chinook salmon diets in 2014.

The ratio of prey length to predator length was also an important factor in juvenile Chinook salmon fish consumption in 2015. Small Chinook (≤ 85 mm) were a relatively large proportion of the catch in June and July 2015 (26% and 43%, respectively). These small salmon were not observed during the same period in 2014 (Howard et al. (in prep)). Fish were a much smaller component of small (≤ 85 mm) Chinook salmon diets in June and July of 2015 than in larger Chinook salmon diets, while in May 2015 the proportion of fish in the diets of large and small fish was similar. Differences in diet may be partially explained by the size of available potential prey. Juvenile Chinook salmon generally consume prey that is less than 50% of their body length (Weitkamp and Sturdevant 2008). In May 2015, the average length of juvenile pink salmon in May 2015 was 33 mm FL which made them available to juvenile Chinook salmon of both size classes. However, in last two weeks of June 2015, average pink salmon length had increased to 50 mm FL (Howard et al. (in prep)) which put them beyond the available size range for small Chinook salmon. Similar patterns occur with chum salmon. Average chum salmon length in May 2015 was 38 mm FL, but this had increased to 53 mm FL by the end of June.

Differences in juvenile Chinook salmon fish consumption between July 2014 and July 2015 may also be the result of a mismatch in predator-prey size between years. Fish were a large component (> 80% by weight) of the diets of both size classes of juvenile Chinook salmon in July 2014. In July 2015, fish were virtually absent from small Chinook salmon diets and comprised just over 50% of the diets of larger Chinook salmon. In both sampling years, the occurrence of fish in the diets of juvenile Chinook salmon in July coincides with an abrupt increase in catch of small (≤ 65 mm) coregonids (whitefish and cisco). In 2014, Coregonids were a dominant component of the catch beginning the first week of July and peaking in the middle of July, while in 2015 catch increased in late June and peaked in the first week of July (Howard et al. (in prep)). The average size of these small coregonids was similar in July of both years with an average of 52 mm (range 19 mm – 65 mm) in 2014 and 52 mm (range 29 mm to 65 mm) in 2015; however the average size of Chinook salmon was different. Small Chinook salmon (≤ 85 mm) comprised 43% of the total catch in July 2015. These salmon likely could only consume small coregonids approximately 43 mm or less in length. The average size of large (≥ 86 mm) Chinook salmon was 104 mm in July 2014, but only 97 mm in July 2015. As a result, a much greater proportion of the small coregonid prey was within the prey size range of juvenile Chinook salmon in 2014.

Juvenile coregonids have received relatively little study, but research on the effects of increasing temperature on least cisco (*Coregonus sardinella*) found a positive relationship between temperature and somatic growth particularly for age-0 fish (Carey and Zimmerman 2014). River water temperatures in both study years were above the long-term historic average, with temperatures in 2015 being substantially higher than normal (Howard et al. (in prep)). Although the length of this study is too short to draw conclusions regarding temperature and juvenile coregonid abundance and length, the data and literature suggest that warmer temperatures may encourage faster coregonid growth that may decrease coregonid vulnerability to predation by juvenile Chinook salmon. A similar relationship may also exist for juvenile pink and chum salmon; however the relationship between earlier emigration and temperature is a confounding factor.

Terrestrial and aquatic insects are important prey components for juvenile Chinook salmon in the Yukon River, with insects comprising as much as 70% of juvenile salmon diets. Since prey analysis was restricted to stomach contents much of the insect diet consisted of insect parts rather than whole organisms; however, evaluation of intact or relatively intact organisms showed that juvenile Chinook salmon are consuming a variety of insect prey. Distributary sampling in 2014 included the use of push trawls and seines to evaluate juvenile Chinook salmon use of slough and tidal channel habitats. These sampling methods were ineffective at capturing juvenile Chinook salmon and they were abandoned in 2015. It is not clear whether juvenile Chinook salmon are using these slower water habitats for foraging, or whether prey is being washed from these habitats into the main river distributaries. In the 2016 field season, the prey field will be sampled to allow comparison between juvenile Chinook salmon diets and prey availability in the areas where the salmon are captured.

Insects were the largest component of small juvenile Chinook salmon prey in July of 2015. There is very little research with which to compare the relative caloric value of fish versus insect prey to juvenile Chinook salmon in river habitats. Research on juvenile Chinook in estuaries suggests that insects may have a slightly higher energy density (5,311 J/g wet weight) than fish (4,649 J/g wet weight) (Duffy et al. 2010), but the fish prey used in these analyses were Pacific herring and sand lance (*Ammodytes personatus*) and it is not known how the caloric value of young-of-the-year coregonids, or juvenile pink and chum salmon, compares with these other species. The condition of these small Chinook salmon in

July 2015 was not significantly different ($p > 0.05$) than the condition of either small or large salmon in July 2014; however, condition of large salmon from July 2015 was lower than both small salmon from the same period and large salmon from the previous year (Chapter 3). This implies that food quality is not just a factor of type of food consumed. Stomach fullness did not differ significantly between large and small Chinook salmon in 2015 suggesting that, despite lower fish consumption, small Chinook were not food limited.

There was substantial overlap between the diets of juvenile Chinook salmon and juvenile coho in the Yukon River distributaries. In June 2014, juvenile coho salmon consumed a higher proportion of fish and had a substantially higher stomach fullness than juvenile Chinook salmon. This may reflect a greater ability for the larger coho salmon to exploit the availability of juvenile chum salmon as prey. Juvenile coho salmon were larger than juvenile Chinook salmon average 100 mm (SD 11.6) compared with 88 mm (SD 11.5). In 2015, fish consumption by juvenile Chinook was much higher than coho salmon in May, and was also higher than coho salmon in June. These findings are surprising given the high abundance of pink salmon in May 2015. During this period, nearly half of the coho salmon diets were comprised of insects. In general, juvenile Chinook salmon diets were more diverse than coho salmon diets for the same sampling periods which could suggest that Chinook were more opportunistic predators.

The small number of juvenile Chinook salmon captured on the Yukon Delta front makes it difficult to quantitatively compare diets between transects or regions. Fish consumption was relatively high in all sampling periods. Although the majority of fish diet items were classified only as fish or fish larvae, Pacific sand lance and Pacific herring) were noted in the stomachs of fish from the north region. Larval Pacific herring were abundant at northern transects in August (see Chapter 1), but were not abundant in the catch when juvenile Chinook salmon were caught. Larval Pacific sand lance were not a large component of the catch in any sampling period. Although the trawl nets captured larval and fish as small as 20 mm, the abundance of these species in the catch may not accurately represent their availability in the environment. Additional sampling with a plankton net could provide more information on prey availability in locations where juvenile Chinook salmon were caught.

SECTION 3: JUVENILE CHINOOK SALMON NUTRITIONAL STATUS

INTRODUCTION

The period of emigration and estuarine residence for juvenile Chinook salmon is believed to be a critical period for growth and survival (Beamish and Mahnken 2001). During this period, the fish must grow large enough to avoid predation while at the same time ensuring that their physiological condition is strong enough to survive the winter in the marine environment. The allocation of energy from food to metabolism, growth, and fat storage is affected by environmental factors, prey availability and type of prey consumed (Daly and Brodeur 2015, Brett 1995). Analysis of growth and stored energy can therefore provide information on the physiological status of juvenile salmon in the habitats where they are captured and the influence of the environment and food availability on that status.

There are few studies evaluating energetic changes as juvenile salmon move from fresh to marine waters (MacFarlane 2010). During this period salmon undergo a variety of physiological and dietary changes. This often involves a transition from a diet comprised primarily of terrestrial and aquatic invertebrates to a diet with a larger component of fish. In the Yukon River, emigrating Chinook salmon consume fish prey while still in the river (Section 2), so their dietary changes involve transitioning from a diet of freshwater fish and invertebrates to diet comprised of marine species. Environmental factors that affect juvenile salmon metabolism may also affect their fish prey, potentially reducing their caloric value, and thus affecting the energy derived from them. This section evaluates differences in energy content of juvenile Chinook salmon in distributary and estuarine habitats of the Yukon River in 2014 and 2015.

METHODS

Juvenile salmon retained for energetic analysis were measured to the nearest 1 mm fork length (FL) and frozen in the field and remained frozen until processed in the laboratory. In the laboratory, fish were weighed to the nearest 0.001 g, and sagittal otoliths were removed for later analysis of age and microchemistry. The stomachs were removed and all the bolus of prey was measured to obtain an estimate of stomach fullness. The empty stomach was returned to the body cavity, and the 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). A total of 381 juvenile Chinook salmon were analyzed for energy content: 155 distributary and 7 front for 2014 and 204 distributary and 15 front for 2015.

Sample sizes differed between months and years resulting in unbalanced data and unequal variances (Levene's test $F=4.082$, $p=0.003$). Therefore, a Welch's t-test, which does not make the assumption of equal variances, was used to compare energy density by sampling month and size class.

RESULTS

Juvenile Chinook salmon processed for energy content ranged in length from 56 mm to 124 mm (average = 92.4, SD = 11.22) in 2014, and 61 mm to 136 mm (mean = 90.98, SD = 11.95). Weight ranged from 4.48 g to 20.54 g (mean = 9.26 g, SD = 3.19 g) wet weight in 2014 and from 2.18 g to 26.17 g (mean = 7.60 g, SD= 3.66 g) wet weight in 2015. Average energy density of juvenile Chinook salmon was 4,964 cal/g (SD=159.54) in 2014 and 4,947 cal/g (SD=187.69) in 2015.

Energy density for juvenile Chinook salmon sampled in the distributaties varied significantly by month. In 2014, average energy density for all size classes of salmon increased between June and July ($p = 0.02$). In 2015, energy density was significantly higher in May ($p < 0.05$) than the other 2 months of the sampling period, but was similar between June and July ($p > 0.05$) (Fig. 1). There was no difference between the energy density of small (≤ 85 mm FL) and large (≥ 86 mm FL) juvenile Chinook salmon in 2014 (Fig. 2). Large juvenile Chinook salmon in July 2015 had a lower energy density than small Chinook salmon from that same time period ($p = 0.03$). Large juvenile Chinook in July 2015 also had significantly ($p = 0.03$) lower energy density than the large juvenile Chinook from July 2014.

Average energy densities varied by week and with the size class of salmon (Fig. 3). Juvenile Chinook salmon in 2015 started off with relatively high energy densities in May which then decreased through the middle of June and increased again to the middle of July before falling off. The pattern in 2014 was similar through the beginning of July. However, the patterns of the two years diverged strongly starting in the second week of July with energy content of 2014 chinook salmon increasing through the end of the sampling season, while energy content of 2015 chinook salmon decreased back to early June levels. With the exception of the last week in May, small juvenile Chinook salmon had higher average weekly energy densities than large Chinook throughout 2015 (Fig. 4). After a drop at the beginning of June, the energy densities of small Chinook salmon increased through the middle of July when they began to fall. There was much more variability in large Chinook.

Energy densities of juvenile Chinook salmon from the Yukon Delta front in June 2014 were slightly lower than densities of distributary-caught Chinook from the same period (Fig. 3). The average length of Chinook salmon used in condition analyses also differed with front-caught salmon averaging 94 mm FL (SD=9.80) and distributary salmon averaging 90 mm FL (SD=11.91). June 2015 energy densities from distributary and front Chinook salmon were similar, as were the mean lengths of salmon used in the analyses (93 (SD=11.87) and 94 mm FL (SD=14.59), respectively). Energy densities were also lower in front-caught salmon than distributary-caught salmon in July 2015; however, the average length of salmon used in the analyses were much different (121 mm and 83.7 mm, respectively). Front energy densities were similar between regions and years (Fig. 4). Sample sizes were too small for statistical comparisons.

DISCUSSION

Energy allocation strategies for emigrating juvenile Chinook salmon are not well documented. In the Northern Bering Sea, juvenile Chinook salmon have a relatively well defined relationship between energy density and weight by September (Murphy et al. 2013) but a relationship between size and energy density are not necessarily well defined during the initial stages of their marine life-history. In this study, energy density was not related to fish length or weight, but did vary temporally within and between sampling years, and with the size class of fish. Small juvenile Chinook salmon had higher energy densities than large Chinook for all months except May 2015, although this difference was only significant for July 2015.

Prey type can affect juvenile Chinook salmon energetics, and the higher energy densities of juvenile Chinook salmon from May 2015 and July 2014 are coincident with higher consumption of fish prey during these periods (Chapter 2). Fish consumption in May 2015 is concurrent with a large emigration of pink salmon while fish consumption in July 2014 coincides with an abundance of small coregonids. During both these periods, fish was the primary component of juvenile Chinook salmon diets for both fish size classes. Other studies that have suggested that fish is a relatively energy dense diet for juvenile salmon (Davis 1993); however the results from the present study appear to be mixed. Energy densities did not differ between small salmon from July 2015 and either small or large salmon from July 2014 even though 80% of the diets of small salmon from 2015 were comprised of invertebrates, compared with 20% of the diets of salmon from 2014. In addition, fish made up just over 50% of the diets of large salmon in July 2015, yet the energy density of these salmon was significantly lower than small salmon in the same period which were consuming primarily invertebrates, and large salmon from the previous year which were consuming primarily fish. Because somatic energy is a reflection of the caloric value of food stored in tissues, there are lags between prey consumption and energy storage that make comparison of diets and energy density challenging.

Energy densities were highly variable throughout the season in both years. Environmental conditions can also affect the conversion of prey to energy and how that energy is allocated. Water temperatures in particular can increase metabolic rates and use up energy reserves (Myrick and Cech Jr. 2004). Weekly distributary water temperatures were on average 1.2 °C higher in 2014 than in 2015 (Chapter 1). In 2015, water temperatures increased abruptly from 14.42 °C in the third week of June to 18.15 °C in the last week of June. Temperatures in 2015 remained above 18 °C until the third week of July. These increasing temperatures may have affected metabolic rates of juvenile salmon and their fish prey. Despite the high contribution of fish to the diets of large juvenile Chinook salmon throughout the 2015 sampling period, energy densities declined between May and June and did not show any increase between June and July. Higher temperatures may have affected juvenile Chinook salmon in two ways: directly through an increased metabolic demand, and indirectly through lower energy density of thermally stressed fish prey. Lower energy content of fish prey as a result of higher metabolic demands may have reduced the prey's value as a food source compared with invertebrate prey. This would explain why small Chinook salmon, whose diet was mostly comprised of invertebrates, had higher energy densities than their larger counterparts in July 2015. The energy content of juvenile Chinook salmon diet components was not measured but will be added to the study in the future. Direct comparison of diets to the energy content of prey could provide insight into the effects of climate changes on energy allocation and health of emigrating salmon. Weekly differences in energy densities throughout both sampling years also suggest that prey availability and environmental variability are affecting juvenile Chinook salmon condition.

Energy densities of juvenile Chinook salmon from front and distributary habitats varied between years. In the Yukon River, juvenile Chinook salmon exit the river mouths and enter the offshore estuary of the Yukon River Plume (see Section 1). Observed energetic differences between front and distributary salmon may result from energetic costs associated with the transition from freshwater; however the size and transience of this energetic cost is debated (Brett 1995, Webster and Dill 2006). Energy density of juvenile Chinook salmon from the front was similar across sampling months and locations and did not increase with fish length. This suggests that these salmon are converting food energy to growth rather than storage, which is consistent with other research (De Robertis et al. 2005)

CONCLUSIONS

This research provides new information on the spatial distribution of juvenile salmon on the Yukon Delta and expands on previous research on salmon distribution and abundance in this area. Notably, during this research, stations within the three main lower Yukon tributaries were sampled at least three times per week from mid-May through the end of July, documenting the spatial and temporal distribution of salmon and other species in these habitats. Sampling at transects stationed around the Yukon Delta front provides the first comprehensive study of species composition within the Yukon Delta plume in June through August. Catch of juvenile Chinook salmon on the front was higher at stations on the north and northwest sides of the delta, and did not correspond to the size of catches within adjacent tributaries. Prevailing northerly currents around the delta may move juvenile salmon northward toward Norton Sound, a finding that concurs with other research (Martin et al. 1987, Farley et al. 2005). Estuarine conditions exist at the interface of fresh and marine water along the front and provide the first opportunity for marine transition for juvenile salmonids.

Temporal differences in prey consumption and energy density were observed in both the distributaries and on the front. High variability in the date of ice retreat, river discharge, and water temperatures between study years do not allow conclusions to be reached regarding potential causal mechanisms, but do suggest areas for additional study. In 2014, energy density for juvenile Chinook salmon in the distributaries increased with size during the sampling period. In 2015, overall energy density was similar to 2014, but there was a significant decrease in energy density of large Chinook salmon late in the season. These differences in energy density are not easily attributed to changes in prey, but may be related to the energy density of the prey at the time it was consumed. The potential importance of water temperature in creating stress for both juvenile Chinook salmon and their fish prey cannot be assessed without additional years of data. Similarly, there may be a mismatch between the abundance of prey on the front and the number of emigrating Chinook salmon; however, there is currently no evidence of food limitation. This difference may be the result of natural variation in prey populations or related to river discharge or other environmental factors.

An unusual finding was the relatively high abundance of small Chinook salmon in the distributary catches in July 2015. Fish in this size range were relatively rare in catches from 2014. These small fish could be age-0 Chinook that moved into the lower river from upper river habitats (Howard et al. (in prep)). In the previous study of this area, only a small proportion of Chinook salmon within the size range of age-0 fish were caught during July and August. Additional data are needed to evaluate whether these small Chinook regularly occur in the river late in the season.

Piscivory was evident in the Yukon River juvenile Chinook salmon from the start of sampling in May. Abundant fish prey resources occur from May through late July, but showed evidence of temporal variability in the size and timing of peak catch. Predation on fish differed by season and year, and there is an indication that the average size of fish prey in July 2015 may have been too large for Chinook salmon to utilize. The role of water temperature and other environmental factors during prey spawning and rearing are unknown, but faster prey growth may affect juvenile Chinook salmon condition.

Recommendations

Continued sampling in the Yukon River estuary is needed to address the high temporal and spatial variation in the data and to understand how environmental variability may influence salmon distribution, diet, and condition. Distributary sampling should continue in all three distributaries, and should be extended through the end of August to capture the full extent of emigration. Temporal variability in the caloric content of prey items commonly consumed by Chinook salmon should be examined in relation to juvenile Chinook salmon energy density and environmental factors such as water temperature. Resolution of fish prey in diets would allow better understanding of which fish prey species are important and when. Improved understanding of the temporal (and potentially spatial) gap between diet and energetic condition could increase understanding of the relationship between diets and fish condition.

The expansive spatial scale of the front study resulted in relatively limited sampling effort over a large area, which likely contributed to the low total catch of juvenile Chinook salmon. Future sampling should focus on a more restricted spatial area with increased sampling frequency and density of sampling locations and potentially longer tow duration to increase juvenile Chinook salmon sample sizes. Forage dependencies of juvenile Chinook salmon within the plume are not well known. Temporal and spatial variation in prey resources should be evaluated in relation to Chinook size, condition, and abundance to assess perceived mismatch between prey abundance and Chinook salmon presence.

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Figure 18. -- Comparison of energy content of juvenile Chinook salmon from the Yukon River Delta by size class and sampling week for 2014 and 2015.

Figure 19. -- Comparison of energy content of juvenile Chinook salmon from the Yukon Delta Front region and month for 2014 and 2015.

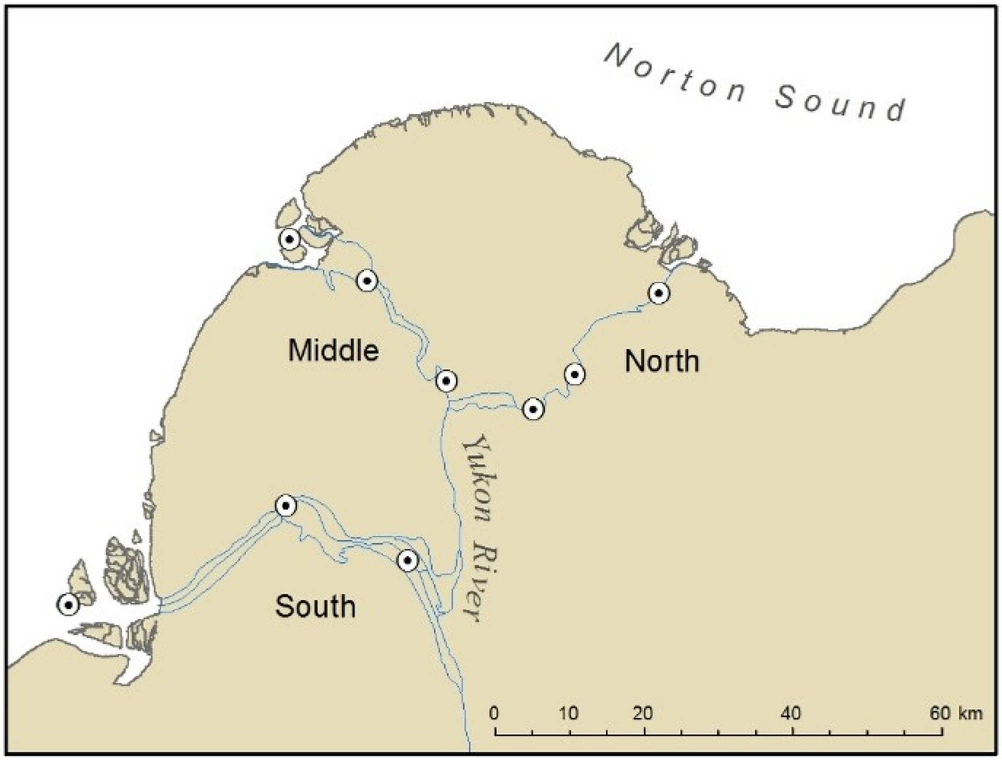


Figure 1. -- Location of sampling stations on the Yukon River 2015 and 2015.

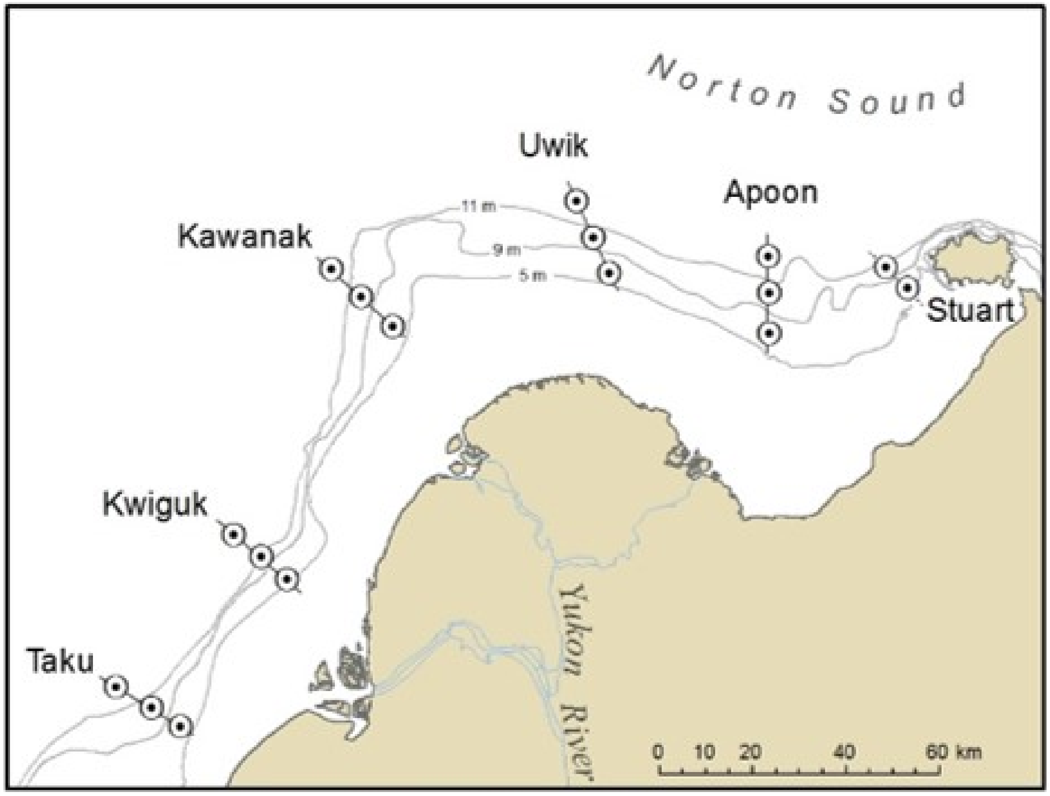


Figure 2. -- Location of transects and sampling stations on the Yukon Delta front, 2014 and 2015.

