Diet changes of Pacific cod (*Gadus macrocephalus*) in Pavlof Bay associated with climate changes in the Gulf of Alaska between 1980 and 1995

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The diet of Pacific cod (*Gadus macrocephalus*) in the area of Pavlof Bay, Alaska, was studied in the early 1980s by Albers and Anderson (1985). They found that the dominant prey species were forage species like pandalid shrimp, capelin (*Mallotus villosus*), and walleye pollock (*Theragra chalcogramma*). The shrimp fishery in Pavlof Bay began in 1968 and closed in 1980 because of low shrimp abundance (Ruccio and Worton[1]). Survey data indicate that, during the period between 1972 and 1997, the abundance of forage species such as pandalid shrimp and capelin declined and higher trophic-level groundfish such as Pacific cod increased. There is a general recognition that a long-term ocean climate shift in the Gulf of Alaska has been partially responsible for the observed reorganization of the community structure (Anderson and Piatt, 1999).

Because there has been an apparent shift in the abundance of both predators and prey in Pavlof Bay, it is important to understand how trophic relationships may also have changed. In order to partially address this question, stomach samples of Pacific cod and other groundfishes were taken in 1995. By performing a comparison of the diet of Pacific cod right after the climate shift with Pacific cod and other groundfishes well after the shift, this analysis may demonstrate how the relative abundance of prey in the Gulf of Alaska may have changed.

Methods

Stomachs of Pacific cod, walleye pollock, and arrowtooth flounder (*Atheresthes stomias*) were collected by National Marine Fisheries Service (NMFS) scientists on board the chartered vessel FV *Arcturus* conducting a trawl survey in Pavlof Bay, Alaska, (Fig. 1) from 5 August to 7 August 1995. The survey targeted shrimp and used a high-opening net with small mesh (32-mm stretched mesh). Each tow was about 1.2 km in length. The average depth of the 13 hauls where stomachs were collected was 108.9 (±9.5) m with a range from 90 to 123 m. When a sampled stomach was retained, it was put in a cloth stomach bag. A field tag with the species name, fork length (FL in cm) of the fish, and haul data (vessel, cruise, haul number, specimen number) was also put in the bag. All the samples collected were then preserved in buckets containing a 10% formalin solution. When the samples arrived at the laboratory, they were transferred into 70% ethanol before the stomach contents were analyzed. In the laboratory, the stomach was cut open, the contents were removed and blotted with a paper towel. Wet weight was then recorded to the nearest 0.1 g. After obtaining the total weight for a stomach's contents, the contents were placed in a Petri dish and examined under a microscope. Each prey item was classified to the lowest practical taxonomic level. Prey weights and numbers of commercially important fish were recorded. Standard lengths of prey fish and carapace width of crabs were also recorded. The diet of Pacific cod was summarized to show the percent frequency of occurrence, the percentage by number, and the percentage of the total weight of each prey item found in the stomachs. Stomach contents of walleye pollock and arrowtooth flounder were analyzed for comparisons.

Results

Of 130 Pacific cod stomachs analyzed, 129 contained food. Pacific cod sizes ranged from 40 to 80 cm FL (fork length); a mean size was 55.4 (SD ±7.2) cm.

Polychaetes, crangonid shrimp, pea crab, and clams were the most frequently found prey items in Pacific cod stomachs (Table 1). However, in terms of weight, eelpouts (zoarcids), Tanner crab (*Chionoecetes bairdi*), crangonid shrimp, hermit crab, and polychaetes were the most important prey of Pacific cod. Pandalid shrimp, spinyhead sculpin (*Dasycottus setiger*), pricklebacks (stichaeid), Pacific sandlance (*Ammodytes hexapterus*), arrowtooth flounder (*Atheresthes stomias*), and flathead sole (*Hippoglossoides elassodon*) were minor prey.

Invertebrates (mainly crangonid shrimp, polychaetes, and crabs) were the principal prey of Pacific cod smaller than 60 cm (Fig. 2). There were nine prey categories as shown in Figure 2. The miscellaneous prey included Sipuncula, Echiura, fish offal (processed

[1] Ruccio, M. P., and C. L. Worton. 1999. Annual management report for the shellfish fisheries of the Alaska peninsula area, 1998. *In* Annual management report for the shellfish fisheries of the westward region, 1998. Regional Information Report 4K99-49, 312 p. Alaska Department of Fish and Game, Division of Commercial Fisheries, 211 Mission Road, Kodiak, Alaska 99615.

