North Pacific Anadromous Fish Commission
Bulletin No. 4: 127–131, 2007

Food Supply and Trophic Relationships of Pacific Salmon (*Oncorhynchus* spp.) and Atka Mackerel (*Pleurogrammus monopterygius*) in the Western Bering Sea in Fall 2002–2004

Alexander V. Zavolokin, Alexander Ya. Efimkin, Alexander M. Slabinskiy, and **Natalya S. Kosenok**

Pacific Research Fisheries Center (TINRO-Centre),
4 Shevchenko Alley, Vladivostok 690950, Russia

Zavolokin, A.V., A. Ya. Efimkin, A.M. Slabinskiy and N.S. Kosenok. 2007. Food supply and trophic relationships of Pacific salmon (*Oncorhynchus* spp.) and Atka mackerel (*Pleurogrammus monopterygius*) in the western Bering Sea in fall 2002–2004. N. Pac. Anadr. Fish Comm. Bull. 4: 127–131.

Abstract: We examined the food supply and trophic relationships of pink (*Oncorhynchus gorbuscha*), chum (*O. keta*) and sockeye (*O. nerka*) salmon and juvenile Atka mackerel (*Pleurogrammus monopterygius*). We studied interannual variability in feeding habits, zooplankton prey fields, diel feeding chronology and diet overlap in the deepwater regions of the western Bering Sea in September–October, 2002–2004. Pacific salmon and Atka mackerel fed primarily on zooplankton. Most of their diets consisted of few food items. All fish showed similar diel feeding rhythms and consumed food mostly during the day. Diet overlaps were high for small- and medium-size salmon and moderate for large salmon. We conclude there was a low potential for feeding competition among major salmon species and juvenile Atka mackerel in the western Bering Sea in fall 2002–2004.

Keywords: pink salmon, chum salmon, sockeye salmon, Atka mackerel, salmon diet, diet overlap, western Bering Sea

INTRODUCTION

In the last decade the abundance and percentage in nekton of the some Asian Pacific salmon stocks have increased (Temnykh et al. 2004). These fish are one of the dominant species in the upper epipelagic zone (0–50 m) of the western Bering Sea. Juvenile Atka mackerel (*Pleurogrammus monopterygius*) also forage at these depths in the water column. In fact, the biomass of Atka mackerel in some years is comparable with the biomass of abundant salmon species.

Increased salmon abundance may be related to their food supply. Some recent studies have suggested the possibility that a limitation of food resources and/or the carrying capacity of the epipelagic zone can affect Pacific salmon (Azumaya and Ishida 2000; Klovatch 2000; Kaeriyama 2003). Alternatively, other studies have concluded that salmon do not exhaust the carrying capacity of epipelagic ecosystems (Shuntov and Temnykh 2004; Dulepova et al. 2005).

In this work we describe feeding habits of all size-classes of chum (*Oncorhynchus keta*) and sockeye (*O. nerka*) salmon as well as juvenile pink salmon (*O. gorbuscha*) and juvenile Atka mackerel. We compare zooplankton prey fields, diel feeding chronology and diet overlap of these fish in order to determine their food supply and the potential for feeding competition among them.

MATERIALS AND METHODS

The study was based on data collected as part of epipelagic surveys by TINRO-Centre in deepwater regions (Komandor Basin and western Aleutian Basin) of the western Bering Sea in September–October, 2002–2004 (Fig. 1). All surveys were conducted by the R/V *TINRO*. During the surveys trawl tows in the surface layer were conducted over 24-h periods. The vertical spread of the trawl was 31–41 m, depending on the towing speed. The trawl was usually towed for one hour at about 4.6 kts.

Stomach contents were analyzed aboard the vessel using the method described by Chuchukalo and Volkov (1986). Stomachs were removed from up to 25 fish of each size-class (10–30, 31–40, 41–50, 51–60 cm) at each station. Stomach contents of each size-class of fish were mixed and weighed. Prey composition was determined to the lowest possible taxonomic category and the percentage of each prey item was estimated visually. The total number of stations and stomachs analyzed were: pink salmon – 100/1255, chum salmon – 297/2469, sockeye salmon – 292/1836, Atka mackerel – 41/671.

