

Diet Composition and Feeding Behavior of Juvenile Salmonids Collected in the Northern Bering Sea from August to October, 2009–2011

Mary E. A. Cook¹ and Molly V. Sturdevant²

¹*Inverte Inc., 201 Fuller Lake Road, Susquehanna, PA 18847, USA*

²*NOAA Fisheries, Alaska Fisheries Science Center, Ted Stevens Marine Research Institute, Auke Bay Laboratories, 17109 Point Lena Loop Road, Juneau, Alaska 99801, USA*

Keywords: juvenile Chinook salmon, pink salmon, chum salmon, coho salmon, sockeye salmon, diel feeding, diet overlap, prey composition, northern Bering Sea

An understanding of the feeding habits and prey composition of juvenile Pacific salmon species in the northern Bering Sea is essential for assessing the growth and stock productivity of salmonids confronted with a short growing season, population changes, and changing oceanic conditions (Farley et al. 2007; Irvine and Fukuwaka 2011). Juvenile salmon food habits were examined from samples collected during BASIS (Bering-Aleutian Salmon International Survey) surface trawl operations in the northern Bering Sea in August-October, 2009-2011 (Farley et al. 2005; Moss et al. 2009). This study describes juvenile salmon diet composition, identifies important salmon prey taxa, and relates feeding patterns and behavior to diel periodicity for juvenile Chinook, pink, chum, coho, and sockeye salmon in the northern Bering Sea.

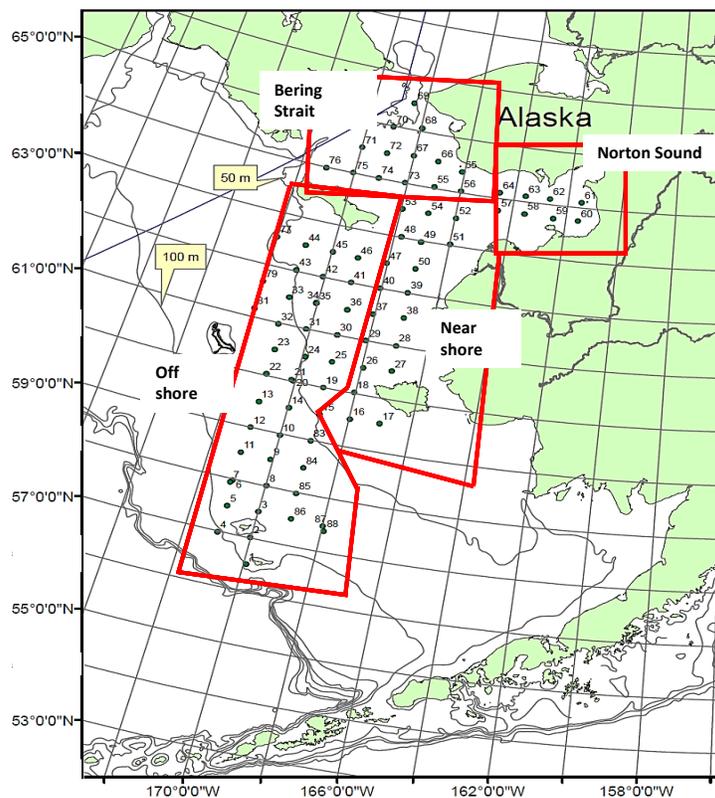


Fig. 1. Regions of the Bering Sea sampled by the BASIS (Bering-Aleutian Salmon International Survey) Program for juvenile salmon diet analysis in August-October, 2009-2011. Regions of the sampling grid are identified by the areas indicated by red lines.

Diets of 1,145 juvenile salmon were examined on board the research vessel from samples collected from four regions of the northern Bering Sea (near shore, Norton Sound, Bering Strait, and off shore; Fig. 1) in August to October, 2009-2011. Feeding intensity was assessed by both volume and weight of prey. The volumetric fullness index (% volume) was determined by visually ranking the total volume of food consumed relative to stomach size based on a scale of 1-4

(where 1 = empty, 2 = less than 25%, 3 = 50-75%, and 4 = 100% full to distended stomachs). Diet composition was then determined by sorting, enumerating, and identifying prey to the lowest possible taxonomic category. Individual prey were pooled and weighed by category, or assigned a percentage of total contents when weights could not be obtained. General diet composition was characterized as the percentage of total prey weight comprising seven prey categories (Fig. 2). Prey encountered infrequently (chaetognaths, insects, ctenophores, and pteropods) were grouped and categorized as “other.” The index of fullness (percent body weight: %BW) for $i = 1$ to n prey taxa was computed as follows:

$$\%BW = [\sum(x_i) \cdot (w_i) / (BW - \sum(x_i) \cdot (w_i))] \cdot 100$$

where w_i is the weight for $i = 1$ to n prey taxa and BW is fish body weight. Specific diet composition by prey taxa (e.g., *Ammodytes hexapterus*) was computed as the stomach content index (SCI; Hyslop 1980; Orlova et al. 2005).

$$SCI = (w_i / BW \cdot 10^4)$$

The SCI values sum to the total stomach fullness index (SFI; Starovoytov 2007a). Diet similarity between species pairs was calculated as the percent similarity index (PSI; Hurlbert 1978) based on percent weight, and diel feeding periodicity was calculated as percent of stomach volume for 3-hour increments.

