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Winter Food Habits of Chinook Salmon in the Eastern Bering Sea

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Abstract: This is the first study of winter diets of Chinook salmon in the eastern Bering Sea. We analyzed Chinook salmon stomach samples collected by U.S. observers on board commercial groundfish trawlers from January to March and July to August, 2007. The proportion of empty stomachs was higher in winter (45%) than summer (8%), suggesting longer time periods between meals in winter. Diversity of squid species in Chinook salmon diets was higher in winter than summer, when more fish, particularly juvenile walleye pollock, were consumed. All age groups of Chinook salmon collected in winter consumed fish offal, likely generated by fishery catch-processing activities, however, fish offal was not observed in summer samples. In winter, the ratio of euphausiids and fish offal weight to Chinook salmon body weight was significantly higher in samples collected at shallow depths (< 200 m), and the ratio of squid was significantly higher in salmon collected at deeper depths (201–600 m). The ratio of euphausiids to fish body weight was significantly higher in immature than maturing Chinook salmon.

Keywords: Chinook salmon, food habits, eastern Bering Sea, winter

INTRODUCTION

In response to the significant environmental and biotic changes seen in the Bering Sea ecosystem in the late 1990s, the Bering-Aleutian Salmon International Survey (BASIS) was established as an international cooperative program of the North Pacific Anadromous Fish Commission (NPAFC 2001). Monitoring salmon food habits during BASIS cruises was planned in order to model the pelagic food web dynamics of the Bering Sea ecosystem. In 2002–2006 BASIS greatly increased the spatial and seasonal coverage of information on salmon food habits in the Bering Sea, particularly for the late-summer and fall period (Davis et al. 2009).

Since 2000 declining Chinook salmon (*Oncorhynchus tshawytscha*) returns to western Alaska resulted in either a reduced or closed commercial harvest in western Alaska (Bue and Hayes 2006). Because Chinook salmon stocks from this area have not maintained expected yields above escapement levels, which would provide for subsistence and commercial harvests (Hayes et al. 2008), information is needed to understand the effects of fishing and ocean conditions on growth, maturation, and survival of Arctic-Yukon-Kuskokwim (AYK) Chinook salmon.

Chinook salmon food habits studies have been conducted in the western (Karpenko 1979, 1982; Karpenko and Maksimenkov 1988; Shuntov et al. 1993; Volkov et al. 1995; Glebov 1998; Karpenko et al. 1998; Koval and Karpenko 1998; Temnykh et al. 2003; Klovach and Gruzevich 2004; Smorodin et al. 2004; Volkov et al. 2007), eastern (Carlson et al. 1998; Murphy et al. 2003; Davis et al. 2004; Volkov et al. 2007), and central (Ito 1964; Murphy et al. 2003; Davis et al. 2004; Volkov et al. 2007) Bering Sea. Originally, winter surveys were included in the BASIS plan, however, no winter BASIS cruises occurred during 2002–2006.

Unlike sockeye (*O. nerka*), chum (*O. keta*), and pink (*O. gorbuscha*) salmon, Chinook salmon appear to remain in the Bering Sea throughout the winter, as evidenced by catches in winter walleye pollock (*Theragra chalcogramma*) fisheries and the recovery of an archival tag from a Yukon River Chinook salmon at liberty for two years (Radchenko and Glebov 1998a; Myers et al. 2003; Berger 2008; Walker and Myers 2009). The mean estimated bycatch of Chinook salmon in Bering Sea and Aleutian Islands U.S. groundfish fisheries in 2001–2006 was 60,150 fish. This figure dramatically increased in 2007 to an estimated 129,530 fish (Berger 2008). Chinook salmon are caught in both the winter “A” (January 20–June 10) and the summer–fall “B” (June 10–November 1) pollock fishery seasons (NOAA 2008). The months during which these Chinook salmon are caught suggest observers on pollock fishing vessels are well positioned to sample them during time periods not sampled during BASIS cruises. Therefore, Chinook salmon samples collected from the observer program could enhance the seasonal coverage from which food habits data were obtained.

Our goal was to examine winter Chinook salmon food habits samples collected by U.S. groundfish observers sampling in the eastern Bering Sea, and determine the major prey types consumed during this season. We wanted to determine if differences in prey composition occurred with respect to depth of fishing, time period of the day when fishing oc-

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curred, and Chinook salmon ocean age, and maturity stage.

