NOAA Technical Memorandum NMFS F/NWC-207

Groundfish Food Habits and Predation on Commercially Important Prey Species in the Eastern Bering Sea from 1984 to 1986

Editor:
Patricia A. Livingston

Authors:
Geoffrey M. Lang, Patricia A. Livingston,
Robert Pacunski, Jeffrey Parkhurst,
and Mei-Sun Yang

August 1991

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information, and has not received complete formal review, editorial control, or detailed editing.

Groundfish Food Habits and Predation on Commercially Important Prey Species in the Eastern Bering Sea from 1984 to 1986

Editor: Patricia A. Livingston

Authors: Geoffrey M. Lang, Patricia A. Livingston,
Robert Pacunski, Jeffrey Parkhurst,
and Mei-Sun Yang

Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, BIN C15700
Seattle, WA 98115-0070

August 1991

This document is available to the public through:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

ABSTRACT

This document describes the feeding habits of major groundfish species in the eastern Bering Sea based on stomach content information collected since 1984. The total consumption of commercially important prey species by groundfish populations is calculated for the main feeding period of May through September during 1984, 1985, and 1986. Estimated predation mortality in terms of numbers and biomass during this period is presented. These estimates are compared with existing knowledge of prey species abundance. Possible impact of predation on prey species abundance patterns is discussed.

CONTENTS

EXECUTIVE SUMMARY

by

Patricia A. Livingston

This document summarizes groundfish predation on commercially important stocks of fish and crabs on the eastern Bering Sea shelf from 1984 to 1986. The amount of predation is calculated using estimates of predator biomass, daily ration, and the proportion of various prey categories in the stomach contents. Estimates are presented in terms of numbers and biomass of prey consumed during the main sampling period of May through September of each year.

Predator and Prey Species

Consumption by the following groundfish predators is included in this report because these species are dominant members of the eastern Bering Sea shelf fish fauna that consume commercially important fish or crab. The commercially important prey eaten by some of these predators are also listed below:

Groundfish predators	Commercially important prey
Walleye pollock	Walleye pollock
Pacific cod	Pacific cod
Yellowfin sole	Yellowfin sole
Greenland turbot	Greenland turbot
Arrowtooth flounder	Arrowtooth flounder
Flathead sole	Flathead sole
	Rock sole
	Pacific halibut
	Pacific herring
	King crab
	Snow crab
	Tanner crab

Food habits of less abundant groundfish such as Pacific halibut, rock sole, and Alaska plaice are summarized in a section on other species, but no consumption estimates are presented for these species due to insufficient sample sizes. Future reports will include these species' consumption in a more comprehensive manner.

Total Groundfish Consumption Estimates

The total amount of each prey consumed from May to September of 1984 to 1986 is presented below. These estimates are the sum of the consumption by each predator species. Consumption of walleye pollock also includes cannibalism estimates during October to December of 1985 and 1986. Biomass consumed is converted to numbers consumed using available prey size information. If prey size information is lacking for a predator, numbers consumed cannot be estimated. Total numbers consumed are underestimates in these cases and are shown in parentheses.

Predation on King Crabs

	1984	1985	1986
Biomass (metric tons)	2,684	1,136	2,867
Numbers (millions)	(35,566)	(2)	(5)

MAIN PREDATORS: Pacific cod, yellowfin sole.
MAIN SIZES CONSUMED: soft-shell females approximately 100 mm CL (cod) and megalops larvae (yellowfin sole).

Cod consumed mainly red king crab although most of the king crab consumed in 1985 was blue king crab. Crabs were assumed to be soft-shell females based on timing and location of consumption by cod. High numbers of king crab consumed in 1984 were due to predation on small megalops larvae of blue king crab by yellowfin sole near the Pribilof Islands.

Predation on Snow Crabs (*Chionoecetes opilio*)

	1984	1985	1986
Biomass (metric tons)	98,818	132,467	149,078
Numbers (millions)	(30,921)	12,235	13,042

MAIN PREDATORS: Pacific cod, yellowfin sole, flathead sole.
MAIN SIZES CONSUMED: pre-fishery juveniles less than 70 mm CW.

Cod were responsible for 80% of the predation in terms of biomass in all 3 years. Yellowfin sole consumed the most snow crab in 1984 in terms of numbers. Biomass and numbers of snow crab consumed by yellowfin sole and flathead sole decreased from 1984 to 1985. A gradual increase in size of snow crab consumed from 1984 to 1986 suggest that these predators were preying on an abundant year class of crab, possibly the 1983 or 1984 year class.

Consumption of age-1 snow crab by all predators, expressed as a proportion of reconstructed age-1 population size in 1984 and 1985, was 83 and 34%, respectively. These large changes in percent predation removals are an indication that predators may be exerting density-dependent influences on snow crab populations at age 1.

Predation on Tanner Crabs (*Chionoecetes bairdi*)

	1984	1985	1986
Biomass (metric tons)	63,189	89,991	48,822
Numbers (millions)	(152,850)	(13,926)	9,898

MAIN PREDATORS: Pacific cod, yellowfin sole, flathead sole.
MAIN SIZES CONSUMED: pre-fishery juveniles less than 70 mm CW.

Most Tanner crab biomass consumed was due to cod predation in all 3 years. In 1984, most Tanner crab eaten in terms of numbers were consumed by yellowfin sole. The increasing size of crab consumed from 1984 to 1986 suggests that predators were tracking an abundant year class of Tanner crab, possibly the 1984 year class.

Predation as a percent of reconstructed age-1 population size in 1984 and 1985 was 95 and 96%, respectively. These are high but stable rates of removal across years, indicating predators may not be exerting a density-dependent influence on Tanner crab population size.

Predation on Pacific Cod

	1984	1985	1986
Biomass (metric tons)	13,430	9,978	9,302
Numbers (millions)	(1,124)	3,263	(76)

MAIN PREDATORS: Pacific cod, walleye pollock, flathead sole, yellowfin sole.
MAIN SIZES CONSUMED: mostly less than 10 cm (age 0).

Pacific cod was the main predator in terms of biomass removals during 1985 and 1986. Flathead sole and yellowfin sole, which tend to eat only age-0 cod, consumed the most cod in terms of numbers in 1984.

Predation on Walleye Pollock

	1984	1985	1986
Biomass (metric tons)	314,783	3,846,851	1,493,712
Numbers (millions)	(47,832)	(1,049,617)	(231,641)

MAIN PREDATORS: Walleye pollock, Pacific cod, arrowtooth flounder, flathead sole, yellowfin sole, Greenland turbot.
MAIN SIZES CONSUMED: mostly less than 15 cm (primarily age 0).

Walleye pollock was the main predator both in terms of numbers and biomass removals during 1985 and 1986. Pollock stomach samples were not taken during 1984, so the total predation estimates in that year are much lower than the other 2 years. More age-0 pollock were consumed in 1985 than in 1986, which may be the result of increased density of age-0 pollock available to predators in 1985 relative to 1986.

Predation on Pacific Herring

	1984	1985	1986
Biomass (metric tons)	0	19,322	44,440
Numbers (millions)	0	(303)	(554)

MAIN PREDATORS: Pacific cod, walleye pollock.
MAIN SIZES CONSUMED: 10 to 30 cm.

Cod consumed the most herring in 1985 while pollock was the main predator in 1986. Groundfish predation, expressed as a percentage of available herring biomass, was 4% in 1985 and 11% in 1986. Herring consumption by these predators tends to be sporadic in time and space and may depend on encounter rates of herring schools rather than overall biomass.

Predation on Flatfish

	1984	1985	1986
Biomass (metric tons)	82,433	70,568	95,908
Numbers (millions)	108,823	(7,957)	(2,760)

MAIN PREDATORS: Pacific cod, yellowfin sole.
MAIN SIZES CONSUMED: 5 to 25 cm (Pacific cod),
less than 5 cm (yellowfin sole).

Flatfish species consumed included arrowtooth flounder, flathead sole, rock sole, yellowfin sole, Greenland turbot, and Pacific halibut. Most of the biomass was consumed by Pacific cod with the main prey species consisting of yellowfin sole. Cod also ate more flathead sole and rock sole, in terms of biomass, than other groundfish predators. Yellowfin sole was the only groundfish predator that consumed Greenland turbot and Pacific halibut. Arrowtooth flounder cannibalism accounted for most of the biomass removals of arrowtooth flounder in 1984 while pollock was the main predator in 1985. Evidence suggests groundfish predators do not have a significant impact on flatfish population size.

INTRODUCTION

by

Patricia A. Livingston

Many large marine fish are predators of either juvenile or small adult fish and crab. Because predation forms the largest part of natural mortality of young fish and crab, it is important to estimate the magnitude of these predation losses from commercially important populations. Population models that assume constant natural mortality rates due to a lack of information on actual rates can be improved by providing more accurate estimates of predation losses. The move towards multispecies management of stocks can be made through studying the food web connections between components of marine ecosystems, which include fish, crabs, marine mammals, and birds.

The primary purpose of the Food Habits Program of the Resource Ecology and Fishery Management Division (REFM) at the Alaska Fisheries Science Center is to study the food habits of key fish predators in the eastern Bering Sea that are consumers of commercially important fish or crab. These fish and the fish they consume are commercially important species and form a major part of the groundfish biomass in the eastern Bering Sea. Program objectives include providing impact assessments relating to fish predation effects on prey species populations, improving population model estimates of predation mortality by marine fish, and detecting possible changes in abundance and distribution of juvenile fish and crab populations.

This collection of papers reports the progress of the Food Habits Program of the Resource Ecology and Fisheries Management Division of the AFSC in analyzing available data from 1984 to 1986 on the predation of commercially important fish and crab species. This first paper details the methods used to estimate the total biomass and numbers of prey consumed by the major groundfish species in the area. Subsequent papers summarize the food habits and total prey consumption by the following predators: walleye pollock, Pacific cod, yellowfin sole, Greenland turbot, arrowtooth flounder, and flathead sole. A section that outlines the available data on food habits of noncommercial fish in the Bering Sea is also included. The final paper summarizes the consumption of commercially important prey by all the major predators.

METHODS

by

Patricia A. Livingston

Sample Collection and Laboratory Analysis

Stomachs were collected from major groundfish species during 1984, 1985, and 1986 in the eastern Bering Sea. Samples were taken year-round, but primarily during May through September, using bottom and pelagic trawl gear on research and commercial fishing vessels. Sampling occurred throughout the 24-hour day, although primary sampling times were between 0600 and 2000 Alaska daylight time. For all species except walleye pollock (Theragra chalcogramma), stomachs were removed at sea and placed in cloth bags labelled with information regarding the location of capture and the fork length, sex, and sexual maturity of the fish. Fish showing evidence of regurgitation (i.e., food in the mouth or throat, or a flaccid stomach) were not included in the sample. Stomachs were preserved in 10% formalin and later transferred to 70% ethyl alcohol. Contents were identified to the lowest taxonomic level possible and enumerated. Wet weights were recorded after the contents were blotted with paper towels. Standard length measurements of prey fish and carapace width or lengths of crab prey were taken when whole prey were available.

There was no quantitative stomach information collected for walleye pollock in 1984 but in subsequent years a combination of collection and analysis methods has been used. Stomach information collected during the main sampling period of May through September (months 5 to 9) includes stomachs collected and analyzed using the methodology described above. Most stomach information collected outside the main sampling period of May through September is from fishery observers aboard commercial fishing vessels. These observers perform quantitative shipboard scans of pollock stomach contents. Only fish that had not regurgitated were selected for scans. Once a fish was selected for scanning, the stomach was excised and the volume of the stomach contents was determined by the water displacement method by emptying the stomach contents into a graduated cylinder or beaker containing a known amount of water. The difference between the initial water level and the new water level after the stomach contents were added was the stomach volume. Volume was later converted to weight by assuming 1 ml of volume displaced was equal to 1 g. The contents were then emptied onto a petri dish or tray, prey were separated into the lowest taxonomic categories possible, and the volume (expressed as a percentage of the total) was visually estimated and recorded for each prey category. Numbers of individuals in a prey category were counted, if practical. Measurements of fish and crab prey were taken if an item was whole.

For both quantitative shipboard scans and detailed laboratory analysis, the prey category "fishery discards" was used if the ingested item was obviously consumed dead upon its return to the sea after being processed aboard a ship (i.e., a consumed fish that had its head sliced off with a clean diagonal cut). Due to the difficulties involved in shipboard identification of taxonomic categories, particularly by inexperienced biologists, some prey taxa may have been misidentified in shipboard stomach scans.

Data Analysis

General Diet

General diet analysis was performed by combining all stomach data for a groundfish species regardless of year, size, season, or sampling area. Seasonal diets were calculated by grouping stomachs according to season of capture. Interannual differences in diet were obtained by lumping stomach data from the main sampling period in each year (months 5 to 9). Percentages of prey items shown in these figures are percentages calculated from each 10 cm predator size group, placed at the midpoint of the size group. Prey size frequencies shown in the general diet section for each species are size frequencies from stomach samples taken throughout the year. Linear regressions of predator size versus prey size were performed using the program P6D in the BMDP statistical package.

Predator Population Consumption

Estimates of the total biomass of each prey species consumed by the shelf portion of each groundfish population were calculated according to Mehl and Westgard (1983):

$$C_i = DR_i * D * B_i * P_i \qquad (1)$$

where C_i is the consumption (by weight) of a prey species by size group i of a predator species, DR_i is the daily ration (as a proportion of body weight daily, BWD) of predator size group i, D is the number of days in the sampling period when the prey species was vulnerable to predation, B_i is the biomass of the predator size group i, and P_i is the proportion by weight of the prey species in the diet of predator size group i.

Total consumption estimates using Equation (1) were computed within each major stratum of the eastern Bering Sea (Fig. 1). These strata were devised by the Resource Assessment and Conservation Engineering (RACE) Division of the Alaska Fisheries

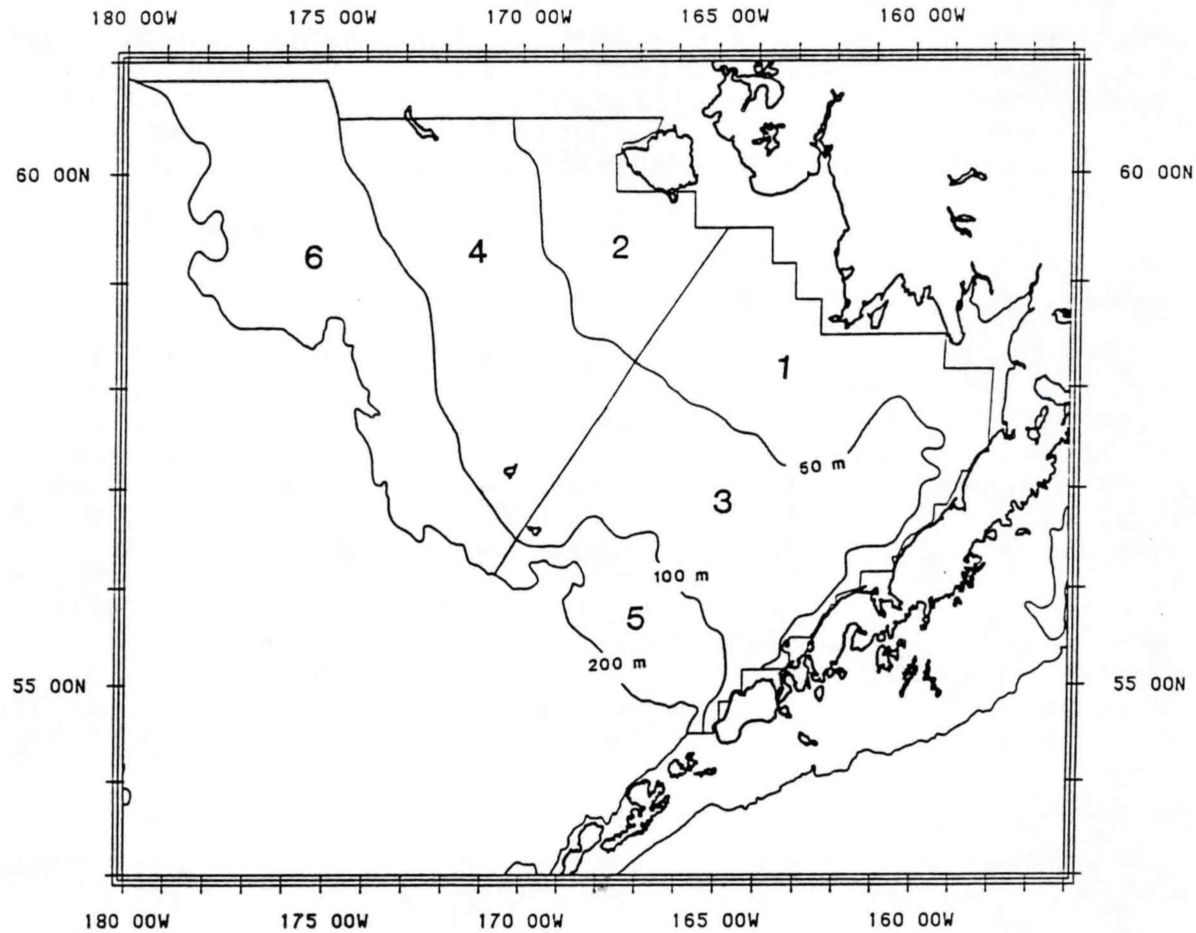


Figure 1.--Map of the eastern Bering Sea showing bottom depth zones and strata.

Science Center to reflect, in a general fashion, natural boundaries based on bottom depth. Strata 1 and 2 are considered inner shelf areas, strata 3 and 4 comprise the middle shelf, and strata 5 and 6 are the outer shelf zones.

Predator size groupings used for total consumption estimates were based on size groupings used previously (Livingston et al. 1986) and on knowledge of each predator's diet. If consumption of commercially important prey groups differed among predator sizes, then predator size groups were chosen to minimize such consumption differences within a size group.

Daily ration (DR) estimates were derived using some basic bioenergetic considerations as an alternative to using rations estimated from gastric evacuation rate models and field estimated stomach content weights. As Livingston et al. (1986) showed, estimates derived from gastric evacuation rate models tend to be lower than expected based on known annual growth patterns of eastern Bering Sea species. Part of the problem with rations estimated in this fashion may be due to low mean stomach content weights from field collected stomachs due to undetected regurgitation of some stomach contents. It is believed that more realistic rations can be derived using bioenergetic considerations such as annual growth increments and food conversion efficiency estimates and thus, that is the approach used here. Daily growth in weight of each species size group was estimated from annual growth increments by length and length-weight relationships for each species. A gross conversion efficiency rate of food to somatic tissue for juvenile fish was assumed to be 25% and for adult fish was assumed to be 10% based on estimates presented by Brett and Groves (1979). Daily growth increments could thus be converted to the amount of food required to produce that growth. When the daily food requirements are divided by mean fish weight then the result is daily ration expressed as a fraction of body weight.

The time period of analysis (D) for total consumption estimates by all predator species was months 5 to 9, or 153 days. The analysis was restricted to this time period because most stomach samples are collected during this period and survey estimates of groundfish biomass are obtained at this time. Unquantified migrations of fish into different strata occur and insufficient numbers of stomach samples are taken in each stratum outside of this time period. Thus, total consumption estimates made outside of this time period would not be very reliable. Since months 5 to 9 are probably the main feeding and growth period for groundfish in the eastern Bering Sea, these total consumption estimates can be considered conservative estimates of total annual predation removals by these groundfish populations.

Total consumption estimates of king crabs by Pacific cod were restricted to a 31-day period during months 5 to 9 when it is most likely that soft-shell (newly molted) king crabs were available.

Total consumption estimates from walleye pollock as a predator were also made for months 10 to 12 since there were more walleye pollock stomach content data available during this time period when compared to the other groundfish species. However, pollock biomass estimates for each stratum were assumed to be the same as during the months 5 to 9 period. Unknown changes in pollock biomass within each stratum cause greater uncertainty in these estimates than those derived during the main feeding period.

Predator biomass estimates (B) for all species except walleye pollock and yellowfin sole were obtained from RACE Division bottom trawl survey data. These trawl surveys are conducted in the eastern Bering Sea during months 6 to 8 of each year. Biomasses of arrowtooth flounder and Greenland turbot include only the shelf portion of the populations. Thus, total predation estimates for these populations refer only to predation occurring on the shelf. Biomass estimates of walleye pollock, a semipelagic fish, are probably underestimated by the trawl survey so cohort analysis estimates of Wespestad, Bakkala, and Dawson (1990) are used and biomass is apportioned into each stratum by using the proportion of the trawl survey biomass found in each stratum. Biomass of yellowfin sole from trawl surveys has fluctuated unreasonably in recent years, so cohort analysis estimates of biomass for age-7+ fish from Bakkala and Wilderbuer (1990) were used along with trawl survey estimates of fish less than age 7. Cohort analysis estimates of yellowfin sole biomass were apportioned into each stratum using the proportion of the trawl survey biomass found in each stratum.

The proportion by weight of each prey item in the diet of each predator size group was calculated for each stratum in the following fashion. First, all stomach content data for a particular fish species size group that was collected in a stratum during months 5 to 9 in a given year were used. Estimates of the percentage by weight of a given prey item in the stomach contents were then calculated for each 20 nautical mile square in the stratum where stomachs were collected. The estimated percent by weight of the prey item in the whole stratum was then calculated as the average of the percentages from each 20 nautical mile square. Standard errors of the stratum percentages were derived from the variance between squares.

For strata where prey size information was available, total consumption estimates in terms of biomass were converted to numbers. The size frequency of a particular prey in the stomach contents of a given predator size group from a stratum in a particular year during months 5 to 9 was used along with the length-weight relationship for the prey to convert biomass consumed within a particular prey size interval to numbers consumed.

Snow (Chionoecetes opilio) and Tanner (C. bairdi) crabs and walleye pollock were assigned to approximate age groups based on the following age-length conversions:

Age (years)	Carapage width (mm) C. opilio	Carapage width (mm) C. bairdi	Standard length (cm) Walleye pollock mo. 5-9	Standard length (cm) Walleye pollock mo. 10-12
0	<5	<9	<10	<14
1	5-24	9-34	10-19	14-22
2	25-39	35-49	20-27	23-29
3	40-59	50-69	28-33	30-34
4	60-74	70-84	34-37	35-38
5	75-94	85-104	38-40	39-41
6+	≥95	≥105	≥41	≥42

CITATIONS

Bakkala, R., and T. K. Wilderbuer. 1990. Yellowfin sole. In assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1991. North Pacific Fishery Management Council, Anchorage, Alaska.

Brett, J. R., and T. D. D. Groves. 1979. Physiological energetics. In W. S. Hoar, D. J. Randall, and J. R. Brett (editors), Fish physiology, Vol. VIII: Bioenergetics and growth, p.279-352. Academic Press, New York.

Livingston, P. A., D. A. Dwyer, D. L. Wencker, M. S. Yang, and G. M. Lang. 1986. Trophic interactions of key fish species in the eastern Bering Sea. Int. N. Pac. Fish. Comm. Bull. 47:49-65.

Mehl, S., and T. Westgard. 1983. The diet and consumption of mackerel in the North Sea. Int. Counc. Explor. Sea, C.M. 1983, Doc. H:34.

Wespestad, V. G., R. G. Bakkala, and P. Dawson. 1990. Walleye pollock. In Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1991. North Pacific Fishery Management Council, Anchorage, Alaska.

FOOD HABITS AND POPULATION LEVEL CONSUMPTION OF GROUNDFISH

WALLEYE POLLOCK

by

Patricia A. Livingston

INTRODUCTION

The walleye pollock (Theragra chalcogramma) is the most abundant groundfish species in the eastern Bering Sea, with an estimated biomass of over 5 million metric tons or over one-third of the biomass of the whole groundfish complex in 1988 (Low 1990). Pollock feed pelagically on small crustaceans and with increasing size become cannibalistic on their young. This cannibalistic tendency is probably the largest source of mortality of young pollock and deserves detailed analysis.