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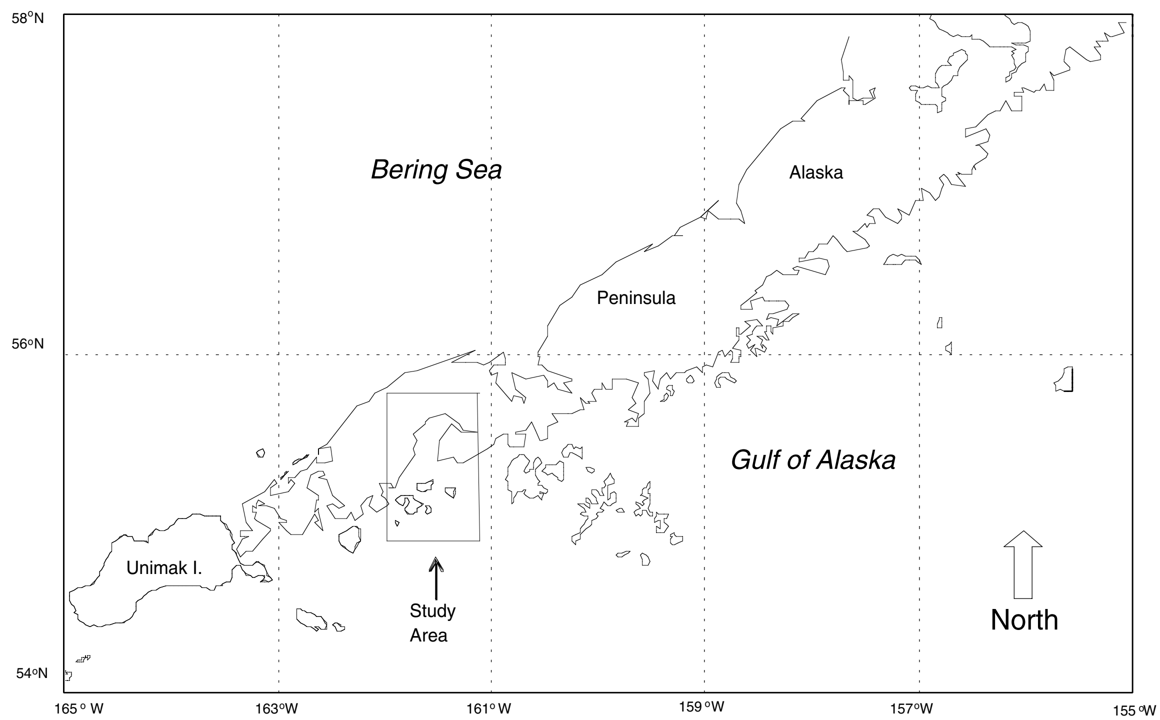

Figure 1
Location of study area in 1980, 1981, and 1995.

fish parts like head, tail, pyloric caeca, etc.), and all other prey organisms not included in the other eight prey categories. The importance of fish in the diet of Pacific cod increased after 60 cm FL. Walleye pollock were consumed only by Pacific cod ≥60 cm FL.

In general, Pacific cod ate prey of small individual size (Table 2). Tanner crabs (*Chionoecetes bairdi*) ranged from 4.5 to 42.3 mm carapace width. Eelpouts ranged in length from 36.2 to 256.6 mm standard length. Other fish prey ranged in length from 32.7 to 81.5 mm. Walleye pollock were consumed by Pacific cod but were not measurable.

In 1995, when Pacific cod stomachs were collected in Pavlof Bay, 218 walleye pollock and 80 arrowtooth flounder stomachs were also collected. Similar to the results for Pacific cod, pandalid shrimp and capelin were not important food of walleye pollock and arrowtooth flounder either (Fig. 3). These prey each comprised less than 3% of the total stomach content weight of walleye pollock and arrowtooth flounder. Instead, eelpouts, pricklebacks, euphausiids, and walleye pollock were important food of arrowtooth flounder, and euphausiids (83% by weight) were the main food of walleye pollock.