MATERIALS AND METHODS

Frozen Chinook salmon stomach samples, fish scales, and biological data were collected by U.S. groundfish observers aboard commercial catcher-processors in the walleye pollock midwater trawl fishery during winter (January–March) and summer (July–August), 2007. Trawl gear fishing depth (average gear depth measured by various instrumentation), trawl gear deployment and retrieval time (tow time period), and Chinook salmon biological characteristics (fork length, body weight, sex, and maturity) were recorded by observers from bridge data and from Chinook salmon when stomach samples were collected. Trawl fishing depth was grouped into three categories (< 200 m, 201–400 m, 401–600 m) and tow time period was divided into four six-hour periods of the day (0001–0600 hr, 0601–1200 hr, 1201–1800 hr, and 1801–2400 hr). When a tow was not completed within one time period, a stomach sample was attributed to the time period when at least 50% of the tow was conducted. Observers classified Chinook salmon maturity as either immature or maturing based on appearance of the gonads (immature ovaries are approximately uniform in thickness and contain tiny eggs; immature testes are thin pinkish translucent tubes; AFSC 2007). Chinook salmon ocean age (count of annuli in the ocean zone of the scale) was determined from scales (Davis et al. 1990).

Chinook salmon stomach contents were counted, weighed, and identified to the lowest possible taxonomic group. When possible, estimates of prey size were obtained by measuring squid (mantle length), fish (standard length), and pollock otoliths (maximum length). Pollock standard length and age were estimated based on otolith maximum size, and the pollock subopercle size, from information provided by T. Buckley (Troy.Buckley@noaa.gov, pers. comm.). When fish offal was observed in stomach contents, it was identified by the presence of distinct isolated prey fish body parts, such as wads of skin, individual fins, sections of vertebral column, or the head from a large-bodied fish. The presence of individual body parts in the stomach was inconsistent with fish prey consumed whole, which is typical for Chinook salmon. Samples of fish offal were frozen and analyzed using genetic techniques by Buser et al. (2009) to confirm the fish species identification.

The prey composition was summarized in two ways. First, results were summarized at a high level of detail with regard to prey identification. Individual stomach samples were grouped by ocean age and season, and the prey weights in each prey group were summed, then divided by the total prey weight in each stratum. A second approach aggregated data for statistical comparison of winter prey composition of the major prey categories (euphausiids, squid, fish, and fish offal) to fishing depth zones, tow time period, Chinook salmon ocean age, and maturity. For each individual stomach sample containing prey, the weight of each of the four prey categories was divided by the fish's body weight to get a prey index (PI). The PI was arcsine square-root transformed for statistical analysis (Zar 1984). The transformed PI was compared among strata with the Kruskal Wallis or the Wilcoxon rank sum test. Only the winter samples were statistically analyzed because summer samples were too few in number.

RESULTS

A total of 282 Chinook salmon stomach samples was collected in winter (91%) and summer (9%) 2007 (Table 1). Samples were collected along the eastern Bering Sea slope in a northwesterly to southeasterly axis, with summer samples extending further to the northwest than winter samples (Fig. 1). Half the Chinook salmon collected in winter (50%) were ocean age-2 and most of the summer samples (64%) were ocean age-3 fish. Winter samples were collected from significantly (*t*-test, one tail, $P < 0.001$) deeper depths (mean 308 m, range 51–569 m) than summer samples (mean 138 m, range 95–272 m; Table 1; Fig. 2). Among winter samples, the age frequency in samples from each fishing depth and tow time period were not equal (both x^2, df = 2, $P < 0.001$). More young fish were collected from the deepest depth strata and more ocean age-3 fish were collected in afternoon tows than would be expected if the age composition were equal across tow time periods.

Results showed qualitative differences in samples collected during winter and summer. In winter, Chinook salmon had a high percentage of empty stomachs (20–54%; Table 1). The squid species identified from stomach contents included a variety of species including *Berryteuthis magister*, *Gonatopsis (Go.) borealis*, and a mixture of other *Gonatus*

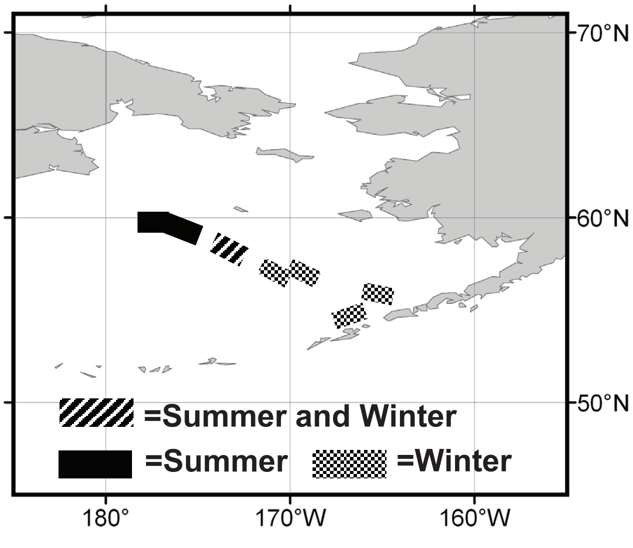

Fig. 1. Areas in the eastern Bering Sea where U.S. ground fish observers collected Chinook salmon stomach samples in winter and summer, 2007.