GENERAL FOOD HABITS

Diet

The pollock's feeding mode and tendency toward consumption of commercially important prey can be derived by looking at the percent contribution of various prey in the overall diet (Table 1). Prey items listed in Table 1 are data obtained solely from laboratory-based stomach content analysis. These analyses provide the most accurate data on prey identification and also include counts of prey items. The most frequently occurring prey were invertebrates, primarily copepods, euphausiids, and amphipods. Because of their small size, these crustaceans also tended to dominate the diet in terms of number. Major prey in terms of weight were euphausiids and juvenile pollock. Several commercially important species were consumed by pollock, including Pacific herring (Clupea harengus pallasi), snow crabs (Chionoecetes spp.), Pacific cod (Gadus macrocephalus), juvenile walleye pollock, arrowtooth flounder (Atheresthes stomias), and flathead sole (Hippoglossoides elassodon). Rock sole (Lepidopsetta bilineata) were also noted in the stomach contents of pollock analyzed during shipboard scans. Of these species, only juvenile pollock constituted a large portion of the diet.

The pelagic nature of pollock feeding behavior is well documented in other feeding studies in the Bering Sea (Mito 1974; Dwyer et al. 1987) and the Gulf of Alaska (Clausen 1983). Similar prey types, especially small crustaceans, are consumed by

Table 1.--Diet of walleye pollock, *Theragra chalcogramma*, in the eastern Bering Sea, expressed in percent frequency of occurrence (FO), numerical percentage (N) and percent of total weight (W) of diet.

Prey name*	FO	N	W
Thecosomata (pteropod)	14.60	2.21	0.27
Cephalopoda (squid & octopus)	5.56	0.03	1.40
Crustacea	2.41	0.03	0.01
Copepoda	51.06	49.82	6.31
Mysidacea (mysid)	11.02	0.61	1.41
Cumacea (cumacean)	2.62	0.06	0.02
Amphipoda (amphipod)	42.35	5.16	1.00
Euphausiacea (euphausiid)	63.64	15.32	24.57
Decapoda (shrimp & crab)	11.23	0.91	0.27
Caridea (shrimp)	5.99	0.08	0.45
Pandalidae (shrimp)	7.16	0.09	3.83
Crangonidae (shrimp)	4.78	0.05	0.91
Chionoecetes sp.	1.38	0.06	0.06
Chionoecetes opilio (snow crab)	0.43	0.07	0.00
Chionoecetes bairdi (Tanner crab)	0.11	0.00	0.00
Chaetognatha (arrow worm)	15.98	1.43	0.31
Larvacea Copelata	16.05	23.36	2.45
Osteichthyes Teleostei (fish)	13.68	0.22	7.70
Clupea harengus pallasi (Pacific herring)	0.14	0.00	0.58
Myctophidae (lanternfish)	1.56	0.02	1.49
Gadidae (gadid fish)	2.20	0.01	3.25
Gadus macrocephalus (Pacific cod)	0.04	0.00	0.02
Theragra chalcogramma (walleye pollock)	9.92	0.20	40.96
Pleuronectidae (flatfish)	0.46	0.00	0.07
Atheresthes stomias (arrowtooth flounder)	0.04	0.00	0.18
Hippoglossoides elassodon (flathead sole)	0.11	0.00	0.00
Miscellaneous and unidentified prey	20.20	0.26	2.48

Total prey count is	794,970
Total prey weight is	19,555 g
Number of stomachs with food	2,822
Number of empty stomachs	435

*Prey name indicates highest level of identification possible for that category.

pollock in other regions. The main difference in pollock feeding in the eastern Bering Sea compared with other regions appears to be the predominance of cannibalism in the eastern Bering Sea compared with the relatively low occurrence of cannibalism documented in other regions.

Seasonal and Annual Changes in Diet

Prey composition of the walleye pollock diet changed seasonally (Fig. 1). Euphausiids tended to dominate the diet during winter and spring while copepods were important in spring and summer. Pollock larger than 45 cm were cannibalistic in all seasons although they consumed only small amounts of juveniles in spring. Smaller pollock were cannibalistic mainly during autumn.

There were also some differences in diet during the main sampling periods (months 5 to 9 and months 10 to 12) across years (Fig. 2). No quantitative stomach content information was collected for pollock during 1984. The diet composition in the warmer feeding period (months 5 to 9) of the 2 years was very similar. Copepods, euphausiids, and pollock were the main prey items in both 1985 and 1986. The only differences appear to be the larger proportion of copepods in the diet in 1986 and the occurrence of slightly more cannibalism in 1985. These differences might be partly attributable to differences in timing and location of stomach sample collection during the 2 years. Also, survey estimates of pollock abundance at age 1 indicate that the 1985 year class is more abundant than the 1986 year class (Wespestad and Traynor 1990).

Similarly, the interannual differences in diet during the colder portion of the year (months 10 to 12) occurred mainly in the proportions of the main prey items (pollock, euphausiids, and miscellaneous fish) in the diet and not in the prey types consumed. Juvenile pollock formed the largest proportion of the diet in late 1985 while euphausiids were the dominant food in the 1986 diet. Miscellaneous fish consumed in both years were mainly unidentifiable fish remains. Since data from this time of year were mostly obtained from shipboard scans of stomach contents by fishery observers, prey identification was less reliable than at other times of year.

Sizes of Commercially Important Prey Consumed

The relationship between predator size and prey size for walleye pollock consuming other walleye pollock is shown in Figure 3. Although the linear regression is significant ($P < 0.01$), the r-squared value is fairly low (0.14). In general, prey pollock size does increase with increasing predator size but large predatory pollock still seem to focus primarily on small (mostly age-0) prey pollock. This general tendency appears to hold true in particular for 1985 and 1986 (Fig. 4). All size

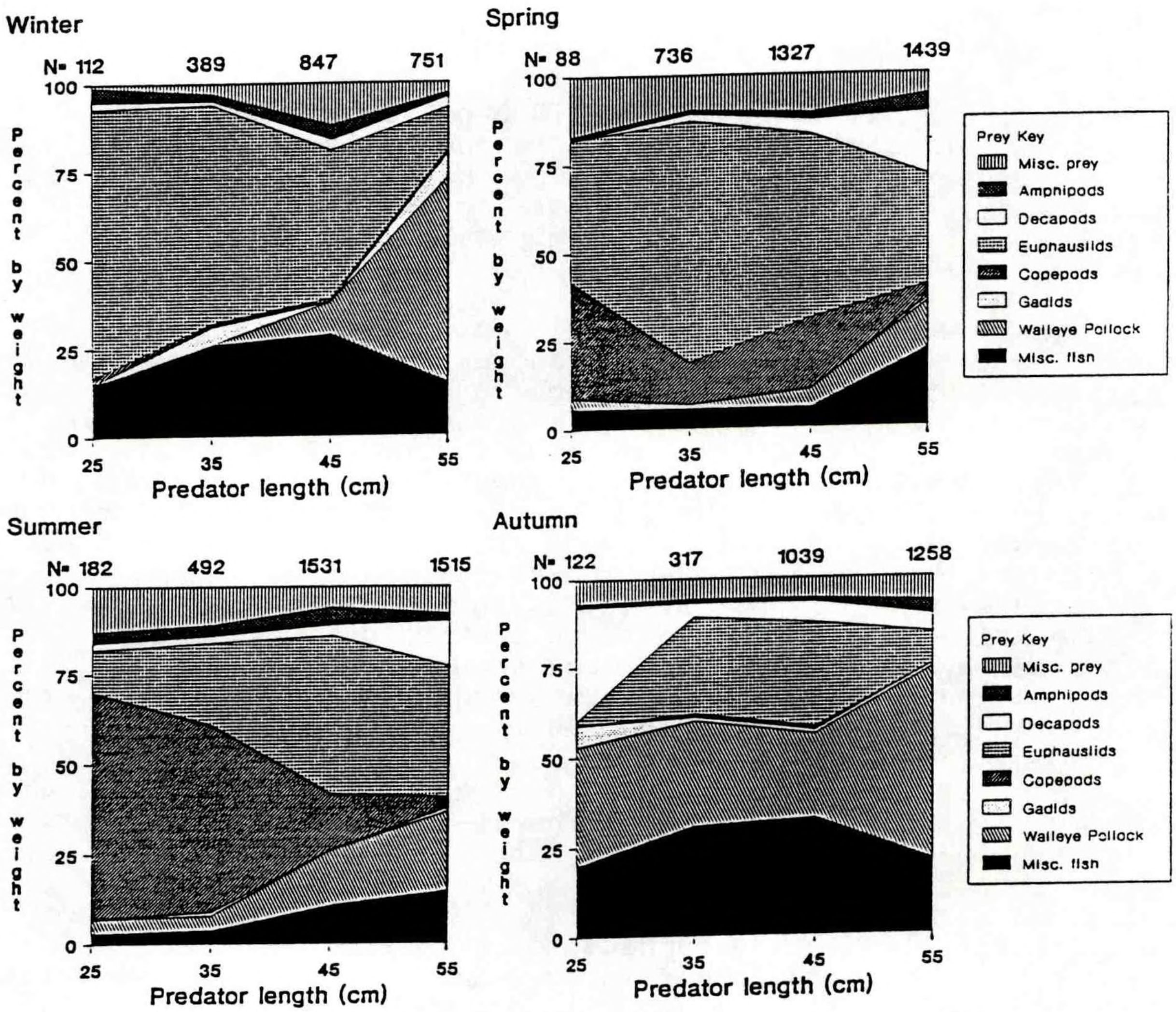


Figure 1.--Diet composition of walleye pollock, in terms of percent by weight, by season and predator size in the eastern Bering Sea; N = number of stomachs.

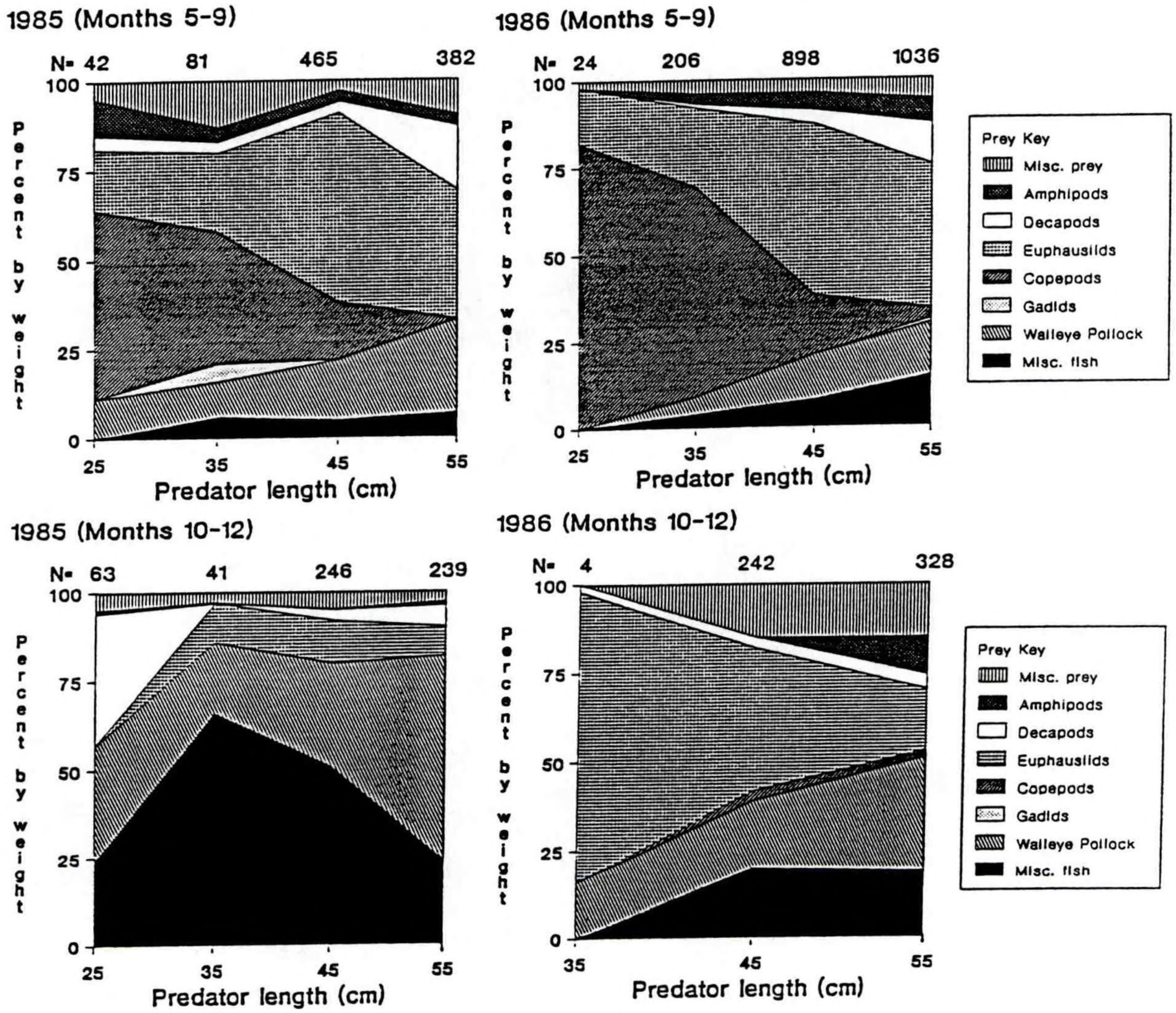


Figure 2.--Diet composition of walleye pollock, in terms of percent by weight, during months 5 to 9 and months 10 to 12 by year and predator size in the eastern Bering Sea; N = number of stomachs.

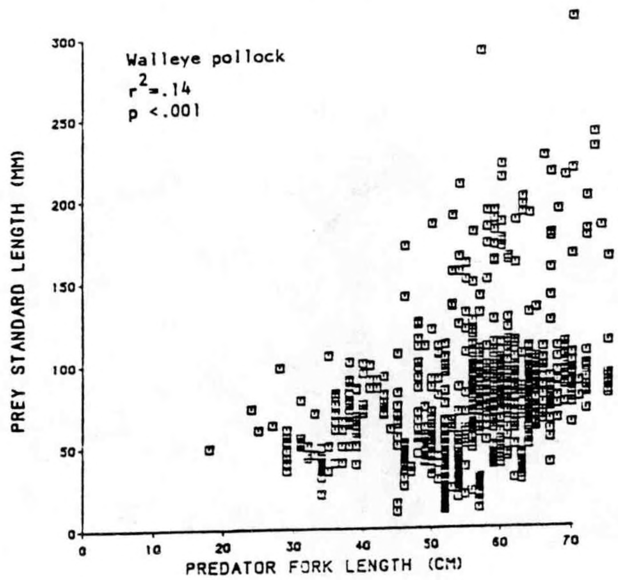


Figure 3.--Scattergram of predator walleye pollock fork length (cm) versus prey walleye pollock standard length (mm).

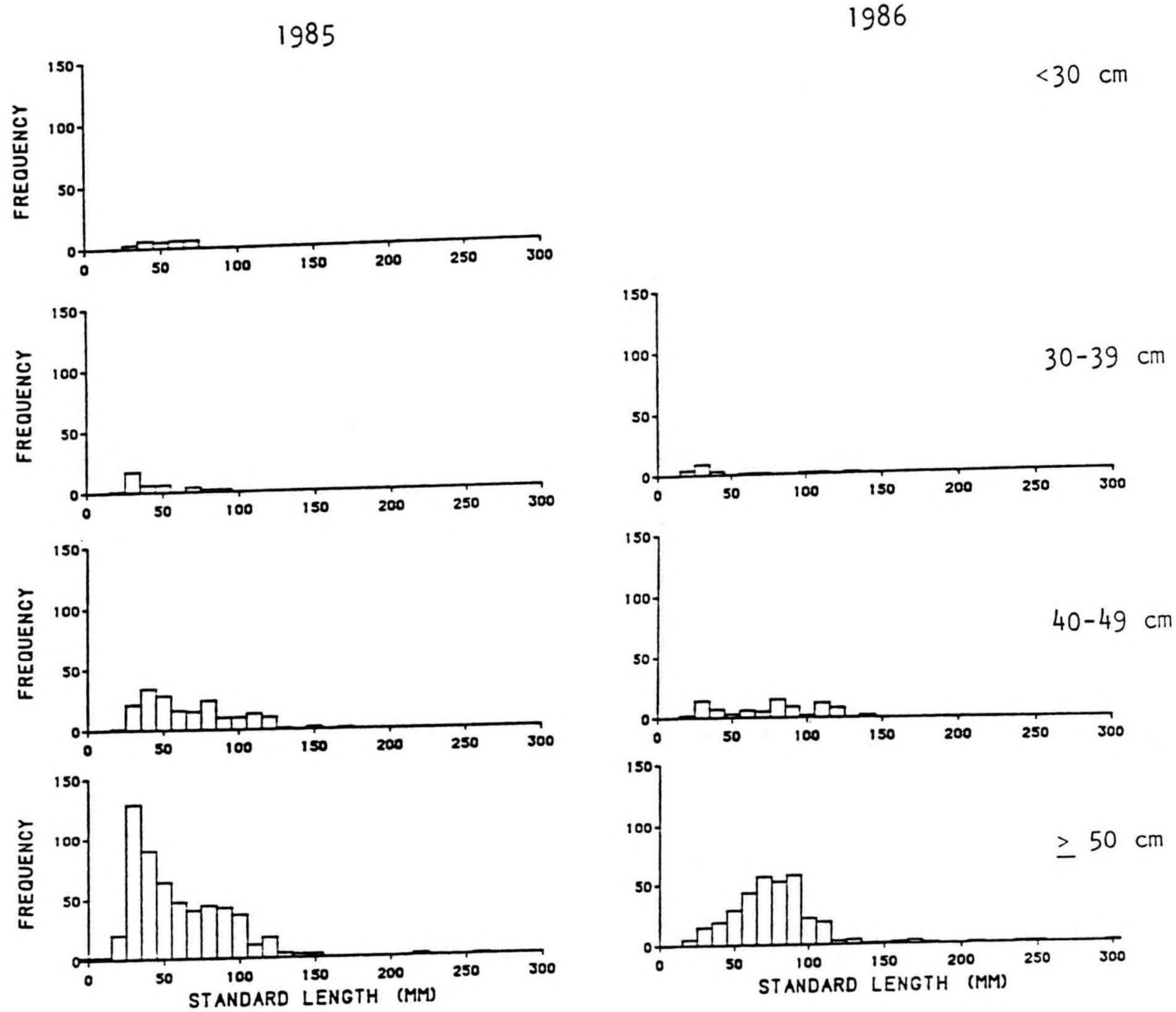


Figure 4.--Size frequency of prey walleye pollock found in four size groups of walleye pollock in 1985 and 1986 in the eastern Bering Sea.

groups of predator pollock focused on prey pollock less than about 100 mm standard length (SL), which are age-0 pollock. Other analyses of pollock cannibalism have shown similar trends (Mito 1974; Dwyer et al. 1987; Livingston 1989a, b).

Other commercially important prey were consumed by pollock but not in adequate numbers to perform a detailed size analysis. Limited measurements were available for these prey including Pacific herring (average SL of 116 mm), Pacific cod (average SL of 64 mm), flathead sole (average SL of 63 mm), and rock sole (average SL of 86 mm).

PREDATOR POPULATION CONSUMPTION OF COMMERCIALLY IMPORTANT PREY

Geographic Trends in Consumption

The amount of prey walleye pollock consumed by walleye pollock according to geographic location in the two main sampling periods (months 5 to 9 and months 10 to 12) in 1985 and 1986 is shown in Figure 5. During months 5 to 9 of both years, pollock cannibalism was high on the northwest outer shelf area of stratum 6 (see Methods section of this report, Fig. 1) where bottom depths are greater than 100 m. Some cannibalism was also seen in the middle shelf (50 to 100 m) east of the Pribilof Islands. Samples taken during months 10 to 12 were limited mostly to the middle shelf region. Prey pollock formed a large portion of the diet at a majority of those stations. Mito (1974) sampled the continental shelf break area south of the Pribilof Islands in October and November of 1973 and found a large amount of cannibalism also occurring in that area. Similar trends to those noted here were shown by Livingston (1989a) for 1981 and 1982 although the year 1987 was an exception, showing large amounts of cannibalism along the shelf break at depths of about 200 m from the upper northwest region as far south as the Pribilof Islands during autumn and winter.

Total Consumption Parameters

Tables 2-4 present the parameters, outlined in Equation (1) of the Methods section of this report, necessary to estimate the total amount of a particular prey item consumed by the walleye pollock population on the eastern Bering Sea shelf during the main sampling periods of months 5 to 9 and months 10 to 12. Estimated pollock biomass from the cohort analysis of Wespestad, Bakkala, and Dawson (1990) for 1985 and 1986 is shown in Table 2. Total estimated biomass is slightly higher in 1986.

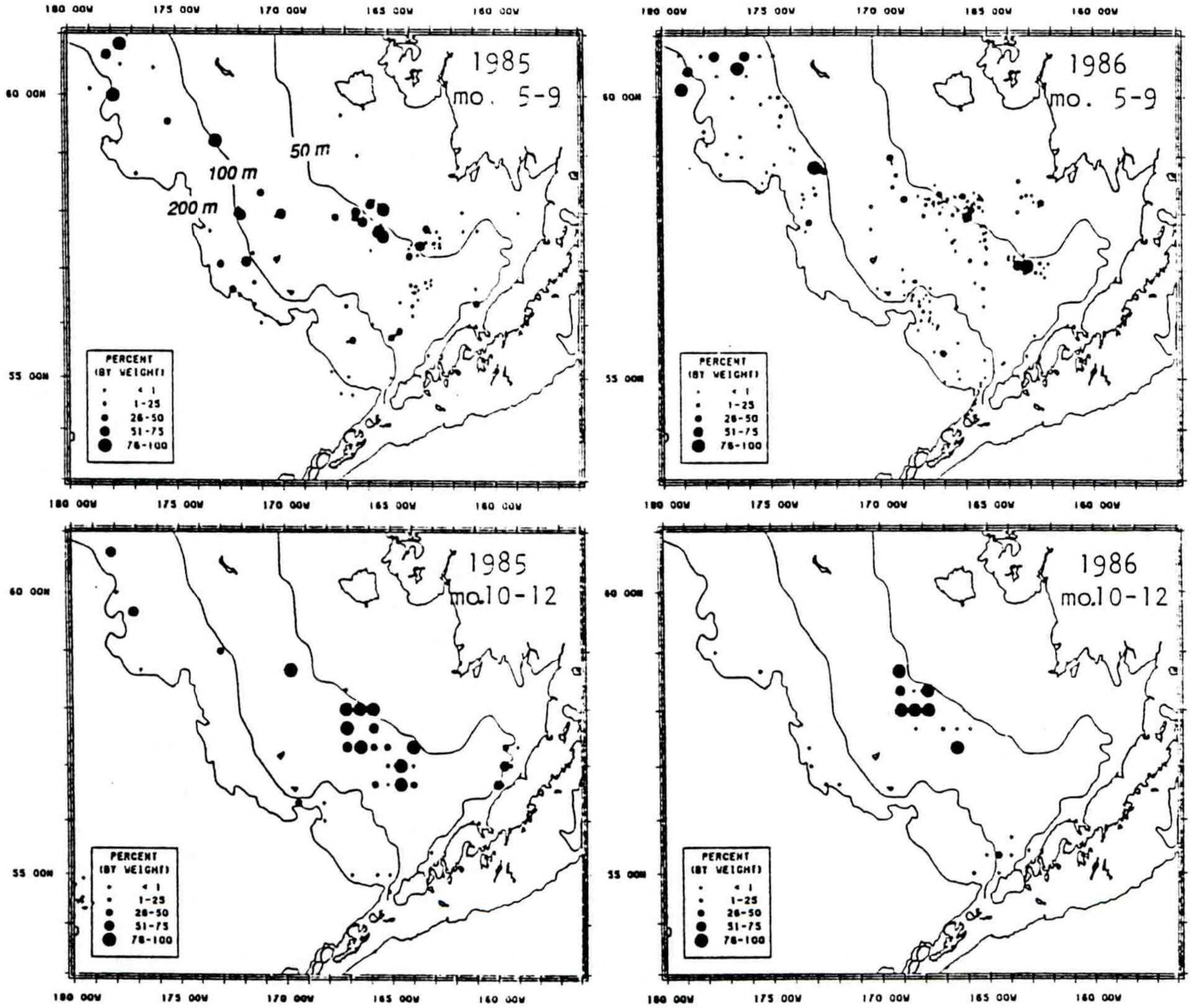


Figure 5.--Percent by weight of prey walleye pollock in the diet of walleye pollock by sampling station in two different time periods in 1985 and 1986.

