DIET OF PACIFIC COD, *GADUS MACROCEPHALUS*, AND PREDATION ON THE NORTHERN PINK SHRIMP, *PANDALUS BOREALIS*, IN PAVLOF BAY, ALASKA

W. D. ALBERS AND P. J. ANDERSON[1]

ABSTRACT

Analysis of 455 Pacific cod, *Gadus macrocephalus*, stomachs collected in 1980 and 1981 from Pavlof Bay, in the western Gulf of Alaska, showed considerable predation on northern pink shimp, *Pandalus borealis*. The most frequently occurring prey items were pink shrimp, *P. borealis*, 63%; euphausids, 41%; walleye pollock, *Theragra chalcogramma*, 27%; and capelin, *Mallotus villosus*, 26%. Pandalid shrimp and snow (Tanner) crab occurred more frequently with increasing cod size (30-69 cm fork length). Euphausids decreased in frequency of occurrence with increasing cod size. Pink shrimp length distributions from cod stomachs and trawl samples were similar. Estimated consumption of pink shrimp by cod in Pavlof Bay ranged from 142 to 857 t over a 112-day period from late May through mid-September 1981. Cod predation may be one reason for the failure of the pink shrimp stock to rebuild in Pavlof Bay following closure of the commercial fishery in 1979. Cod predation may also play a role in keeping other reduced pink shrimp stocks in the western Gulf of Alaska from rebuilding to former levels.

Pacific cod, *Gadus macrocephalus*, predation on northern pink shrimp, *Pandalus borealis*, in Pavlof Bay (Fig. 1) was studied to determine if it is a factor in keeping the pink shrimp stock from rebuilding there. National Marine Fisheries Service (NMFS) and Alaska Department of Fish and Game (ADF&G) survey data from the late 1970's indicate that when pink shrimp populations in regions of western Alaska began to decrease, cod abundance started to increase. Pink shrimp has been reported to be an important food item in the diet of Pacific cod in the Gulf of Alaska (Jewett 1978; Hunter 1979). Predation of pink shrimp by cod may have substantial influence on shrimp stock abundance.

Pavlof Bay was chosen as the study area because it supported a commercial fishery for pandalid shrimp in the 1970's and is suspected to contain a geographically isolated stock of pink shrimp (Anderson 1981). From 1972 through 1979, 13,641 t of pink shrimp were commercially harvested from Pavlof Bay (calculated from ADF&G commercial catch data and NMFS survey data). Survey data from Pavlof Bay indicate that in 1977 and 1978 when pink shrimp abundance began decreasing, cod abundance began increasing (Fig. 2). Following the 1979 season the bay was closed to commercial shrimping due to depressed shrimp abundance levels which remained low through 1983.

This report presents data which suggest that Pacific cod predation is a factor in keeping shrimp stocks from rebuilding. The summer diet of cod, prey size selectivity, and an estimate of pink shrimp biomass consumed by cod in Pavlof Bay during a 112-d period from late May through mid-September 1981 are discussed.

MATERIALS AND METHODS

Pacific cod were collected from 31 tows during three trawl surveys. The first collection was done by NMFS on 25-26 August 1980, the second by ADF&G on 23-25 May 1981, and the third by NMFS on 10-11 September 1981. The collecting was done during daylight hours over a period of about 14 h a day. All three surveys used a high-opening shrimp trawl with an 18.6 m headrope and footrope described by Wathne (1977). Mesh size of the trawl is 32 mm and path-width is about 10 m. Each tow was about 1.8 km in length. Randomly selected sampling locations were restricted to depths >55 m since previous surveys showed that neither shrimp nor cod were found in abundance in shallow water. Both shrimp and cod are uniformly distributed at depths >55 m in Pavlof Bay.

When possible, five stomachs per 5 cm interval of fork length (FL) were removed from every trawl catch and preserved in 10% Formalin[2]. In the

[1]Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Manuscript accepted January 1985.

