Oceanic feeding habits of chinook salmon, *Oncorhynchus tshawytscha*, off northern California

Sharon L. Hunt

Timothy J. Mulligan

Department of Fisheries
Humboldt State University, Arcata, California 95521
E-mail address (for T. J. Mulligan, contact author): tjm2@axe.humboldt.edu

Kenichiro Komori

School of Biological Sciences
Macquarie University, New South Wales 2109, Australia

The chinook salmon, *Oncorhynchus tshawytscha*, is an important commercial and recreational species inhabiting rivers and nearshore coastal waters from San Diego, California, to the Bering Sea and Japan (Miller and Lea, 1972). Many West Coast populations are in a serious decline (Pearcy, 1992). Nehlsen et al. (1991) reported an overall decrease in salmonid numbers in the coastal waters of the Pacific Northwest and suggested that northern California chinook salmon runs may be at high risk of extinction owing to 1) habitat damage and mainstream passage problems; 2) overharvesting; and 3) hybridization, predation, competition, disease, and poor ocean survival conditions. Surprisingly, little research has been done off the northern California coast regarding the diet of salmonids during oceanic migrations.

Studies on the feeding habits of adult chinook salmon have been conducted from San Francisco, California, to southeastern Alaska. Northern anchovy (*Engraulis mordax*), juvenile rockfishes (*Sebastes* spp.), euphausiids, Pacific herring (*Clupea pallasii*), osmerids, and crab megalopae (*Cancer magister)* have been reported as main prey items of chinook salmon ranging from San Francisco to the Washington coast (Heg and Van Hyning, 1951; Merkel, 1957; Petrovich, 1970; Brodeur et al., 1987). Various studies conducted in more northern regions of the Eastern Pacific Ocean have shown Pacific herring and Pacific sandlance (*Ammodytes hexapterus*) as dominant food items (Pritchard and Tester, 1944; Reid, 1961; Prakash, 1962). All of the above studies noted seasonal and or annual differences in the dominant prey items. Overall, it appears that northern anchovy and rockfishes are the most important prey items for chinook salmon in southern coastal regions (i.e. San Francisco Bay area) whereas the importance of Pacific herring and Pacific sandlance increases in more northern regions (Healey, 1991). To adequately describe the trophic resources utilized by a fish population, it is necessary to sample at consistent times throughout the year (Bowen, 1996). Furthermore, in an upwelling zone, such as northern California, the food habits of many fish species may fluctuate considerably between years owing to environmental variability (Brodeur and Pearcy, 1992). For example, diets of pelagic nekton may vary owing to changes in oceanographic conditions, such as onshore and alongshore transport, primary productivity, and prey abundances (Brodeur et al., 1987). In our study, we examined the diet of chinook salmon off northern California. The main objectives were 1) to compare the diet between two consecutive years and 2) to examine seasonal variation in the prey items consumed.

Materials and methods

Stomach samples were collected from fish caught in coastal waters off Humboldt Bay (40°46'N, 124° 14'W), Trinidad Bay (41°03'N, 124°09'W), and Crescent City (41°46'N, 124°13'W), California (Fig. 1). From May through September 1994, 196 stomachs were collected from Chinook salmon from the three areas. During 1995, 112 stomachs were collected from the same ports but only in June and September. Approximately 60%, 10%, and 30% of the total stomachs collected were taken from Humboldt Bay, Trinidad Bay, and Crescent City, California, respectively, in both years. Stomach collections were obtained from California Department of Fish and Game (CDF &G) port samplers and directly from sportfishermen. Owing to changing and sporadic season opening dates, as well as to varied placement of port samplers and weather conditions, an unbiased random sampling scheme was not possible. All fish were obtained from the recreational fishery and were greater than or equal to 22 inches (≥56 cm), the CDF&G minimum size limit. Total length measurements were obtained for 54 fish in 1994 and ranged from 59 to 96 cm ($\bar{x}$=74 cm). Although no fish were measured in 1995, they were similar in size to those collected in 1994. This finding suggests that all fish sampled were three to five years of age (Healey, 1991).

Manuscript accepted 23 October 1998.
Fish. Bull. 97:717–721 (1999).

Chinook salmon stomach contents were removed from the digestive tract, fixed in 10% formalin, transferred to 40% isopropyl alcohol, and sorted under a dissecting microscope into major taxonomic groups. When possible, stomach contents were identified to species.