Table 2.--Cohort analysis estimates of walleye pollock biomass (metric tons) in the eastern Bering Sea from Wespestad, Bakkala and Dawson (1991) by pollock size, year, and stratum.

Size group	Stratum	Biomass 1985	Biomass 1986
<30 cm	1	109,445	63,484
	2	14,566	25,042
	3	24,646	356,182
	4	76,072	211,075
	5	287	11,438
	6	315,984	833,779
30-39 cm	1	559	5,540
	2	248	45
	3	590,271	74,913
	4	44,937	26,843
	5	977,584	113,446
	6	2,097,401	3,697,213
40-49 cm	1	44,859	32,794
	2	0	0
	3	706,915	527,566
	4	331,726	204,446
	5	876,838	389,788
	6	1,927,162	1,405,906
≥50 cm	1	254,448	430,672
	2	40,055	36,187
	3	628,311	715,849
	4	303,337	340,042
	5	220,540	132,095
	6	377,809	545,655
Total		9,964,000	10,180,000

The daily ration of pollock, in terms of fraction of body weight daily (BWD), by each size group is as follows:

Size group (cm)	Daily ration (fraction body weight daily)
<30	0.011
30-39	0.011
40-49	0.008
≥50	0.004

These estimates are higher than those used by Livingston et al. (1986) and Dwyer et al. (1987), particularly for the smaller size groups, but they are thought to be more reasonable. This seems to be true since estimates of pollock mean stomach weight needed to derive daily rations using gastric evacuation rates (as done by the above-mentioned authors) are probably biased downwards because of undetected regurgitation of pollock stomach contents in field collections. The daily ration estimates used here, although they appear more reasonable than those derived from gastric evacuation models, could be improved through more formal bioenergetic models such as those employed by Hewett and Johnson (1987) that take into consideration changes in water temperature and prey energy content.

The percentages by weight of pollock prey in the diet (Table 3) varied considerably by stratum, sampling period, and year. In general, the percentages appear higher in 1985 than in 1986 for both sampling periods. There was also a tendency for the percentage consumed by a particular size group in a stratum to increase from the months 5 to 9 period to the months 10 to 12 period. These estimates are comparable to those reported by Dwyer et al. (1987) for 1981 to 1983, although the calculation and stratification methods are different than those used here.

Other commercially important prey did not form a consistent or large proportion of the diet (Table 4). Although Pacific herring appear to constitute up to 14% by weight of the diet of larger pollock, these data are suspect. Herring sizes reported in pollock stomach contents during October to December in offshore waters (stratum 6) included some 40 to 60 mm herring, seemingly too small for that time of year so far offshore. It is more likely these were juvenile pollock that had been misidentified in shipboard scans of stomach contents. Pacific cod, flathead sole, arrowtooth flounder, and rock sole occasionally formed small proportions of the diet.

Total Consumption Estimates

Estimates of the total biomass of each commercially important prey consumed by the pollock population were calculated for every pollock size group in each stratum using the parameters given above in Equation (1) of the Methods section of this

Table 3.--Mean percent by weight (%W) and standard error (SE) of prey walleye pollock in the stomach contents of predator walleye pollock by year, stratum, predator size group, and time of year in the eastern Bering Sea. (* = no standard error estimate since only one station was sampled, - = no samples taken.)

Predator size group	Stratum	1985 Mo. 5-9 %W	1985 Mo. 5-9 SE	1985 Mo. 10-12 %W	1985 Mo. 10-12 SE	1986 Mo. 5-9 %W	1986 Mo. 5-9 SE	1986 Mo. 10-12 %W	1986 Mo. 10-12 SE
<30 cm	1	0	0	29.4	16.5	-	-	-	-
	3	0	0	89.6	10.4	0	0	-	-
	6	10.0	5.9	-	-	0	0	-	-
30-39 cm	3	0	0	25.0	25.0	0	0	0	0
	4	39.5	27.1	-	-	0	0	100.0	*
	5	0	0	0	0	1.8	1.8	-	-
	6	3.3	2.5	56.2	23.2	3.3	2.5	-	-
40-49 cm	1	0	0	33.0	33.0	0	0	-	-
	3	3.3	2.8	50.4	12.8	0	0	19.6	16.4
	4	35.1	22.5	-	-	11.0	5.9	53.8	20.5
	5	5.1	5.1	8.8	8.8	2.4	1.5	0	0
	6	17.9	5.9	28.4	15.9	14.0	5.7	1.9	1.9
≥50 cm	1	18.5	7.9	39.6	27.4	6.2	1.8	-	-
	2	0	0	17.4	*	3.0	3.0	-	-
	3	16.9	6.4	51.5	9.1	5.0	2.2	11.9	7.5
	4	50.6	10.4	94.8	*	7.1	2.7	79.4	6.3
	5	5.5	5.5	13.5	13.5	2.8	2.2	0.2	0.2
	6	36.2	11.9	0	0	20.9	8.6	0.4	0.4

Table 4.--Mean percent by weight (%W) and standard error (SE) of miscellaneous commercial fish species in the stomach contents of walleye pollock by species, pollock size group, year, strata, and time of year. (- = no samples taken.)

Prey	Pollock size(cm)	Year	Stratum	Mo. 5-9 %W	Mo. 5-9 SE	Mo. 10-12 %W	Mo. 10-12 SE
Pacific herring	40-49	1985	6	0	0	0.28	0.28
	≥50	1985	6	0	0	14.33	14.33
		1986	1	1.14	1.14	-	-
			2	2.79	2.79	-	-
			3	0.07	0.07	2.36	2.36
			4	10.89	7.30	-	-
Pacific cod	40-49	1985	6	0.19	0.19	0	0
	≥50	1986	1	0.96	0.96	-	-
			3	0	0	0.13	0.13
Flathead sole	30-39	1985	6	0.04	0.04	0	0
	40-49	1985	6	0.01	0.01	-	-
	≥50	1986	4	0	0	0.03	0.03
Arrowtooth flounder	≥50	1985	4	8.26	8.26	0	0
Rock sole	≥50	1985	1	0.65	0.65	0	0
		1986	1	1.46	0.92	-	-

report. Total numbers of each prey consumed were also calculated in strata where prey size information was available. Results are shown in Figures 6-7 and Tables 5-8.

Walleye Pollock as Prey

Estimated total biomass and numbers of pollock consumed through cannibalism were larger in both time periods of 1985 than in 1986 (Tables 5 and 6). Although the biomass of pollock as predators was higher in 1986, the percentages of pollock in the diet were higher in 1985. Therefore, the higher proportion of pollock in the diet seems to be the main reason for higher prey pollock consumption in 1985. Wespestad and Traynor (1990) show that the 1985 pollock year class was larger than the 1986 year class, both as age-1 fish caught in survey trawls and as age-3 fish estimated from cohort analysis. It seems likely, since cannibalism occurs mainly on age-0 fish (which are less than about 100 mm SL in the May-September period and 140 mm SL in October-December) as shown in Figures 6-7, that the larger amount of pollock consumed in 1985 was the result of increased density of age-0 pollock available to adults relative to 1986.

It also appears that most cannibalism on age-0 pollock during months 5 to 9 in these 2 years was produced by adult pollock in the 40-49 cm size range. During months 10 to 12, pollock 30-39 cm long consumed most of the juvenile pollock particularly in strata 6 on the outer shelf. Pollock larger than 50 cm prey on both age-0 and older pollock. A similar trend was reported by Dwyer et al. (1987) for the 1981-83 period in the eastern Bering Sea.

These estimates of total number and biomass of juvenile pollock consumed by adults are in the same order of magnitude as those presented by Dwyer et al. (1987) for the 1981-82 period in the eastern Bering Sea. There is some uncertainty in these estimates, particularly for the time period of October-December in each year. Sampling during this period was sparse and it was assumed that adult pollock biomass in each stratum was the same as in May-September. Since most of these data were from shipboard scans of stomach contents, there is also a greater likelihood of misidentification of prey.

Other Commercially Important Prey

Total biomass of other commercially important prey consumed by pollock is shown in Table 7. Estimates of numbers consumed from strata where prey size information was available is shown in Table 8. Although estimates of the total amount of Pacific herring consumed by pollock are calculated and shown in these tables, these results are questionable since, as mentioned earlier, sizes of herring reportedly in the stomach contents were too small and too far offshore for the time of year. The sizes and locations for prey herring corresponded more closely to the sizes and locations of prey walleye pollock. Since these samples

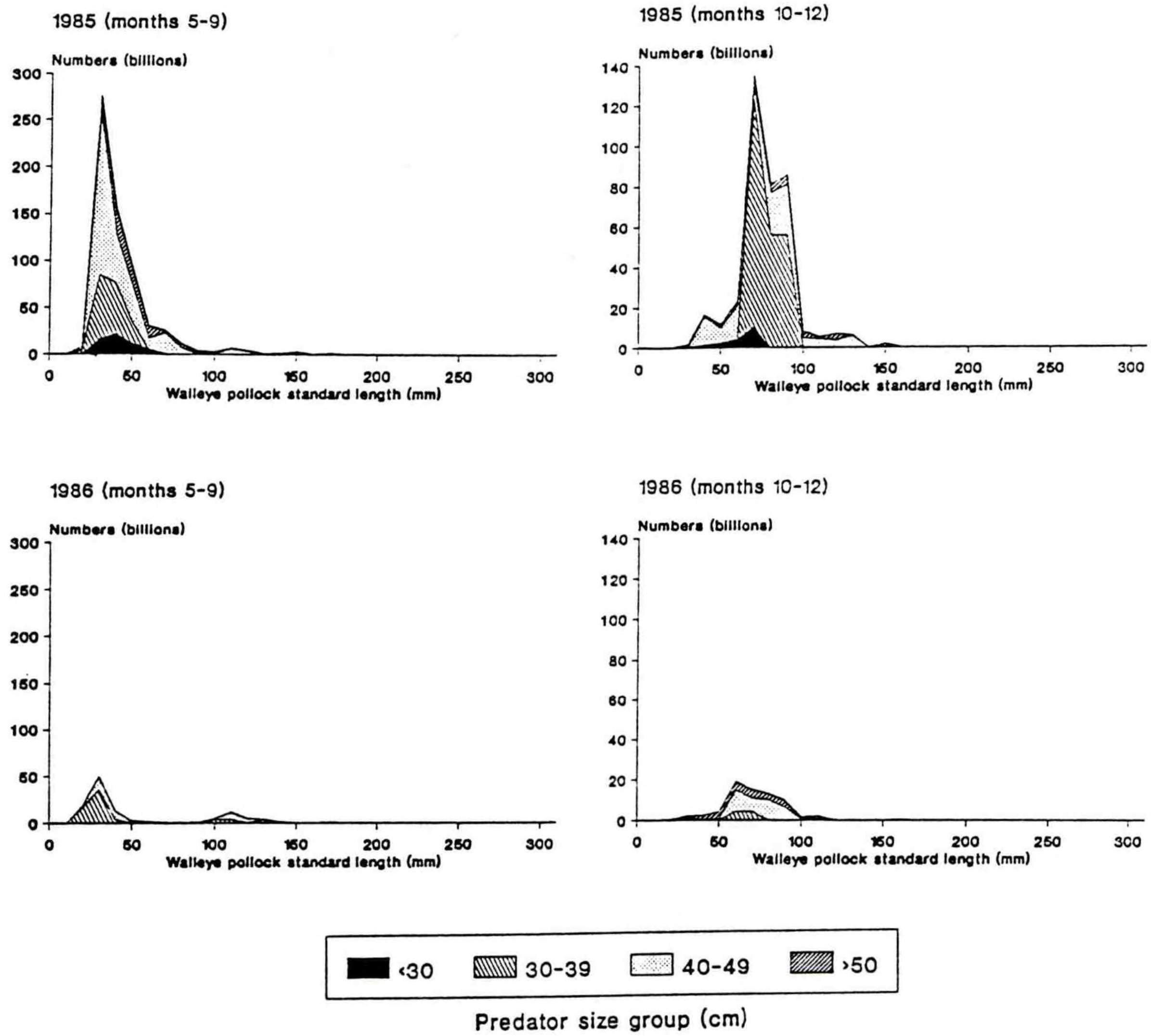


Figure 6.--Estimated numbers of prey walleye pollock consumed by four size groups of walleye pollock in two different time periods in 1985 and 1986 by prey size.

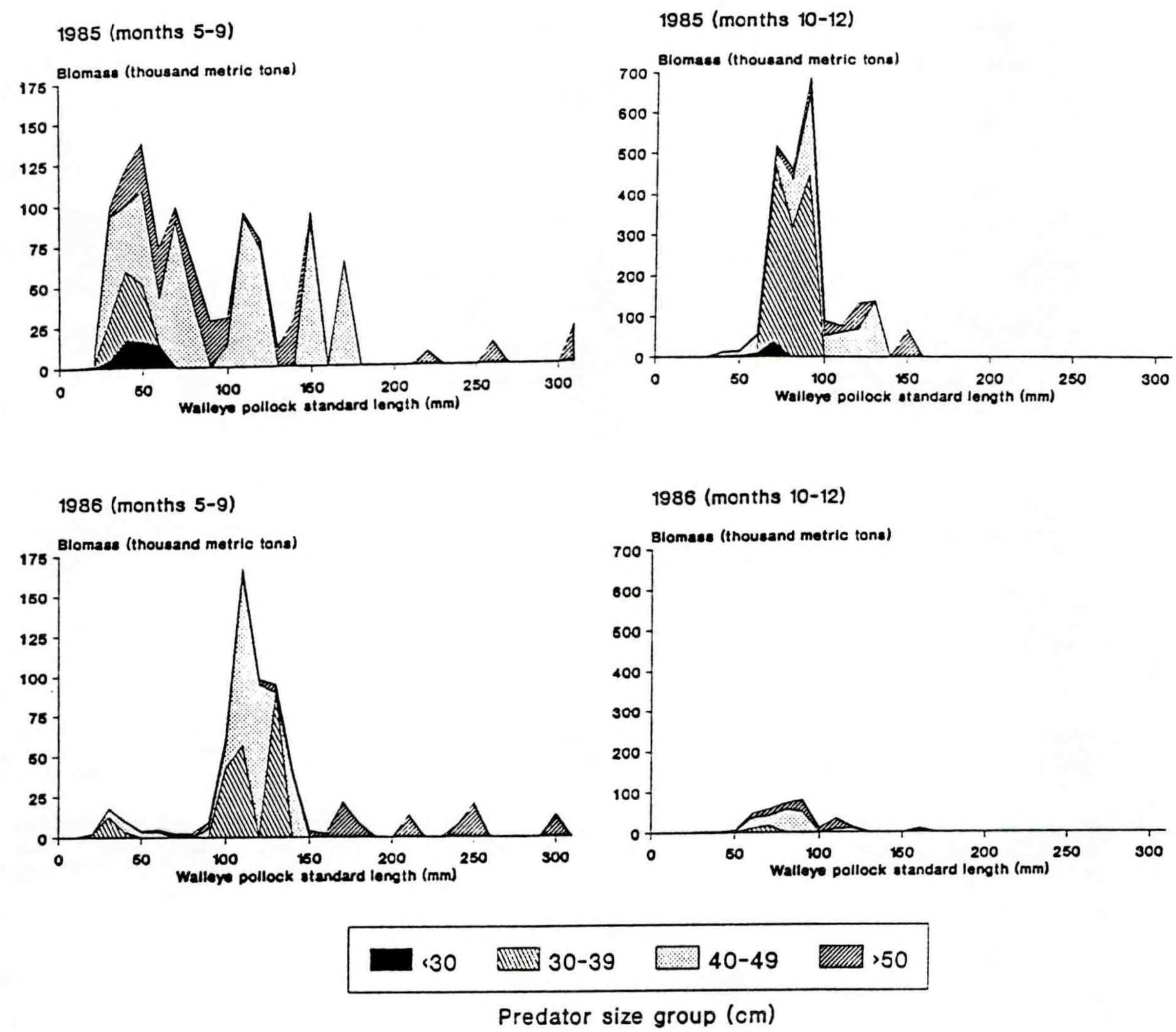


Figure 7.--Estimated biomass of prey walleye pollock consumed by four size groups of walleye pollock in two different time periods in 1985 and 1986 by prey size.

Table 5.--Estimated total biomass (thousand metric tons) of prey walleye pollock consumed by walleye pollock predators by year, stratum, predator size group, and time of year in the eastern Bering Sea. Numbers in parentheses indicate cells where no prey size information was available. (- = no samples taken.)

Predator size group	Stratum	Biomass consumed 1985 Mo. 5-9	1985 Mo. 10-12	1986 Mo. 5-9	1986 Mo. 10-12
<30 cm	1	0	32.55	-	-
	3	0	22.34	0	-
	6	53.23	-	0	-
30-39 cm	3	0	(149.34)	0	0
	4	29.91	-	0	27.16
	5	-	-	3.40	-
	6	73.07	1,192.03	204.72	-
40-49 cm	1	0	10.89	0	-
	3	28.55	262.07	0	76.26
	4	142.56	-	27.45	81.03
	5	55.16	56.73	11.40	0
	6	421.76	402.25	240.23	19.45
≥50 cm	1	28.87	37.12	16.24	-
	2	0	2.60	0.66	-
	3	65.18	119.08	22.08	31.43
	4	94.01	105.79	14.75	99.32
	5	(7.40)	10.94	2.28	(0.10)
	6	83.68	0	68.99	0.94
Total		1,083.38	2,403.73	612.20	335.69

Table 6.--Estimated numbers (billions) of prey walleye pollock consumed by walleye pollock predators by year, stratum, predator size group, and time of year in the eastern Bering Sea. Parentheses indicate cells where no prey size information was available. (- = no samples taken.)

Predator size group	Stratum	Numbers consumed 1985 Mo. 5-9	1985 Mo. 10-12	1986 Mo. 5-9	1986 Mo. 10-12
<30 cm	1	0	13.04	-	-
	3	0	5.83	0	-
	6	55.33	-	0	-
30-39 cm	3	0	(0)	0	0
	4	38.02	-	0	8.63
	5	0	0	4.32	-
	6	112.39	223.94	63.29	-
40-49 cm	1	0	2.07	0	-
	3	7.24	29.17	0	19.60
	4	54.58	-	16.89	13.14
	5	152.83	19.60	12.58	0
	6	107.48	60.52	14.81	3.22
≥50 cm	1	11.13	5.03	0.93	-
	2	0	0.33	0.07	-
	3	22.95	17.40	1.12	6.99
	4	43.23	5.92	2.20	19.39
	5	(0)	2.30	0.27	(0)
	6	18.93	0	1.44	0.16
Total		624.11	385.15	117.92	71.13

Table 7.--Total biomass (thousand metric tons) of miscellaneous commercial prey species consumed by walleye pollock by prey species, pollock size group, year, strata, and time of year. Values in parentheses indicate cells where no prey size information was available. (- = no samples taken.)

Prey	Pollock size(cm)	Year	Stratum	Biomass consumed Mo. 5-9	Biomass consumed Mo. 10-12
Pacific herring	40-49	1985	6	0	3.97
	≥50	1985	6	0	19.92
		1986	1	(3.00)	-
			2	0.62	-
			3	(0.31)	6.22
			4	22.66	0
Pacific cod	40-49	1985	6	4.48	0
	≥50	1986	1	(2.53)	-
			3	0	(0.34)
Flathead sole	30-39	1985	6	1.41	0
	40-49	1985	6	0.24	0
	≥50	1986	4	0	0.04
Arrowtooth flounder	≥50	1985	4	(15.33)	0
Rock sole	≥50	1985	1	1.01	0
		1986	1	3.85	-

Table 8.--Estimated numbers (billions) of miscellaneous commercial prey species consumed by walleye pollock by prey species, pollock size group, year, strata, and time of year. Parentheses indicate cells where no prey size information was available. (- = no samples taken.)

Prey	Pollock size(cm)	Year	Stratum	Numbers consumed Mo. 5-9	Numbers consumed Mo. 10-12
Pacific herring	40-49	1985	6	0	0.43
	≥50	1985	6	0	1.55
		1986	1	(0)	-
			2	0.01	-
			3	(0)	354.94
			4	0.29	0
Pacific cod	40-49	1985	6	2.68	0
	≥50	1986	1	(0)	-
			3	0	(0)
Flathead sole	30-39	1985	6	1.67	0
	40-49	1985	6	0.28	0
	≥50	1986	4	0	0.01
Arrowtooth flounder	≥50	1985	4	(0)	0
Rock sole	≥50	1985	1	0.34	0
		1986	1	0.14	-

are from shipboard stomach scans, there is no verification for these results. This problem will be avoided to some extent in future years because pollock stomachs are again being collected for expert laboratory analysis of species composition of the contents.

Approximately 4,000 t of Pacific cod were estimated to be consumed by walleye pollock in 1985 and about 3,000 t were consumed in 1986. Based on the sizes of the consumed fish (64 mm SL), these cod are probably age 0.

About 2,000 t of flathead sole were consumed by pollock in 1985 and 40 t were consumed in 1986. Again, these are probably age-0 fish based on size (63 mm SL). No size information was available for arrowtooth flounder, which was consumed only in 1985. Predation mortality inflicted on flatfish by pollock appears to be small relative to flatfish population sizes.

CITATIONS

Clausen, D. M. 1983. Food of walleye pollock, Theragra chalcogramma, in an embayment of southeastern Alaska. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 81:637-642.

Dwyer, D. A., K. M. Bailey, and P. A. Livingston. 1987. Feeding habits and daily ration of walleye pollock (Theragra chalcogramma) in the eastern Bering Sea, with special references to cannibalism. Can. J. Fish. Aquat. Sci. 44: 1972-1984.

Hewett, S. W., and B. L. Johnson. 1987. A generalized bioenergetics model of fish growth for microcomputers. Univ. Wisconsin Sea Grant Tech. Rep. No. WIS-SG-87-245.

Livingston, P.A. 1989a. Interannual trends in walleye pollock, Theragra chalcogramma, cannibalism in the eastern Bering Sea, p. 275-296. Proceedings of International Symposium on the Biology and Management of Walleye Pollock, Nov. 14-16, 1988, Univ. Alaska, Fairbanks. Sea Grant Rep. AK-SG-89-01.

Livingston, P.A. 1989b. Key fish species, northern fur seals, Callorhinus ursinus, and fisheries interactions involving walleye pollock, Theragra chalcogramma, in the eastern Bering Sea. J. Fish. Biol. 35(A):179-186.

Livingston, P.A., D. A. Dwyer, D. L. Wencker, M. S. Yang, and G. M. Lang. 1986. Trophic interactions of key fish species in the eastern Bering Sea. Int. North Pac. Fish. Comm. Bull. 47:49-65.