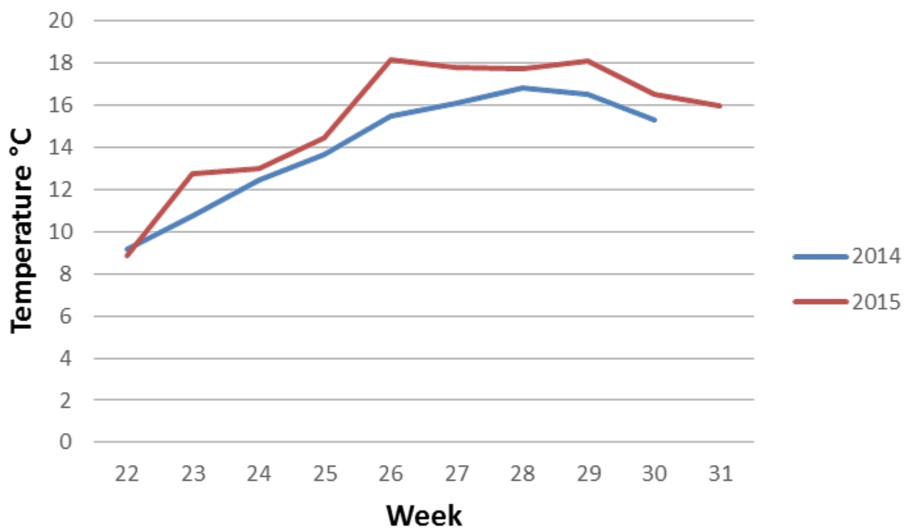
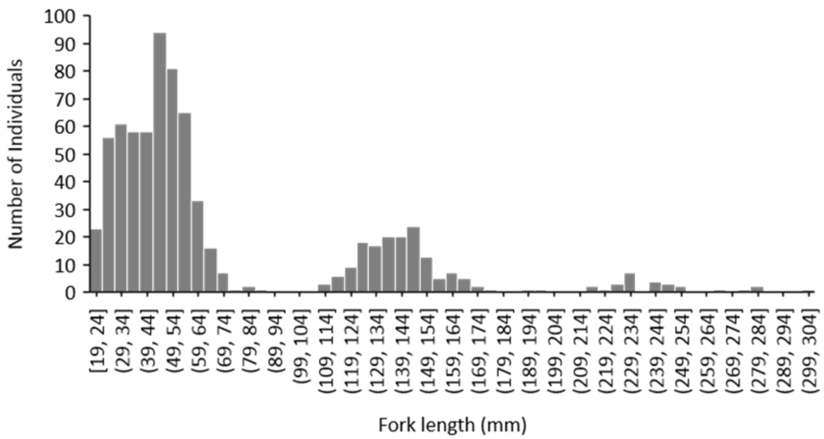


Figure 3. -- Weekly average water temperature (° C) in the Yukon River by sampling week and year for 2014 and 2015.

a)



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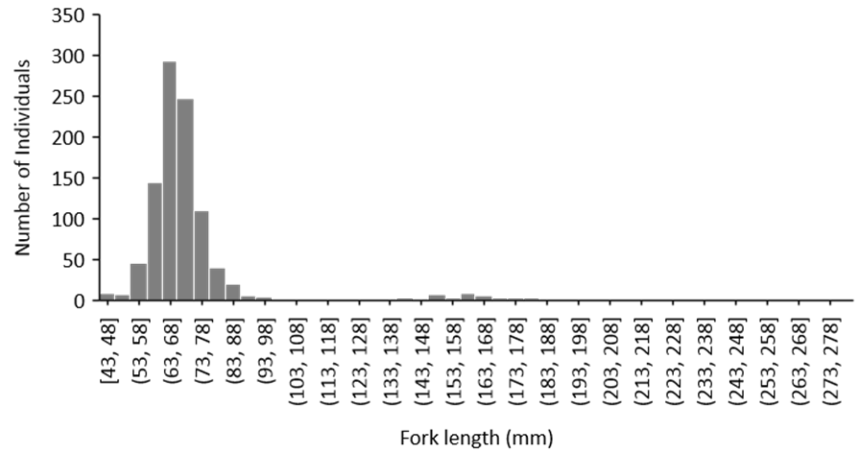


Figure 4. -- Length frequency distributions for juvenile and young-of-the-year saffron cod at Yukon Delta front stations in a) July and b) August of 2014 and 2015 combined.

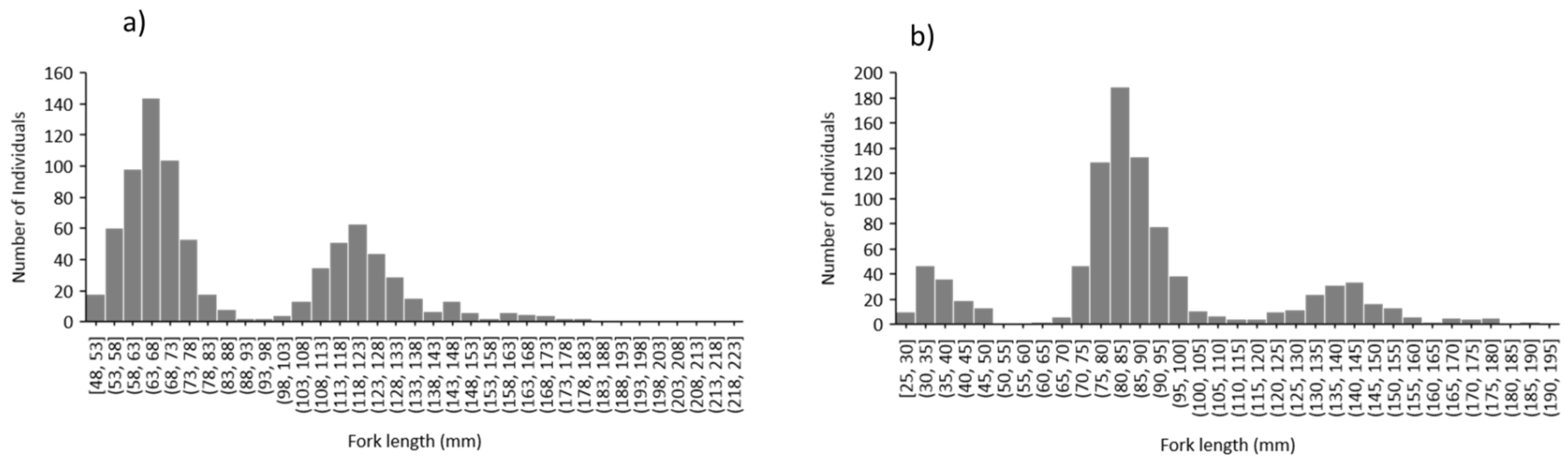


Figure 5. -- Length frequency distributions for juvenile and young-of-the-year Pacific rainbow smelt at Yukon Delta front stations in a) July and b) August of 2014 and 2015 combined.

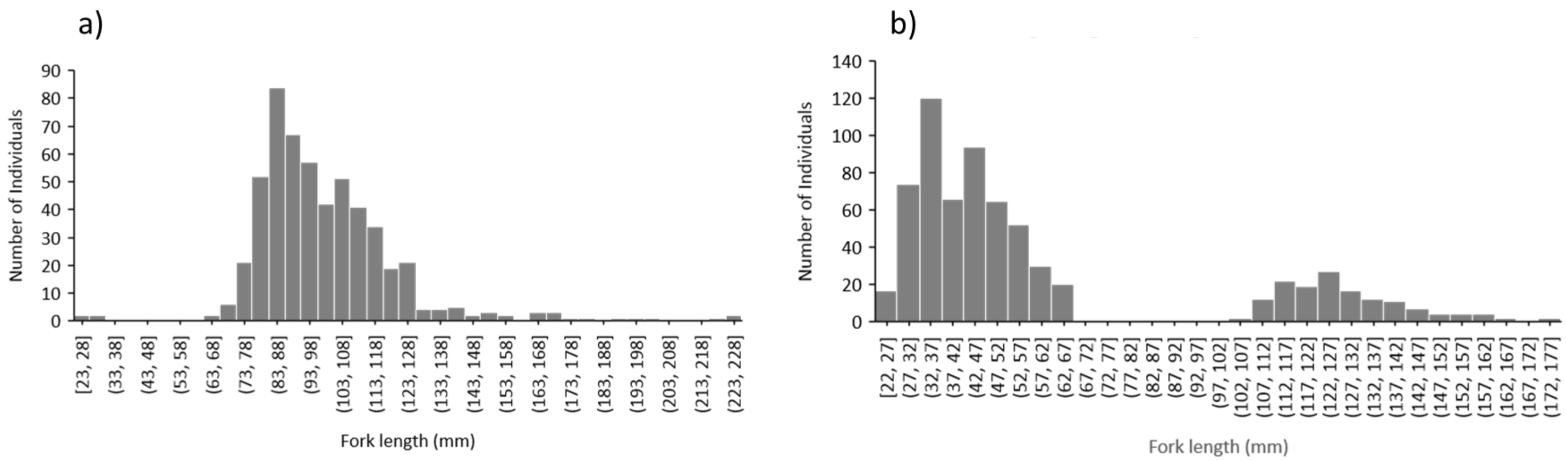


Figure 6. -- Length frequency distributions for juvenile and young-of-the-year Pacific herring at Yukon Delta front stations in a) July and b) August of 2014 and 2015 combined.

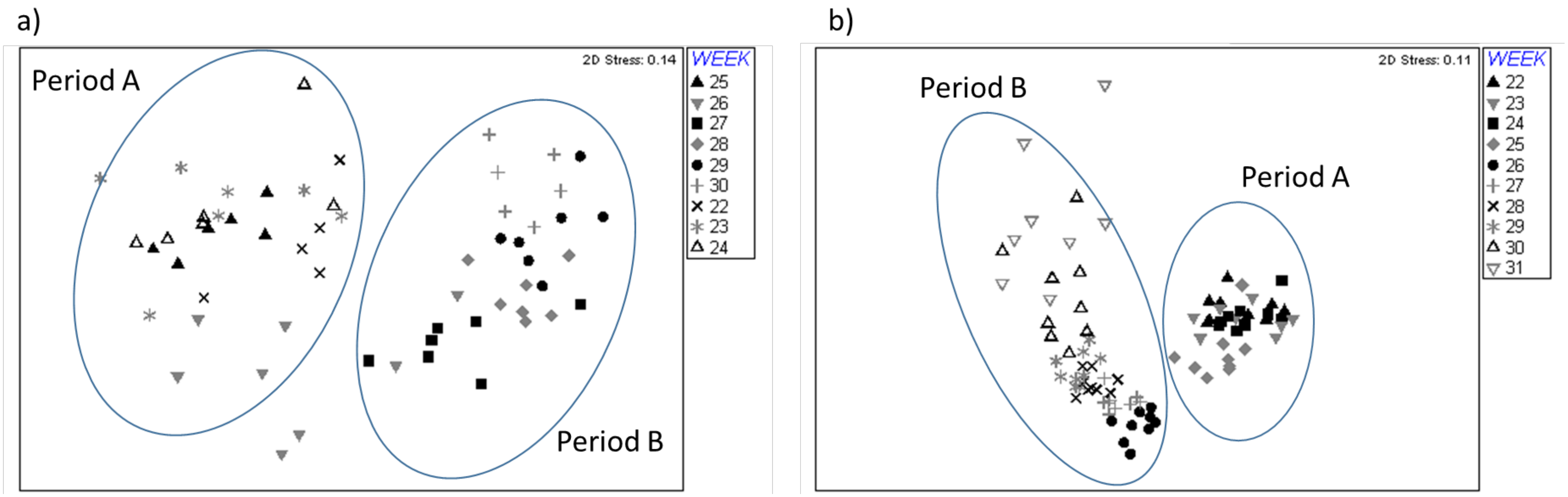


Figure 7. -- MDS ordination of Yukon River distributary fish assemblages by sampling week in a) 2014 and b) 2015. Weeks 22 through 25 are in Period A, and weeks 26 through 31 are in Period B.

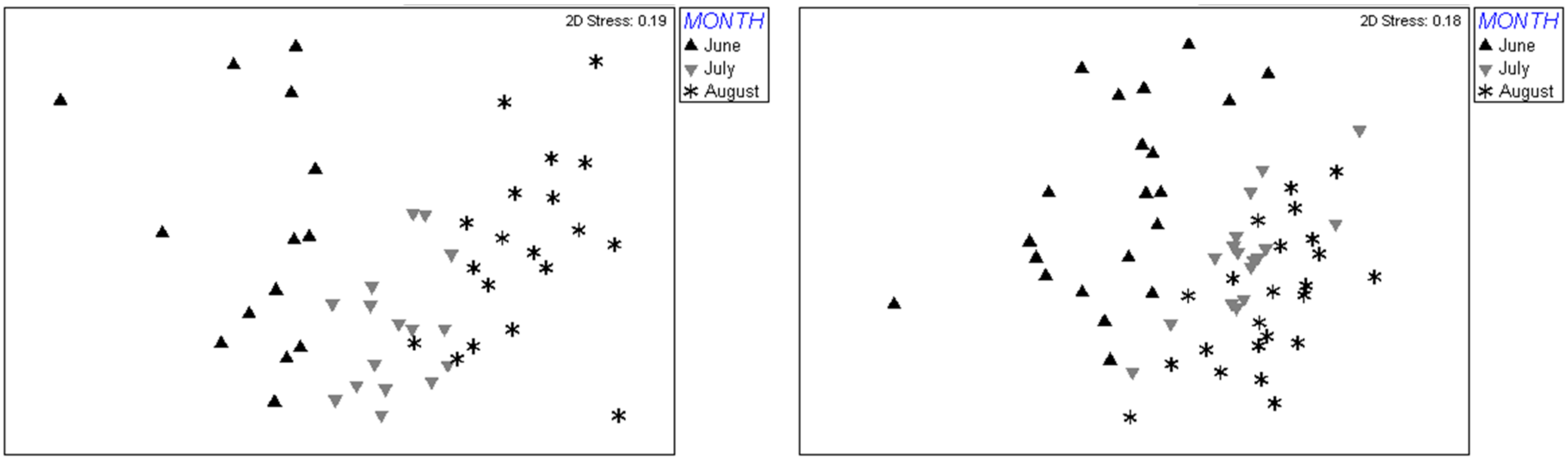


Figure 8. -- MDS ordination of Yukon Delta front fish assemblages by sampling month in a) 2014 and b) 2015.

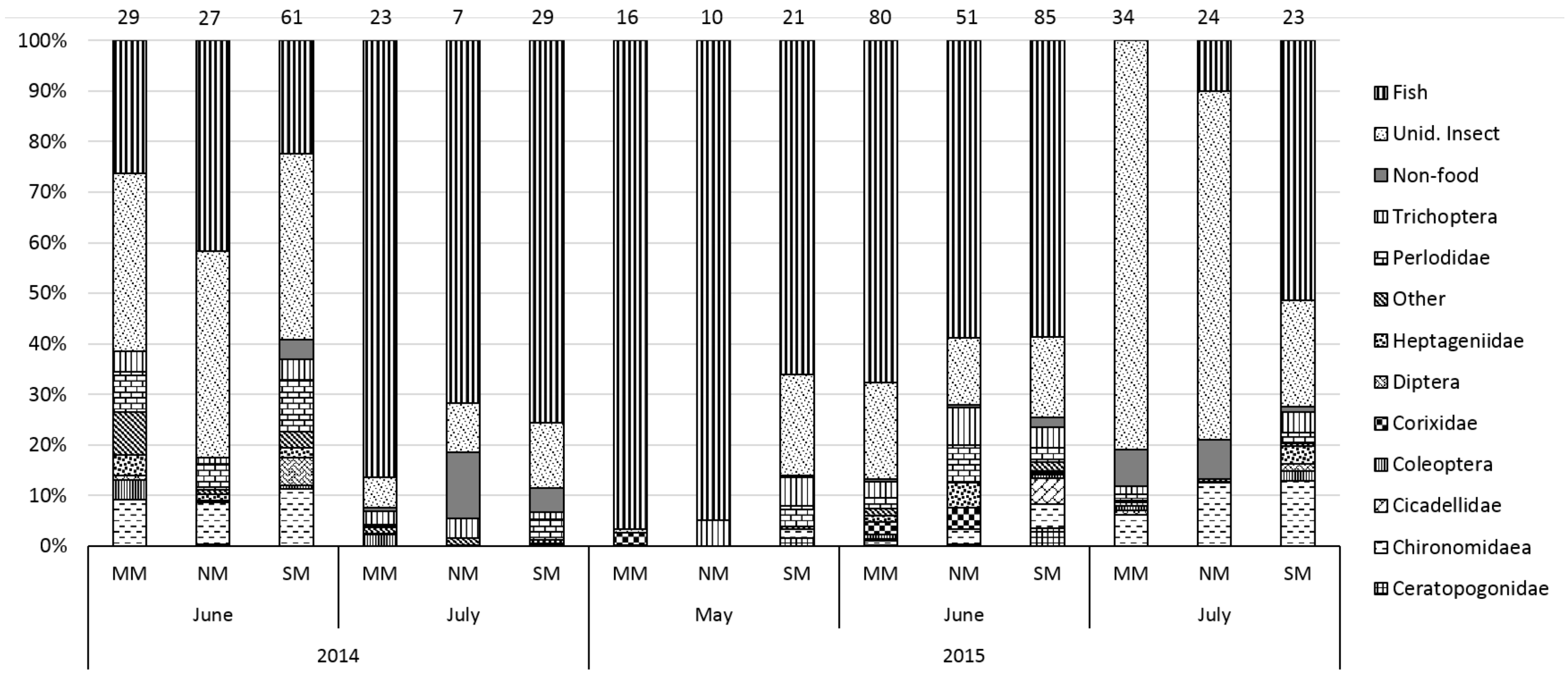


Figure 9. -- Proportion of major prey categories by weight (%W) for distributaries and sample years on the Yukon River for 2014 and 2015. Numbers over columns indicate sample size. **MM = Middle Mouth, SM = South Mouth, NM = North Mouth.**

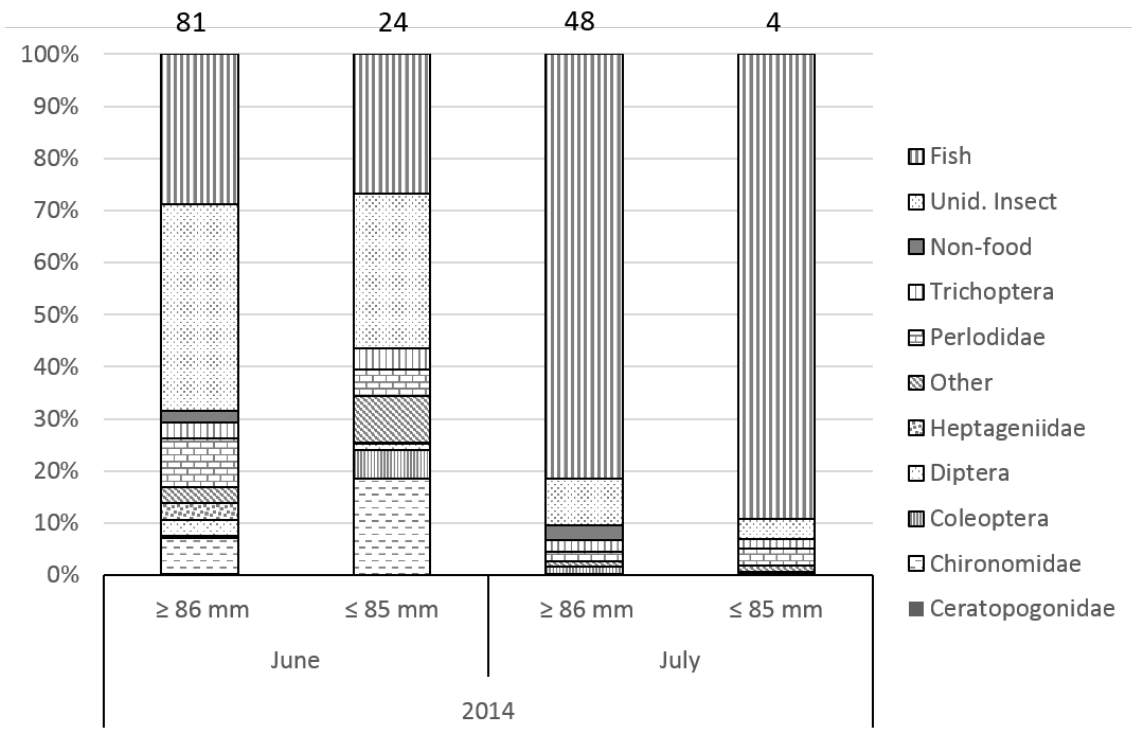


Figure 10. -- Proportion of major prey categories by weight (%W) for large (≥ 86 mm) and small (≤ 85 mm) Chinook salmon on the Yukon River for 2014.

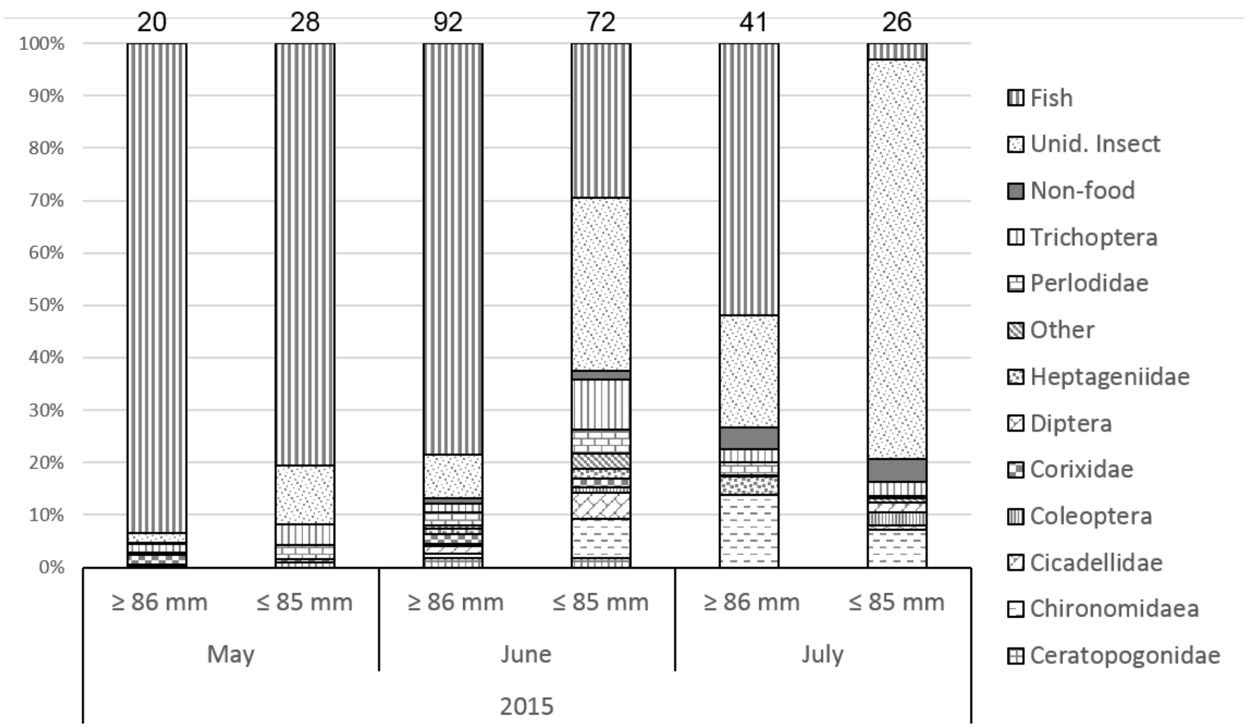


Figure 11. -- Proportion of major prey categories by weight (%W) for large (≥ 86 mm) and small (≤ 85 mm) juvenile Chinook salmon on the Yukon River for 2015.

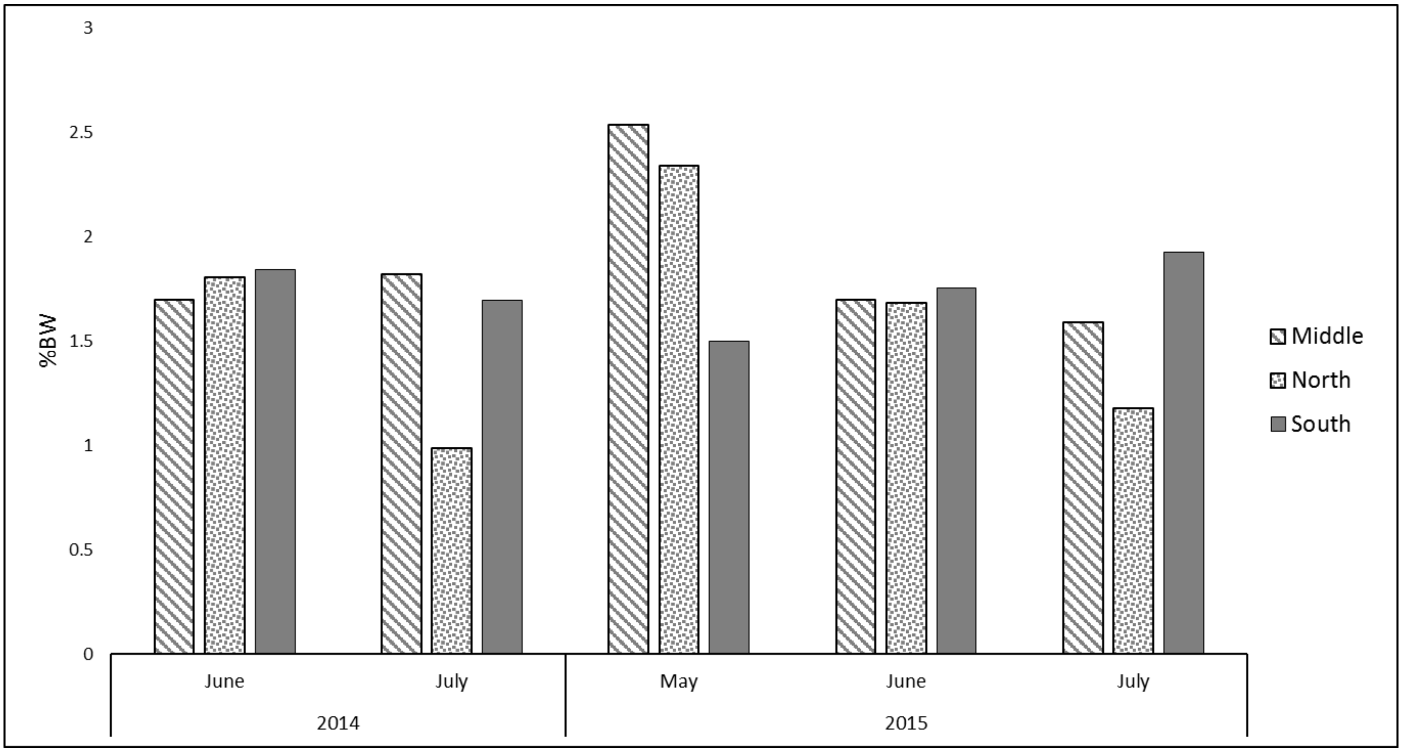
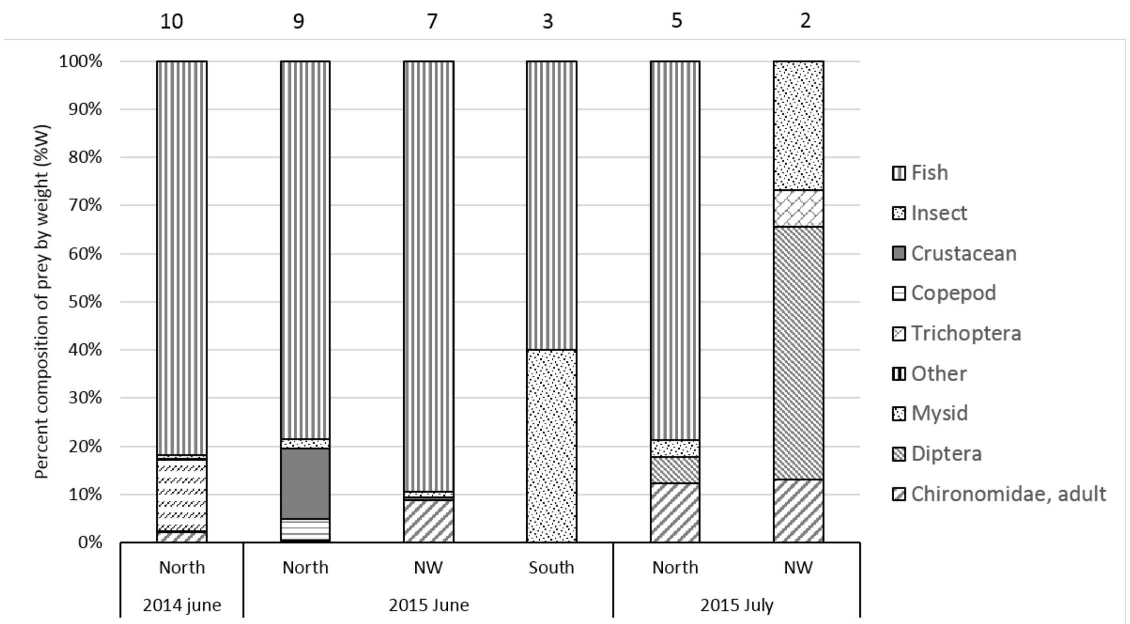


Figure 12. -- Stomach fullness (prey weight as a percent of juvenile Chinook body weight (% BW)) by Yukon River distributary and year. **Middle = Middle Mouth, South= South Mouth, North = North Mouth.**



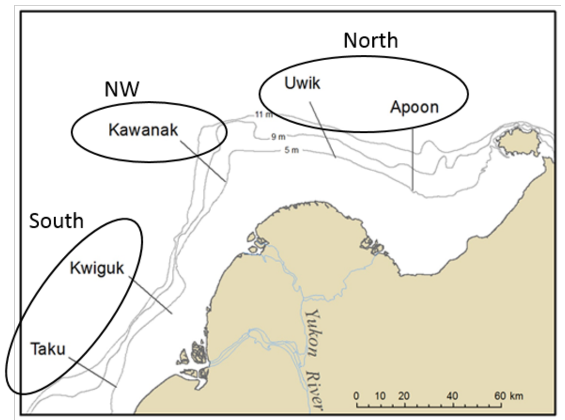


Figure 13. -- Proportion of major prey categories by weight (%W) in juvenile Chinook salmon from Yukon Delta front regions for 2014 and 2015.