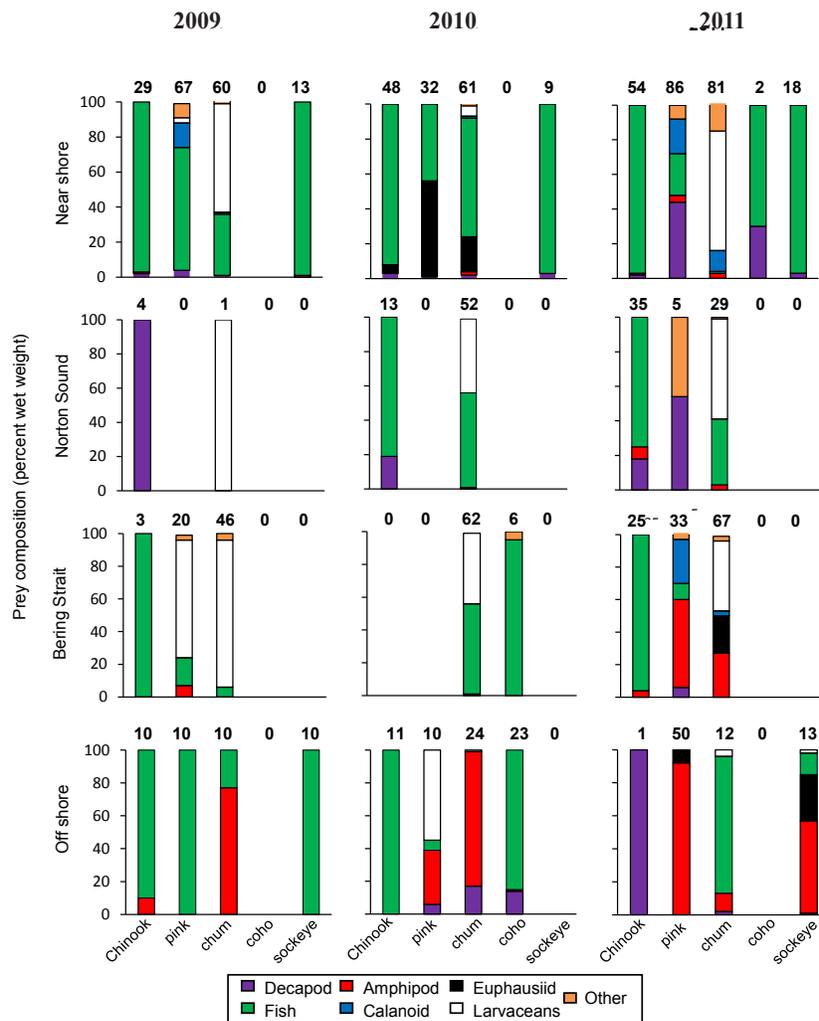


Fig. 2. Prey composition (percent wet weight) of juvenile Chinook, pink, chum coho, and sockeye salmon stomach contents collected in August-October in four regions of the northern Bering Sea, 2009-2011. Fish sample size is indicated above the bars.

Juvenile salmon diets were summarized by region, year, and diel feeding period to assess potential prey differences and feeding patterns among the species. Most salmon species were sampled in the nearshore, strait, and offshore regions (Fig. 1). Catches in the Norton Sound region were limited and catches of coho salmon were mainly in the nearshore region (Murphy et al. 2009). Diets differed among the regions and years and included both fish and plankton (Landingham 1998; Boldt and Haldorson 2003; Davis et al. 2009). Prey was diverse for piscivorous Chinook and coho salmon and for planktivorous pink, chum, and sockeye salmon (Brodeur et al. 2007). Fish were the primary prey in the nearshore region each year, especially for Chinook and coho salmon (Fig. 2). The larger body size of these salmon requires larger high-energy prey for growth (Schabetsberger et al. 2003), although intensive feeding on alternative, lower-quality prey can also enhance survival (Weitkamp and Sturdevant 2008). The most common fish prey included sand lance (*A. hexapterus*; 40-50 mm) and capelin (*Mallotus villosus*; 60-80 mm), taxa rich in lipids necessary for growth and development (Litzow et al. 2006). Chum and pink salmon diets varied in odd- and even-numbered years, a strategy that may reduce competition (Wilson et al. 2006) and be related to the lower lipid content of chum salmon observed in years when pink salmon are abundant (Kaga et al. 2013). Chum salmon consumed more larvaceans (*Oikopleura* spp.) in samples collected in odd-numbered years and switched to consuming more fish in 2010, whereas pink salmon consumed more crustaceans in odd-numbered years as compared to consumption of more euphausiids and fish in 2010 (Fig. 2). Sockeye salmon diets included fish and brachyuran megalopae in samples collected near shore as compared to diets including hyperiid amphipods and euphausiids (*Thysanoessa* spp.) in offshore samples.