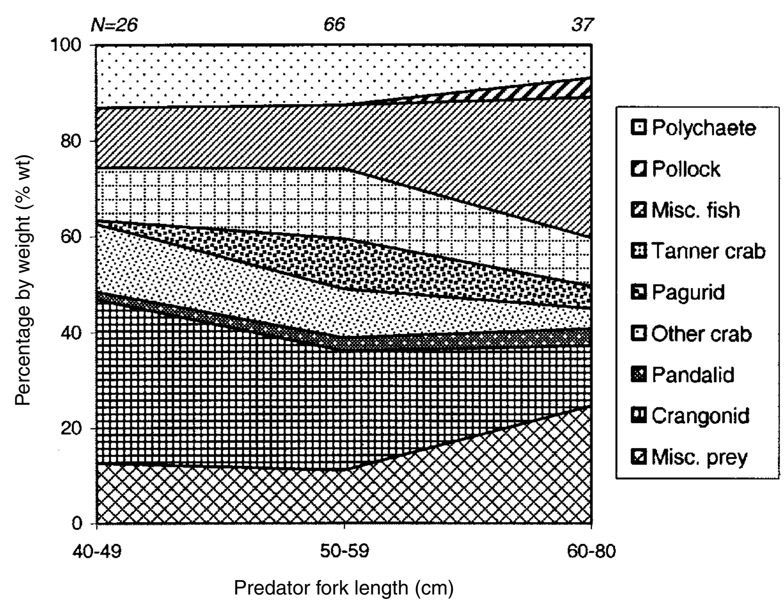

Figure 2
Variations in the main food items of Pacific cod, by predator size, in Pavlof Bay in 1995. n=sample size.

Discussion

This study shows that eelpouts, Tanner crabs, crangonids, hermit crabs, polychaetes, and echiuroids were the princi-

Table 1

Percent frequency of occurrence (%*F*), percentage by number (%*N*), and percentage by weight (%*W*) of prey items of Pacific cod collected in Pavlof Bay, Alaska, 1995.

Prey name	%*F*	%*N*	%*W*
Polychaeta (worm)	79.8	11.4	9.2
Gastropoda (snail)	14.0	0.8	0.4
Bivalvia (clam)	55.0	6.1	2.1
Cephalopoda (squid and octopus)	10.1	0.5	2.1
Copepoda	0.8	0.0	0.0
Peracarida Mysidacea (mysid)	31.8	11.5	0.2
Cumacea (cumacean)	13.2	0.9	0.0
Amphipoda (amphipod)	17.1	1.2	0.0
Euphausiacea (euphausiid)	15.5	10.0	0.7
Natantia (unidentified shrimp)	12.4	0.7	0.1
Caridea (shrimp)	12.4	1.2	1.2
Hippolytidae (shrimp)	17.8	1.2	0.2
Pandalidae (shrimp)	41.1	5.7	2.3
Crangonidae (shrimp)	76.0	18.9	13.3
Reptantia (unidentified crab)	11.6	0.5	1.9
Paguridae (hermit crab)	22.5	1.3	9.5
Decapoda Brachyura (crab)	0.8	0.0	0.1
Hyas sp. (lyre crab)	0.8	0.0	0.9
Hyas lyratus (lyre crab)	1.6	0.1	0.6
Chionoecetes sp. (snow and Tanner crab)	40.3	3.5	13.9
Pinnotheridae (pea crab)	1.6	0.1	0.1
Pinnixa sp. (pea crab)	68.2	8.4	3.2
Sipuncula (marine worm)	0.8	0.0	0.6
Echiura (marine worm)	24.0	1.4	6.6
Ophiuroidea (basket and brittle star)	9.3	0.7	0.1
Chaetognatha (arrow worm)	1.6	0.2	0.0
Rajidae (skate)	2.3	0.1	0.4
Osteichthyes Teleostei (fish)	12.4	1.1	0.6
Nongadoid fish remains	47.3	6.5	2.3
Gadidae (unidentified)	1.6	0.1	0.4
Theragra chalcogramma (walleye pollock)	2.3	0.1	1.4
Zoarcidae (eelpout)	16.3	0.9	14.0
Cottoidei (Sculpin)	2.3	0.1	0.2
Dasycottus setiger (spinyhead sculpin)	0.8	0.0	0.2
Stichaeidae (prickleback)	8.5	1.5	0.6
Lumpenus sp. (prickleback)	0.8	0.0	0.0
Ammodytes hexapterus (Pacific sand lance)	0.8	0.0	0.0
Pleuronectidae (flatfish)	2.3	0.2	0.2
Atheresthes stomias (arrowtooth flounder)	1.6	0.1	0.0
Hippoglossoides elassodon (flathead sole)	3.9	0.2	0.5
Unidentified organic material	10.1	0.5	0.6
Unidentified worm-like organism	5.4	0.3	0.5
Fish offal (processed fish parts, e.g., head, tail)	0.8	0.0	8.1
Total prey weight	2715 g		
Total stomachs	130		
Total empty stomachs	1		