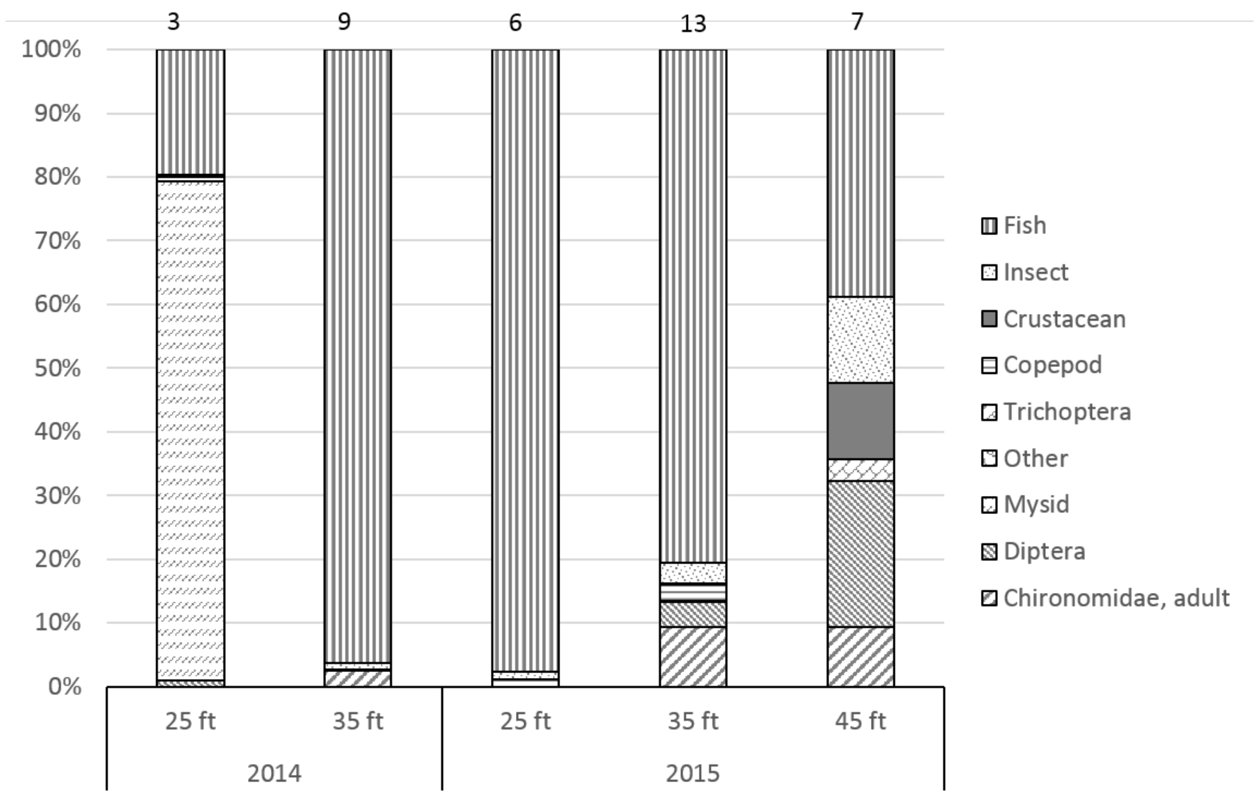


Figure 14. -- Proportion of major prey categories by weight (%W) in juvenile Chinook salmon from Yukon Delta front regions for 2014 and 2015.

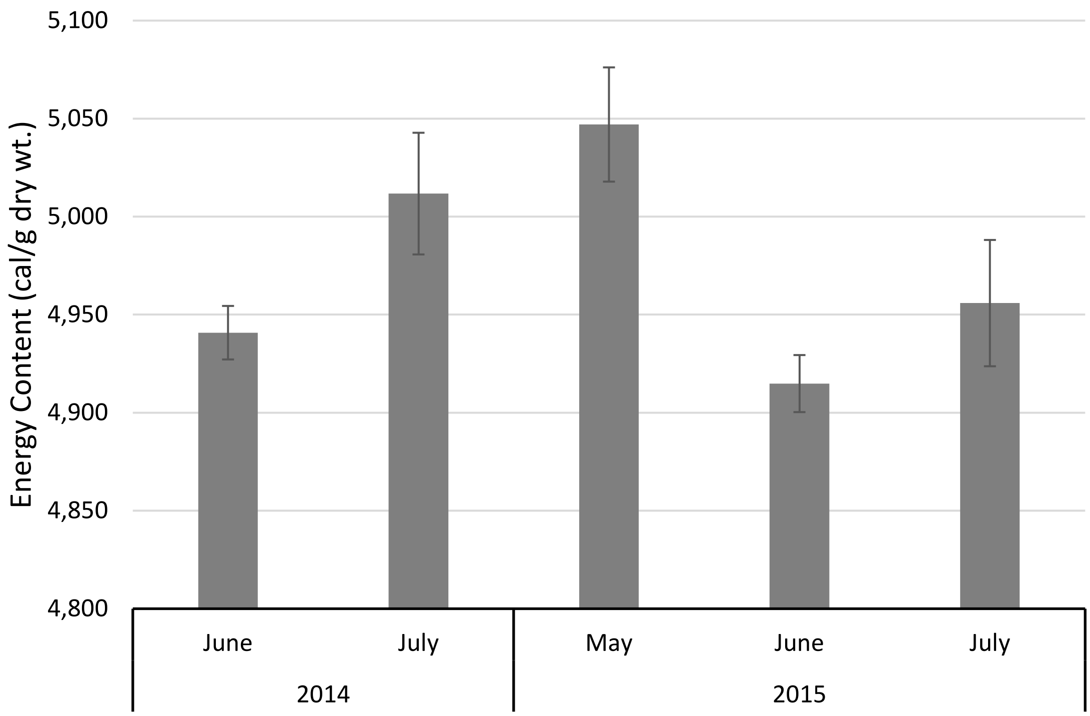


Figure 15. -- Comparison of energy content of juvenile Chinook salmon Yukon River by month for 2014 and 2015. Bars show the standard error.

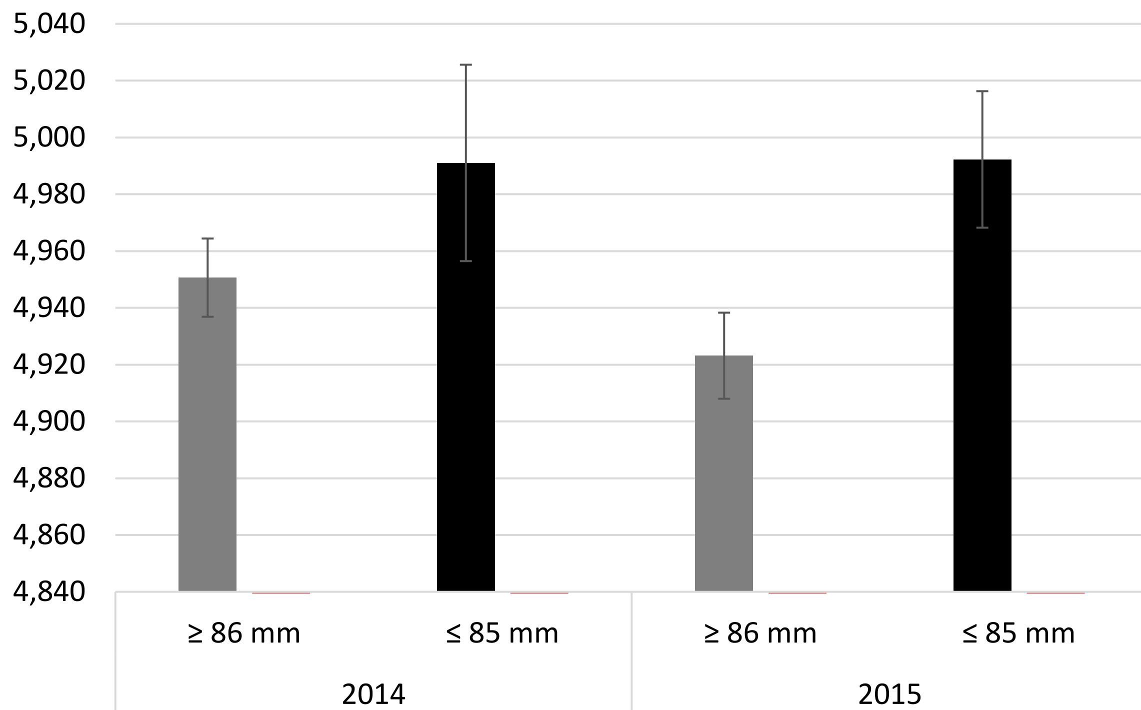


Figure 16. -- Comparison of energy content of large (≥ 86 mm) and small (≤ 85 mm) juvenile Chinook salmon Yukon River for 2014 and 2015. Bars show the standard error.

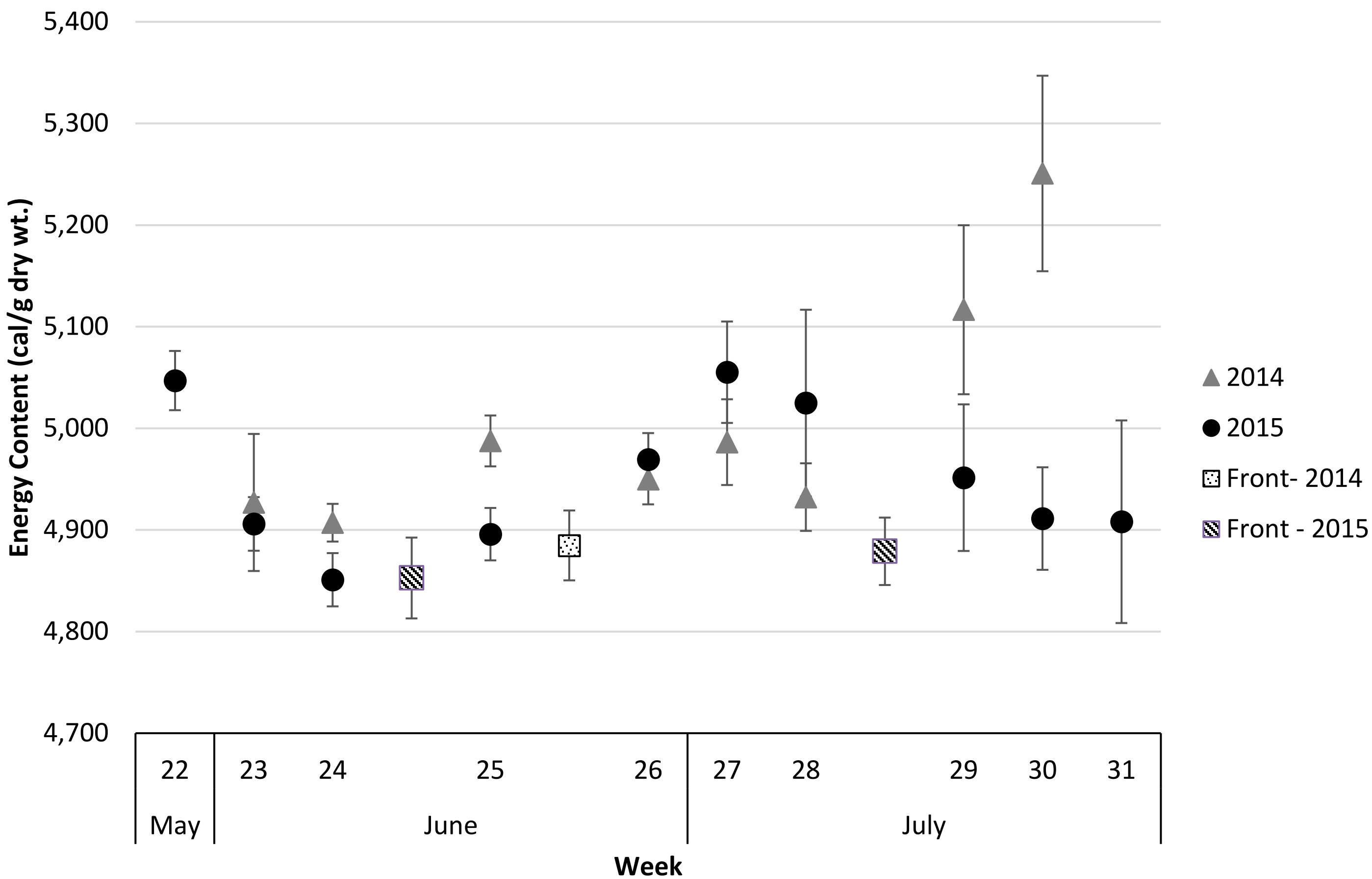


Figure 17. -- Comparison of energy content of juvenile Chinook salmon from the Yukon River Delta and Delta Front by sampling week and month for 2014 and 2015. Bars show the standard error.

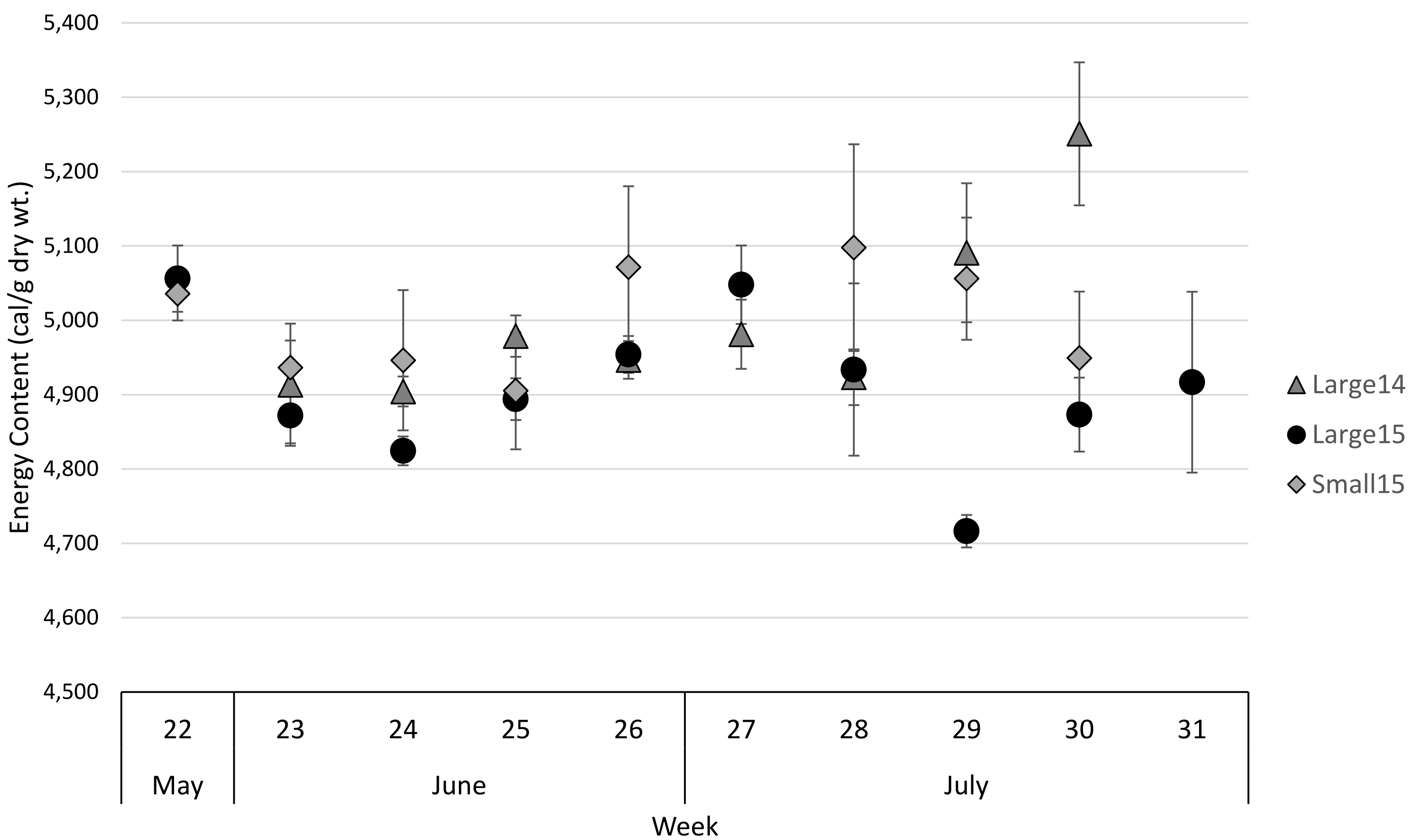


Figure 18. -- Comparison of energy content of large (≥ 86 mm) and small (≤ 85 mm) juvenile Chinook salmon from the Yukon River Delta by sampling week and month for 2014 and 2015. Bars show the standard error. Samples sizes of small Chinook salmon in 2014 were insufficient for weekly comparisons.

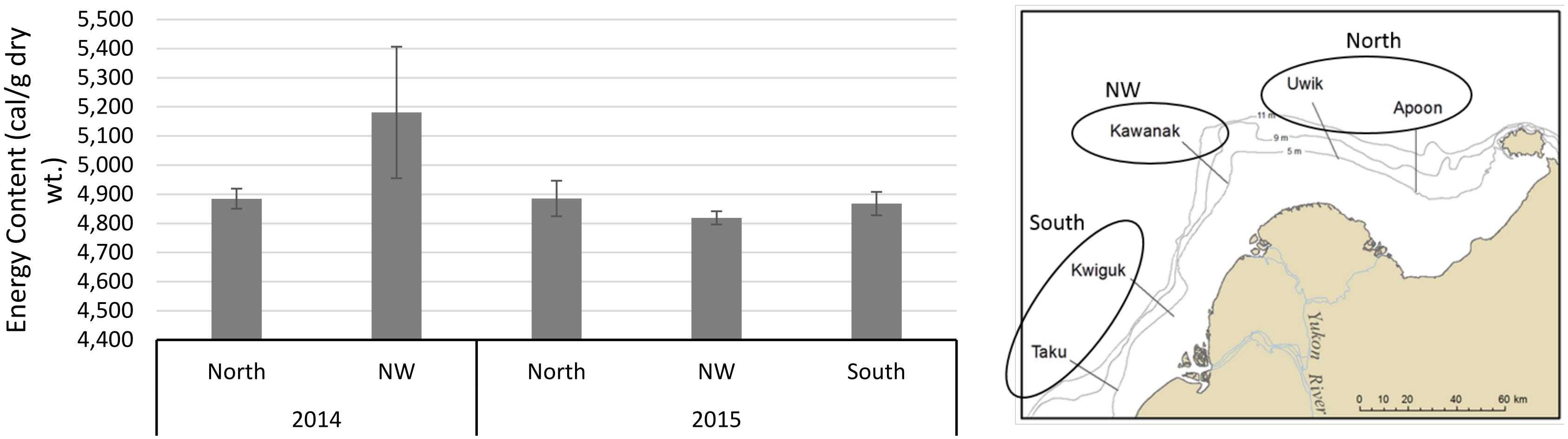


Figure 19. -- Comparison of energy content of juvenile Chinook salmon from the Yukon Delta Front region and month for 2014 and 2015. Bars show the standard error.

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Table 1. -- Catch composition from stations in the lower Yukon River distributaries in summer 2014 and 2015.

	2014		2015	
Species	Catch	Percent	Catch	Percent
Juvenile Chinook salmon	406	1.5%	951	1.1%
Juvenile chum salmon	9,727	36.7%	11,834	13.5%
Juvenile coho salmon	218	0.8%	329	0.4%
Juvenile pink Salmon	430	1.6%	8,825	10.0%
Immature burbot	756	2.9%	8,494	9.7%
Immature coregonid	11,543	43.6%	49,309	56.2%
Juvenile arctic lamprey	1,052	4.0%	2,342	2.7%
Immature sheefish	2,106	8.0%	4,928	5.6%
Other	244	0.9%	803	0.9%
Total	26,482	100%	87,815	100%

(From Howard et al. 2016)

Table 2. -- Catch composition from stations on the Yukon Delta front in summer 2014 and 2015.

	2014		2015	
Species	Catch	Percent	Catch	Percent
Ninespine stickleback (*Pungitius pungitius*)				
Adult	1314	5.71%	1858	15.87%
Juvenile	2150	9.34%	1653	14.12%
Arctic lamprey (*Lethenteron camtschaticum*)	66	0.29%	59	0.50%
Blackline prickleback (*Acantholumpenus mackayi*)				
Juvenile	29	0.13%	3	0.03%
Young of the year	6	0.03%		
Capelin (*Mallotus villosus*)				
Adult	3	0.01%	5	0.04%
Juvenile	9	0.04%	28	0.24%
Young of the year	17	0.07%	363	3.10%
Chinook salmon (*O. tshawytscha*)	25	0.11%	42	0.36%
Chum salmon (*O. keta*)	182	0.79%	480	4.10%
Coho salmon (*O. kisutch*)	0	0.00%	10	0.09%
Pacific Herring (*Clupea pallasii*)				
Adult	16	0.07%	20	0.17%
Second year	596	2.59%	260	2.22%
Young of the year	2349	10.20%	3034	25.91%
Larval	78	0.34%	616	5.26%
Rainbow smelt (*Osmerus mordax*)				
Adult	190	0.83%	69	0.59%
Juvenile	1501	6.52%	589	5.03%
Young of the year	2844	12.35%	49	0.42%
Larval	3606	15.66%	299	2.55%
Saffron cod (*Eleginius gracilis*)				
Adult	4	0.02%	3	0.03%
Juvenile	430	1.87%	73	0.62%
Young of the year	7350	31.93%	1901	16.24%
Other	256	1.11%	289	2.47%

Table 3. -- Standardized density (catch/ km^2) of juvenile Chinook salmon at Yukon Delta distributary stations by month and year. NS indicates stations that were added to the sampling plan in 2015 and were not sampled in 2014.

		2014			2015		
Distributary	**Station**	**May**	**June**	**July**	**May**	**June**	**July**
SM	Aproka	NS	304	109	279	412	101
	Martin	NS	361	217	405	1234	234
	Flat Is.	50	200	43	304	279	90
MM	Fish and Game Eddy	76	196	144	190	490	51
	Seagull	NS	228	123	342	285	209
	Nunatak	NS	0		456	633	215
NM	Hamilton	25	214	60	152	146	108
	NM Slough	NS	NS	NS	51	181	57
	OPP	NS	507	25	127	281	260

Table 4. -- Catch per unit area (CPUA; catch/ km^2) of juvenile Chinook salmon at Yukon Delta front stations by month and year. Dashes indicate stations where no Chinook salmon were caught. NS indicates stations that were not sampled due to weather or technical issues.