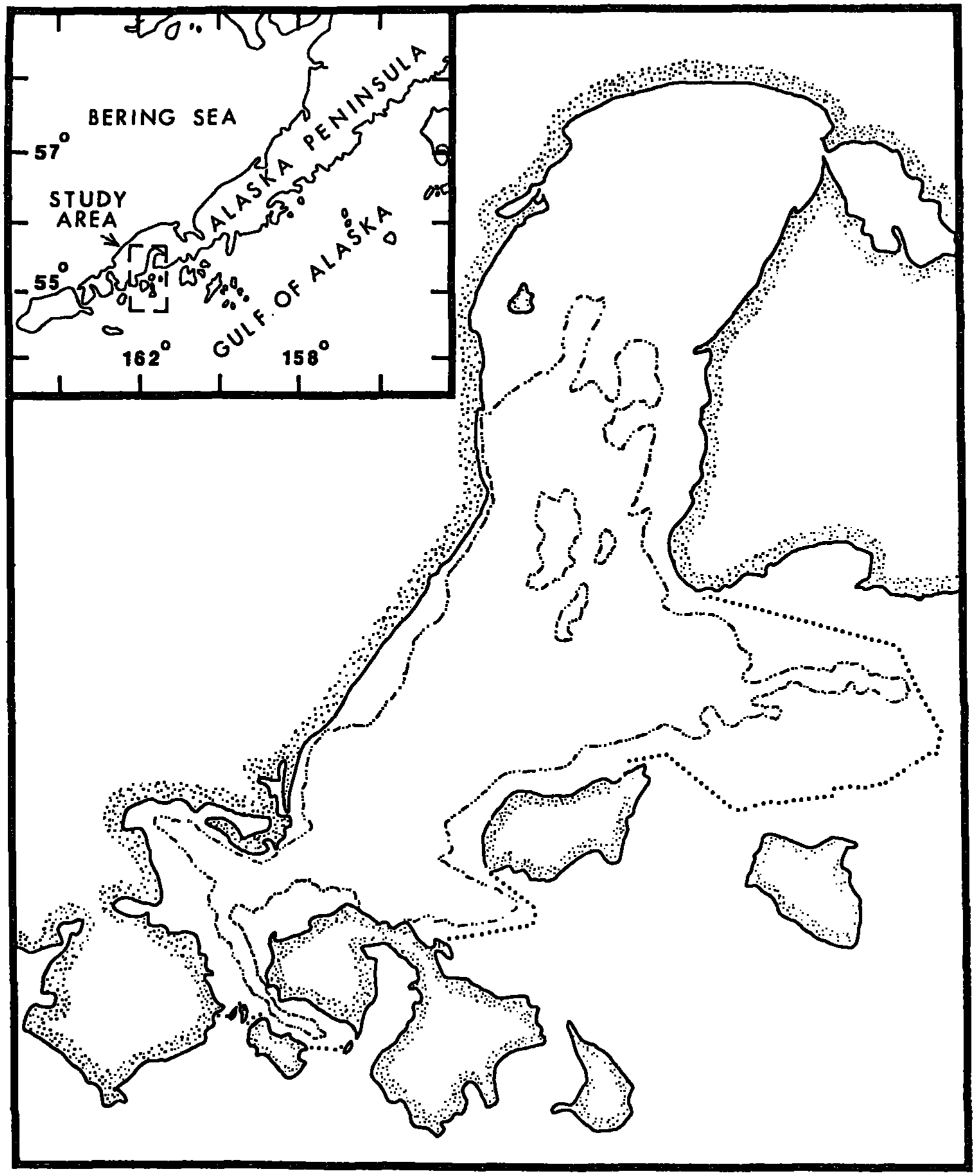


FIGURE 1.—Location of the study area of pink shrimp and Pacific cod (55 m isobath indicated by dotted/dash-line).

laboratory, prey items were sorted to the lowest possible taxon. Frequency of occurrence (number of stomachs containing the food item), number of each prey item, volume by water displacement (nearest 0.1 mL), and wet weight (nearest gram) were recorded. From these measurements, percentages by frequency of occurrence, number, and volume were calculated from non-empty stomachs only.

Size composition was recorded for prey species of commercial importance including pink shrimp (carapace length, CL); humpy shrimp, *Pandalus goniurus*, CL; snow (Tanner) crab, *Chionoecetes bairdi*, carapace width (CW); and walleye pollock, *Theragra chalcogramma*, fork length (FL). Additionally, size composition was recorded for samples of pink shrimp (CL), humpy shrimp (CL), Pacific cod (FL), and walleye pollock (FL) caught in each tow.

To determine if Pacific cod were feeding on selected sizes of pink shrimp, the Kolmogorov-Smirnov test (Sokal and Rohlf 1969) was used to test for a significant difference between pink shrimp length distributions measured from Pacific cod stomachs and those measured from the trawl. Pink shrimp lengths tested were ≥16.5 mm CL. Anderson (1981) reported that shrimp <16.5 mm CL are not fully vulnerable to trawl capture.

Population biomass estimates for pink shrimp and Pacific cod were calculated using the area swept technique (Alverson and Pereyra 1969).

An estimate of pink shrimp biomass consumed by Pacific cod in Pavlof Bay during the 112-d period between the late May and mid-September 1981 surveys was determined through methods described by Minet and Perodou (1978). Undigested weights (W) of pink shrimp were determined from carapace lengths using the weight-length relationship $W = 0.000802\ (CL)^{2.903}$ (calculated from Pavlof Bay pink shrimp length-weight data). The mean weight of pink shrimp per stomach for each 5 cm length group of Pacific cod was calculated from stomachs where at least 80% of the pink shrimp were measurable (Table 1). A stomach which contained <80% measurable pink shrimp was deemed not suitable for determining the weight of undigested shrimp consumed. These data were then weighted using 768 cod lengths measured during the three surveys. The mean weight of pink shrimp in the stomach of an average-sized cod was then estimated for each survey (Table 1).

The average rates of elimination (r) of food from Pacific cod stomachs collected during the May and September 1981 surveys were calculated from Jones' (1974) equation for food elimination rates from Atlantic gadoids including Atlantic cod, *Gadus morhua*. Jones found that the rates of elimination for the three species of gadoids studied were effectively the same, adjusting for fish and meal size, and temperature. Since Pacific cod are very similar to Atlantic cod, we used Jones' equation in the absence of more relevant information:

$$r\ (\text{g/h}) = \frac{10^{0.035\ (Tb\ -\ Tc)}\ X^{0.46}\ QL^{1.4}}{175}$$

where Tc = 6°C; temperature of the experiment (Jones 1974).

Tb = 5°C (May), 7°C (September); observed temperature in Pavlof Bay from expendable bathythermograph data.

X = 98.9 g (May), 109.0 g (September); the average weight of food found in one stomach. The average weight of food was estimated for each 5 cm length group of Pacific cod and then weighted using 502 cod lengths measured during the May and September surveys. Stomachs containing at least 60% of the greatest weight of food encountered for each cod length group were used to determine X.

Q = 0.12; the average rate of elimination of 1 g of food from the stomach of a 40 cm gadoid (Jones 1974).

L = 52.7 cm (May), 53.0 cm (September); the average length of Pacific cod calculated from 236 fish measured in May and 266 fish measured in September.