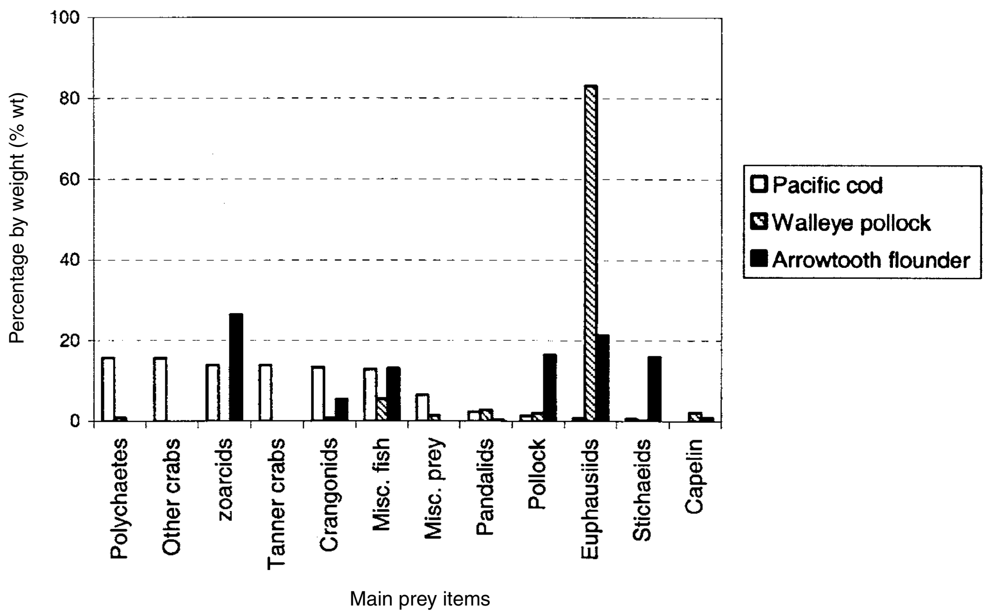

Figure 3

Percentage by weight of the main prey in the diet of Pacific cod (n=129), walleye pollock (n=216), and arrowtooth flounder (n=43) collected in Pavlof Bay in 1995.

pal prey of Pacific cod collected in Pavlof Bay in 1995. This is a large change in diet composition compared with that observed 15 years earlier (Albers and Anderson, 1985). In Albers and Anderson's (1985) study, pandalid shrimp, capelin, and walleye pollock were the main prey of Pacific cod (Fig. 4). The change in main prey from pelagic prey in the 1980s to benthic prey in 1995 corresponds to changes in species abundance trends in nearshore small-mesh trawl surveys observed by Anderson and Piatt (1999). In that study, they described that the community reorganization in the Gulf of Alaska was triggered by a shift in ocean climate during the late 1970s. They showed that the abundance of species such as pandalid shrimp and capelin declined while the abundance of predators such as Pacific cod, walleye pollock, and flatfish increased between 1972 and 1997.

The mean weight of pandalid shrimp consumed by Pacific cod in 1995 was only 0.5 g/cod. In contrast, the mean weights of undigested pink shrimp in Pacific cod stomachs ranged between 4.5 g/cod and 24.4 g/cod during 1980 and 1981. This finding corroborates those of Anderson (2000) and show that pandalid shrimp abundance continued to decrease in the late 1990s and Pacific cod abundance continued to increase during that same period.