		2014			2015		
Transect	Station	June	July	August	June	July	August
Stuart	Inner	299	NS	NS	NS	-	NS
	Middle	-	NS	NS	NS	376	NS
Apoon	Inner	80	-	-	197	-	NS
	Middle	559	-	-	396	92	NS
	Outer	56	-	-	-	241	-
Uwik	Inner	352	-	-	-	-	-
	Middle	124	-	64	157	-	-
	Outer	151	-	-	87	-	31
Kawanak	Inner	NS	-	-	215	-	-
	Middle	NS	122	43	211	-	-
	Outer	NS	-	56	55	318	-
Kwiguk	Inner	-	-	-	43	NS	-
	Middle	-	-	-	-	NS	-
	Outer	-	-	-	-	NS	-
Taku	Inner	-	NS	-	-	-	-
	Middle	-	NS	-	81	-	-
	Outer	-	NS	-	240	-	-

Table 5. -- Results of SIMPER analysis for Period A (weeks 22 through 25) and Period B (weeks 27 through 31) in Yukon River fish assemblages showing within group similarity, taxa contributing most to group similarity, and the percent contribution.

	PERIOD A			PERIOD B		
Year	**Similarity**	**Species**	**Contrib**	**Similarity**	**Species**	**Contrib**
2014	68%	Chum salmon	42.7%	60%	Coregonid	28.0%
		Arctic lamprey (smolt)	18.2%		Chum salmon	24.4%
		Chinook salmon	14.0%		Sheefish	15.8%
		Coho salmon	12.6%		Burbot	11.5%
2015	74%	Chum salmon	26.4%	75%	Coregonids	37.5%
		Pink salmon	19.3%		Sheefish	14.2%
		Arctic lamprey (smolt)	16.4%		Chum salmon	13.0%
		Chinook salmon	12.3%		Burbot	10.2%
		Coho salmon	10.0%			

Table 6. -- Results of SIMPER analysis for Yukon Delta front species assemblages by month showing within group similarity, taxa contributing most to group similarity, and the percent contribution.

	JUNE			JULY			AUGUST		
Year	Similarity	Species	Contrib.	Similarity	Species	Contrib.	Similarity	Species	Contrib.
2014	39%	Mysid	24.4%	54%	Mysid	33.2%	49%	Saffron cod, YOY	22.0%
		Chum salmon	11.4%		Pacific herring, juv	14.0%		Jellyfish	19.0%
		Chinook salmon	11.2%		Rainbow smelt, juv	13.0%		Ninespine sticklebac	14.0%
		Crangon	10.4%		Saffron cod, young-of-year	10.6%		Rainbow smelt, YOY	13.0%
								Pacific herring, juv	10.6%
2015	25%	Chum salmon	23.8%	46%	Jellyfish	25.2%	40%	Ninespine sticklebac	30.2%
		Saffron cod, juvenile	13.0%		Ninespine stickleback	17.9%		Jellyfish	23.5%
		Ninespine stickleback	11.5%		Chum salmon	12.4%		Saffron cod, YOY	19.6%
		Chinook salmon	11.3%		Saffron cod, young-of-year	11.1%		Pacific herring, juv	11.8%

Table 7. -- Average percent weight and frequency of occurrence of major prey categories in the diets of juvenile Chinook salmon in the lower Yukon River for 2014 and 2015.

	2014				2015					
	June		**July**		**May**		**June**		**July**	
	% W	**% FO**	**% W**	**% FO**	**% W**	**% FO**	**% W**	**% FO**	**% W**	**% FO**
Fish	28.3	9.5	82.0	30.8	89.9	56.3	62.0	31.1	27.4	6.0
Unid. Insect	37.2	65.7	8.5	59.6	4.5	27.1	16.7	49.4	48.9	67.2
Ceratopogonidae, larvae	0.1	3.8	0.1	5.8	0.3	4.2	1.8	17.1	-	-
Chironomid, adult	0.3	7.6	-	-	-	-	0.3	5.5	7.1	10.4
Chironomid, larvae	1.8	32.4	0.1	13.5	0.4	16.7	0.9	22.6	0.1	6.0
Chironomid, pupae	7.7	27.6	-	3.8	-	-	1.8	11.6	3.3	4.5
Cicadellidae	-	-	-	-	-	-	2.6	4.3	0.3	3.0
Coleoptera	1.8	3.8	1.4	1.9	-	-	0.7	5.5	1.2	3.0
Corixidae	-	-	-	-	1.4	6.3	1.8	4.3	-	-
Diptera	2.6	6.7	-	-	-	-	-		1.0	4.5
Heptageniidae, larvae	2.5	10.5	0.0	1.9	-	-	1.4	4.3	1.7	1.5
Other	2.6	4.8	1.0	11.5	0.1	2.1	1.3	11.6	0.5	9.0
Perlodidae, larvae	8.2	29.5	1.8	19.2	0.9	4.2	3.2	18.9	1.5	6.0
Non-food	1.6	3.8	2.8	17.3	0.1	2.1	1.2	7.3	4.2	29.9
Plecoptera, larvae	2.0	3.8	0.1	1.9	-	-	0.1	0.6	-	-
Trichoptera, larvae	3.4	12.4	2.2	23.1	2.4	8.3	4.3	22.0	2.7	4.5
Number processed	121		61		48		219		84	
Empty	18		9		0		55		16	
Proportion empty	15		15		0		25		19	
Average length*	89.3		98.8		89.5		84.7		83.3	
Average weight†	8.4		11.8		6.8		7.8		6.7	
Average BW‡	0.87		1.13		2.10		1.48		1.31	
Average prey weight	0.08		0.18		0.13		0.15		0.09	

*Fork length (mm); †Wet weight (g); ‡Stomach fullness expressed as percent of body weight. Prey weight (g) is the weight of each prey group.

Table 8. -- Average percent weight and frequency of occurrence of major prey categories in the diets of juvenile Chinook salmon on the Yukon Delta front for 2014 and 2015.

	2014		2015			
	June		June		July	
	% W	**% FO**	**% W**	**% FO**	**% W**	**% FO**
Fish	81.8	66.7	82.1	76.5	53.0	66.7
Copepod	0.2	44.4	2.8	29.4	-	-
Chironomidae, adult	2.1	11.1	3.2	11.8	12.6	83.3
Diptera	0.2	11.1	-	-	20.8	50.0
Unid. Insect	0.9	22.2	2.5	52.9	11.1	66.7
Mysid	14.8	22.2	-	-	-	-
Trichoptera	-	-	-	-	2.5	16.7
Other	-	-	9.4	11.8	-	-
Number	10		18		7	
Empty	1		2		1	
Proportion empty	10.0		11.1		14.3	
Average length*	98.6		94.5		112.3	
Average weight†	10.4		7.0		13.6	
Average BW‡	3.7		1.9		2.6	
Average prey weight	0.4		0.1		0.3	

*Fork length (mm); †Wet weight (g); ‡Stomach fullness expressed as percent of body weight.

Table 9. -- Average percent weight and frequency of occurrence of major prey categories in the diets of juvenile coho salmon in the lower Yukon River for 2014 and 2015.

	2014		2015			
	June		May		June	
	% W	% FO	% W	% FO	% W	% FO
Fish	50.4	16.1	73.4	40.0	39.5	15.8
Unid. Insect	21.7	67.7	2.5	20.0	26.3	51.3
Ceratopogonidae, larvae	0.2	16.1	-	-	2.8	18.4
Chironomid, larvae	3.1	41.9	-	-	1.0	17.1
Chironomid, pupae	12.3	51.6	-	-	1.3	11.8
Cicadellidae	-	-	-	-	7.8	5.3
Coleoptera	2.2	16.1	-	-	1.8	7.9
Corixidae	-	-	22.8	30.0	1.5	7.9
Other	4.1	38.7	1.3	10.0	3.5	19.7
Perlodidae, larvae	4.8	22.6	-	-	7.6	13.2
Non-food	1.1	6.5	-	-	1.9	6.6
Trichoptera, larvae	-	6.5	-	-	4.9	19.7
Number processed	37		17		91	
Empty	6		7		14	
Proportion empty	16		41		15	
Average length*	103.1		109.5		96.8	
Average weight†	10.0		11.7		8.3	
Average BW‡	1.41		1.65		1.22	
Average prey weight	0.15		0.12		0.11	

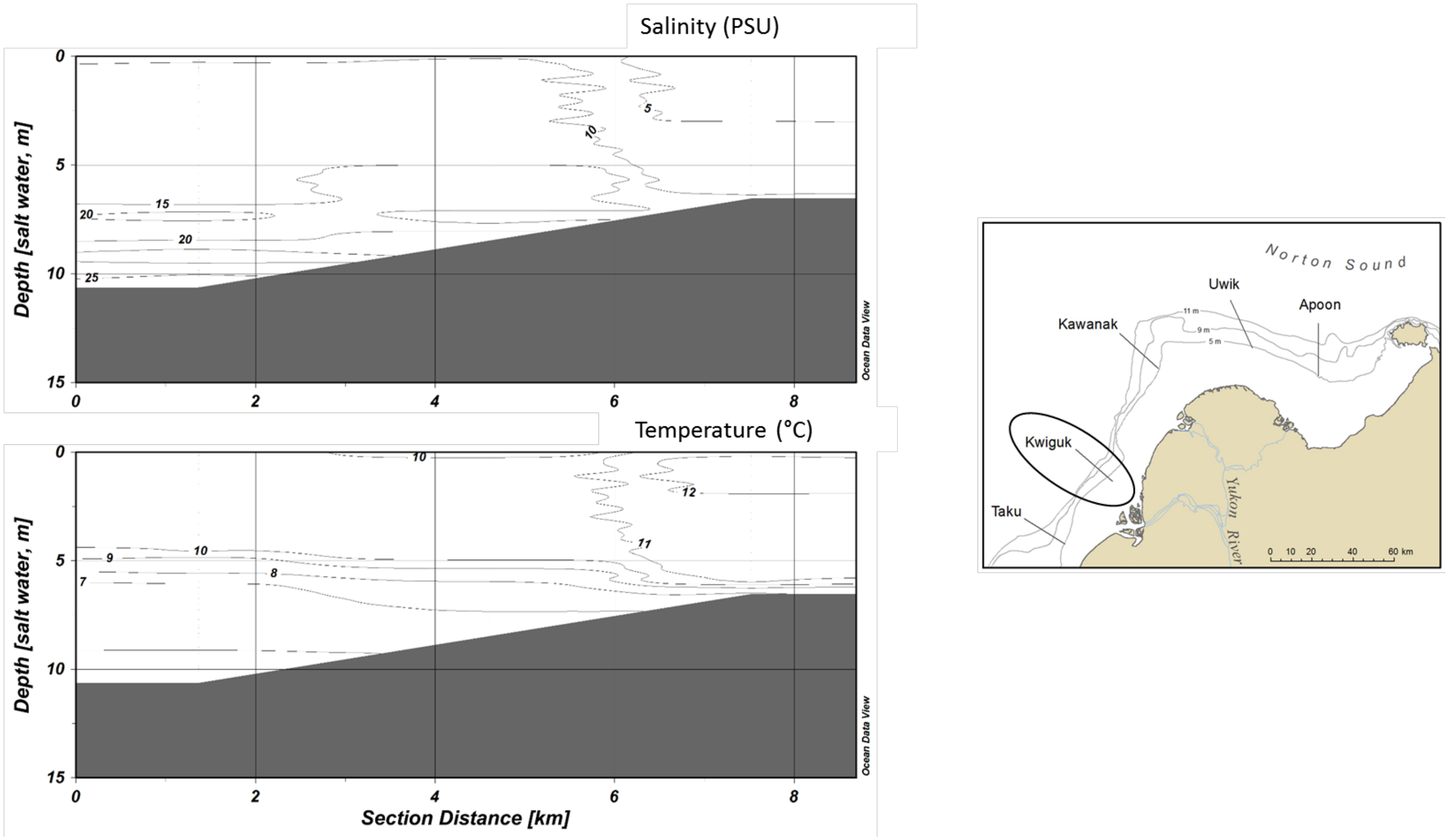
*Fork length (mm); †Wet weight (g); ‡Stomach fullness expressed as percent of body weight.

APPENDIX A
TEMPERATURE AND SALINITY PROFILES FOR YUKON DELTA FRONT TRANSECTS BY MONTH AND YEAR

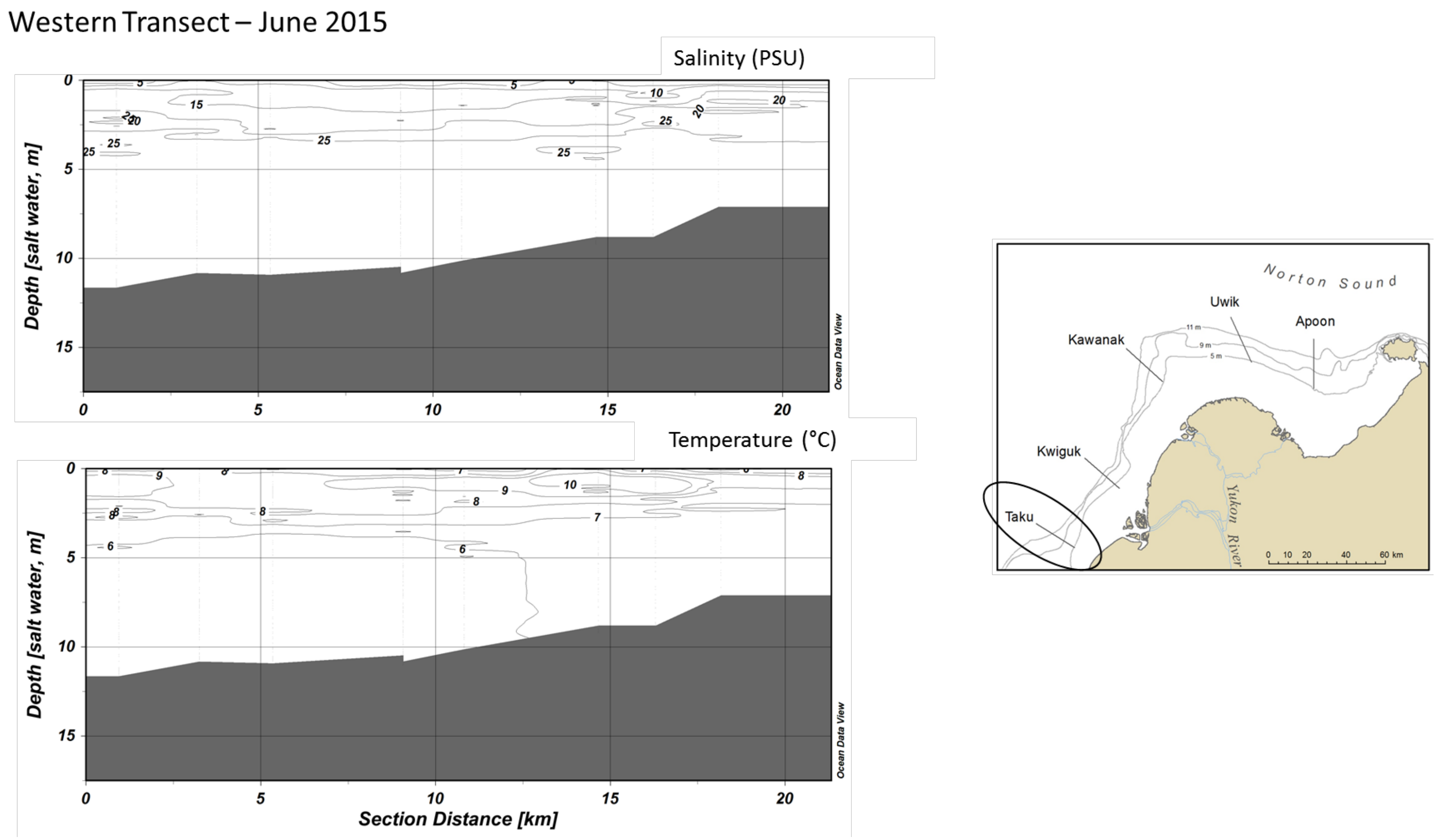
These figures show vertical sections of salinity and temperature from transects on the west and north sides of the Yukon Delta Front by sampling month for 2014 and 2015. Lines show areas of equal temperature (isotherms) or salinity (isohalines). Distance is measured from the deepest station to the shallowest. Profiles were created using Ocean Data View version 4.7.6[1].

[1] Ocean Data View. 2016. https://odv.awi.de/en/home. Accessed 20 October 2016

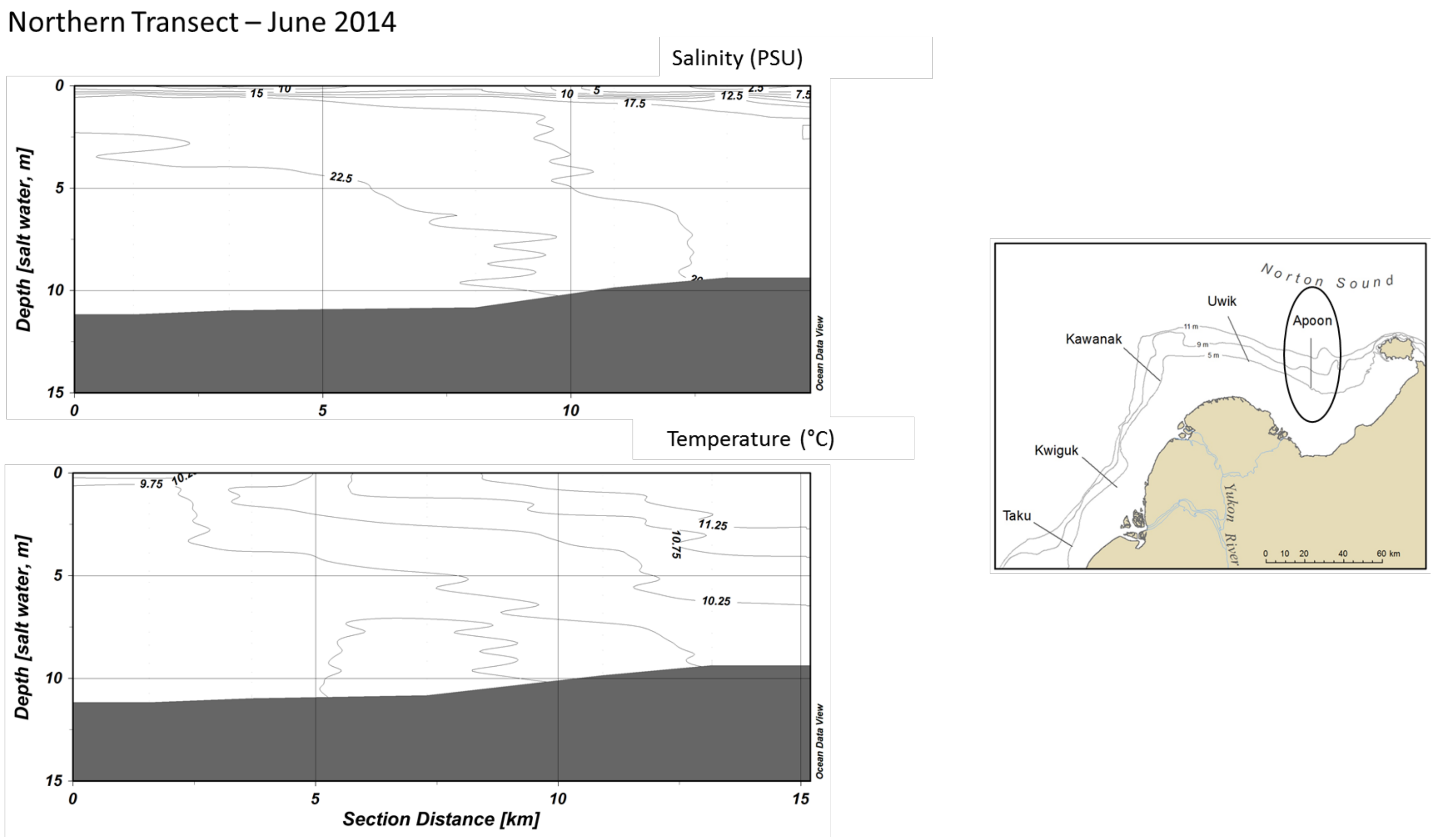
Western Transect – June 2014



Appendix Figure A1. -- Temperature and salinity profiles for the west side of the Yukon Delta front for June 2014.



Appendix Figure A2. -- Temperature and salinity profiles for the west side of the Yukon Delta front for June 2015.



Appendix Figure A3. -- Temperature and salinity profiles for the north side of the Yukon Delta front for June 2014.

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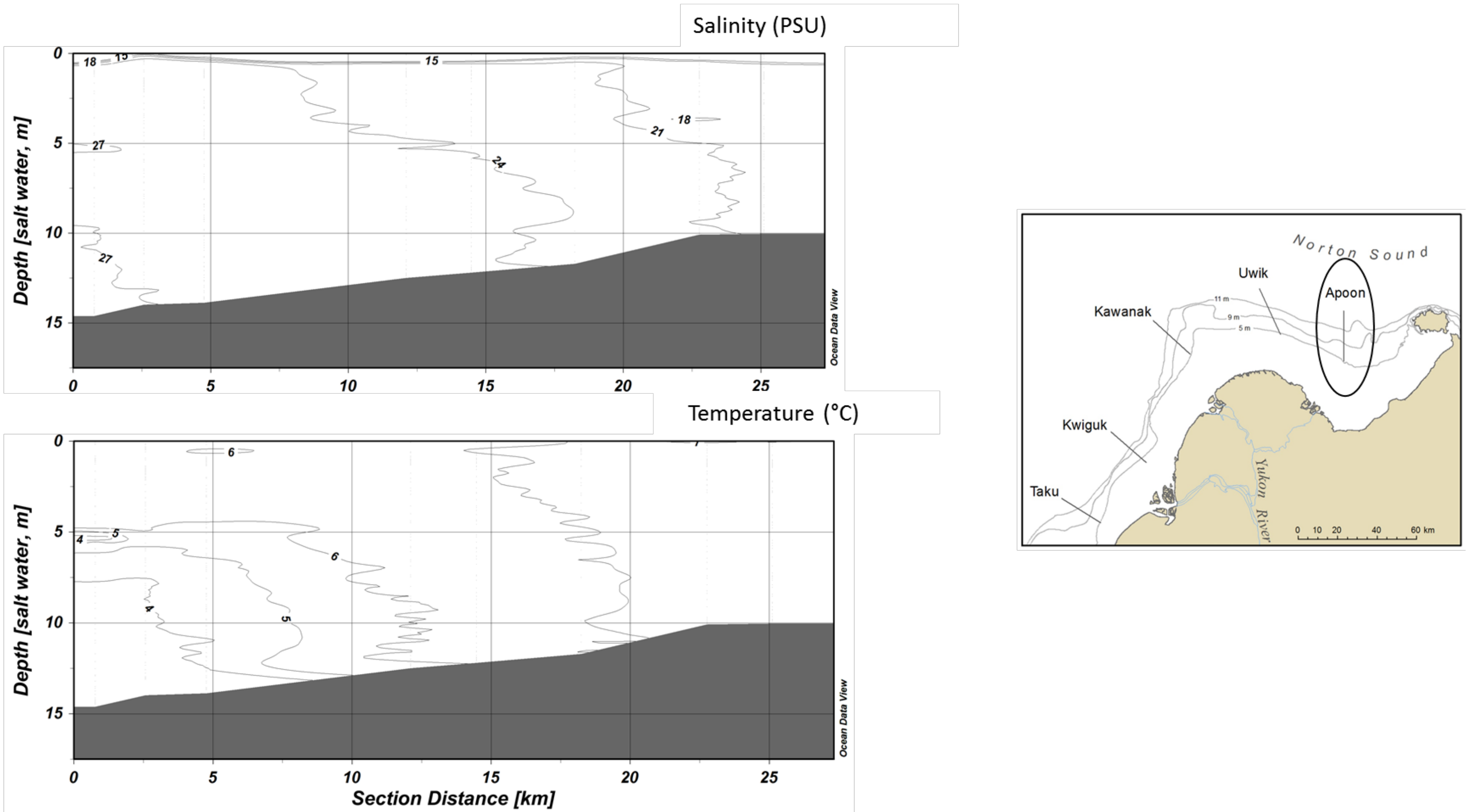
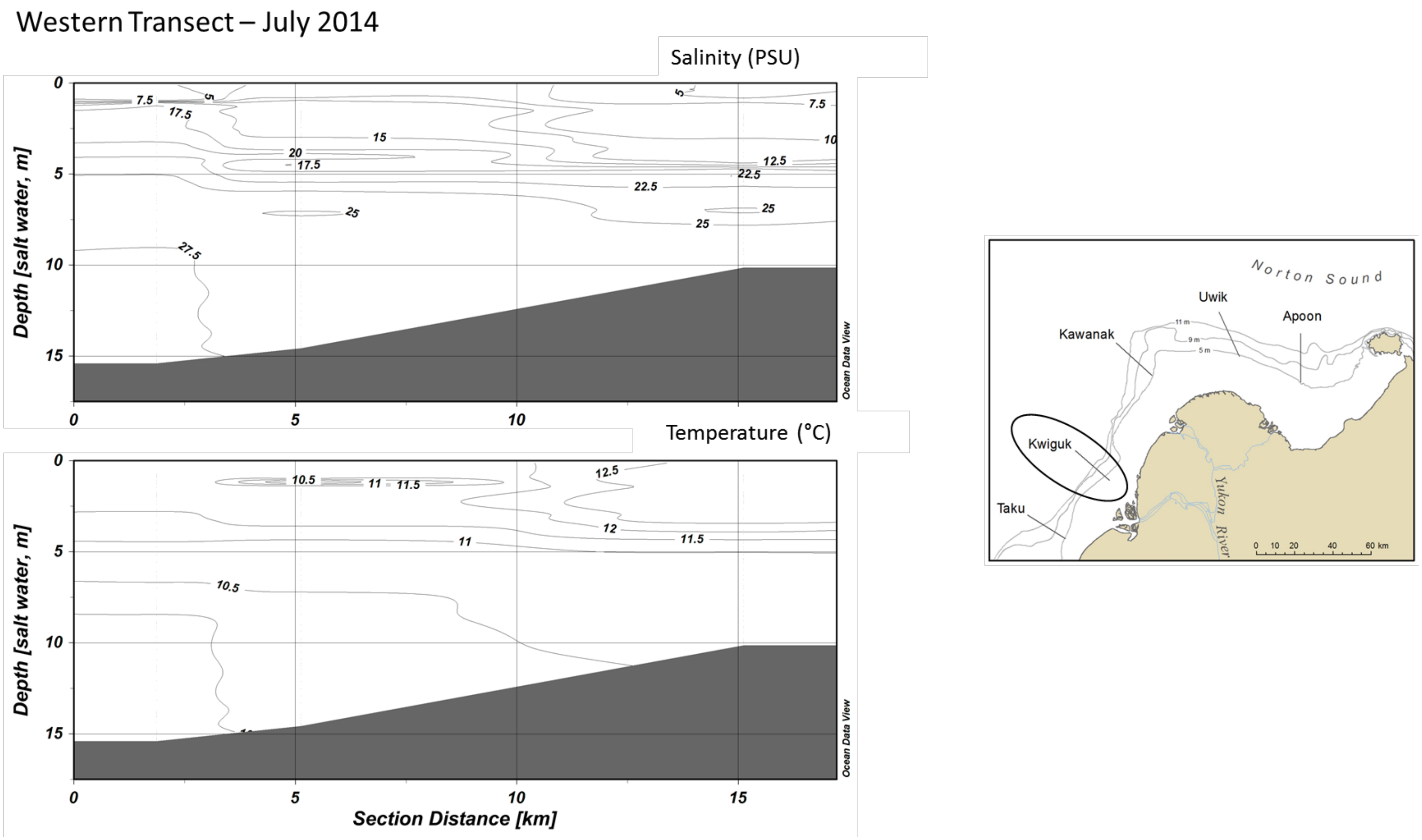
Northern Transect – June 2014