Table 1. Total number of Chinook salmon stomach samples, percent age composition, and body size at age for samples collected by groundfish observers in 2007. Winter is January–March and summer is June–August. Fishing depth is the depth where the tow was conducted. Fork length, body weight, and salmon maturity from data provided by observers. Tow time period indicates the six-hour time period of the day when at least 50% of the tow duration occurred.

Description	Winter	Summer
Total number of Chinook samples	257	25
mean fishing depth m (sd; min, max)	308 (177; 51, 569)	138 (56; 95, 272)
tow time period		
0001 to 0600 hours (% of seasonal samples)	28	16
0601 to 1200 hours (% of seasonal samples)	19	12
1201 to 1800 hours (% of seasonal samples)	30	52
1801 to 2400 hours (% of seasonal samples)	23	20
Ocean age-1		
number (% of seasonal total)	5 (2)	0
mean fishing depth m (sd)	155 (195)	
number immature (% of age group)	5 (100)	
mean fork length cm (sd)	28 (4.5)	
mean body weight kg (sd)	0.25 (0.11)	
proportion empty stomachs (for age group)	0.20	
Ocean age-2		
number (% of seasonal total)	128 (50)	9 (36)
mean fishing depth m (sd)	382 (144)	136 (60)
number immature (% of age group)	107 (84)	5 (56)
mean fork length cm (sd)	52 (5.0)	64 (6.6)
mean body weight kg (sd)	1.71 (0.61)	3.63 (1.08)
proportion empty stomachs (for age group)	0.52	0.00
Ocean age-3		
number (% of seasonal total)	89 (35)	16 (64)
mean fishing depth m (sd)	258 (176)	139 (56)
number immature (% of age group)	50 (56)	7 (44)
mean fork length cm (sd)	66 (5.1)	73 (5.9)
mean body weight kg (sd)	3.58 (1.14)	5.27 (1.30)
proportion empty stomachs (for age group)	0.54	0.19
Ocean age-4 or more		
number (% of seasonal total)	35 (14)	0
mean fishing depth m (sd)	191 (168)	
number immature (% of age group)	17 (49)	
mean fork length cm (sd)	76 (6.5)	
mean body weight kg (sd)	5.68 (1.90)	
proportion empty stomachs (for age group)	0.40	

species (Table 2). Fish offal was present in the diets of all age groups, ranging from 3.7% in ocean age-3 fish to 22.8% in ocean age-1 fish. By comparison, in summer Chinook salmon had a low percentage of empty stomachs (0–19%; Table 1). Two species of squid were identified from samples collected in summer, including *B. magister* and *Gonatus (G.) kamtschaticus*, the latter identified only in summer samples (Table 2). In the summer stomach samples, whole young pollock were common, but euphausiids, fish offal, and plastic debris were not found in these samples.