The best measure of dietary importance is one where both the number and weight of a food category are recorded (Hyslop, 1980) . Stomach content data were summarized by four methods: 1) numerical, 2) gravimetric, 3) frequency of occurrence, and 4) index of importance. Each food group was enumerated and weighed from each stomach. Wet weight of prey items was measured to the nearest 0.01 g. By using these data, percentage of total number (%*N*), percentage of total weight (%*W*), and percentage frequency of occurrence (%*F*) were calculated for each food group. "Index of importance" (IOI) was calculated for each food group as follows:

$$IOI_a = \frac{100 \times HI_a}{\sum_{a=1}^{n} HI},$$

where HI_a = $\%F_a + \%W_a$ for food group a; and
n = the number of different food groups (Hannah, 1980; Gray et al., 1997).

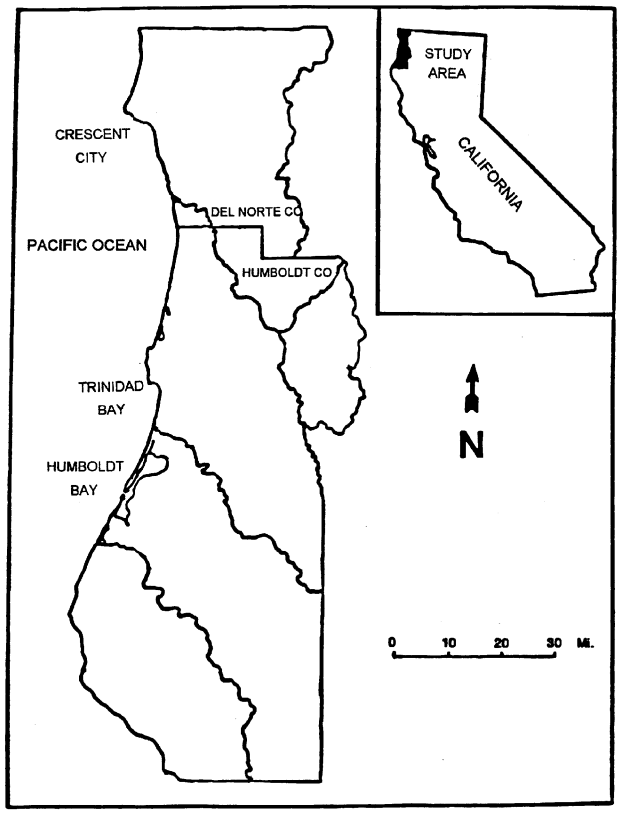

Figure 1
Humboldt Bay, Trinidad Bay, and Crescent City, California.

Because this index calculation is based on %*F* as well as %*W*, the bias towards heavier, infrequently found prey items is reduced.

Results

Values for %*N*, %*F*, %*W*, and *IOI* for prey items encountered in the stomach analyses are listed in Table 1. All stomachs examined (308) contained food items except one from 1994 and two from 1995. Each prey item was present in stomachs sampled from both 1994 and 1995 except for octopi (*Octopus rubescens*) (2), jacksmelt *(Atherinopsis californiensis*) (1), cottids (1), pleuronectids (1), Pacific sandlance (108), and rockfishes (45), which were observed only in 1994 samples and isopods (3) which were present only in 1995 samples. Total values for %*F* did not equal 100% owing to unidentifiable prey items in the diet, especially in 1995 (Table 1).

In 1994, the *IOI* indicated that euphausiids were the predominant food item, accounting for over 27% of the total. Euphausiids not only ranked highest by %*N* and %*F* but also were the leading prey item by %*W*. In addition, notable *IOI* values were observed for crab megalopae, Pacific herring, surf smelt (*Hypomesus pretiosus*), Pacific sandlance, northern anchovy, night smelt (*Spirinchus starksi*), and squid (*Loligo opalescens*). Infrequently encountered prey items included Pacific saury (*Cololabis saira*), rockfishes, amphipods, jacksmelt, octopi, shrimp (mysid), juvenile pleuronectids, and juvenile cottids. In 1995, chinook consumed primarily northern anchovy, which represented over 33% of the total *IOI* but also preyed upon Pacific herring, squid, Pacific saury, surf smelt, night smelt, euphausiids, and crab megalopae. Only rarely were amphipods, isopods, and shrimp found in stomachs. Large interannual variations in *IOI* can be seen for euphausiids, crab megalopae, Pacific sandlance, northern anchovy, squid, and Pacific saury.