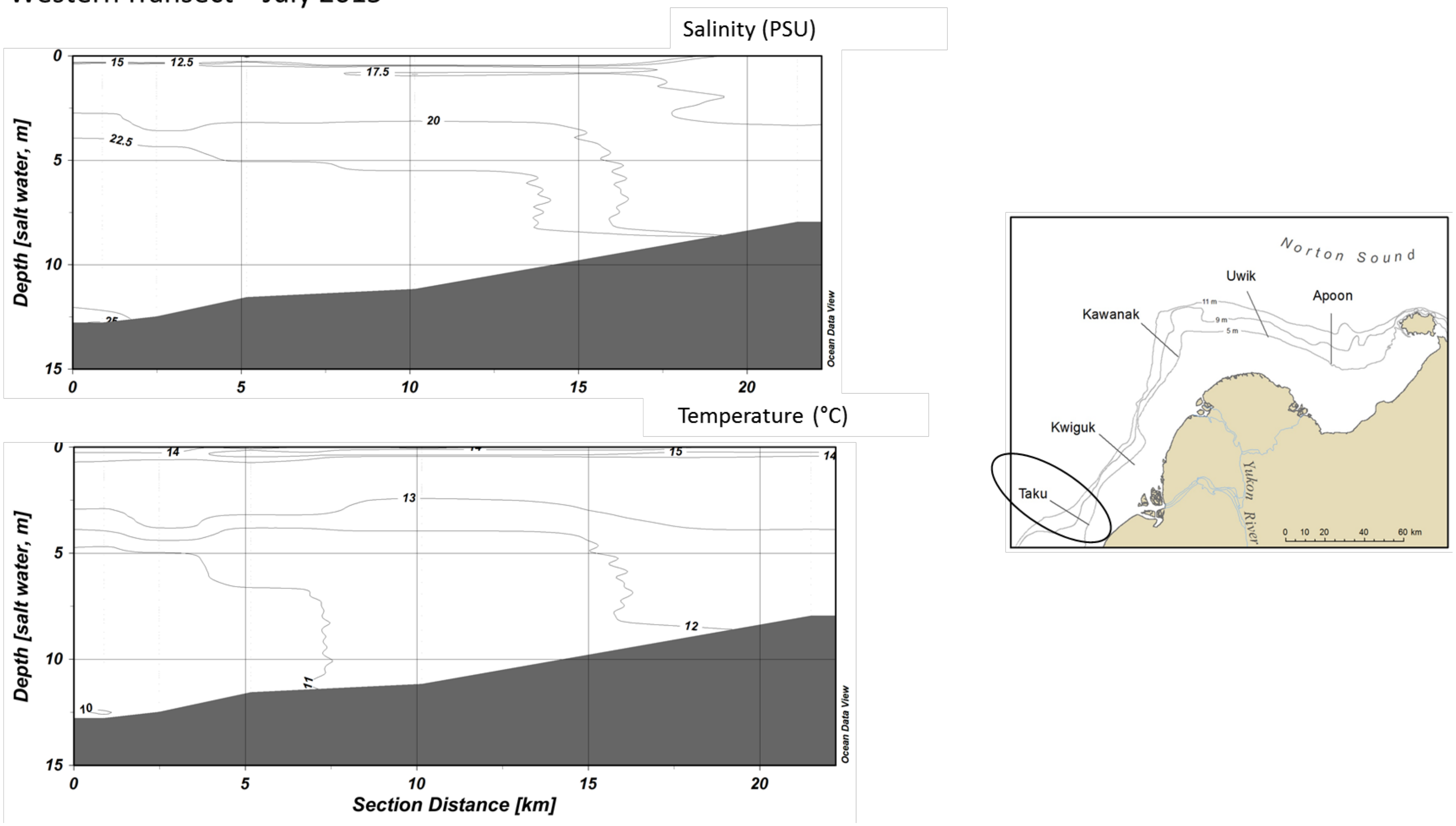


Appendix Figure A4. -- Temperature and salinity profiles for the north side of the Yukon Delta front for June 2015.



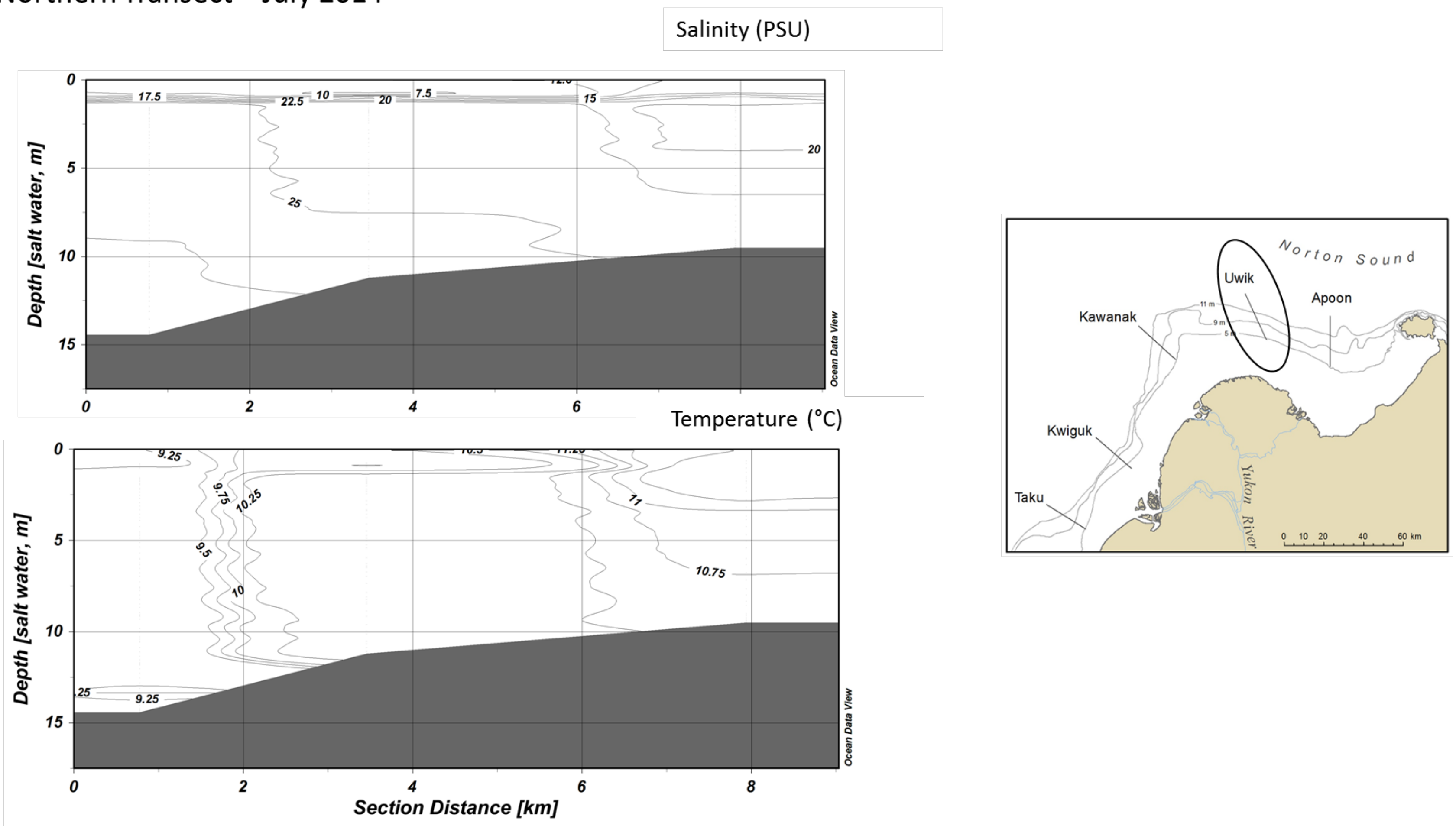
Appendix Figure A5. -- Temperature and salinity profiles for the west side of the Yukon Delta front for July 2014.

Western Transect – July 2015



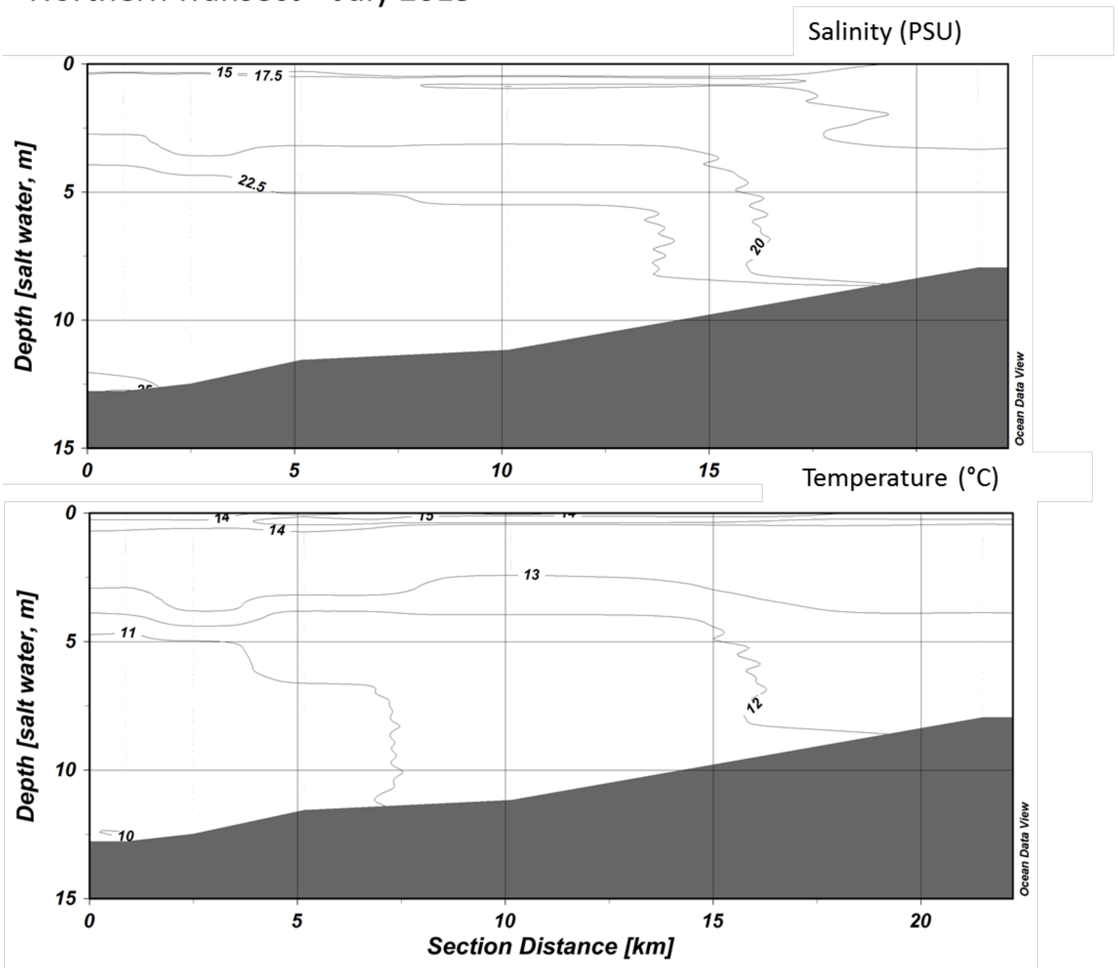
Appendix Figure A6. -- Temperature and salinity profiles for the west side of the Yukon Delta front for July 2015.

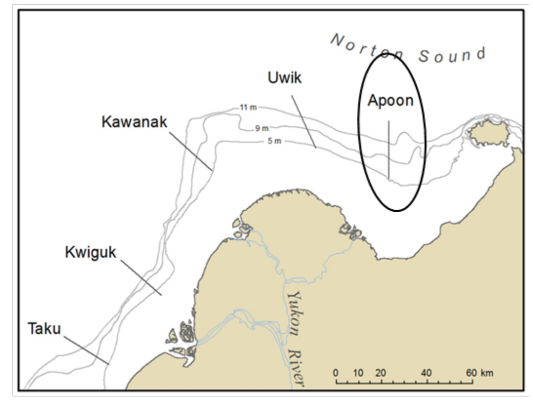
Northern Transect – July 2014



Appendix Figure A7. -- Temperature and salinity profiles for the north side of the Yukon Delta front for July 2014.

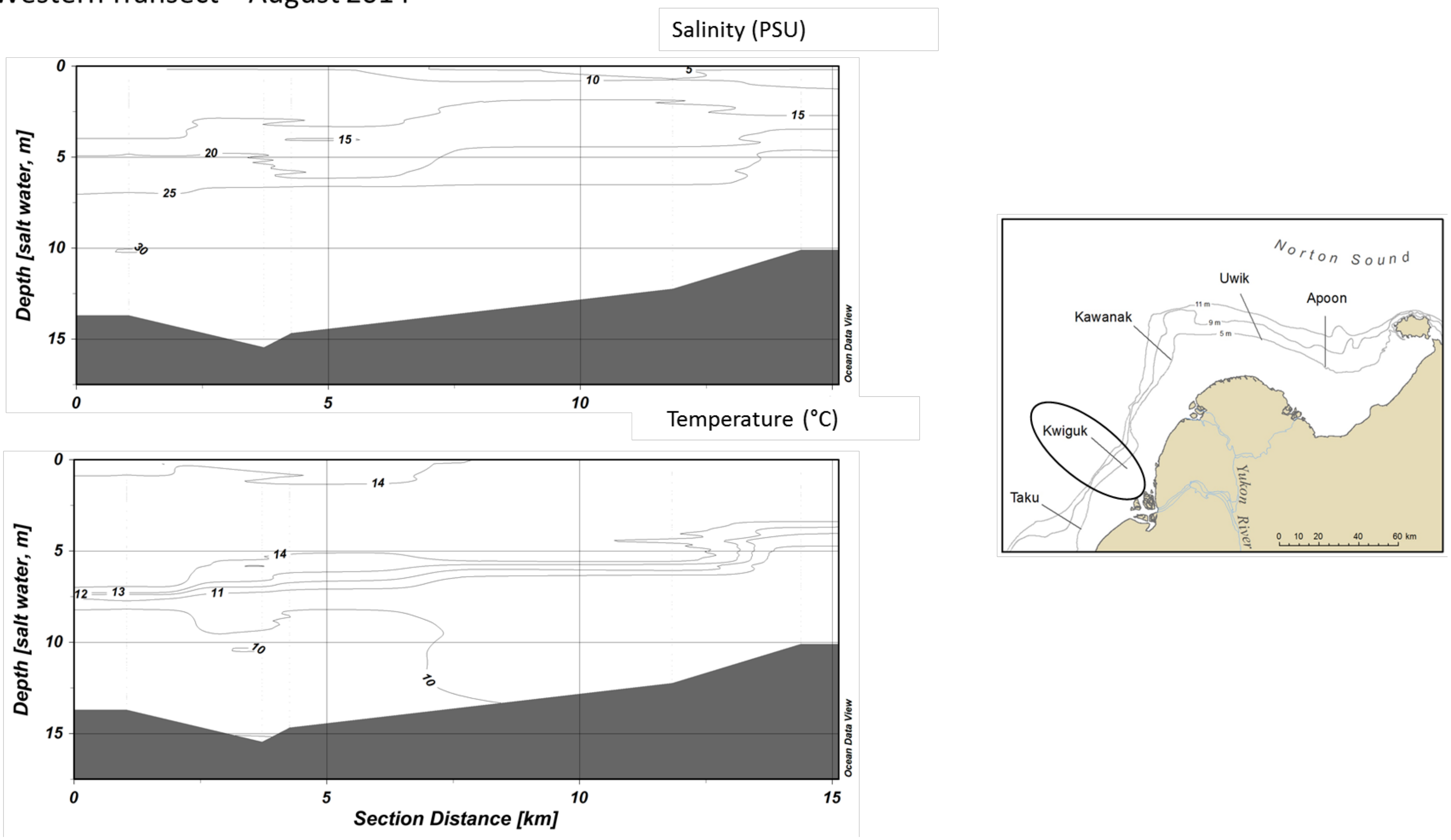
Northern Transect – July 2015





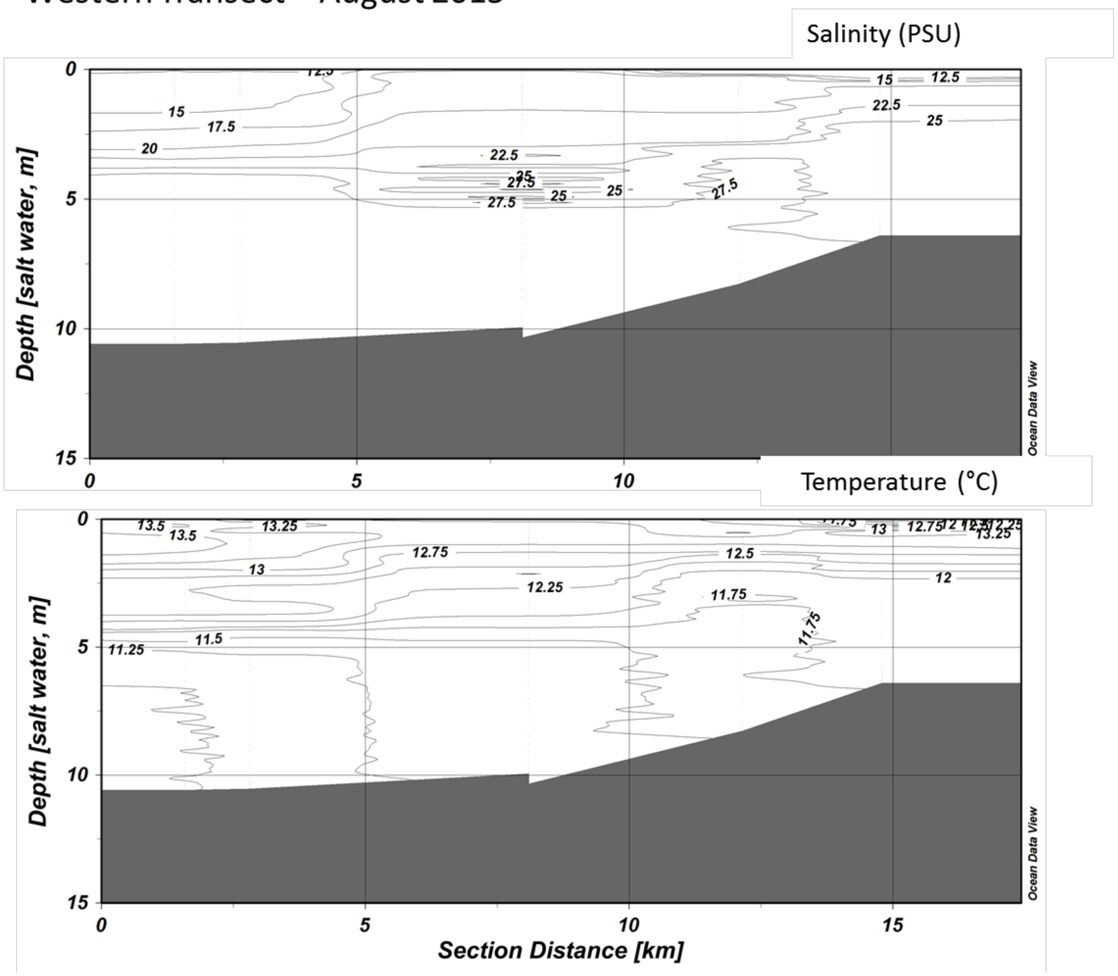
Appendix Figure A8. -- Temperature and salinity profiles for the north side of the Yukon Delta front for July 2015.

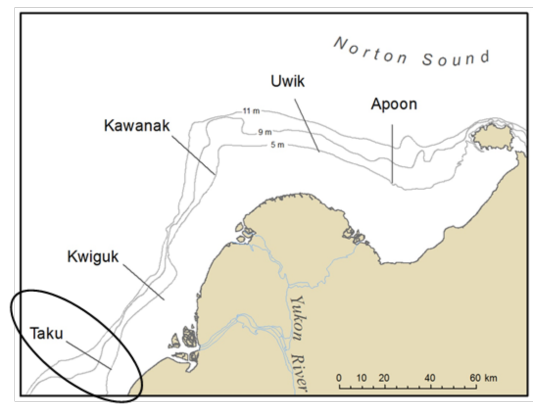
Western Transect – August 2014



Appendix Figure A9. -- Temperature and salinity profiles for the west side of the Yukon Delta front for August 2014.

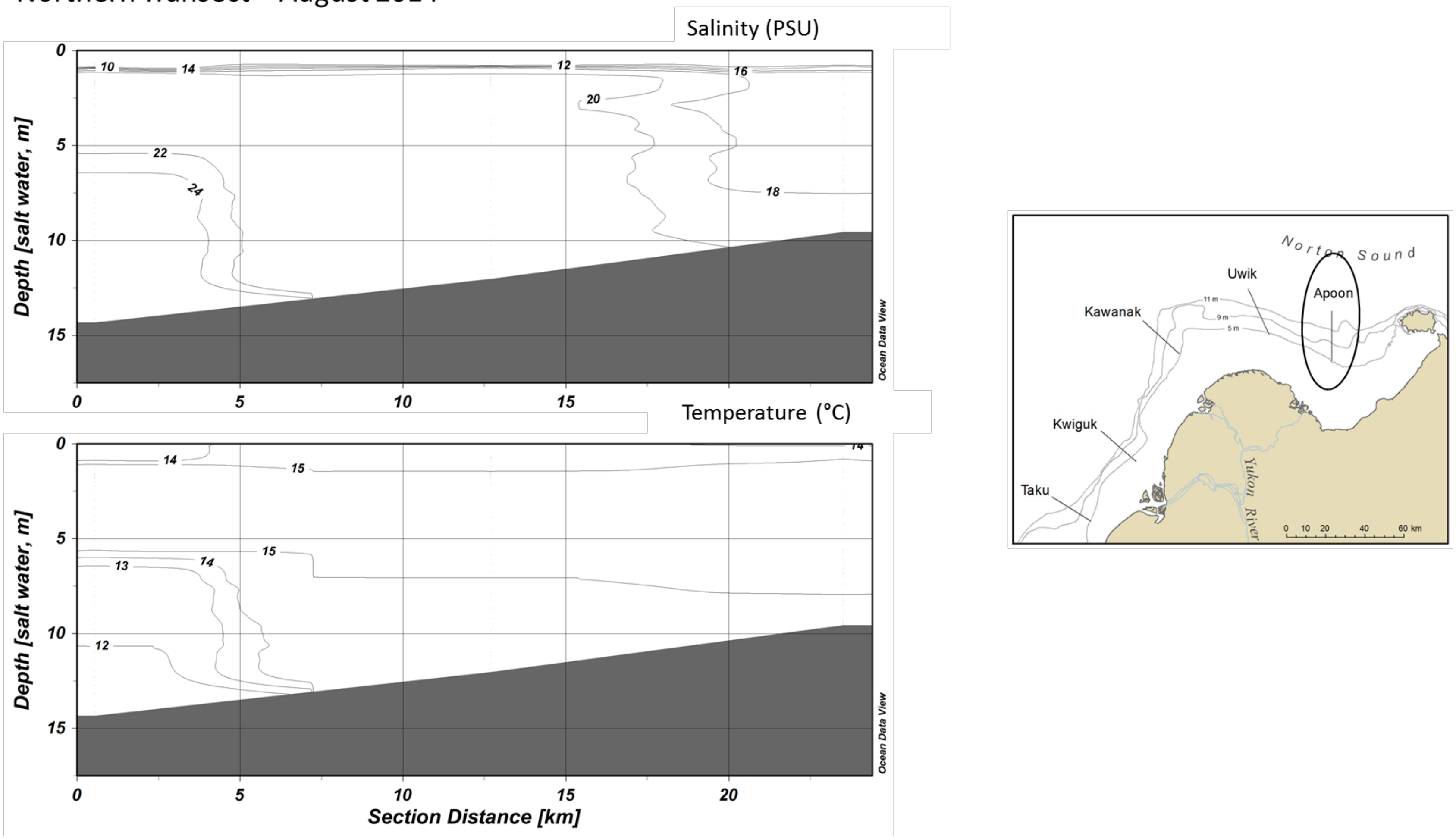
Western Transect – August 2015





Appendix Figure A10. -- Temperature and salinity profiles for the west side of the Yukon Delta front for August 2015.