Low, L-L. 1990. Executive summary. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 1-18. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Mito, K. I. 1974. Food relationships among benthic fish populations in the Bering Sea. M.S. thesis, Hokkaido University, Hakodate, Japan, 135 p.

Wespestad, V.G., R. G. Bakkala, and P. Dawson. 1990. Walleye pollock. In Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea Aleutian Islands region as projected for 1991. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Wespestad, V. G., and J. J. Traynor. 1990. Walleye pollock. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 19-43. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

PACIFIC COD

by

Patricia A. Livingston

INTRODUCTION

Pacific cod (Gadus macrocephalus) ranks fourth in biomass within the eastern Bering Sea groundfish complex. It has been the target of a growing domestic fishery since the early 1980s. Annual catch in recent years has been over 100,000 t (Thompson and Shimada 1990). Cod feed extensively on both nektonic and benthic prey, including many commercially important species of crabs and fish. These numerous trophic links to other abundant species make cod one of the most important predators in the eastern Bering Sea.

GENERAL FOOD HABITS

Diet

A general view of the Pacific cod's diet is presented in Table 1 by showing the proportions of various prey items in the overall diet. Several prey categories occurred frequently in the diet, including small invertebrates such as polychaetes and amphipods. Intermediate-sized crustaceans such as hermit crabs and shrimp were regularly occurring items along with fish. Small crustaceans tended to dominate the diet numerically while large items, particularly fish such as walleye pollock (Theragra chalcogramma) provided the bulk of the food consumed in terms of weight.

Many different commercially important prey were found in the stomach contents including red king crabs (Paralithodes camtschaticus), Tanner crabs (Chionoecetes bairdi), snow crabs (C. opilio), Pacific herring (Clupea harengus pallasi), Pacific cod, walleye pollock, arrowtooth flounder (Atheresthes stomias), flathead sole (Hippoglossoides elassodon), rock sole (Lepidopsetta bilineata), and yellowfin sole (Limanda aspera). Fishery discards, which are usually fish carcasses, were also consumed by cod.

The mostly demersal nature of cod feeding behavior is demonstrated by the dominance of the above-mentioned items in its diet. Fish, crabs, and shrimp are also major components of the cod diet in the Gulf of Alaska (Jewett 1978; Clausen 1981) and include walleye pollock and snow crabs as dominant prey. The

Table 1.--Diet of Pacific cod, *Gadus macrocephalus*, in the eastern Bering Sea expressed in percent frequency of occurrence (FO), percent number (N), and percent weight (W).

Prey name*	FO	N	W
Polychaeta (worm)	46.30	6.17	1.16
Gastropoda (snail)	9.89	0.74	0.69
Bivalvia (clam)	6.63	0.53	0.18
Cephalopoda (squid & octopus)	5.51	0.27	1.64
Crustacea	3.53	1.04	0.01
Mysidacea (mysid)	17.33	3.93	0.09
Amphipoda (amphipod)	42.81	14.90	0.23
Euphausiacea (euphausiid)	13.20	25.51	0.48
Decapoda (shrimp & crab)	5.74	0.31	0.32
Caridea (shrimp)	9.81	1.34	0.10
Pandalidae (shrimp)	9.06	1.11	0.96
Crangonidae (shrimp)	36.93	7.08	0.97
Paguridae (hermit crab)	23.31	1.20	1.98
Lithodidae (king crab)	0.31	0.01	0.04
Paralithodes sp. (king crab)	1.18	0.05	0.43
Paralithodes camtschatica (red king crab)	0.81	0.04	1.28
Paralithodes platypus (blue king crab)	0.01	0.00	0.01
Chionoecetes sp.	11.97	1.10	1.49
Chionoecetes opilio (snow crab)	12.06	1.63	4.93
Chionoecetes bairdi (Tanner crab)	13.74	2.08	2.42
Echiura (marine worm)	15.39	1.74	1.00
Osteichthyes Teleostei (fish)	30.50	17.71	4.96
Clupea harengus pallasi (Pacific herring)	0.50	0.05	0.99
Oncorhynchus sp. (salmon)	0.01	0.00	0.01
Osmeridae (smelts)	0.32	0.07	0.23
Gadidae (gadid fish)	6.63	0.38	4.76
Gadus macrocephalus (Pacific cod)	0.39	0.03	0.69
Theragra chalcogramma (walleye pollock)	15.52	1.28	39.33
Zoarcidae (eelpout)	2.79	0.19	1.64
Cottidae (sculpin)	1.02	0.05	0.36
Agonidae (poacher)	1.57	0.09	0.11
Stichaeidae (prickleback)	0.89	0.05	0.08
Ammodytes sp. (sandlance)	2.71	0.63	0.66
Pleuronectidae (flatfish)	6.96	0.50	3.60
Atheresthes stomias (arrowtooth flounder)	0.21	0.01	0.15
Hippoglossoides elassodon (flathead sole)	0.61	0.03	0.40
Lepidopsetta bilineata (rock sole)	1.21	0.10	1.32
Limanda aspera (yellowfin sole)	2.43	0.24	6.01
Limanda proboscidea (longhead dab)	0.07	0.00	0.08
Hippoglossus stenolepis (Pacific halibut)	0.01	0.00	0.09
Fishery discards	5.22	0.57	13.14
Miscellaneous and unidentified prey	12.91	7.23	1.00

Table 1.--Continued.

Total prey count	221,108
Total prey weight	680,993 g
Number of stomachs with food	8,988
Number of empty stomachs	193

*Prey name indicates highest level of identification possible for that category.

large variety of prey consumed by cod in the Bering Sea is also seen in these other studies. This opportunistic feeding behavior enables cod to take advantage of whatever bottom or near-bottom animals are locally abundant, including many noncommercially important animals such as hermit crabs (Paguridae), eelpouts (Zoarcidae), and sculpins (Cottidae).

Seasonal and Annual Changes in Diet

Prey composition of the Pacific cod diet changed seasonally (Fig. 1). Walleye pollock were a dominant prey item in the winter, particularly for larger cod. In spring, as cod move more inshore, king crabs (generally soft-shelled females and the legs only of hard-shell crabs) and flatfish appeared in the diet. Fish dominated the diet of large cod in all seasons while invertebrates such as polychaetes, amphipods, shrimp, and hermit crabs were most important to small cod.

There are also some differences in diet during the main sampling period (months 5 to 9) between years (Fig. 2). The principal difference was the larger proportion of flatfish and smaller proportion of walleye pollock in the diet in 1984 compared with 1985 and 1986. Since these data were grouped by areas, unequal sampling by geographic area could produce such a trend. Similarly, king crabs, which constituted less than 4% of the diet by weight in the diet grouped across area, formed a larger portion of the diet in inshore areas that cannot be observed from this table. However, the proportion of general prey categories in the diet, such as the amount of fish relative to crabs and other invertebrates, remain relatively constant between years within each cod size group.

Sizes of Commercially Important Prey Consumed

The relationships between Pacific cod size and prey size for cod consuming gadid fishes, flatfishes, and Tanner and snow crabs are significant ($P < 0.01$), and the r^2 values are fairly low (0.22-0.37) (Figs. 3-5). In general, prey size increased with increasing predator size but large cod continued to consume some smaller prey.

Interannual differences in the size composition of important prey consumed by Pacific cod greater than 30 cm in length are shown in Figures 6-13. Small cod (<30 cm in length) had insufficient numbers of measurable prey in each category to be included in these figures. Few measurable pollock were consumed in 1984 but in all years, mid-sized cod (30-59 cm in length) consumed primarily age-0 pollock (approximately <100 mm SL) (Fig. 6). This size group of Pacific cod contained a higher frequency of age-1 pollock in 1986 than in 1985. Large cod (≥60 cm) consumed age-0 pollock in 1985 and a broad range of pollock sizes up to about 450 mm in all years. The size

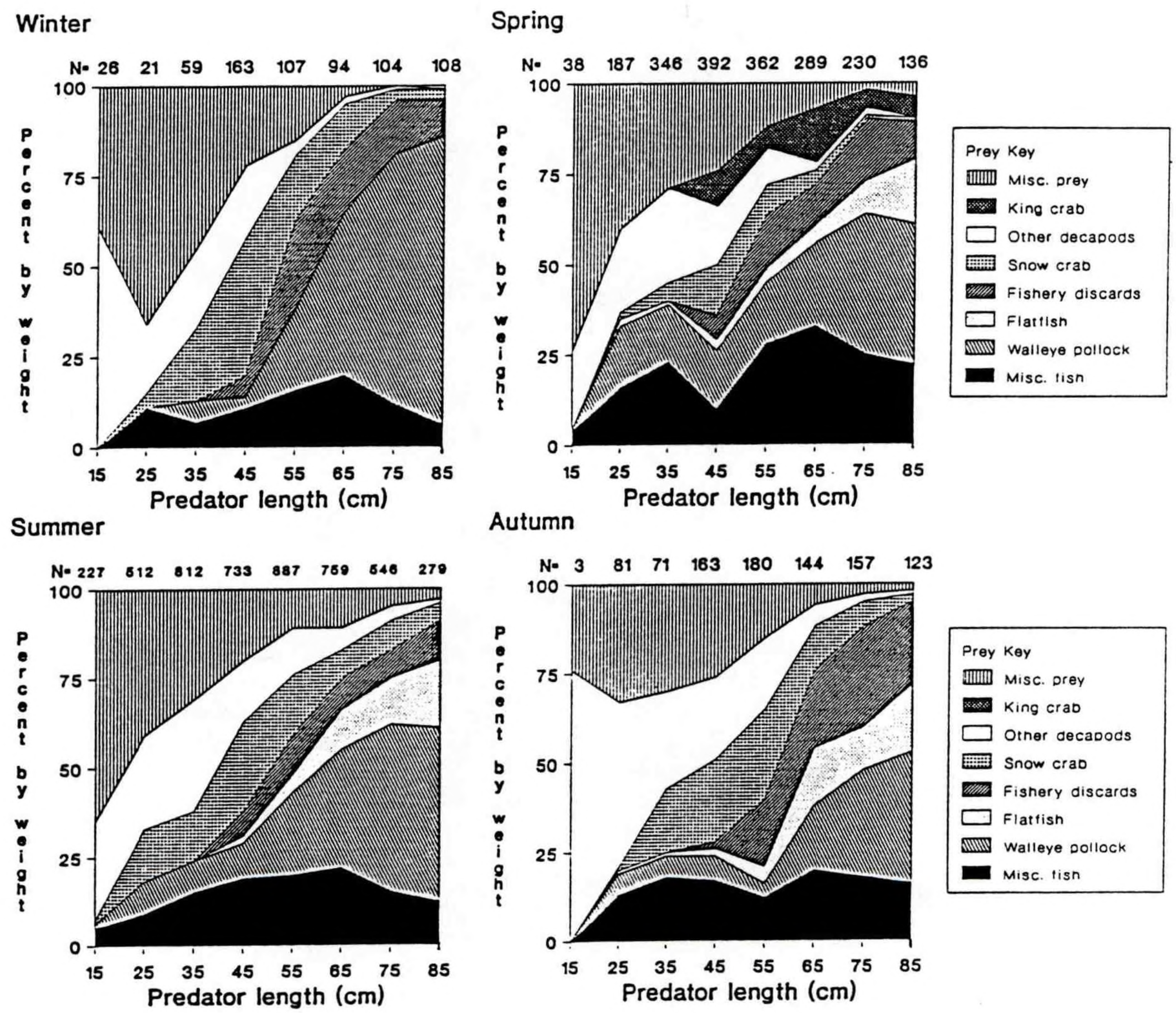


Figure 1.--Diet composition of Pacific cod, in terms of percent by weight, season and predator size in the eastern Bering Sea. N = number of stomachs.

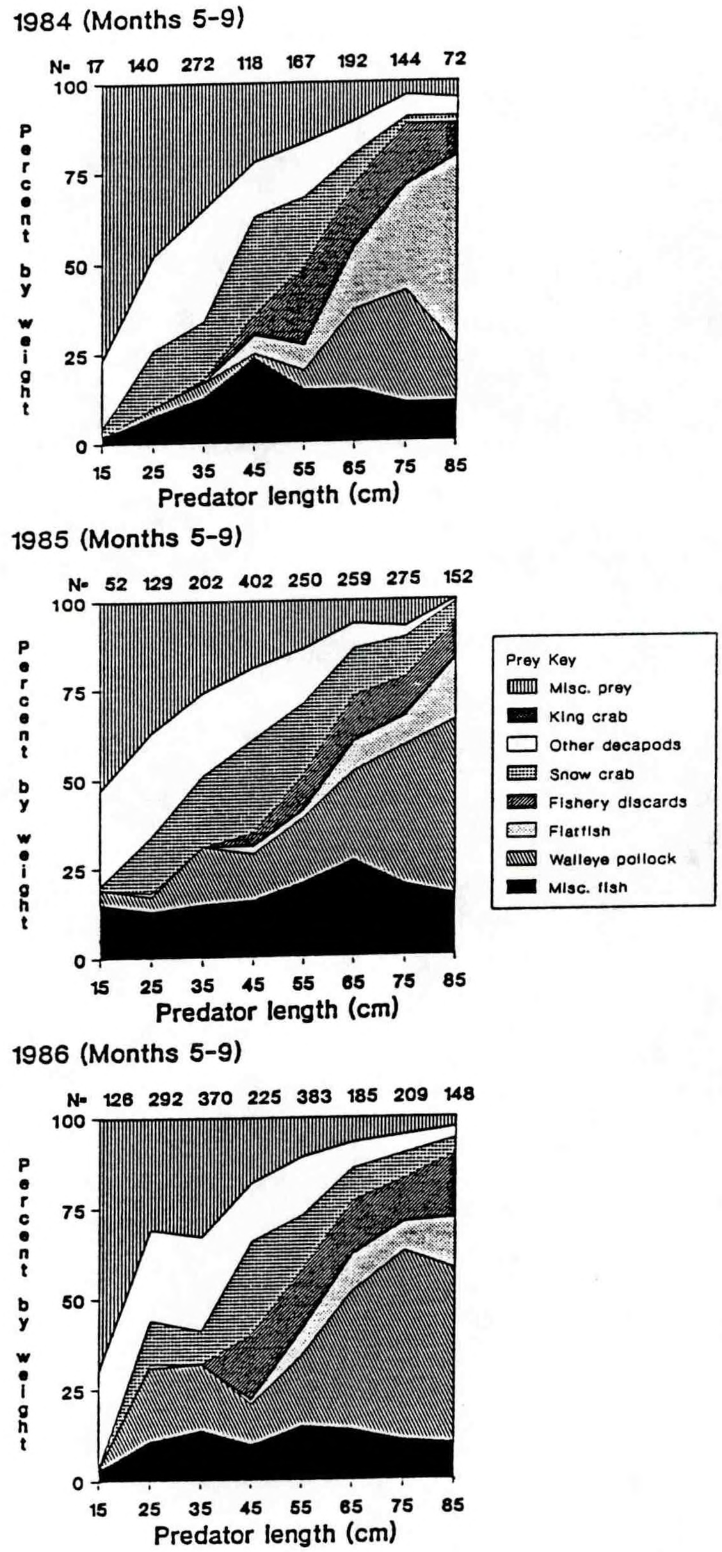


Figure 2.--Diet composition of Pacific cod, in terms of percent by weight, during months 5 to 9 by year and predator size in the eastern Bering Sea. N = number of stomachs.

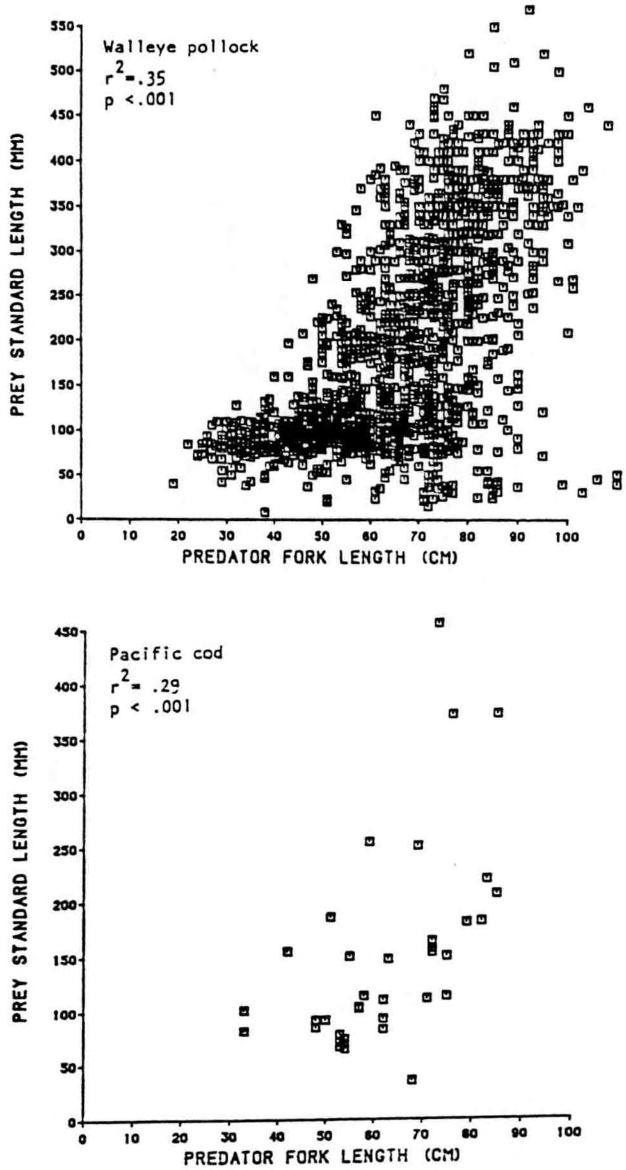


Figure 3.--Scattergram of predator Pacific cod fork length (cm) versus prey standard length (mm) for gadid prey: walleye pollock (upper) and Pacific cod (lower).

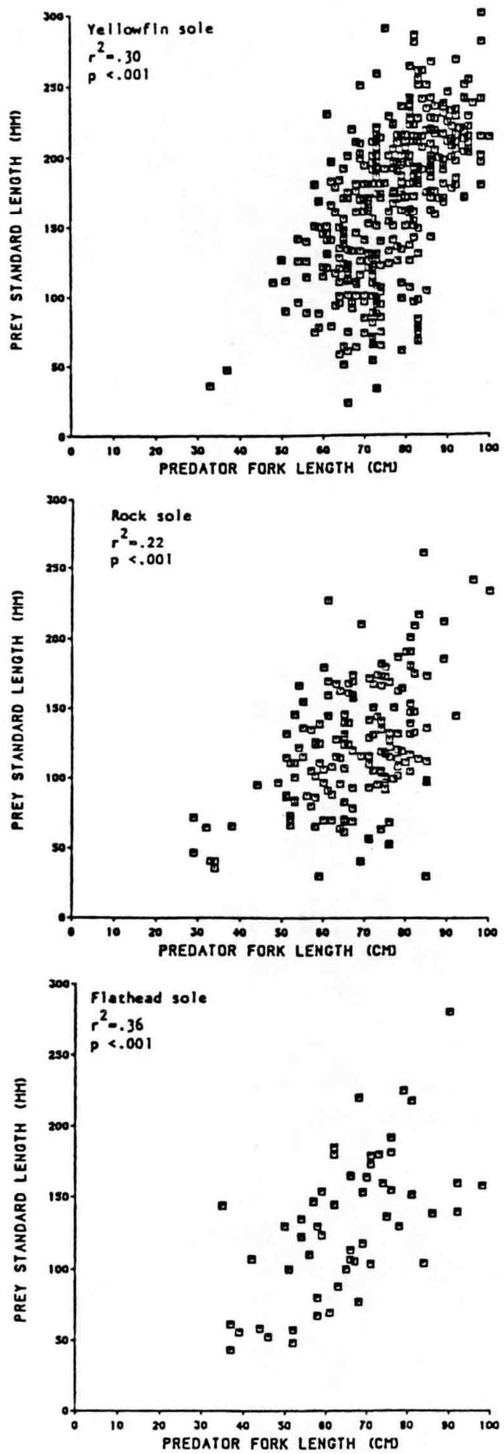


Figure 4.--Scattergram of Pacific cod fork length (cm) versus standard length (mm) of flatfish prey: yellowfin sole, rock sole, and flathead sole.

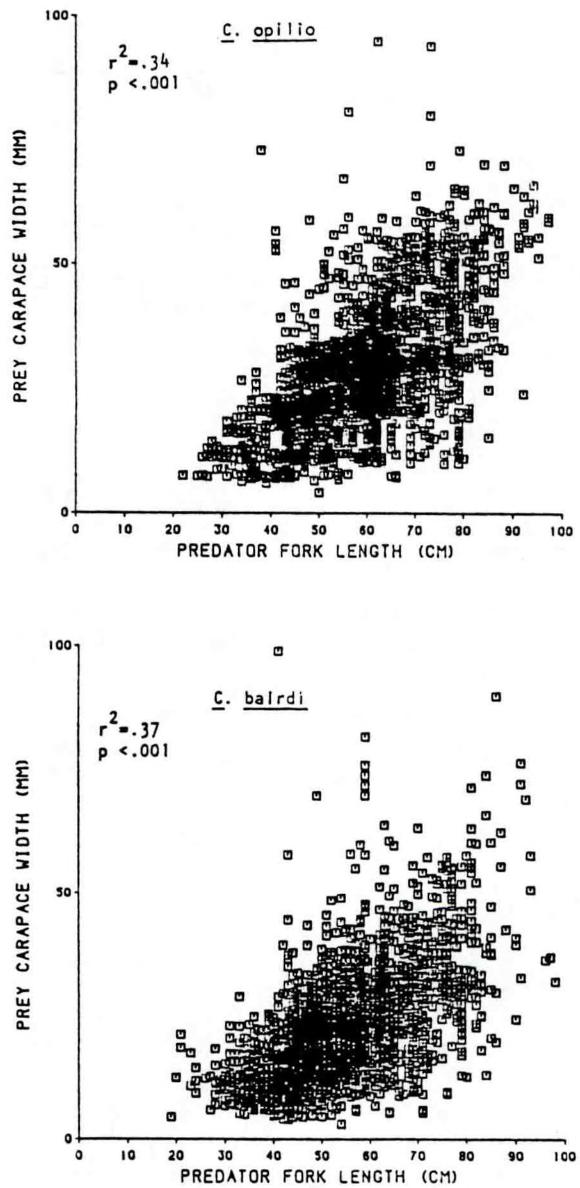


Figure 5.--Scattergram of Pacific cod fork length (cm) versus carapace width (mm) of Tanner (<u>Chionoecetes bairdi</u>) and snow (<u>C. opilio</u>) crab prey.