Stomach content indices (SCI) were determined to standardize for differences in body size. SCI is the prey weight•10,000/body weight (‱) (we multiply the index by 10,000 for easy reading). The relationship between time of day and SCI of fish was approximated by a fourth-order

All correspondence should be addressed to A. Zavolokin.
e-mail: zavolokin@tinro.ru

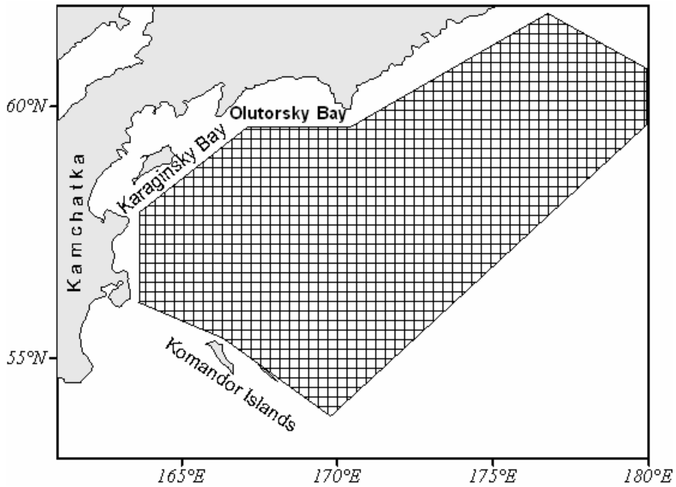

Fig. 1. Regions and stations for collecting pink, chum and sockeye salmon and Atka mackerel in the western Bering Sea in fall 2002–2004.

polynomial. Daily rations were estimated using the method of Kogan (1963) and Novikova (1949). Daily ration was equal to the sum of food consumed food at each time period (% body weight). Diet overlap was evaluated only for co-occurring fish. Two fish were considered to be co-occurring if they were caught together. This approach allows us to exclude the influence of spatial segregation on our conclusions on the potential for feeding competition between fish.

Feeding similarity indices were calculated using the formula of Schoener (1970):

$$C_{xy} = 1 - 0.5 \sum (| p_x - p_y |)$$

where C_{xy} is the feeding similarity index of species *x* and *y*, and p is the fraction of each prey item in the diet of species *x* and *y*.

Zooplankton samples were collected in a Jedy net with a 0.1 m^2 mouth opening and a 0.168-mm mesh net. Tows were conducted from 50 m depth to the surface. Plankton samples were sorted and counted aboard the vessel using the method of Volkov et al. (2004). Because salmon and Atka mackerel ingested primarily large zooplankton (> 3 mm), zooplankton biomass was evaluated for items > 3 mm. To estimate zooplankton biomass we used corrective catchability coefficients: for euphausiids, mysids and chaetognaths < 10 mm = 2, 10–20 mm = 5, > 20 mm = 10; for hyperiid amphipods < 5 mm = 1.5, 5–10 mm = 3, > 10 mm = 5; for copepods < 5 mm = 2, > 5 mm = 3; for polychaetes, small jellyfish and other slow-moving animals = 1.

RESULTS AND DISCUSSION

Copepods and chaetognaths dominated the zooplankton in fall 2002–2004 (Table 1). These taxa comprised 75–90% of the overall zooplankton biomass. The total proportion of euphausiids, hyperiid amphipods and pteropods was rela-

Table 1. Average densities (mg/m^3) of the dominant zooplankton categories in the upper epipelagic zone of the western Bering Sea in fall 2002–2004.