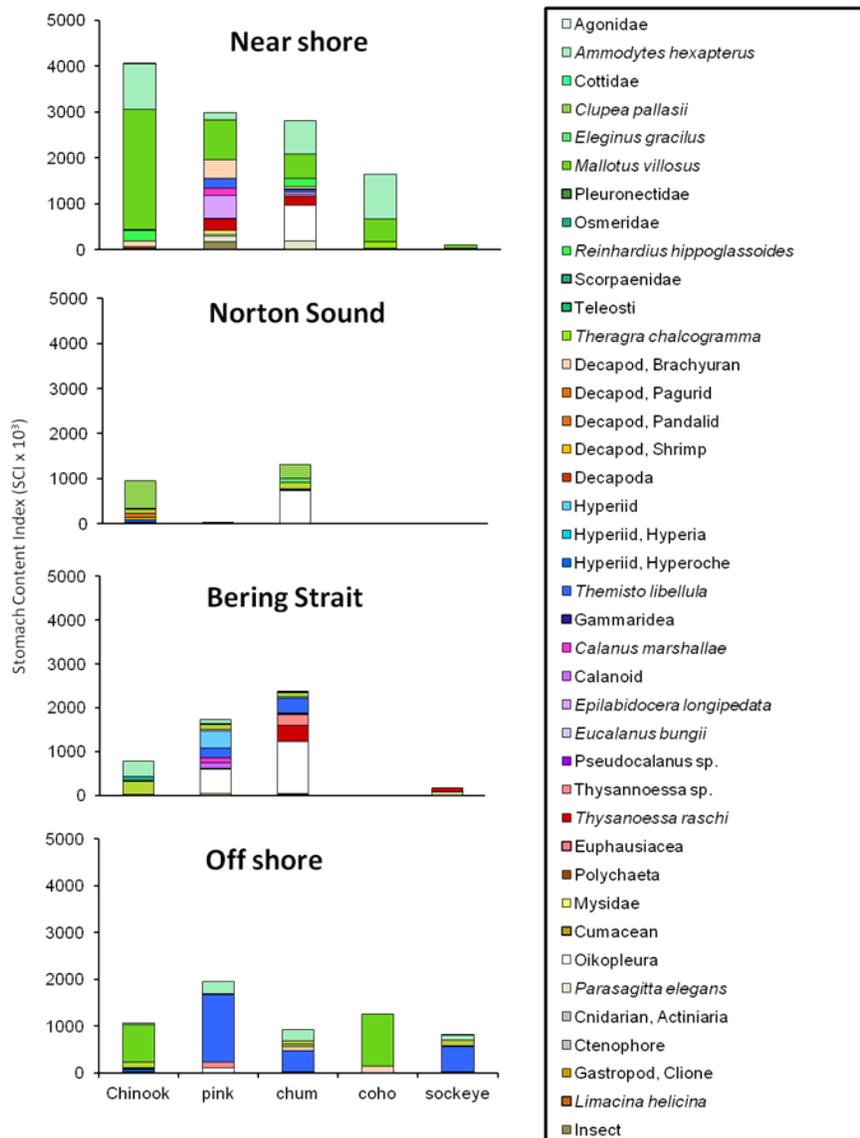


Fig. 3. Stomach content indices (SCI) of juvenile Chinook, pink, chum coho, and sockeye salmon collected in the northern Bering Sea in August-October, 2009-2011. The SCI values are based upon individual prey types.

In the Norton Sound region, Pacific herring (*Clupea pallasii*; 30-40 mm) were the primary foods of juvenile Chinook and chum salmon. Local populations of herring over-winter north of the sound and can be an important prey for piscivorous juvenile salmon (Funk 2001; Tojo 2007). Larvaceans and hyperiid amphipods (*Hyperoche* sp. and *Themisto libellula*) were consumed by juvenile chum salmon (Fig. 2). Juvenile chum salmon preference for rapidly-digested gelatinous prey (Boldt and Haldorson 2003) has been described throughout its range (Brodeur et al. 2007; Karpenko and Koval 2012). Reports of pink salmon feeding on larvaceans are also common (Purcell et al. 2005), however, insects and brachyuran megalopae were the common pink salmon prey in this study (Fig. 2).

Catches of juvenile salmon other than chum salmon were patchy in the Bering Strait. In contrast to samples from Norton Sound, fish prey from the strait region included rainbow smelt (*Osmerus mordax*), Pleuronectidae, and sand lance consumed by Chinook salmon, Pleuronectidae consumed by pink salmon, and Pleuronectidae and Cottidae consumed by chum salmon (Fig. 3). In 2011, pink and chum salmon diets principally comprised of the amphipod *T. libellula*. Chum salmon also consumed euphausiids and larvaceans, while pink salmon consumed more of the large calanoid copepod *Calanus marshallae* (Fig. 2). Since *C. marshallae* is also important in the diet of *T. libellula* (Auel and Werner 2003; Pinchuk et al. 2013), the carrying capacity of the Bering Strait could be affected by interactions between juvenile salmon and carnivorous macrozooplankton if climate change impacts the availability of these prey (Coyle et al. 2011). These amphipods and calanoids are substantial sources of fatty acids that juvenile salmon require during cold periods (Scott et al. 2002; Persson and Vrede 2006).

In the offshore region, hyperiid amphipods, *Themisto* spp., were important prey and contributed a high percentage of the diets of juvenile salmon diets in 2010 and 2011 (Starovoytov 2007b; Temnykh et al. 2010). Fish, such as sand lance (35-45 mm), capelin (60-80mm), Cottidae (16-20 mm), Scorpaenidae (15-25 mm), and Agonidae (20-27mm), were also a high percentage of the diet. The SCI values indicated that hyperiid amphipods were important prey to all species except coho and Chinook salmon (Fig. 3), which consumed large percentages of capelin in this region. Capelin located along the continental shelf provide substantial food to migrating salmon (Vilhjalmsson et al. 2005). Larvaceans contributed a substantial percentage to the diets of pink salmon in 2010 (Fig. 2), but overall SCI values for hyperiid amphipods were higher for pink salmon caught off shore in all three years (Fig. 3).