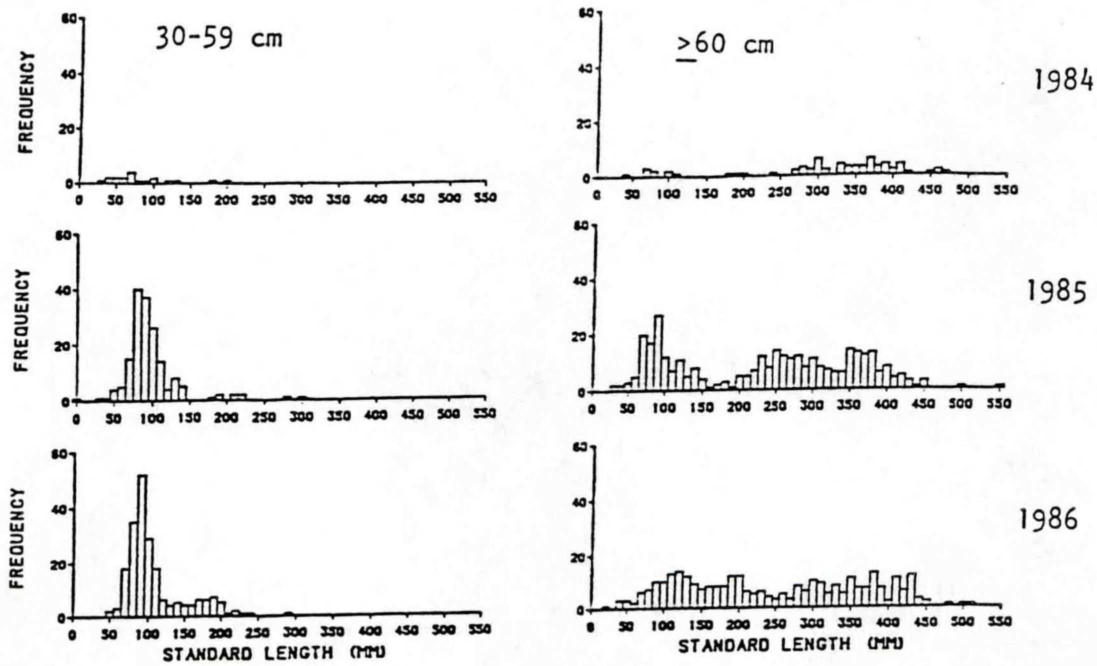


Figure 6.--Size frequency of walleye pollock as prey in two size groups of Pacific cod from 1984 to 1986 in the eastern Bering Sea.

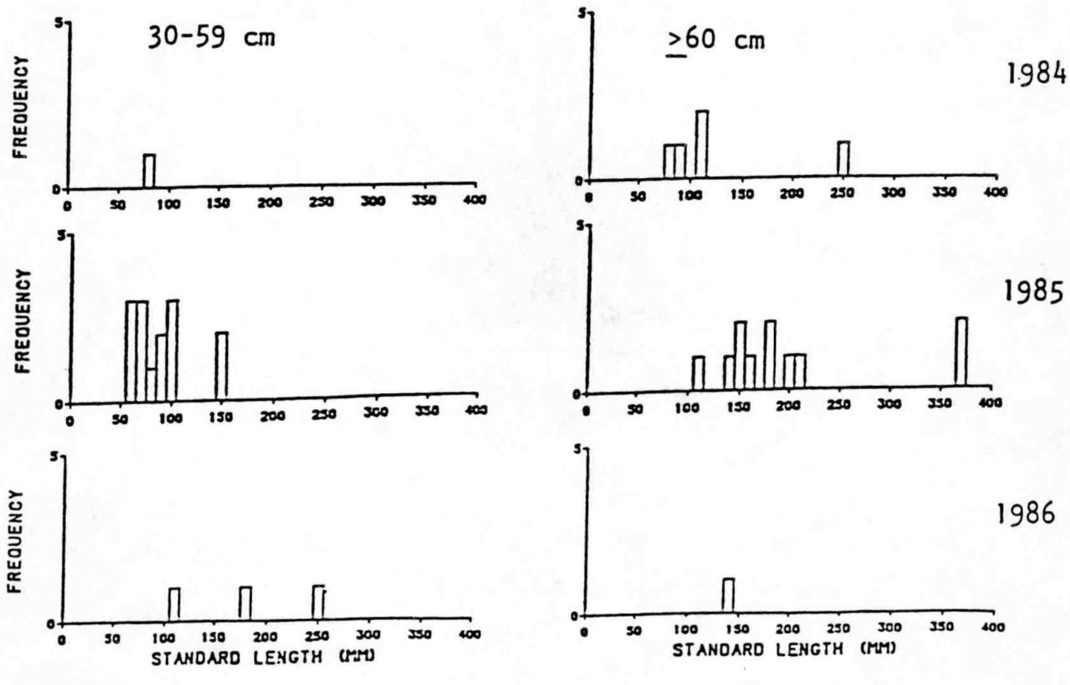


Figure 7.--Size frequency of Pacific cod as prey in two size groups of Pacific cod from 1984 to 1986 in the eastern Bering Sea.

frequencies of young cod consumed by cod show little differences across years (Fig. 7). Most cod consumed are approximately age 0 or less than 185 mm SL.

Sizes of three species of flatfish consumed by Pacific cod are shown in Figures 8-10. Yellowfin sole encountered in the stomach contents of large cod reached sizes up to about 300 mm SL. Peak consumption of yellowfin sole usually occurred between about 150 and 250 mm; these lengths correspond to several ages greater than about age 5. Most rock sole consumed by smaller cod were less than 100 mm while those consumed by large cod mostly ranged from about 100 to 200 mm -- slightly smaller than the yellowfin sole consumed. Flathead sole were mostly less than 100 mm for smaller cod and between 100 and 200 mm for larger cod, fairly similar to the sizes of rock sole consumed.

The sizes of other important prey consumed by Pacific cod were grouped over years and predator size due to the scarcity of these prey in stomach contents (Fig. 11). Although king crabs may be an important prey item in certain seasons and areas of the eastern Bering Sea, most of these crabs are probably consumed while in the soft-shell state, which makes size measurements difficult. Most whole king crab consumed ranged from about 50 to 150 mm carapace length, and averaged about 97.5 mm, which for female red king crab would be approximately 5 or 6 years old. Most Pacific herring consumed were about age 1 (100-180 mm SL) and averaged about 165 mm, although larger herring up to about 280 mm were also found. Arrowtooth flounder sizes ranged from 30 to 210 mm SL.

Tanner and snow crabs were consumed by the two larger size groups of Pacific cod from 1984 to 1986 (Figs. 12-13). Mid-sized cod consumed both species of snow crabs in sizes up to about 30 mm carapace width (CW). Large cod consumed slightly larger snow crab, which were up to about 60 mm wide.

PREDATOR POPULATION CONSUMPTION OF COMMERCIALLY IMPORTANT PREY

Geographic Trends in Consumption

Figures 14-22 display the relative amounts (in terms of percent by weight) of various important prey in the stomach contents of Pacific cod from May to September in the years 1984 to 1986 at each station where stomachs were collected.

Cannibalism by Pacific cod was not a widespread phenomenon; it occurred at fewer than four sampling stations in a particular year (Fig. 14). Less than 50% of the stomach contents of cod at these stations consisted of young cod. Most stations where cod were eaten are in water with bottom depths less than 50 m, although cannibalism also occurred in middle and outer shelf areas. A bottom trawl survey in 1985 showed that most small cod

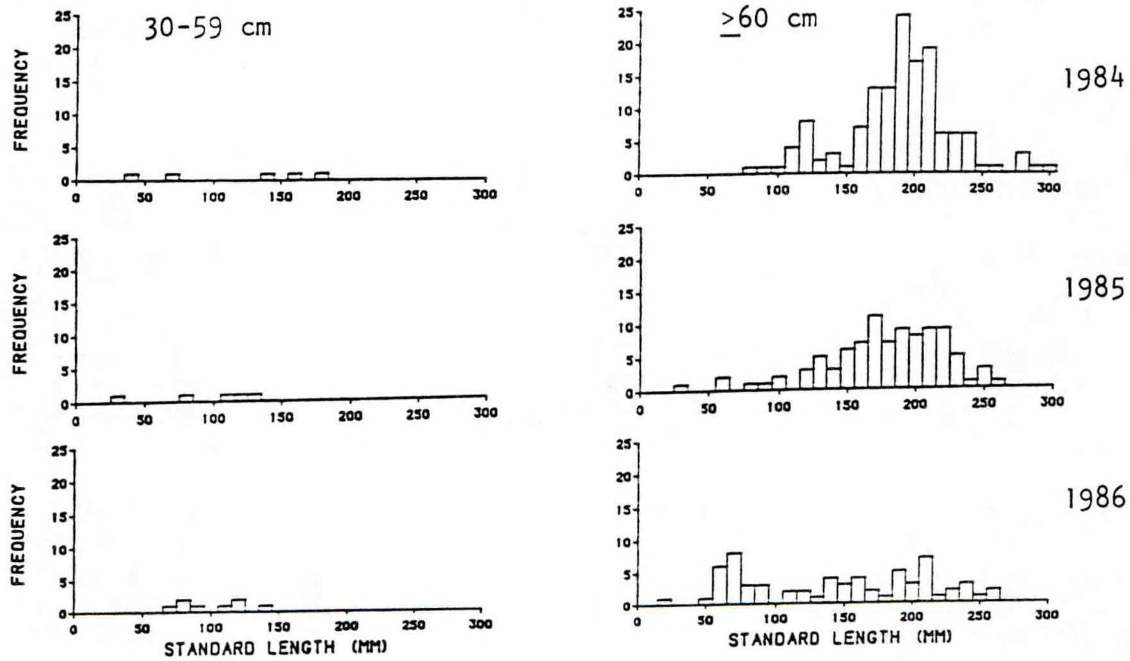


Figure 8.--Size frequency of yellowfin sole as prey in two size groups of Pacific cod from 1984 to 1986 in the eastern Bering Sea.

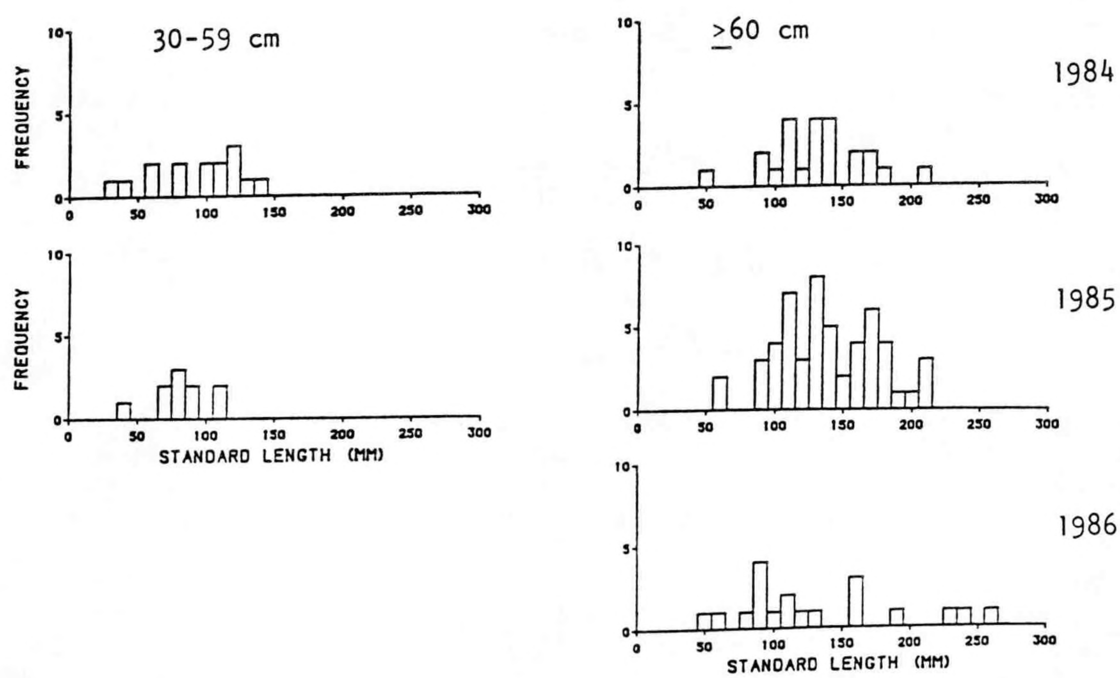


Figure 9.--Size frequency of rock sole as prey in two size groups of Pacific cod from 1984 to 1986 in the eastern Bering Sea.

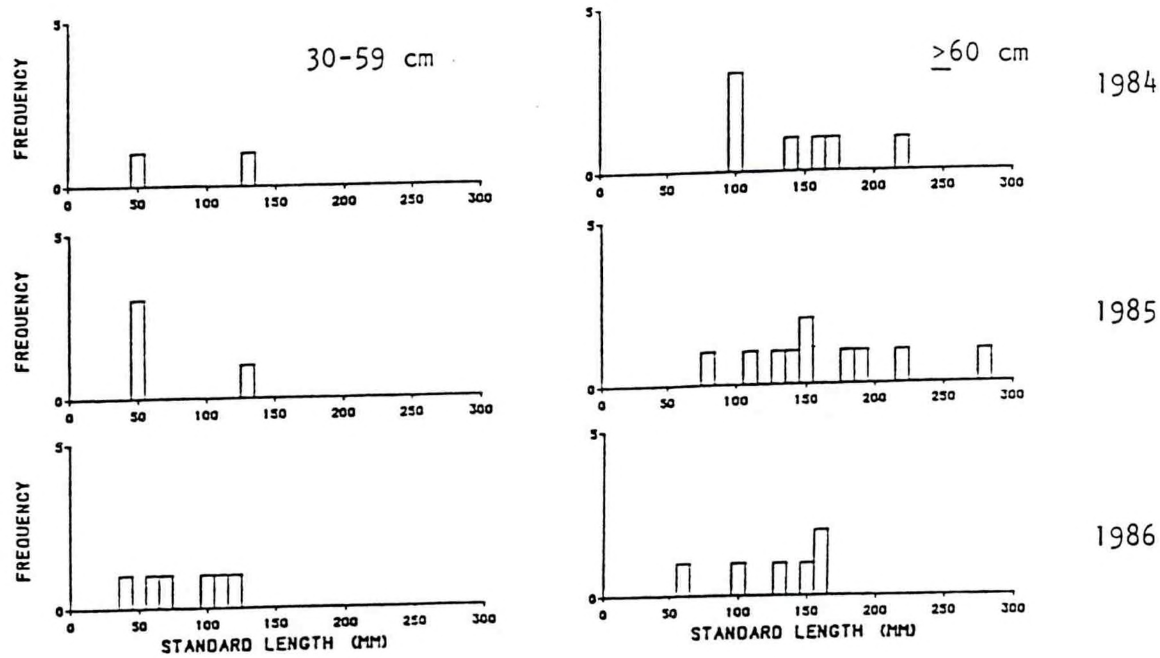


Figure 10.--Size frequency of flathead sole as prey in two size groups of Pacific cod from 1984 to 1986 in the eastern Bering Sea.

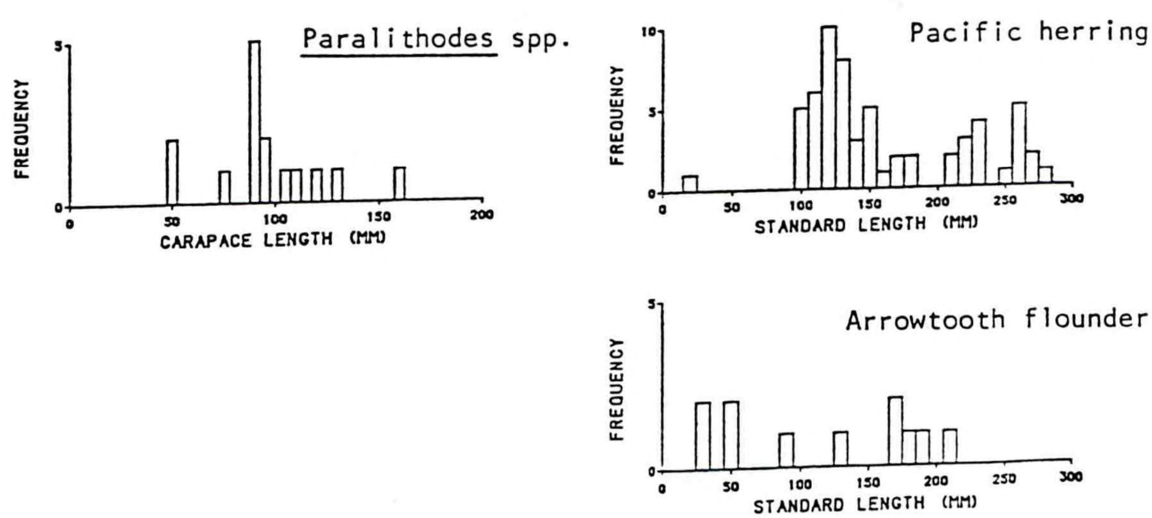


Figure 11.--Size frequency of king crabs (Paralithodes spp.), Pacific herring, and arrowtooth flounder as prey in Pacific cod during 1984-86 (data for all predator sizes and years combined) in the eastern Bering Sea.

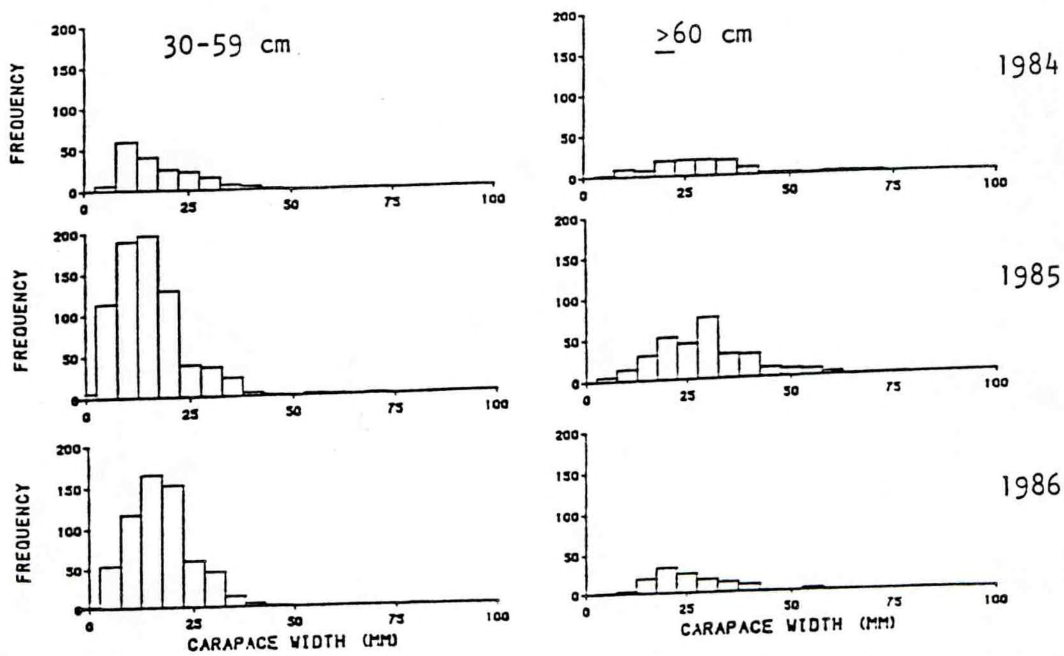


Figure 12.--Size frequency of Chionoecetes bairdi as prey in two size groups of Pacific cod from 1984 to 1986 in the eastern Bering Sea.

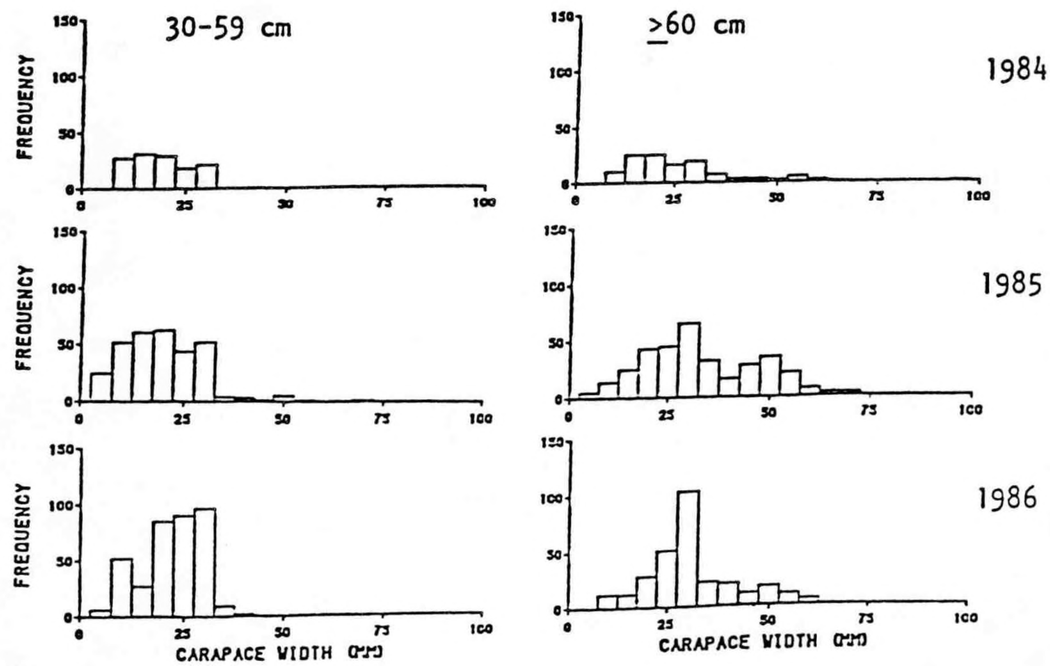


Figure 13.--Size frequency of Chionoecetes opilio as prey in two size groups of Pacific cod from 1984 to 1986 in the eastern Bering Sea.

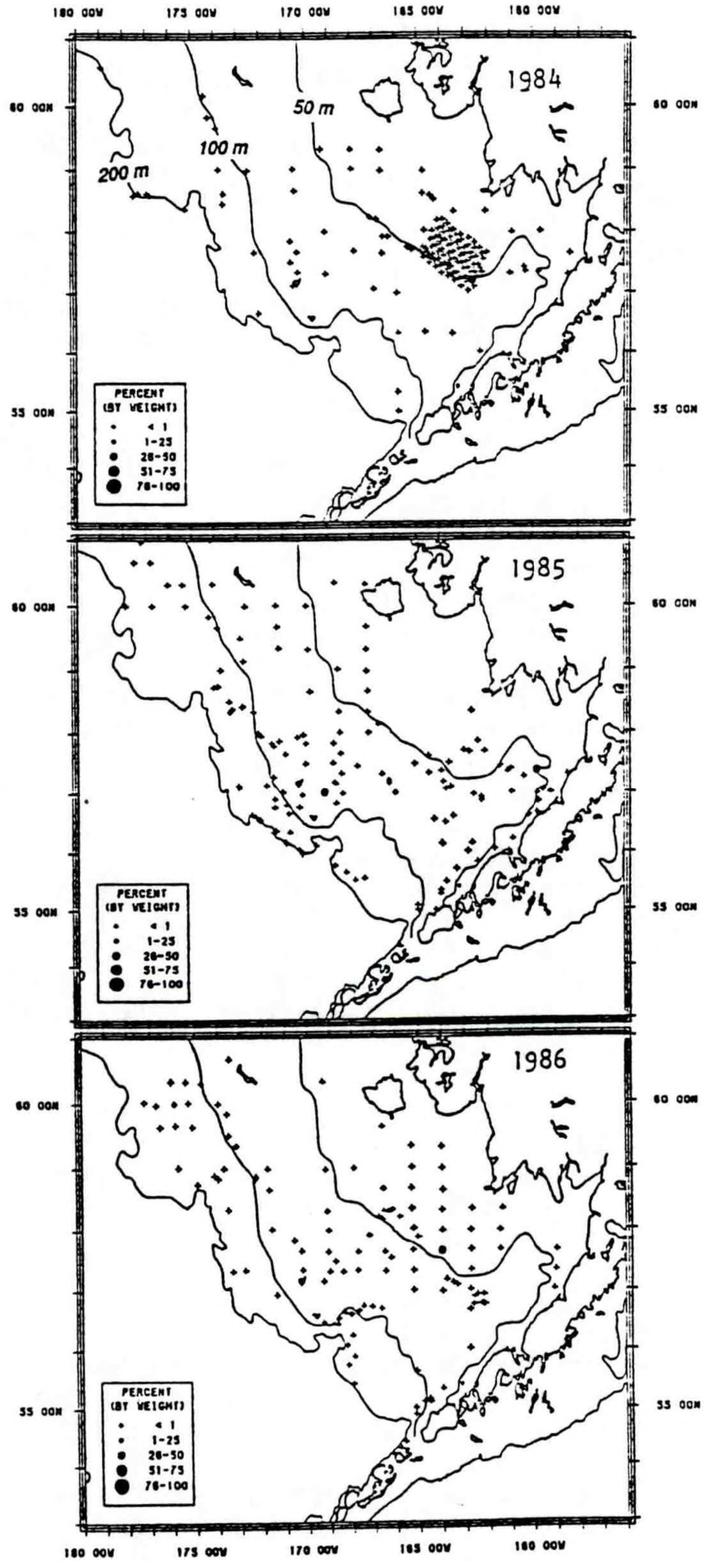


Figure 14.--Percent by weight of prey Pacific cod in the diet of Pacific cod by sampling station during months 5 to 9 from 1984 to 1986.

of the sizes likely to be consumed by adults (<20 cm) are found in areas with bottom depths less than 100 m (Walters et al. 1988).