	2002		2003		2004	
	mg/m^3	%	mg/m^3	%	mg/m^3	%
Copepoda						
Neocalanus plumchrus	702.1	55.3	207.0	26.6	23.7	4.9
Eucalanus bungii	36.2	2.8	42.3	5.4	14.3	3.0
Other Copepoda	20.7	1.6	38.0	4.9	35.2	7.3
Euphausiacea						
Thysanoessa longipes	30.1	2.4	49.1	6.3	54.5	11.3
T. inermis	12.5	1.0	2.5	0.3	10.7	2.2
Other Euphausiacea	10.3	0.8	3.5	0.5	14.7	3.0
Amphipoda						
Themisto pacifica	16.9	1.3	24.2	3.1	18.8	3.9
Other Amphipoda	0.2	< 0.1	0.1	< 0.1	0.6	0.1
Pteropoda						
Clione limacina	0.2	< 0.1	9.3	1.2	< 0.1	< 0.1
Limacina helicina	0.4	< 0.1	11.7	1.5	2.0	0.4
Chaetognatha	388.7	30.6	350.2	45.0	287.5	59.6
Decapoda	2.0	0.2	1.4	0.2	2.6	0.5
Cnidaria						
Aglantha digitale	49.3	3.9	31.7	4.1	14.7	3.0
Other Cnidaria	0.3	< 0.1	1.6	0.2	-	-
Other	0.5	< 0.1	6.1	0.8	3.3	0.7
Total	1270.5	100	778.7	100	482.4	100
Sample Size	48	-	42	-	39	-

tively low: 6% in 2002, 13% in 2003 and 21% in 2004. The density of the predominant copepod *Neocalanus plumchrus* decreased sharply from 2002 to 2004, resulting in a decrease in total zooplankton biomass. In contrast, the euphausiid density (mainly *Thysanoessa longipes*) increased from 2002 to 2004. Nevertheless, the proportion of *T. longipes* was consistently low, never exceeding 12%. In 2003, the pteropod biomass was much higher than in 2002 and 2004.

In fall 2002–2004, most of the diets of juvenile pink, chum and sockeye salmon consisted of two prey items – the hyperiid amphipod *Themisto pacifica* and the euphausiid *Thysanoessa longipes*, except in 2003, when *T. longipes* was replaced by the pteropod *Limacina helicina* (Fig. 2). Prey composition for juvenile Atka mackerel was similar to that for juvenile salmon, but the fraction contributed by the copepod *Neocalanus plumchrus* was higher.

Diets of adult chum and sockeye salmon also consisted of few prey items. The three prevalent food items of chum and sockeye salmon constituted 56–77% and 65–92% of the diet, respectively. In 2002 and 2004, the hyperiid amphipod *Themisto pacifica*, the euphausiid *Thysanoessa longipes* and fish (juvenile Atka mackerel, walleye pollock *Theragra chalcogramma*, and myctophids *Stenobrachius leucopsarus* and *S. nannochir*) were the dominant prey (Fig. 3). Small nektonic organisms became more important in the diet of larger fish. In fall 2003, the adult salmon stomachs contained mostly pteropods and small squids. Chum salmon fed almost exclusively on the pteropod *Clione limacina*, and sockeye salmon fed mainly on small squids, the pteropod *L. helicina* and the amphipod *Themisto pacifica*. Probably, the high proportion of pteropods in the salmon diet is related to the increasing biomass of *C. limacina* and *L. helicina* (Table 1). It is important to note that the above-mentioned plankton species are much less abundant in the upper epipelagic zone than are copepods and chaetognaths (Table 1).

All fish showed similar diel feeding rhythms, especially juveniles (Fig. 4). Maximum stomach fullness occurred from the afternoon to midnight and decreased from night to morning (see Efimkin et al. 2004; Volkov and Kosenok this volume).