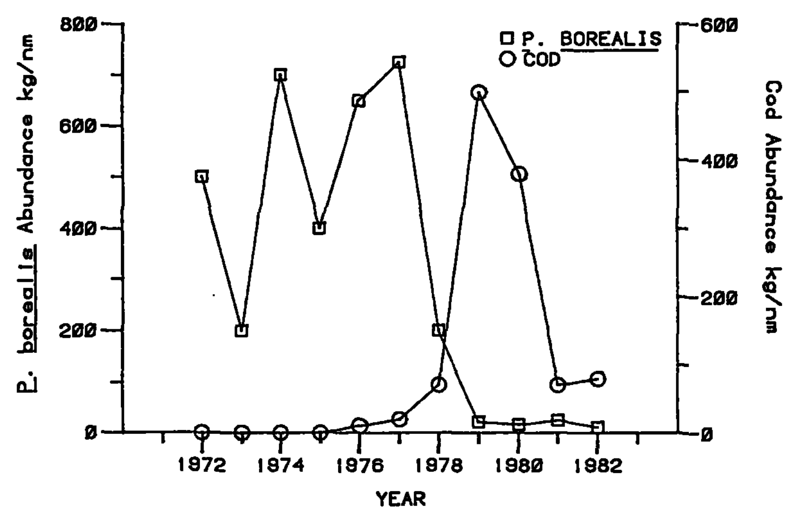


FIGURE 2.—Abundance of pink shrimp and Pacific cod from NMFS summer trawl survey data collected in Pavlof Bay, 1972-82.

TABLE 1.—Calculation of the mean weight of undigested pink shrimp in one stomach for August 1980, May and September 1981.

Length groups of cod (cm)	August 1980 A Number of cod	August 1980 B Mean weight of undigested pink shrimp (g)	August 1980 AxB Total weight of undigested pink shrimp (g)	May 1981 A Number of cod	May 1981 B Mean weight of undigested pink shrimp (g)	May 1981 AxB Total weight of undigested pink shrimp (g)	September 1981 A Number of cod	September 1981 B Mean weight of undigested pink shrimp (g)	September 1981 AxB Total weight of undigested pink shrimp (g)
30-34	2	0	0	—	—	—	—	—	—
35-39	12	0.2	2.4	2	13.6	27.2	3	2.0	6.0
40-44	49	3.5	171.5	9	9.8	88.2	14	3.0	42.0
45-49	137	3.8	520.6	44	19.3	849.2	34	10.1	343.4
50-54	56	7.7	431.2	98	27.2	2,665.6	112	11.3	1,265.6
55-59	9	8.1	72.9	66	17.8	1,174.8	81	12.9	1,044.9
60-64	1	2.5	2.5	14	57.3	802.2	22	12.7	279.4
65-69	—	—	—	3	50.8	152.4	—	—	—
Totals	266		1,201.1	236		5,759.6	266		2,981.3
Mean weight of undigested pink shrimp		1,201.1/266 = 4.5 g			5,759.6/236 = 24.4 g			2,981.3/266 = 11.2 g	

RESULTS

Cod Diet

Of 455 Pacific cod stomachs examined, 435 contained food. Data obtained from cod stomachs collected in August 1980, May 1981, and September 1981 are presented in Table 2. Combining these data, the most frequently occurring prey items were pink shrimp (63%), euphausids (41%), walleye pollock (27%), and capelin, *Mallotus villosus*, (26%). Crustaceans, mostly shrimp, crab, and euphausids, were present in 93% of the stomachs containing food and comprised 45% of the volume. Teleosts, mostly walleye pollock and capelin, were present in 60% of the stomachs containing food and comprised 54% of the volume. Gastropods, bivalves, sipunculids, and ascidians together comprised 1% of the volume.

Crustaceans made up the greatest part of the diet in the May sample and teleosts comprised the greatest part of the diet in the August and September samples (Table 2). Shrimp, mostly pink shrimp, made up 67% of the volume in May compared with 28%, combining August and September data. Crabs, mainly snow crab, comprised 10% of the volume in May compared with 3% in August-September. Teleosts, primarily walleye pollock and capelin, made up 4% of the volume in May and 65% in August-September.

Data on the 10 most frequently occurring food items was categorized by 10 cm length (FL) groups of Pacific cod in a size range of 30 through 69 cm (Table 3). Hurtubia's (1973) trophic diversity method was used to assure that enough stomach samples had been analyzed to give representative values for each length group. Pink shrimp occurred most frequently in all but one length group (30-39 cm) and was the dominant food item by volume in all length groups. Pink shrimp and snow crab increased both in frequency of occurrence and volume with increasing cod size. Conversely, euphausids were the most frequently encountered food item in the 30-39 cm length group, but their frequency of occurrence and volume decreased with increasing cod size. No trends were evident for the occurrence of teleosts. Although data from the three surveys were combined for Table 3, the above trends were evident in each of the surveys.

The size ranges and mean sizes of pink shrimp and humpy shrimp consumed by Pacific cod were similar in general to those found in the trawl (Table 4). Size range and mean size of walleye pollock consumed by cod were considerably smaller than those fish captured by the trawl.

TABLE 2.—Percent frequency of occurrence (*F*), percent by number (*N*), and percent by volume (*V*) of food items in Pacific cod stomachs for August 1980 and May and September 1981. Food categories followed by (total) is the sum of the food items that fall within that category for percent number and percent volume. Percent frequency of occurrence is the number of stomachs containing the food category or item divided by the total number of stomachs containing food.