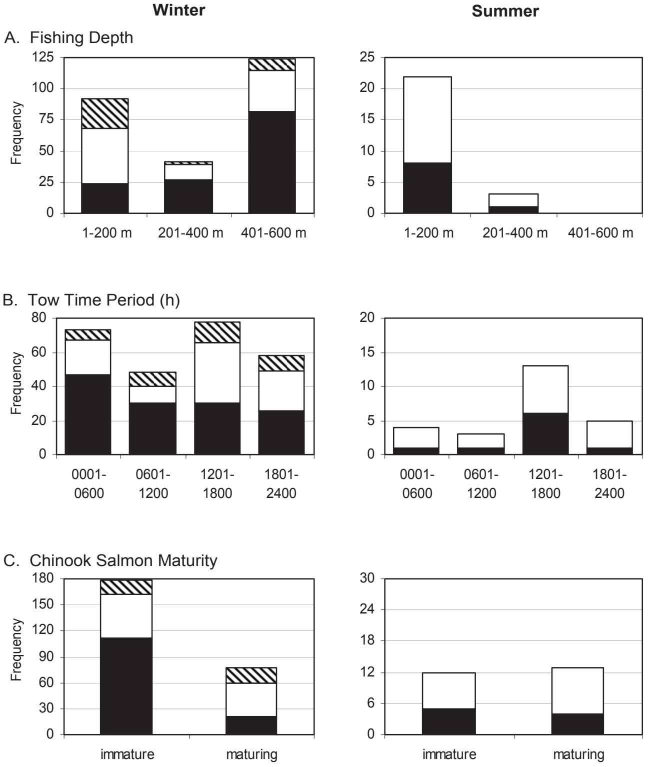

Fig. 2. Comparison of Chinook salmon age composition in samples collected in winter (left panels) and summer (right panels) in the eastern Bering Sea, 2007. Note difference in frequencies (y-axis) between winter and summer samples. Solid fill = Ocean age-1 and -2; open fill = ocean age-3; diagonal fill = ocean age-4 and -5. A. Age composition among fishing depth zones (m). B. Age composition among tow time periods of the day (hr). C. Age composition of immature and maturing fish.

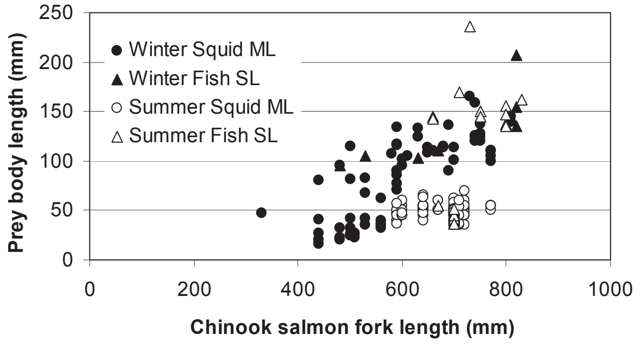

Fig. 3. Comparison of squid and fish prey size with Chinook salmon fork length of fish in which the prey were observed.

Comparison of Chinook salmon fork length to fish and squid prey size in winter showed a positive relation between predator size and maximum size of squid and fish consumed (Fig. 3). In summer, there is no relation between Chinook salmon size and either squid or fish prey size. In summer Chinook salmon might consume fish and squid that are smaller, or younger, than those encountered in winter.

Twenty-one of 23 pairs of walleye pollock otoliths recovered from Chinook salmon stomach contents were collected from summer samples (Table 3). All pollock otoliths were recovered from whole fish consumed naturally by Chinook salmon. One pair of pollock subopercles was recovered from fish offal found in a winter Chinook salmon stomach sample. Most commonly, ocean age-3 Chinook salmon consumed age-1 pollock. The otoliths collected in the winter samples were found in two ocean age-4 Chinook salmon that consumed an age-1, and an age-3 or possibly age-4 pollock. The pollock subopercles were recovered from a Chinook salmon 77 cm long. The subopercle bones were likely from an age-5+ pollock, approximately 50 cm in size, a fish too large for the Chinook salmon to swallow whole.

Among winter samples, results of nonparametric analysis indicated that prey composition was different among fishing depth zones and between maturity groups (Table 4). The PI of euphausiids in stomach contents of fish collected at depths < 200 m was significantly higher than observed in the diet of fish collected at depths from 201–600 m (Kruskal Wallis test, df = 2, $P < 0.001$). The opposite was true for the PI of squid (Table 4; Fig. 4). The PI of squid was significantly greater in Chinook caught at 201–600 m than at depths < 200 m (Kruskal Wallis test, df = 2, $P < 0.001$). The PI of fish offal in the diet was significantly higher in Chinook salmon caught at depths < 200 m than fish caught at 401–600 m (Kruskal Wallis test, df = 2, $P < 0.01$). The value of fish offal PI in stomach contents of fish sampled at 201–400 m was intermediate between shallow and deep samples and was not significantly different from either. Fish PI was not significantly different among depth strata. Euphausiid PI was significantly higher among immature Chinook salmon than maturing fish, but the PI of the other prey types were not different between maturity groups (Wilcoxon rank sum test, df = 1, $P < 0.01$). The PI of euphausiids, squid, fish, or fish offal were not significantly different among tow time periods or Chinook salmon ocean ages.