Consumption of walleye pollock by Pacific cod (Fig. 15) was fairly widespread in the middle and outer shelf areas where bottom depths are greater than 50 m. Sampling in 1984 was sparse in the outer shelf area. In the middle shelf area, high proportions of pollock occurred in the stomach contents of cod more frequently in 1985 than in 1986. Although most pollock age 1 and greater are found in the outer shelf, age-0 pollock may also be abundant in middle and inner shelf waters in certain years (Walters et al. 1988). Age-0 pollock dominated the diet of mid-sized cod and in some years such as 1985, large cod also consumed age-0 pollock. The higher proportions of pollock in the stomach contents of cod sampled in the middle shelf in 1985 relative to those of 1986 may be due to the greater abundance of age-0 pollock in the eastern Bering Sea in 1985 found by Wespestad and Traynor (1990).

Yellowfin sole were consumed by Pacific cod in all 3 years, primarily in areas with bottom depths less than 50 m (Fig. 16). This area off of Cape Newenham has the highest density of yellowfin sole in the eastern Bering Sea (Walters et al. 1988). Rock sole were also eaten in all 3 years in the inner shelf area (Fig. 17), although they did not form a large portion of the stomach contents at most stations. The highest densities of rock sole were farther inside Bristol Bay than yellowfin sole, as assessed by bottom trawl survey (Walters et al. 1988). Although current biomass levels of yellowfin sole and rock sole are almost equal (Low 1990), 1985 levels of rock sole were about three times less than those of yellowfin sole (Bakkala and Walters 1986). This may explain the lesser amount of rock sole consumed by cod relative to yellowfin sole in the 1984 to 1986 period.

Evidence of Pacific herring consumption occurred only in 1985 and 1986 (Fig. 18). The amount of herring in the diet at each station was generally less than 50% by weight. Consumption occurred at isolated stations in all shelf subregions with no apparent pattern.

King crabs, identified to either genus or species levels, were consumed primarily near the inner and middle shelf boundary in the southeastern Bering Sea and along the Alaskan Peninsula (Figs. 19-20). No king crabs consumed in 1985 were identified as red king crab, although most listed as <u>Paralithodes</u> sp. were almost certainly red king crabs due to their location in the Bristol Bay area (Fig. 19). <u>Paralithodes</u> sp. were consumed at two stations near St. Matthew Island in 1985 and these were most likely blue king crabs (<u>Paralithodes platypus</u>). No trend in the amount of king crab in stomach contents was apparent across years.

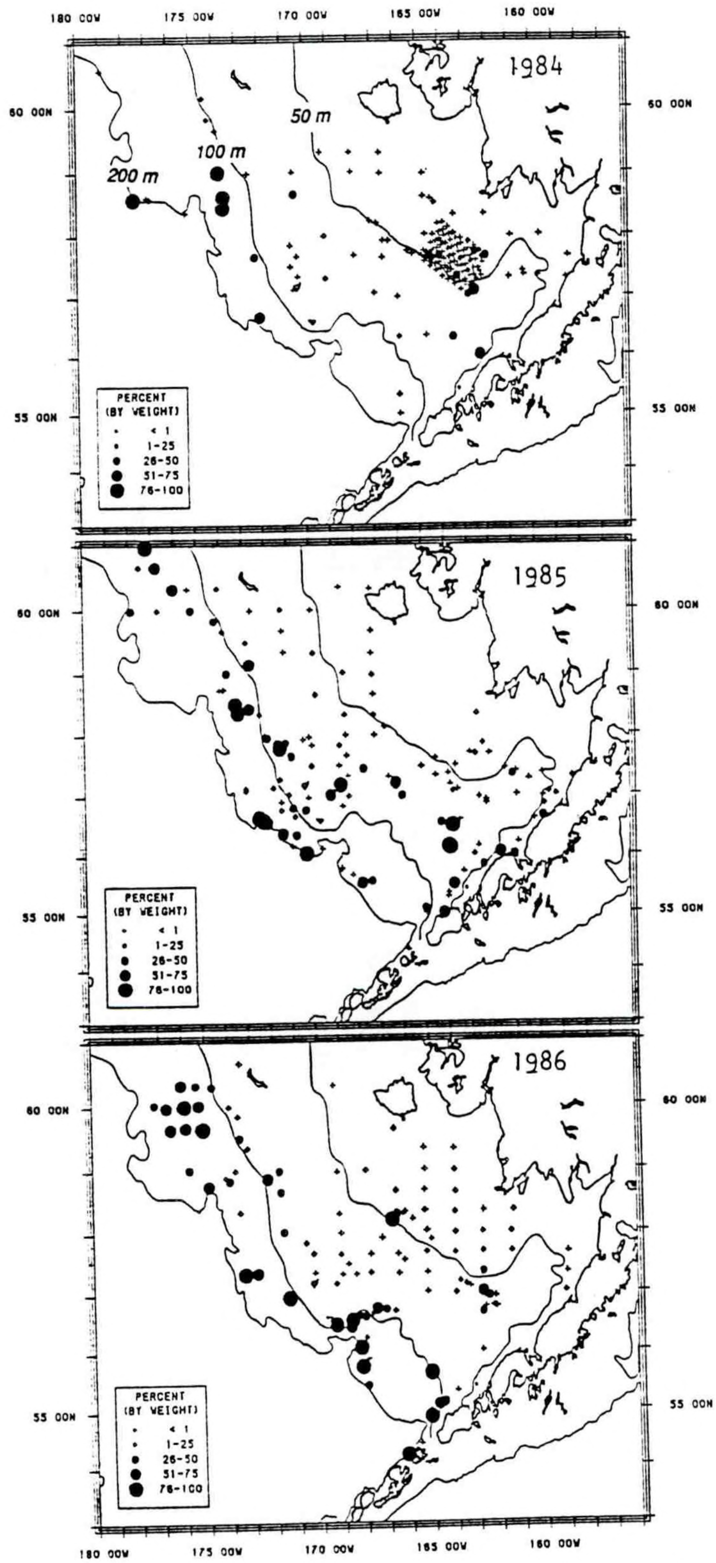


Figure 15.--Percent by weight of prey walleye pollock in the diet of Pacific cod by sampling station during months 5 to 9 from 1984 to 1986.

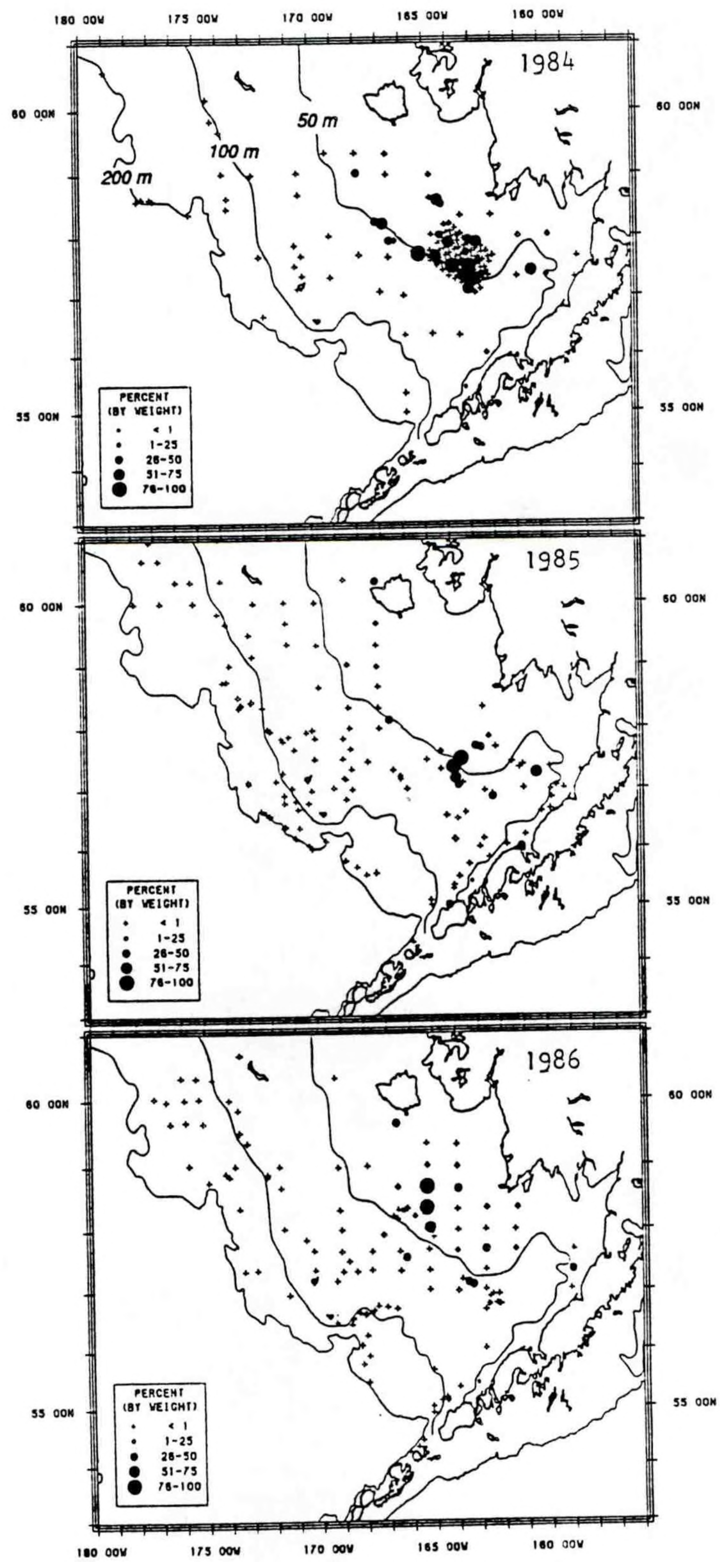


Figure 16.--Percent by weight of prey yellowfin sole in the diet of Pacific cod by sampling station during months 5 to 9 from 1984 to 1986.

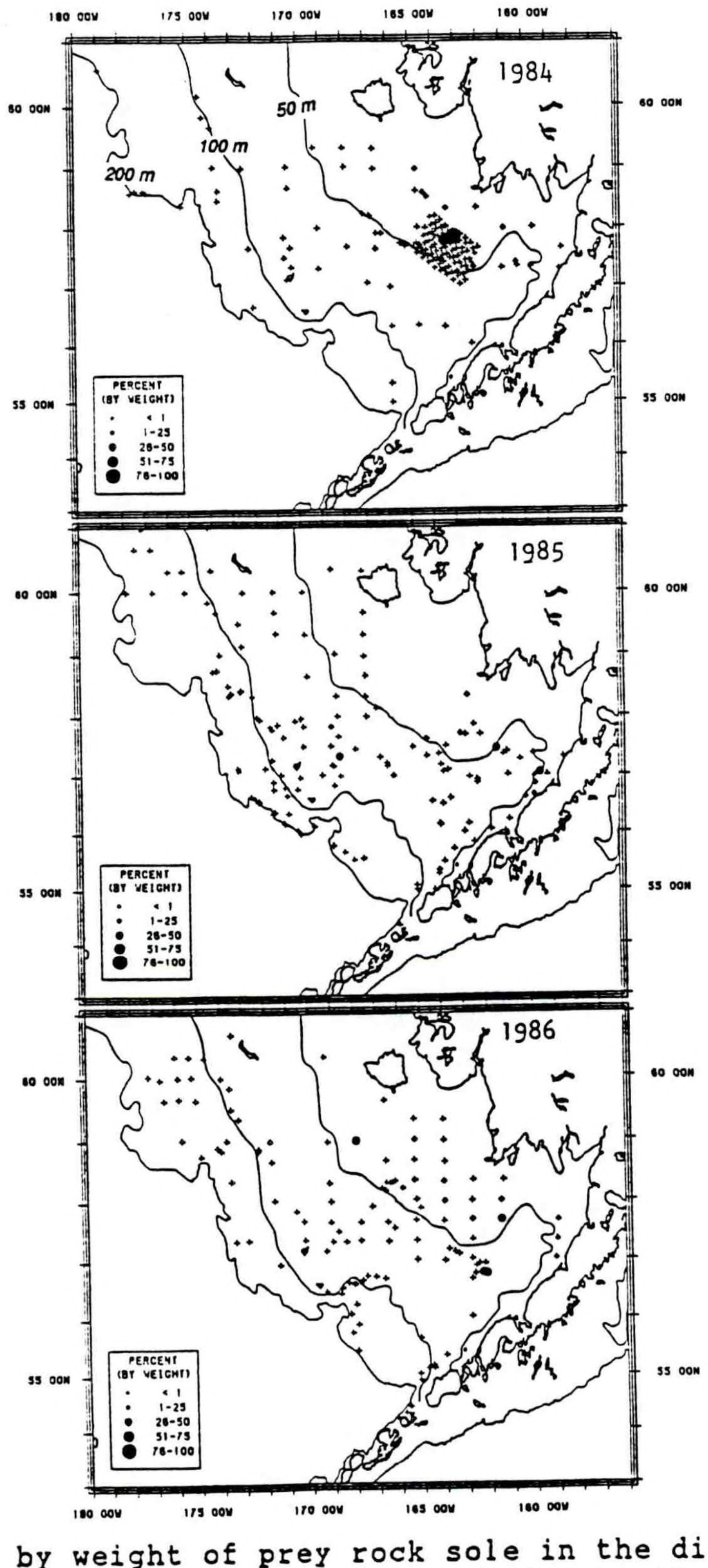


Figure 17.--Percent by weight of prey rock sole in the diet of Pacific cod by sampling station during months 5 to 9 from 1984 to 1986.

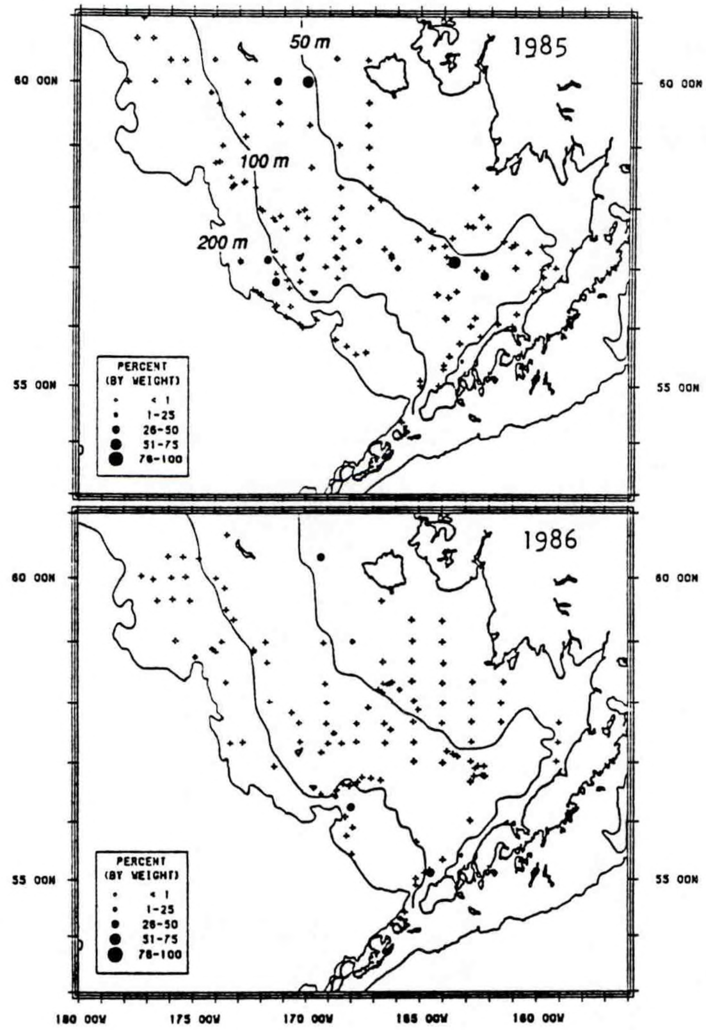


Figure 18.--Percent by weight of prey Pacific herring in the diet of Pacific cod by sampling station during months 5 to 9 in 1985 and 1986.

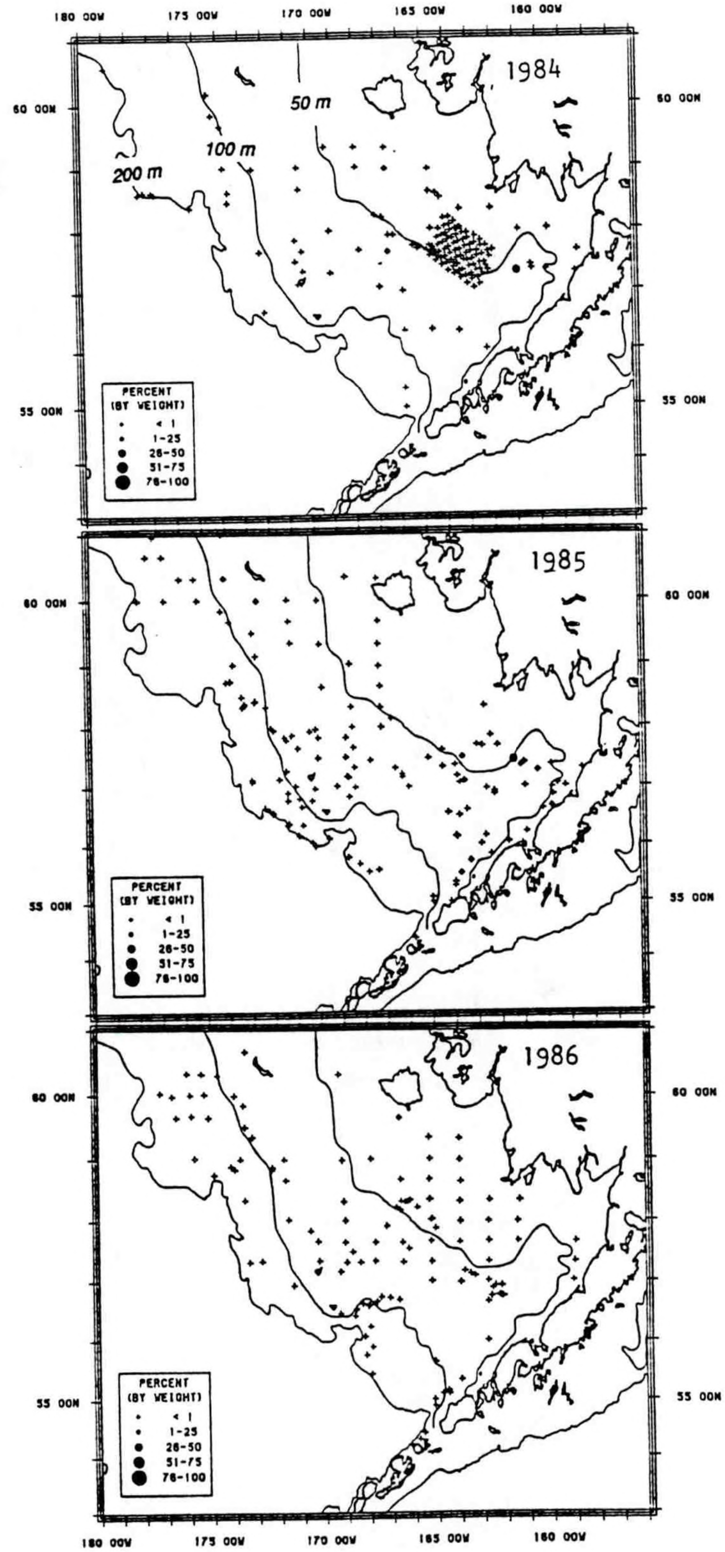


Figure 19.--Percent by weight of prey king crab (Paralithodes sp.) in the diet of Pacific cod by sampling station during months 5 to 9 from 1984 to 1986.

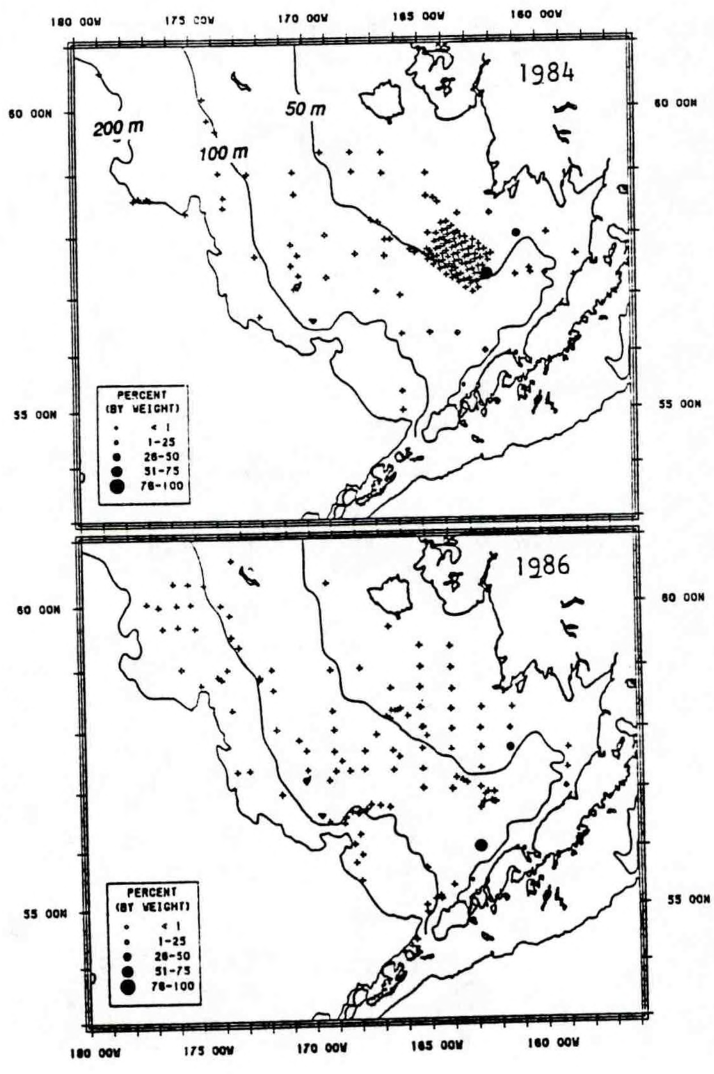


Figure 20.--Percent by weight of prey red king crab in the diet of Pacific cod by sampling station during months 5 to 9 in 1984 and 1986.

Consumption of snow and Tanner crabs from 1984 to 1986 is shown in Figures 21-22. Most snow crabs were consumed in the northern area of the eastern Bering Sea at bottom depths of 50 to 100 m. The amounts found in the Pacific cod stomach contents were much larger in 1985 and 1986 than in 1984, although sampling was sparse in the northern areas in 1984. Although the RACE Division bottom trawl survey of this area does not adequately sample the smaller sizes of crabs consumed by Pacific cod, the surveys do show most prerecruit snow crabs are found in the middle shelf area. Consumption of Tanner crabs by cod was not as high as consumption of snow crabs. Most Tanner crabs were consumed farther offshore in northern areas than were most snow crabs, and they were consumed farther south in middle shelf areas than were snow crabs.