	August 1980 (*n* = 202)			May 1981 (*n* = 63)			September 1981 (*n* = 170)		
Food items	*F*	*N*	*V*	*F*	*N*	*V*	*F*	*N*	*V*
Crustacea (total)	93.1	92.2	29.4	100.0	99.5	95.0	91.2	57.6	37.6
Amphipoda	—	—	—	—	—	—	1.8	0.3	<0.1
Euphausiacea	53.5	77.0	6.1	81.0	87.3	17.8	12.4	3.3	0.1
Decapoda									
Natantia (total)	71.3	15.0	23.0	76.2	10.4	67.1	80.6	46.1	32.2
Pandalidae	—	—	—	3.2	0.1	0.1	1.8	0.2	<0.1
Pandalus borealis	56.9	9.3	18.5	65.1	7.6	59.7	70.6	34.9	29.9
Pandalopsis dispar	—	—	—	17.5	0.5	1.0	1.2	0.1	<0.1
Pandalus goniurus	20.3	1.7	2.3	25.4	0.4	1.7	4.1	0.9	0.5
Pandalus hypsinotus	0.5	<0.1	0.1	4.8	0.1	1.1	1.2	0.1	0.3
Crangonidae	—	—	—	—	—	—	4.1	0.8	0.2
Crangon sp.	3.0	0.2	0.1	7.9	0.1	0.2	2.9	0.5	<0.1
Crangon communis	2.5	0.2	0.1	12.7	0.2	0.3	18.2	2.9	0.5
Crangon dalli	—	—	—	—	—	—	3.5	0.5	0.1
Argis sp.	—	—	—	4.8	0.1	0.3	1.2	0.1	<0.1
Argis dentata	—	—	—	4.8	0.1	0.3	1.8	0.2	<0.1
Argis lar	—	—	—	—	—	—	4.7	0.7	0.2
Hippolytidae	0.5	<0.1	<0.1	6.3	0.1	0.1	—	—	—
Eualus sp.	0.5	<0.1	<0.1	—	—	—	—	—	—
Eualus macilenta	—	—	—	11.1	0.3	0.2	5.3	0.8	<0.1
Eualus suckleyi	0.5	<0.1	<0.1	1.6	0.1	0.2	2.9	0.4	0.1
Unidentified Natantia	26.7	3.6	1.9	30.2	0.7	1.9	20.0	3.0	0.4
Reptantia (total)	3.5	0.2	0.3	39.7	1.8	10.1	31.2	7.9	5.3
Lithodidae									
Paralithodes camtschatica	0.5	<0.1	<0.1	—	—	—	—	—	—
Majidae									
Chionoecetes bairdi	1.5	0.1	0.2	41.2	1.8	10.0	25.3	6.2	4.7
Paguridae	2.0	0.1	0.1	—	—	—	0.6	0.1	<0.1
Pagurus aleuticus	—	—	—	—	—	—	0.6	0.1	0.2
Pinnotheridae									
Pinnixa sp.	—	—	—	1.6	<0.1	0.1	8.2	1.5	0.4
Osteichthyes (total)	59.4	8.1	68.8	15.9	0.4	3.7	77.1	38.2	60.6
Ammodytes hexapterus	1.5	0.1	0.1	1.6	<0.1	<0.1	—	—	—
Gadus macrocephalus	—	—	—	—	—	—	1.2	0.1	1.8
Hippoglossoides elassodon	0.5	<0.1	1.3	—	—	—	4.7	0.7	4.1
Icelus sp.	—	—	—	—	—	—	0.6	0.1	0.3
Lumpenella longirostris	—	—	—	1.6	<0.1	0.1	—	—	—
Lumpenus sp.	—	—	—	1.6	<0.1	0.1	10.0	1.8	1.3
Lumpenus fabricii	—	—	—	—	—	—	0.6	0.1	<0.1
Lumpenus maculatus	0.5	<0.1	<0.1	—	—	—	—	—	—
Lumpenus sagitta	—	—	—	1.6	<0.1	0.1	—	—	—
Lycodes sp.	—	—	—	—	—	—	0.6	0.1	0.6
Lycodes brevipes	—	—	—	—	—	—	1.2	0.1	0.9
Mallotus villosus	28.7	4.6	32.7	4.8	0.1	1.4	29.4	8.9	20.5
Theragra chalcogramma	13.4	.7	24.8	1.6	<0.1	1.2	51.8	17.0	21.9
Trichodon trichodon	—	—	—	—	—	—	5.9	0.7	4.3
Zaprora silenus	—	—	—	—	—	—	0.6	0.1	0.7
Unidentified Osteichthyes	30.7	2.7	9.9	14.3	0.3	0.8	37.1	8.5	4.2
Bivalvia (total)	1.0	0.1	0.1	4.8	0.1	0.1	14.7	3.1	0.1
Clinocardium sp.	0.5	<0.1	<0.1	3.2	<0.1	<0.1	1.8	0.2	<0.1
Macoma sp.	—	—	—	—	—	—	0.6	0.1	<0.1
Yoldia sp.	—	—	—	3.2	<0.1	<0.1	12.4	2.6	<0.1
Unidentified Bivalvia	0.5	<0.1	<0.1	1.6	<0.1	<0.1	1.8	0.2	<0.1
Gastropoda (total)	1.0	0.1	0.1	3.2	0.1	0.1	0.6	0.1	<0.1
Naticidae	1.5	0.1	0.1	1.6	<0.1	<0.1	—	—	—
Neptunidae	—	—	—	1.6	<0.1	<0.1	0.6	0.1	<0.1
Trochidae									
Margarities sp.	—	—	—	1.6	<0.1	<0.1	—	—	—
Unidentified Gastropoda	—	—	—	1.6	<0.1	<0.1	—	—	—
Ascidiacea	0.5	<0.1	0.2	—	—	—	—	—	—
Sipuncula (Phylum)	0.1	<0.1	0.1	1.6	<0.1	0.1	2.4	0.4	0.6
Plant	2.0	0.1	1.4	3.2	<0.1	0.9	4.7	0.6	1.0
Pebbles	2.5	—	0.1	19.0	—	0.4	18.8	—	0.4

TABLE 3.—The 10 most frequently occurring food items are categorized by 10 cm length (FL) groups of Pacific cod from 30 to 69 cm. Data is presented by percent frequency of occurrence (*F*), percent by number (*N*), and percent by volume (*V*).