DISCUSSION

There is a paucity of Bering Sea salmon food habits data available from wintertime surveys, and this study is the first to analyze samples from the eastern Bering Sea in the January–March period. Previous November–December surveys offshore of southeast Kamchatka in the North Pacific (Sobelevskii and Senchenko 1996), Okhotsk Sea (Volkov 1996), and southwestern Bering Sea (Glebov 1998) reported ocean

Table 2. Percent prey composition of Chinook salmon stomach samples collected by groundfish observers in 2007. Percent prey composition calculated by adding prey weights in each category for each ocean age group and season, then dividing by the total prey weight in each stratum. Mean and range of prey weight calculated from among stomach samples that contain prey. Stomach index was the total prey weight (g) divided by fish body weight (g) times 100. Mean stomach index was averaged over the number of stomach samples containing prey. Fish offal and plastic material (n, mean wt) based on the number of stomachs and average weight among stomachs containing those materials.

	Percent prey composition by weight					
	Winter 2007				Summer 2007	
Prey items	Ocean age-1	Ocean age-2	Ocean age-3	Ocean age-4 & -5	Ocean age-2	Ocean age-3
Total Euphausiacea	22.8	4.9	13.2	0.9	0.0	0.0
Total Other/Unid Crustaceans	0.0	0.9	0.0	0.4	0.0	0.0
Total Cephalopods	47.4	73.9	80.7	81.6	45.2	26.7
Berryteuthis magister	47.4	49.8	29.3	38.2	14.0	10.7
Gonatopsis borealis	0.0	12.5	50.1	43.5	0.0	0.0
Gonatus kamtschaticus	0.0	0.0	0.0	0.0	31.2	15.9
Gonatus pyros	0.0	2.1	0.0	0.0	0.0	0.0
Gonatus berryi	0.0	1.2	0.3	0.0	0.0	0.0
Unidentified Cephalopods	0.0	8.2	1.0	0.0	0.0	0.1
Total Pisces	7.0	5.7	2.3	12.1	54.8	73.3
Bathymasteridae	0.0	0.0	0.0	0.0	0.0	0.1
Mallotus villosus	0.0	0.0	1.4	0.0	0.0	0.0
Stenobrachius leucopsarus	0.0	2.6	0.0	0.0	0.0	0.0
Ammodytes hexapterus	0.0	0.5	0.0	0.0	0.0	0.0
Blepsias bilobus	0.0	0.0	0.0	0.0	0.0	16.4
Theragra chalcogramma	0.0	1.3	0.0	1.5	50.3	56.3
Leuroglossus schmidti	0.0	0.0	0.1	0.0	0.0	0.0
Unidentified Pisces	7.0	1.2	0.8	10.6	4.5	0.5
Fish Offal	22.8	15.1	3.7	4.8	0.0	0.0
Plastic Debris	0.0	0.0	0.1	0.2	0.0	0.0
Number of stomachs	5	128	89	35	9	16
% empty stomachs	20	49	54	40	0	19
Mean prey weight (g) (sd)	1.43 (1.18)	16.20 (27.26)	29.42 (37.68)	56.39 (72.20)	28.33 (38.62)	72.24 (39.45)
Range prey weight (g)	0.4-3.1	0.1-155.1	0.1-165.9	0.1-244.0	1.6-127.30	1.1-145.8
Mean stomach index (sd)	0.547 (0.191)	0.781 (1.006)	0.803 (0.999)	1.049 (1.348)	0.721 (0.831)	1.465 (0.779)
Fish offal (n, mean wt)	1, 1.3 g	7, 21.0 g	5, 8.9 g	3, 18.8 g	0	0
Plastic debris (n, mean wt)	0	0	1, 1.1 g	1, 2.0 g	0	0

age-0 and older Chinook salmon consumed primarily nekton. Young Chinook salmon (21–40 cm FL) consumed up to 87% juvenile squids (including *B. magister*) and the remaining component of the diet was euphausiids (Sobelevskii and Senchenko 1996). In the winter, fish species consumed by Chinook salmon included capelin (*Mallotus villosus*), northern lampfish (*Stenobrachius leucopsarus*), Pacific sand lance (*Ammodytes hexapterus*), and walleye pollock. Some of the same species were identified from earlier winter Chinook salmon diet studies, including Myctophidae and capelin (Glebov 1998). Squid identified in winter 2007 diet samples included several species of gonatid squid, including *B. magister*, *Go. borealis*, *G. pyros*, and *G. berryi*. *G. kamtschaticus* has been identified in winter diets of Chinook salmon

Table 3. Estimated body length (SL, mm) and age of walleye pollock (year) based on pollock otoliths and subopercles collected from Chinook salmon stomach contents in the eastern Bering Sea, 2007. Pollock otoliths were recovered from whole fish consumed naturally by Chinook salmon and pollock subopercles were obtained from salmon consumption of pollock offal. Identical lengths listed for Chinook salmon indicate multiple otolith samples obtained from a single salmon stomach. Otolith length is the maximum dimension of the larger otolith of the pair. Conversion of otolith length and subopercle size to estimated pollock length and age from information provided by T. Buckley (Troy.Buckley@noaa.gov, pers. comm.).