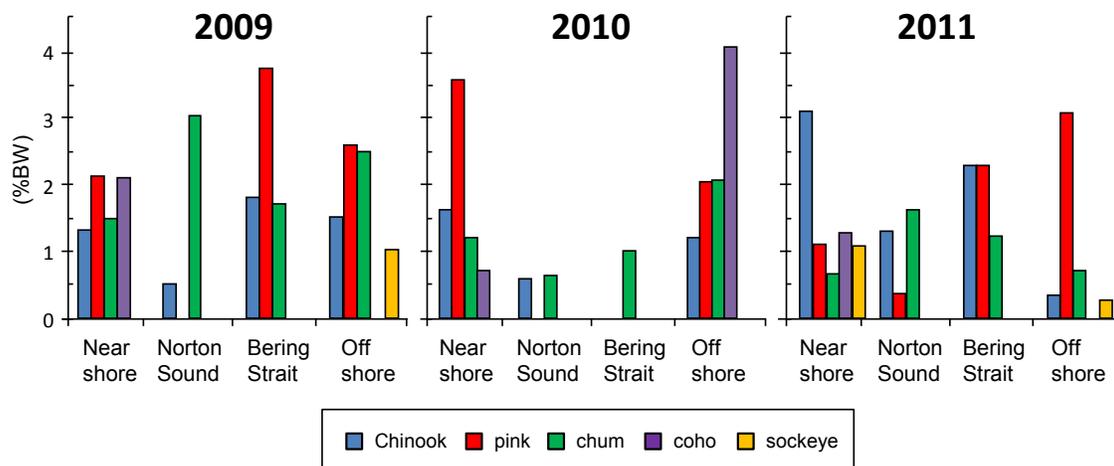


Fig. 4. Percent of salmon body weight (% BW) comprising prey and observed in salmon stomach contents of juvenile Chinook, pink, chum coho, and sockeye salmon collected in four regions of the northern Bering Sea in August-October, 2009-2011.

The amount of prey as a percentage of salmon body weight is a size-related index of feeding intensity and prey availability (Graeb and Dettmers 2004). The percent body weight of prey in stomach contents of Chinook salmon was highest (> 1%) in samples from the nearshore and strait regions, whereas coho salmon fed most intensively in the offshore region (> 4 %BW; Fig. 4). The percentage of Chinook salmon body weight represented by prey in samples collected near shore was unusually high in 2011, despite similar sizes across years in this region (Fig. 5). Pink salmon tended to have the highest percent body weight comprising prey among the salmon species, but their annual body size varied in both the nearshore and off-shore regions where it was often highest. Percent body weight of prey observed in Chinook and chum salmon stomach contents collected off shore decreased over the study period, and pink salmon values increased overall. Small sample sizes and differences in salmon distributions (Sturdevant et al. 2012) may have contributed to some of the feeding differences observed.

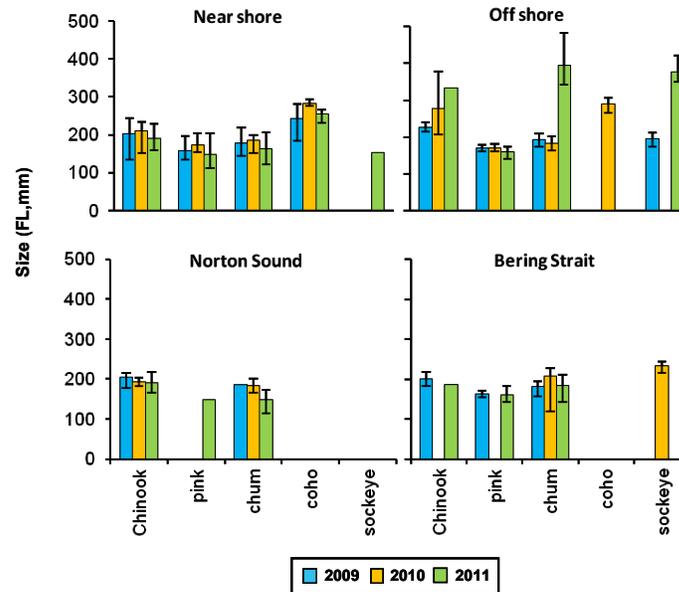


Fig. 5. Average fork length (FL, mm) of juvenile Chinook, pink, chum coho, and sockeye salmon collected in four regions of the northern Bering Sea and pooled over the three-year period, 2009-2011.