	30-39 cm (*n* = 20)			40-49 cm (*n* = 216)			50-59 cm (*n* = 173)			60-69 cm (*n* = 23)		
Food items	*F*	*N*	*V*	*F*	*N*	*V*	*F*	*N*	*V*	*F*	*N*	*V*
Euphausiacea	78.8	51.3	7.5	54.7	58.3	9.0	48.1	54.8	8.9	27.3	32.7	3.0
Pandalus borealis	36.4	15.1	31.9	61.0	19.0	30.6	69.9	17.7	36.4	81.8	29.7	47.6
Pandalus goniurus	3.0	0.5	0.9	13.8	0.7	1.2	20.2	1.3	1.2	22.8	0.6	0.9
Crangon sp.	5.6	2.4	<0.1	3.5	0.2	0.1	4.0	0.3	0.1	9.0	0.3	0.2
Crangon communis	—	—	—	10.1	0.9	0.4	12.9	1.2	0.3	18.2	1.4	0.5
Eualus macilenta	11.1	0.3	0.3	5.2	0.3	0.1	6.7	0.4	0.1	—	—	—
Chionoecetes bairdi	—	—	—	11.5	1.4	2.5	26.7	3.0	5.1	59.1	5.3	9.0
Lumpenus sp.	—	—	—	4.3	0.9	0.8	3.5	0.5	0.4	4.5	0.2	0.3
Mallotus villosus	14.1	8.7	28.3	19.6	3.5	18.3	24.4	4.7	17.5	22.8	4.7	9.3
Theragra chalcogramma	16.7	9.5	8.5	20.5	4.4	15.2	22.7	6.3	16.7	13.7	6.3	3.9

All sizes of cod examined were feeding on both small and large pink shrimp. Pink shrimp length (CL) distributions measured from cod stomachs and from trawl samples began to overlap at about 12 mm (Fig. 3). Results from the Kolmogorov-Smirnov test comparing pink shrimp length distributions ≥16.5 mm CL from cod stomachs and trawl samples showed no significant difference ($P > 0.10$) in August 1980 and May 1981. There was a significant difference ($P = 0.009$) in the September 1981 sample. No significant difference between length distributions indicates that cod were not feeding on selective sizes of pink shrimp. A significant difference indicates that cod consumed a greater proportion of smaller shrimp than was captured by the trawl.

stomach were 24.4 g for May and 11.2 g for September 1981 (Table 1). Per day, the average amount of pink shrimp consumed by one cod was 8.1 g and 3.7 g for May and September, respectively. The estimated weight of an average length cod was 1,689.5 g for the May survey and 1,720.1 g for the September survey ($W = 0.00000593L^{3.168}$; Owen and Blackburn 1983). Cod biomass estimates were 1,621 t for May and 591 t September, respectively.

Based on the above parameters, estimates of pink shrimp biomass consumed were calculated using the May and September data (Table 5). With May data, Pacific cod consumed an estimated 875 t of pink shrimp over the 112-d period, whereas the

TABLE 4.—Size range and mean size of prey and trawl caught animals. Size data were not collected for snow crab in the trawl. CL = carapace length; FL = fork length; CW = carapace width.

	Number measured		Size range		Mean size	
	Prey	Trawl	Prey	Trawl	Prey	Trawl
Pink shrimp	1,143	7,823	6.5-26.0 mm (CL)	10.0-26.0 mm (CL)	16.2 mm	18.0 mm
Humpy shrimp	102	202	8.0-17.5 mm (CL)	10.5-18.5 mm (CL)	13.5 mm	13.9 mm
Walleye pollock	236	2,100	6.0-25.0 cm (FL)	6.0-63.0 cm (FL)	10.3 cm	22.8 cm
Snow crab	69	—	6.0-42.0 mm (CW)	—	22.2 mm	—

Estimate of Pink Shrimp Biomass Consumed

The extent of the Pacific cod predation on pink shrimp in Pavlof Bay was examined by estimating total biomass consumed during a 112-d period from late May through mid-September 1981. Analysis using Jones' (1974) equation indicated that for both 1981 surveys the average amount of food found in a cod stomach was digested in about 3 d. The average weights of undigested pink shrimp found in a cod

TABLE 5.—Calculation of the total pink shrimp biomass consumed by Pacific cod during a 112-d period from late May through mid-September 1981. Two estimates are presented using the May and September data.

	May 1981	Sept. 1981
Mean weight of pink shrimp consumed daily by one cod (g)	8.1	3.7
112-d consumption by one cod (g)	907.2	414.4
Weight of an average length cod (g)	1,689.5	1,720.1
Proportion of pink shrimp eaten relative to cod weight	0.54	0.24
Cod biomass estimate (t)	1,621	591
Pink shrimp biomass consumed (t)	875	142

September information suggests that cod consumed an estimated 142 t of pink shrimp over the same period.

DISCUSSION

Cod Diet

Pink shrimp was the dominant food item identified by frequency of occurrence (63%) and percent volume (31%). In the Gulf of Alaska near Kodiak Island, Jewett (1978) reported pink shrimp occurring in 4% of the Pacific cod examined, and Hunter (1979) found pink shrimp occurring in 24% of the cod, representing 16% of the diet by weight. Hunter also identified pink shrimp as the dominant food item in his study. However, our study exhibited a higher percent frequency of occurrence for that species. Unlike our study, Jewett and Hunter's studies included examinations of cod from offshore areas, which were not regions of high pink shrimp density (Gaffney 1977[3]).