Chinook salmon capture month	Chinook salmon fork length (cm)	Chinook salmon ocean age	Pollock otolith maximum length (mm)	Other pollock bone	Estimated pollock SL (mm)	Estimated pollock age (years)
Jan	82	4	7.12		143	1
Mar	79	4	14.90		348	3 or 4
Mar	77	4	n/a	subopercle	~500	5+
Aug	80	3	7.34		147	1
Aug	80	3	6.68		135	1
Aug	80	3	7.94		161	1
Aug	80	3	7.87		160	1
Aug	80	3	7.78		157	1
Aug	74	3	6.49		130	1
Aug	74	3	6.96		140	1
Aug	74	3	6.28		126	1
Aug	74	3	7.62		153	1
Aug	71	3	8.29		168	1
Aug	72	3	8.12		164	1
Aug	73	2	7.52		151	1
Aug	73	2	10.94		231	2
Aug	75	3	8.19		166	1
Aug	75	3	6.84		138	1
Aug	75	3	7.50		151	1
Aug	83	3	8.75		177	1
Aug	83	3	6.98		141	1
Aug	83	3	7.78		157	1
Aug	66	3	7.70		155	1
Aug	66	3	7.56		152	1

(Glebov 1998), however, we observed this species only as juveniles in samples collected during the summer.

While Chinook salmon routinely inhabit waters considerably deeper than 50 m, this is the first study to examine the stomach contents of Chinook salmon caught at considerably greater depths (51–569 m). Salmon trawl surveys that include analysis of salmon food habits generally operate in the upper 50 m of the water column (NPAFC 2001; Volkov et al. 2007; Efimkin et al. 2008; Fukuwaka et al. 2008). Chinook abundance estimates have been obtained to depths of 120 m (Walker et al. 2007) and Chinook salmon bycatch in commercial trawling operations has been reported to 360 m in the northeastern Bering Sea, 300 m in the eastern Bering Sea, and 482 m in U.S. west coast trawl fisheries (Erickson and Pikitch 1994; Radchenko and Glebov 1998a,b; Walker et al. 2007). While some Chinook salmon might have entered the trawl at shallower depths during descent or ascent of the fishing gear, depth-recording data storage tags placed on Chinook salmon show these fish routinely dive to 250 m in spring in southeast Alaska (Murphy and Heard 2001) and inhabit depths to at least 350 m during winter and early spring in the Bering Sea (Walker and Myers 2009). If Chinook salmon generally remain for several hours to feed within the broad 200-m depth intervals where they are caught, then we can assume the difference in the prey composition among the depth categories likely reflects true differences in the diet of fish caught in different depth habitats.

We observed that Chinook salmon stomach contents varied with fishing depth, with more euphausiids and fish offal in the stomach contents of Chinook salmon caught at < 200 m and more squid in the stomach contents of Chinook salmon caught at > 200 m. The preponderance of euphausiids in the stomach contents of Chinook salmon captured at < 200 m might result from higher abundance of these organisms at shallow depths. Preference for a particular depth range is characteristic of euphausiid species, and most of the species

Table 4. Results of nonparametric analysis for differences between prey category and fishing depth zones (1-200, 201-400, 401-600 m), tow time period of the day (0001–0600, 0601–1200, 1201–1800, 1801–2400 hr), maturity (immature, maturing), and Chinook salmon ocean age (age-1 and -2, age-3, and age-4 and -5) for the winter samples. Kruskal Wallis nonparametric chi-square test used to compare prey components with fishing depth zone, tow time period, and Chinook salmon ocean age. Wilcoxon rank sum test used to compare prey composition and maturity. Prey index (PI) = weight of prey component divided by fish body weight. The PI was arcsine square root transformed before statistical analysis. Critical value of P = 0.05, ns = not significant.