Co-occurring juvenile salmon diets were similar. Schoener's diet similarity indices varied from 0.58 to 0.95 (Table 2). Similarity of diets of Atka mackerel and juvenile salmon was lower (0.27–0.59), mainly because copepods were a

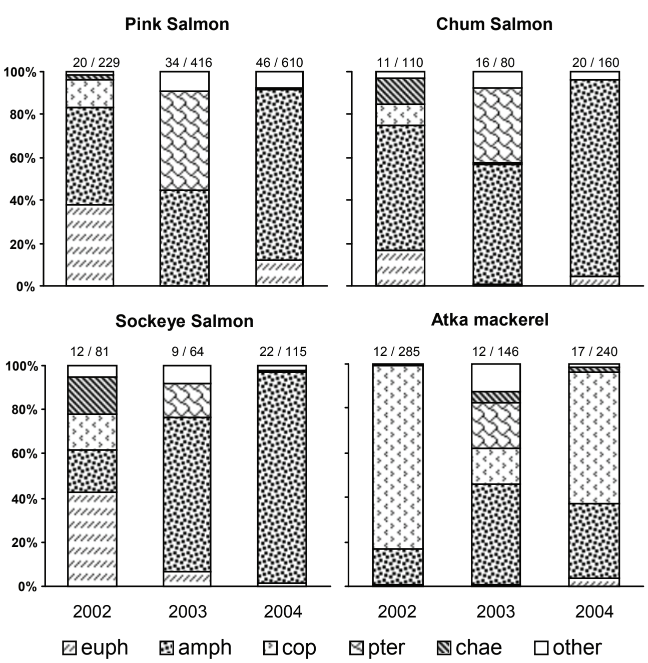

Fig. 2. Percent composition of major prey collected from juvenile pink, chum and sockeye salmon and Atka mackerel stomachs in the western Bering Sea in fall 2002–2004. Number of stations and stomachs analysed are shown above each column. euph = euphausiids, amph = amphipods, cop = copepods, pter = pteropods, chae = chaetognaths.

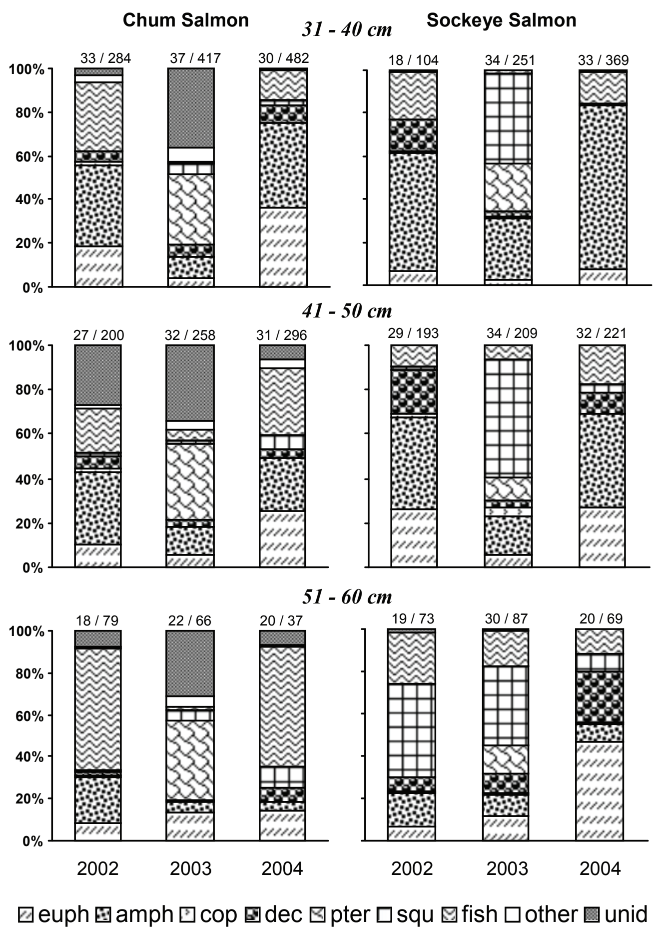

Fig. 3. Percent composition of major prey collected from adult chum and sockeye salmon stomachs by fish size group in the western Bering Sea in fall 2002–2004. Number of stations and stomachs analysed are shown above each column. euph = euphausiids, amph = amphipods, cop = copepods, dec = decapods, pter = pteropods, squ = squid, unid = unidentified.