The prey size ranges of walleye pollock and snow crab in our study were similar to those found by Hunter (1979). In our study, the maximum length of walleye pollock consumed by cod was 25 cm FL, although the majority were between 6 and 20 cm. Hunter (1979) reported that cod around Kodiak Island were feeding on groundfish (including walleye pollock) between 2 and 24 cm. The snow crab consumed by cod in Pavlof Bay ranged from 5 to 45 mm CW, which is similar to the size range of snow crab (1-40 mm) found in cod stomachs by Hunter (1979). Jewett (1978) reported a greater size range of snow crab occurring in cod stomachs (from 1.8 to 70 mm), yet 78% were between 7 and 23 mm. The maximum size of cod examined by Jewett was 92 cm TL (total length) compared with 69 cm FL in our study, and this difference probably accounts for his observation of larger snow crab.

We believe that cod were not feeding on selected sizes of shrimp. The size ranges and mean sizes of pink shrimp and humpy shrimp consumed by cod were similar to those found in the trawl (Table 4). However, cod did consume small (<10.0 mm CL) pink shrimp that were not captured by the trawl. We believe this is due to trawl bias toward larger shrimp. No significant difference was found between pink shrimp length distributions from cod stomachs and trawl samples in two of the three surveys, indicating that cod were not feeding on selected sizes of shrimp. There was a significant difference ($P = 0.009$) for the September 1981 survey. In this sample either cod selected slightly for smaller shrimp or the trawl caught slightly larger shrimp.

Estimate of Pink Shrimp Biomass Consumed

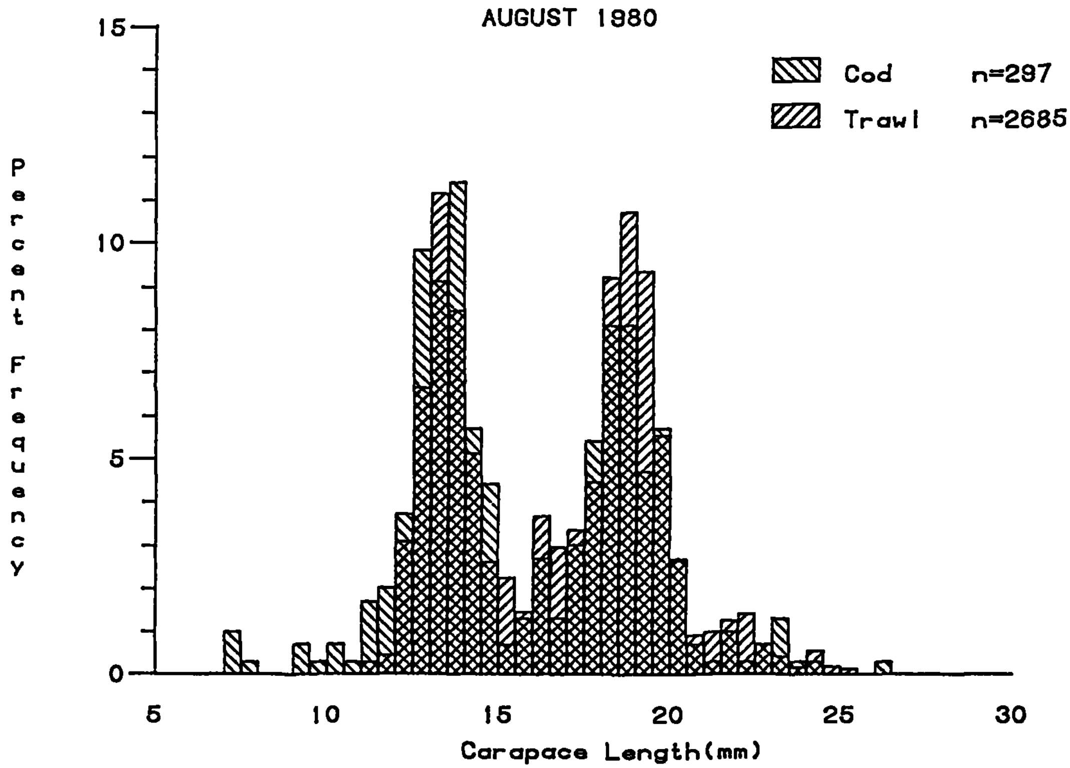
The estimated pink shrimp biomass in Pavlof Bay decreased by 1,501 t between the May and September surveys in 1981. During this period we estimated that Pacific cod consumed between 142 and 875 t of pink shrimp. Since Pavlof Bay is believed to contain a geographically isolated stock of pink shrimp (Anderson 1981) and because the bay was closed to shrimp fishing in 1981, cod predation is responsible for at least part of the biomass decline.