Diet overlap (PSI) was calculated for 44 co-occurring species-pairs collected from nearshore and offshore regions (Table 1), but samples were limited to 12 species-pairs in the Norton Sound and Bering Strait regions. Diet overlap of coho and Chinook salmon was consistently > 95% PSI in nearshore regions each year and was based on consumption of fish prey, whereas overlap between other species-pairs varied from year-to-year and was usually low (< 60%; Brodeur et al. 2007). Differential annual movement patterns of juvenile salmon to offshore regions affect their spatial overlap and therefore could affect diet similarity measures (Farley et al. 2007). By contrast, the PSI was significant (81%) only for pink and chum salmon in 2009 in samples collected from the Bering Strait (Table 1; Fig. 2). Diet overlap between piscivorous Chinook and coho salmon is commonly reported (Bollens et al. 2010), but can be overestimated if fish prey taxa differ (Rindorf and Lewy 2004). In this study, both species consumed capelin and sand lance, however, coho fed on pollock (*Theragra chalcogramma*) more than the other salmon species, perhaps alleviating competition for food (Bollens et al. 2010) or indicating different habitat utilization patterns (Weitkamp and Sturdevant 2008).

Table 1. Diet overlap (percent similarity index: PSI) by region and year based on examination of juvenile Chinook, pink, chum, coho and sockeye salmon stomach samples collected in the northern Bering Sea in August-October, 2009-2011.

2009			2010			2011			
Near shore									
	Chinook	pink	chum	Chinook	pink	chum	Chinook	pink	chum
pink	72.5	-	-	49.3	-	-	27.4	-	-
chum	100	41.5	-	74.1	64.6	-	2.6	24.1	-
coho	100	70.8	35.0	95.2	44.7	69.6	98.6	26.9	1.2
sockeye							72.2	53.8	1.2
Norton Sound									
	Chinook			Chinook			Chinook	pink	
pink	-			-			17.8	-	
chum	-			55.8			46.0	1.0	
Bering Strait									
	Chinook	pink		chum			Chinook	pink	
pink	17.2	-		-			14.5	-	
chum	5.7	81.6		-			5.0	35.7	
sockeye	-	-		0.8					
Off shore									
	Chinook	pink	chum	Chinook	pink	chum	Chinook	pink	chum
pink	90.5	-	-	5.6	-	-	0.2	-	-
chum	32.3	22.8	-	0.0	39.7	-	2.2	11.3	-
coho	-	-	-	85.8	11.8	14.2	-	-	-
sockeye	90.5	100	22.8	-	-	-	1.5	64.4	26.2

Variation in capelin biomass has been linked to climatic changes and abundance of other pelagic species such as herring and pollock (Benson and Trites 2002; Vilhjalmsjon et al. 2005). Similarly, changes in oceanic conditions can limit production of some prey and lead to shifts in planktivorous feeding (Aydin and Mueter 2007; Andrews et al. 2009). Diets of highly piscivorous juvenile salmon species overlapped with planktivorous juvenile salmon species only when the latter ate fish. Thus, diet overlap based on preferred prey is expected to be low when alternate prey is available, but diet quality may differ as a result (Davis et al 2005; Karpenko et al. 2007; Weitkamp and Sturdevant 2008).

A diel feeding rhythm was observed for all juvenile salmon in the northern Bering Sea (Fig. 6). Morning was the period observed with the highest percentage of stomachs that were empty or contained only trace amounts of food. Stomach fullness increased between 09:00 and mid-day hours, dipped in early afternoon, and then remained high until the final sampling period at 21:00 (Temnykh et al. 2010). The afternoon decrease in feeding we observed was similar to sockeye and chum salmon feeding rhythms reported for samples collected in the Bering Sea in summer (Azuma 1992), but rhythms differed with those of pink and chum collected in Southeast Alaska (Sturdevant et al. 2004). Feeding behavior, feeding intensity, and diel prey composition of salmon could be influenced by latitudinal differences in light cycles that affect visual feeding (Schabetsberger et al. 2003; Bieber 2005).

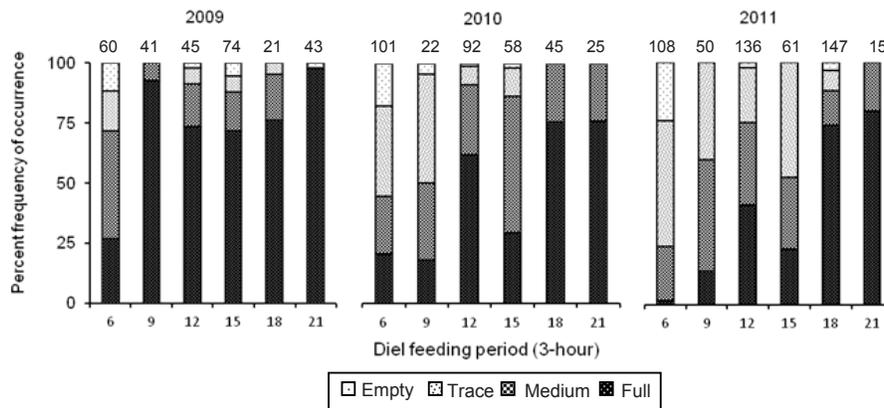


Fig. 6. Juvenile salmon diel feeding rhythm per three-hour period measured as the percent frequency of occurrence of empty, trace, medium, and full stomach volume. Data are grouped for juvenile Chinook, pink, chum, coho, and sockeye salmon collected in all regions of the northern Bering Sea in August-October, 2009-2011. Fish sample size is indicated above the bars.

We examined multivariate trophic relationships among the species and regions using the SCI prey data. Values were square root-transformed and Bray-Curtis similarity matrices were derived. The nonmetric multi-dimensional scaling procedure (nMDS) was used to produce a 2-dimensional ordination plot (PRIMER-E; Plymouth Routines in Multivariate Ecological Research, v6; Clarke and Warwick 2001). The stress value of 0.13 indicates moderately strong relationships among the groups, with species gradients evident in each region except Norton Sound (Fig. 7). The trophic position of sockeye salmon was shown to be distinct from the other species.