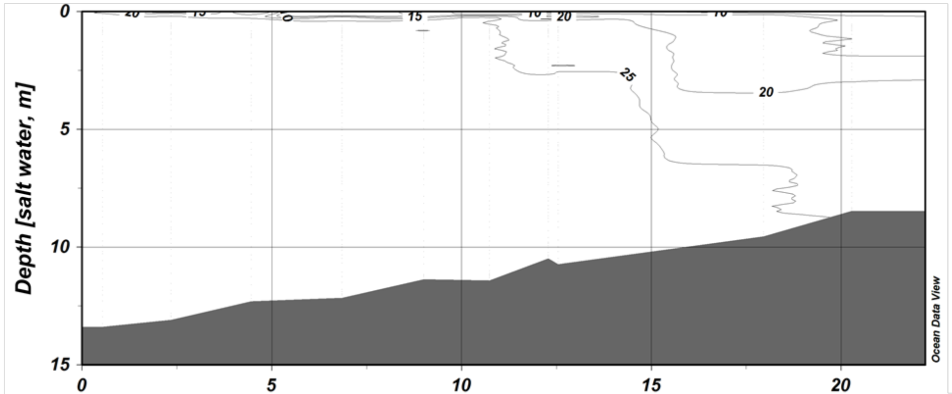
Northern Transect – August 2014



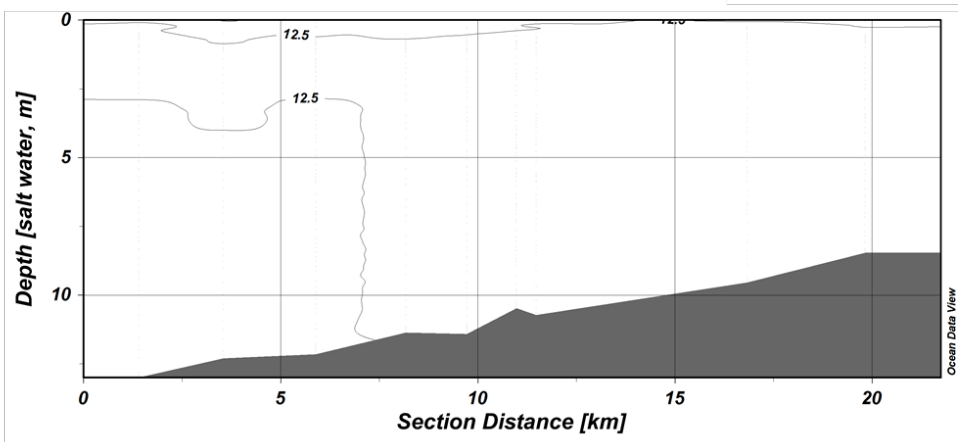
Appendix Figure A11. -- Temperature and salinity profiles for the north side of the Yukon Delta front for August 2014.

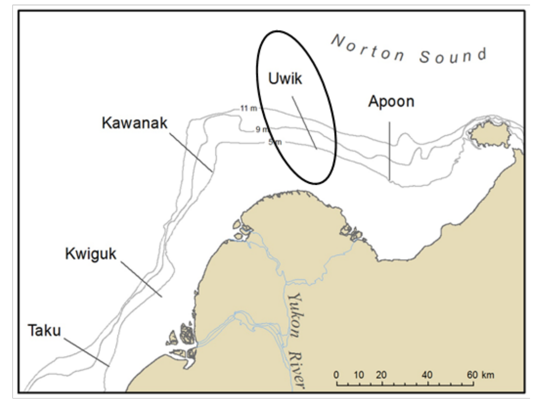
Northern Transect – August 2015

Salinity (PSU)



Temperature (°C)

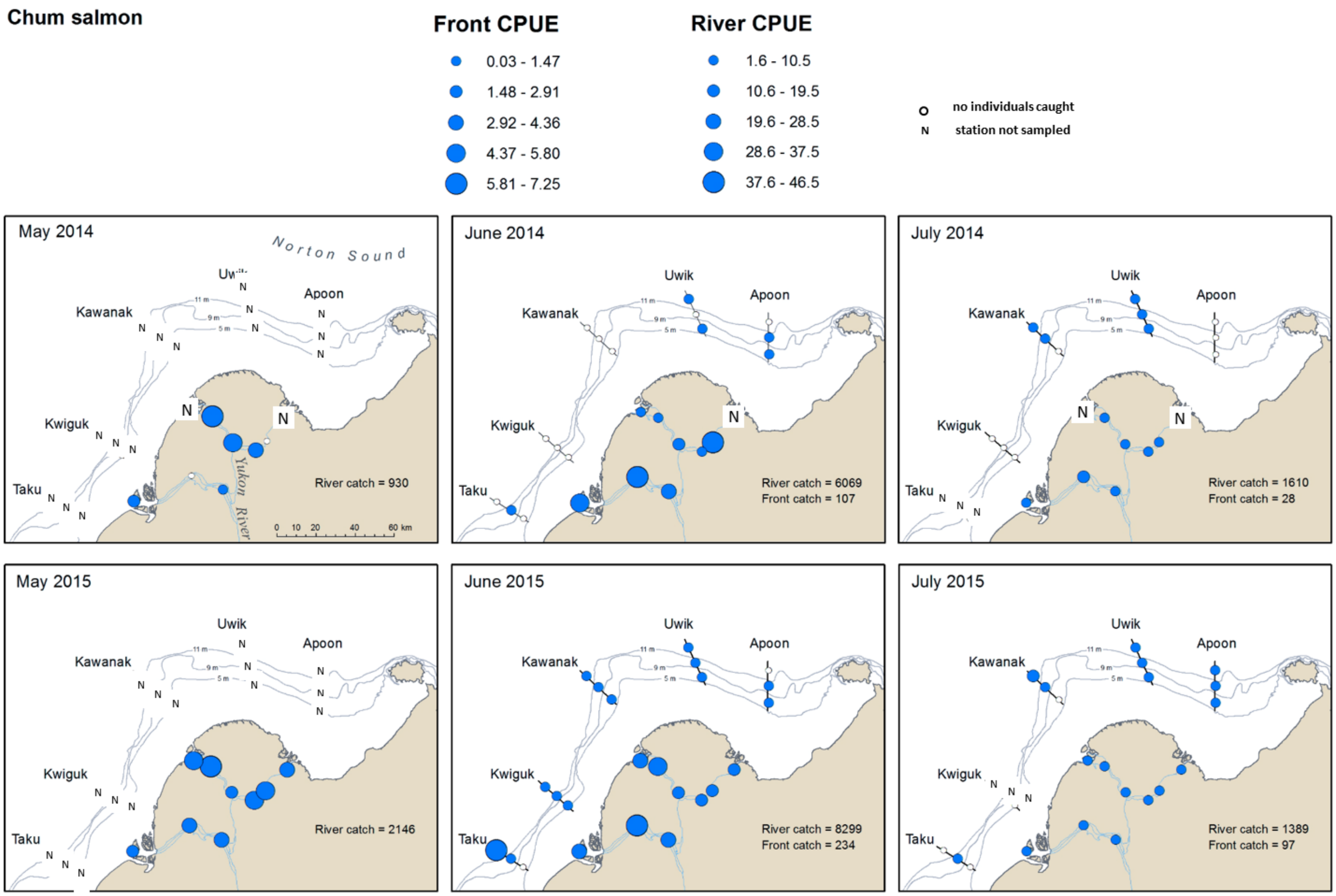




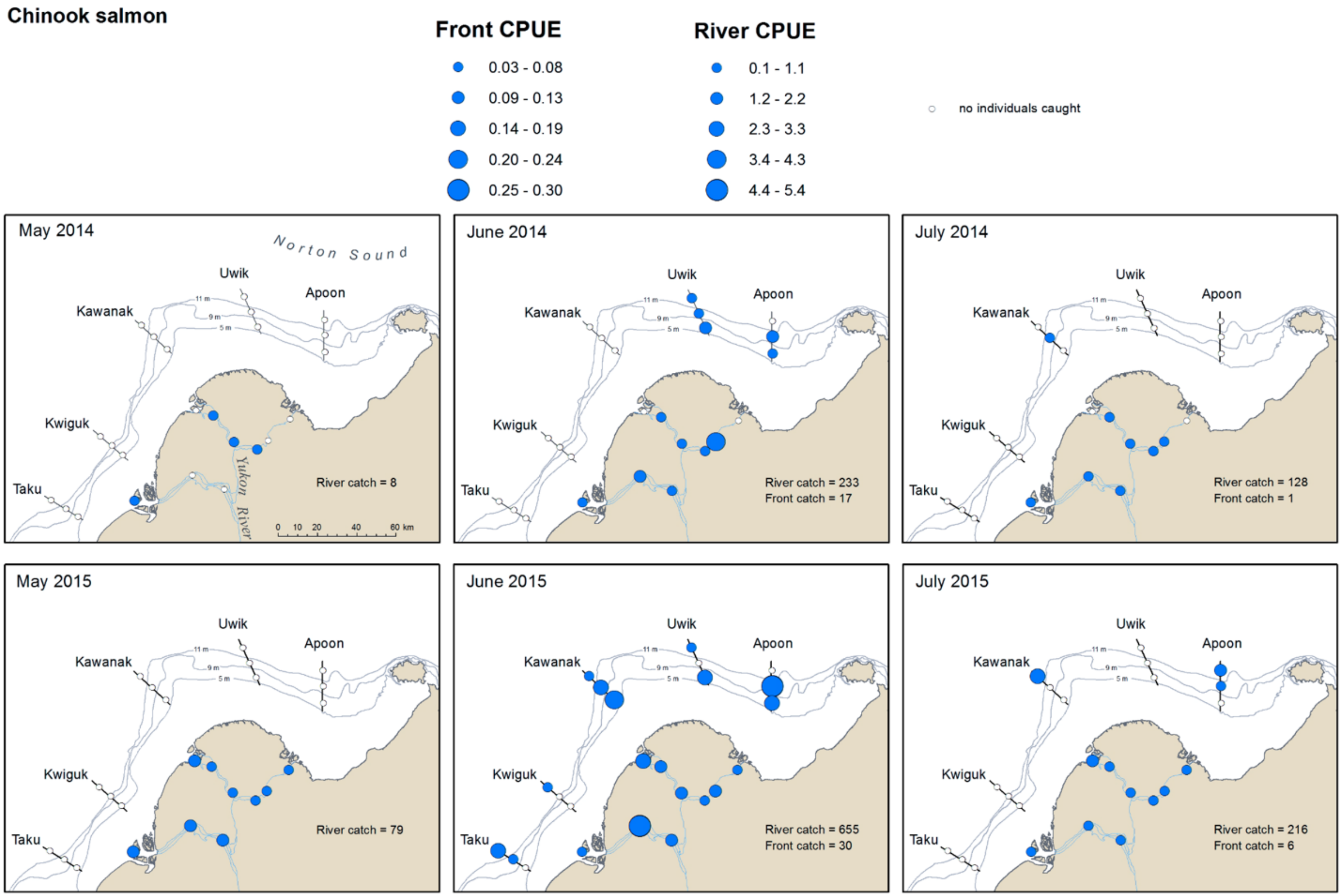
Appendix Figure A12. -- Temperature and salinity profiles for the north side of the Yukon Delta front for August 2015.

APPENDIX B
SPATIAL DISTRIBUTION MAPS FOR SELECTED SPECIES ON THE YUKON DELTA FRONT AND DISTRIBUTARIES

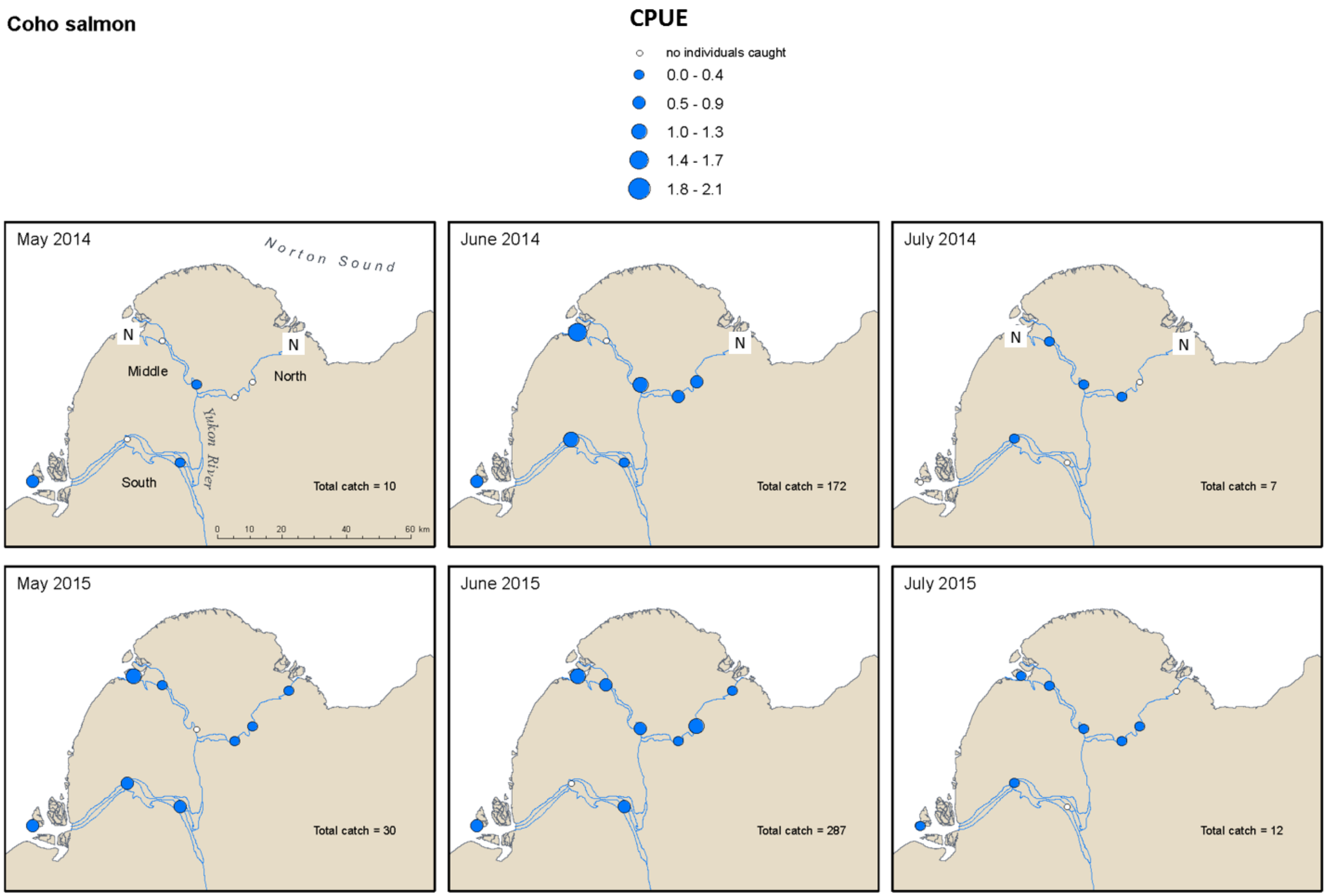
These maps provide a visual comparison of species catch by river distributary and station, and by front transect and station. Catch per unit effort (CPUE) is presented as the total catch divided by the tow length in minutes divided by the number of tows. Because of the different gears used in distributary and front habitats, CPUE is not directly comparable between habitats. The intent is to provide a method for comparing the relative size of catch to evaluate spatial and temporal patterns in habitat use.



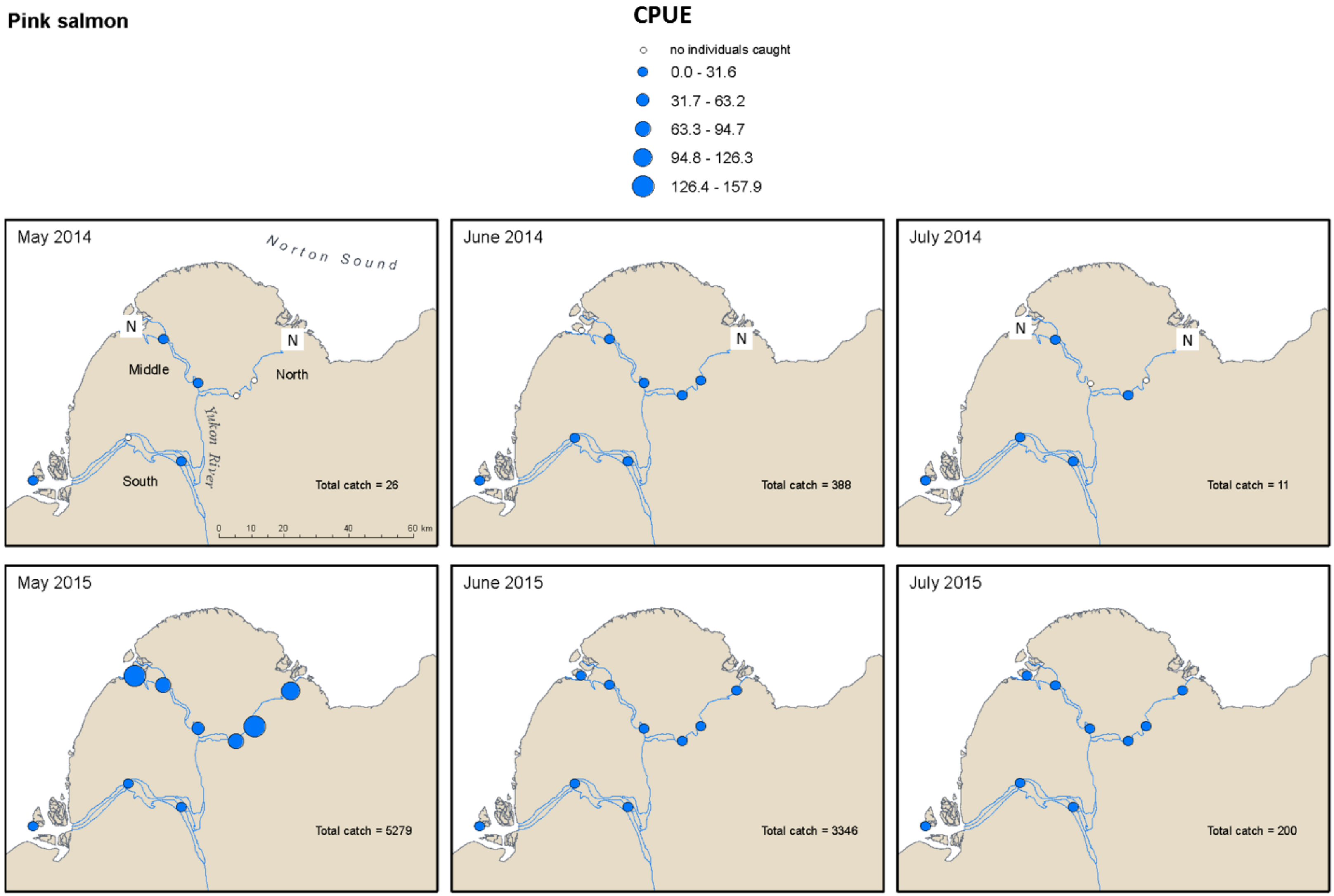
Appendix Figure B1. -- Comparison of YOY chum salmon CPUE at Yukon River distributary and Yukon Delta front stations by month and year. N= stations that were not sampled during the period. Front stations were not sampled in May of either year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.



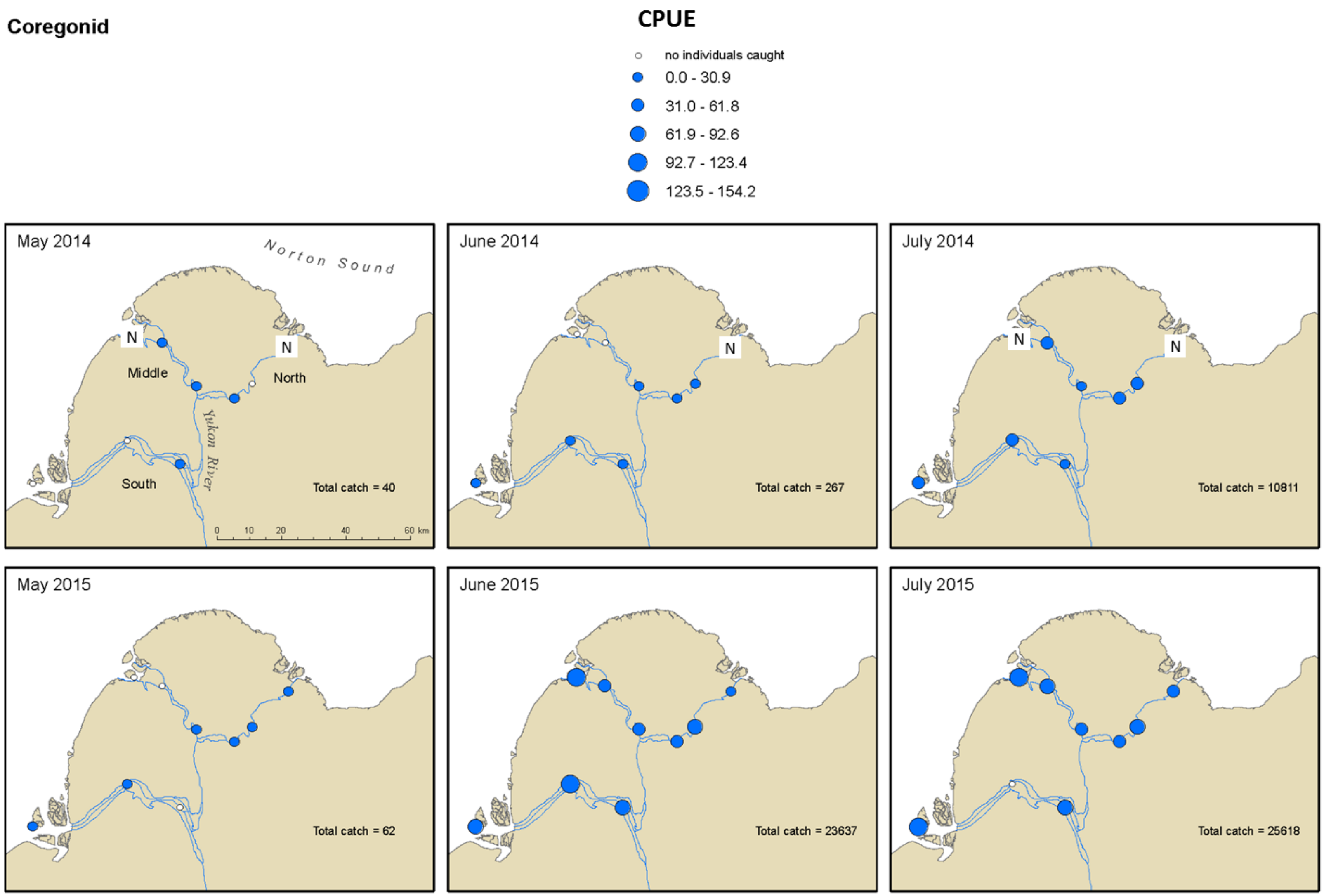
Appendix Figure B2. -- Comparison of YOY Chinook salmon CPUE at Yukon River distributary and Yukon Delta front stations by month and year. N= stations that were not sampled during the period. Front stations were not sampled in May of either year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.



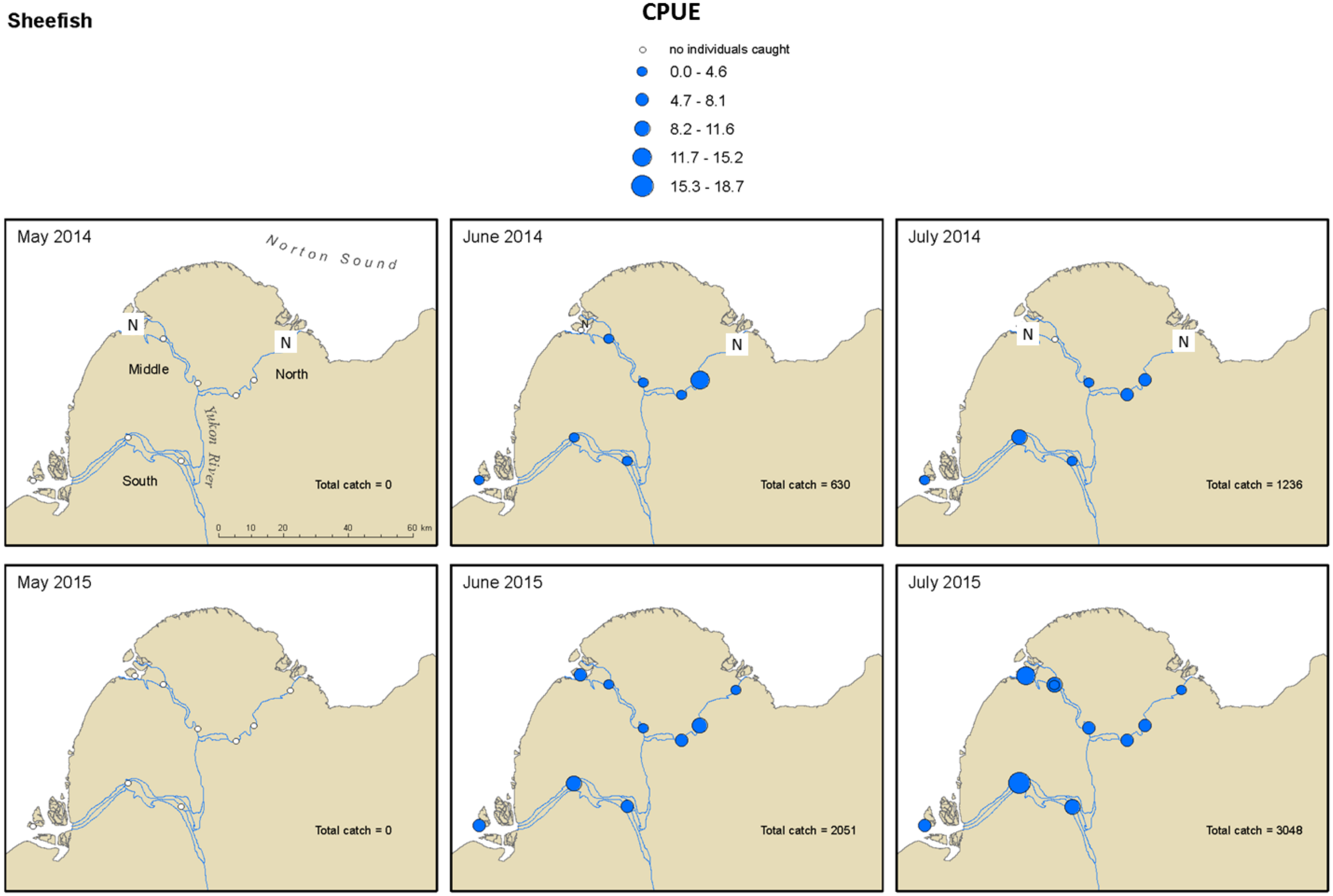
Appendix Figure B3. -- Comparison of YOY coho salmon CPUE at Yukon River distributary stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.