The diet of Pacific cod in the present study was also compared with the diet of Pacific cod in the broader Gulf of Alaska shelf area (Fig. 5) (Yang and Nelson, 2000). The values of the percentage by weight of capelin in Pacific cod stomachs in the Gulf of Alaska in 1990, 1993, and 1996 were similar (all were less than 3%) to that in Pavlof Bay in 1995. However, pandalid shrimp were an important food item of Pacific cod throughout the Gulf of Alaska, comprising from 11% to 15% by weight of the total stomach contents of Pacific cod in the Gulf of Alaska in 3 years (1990, 1993, and 1996) (Yang and Nelson, 2000). These values are higher than that in Pavlof Bay (2% by weight). By comparing the depths of the sampling locations of the Pacific cod, high percentages of pandalid shrimp were found in the cod diet in deeper offshore areas of the Gulf of Alaska in 1990, 1993, and 1996, whereas low percentages of pandalid shrimp were found in cod diet in much

Table 2

Mean standard length (or carapace width), standard deviation, and the size range of prey consumed by Pacific cod in Pavlof Bay 1995.

Prey name	Mean (mm)	SD (mm)	Range (mm)	No. of individuals
Tanner crab	22.1	10.5	4.5–42.3	70
Zoarcid	86.4	73.5	36.2–256.6	15
Cottid	48.2	9.4	41.8–59	3
Stichaeid	46.9	19.6	32.7–81.5	5
Pacific sand lance	44.8	0.0	44.8–44.8	1
Arrowtooth flounder	39.1	7.4	33.8–44.3	2
Flathead sole	58.2	14.4	47.5–80.4	4

shallower areas in the Pavlof Bay area (Fig. 6). From the shrimp survey data, Anderson (2000) showed that pandalid shrimp occupying inshore and shallower water (e.g., Pavlof Bay area) declined to near extinction (<0.1 kg/km) from 1978 to 1982, while offshore and deepwater pandalid shrimp species maintained low population levels (>0.1 kg/km). The data from this study corroborates Anderson's (2000) results.

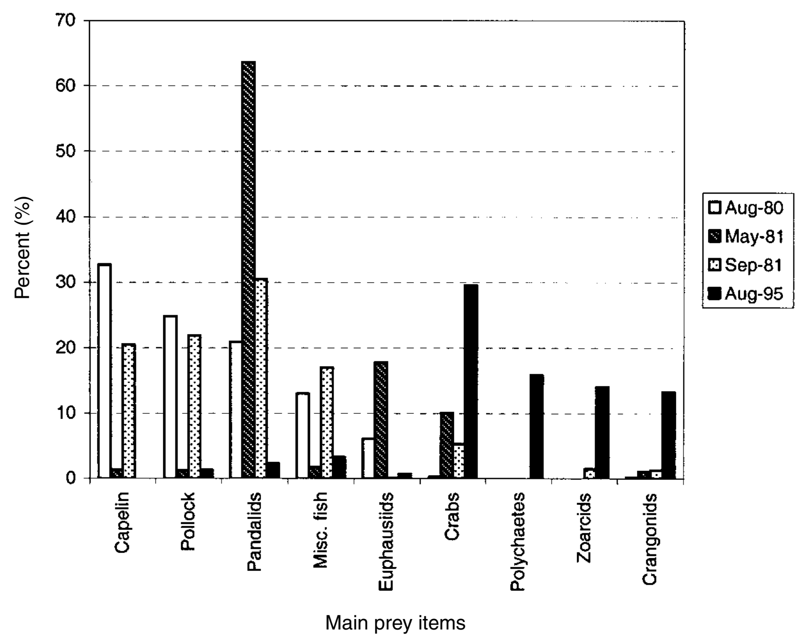

Figure 4

Percentage by volume (for the values in 1980s) and the percentage by weight (for the values in 1995) of the main prey items of Pacific cod collected in Pavlof Bay, Alaska.

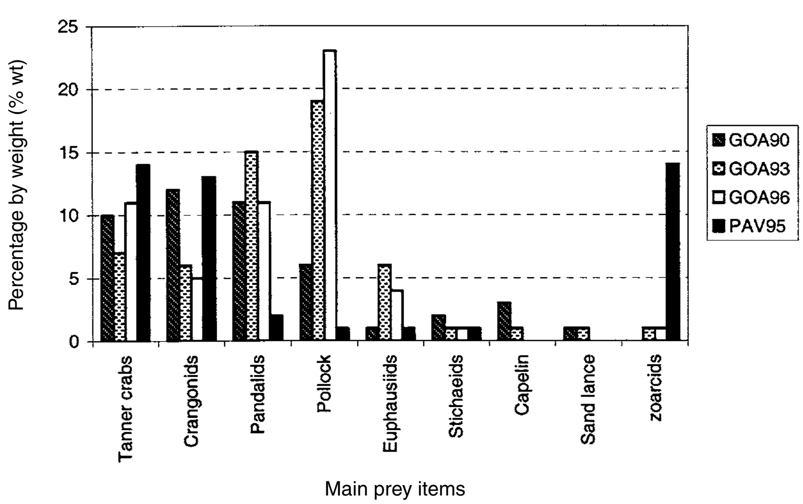

Figure 5

Percentage by weight of the main prey items in the diet of Pacific cod collected in 1990 (GOA90), 1993 (GOA93), and 1996 (GOA96) in the Gulf of Alaska and in 1995 (PAV95) in Pavlof Bay.