Seasonal variation of dominant prey items, for 1994 and 1995, is illustrated in Figure 2, A and B, respectively. In 1994, 88 stomachs were examined from May and June (late spring). *IOI* values for euphausiids (34%), crab megalopae (25%), and Pacific herring (17%) dominated all other prey items. Late summer *IOI* values (based on 108 stomachs acquired in August and September 1994) indicated Pacific sandlance (22%), surf smelt (21%), northern anchovy (17%), and euphausiids (14%) to be major prey items. In 1995, 26 stomachs were examined from fish collected in June and 86 from September. The *IOI* values in our study showed that squid (45%), surf smelt (25%), euphausiids (19%), and Pacific herring (11%) are important prey items in late spring whereas

Table 1

Values for percentages by number (%*N*), frequency (%*F*) and weight (%*W*) for prey items observed in stomachs of chinook salmon, *Oncorhynchus tshawytscha*, collected in the coastal waters off Humboldt Bay, Trinidad Bay, and Crescent City, CA, during the summers of 1994 and 1995.

	1994				1995			
	%*N*	%*F*	%*W*	*IOI*	%*N*	%*F*	%*W*	*IOI*
Fishes								
Clupea pallasii	0.1	5.6	17.5	12.2	0.5	5.5	17.8	15.7
Engraulis mordax	0.1	3.6	8.7	6.5	8.3	14.6	34.6	33.2
Hypomesus pretiosus	0.1	6.7	12.2	10.0	0.4	2.7	9.6	8.3
Spirinchus starksi	0.2	6.7	4.7	6.0	1.3	2.7	7.0	6.5
Cololabis saira	0.0	1.0	4.3	2.8	1.9	4.6	12.7	11.6
Atherinopsis californiensis	0.0	0.5	0.6	0.6	—	—	—	—
Ammodytes hexapterus	0.4	8.7	9.8	9.8	—	—	—	—
Sebastes spp. (juvenile)[1]	0.2	3.6	1.6	2.7	—	—	—	—
Cottidae	0.0	0.5	0.0	0.3	—	—	—	—
Pleuronectidae	0.0	0.5	0.0	0.3	—	—	—	—
Euphausiid								
Thysanoessa spinifera	71.4	23.1	28.7	27.4	80.8	3.6	5.3	6.0
Crustaceans								
Cancer magister (megalopa)	27.5	19.5	8.6	14.9	2.7	5.5	0.1	3.8
Mysid	0.0	1.0	0.0	0.6	0.1	0.9	0.0	0.6
Amphipoda								
Atylus tridens	0.0	2.1	0.0	1.1	2.6	0.9	0.0	0.6
Isopoda								
Tecticeps convexus / *Synidotea bicuspida* } combined	—	—	—	—	0.2	0.9	0.0	0.6
Cephalopods								
Loligo opalescens	0.1	5.1	3.2	4.4	1.2	6.4	12.9	13.0
Octopus rubescens	0.0	1.0	0.0	0.6	—	—	—	—
Total	100.0	89.2	100.0	100.0	100.0	48.2	100.0	100.0

[1] *Sebastes entomelas, S. mystinus, S. melanops, S. pinniger* (in rank order of abundance).

northern anchovy (49%), Pacific herring (19%), Pacific saury (17%), and night smelt (10%) dominate in late summer.

Discussion

The feeding habits of northern California chinook salmon varied between years and season. This result is consistent with previous studies. Petrovich (1970) found northern anchovy, euphausiids, Pacific herring, osmerids, and rockfishes to be the most important prey items in coastal waters off Humboldt Bay and Trinidad Bay in 1960–1964. As in our study, crab megalopae were especially abundant in one year. In contrast to our results, Petrovich reported rockfishes to be present in 13% of all stomachs from 1960 to 1964, and in terms of frequency of occurrence they ranked third to northern anchovy and euphausiids. We encountered only 45 juvenile rockfishes during our study, all of which came from seven stomachs in the spring of 1994, representing only 2% of all stomachs examined.