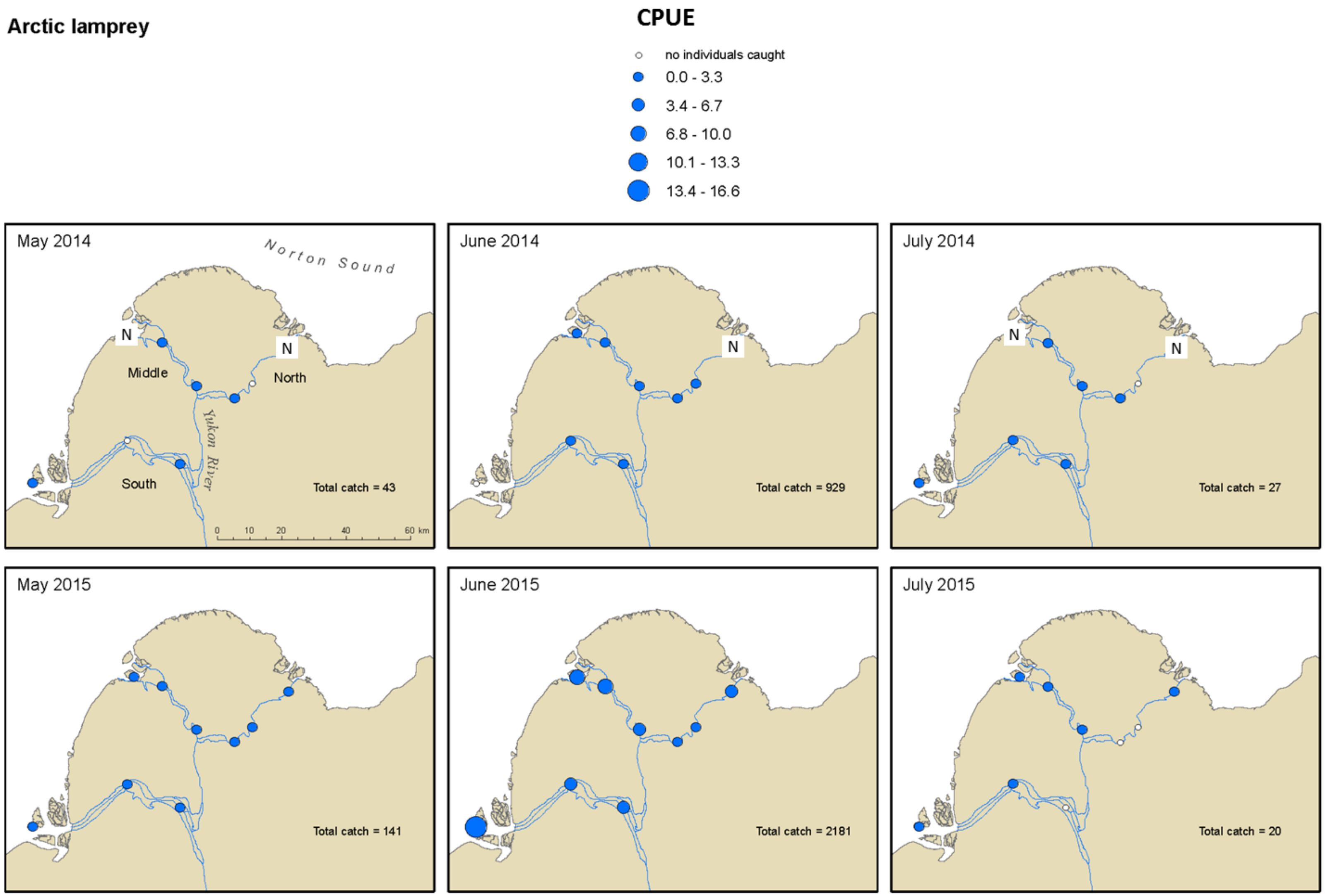
Appendix Figure B4. -- Comparison of YOY pink salmon CPUE at Yukon River distributary stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.



Appendix Figure B5. -- Comparison of juvenile Coregonid spp. CPUE at Yukon River distributary stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

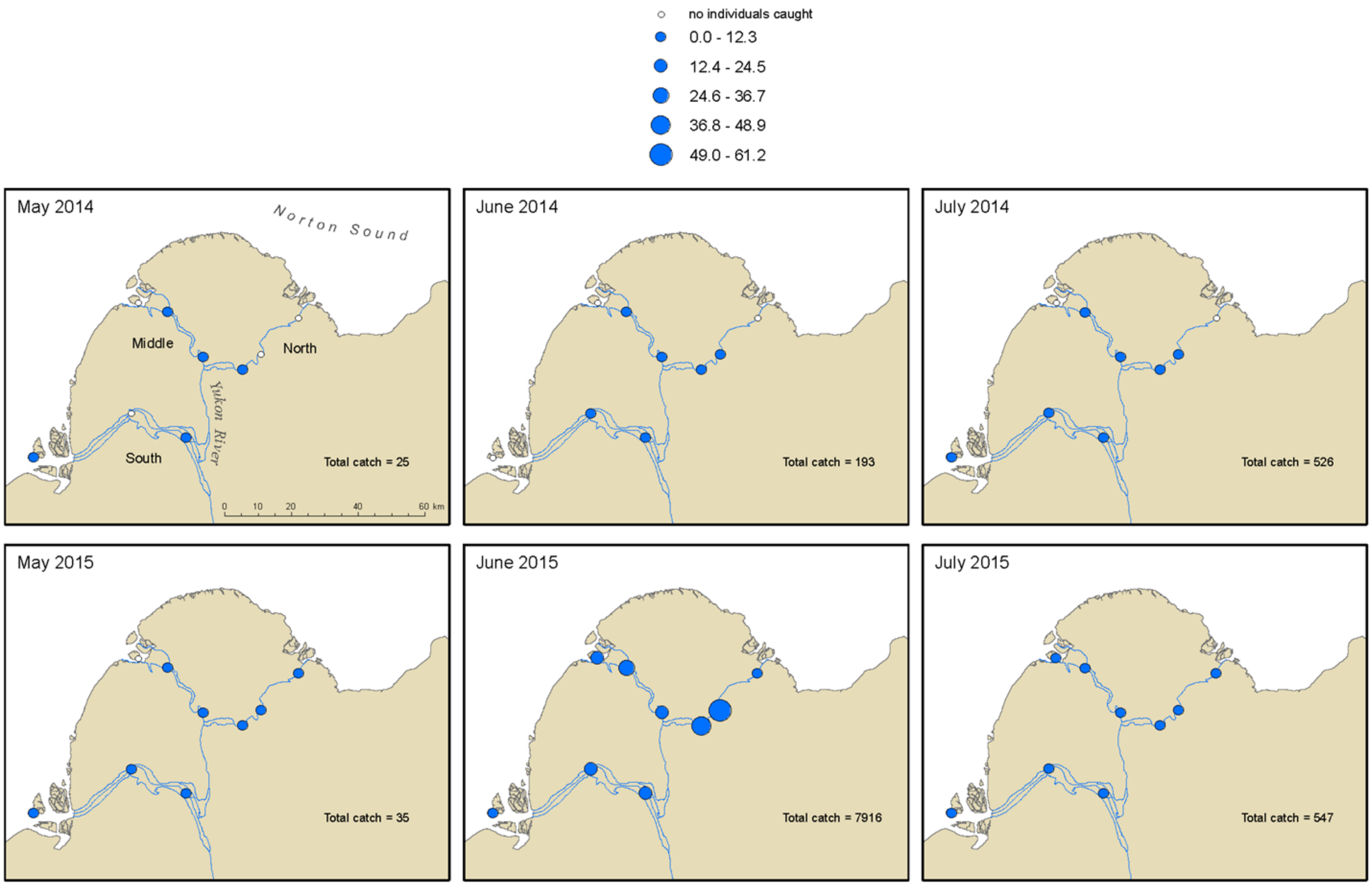


Appendix Figure B6. -- Comparison of juvenile sheefish CPUE at Yukon River distributary stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

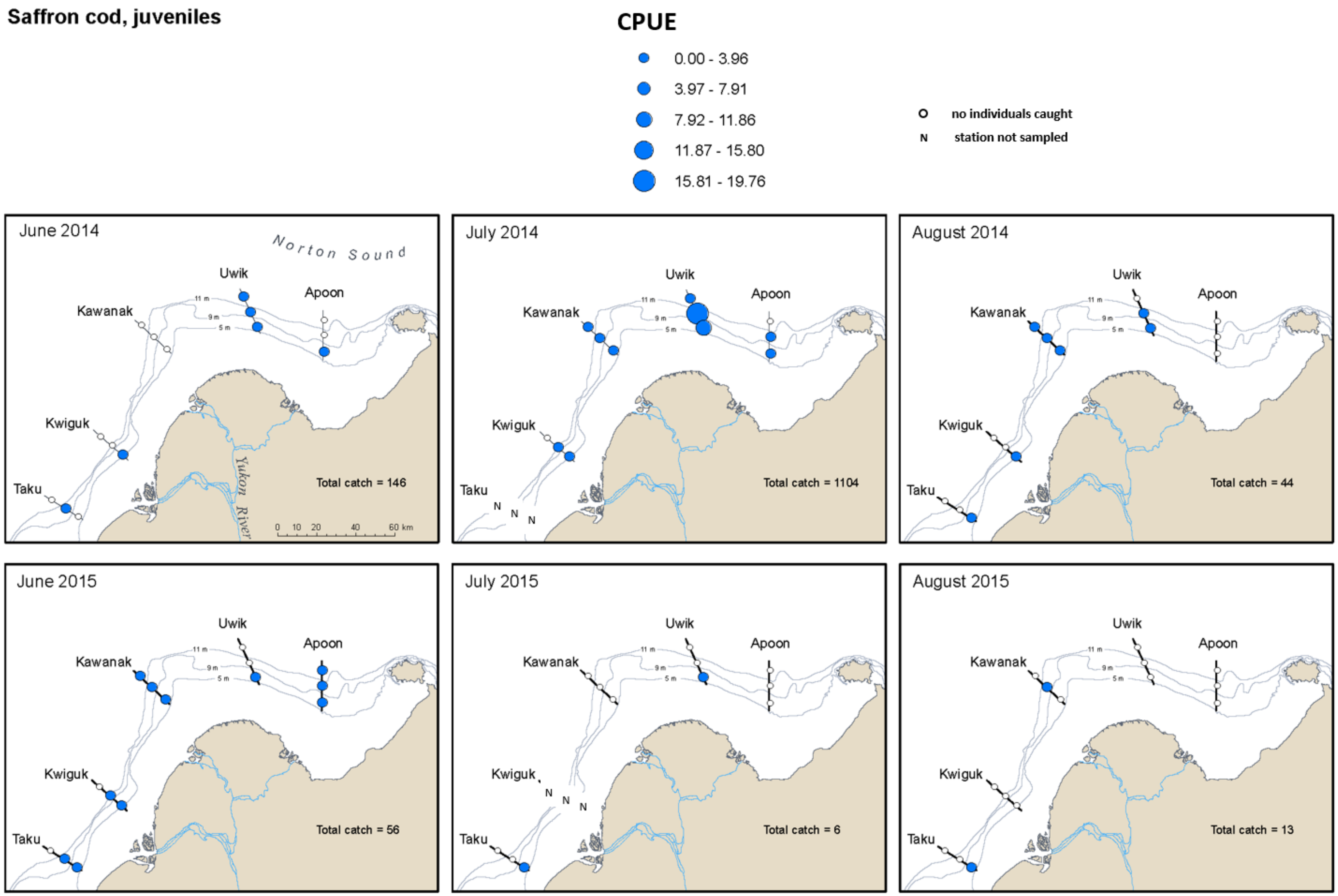


Appendix Figure B7. -- Comparison of Arctic lamprey smolt CPUE at Yukon River distributary stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

Burbot

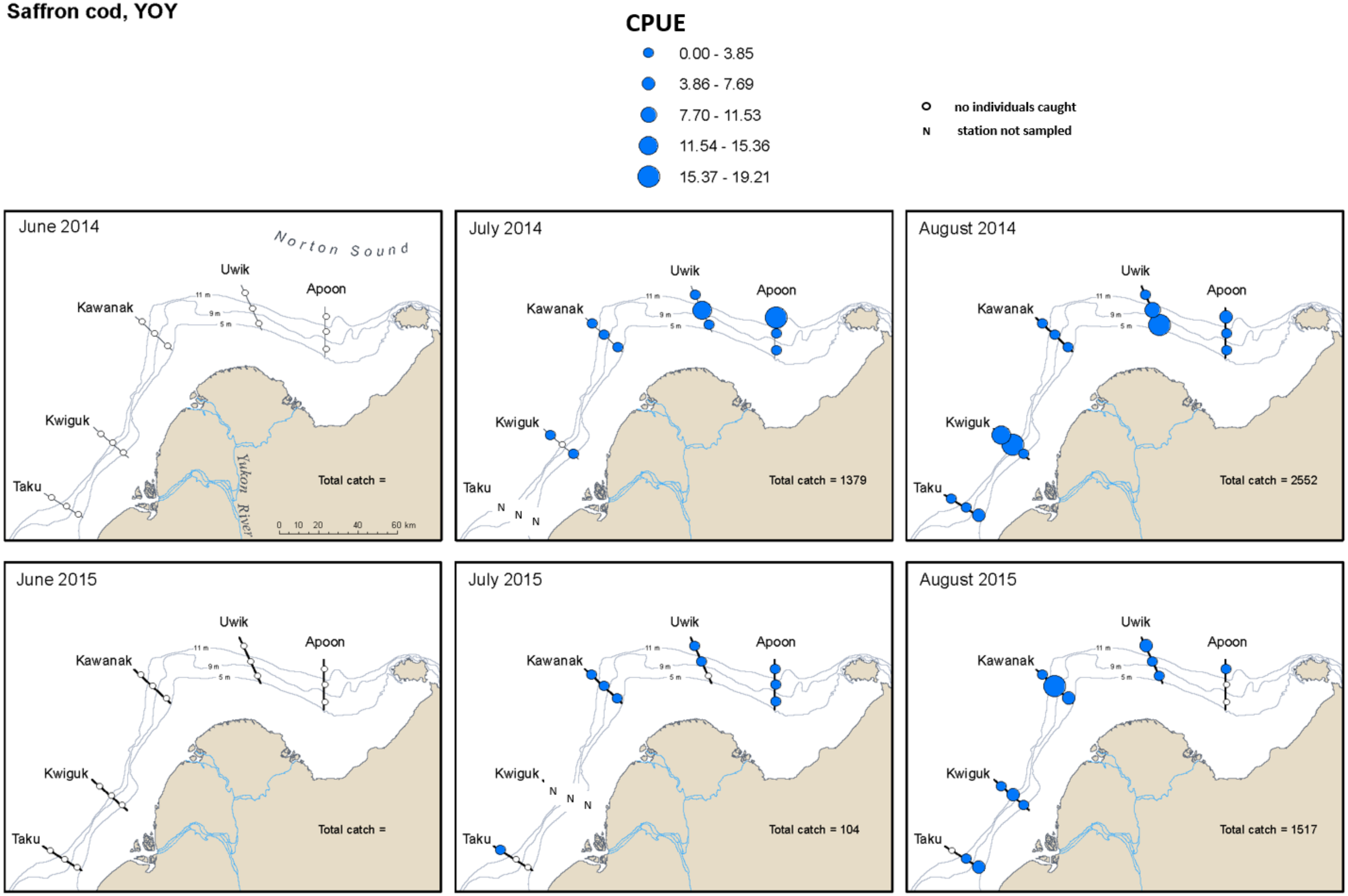


Appendix Figure B8. -- Comparison of juvenile burbot CPUE at Yukon River distributary stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

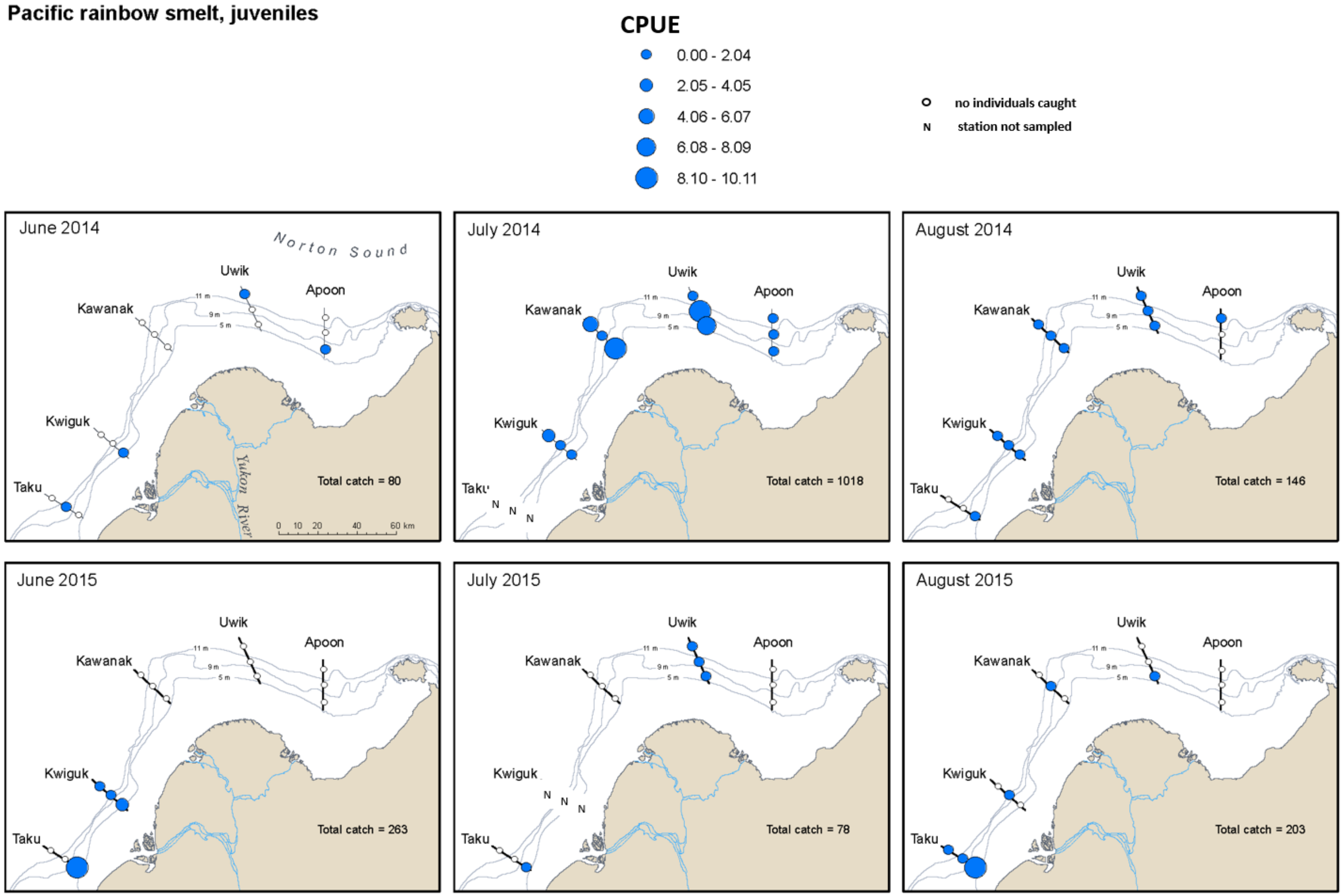


Appendix Figure B9. -- Comparison of juvenile saffron cod CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

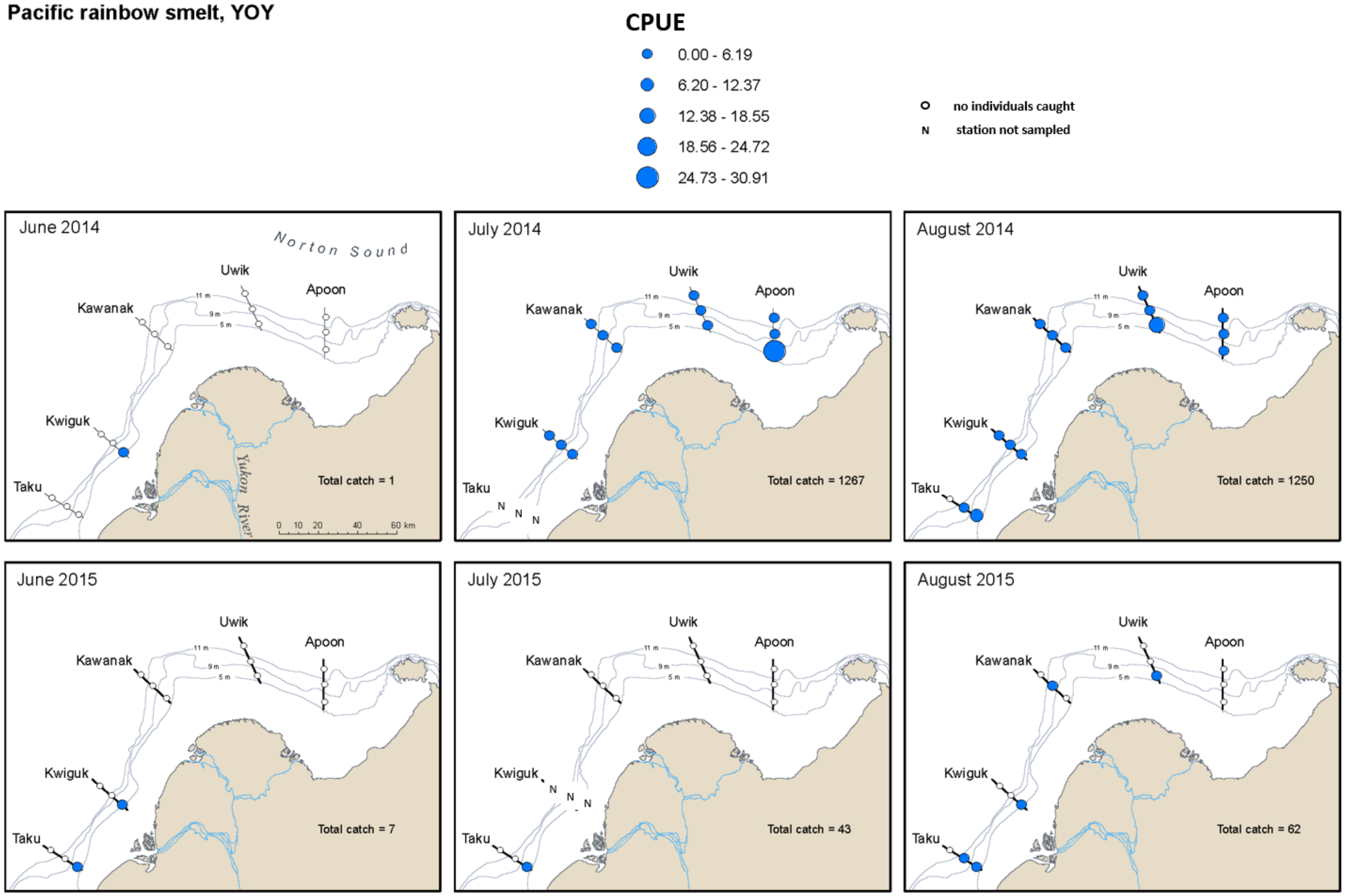
Saffron cod, YOY



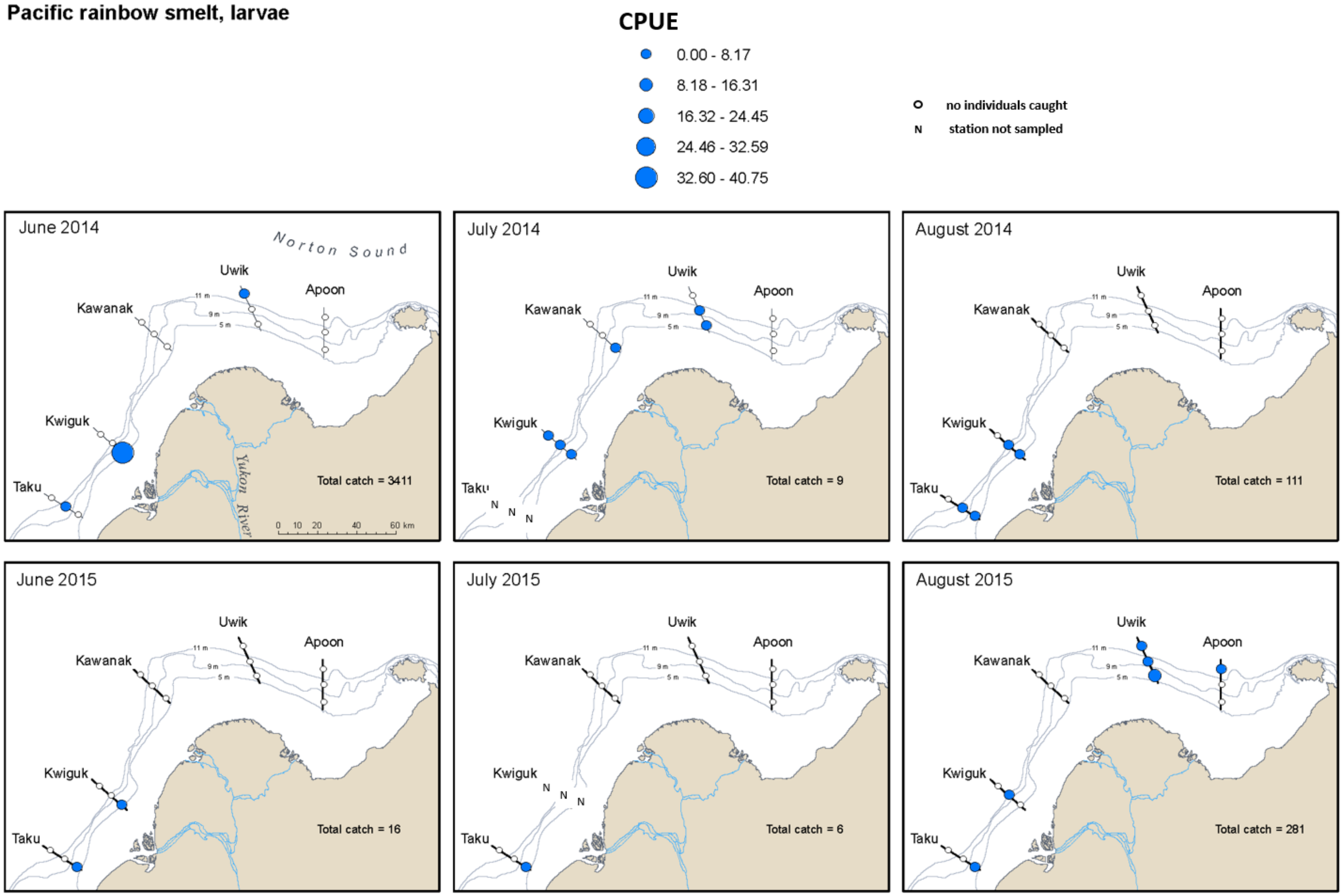
Appendix Figure B10. -- Comparison of YOY saffron cod CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.