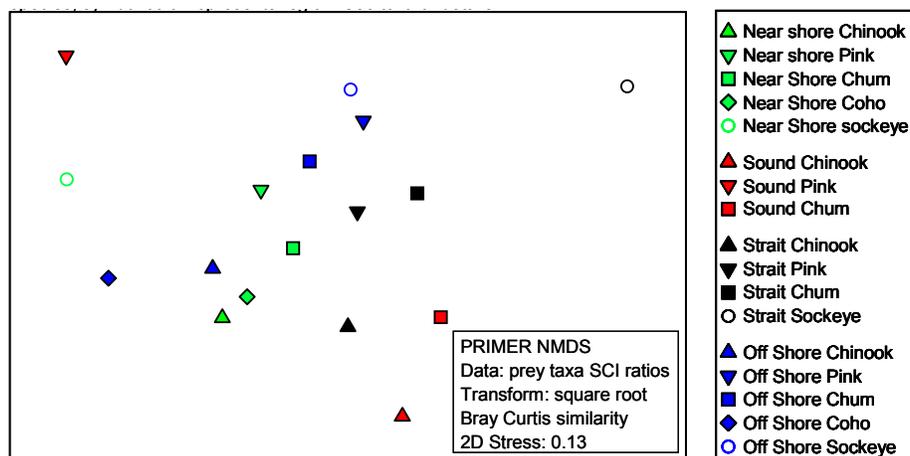


Fig. 7. Multivariate trophic relationships among juvenile Chinook, pink, chum coho, and sockeye collected in the four regions in the northern Bering Sea in August-October, 2009-2011. Diet data are stomach content indices for 40 prey taxa averaged across the three years. Symbol shape represents species; symbol color represents region.

We documented regional and inter-annual differences in juvenile salmon diets for the northern Bering Sea and corroborated previous reports of trophic niches for Chinook, pink, chum, coho, and sockeye salmon and high overlap in the diets of piscivorous Chinook and coho salmon.

As prey fish and invertebrate populations adapt to climate change in the Bering Sea (Overland and Stabeno 2004; Coyle et al. 2011), availability of important pelagic salmon prey resources that can fill the nutritional requirements of juvenile salmon is a concern (Miller et al. 2013), particularly in the face of salmon stock collapses (Orsi et al. 2013). The feeding patterns of migrating juvenile salmon in the Bering Sea suggest that flexibility in feeding on a diverse spectrum of prey types alleviates competition for preferred food types among co-occurring species (Benson and Trites 2002). In the current period of climate and cyclic changes (Andrews et al. 2009; Chittenden et al. 2009; Coyle et al. 2011), information from this and other diet studies contributes to a clearer understanding of the trophic patterns important to the early marine survival of juvenile Pacific salmon in the northern Bering Sea.

Acknowledgments—We thank the BASIS Program of the NOAA Ted Stevens Marine Research Institute, the captain and crew of the F/V *Epic Explorer* and F/V *Bristol Explorer*, and colleagues and co-workers who contributed advice and guidance for this project.