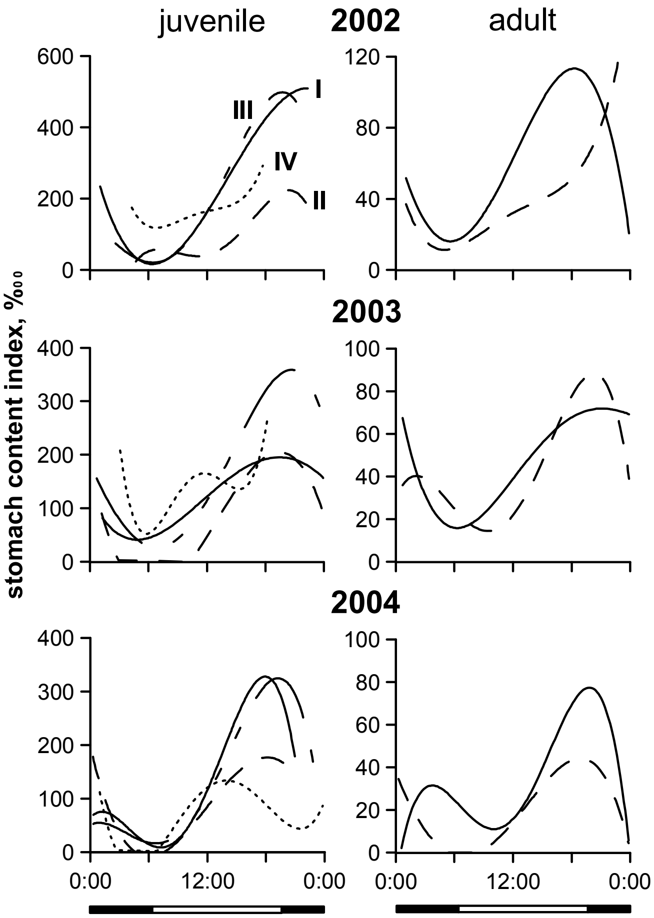

Fig. 4. The relationship between time of day and stomach content index (polynomial trends) of chum (I), sockeye (II) and pink (III) salmon and Atka mackerel (IV). Black bars at bottom of graphs indicate darkness.

more important prey item for Atka mackerel.

Diet similarity of co-occurring adult chum and sockeye salmon was the highest for fish 31–40 cm body length, decreasing for larger fish (Table 3). Similarity of diets was lower (0.21–0.26) only in 2003 as a result of chum feeding on pteropods and of sockeye feeding on squids. In 2003, Pacific salmon were very abundant in the western Bering Sea (Shuntov and Temnykh 2004). Despite this high abundance, daily rations of chum and sockeye salmon in 2002, 2003 and 2004 were similar (Table 4). This may be explained by plasticity in salmon feeding and/or the presence of sufficient food resources in the upper epipelagic zone of the western Bering Sea.

In summary, we report that chum, pink and sockeye salmon and Atka mackerel feed on few food items (mainly two or three species). The fractions of plankton in these diets were low. There were either no or very few chaetognaths in any diet. There was only weak feeding specialization. Feeding rhythms of fish were stable and similar but feeding similarity indices were high. Our results suggest that there was a low potential for feeding competition among major salmon species and juvenile Atka mackerel in the western Bering Sea in fall 2002–2004.

REFERENCES

Azumaya, T., and Y. Ishida. 2000. Density interactions between pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) and their possible effects on distribution and growth in the north Pacific Ocean and Bering Sea. N. Pac. Anadr. Fish Comm. Bull. 2: 165–174. (Available at http://www.npafc.org).

Chuchukalo, V.I., and A.F. Volkov. 1986. Guide book of fish

Table 2. Diet similarity of co-occurring juvenile pink, chum and sockeye salmon and Atka mackerel in the western Bering Sea in fall 2002–2004. Subscripts are station numbers.