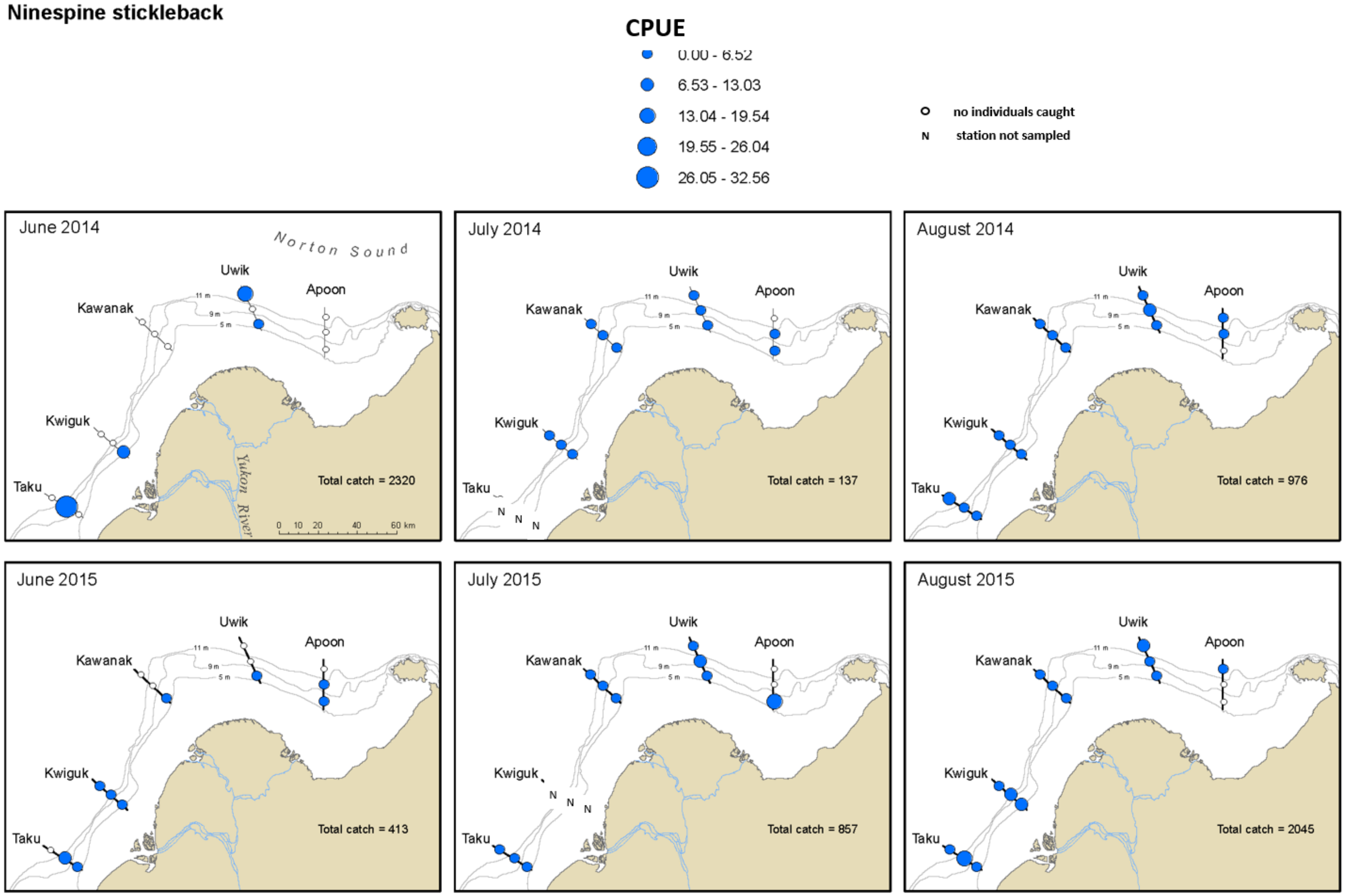
Appendix Figure B11. -- Comparison of juvenile Pacific rainbow smelt CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.



Appendix Figure B12. -- Comparison of YOY Pacific rainbow smelt CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

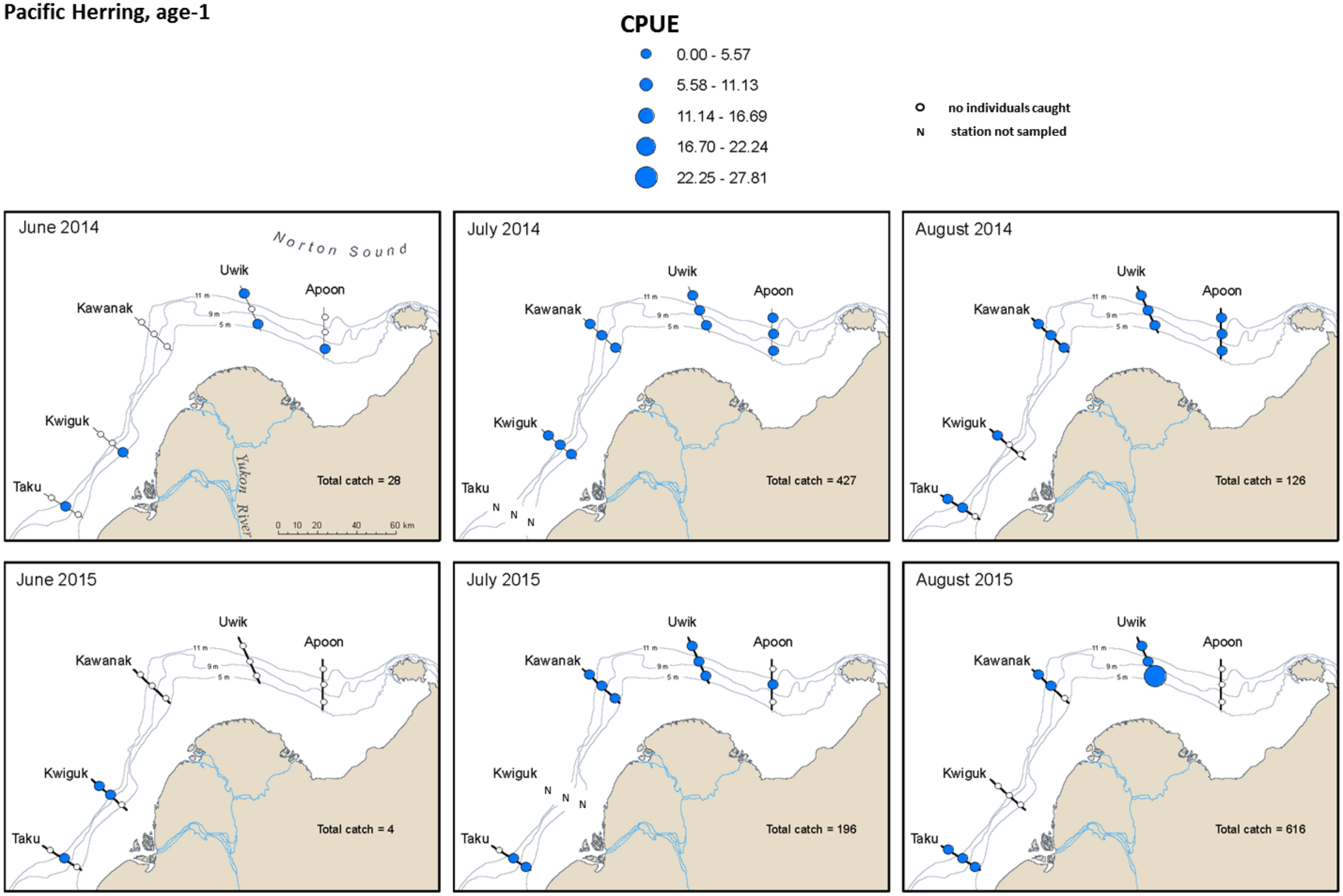


Appendix Figure B13. -- Comparison of larval Pacific rainbow smelt CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.



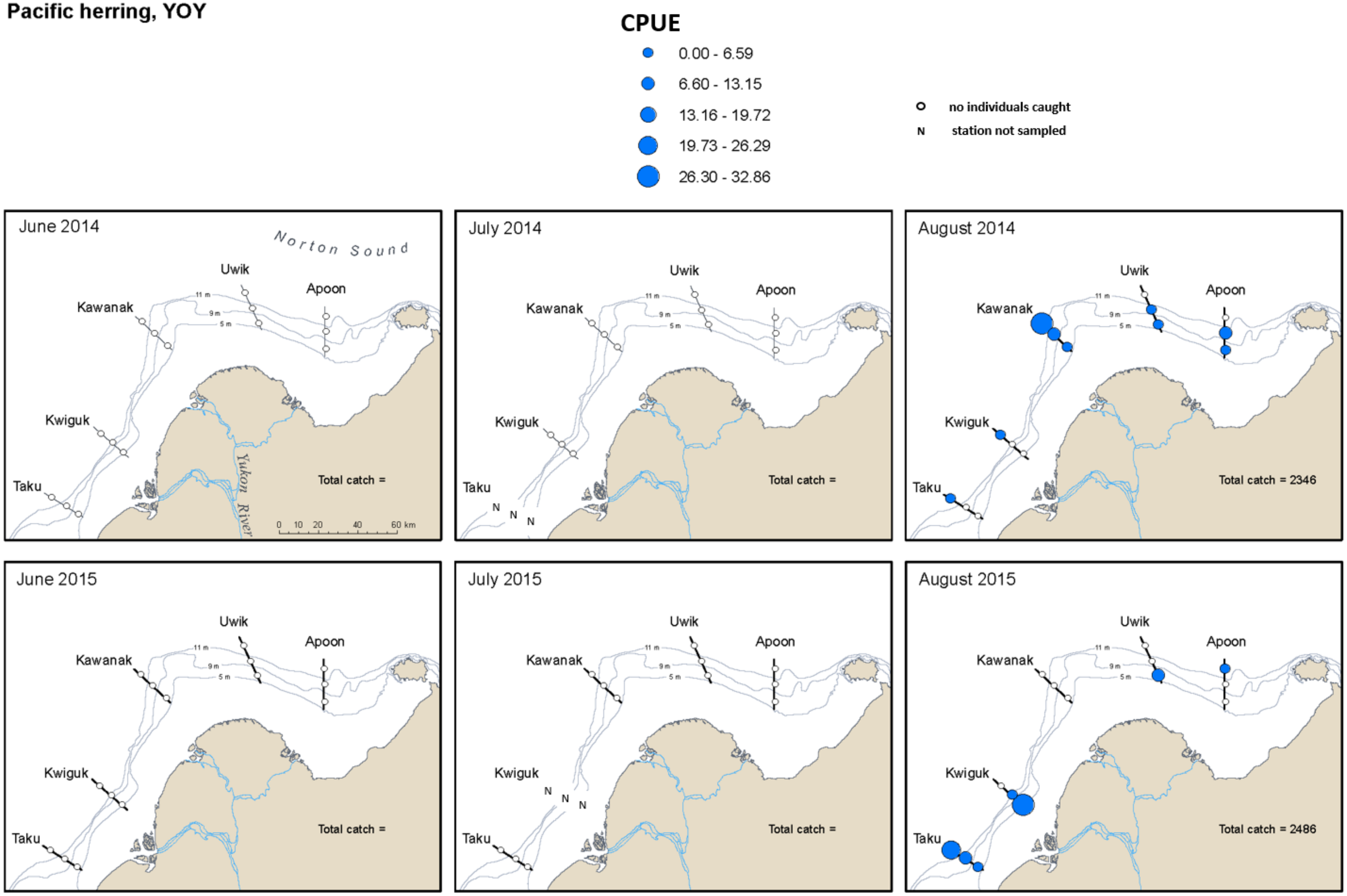
Appendix Figure B14. -- Comparison of ninespine stickleback CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

Pacific Herring, age-1

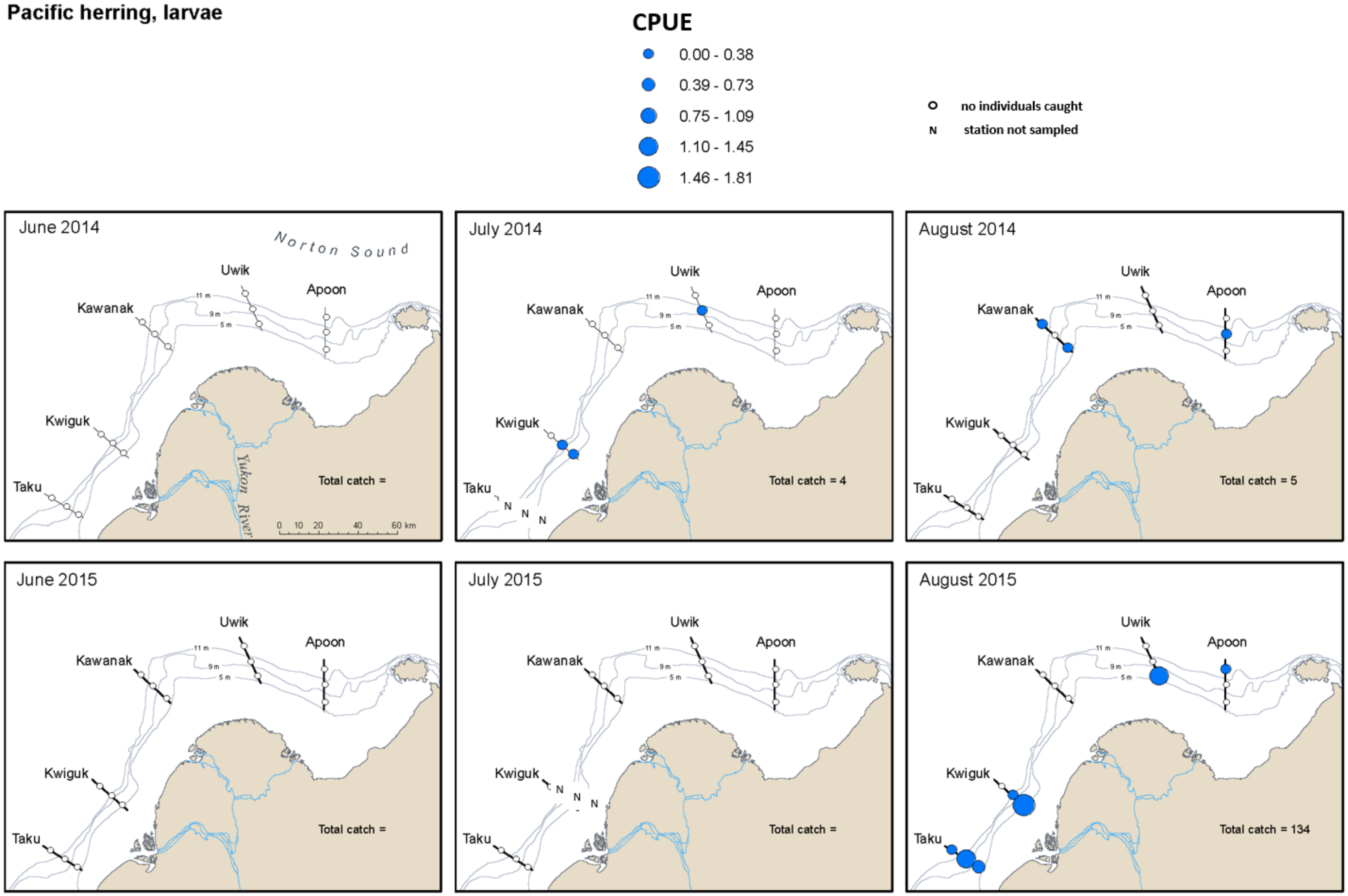


Appendix Figure B15. -- Comparison of age-1 Pacific herring CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

Pacific herring, YOY

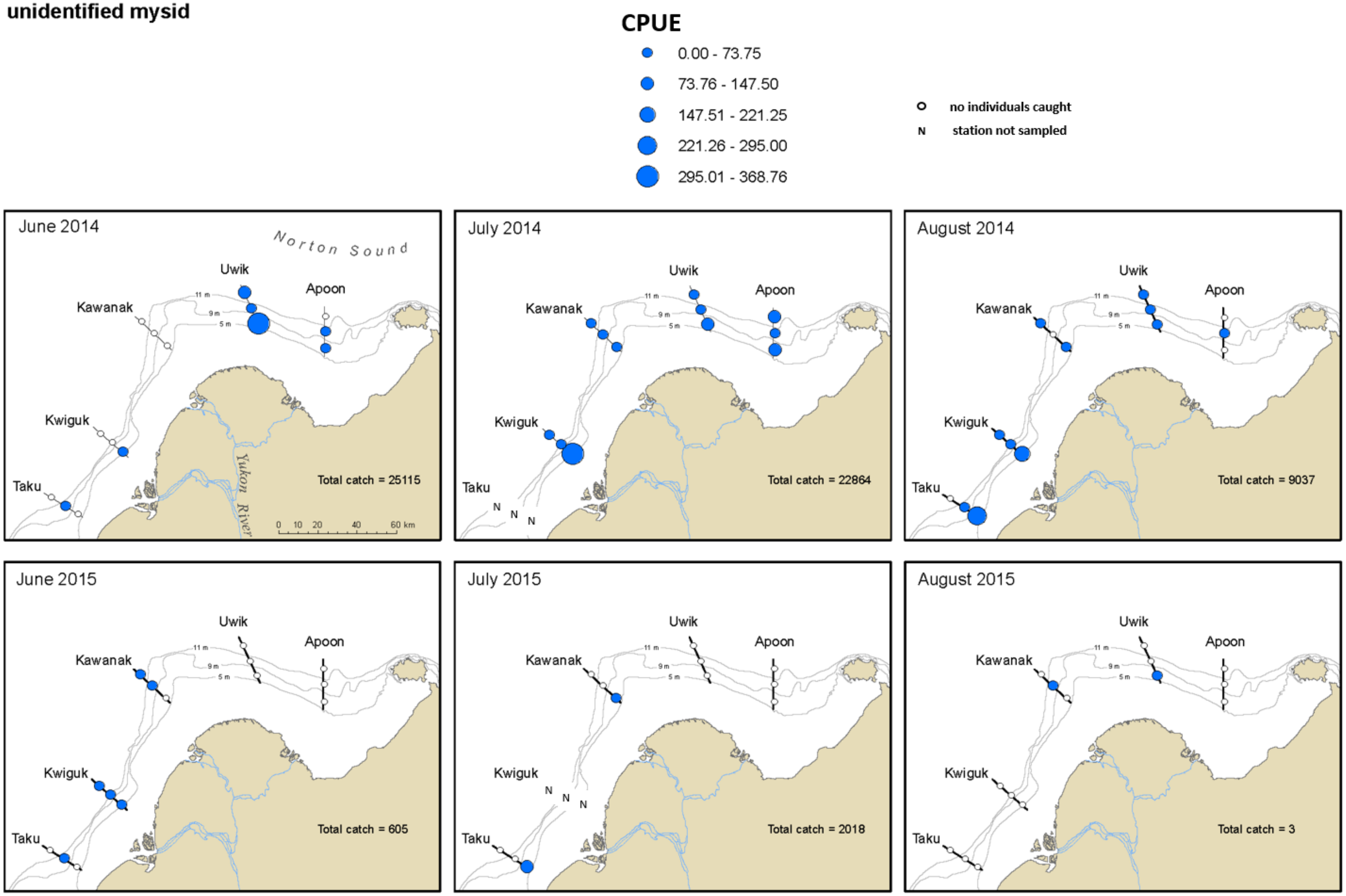


Appendix Figure B16. -- Comparison of YOY Pacific herring CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

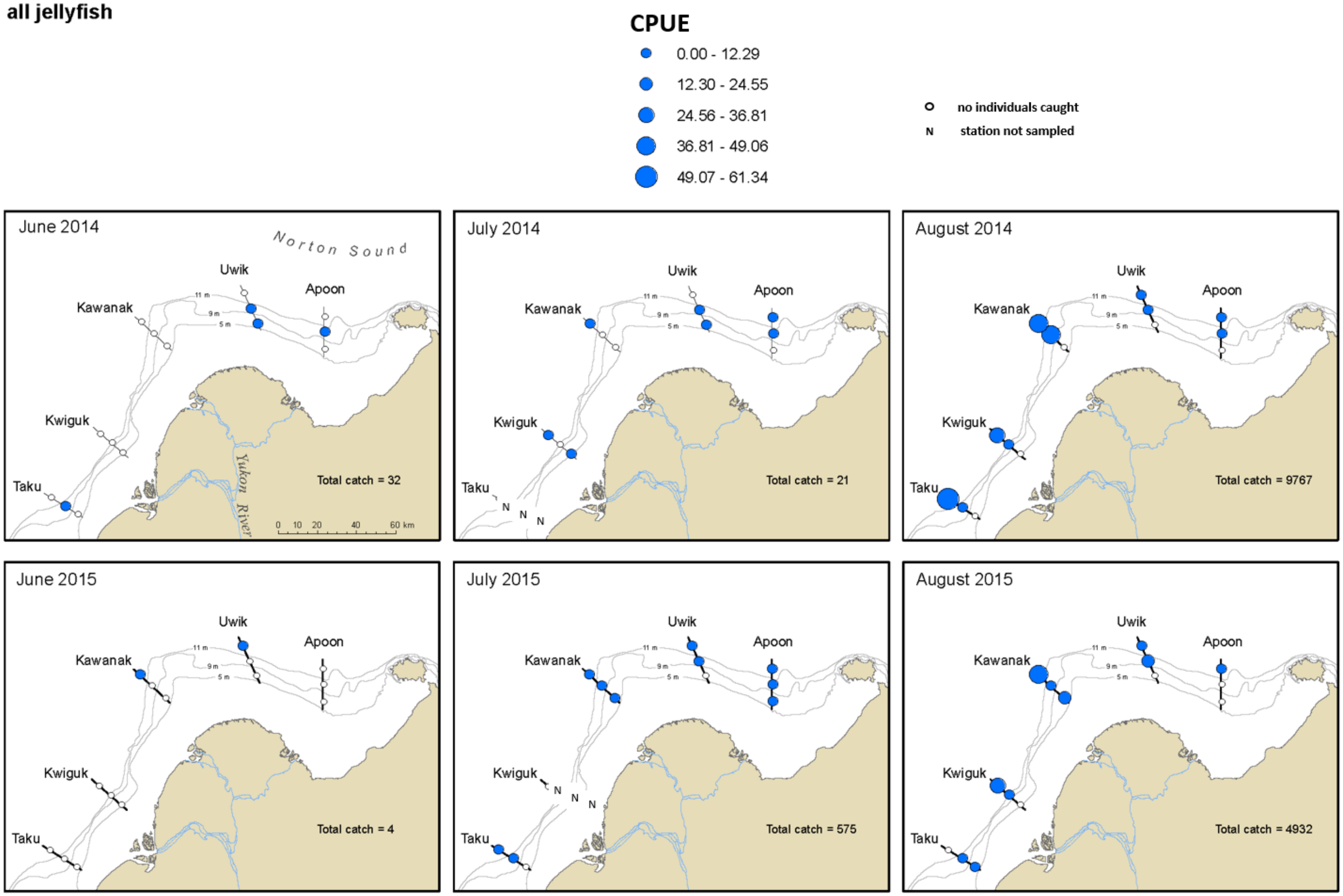


Appendix Figure B17. -- Comparison of YOY Pacific herring CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

unidentified mysid



Appendix Figure B18. -- Comparison of mysid CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.



Appendix Figure B19. -- Comparison of jellyfish CPUE at Yukon Delta Front stations by month and year. CPUE is calculated as the total catch divided by the tow length in minutes divided by the number of tows.

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