Total Consumption Parameters

Tables 2-7 present the parameters, outlined in Equation (1) of the Methods section of this report, necessary to estimate the total amount of a particular prey item consumed the cod population on the eastern Bering Sea shelf during the main sampling period of May through September in each year. The estimated biomass of Pacific cod from RACE Division bottom trawl surveys from 1984 to 1986 are shown in Table 2. Total estimated biomass was lower in 1985 than in 1984 and 1986.

Daily ration of Pacific cod, in terms of fraction of body weight daily (BWD) for each size group is as follows:

Size group (cm)	Daily ration (fraction body weight daily)
<30	0.012
30-59	0.009
≥60	0.007

Although these estimates were derived in a different fashion, they are similar to those used by Livingston (1989b). The daily ration estimates used here, although they appear more reasonable than those derived from gastric evacuation models, could be improved through more formal bioenergetic models such as those employed by Hewett and Johnson (1987) that take into consideration changes in water temperature and prey energy content.

Estimates of the percentages by weight of commercially important prey in the diet of cod by cod size group and stratum are presented in Tables 3 through 7. Small percentages of Pacific cod were found in stomach contents (Table 3). The percentages of walleye pollock in the diet generally increased from 1984 to 1986 with larger cod containing larger percentages of pollock (Table 3).

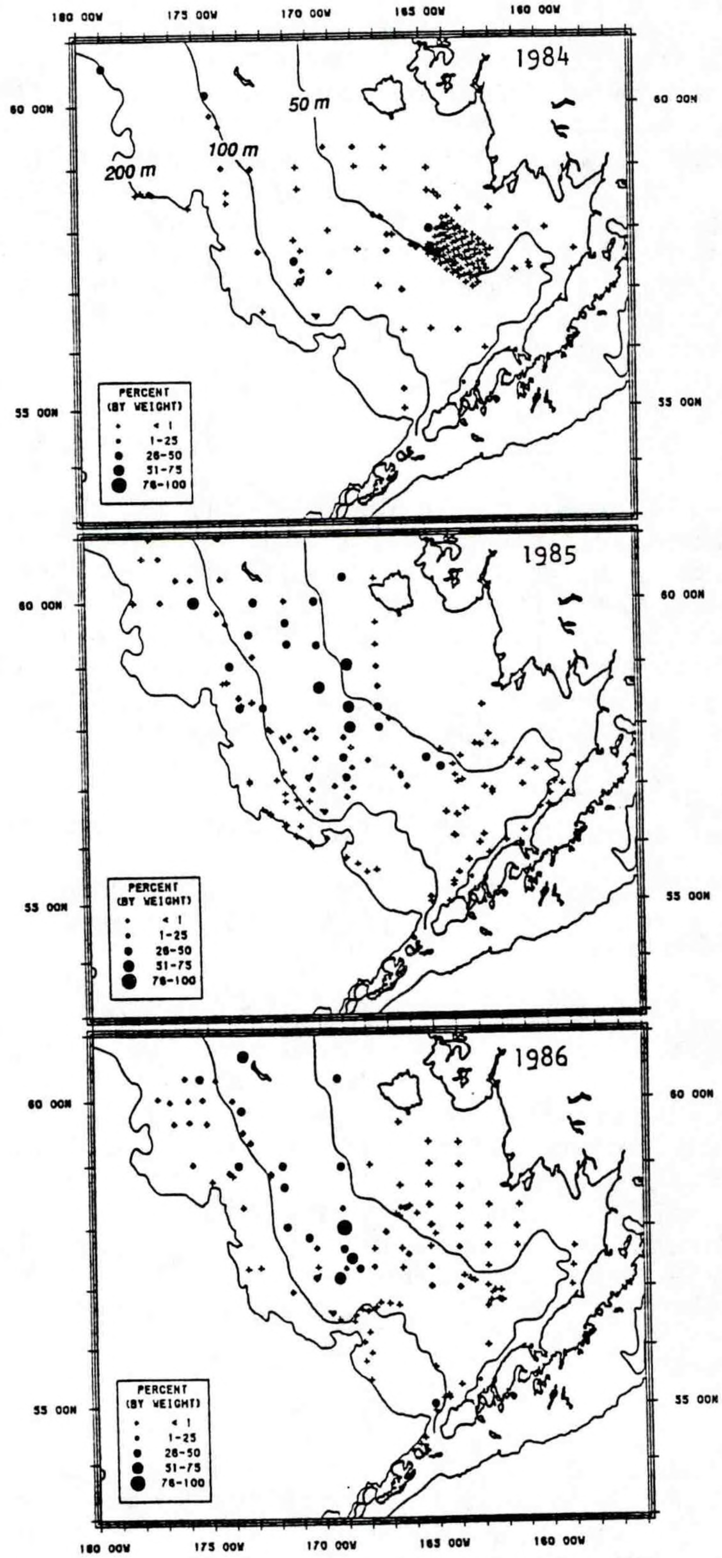


Figure 21.--Percent by weight of prey snow crab in the diet of Pacific cod by sampling station during months 5 to 9 from 1984 to 1986.

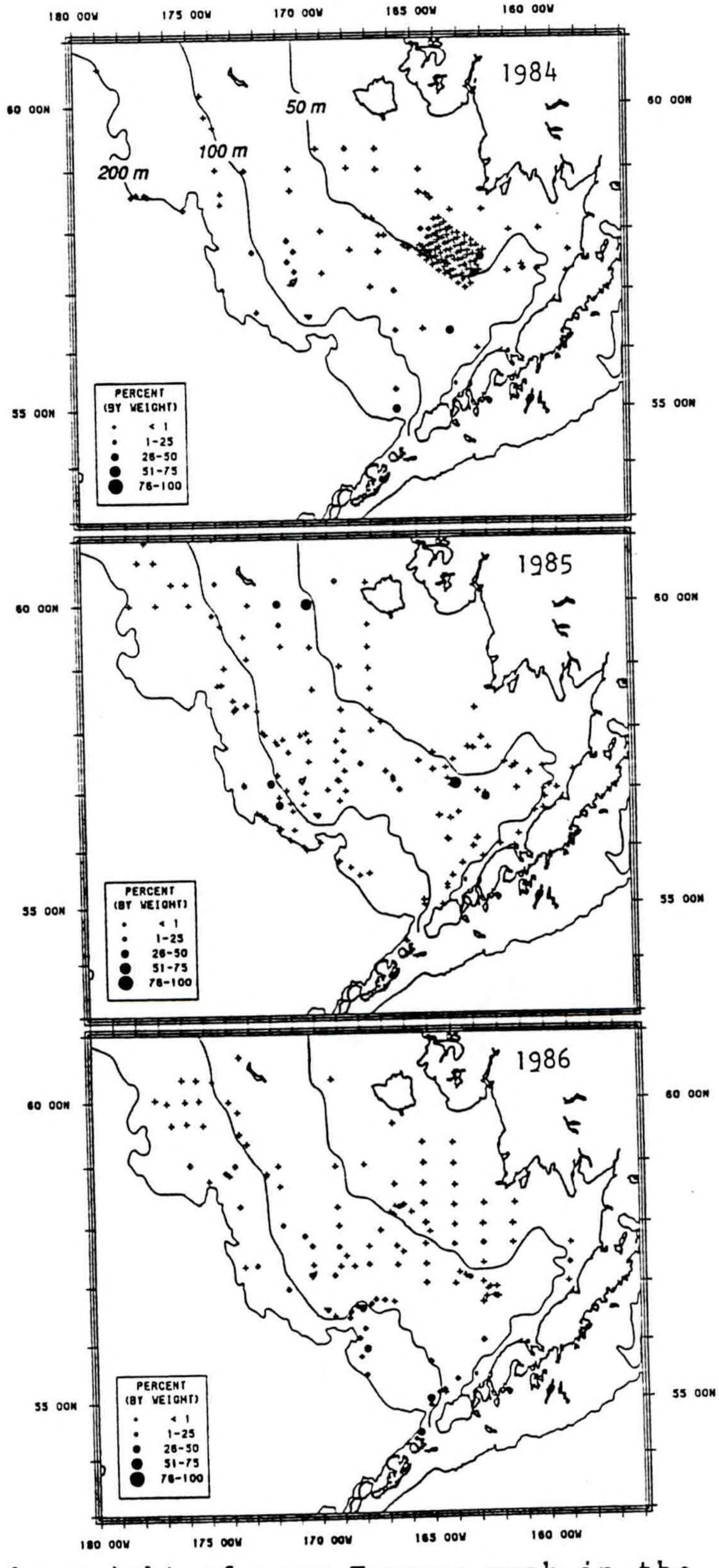


Figure 22.--Percent by weight of prey Tanner crab in the diet of Pacific cod by sampling station during months 5 to 9 from 1984 to 1986.

Table 2.--Estimated biomass in metric tons of Pacific cod in the eastern Bering Sea by cod size, year, and stratum.

Cod size (cm)	Stratum	Biomass 1984	1985	1986
<30	1	10,743	7,791	8,772
	2	1,717	6,513	1,144
	3	7,129	1,570	11,582
	4	8,571	4,127	8,672
	5	49	0	0
	6	1,921	438	446
30-59	1	76,873	45,796	79,294
	2	13,279	9,332	9,563
	3	42,980	105,420	133,497
	4	60,686	110,216	128,288
	5	8,065	10,919	23,365
	6	67,751	60,644	96,657
≥60	1	162,231	117,346	91,568
	2	60,008	50,106	56,144
	3	52,714	61,091	76,371
	4	65,192	75,344	53,973
	5	49,036	67,384	39,197
	6	312,994	227,012	315,574
Total		1,001,939	961,049	1,134,107

Table 3.--Mean percent by weight (%W) and standard error (SE) of gadid fish in the stomach contents of Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea.

Prey	Cod size (cm)	Stratum	1984 %W	1984 SE	1985 %W	1985 SE	1986 %W	1986 SE
Pacific cod	30-59	1	0	0	1.21	1.21	2.37	2.37
		2	0	0	0	0	1.06	1.06
		3	0	0	0.23	0.23	0	0
		4	0	0	0	0	1.58	1.58
	≥60	1	0.43	0.43	2.00	1.97	0	0
		2	0	0	0	0	0.96	0.96
		3	0	0	2.87	1.79	0	0
		6	0	0	0	0	0.20	0.20
Walleye pollock	<30	1	3.91	3.91	0	0	13.07	6.52
		2	13.41	13.41	21.54	13.65	7.17	7.17
		3	0	0	0	0	11.24	5.84
		4	0	0	0.76	0.76	22.62	6.75
		6	0	0	0	0	9.99	9.99
	30-59	1	1.35	0.68	10.22	5.58	9.73	5.15
		2	0	0	7.84	5.45	23.79	20.43
		3	5.27	4.11	11.05	4.21	12.87	4.92
		4	1.57	1.17	9.20	3.13	15.68	4.42
		5	0	0	0	0	2.70	2.70
		6	8.71	5.87	11.93	4.67	29.41	5.92
	≥60	1	2.21	1.01	11.25	5.01	9.72	5.27
		2	0	0	0.19	0.12	0.85	0.49
		3	14.70	8.50	21.67	6.07	19.80	10.86
		4	13.93	13.93	17.73	7.45	15.60	8.35
		5	4.13	4.13	31.35	14.59	62.40	12.49
		6	35.76	11.77	35.46	5.91	57.27	6.84

Table 4.--Mean percent by weight (%W) and standard error (SE) of flatfish in the stomach contents of Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. (* = no standard error estimate since only one station was sampled.)

Prey	Cod size (cm)	Stratum	1984 %W	1984 SE	1985 %W	1985 SE	1986 %W	1986 SE
Arrowtooth flounder	30-59	3	0	0	0	0	0.17	0.17
		4	0	0	0	0	0.23	0.23
		6	0	0	0.12	0.12	0	0
	≥60	6	0.29	0.29	0	0	0	0
Flathead sole	30-59	1	0	0	0.20	0.20	1.63	1.24
		3	0	0	0.02	0.02	0	0
		4	0.40	0.40	0.85	0.85	0	0
		5	1.78	*	0	0	0	0
		6	0	0	0	0	0.26	0.22
	≥60	1	0.77	0.51	0	0	0.04	0.04
		3	0	0	0	0	0.31	0.31
		4	0	0	0.08	0.08	0	0
		5	9.31	9.31	0	0	0.01	0.01
		6	0	0	1.14	0.75	3.37	3.02
Rock sole	<30	1	0	0	0	0	1.73	1.40
	30-59	1	0	0	0.35	0.33	7.63	3.48
		3	0	0	0	0	0.94	0.94
		4	0	0	0.34	0.34	0	0
	≥60	1	3.85	2.07	8.88	4.74	6.84	3.36
		2	0	0	0.14	0.14	20.13	20.13
		3	0.46	0.46	5.82	3.43	5.31	5.31
		4	0	0	0	0	2.53	2.53
Yellowfin sole	30-59	1	0.82	0.65	0	0	5.18	2.30
		2	17.04	17.04	0	0	0	0
		3	0	0	0.04	0.04	0	0
		5	0.90	*	0	0	0	0
	≥60	1	17.96	4.15	11.93	5.71	20.73	7.28
		2	7.73	5.02	8.79	4.16	11.43	8.78
		3	28.40	10.22	13.13	4.96	11.58	4.75

Table 5.--Mean percent by weight (%W) and standard error (SE) of Pacific herring in the stomach contents of Pacific cod by cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea.

Cod size (cm)	Stratum	1984		1985		1986	
		%W	SE	%W	SE	%W	SE
<30	2	0	0	0	0	5.16	5.16
30-59	2	0	0	0.71	0.71	0	0
	3	0	0	2.40	2.40	0	0
	4	0	0	0	0	0.34	0.34
	5	0	0	0	0	0.58	0.58
	6	0	0	0.37	0.37	0.93	0.93
≥60	1	0	0	0	0	0.19	0.19
	2	0	0	0	0	8.04	7.79
	3	0	0	3.33	1.97	3.56	3.56
	4	0	0	6.66	3.57	0	0
	5	0	0	0	0	6.30	4.79
	6	0	0	3.20	2.83	0.38	0.38

Table 6.--Mean percent by weight (%W) and standard error (SE) of king crabs in the stomach contents of Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea.

Prey	Cod size (cm)	Stratum	1984 %W	1984 SE	1985 %W	1985 SE	1986 %W	1986 SE
Lithodidae	30-59	1	0.19	0.19	0	0	0.06	0.06
	≥60	1	0	0	0.07	0.07	0.01	0.01
		3	0	0	0	0	0.01	0.01
Paralithodes sp.	<30	4	0.01	0.01	0	0	0	0
	30-59	1	0	0	0.12	0.12	0	0
		2	5.02	5.02	0	0	0	0
		4	0	0	2.25	2.25	0	0
	≥60	1	0	0	0.69	0.65	0	0
		2	0	0	0	0	0.95	0.95
		3	3.38	3.38	1.18	0.72	0	0
		4	0	0	0.48	0.48	0.01	0.01
Paralithodes camtschatica (red king crab)	30-59	1	0.37	0.30	0	0	1.39	1.19
	≥60	1	5.05	2.97	0	0	3.90	2.63
		3	0	0	0	0	9.96	9.96

Table 7.--Mean percent by weight (%W) and standard error (SE) of snow (Chionoecetes opilio) and Tanner (C. bairdi) crabs in the stomach contents of Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. (* = no standard error estimate since only one station was sampled.)

Prey	Cod size (cm)	Stratum	1984 %W	1984 SE	1985 %W	1985 SE	1986 %W	1986 SE
C. opilio	<30	3	0	0	4.78	4.78	0.44	0.44
		4	0	0	0	0	2.98	1.57
		6	0	0	2.42	2.42	0	0
	30-59	1	6.74	3.93	0	0	0.63	0.41
		2	2.83	1.75	23.77	12.92	0.11	0.11
		3	5.25	2.65	8.60	3.03	2.16	1.37
		4	5.71	4.49	21.23	4.01	30.13	4.11
		5	0	0	0.02	0.02	1.25	1.25
		6	6.60	3.56	4.89	1.81	15.20	4.02
	≥60	1	0.43	0.19	0	0	0.08	0.08
		2	4.24	2.73	28.88	13.13	8.66	8.66
		3	1.76	0.86	3.01	1.67	1.07	0.79
		4	13.90	11.90	30.38	6.05	47.29	9.44
		5	12.46	12.46	2.12	1.36	0	0
		6	11.34	4.41	12.61	4.11	10.41	3.54
C. bairdi	<30	1	0.15	0.15	0	0	0	0
		3	6.11	5.83	0	0	0.17	0.17
		4	3.59	1.75	0.53	0.53	0.27	0.17
		6	0	0	2.01	2.01	16.01	16.01
	30-59	1	0.98	0.34	1.46	1.23	0.57	0.39
		2	2.13	2.13	0	0	0	0
		3	5.64	3.25	10.43	4.07	6.65	2.50
		4	2.86	1.65	4.58	1.62	2.13	1.46
		5	33.12	*	40.65	17.84	38.65	10.94
		6	11.82	6.02	8.08	3.59	3.13	1.42
	≥60	1	0.04	0.03	1.67	1.26	0.44	0.31
		3	1.56	1.56	1.48	0.60	0.18	0.12
		4	0	0	6.84	3.57	0.86	0.86
		5	20.24	9.96	12.70	11.04	10.73	7.87
		6	1.14	0.62	7.54	2.92	0.31	0.14

Various flatfish species were found in the Pacific cod stomachs (Table 4). Less than 1% of the stomach contents consisted of arrowtooth flounder in any year or stratum. Percentages of flathead sole consumed were usually less than 2% with only two exceptions. Rock sole were most consistently consumed by the largest cod size group with amounts in stomach contents increasing from 1984 to 1986. The largest cod also consistently ate yellowfin sole with most consumption occurring in strata 1 and 3 (see Fig. 1, Methods section of this report), the areas of highest yellowfin sole biomass (Walters et al. 1988).

Pacific herring were found in Pacific cod stomach contents only in 1985 and 1986 (Table 5). They formed from 0 to 8% of the stomach contents by weight.

King crabs usually made up to 5% of the stomach contents by weight (Table 6). The one exception was in stratum 3 in 1986 where almost 10% of the stomach content weight of large Pacific cod was red king crab. Most consumption of king crabs occurred in strata 1 and 3.

Tanner and snow crabs constituted large proportions of the Pacific cod's diet in some strata (Table 7) and were mainly consumed by mid- and large-sized cod. The largest fractions of snow crab in the diet occurred in stratum 4, the northern middle shelf area, and the amounts in the diet increased from 1984 to 1986. Consumption of Tanner crab was highest in stratum 5, the southern outer shelf area, and there was no discernible trend in the proportions in the diet across years.

Total Consumption Estimates

Estimates of the total biomass of each commercially important prey consumed by the cod population were calculated for every cod size group in each stratum using the parameters given above in Equation (1) of the Methods section of this report. Numbers of each prey consumed were also calculated in strata where prey size information was available. Results are shown in Figures 23-28 and Tables 8-17.

Consumption of Gadid Fish

Total biomass and numbers of Pacific cod consumed through cannibalism were larger in 1985 and 1986 than in 1984 (Tables 8-9). The highest numbers consumed were in 1985, suggesting that smaller cod were consumed in 1985 relative to 1986. However, as seen previously in Figure 7, few prey cod were measurable in 1986 so these conclusions are uncertain. Little information is available on the abundance of age-0 cod, which was the age most frequently consumed by adults. However, some indication of relative year-class size is given by Thompson and Shimada (1990) for the 1984 and 1985 year classes. Their analysis shows that

Table 8.--Estimated total weight (metric tons) of gadid fish consumed by Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells where no prey size information was available.

Prey	Cod size (cm)	Stratum	Biomass 1984	1985	1986
Pacific cod	30-59	1	0	763.0	2,587.8
		2	0	0	139.6
		3	0	333.9	0
		4	0	0	2,791.1
	≥60	1	747.1	2,513.6	0
		2	0	0	577.2
		3	0	1,877.8	0
		6	0	0	(676.0)
Total			747.1	5,488.3	6,771.7
Walleye pollock	<30	1	771.2	0	2,105.0
		2	(422.7)	2,575.7	150.6
		3	0	0	2,390.1
		4	0	57.6	3,601.5
		6	0	0	(81.8)
	30-59	1	1,429.0	6,444.8	10,624.0
		2	0	1,007.4	3,132.7
		3	3,119.0	16,040.6	23,658.3
		4	1,312.0	13,962.6	27,699.1
		5	0	0	868.7
		6	8,125.8	9,962.4	39,143.7
	≥60	1	3,839.9	14,138.7	9,532.3
		2	0	102.0	511.1
		3	8,299.1	14,178.4	16,195.1
		4	(9,726.0)	14,306.9	9,017.6
		5	(2,169.0)	22,624.8	26,195.5
		6	119,873.4	86,213.8	193,561.0
Total			159,087.1	201,615.7	368,468.1

Table 9.--Estimated numbers (millions) of gadid fish consumed by Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. (Parentheses indicate cells where no prey size information was available.)

Prey	Cod size (cm)	Stratum	Number 1984	1985	1986
Pacific cod	30-59	1	0	220.4	12.6
		2	0	0	8.5
		3	0	7.9	0
		4	0	0	37.6
	≥60	1	3.6	33.9	0
		2	0	0	16.8
		3	0	12.0	0
		6	0	0	(0)
Total			3.6	274.2	75.5
Walleye pollock	<30	1	980.3	0	405.1
		2	(0)	543.2	39.3
		3	0	0	671.8
		4	0	73.2	537.9
		6	0	0	(0)
	30-59	1	472.6	713.7	1,921.1
		2	0	123.3	378.6
		3	101.1	2,381.2	915.5
		4	120.6	1,082.7	2,608.7
		5	0	0	38.3
		6	244.0	356.1	1,187.5
	≥60	1	13.0	169.6	69.0
		2	0	16.0	64.1
		3	16.0	101.9	45.4
		4	(0)	66.5	75.0
		5	(0)	57.6	77.1
		6	291.6	451.0	1,379.1
Total			2,239.2	6,136.0	10,413.5

the 1984 year class was almost twice as abundant as the 1985 year class when the numbers remaining at age 3 were considered. The estimated numbers cannibalized at about age 0 in 1984 and 1985 were 3.6 million and 274.2 million, respectively (Table 9). This seems to indicate that, at least for 1984 and 1985, cod were not consuming age-0 cod in proportion to their relative abundance. It appears that cod cannibalism is not as important in the eastern Bering Sea as it is in the North Sea (Daan 1987). However, stomach sampling of cod in the eastern Bering Sea was sparse in 1984 and may be a contributing factor to the low cannibalism estimates observed during that year.

Estimated consumption of walleye pollock by Pacific cod, in terms of weight and numbers, increased from 1984 to 1986 (Tables 8-9). Most of the pollock consumed in all years ranged from 50 mm to 100 mm in size, which is approximately age 0 (Fig. 23). The largest size group of cod consumed pollock that were mainly age 2 or older, the middle size group consumed age-0 and age-1 pollock, and the smallest size group of cod consumed only age-0 pollock.

Although the amount of walleye pollock consumed increased from 1984 to 1986, estimates of pollock year-class size from these 3 years exhibit a downward trend, especially from 1985 to 1986 (Wespestad and Traynor 1990). Estimated numbers of pollock consumed (in billions) for the 3 years were 2.2, 6.1, and 10.4, respectively. Pacific cod consumption of age-0 pollock is two orders of magnitude less than the numbers of age-0 pollock consumed by adult pollock (Dwyer et al. 1987; Livingston 1989a).