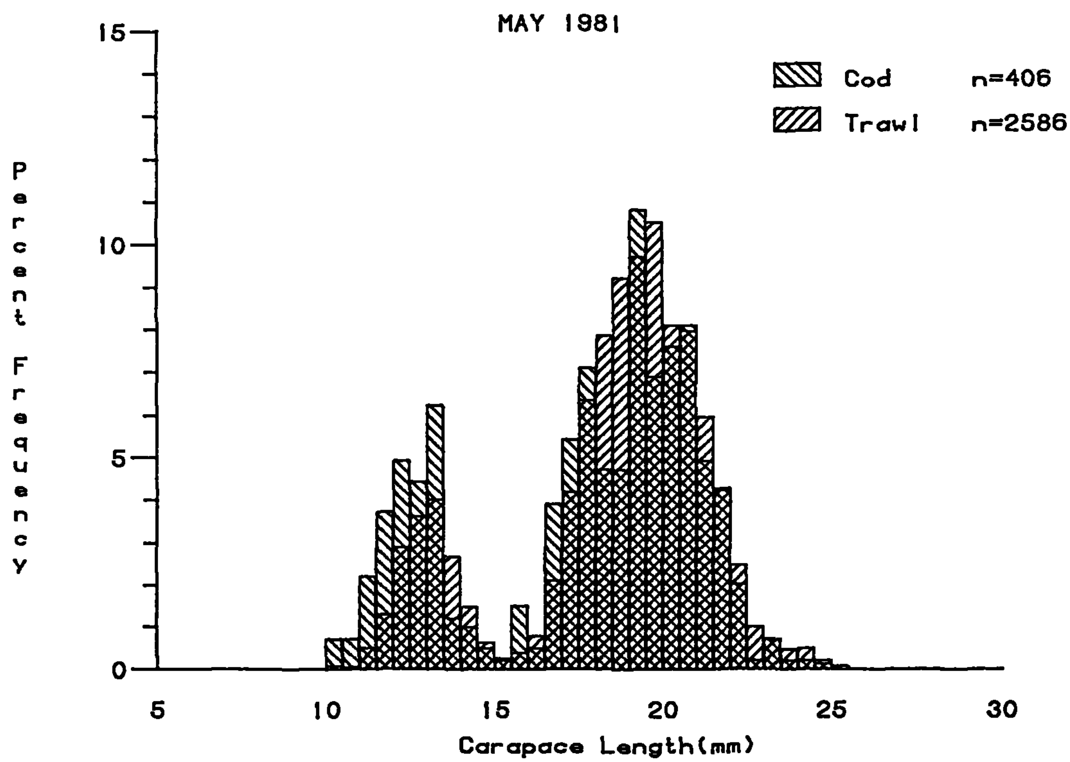
The estimate of pink shrimp biomass consumed over the 112-d period using the May survey data was 733 t more than was estimated using September data. Two of the parameters used to calculate consumption estimates were responsible for this difference. In May the mean weight of pink shrimp consumed daily by one cod was about double the amount in September. Pink shrimp were more abundant and made up a larger percentage of the diet in May than in September. Additionally, cod biomass was estimated to be almost three times higher in May than it was in September causing the consumption estimate to be higher in May (Table 5).

We belive that consumption of pink shrimp by cod probably lies toward the high end of the calculated range (142-875 t). Biomass estimates were probably conservative for pink shrimp and Pacific cod. Biomass was calculated on the assumption that all cod and shrimp were on bottom and all those in the path of the trawl were caught. This is not true for cod or shrimp. For example, Edwards (1968) reported that up to 49% of the gadoids in the path of a trawl avoid capture. Also, an estimate of the catchability of shrimp with the high-opening shrimp trawl was about 56% (Alaska Department of Fish and Game 1982[4]). If the cod biomass estimate was conservative, the consumption of pink shrimp by cod would be higher than calculated. Further, if the pink shrimp biomass estimate was conservative, the calculated

[3]Gaffney, F. G. 1977. Kodiak pandalid shrimp research. Commercial Fisheries Research and Development Act, Project No. 5-36-R. Unpubl. manuscr., 76 p. National Marine Fisheries Service, NOAA, Wash., DC 20235.

[4]Westward Region Shellfish Staff, Alaska Department of Fish and Game. 1982. Westward Region Shrimp Fishery Management Plan. Unpubl. manuscr., 70 p. Alaska Department of Fish and Game, Kasheruaroff, Mission Road, P.O. Box 686, Kodiak, AK 99615.


AUGUST 1980
Cod n=297
Trawl n=2685
Percent Frequency
Carapace Length(mm)
0
5
10
15
5
10
15
20
25
30


MAY 1981
Cod n=406
Trawl n=2586
Percent Frequency
Carapace Length(mm)
0
5
10
15
5
10
15
20
25
30

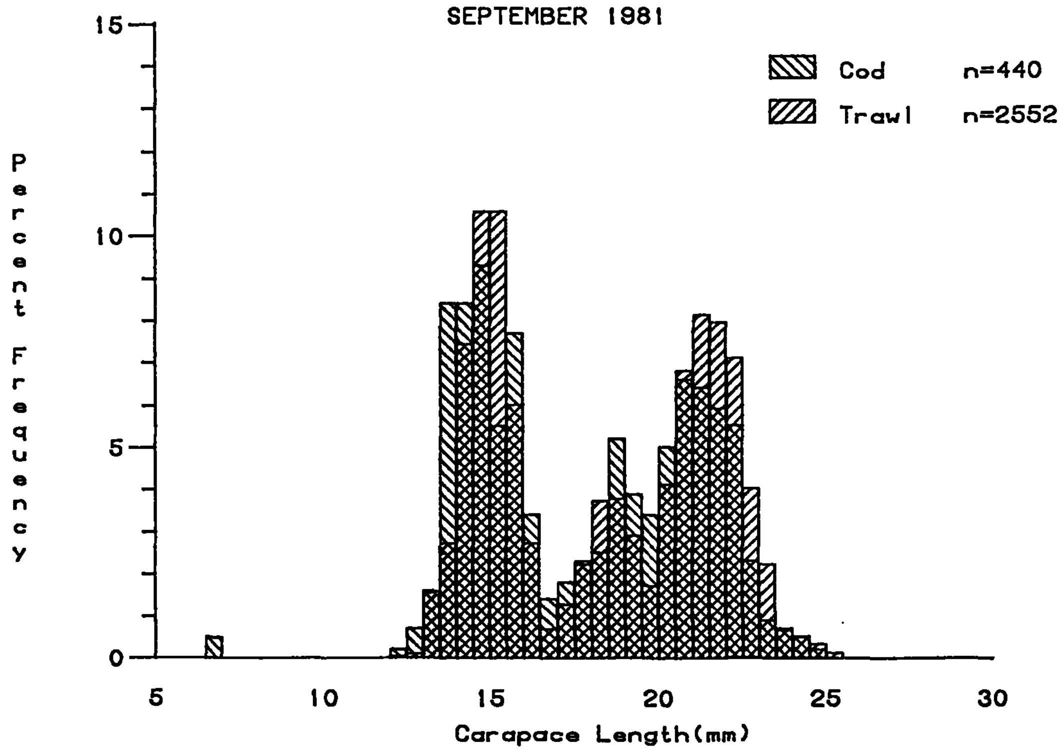


FIGURE 3.—Size distribution of pink shrimp from trawl samples and Pacific cod stomachs for August 1980 and May and September 1981.

biomass decline of pink shrimp between May and September 1981 would also be greater.