	2002			2003			2004		
Species	Pink	Chum	Sockeye	Pink	Chum	Sockeye	Pink	Chum	Sockeye
Pink	1			1			1		
Chum	0.87_{8}	1		0.88_{11}	1		0.75_{16}	1	
Sockeye	0.69_{10}	0.58_{9}	1	0.70_{8}	0.72_{7}	1	0.88_{19}	0.95_{12}	1
Atka mack.	-	-	-	0.52_{8}	0.27_{2}	-	0.43_{14}	0.53_{7}	0.59_{5}

Table 3. Diet similarity of co-occurring adult chum and sockeye salmon in the western Bering Sea in fall 2002–2004. Subscripts are station numbers.

	Sockeye								
	31–40 cm			41–50 cm			51–60 cm		
	2002	2003	2004	2002	2003	2004	2002	2003	2004
Chum	0.81_{13}	0.21_{28}	0.53_{24}	0.54_{24}	0.26_{26}	0.78_{26}	0.42_{14}	0.21_{17}	0.39_{8}

Table 4. Daily rations of chum and sockeye salmon in the western Bering Sea in fall 2002–2004.

Size group (cm)	2002	2003	2004
Chum Salmon			
10–20	7.5	7.0	7.9
30–40	4.6	3.9	2.1
40–50	3.8	3.9	2.4
50–60	4.5	3.8	3.2
Sockeye Salmon			
20–30	4.7	6.0	6.0
30–40	2.8	4.8	3.2
40–50	1.8	3.6	2.8
50–60	1.8	3.8	1.0

feeding study. TINRO, Vladivostok. 32 pp. (In Russian).

Dulepova, E.P., V.I. Dulepov, and A.Ya. Efimkin. 2005. Comparative analysis of feeding of the chum *Oncorhynchus keta* (Walbaum) and pink *Oncorhynchus gorbuscha* (Walbaum) salmon in the Bering Sea in summer. Izv. TINRO 140: 118–129. (In Russian with English abstract).

Efimkin, A.Ya., A.F. Volkov, and N.A. Kuznetsova. 2004. Pacific salmon feeding in the Bering Sea in autumn 2003 and summer 2004. Izv. TINRO 139: 370–387. (In Russian with English abstract).

Kaeriyama, M. 2003. Evaluation of carrying capacity of Pacific salmon in the north Pacific Ocean for ecosystem–based sustainable conservation management. N. Pac. Anadr. Fish Comm. Tech. Rep. 5: 1–4. (Available at http://www.npafc.org).

Klovatch, N. 2000. Tissue degeneration in chum salmon and carrying capacity of the North Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull. 2: 83–88. (Available at http://www.npafc.org).

Kogan, A.V. 1963. About daily ration and feeding rhythm of ziege of Tsimlyanskiy reservoir. J. Zool. 42: 596–601. (In Russian).

Novikova, N.S. 1949. About possibility of daily ration estimate at nature conditions. Vestnik MGU. 9: 107–111. (In Russian).

Schoener, T.W. 1970. Nonsynchronous spatial overlap of lizards in patchy habitats. Ecology 51(3): 408–418.

Shuntov, V.P., and O.S. Temnykh. 2004. The north Pacific Ocean carrying capacity – Is it really too low for highly abundant salmon stories? Myths and reality. N. Pac. Anadr. Fish Comm. Tech. Rep. 6: 3–7. (Available at http://www.npafc.org).

Temnykh, O.S., I.I. Glebov, S.V. Naydenko, A.N. Starovoitov, and A.Ya. Efimkin. 2004. Contemporary status of Pacific salmon in the pelagic communities of the Far Eastern Seas. Izv. TINRO 137: 28–44. (In Russian with English abstract).

Volkov, A.F., A.Ya. Efimkin, N.A. Kuznetsova, and A.M. Slabinsky. 2004. Description of the Bering Sea plankton population in the autumn of 2003 (the results of the BASIS joint Russian-Japanese-U.S. expedition). Izv. TINRO 139: 282–307. (In Russian with English abstract).

Volkov, A.F., and N.S. Kosenok. 2007. Similarity of diurnal rhythms of Pacific salmon feeding in the western Bering Sea. N. Pac. Anadr. Fish Comm. Bull. 4: 327–333. (Available at http://www.npafc.org).