REFERENCES

- Andrews, A., E. Farley Jr., J. Moss, J. Murphy, and E. Husoe. 2009. Energy density and length of juvenile salmon *Oncorhynchus gorbuscha* in the eastern Bering Sea from 2004 to 2007: a period of relatively warm and cool sea surface temperatures. N. Pac. Anadr. Fish Comm. Bull. 5: 183-189. (available at www.npafc.org)
- Auel, H., and I. Werner. 2003. Feeding, respiration and life history of the hyperiid amphipod *Themisto libellula* in the arctic marginal ice zone of the Greenland Sea. J. Exp. Mar. Biol. Ecol. 296(2): 183-197.
- Aydin, K., and F. Mueter. 2007. The Bering Sea – A dynamic food web perspective. Deep-Sea Res. II 54: 2501-2525.
- Azuma, T. 1992. Diel feeding habits of sockeye and chum salmon in the Bering Sea during the summer. Salmon Rep. Ser. 58: 2019-2025. (Available from the Hokkaido National Fisheries Research Institute, Fisheries Research Agency, 116 Katsurakoi, Kushiro 085-0802, Japan)
- Bensen, A.J., and A.W. Trites. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific Ocean. Fisheries 3: 95-113.
- Bieber, A.J. 2005. Variability in juvenile Chinook foraging and growth potential in Oregon estuaries: Implications for habitat restoration. Unpub. MS Thesis, Univ. Wash. Seattle. 104 pp.
- Boldt, J., and L. Haldorson. 2003. Seasonal and geographic variation in juvenile pink salmon diets in the northern Gulf of Alaska and Prince William Sound. Trans. Am. Fish. Soc. 132: 1035-1052.
- Bollens, S.M., R. vanden Hooff, M. Butler, J.R. Cordell, and B.W. Frost. 2010. Feeding ecology of juvenile Pacific salmon (*Oncorhynchus* spp.) in a northeast Pacific fjord: diet, availability of zooplankton, selectivity for prey, and potential competition for prey resources. Fish. Bull. 108: 393-407.
- Brodeur, R., E.A. Daly, M.V. Sturdevant, T.W. Miller, J.H. Moss, M.E. Thiess, M. Trudel, L.A. Weitkamp, J. Armstrong, and E.C. Norton. 2007. Regional comparisons of juvenile salmon feeding ecology in coastal marine waters off the west coast of North America. Am. Fish. Soc. Symp. 57: 183-203.
- Chittenden, C.M., R.J. Beamish, and R.S. McKinley. 2009. A critical review of Pacific salmon marine research relating to climate. J. of Mar. Sci. 66: 2195-2204.
- Clarke, K.R., and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretations, 2nd edition. PRIMER-E Ltd., Plymouth, UK.
- Coyle, K.O., L.B. Eisner, F.J. Mueter, A.I. Pinchuk, M.A. Janout, K.D. Cieciel, E.V. Farley, and A.G. Andrews. 2011. Climate change in the southeastern Bering Sea: impacts on pollock stocks and implications for the oscillating control hypothesis. Fish. Oceanogr. 20: 139-156.
- Davis, N.D., M. Fukuwaka, J. Armstrong, and K. Myers. 2005. Salmon food habits studies in the Bering Sea, 1960 to present. N. Pac. Anadr. Fish Comm. Tech. Rep. 6: 24-26. (available at www.npafc.org)
- Davis, N.D., A.V. Volkov, A.Y. Efimkin, N.A. Kuznetsova, J.L. Armstrong, and O. Sakai. 2009. Review of BASIS salmon food habits studies. N. Pac. Anadr. Fish Comm. Bull. 5: 197-208. (available at www.npafc.org)
- Farley, E.V. Jr., J.M. Murphy, B.W. Wing, J.H. Moss, and A. Middleton. 2005. Distribution, migration pathways, and size of western Alaska juvenile salmon along the eastern Bering Sea shelf. Alaska Fish. Res. Bull. 11: 15–26.
- Farley, E.V. Jr., J.M. Murphy, M. Adkison, and L. Eisner. 2007. Juvenile sockeye salmon distribution, size, condition and diet during years with warm and cool spring sea temperatures along the eastern Bering Sea. shelf. J. Fish Biol. 71(4): 1145-1158.