Anderson (2000) also reported that during the period of the decline of pandalid shrimp in inshore waters of the Gulf of Alaska, the abundance of some pleuronectids, Pacific cod, and walleye pollock increased. These species are predators of pandalid shrimp (Yang and Nelson, 2000). One hypothesis is that predators keep pandalid shrimp populations low. Albers and Anderson (1985) suggested that cod predation was one reason for the failure of the pink shrimp stock to rebuild in Pavlof Bay. In the Northwest Atlantic, Lilly et al. (2000) showed that the large increase in shrimp biomass seen in the 1990s was related to the collapse of cod (*Gadus morhua*) populations during the late 1980s and 1990s in the northeast Newfoundland shelf. The impact of cod on Barents Sea shrimp (*P. borealis*) was also reported by Berenboim et al. (2000). They found that when cod biomass is high, the shrimp frequency of occurrence in cod stomachs declines; there is a significant inverse correlation between the abundance of cod and shrimp.

Tanner crabs consumed by Pacific cod in this study ranged from 5 to 42 mm carapace width (CW). In general, the size of Tanner crabs consumed increases as Pacific cod size increases. The size range of Tanner crabs consumed by Pacific cod in this study is similar to that (5–45 mm) found in Pacific cod stomachs in Albers and Anderson's (1985) study and is also similar to that (1–40 mm) found in Hunter's (1979) study near Kodiak Island.

Jewett's (1978) Pacific cod diet study around Kodiak Island from 1973 to 1976 showed that Tanner crabs were the most frequent (37%) prey of Pacific cod; pandalid shrimp occurred in 8–10% of the stomachs examined from 1973 to 1975; and walleye pollock were found in 4% of the stomachs examined. The importance of Tanner crabs as food of Pacific cod in Jewett's (1978) study is coincident with our study.

This study suggests that there were substantial differences between the diets of Pacific cod in Pavlof Bay between the early 1980s and 1995. In the 1980s, pandalid shrimp and capelin were the main food of Pacific cod, whereas benthic species (polychaetes,

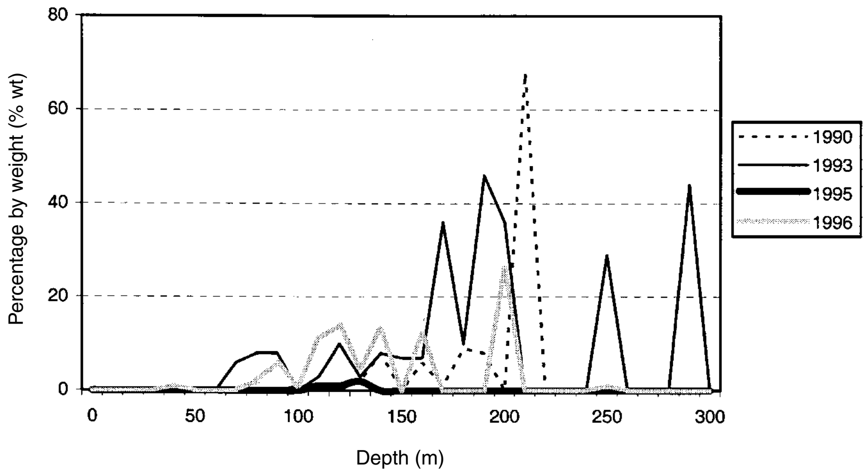

Figure 6

Pandalid shrimp consumed by Pacific cod sampled at different bottom depths (m) in Pavlof Bay in 1995, and in the Gulf of Alaska in 1990, 1993, and 1996.

hermit crabs, Tanner crabs, and eelpouts) were the dominant food in 1995. This change was probably due to the climate shift from cold to warm in the Gulf of Alaska.

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