Analysis	Prey components	Test statistic	df	*P*-value	Comparison of factors with significant *P*-values
Prey components and fishing depth zone		chi-square			
	Euphausiid PI	60.7602	2	< 0.001	1-200 > 201-400 and 401-600
	Squid PI	68.2755	2	< 0.001	1-200 < 201-400 and 401-600
	Fish PI	3.4103	2	ns	
	Fish offal PI	11.8835	2	< 0.01	1-200 > 401-600*
Prey components and tow time period		chi-square			
	Euphausiid PI	7.1513	3	ns	
	Squid PI	3.3642	3	ns	
	Fish PI	0.5559	3	ns	
	Fish offal PI	2.9347	3	ns	
Prey components by maturity		corrected-z			
	Euphausiid PI	2.5786	1	< 0.01	immature > maturing
	Squid PI	-1.9158	1	ns	
	Fish PI	0.9561	1	ns	
	Fish offal PI	-0.0045	1	ns	
Prey components and ocean age		chi-square			
	Euphausiid PI	2.217	2	ns	
	Squid PI	1.277	2	ns	
	Fish PI	0.6382	2	ns	
	Fish offal PI	0.0797	2	ns	

*Fish offal PI for the middle fishing depth range, 201–400 m, was not significantly different from fish offal PI in the shallow (1–200 m) or deep (401–600 m) depth range.

distributed in this area of the eastern Bering Sea generally have a maximum vertical range of 0 to 400 m (Mauchline 1980).

The preponderance of fish offal in the stomach contents of Chinook salmon captured at < 200 m might reflect the greater abundance of this material at shallower depths. Several other authors have described an inverse relationship between the amount of fish offal in stomach contents and water column depth (Hovde et al. 2002; Orlov and Moukhametov 2007). Perhaps the horizontal spread of fish offal away from the surface increases with depth, thus increasing the number of potential scavengers consuming it.

Piscine scavenging on offal generated from fish processing has been reported primarily from the diets of demersal fish, including Greenland halibut (*Reinhardtius hippoglossoides*; Hovde et al. 2002; Roman et al. 2007), Pacific halibut (*Hippoglossus stenolepis*; Orlov and Moukhametov 2007), Pacific black halibut (*R. hippoglossoides matsuurae*) and Kamchatka flounder (*Atheresthes evermanni*; Orlov and Moukhametov 2004), yellowfin sole (*Limanda aspera*; Brown et al. 2005), belligerent sculpin (*Megalocottus platycephalus*) and starry flounder (*Platichthys stellatus*; Tokranov and Maksimenkov 1995), great sculpin (*Myoxocephalus polyacanthocephalus*; Glubokov and Orlov 2005), southern cod (*Patagonotothen ramsayi*) and channel bull blenny (*Cottoperca gobio*; Laptikhovsky and Arkhipkin 2003), Argentine hake (*Merluccius hubbsi*) and bigeye grenadier (*Macrourus holotrachys*; Laptikhovsky and Fetisov 1999), and black dogfish (*Centroscyllium fabricii*; Punzon and Herrara 2000). However, consumption of fish offal has not been previously reported for any salmon species, including Chinook salmon. In winter, we found Chinook salmon feeding on fish offal identified as originating from walleye pollock (Buser et al. 2009). Food resources might be scarce in winter causing some Chinook salmon having a demersal distribution to scavenge offal discarded by the pollock fish-