- Funk, F. 2001. Abundance, biology, and historical trends of Pacific herring, *Clupea pallasii*, in Alaskan waters. In PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the 2000 BASS, MODEL, MONITOR and REX Workshops, and the 2001 BASS/MODEL Workshop. PICES Sci. Rep. 17: 86-93.
- Graeb, B.D.S., and J.M. Dettmers. 2004. Fish size and prey availability affect growth, survival, prey selection, and foraging behavior of larval yellow perch. Am. Fish. Soc. 133: 504-514.
- Hurlbert, S.H. 1978. The measurement of niche overlap and some relatives. Ecology 59: 67-77.
- Hyslop, E.J. 1980. Stomach contents analysis—a review of methods and their application. J. Fish Biol. 17: 411-429.
- Irvine, J., and M. Fukuwaka. 2011. Pacific salmon abundance trends and climate change. J. Mar. Sci. 68 (6): 1122-1130.
- Kaga, T., S. Sato, T. Azumaya, N.D. Davis, and M. Fukuwaka. 2013. Lipid content of chum salmon (*Oncorhynchus keta*) affected by pink salmon (*O. gorbuscha*) abundance in the central Bering Sea. Mar. Ecol. Prog. Ser. 478: 211-221.
- Karpenko, V., and M. Koval. 2012. Feeding strategies and trends of pink and chum salmon growth in the marine waters of Kamchatka. N. Pac. Anadr. Fish Comm. Tech. Rep. 8: 82-86. (Available at www.npafc.org)
- Karpenko, V., A. Volkov, and M. Koval. 2007. Diets of Pacific salmon in the Sea of Okhotsk, Bering Sea, and Northwest Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull. 4: 105-116. (available at www.npafc.org)
- Landingham, J.H., M.V. Sturdevant, and R.D. Brodeur. 1998. Feeding habits of juvenile Pacific salmon in marine waters of southeastern Alaska and northern British Columbia. Fish. Bull. 96: 285-302.
- Litzow, M.A., K. Bailey, F. Prah, and R. Heintz. 2006. Climate regime shifts and reorganization of fish communities: the essential fatty acid limitation hypothesis. Mar. Ecol. Prog. Ser. 315: 1-11.
- Miller, J. A., D. Teel, A. Baptista, and C. Morgan. 2013. Disentangling bottom-up and top-down effects on survival during early ocean residence in a population of Chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 70(4): 617-629.
- Moss, J.H., J.M. Murphy, E.V. Farley, Jr., L.B. Eisner, and A.G. Andrews. 2009. Juvenile pink and chum salmon distribution, diet, and growth in the northern Bering and Chukchi seas. N. Pac. Anadr. Fish Comm. Bull. 5: 191-196. (available at www.npafc.org)
- Murphy, J.M., W.D. Templin, E.V. Farley, Jr., and J.E. Seeb. 2009. Stock-structured distribution of western Alaska and Yukon juvenile Chinook salmon (*Oncorhynchus tshawytscha*) from United States BASIS surveys, 2002–2007. N. Pac. Anadr. Fish Comm. Bull. 5: 51-59. (available at www.npafc.org)
- Orlova, E.L., A.V. Dolgov, G.B. Rudneva, and V.N. Nesterova. 2005. The effect of abiotic and biotic factors on the importance of macroplankton in the diet of northeast Arctic cod in recent years. J. Mar. Sci. 62: 1463-1474.
- Orsi, J.A., M.V. Sturdevant, E.A. Fergusson, W.R. Heard, and E.V. Farley, Jr. 2013. Chinook salmon marine migration and production mechanisms in Alaska. N. Pac. Anadr. Fish Comm. Tech. Rep. 9: 240-243. (available at www.npafc.org)
- Overland, J.E. and P.J. Stabeno. 2004. Is the climate of the Bering Sea warming and affecting the ecosystem? Eos Trans. Am. Geophys. Union. 85(33): 309–316.
- Persson, J., and T. Vrede. 2006. Polyunsaturated fatty acids in zooplankton: variation due to taxonomy and trophic position. Freshw. Biol. 51: 887-900.
- Pinchuk, A.I., K.O. Coyle, E.V. Farley, and H.M. Renner. 2013. Emergence of the Arctic *Themisto libellula* (Amphipoda: Hyperiididae) on the southeast Bering Sea shelf as a result of the recent cooling, and its potential impact on the pelagic food web. ICES J. Mar. Sci. First published online May 19, 2013. doi. 10.1093/icesjms/fst031.
- Purcell, J.E., M.V. Sturdevant, and C.P. Galt. 2005. A review of appendicularians as prey of fish and invertebrate predators. In Response of Marine Ecosystems to Global Change: Ecological Impact of Appendicularians. Edited by G. Gorsky, M.J. Youngbluth, and D. Deibel. Contemporary Publishing International, Paris. pp. 359-435.
- Rindorf, A., and R. Lewy. 2004. Bias in estimating food consumption of fish by stomach-content analysis. Can. J. Fish. Aquat. Sci. 61: 2487-2498.
- Schabetsberger, R., C.A. Morgan, R.D. Brodeur, C.L. Potts, W.T. Peterson, and R.L. Emmett. 2003. Prey selectivity and diel feeding chronology of juvenile Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in the Columbia River plume. Fish. Oceanogr. 12:6: 523-540.
- Scott, C., S. Kwasniewski, S. Falk-Petersen, and J. Sargent. 2002. Species differences, origins and functions of fatty alcohols and fatty acids in the wax esters and phospholipids of *Calanus hyperboreus*, *C. glacialis* and *C. finmarchicus* from Arctic waters. Mar. Ecol. Prog. Ser. 235: 127-134.
- Starovoytov, A. 2007a. Trophic linkages of juvenile chum salmon in the Okhotsk and Bering Seas during the last decade. N. Pac. Anadr. Fish Comm. Tech. Rep. 7: 92-94. (available at www.npafc.org)
- Starovoytov, A. 2007b. Trends in abundance and feeding of chum salmon in the western Bering Sea. N. Pac. Anadr. Fish Comm. Bull. 4: 45-51. (available at www.npafc.org)
- Sturdevant, M.V., E.A. Fergusson, J.A. Orsi, and A.C. Wertheimer. 2004. Diel feeding and gastric evacuation of juvenile pink and chum salmon in Icy Strait, southeastern Alaska, May–September 2001. N. Pac. Anadr. Fish Comm. Tech. Rep. 5: 107-109. (available at www.npafc.org)

- Sturdevant, M.V., E.A. Fergusson, N. Hillgruber, C. Reese, J. Orsi, R. Focht, A. Wertheimer, and W. Smoker. 2012. Lack of trophic competition among wild and hatchery juvenile chum salmon during early marine residence in Taku Inlet, Southeast Alaska. *Environ. Biol. Fish.* 94: 101-116.
- Temnykh, O.S., A.V. Zavolokin, and M.V. Koval. 2010. Russian salmon research under the NPAFC Science Plan 2006-2010: A review and future issues. *N. Pac. Anadr. Fish Comm. Doc.* 1238. 23 pp. (Available at www.npafc.org).
- Tojo, N., G. Kruse, and F. Funk. 2007. Migration dynamics of Pacific herring (*Clupea pallasii*) and response to spring environmental variability in the southeastern Bering Sea. *Deep-Sea Res. II* 54: 2832-2848.
- Vilhjálmsón, H., Alf H. Hoel, S. Agnarsson, R. Arnason, J.E. Carscadden, A. Eide, D. Fluharty, G. Hønneland, C. Hvingel, J. Jakobsson, G. Lilly, O. Nakken, V. Radchenko, S. Ramstad, W. Schrank, N. Vestergaard, T. Wilderbuer. 2005. Fisheries and Aquaculture. *In Arctic Climate Impact Assessment. Edited by C. Symon, L. Arris, and B. Heal.* Univ. Cambridge Press, New York. pp. 691-780.
- Weitkamp, L.A., and M.V. Sturdevant. 2008. Food habits and marine survival of juvenile Chinook and coho salmon from marine waters of southeast Alaska. *Fish. Oceanogr.* 17: 380-395.
- Wilson, M.T., C.M. Jump, and J.T. Duffy-Anderson. 2006. Comparative analysis of the feeding ecology of two pelagic forage fishes: capelin *Mallotus villosus* and walleye pollock *Theragra chalcogramma*. *Mar. Ecol. Prog. Ser.* 317: 245-258.