Pacific cod are probably feeding on pink shrimp in Pavlof Bay the entire year although the largest concentrations of cod are likely to occur from spring through fall. Trawl survey data from Pavlof Bay indicate that cod biomass decreased from 93 t in September 1978 to 20 t in February 1979 and then increased to 371 t in May 1979. Pacific cod are migratory; they move to shallow areas (<90 m) in spring to feed and return to deeper areas (165-247 m) offshore in fall or winter to spawn (Moiseev 1953). The majority of Pavlof Bay is <90 m deep which is not preferred winter habitat.

Although we believe that Pacific cod predation has an effect on the present reduced population of pink shrimp, predation probably was not the primary reason for the initial decline of pink shrimp in Pavlof Bay that began in 1977. At that time Pacific cod abundance was just beginning to increase (Fig. 2). Fishing removed about 3,819 t (calculated from ADF&G commercial catch data and NMFS survey data) of pink shrimp between the 1977 and 1978 surveys, which was 30% of the estimated available biomass in 1977. This harvest and the dying out of the strong 1971 year class (Anderson 1981) were probably responsible for most of that initial decrease. Cod predation did become a factor, however, once the pink shrimp resource was reduced. This impact on pink shrimp appears substantial despite the reduction of cod in Pavlof Bay (Fig. 2).

ADF&G (footnote 4) has reported diminishing pink shrimp stocks in other areas of the western Gulf of Alaska. Some areas that once contained high concentrations of pink shrimp experienced reductions in abundance at the same time as Pavlof Bay. In most areas, no increase in pink shrimp abundance was observed through 1982, though many areas were closed to fishing. Like Pavlof Bay, these other areas experienced an increase in Pacific cod abundance about the same time as pink shrimp populations were declining. Cod predation may play a role in keeping these reduced pink shrimp stocks from rebuilding to former levels.

ACKNOWLEDGMENTS

Thanks to Pete Jackson and Dave Jackson, Alaska

Department of Fish and Game, for collecting the May 1981 stomach samples.

LITERATURE CITED

ALVERSON, D. L., AND W. T. PEREYRA.
1969. Demersal fish explorations in the northeastern Pacific Ocean - an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J. Fish. Res. Board Can. 26:1985-2001.

ANDERSON, P. J.
1981. A technique for estimating growth and total mortality for a population of pink shrimp *Pandalus borealis* from the western Gulf of Alaska. *In* T. Frady (editor), Proceedings of the International Pandalid Shrimp Symposium, February 13-15, 1979, Kodiak, Alaska, p. 331-342. Univ. Alaska, Fairbanks, AK, Sea Grant Program, Sea Grant Rep. 81-3.

EDWARDS, R. L.
1968. Fishery resources of the North Atlantic area. *In* D. W. Gilbert (editor), The future of the fishing industry of the United States, p. 52-60. Univ. Wash. Publ. Fish., New Ser. 4.

HUNTER, M. A.
1979. Food resource partitioning among demersal fishes in the vicinity of Kodiak Island, Alaska. M.S. Thesis, Univ. Washington, Seattle, 120 p.

HURTUBIA, J.
1973. Trophic diversity measurement in sympatric predatory species. Ecology 54:885-890.

JEWETT, S. C.
1978. Summer food of the Pacific cod, *Gadus macrocephalus*, near Kodiak Island, Alaska. Fish. Bull., U.S. 76:700-706.

JONES, R.
1974. The rate of elimination of food from the stomachs of haddock, *Melanogrammus aeglefinus*, cod *Gadus morhua* and whiting *Merlangius merlangus*. J. Cons. Int. Explor. Mer 35:225-243.

MINET, J. P., AND J. B. PERODOU.
1978. Predation of cod, *Gadus morhua*, on capelin, *Mallotus villosus*, off eastern Newfoundland and in the Gulf of St. Lawrence. Int. Comm. Northwest Atl. Fish. Res. Bull. 13: 11-20.

MOISEEV, P. A.
1953. Treska i kambaly dalnevostochnykh morei (Cod and flounders of far-eastern seas). [In Russ.] Izv. Tikhookean. Nauchno-Issled Inst. Rybn. Khoz. Okeanogr. 40:1-287. [Engl. transl. by Fish. Res. Board Can., Transl. Ser. No. 119, 576 p.]

OWEN, D. L., AND J. E. BLACKBURN.
1983. Bottomfish catch and trawl data from an otter trawl survey in northern Shelikof Strait, Chignik area, and Chiniak gully, Alaska, July and August 1981. Alaska Dep. Fish Game, Tech. Data Rep. 82, 68 p.

SOKAL, R. R., AND F. J. ROHLF.
1969. Biometry, the principles and practice of statistics in biological research. W. H. Freeman and Company, San Francisco, 776 p.

WATHNE, F.
1977. Performance of trawls used in resource assessment. Mar. Fish. Rev. 39(6):16-23.