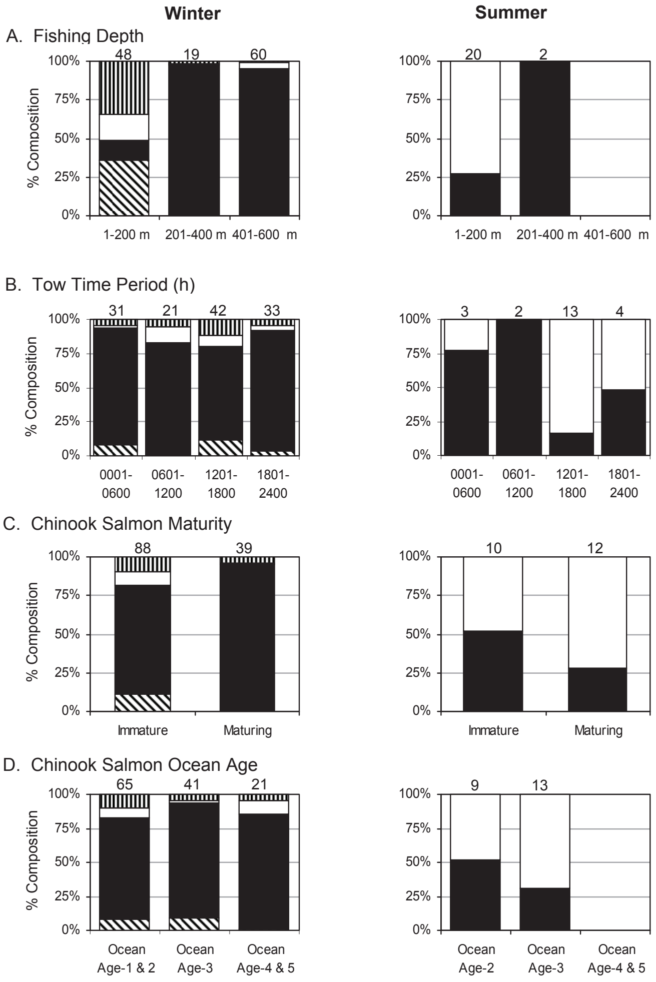

Fig. 4. Comparison of Chinook salmon diets for fish collected in winter (left panels) and summer (right panels) in the eastern Bering Sea, 2007. The percent composition is the mean prey index (PI = weight of prey category/fish body weight) among fish that contain prey. Sample size of fish that contain prey in each category is shown above each histogram. Histogram patterns include the major prey categories: Diagonal fill = euphausiids; solid fill = cephalopods; open fill = pisces; vertical fill = fish offal. A. Chinook salmon diet comparison among fishing depth zones (m). B. Chinook salmon diet comparison among tow time periods of the day (hr). C. Chinook salmon diet comparison between immature and maturing fish. D. Chinook salmon diet comparison among ocean age groups.

ery, thus supplementing their natural diet. Proximity and attraction to fish offal could affect distribution of Chinook salmon by motivating them to move to areas where fish are processed and chunks of fish are discarded.

Our study found immature Chinook salmon contained more euphausiids in their stomach contents than maturing fish (Table 4; Fig. 4). Analyses of Chinook salmon food habits by other investigators working in the Bering Sea have observed that small Chinook (< 40 cm) salmon consume more zooplankton, such as euphausiids, decapods, large crustaceans, and pteropods. Larger (> 40 cm) Chinook salmon consume more nekton, such as squid and fish (Glebov 1998; Farley et al. 2006; Volkov et al. 2007).

We did not observe a statistical difference in the proportion of various prey types in Chinook salmon of different ages. Because of the small number of stomach samples obtained from the youngest (ocean age-1) fish (n = 5; Table 1), data for ocean age-1 and -2 fish were combined. Combining the data from these age groups likely obscured potential differences in diet between small (young) and larger (older) fish. If the number of ocean age-1 fish collected in winter could be increased in future studies, we suspect that significant differences in diet between young and older Chinook salmon will be found.

Consumption of age-0 walleye pollock by Chinook, sockeye, and chum salmon was reported in earlier studies of food habits in the Bering Sea (Davis et al. 2004; Farley et al. 2007; Volkov et al. 2007). Our study showed the age of pollock consumed by Chinook salmon extends beyond consumption of juvenile (age-0) pollock to older age groups such as age-3 and possibly age-4 pollock (Table 3). This suggests pollock of the same age-class are susceptible to predation by Chinook salmon for several years, rather than escaping from salmon predation after the first year of life. Pollock might be vulnerable to predation by Chinook salmon until age-4, when pollock fully recruit into the eastern Bering Sea pollock fishery (Wespestad 1993). The impact of salmon predation on pollock abundance has not been estimated, but future estimates will need to account for the successive years that a single cohort of pollock is vulnerable to salmon predation.

Future research will include analysis of samples collected by observers in 2008, which we anticipate will improve information on interannual and seasonal changes, and effects of Chinook body size on Chinook salmon diets in the eastern Bering Sea.

CONCLUSIONS

This was the first study of winter diets of Chinook salmon in the eastern Bering Sea, and we found their diets varied by fishing depth and maturity group. The ratio of euphausiids and fish offal in the diet was significantly higher in Chinook salmon collected at shallower depths (< 200 m), and the ratio of squid was significantly higher in Chinook salmon collected at deeper depths (201–600 m). Euphausiids were more common in the diet of immature Chinook salmon than maturing fish. The percentage of empty stomachs was higher in winter than summer, suggesting wintertime feeding might occur after longer time periods between meals than in summer. In winter, Chinook salmon of all age groups consumed fish offal, which was likely generated by human fishing activities. Consumption of fish offal could also have deleterious effects, therefore the implications of scavenging by Chinook salmon needs to be further explored. Future studies examining the winter and summer samples collected by groundfish observers will allow for a more detailed examination of Chinook salmon food habits with respect to inter-annual and seasonal variability.

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