Petrovich found relatively few Pacific sandlance and squid, and no Pacific saury in salmon stomachs that he examined. Our study shows that each of these food items contributes significantly to the diet of chinook salmon off Northern California (Fig. 2). Pacific sandlance, although absent in 1995 and only present in small numbers during late spring of 1994, were the major food source (*IOI*=22%) in late summer of 1994. Squid were present in late spring and late summer of both years and greatly outranked (*IOI*=45%) all prey items in late spring 1995. Pacific saury were present in stomachs collected during late summer 1994 (*IOI*=8%) and late summer 1995

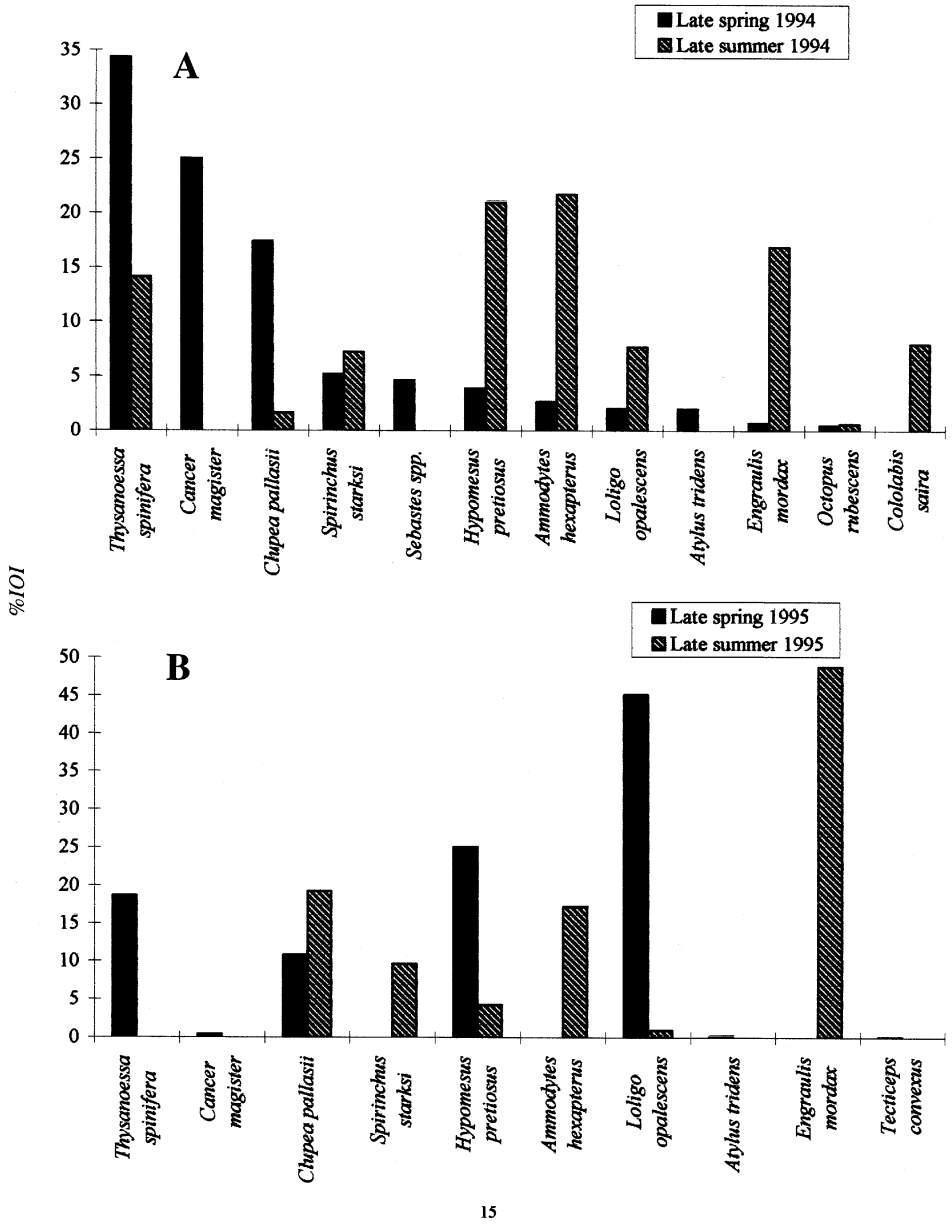

Figure 2

(**A**) 1994 late spring and late summer index of importance (*IOI*) values for predominant prey items consumed by chinook salmon, *Oncorhynchus tshawytscha*, in the coastal waters off Humboldt Bay, Trinidad Bay, and Crescent City, California. (**B**) 1995 late spring and late summer index of importance (*IOI*) values for predominant prey items consumed by chinook salmon, *Oncorhynchus tshawytscha*, in the coastal waters off Humboldt Bay, Trinidad Bay, and Crescent City, California.

(*IOI*=17%). The index of importance indicates that interannual and seasonal variation in the feeding habits of chinook salmon does in fact occur, most likely, in response to variation in the relative abundance of prey along the coast.

Healey (1991) summarized regional trends for coastwide data on chinook feeding habits and recognized that the importance of Pacific herring and Pacific sandlance increased from south to north whereas the importance of rockfishes and northern anchovy decreased. Our data agree with this summary. The diet of chinook salmon off northern California contained characteristic prey items important to chinook found both to the north and south. Although our study

found rockfishes not to be a major prey item of chinook salmon, northern anchovy were in fact commonly taken. In addition, the importance of Pacific herring and Pacific sandlance was substantial. The occurrence of invertebrate prey items (euphausiids, crab megalopae, and squid) during spring months agrees with studies conducted both to the south (Merkel, 1957) and north (Reid, 1961; Prakash, 1962; Brodeur et al., 1987) of the region of our study. Merkel (1957) commonly found euphausiids and squid, April through June, and crab megalopae (presumed to be *Cancer magister*), March through May, in stomachs of fish caught off San Francisco. Similarly, Brodeur et al. (1987), in coastal waters off Oregon and Washington, and Prakash (1962), in British Columbian waters, found euphausiids to be a major prey item during the months of May and June. Prakash also observed an abundance of crab megalopae in chinook diet during June. Squid were a dominant prey item one year in Reid's study off southeastern Alaska during late spring. These results and the great importance of euphausiids, crab megalopae, and squid in our study (Fig. 2) confirm the importance of invertebrate prey, in some years, to chinook salmon.

Acknowledgments

Financial support for this research was provided by the U.S. National Marine Fisheries Service. An earlier version of this manuscript was critically reviewed by R. D. Brodeur.

Literature cited

Bowen , S. H.
1996. Quantitative description of the diet. *In* B. Murphy and D. Willis (eds.), Fisheries techniques, p. 513–532. Am. Fish. Soc. Bethesda, MD, 732 p.

Brodeur, R. D., H. V. Lorz, and W. G. Pearcy.
1987. Food habits and dietary variability of pelagic nekton off Oregon and Washington, 1979–1984. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 57, 32 p.

Brodeur, R.D., and W.G. Pearcy.
1992. Effects of environmental variability on trophic interactions and food web structure in a pelagic upwelling ecosystem. Mar. Ecol. Prog. Ser. Vol. 84:101–119.

Gray, A. E., T. J. Mulligan, and R. W. Hannah.
1997. Food habits, occurrence, and population structure of the bat ray, *Myliobatis californica*, in Humboldt Bay, CA. Environ. Biol. Fish. 49:227–238.

Hannah, R.
1980. Age, growth and food habits of the small mouth bass, *Micropterus dolomieui*, in Clair Eagle Reservoir, CA. Unpubl. M.S. thesis, Humboldt State University, Arcata, CA, 57 p.

Healey, M. C.
1991. Life history of chinook salmon. *In* C. Groot and L. Margolis, (eds.), Pacific salmon life histories, p. 311–393. Univ. British Columbia Press, Vancouver, Canada, 564 p.

Heg, R., and J. Van Hyning.
1951. Food of chinook and silver salmon taken off the Oregon Coast. Oregon Fish Commission Research Briefs 3(2):32–40.

Hyslop, E. J.
1980. Stomach content analysis-a review of methods and their applications. J. Fish Biol. 17:411–429.

Merkel, T. J.
1957. Food habits of king salmon, *Oncorhynchus tshawytscha* (Walbaum), in the vicinity of San Francisco, California. California Fish Game 43(4):249–270.

Miller , D. J., and R. N. Lea.
1972. Guide to coastal marine fishes of California. Calif. Dep. Fish Game Fish Bull. 157:1–249

Nehlsen, W., J. E. Williams, and J. A. Lichatowich.
1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4–21.

Pearcy, W. G.
1992. Ecology of North Pacific salmonids. Univ. Washington Press, Seattle, WA, 179 p.

Petrovich, A., Jr.
1970. Biota of near-shore waters off Humboldt Bay and Trinidad Head, 1960–1964, as shown by diet of Pacific Salmon. Unpubl. M.S. thesis, Humboldt State University, Arcata, CA, 69 p.

Prakash, A.
1962. Seasonal changes in feeding of coho and chinook (spring) salmon in southern British Columbia waters. J. Fish. Res. Board Can. 19:851–866.

Pritchard, A. L., and A. L. Tester.
1944. Food of spring and coho salmon in British Columbia. Bull. Fish. Res. Board Can. 65, 23 p.

Reid, G.
1961. Stomach content analysis of troll caught king and coho salmon, southeastern Alaska, 1957–1958. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 379, 8 p.