Livingston et al. (1986) showed that Pacific cod is a major consumer of large walleye pollock, a result also supported here. At least half of the pollock biomass consumed by cod in each of the 3 years consisted mainly of pollock of ages 3, 4, and 5. But even if the total pollock biomass consumed in each year is compared to estimates of pollock age 3 to 5 standing stocks in those years from Wespestad and Traynor (1990), cod removals are 2.7, 3.8 and 10.8% of the pollock standing stock in 1984, 1985, and 1986, respectively. These are fairly small proportions of the pollock stock, indicating that cod predation may not be a high source of mortality of older pollock. Sparse sampling of cod in outer shelf regions, particularly in 1984, could be a source of error in these estimates since most pollock is consumed by cod in these outer shelf areas.

Consumption of Flatfishes

Arrowtooth flounder was the flatfish preyed upon the least by Pacific cod (Tables 10-11). Biomass (100 to 972 t) and numbers consumed (2.9 to 39.9 million) were at least an order of magnitude less than the amounts consumed of flathead sole, rock sole, and yellowfin sole. Although little prey size information was available for arrowtooth flounder, most flounder consumed were less than 20 cm SL (Fig. 11).

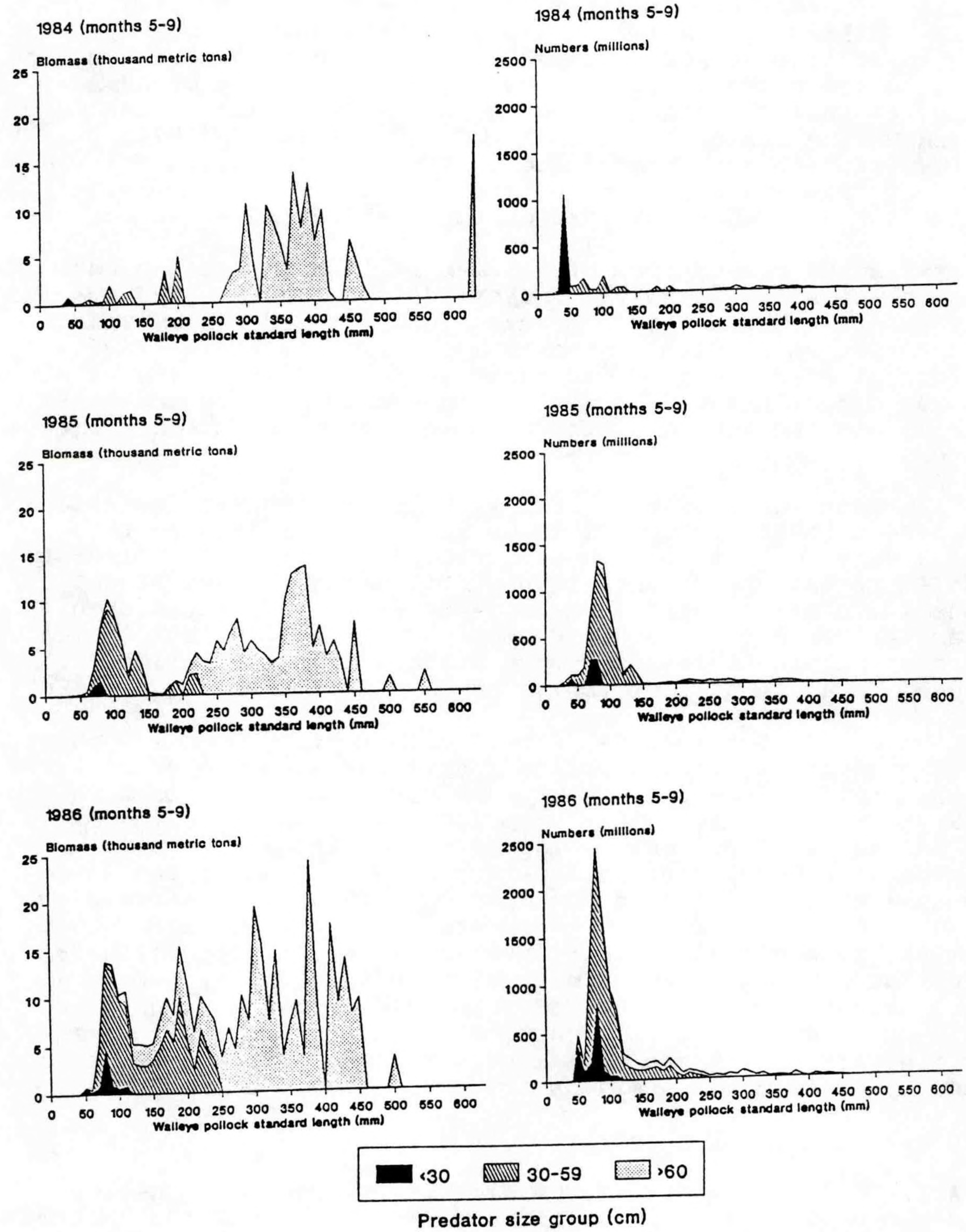


Figure 23.--Biomass and numbers of prey walleye pollock consumed by three size groups of Pacific cod during months 5 to 9 from 1984 to 1986 in the eastern Bering Sea by prey size.

Table 10.--Estimated total biomass (metric tons) of flatfish consumed by Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells where no prey size information was available.

Prey	Cod size (cm)	Stratum	Biomass 1984	Biomass 1985	Biomass 1986
Arrowtooth flounder	30-59	3	0	0	312.5
		4	0	0	406.3
		6	0	100.2	0
	≥60	6	972.1	0	0
Total			972.1	100.2	718.8
Flathead sole	30-59	1	0	126.1	1,779.8
		3	0	29.0	0
		4	334.3	1,290.0	0
		5	197.7	0	0
		6	0	0	346.0
	≥60	1	1,337.9	0	39.2
		3	0	0	253.6
		4	0	64.6	0
		5	4,889.4	0	4.2
		6	0	2,771.7	11,389.9
Total			6,759.3	4,281.4	13,812.7
Rock sole	<30	1	0	0	278.6
	30-59	1	0	220.7	8,331.0
		3	0	0	1,728.0
		4	0	516.0	0
	≥60	1	6,689.4	11,160.2	6,707.9
		2	0	75.1	12,104.2
		3	259.7	3,807.9	4,343.2
		4	0	0	1,462.5
Total			6,949.1	15,779.9	34,955.4
Yellowfin sole	30-59	1	868.0	0	5,655.9
		2	3,115.8	0	0
		3	0	58.1	0
		5	100.0	0	0
	≥60	1	31,205.4	14,993.3	20,329.8
		2	4,968.0	4,717.0	6,872.9
		3	16,033.7	8,590.8	9,471.7
Total			56,290.9	28,359.2	42,330.3

Table 11.--Estimated numbers (millions) of flatfish consumed by Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea.

Prey	Cod size (cm)	Stratum	Number 1984	1985	1986
Arrowtooth flounder	30-59	3	0	0	4.0
		4	0	0	35.9
		6	0	2.9	0
	≥60	6	6.4	0	0
Total			6.4	2.9	39.9
Flathead sole	30-59	1	0	77.0	82.9
		3	0	17.7	0
		4	10.6	41.1	0
		5	120.6	0	0
		6	0	0	47.4
	≥60	1	15.8	0	2.8
		3	0	0	8.1
		4	0	9.4	0
		5	128.7	0	1.5
		6	0	29.9	200.5
Total			275.7	175.1	343.2
Rock sole	<30	1	0	0	70.8
	30-59	1	0	45.8	423.4
		3	0	0	40.1
		4	0	36.7	0
	≥60	1	123.7	270.6	93.0
		2	0	3.9	861.9
		3	3.2	55.2	53.2
		4	0	0	4.0
Total			126.9	412.2	1,546.4
Yellowfin sole	30-59	1	13.8	0	222.0
		2	37.3	0	0
		3	0	75.4	0
		5	60.4	0	0
	≥60	1	211.9	113.2	197.1
		2	57.9	64.9	166.3
		3	99.1	59.5	65.7
Total			480.4	313.0	651.1

Flathead sole and rock sole were consumed in fairly similar amounts in 1985 (6,759 and 6,949 t, respectively) and both were consumed in much larger amounts in 1986 (13,812 and 34,955 t, respectively) relative to the other 2 years. The largest size group of Pacific cod was responsible for most of the biomass consumed (Figs. 24-25). Cod in the 30-59 cm size range tended to eat smaller flatfish than larger cod. Most flatfish consumed were less than 20 cm SL.

Most flatfish biomass consumed by Pacific cod in all 3 years was yellowfin sole (Table 10). Although the biomass eaten decreased from 1984 (56,290 t) to 1986 (42,330 t), more numbers were eaten in 1986 (651 million) than in the other 2 years (1984, 480 million; 1985, 313 million) (Table 11). Both mid- and large-sized groups of cod consumed large numbers of yellowfin sole less than 10 cm SL in 1986 (Fig. 26). Although most yellowfin sole eaten in terms of numbers were less than 20 cm SL, a larger proportion of the biomass eaten was of fish greater than 20 cm than in the other flatfish species.

The biomass consumed of each species on the shelf was compared with the RACE Division bottom trawl survey estimate of standing stock and a percent of standing stock removed due to Pacific cod consumption was calculated (Table 12). Percent removals were small for all species, ranging from 0.1 to 3.4% of the standing stock biomass on the shelf. The percentages removed across years within a species show some variation and might be an indication of density-dependent predation. Pacific cod might be responding to increases in rock sole biomass by increasing their predation rate on rock sole. However, these percentages are not very accurate since cod consume flatfish mostly <20 cm SL while the trawl survey estimates take into account all sizes of flatfish.

Because most fish eaten were less than 20 cm, a comparison of numbers consumed (in millions) versus numbers of flatfish less than 20 cm from trawl survey estimates given for 1985 by Walters et al. (1988) may be more appropriate.

Species	Number eaten	Number from trawl survey	Percent consumed
Arrowtooth flounder	2.9	23.0	12.6
Flathead sole	175.1	422.0	41.5
Rock sole	412.2	1,340.0	30.8
Yellowfin sole	313.0	2,400.0	13.0

Although the high removal rates may be an indication of high predation mortality induced by cod, these high removal rates may also be an indication that trawl survey estimates of flatfish less than 20 cm might be low due to escapement of smaller fish through the trawl mesh or other trawl effects on the catchability

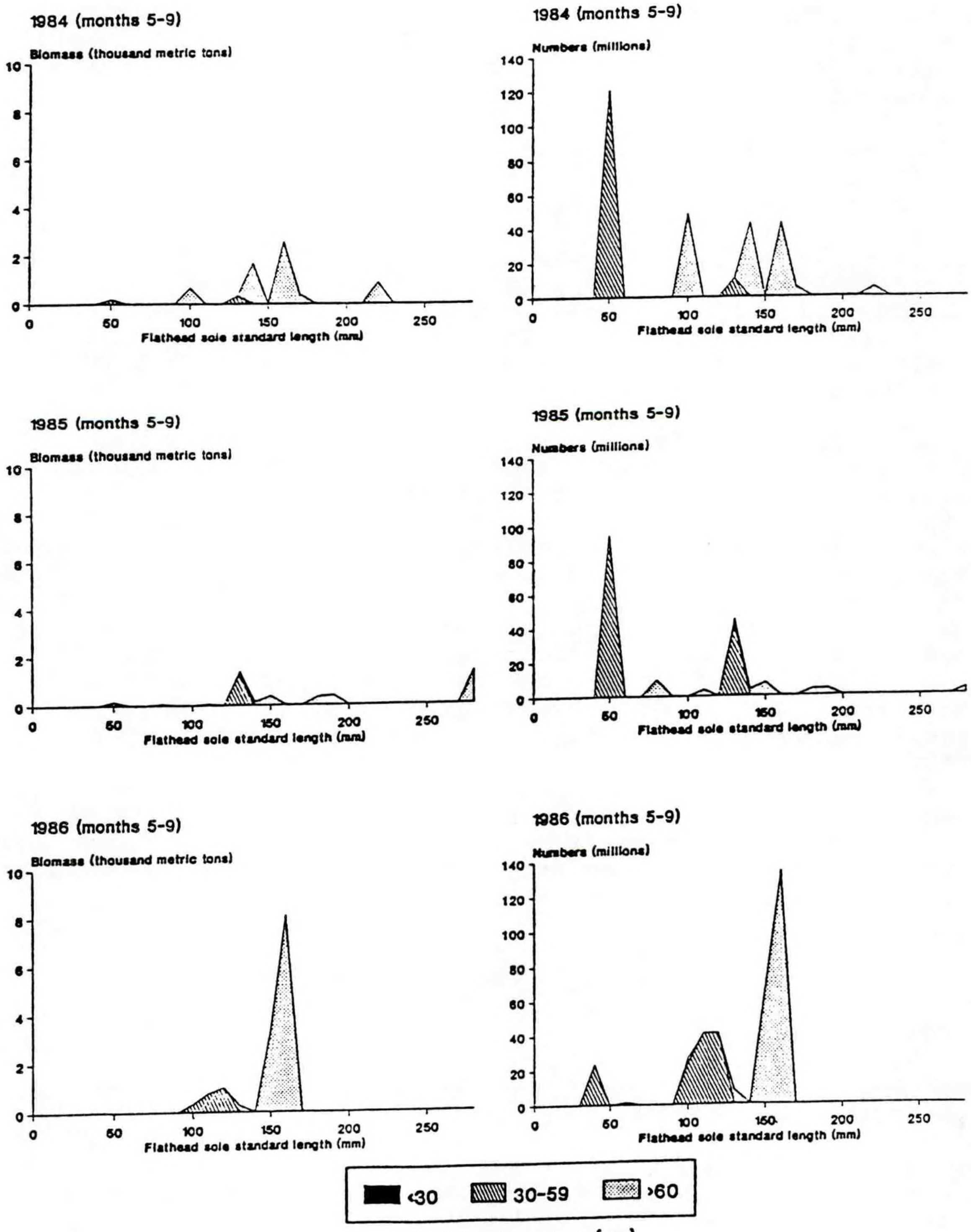


Figure 24.--Biomass and numbers of prey flathead sole consumed by three size groups of Pacific cod during months 5 to 9 from 1984 to 1986 in the eastern Bering Sea by prey size.

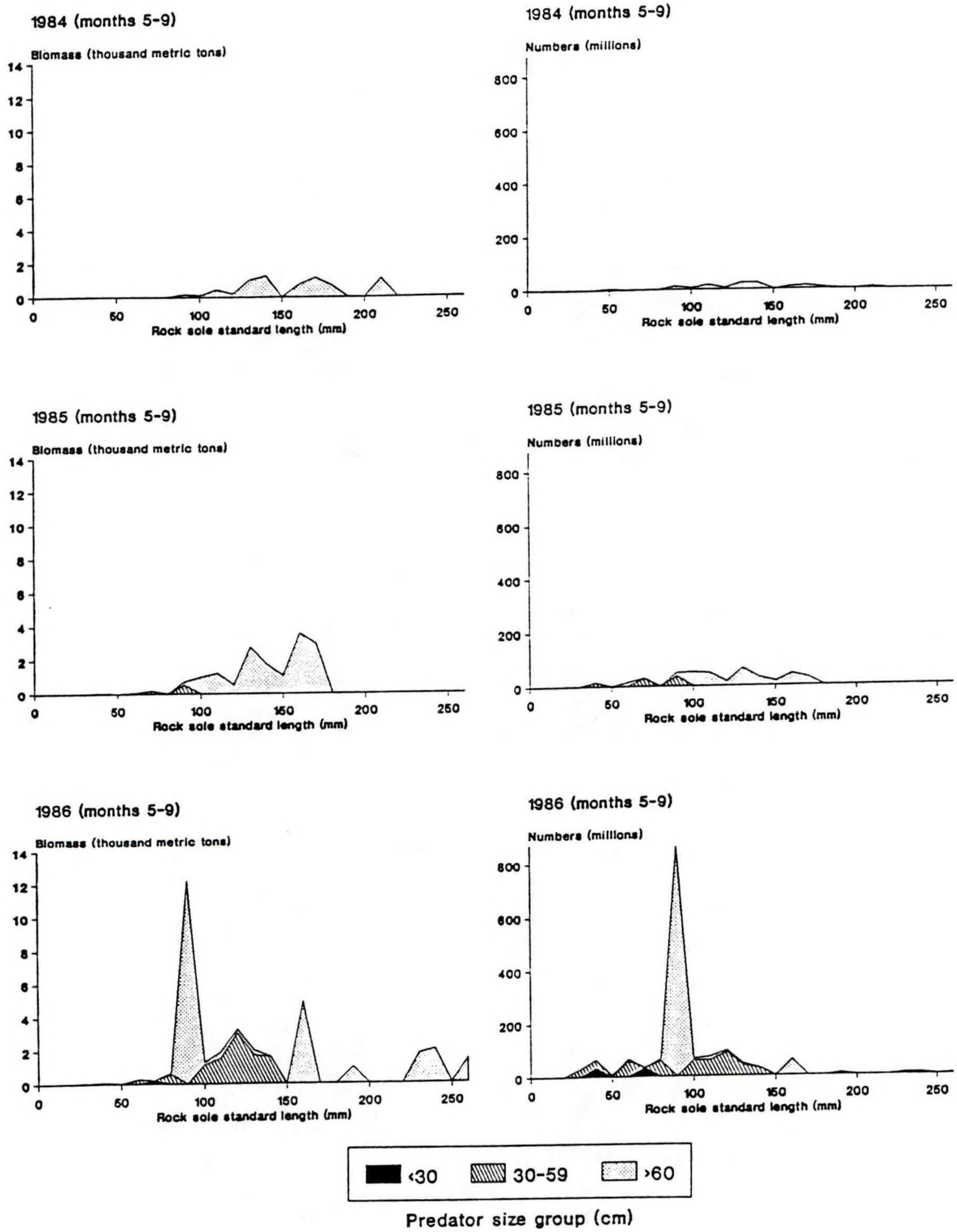


Figure 25.--Biomass and numbers of prey rock sole consumed by three size groups of Pacific cod during months 5 to 9 from 1984 to 1986 in the eastern Bering Sea by prey size.

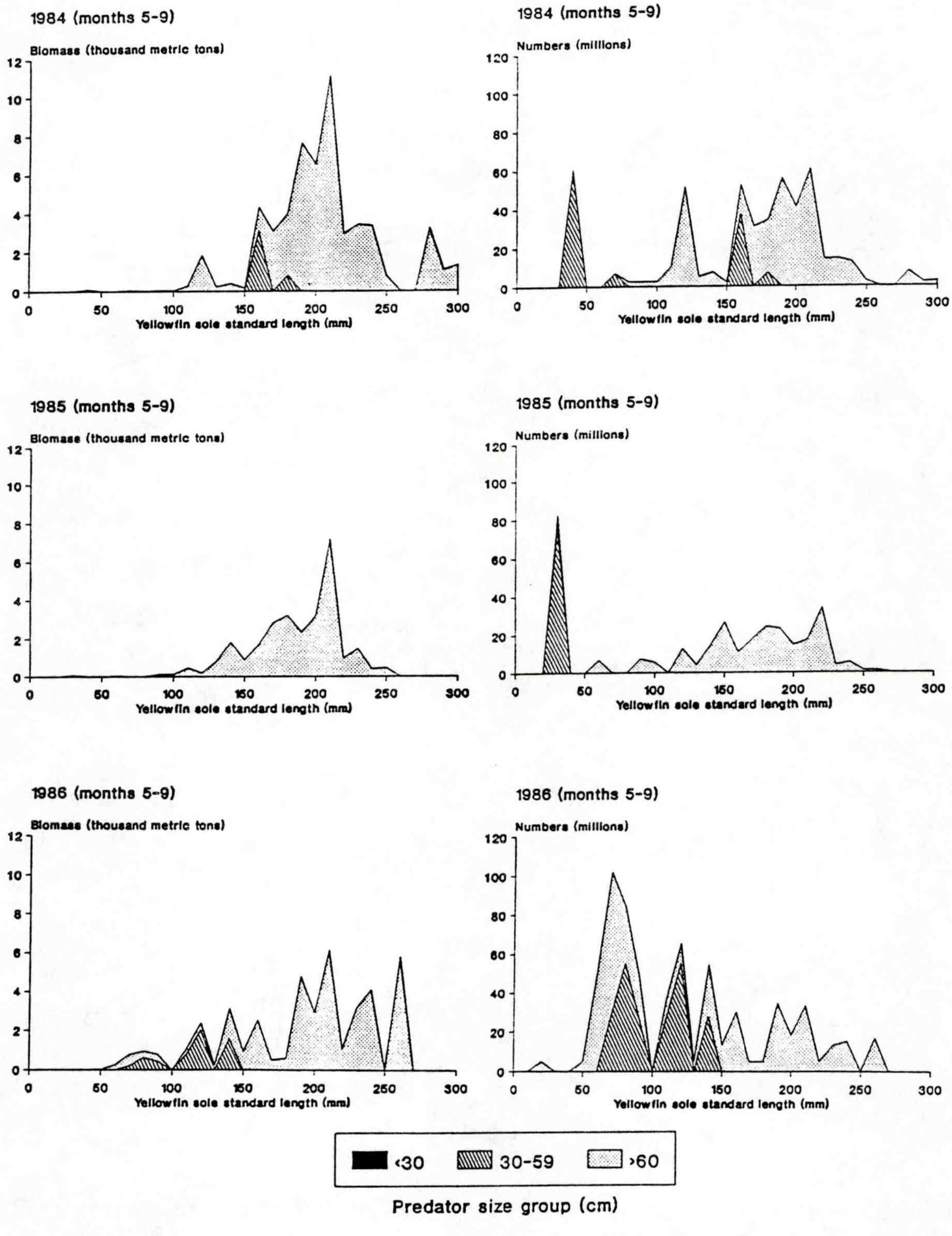


Figure 26.--Biomass and numbers of prey yellowfin sole consumed by three size groups of Pacific cod during months 5 to 9 from 1984 to 1986 in the eastern Bering Sea by prey size.

Table 12.--Total biomass of flatfish consumed by Pacific cod, trawl survey estimates of biomass, and percent consumed by year in the eastern Bering Sea. (Biomass in metric tons.)

Species	Year	Biomass consumed	Trawl biomass*	Percent consumed
Arrowtooth flounder				
	1984	972.1	182,900	0.5
	1985	100.2	159,900	0.1
	1986	718.8	232,100	0.3
Flathead sole				
	1984	6,759.3	344,800	2.0
	1985	4,281.4	329,900	1.3
	1986	13,812.7	369,300	3.7
Rock sole				
	1984	6,949.1	950,600	0.7
	1985	15,779.9	720,300	2.2
	1986	34,955.4	1,013,700	3.4
Yellowfin sole				
	1984	56,290.9	3,320,300	1.7
	1985	28,359.2	2,277,400	1.2
	1986	42,330.3	1,866,400	2.3

*Source: Low and Narita 1990.

of small flatfish. It is likely that percent removals of flatfish by cod are somewhere between those in Table 12 and those presented above.

Consumption of Pacific Herring

Pacific herring were consumed only in 1985 and 1986; similar biomasses (19,217 and 13,995 t, respectively; Table 13) and numbers (310 and 337 million, respectively; Table 14) were consumed in both years. Most of the herring were taken by large cod (Fig. 27). The majority of herring (by number) removed by cod were in the 100 to 150 mm SL range, corresponding to age-1 or age-2 herring. Pacific herring escapement from coastal fisheries in 1986 was 112,703 t (Lebida 1987). Cod predation on herring as a percent of escapement in 1986 is 12.4%. However, these escapement figures are based on herring age 3 and greater and do not include age-1 or age-2 herring.

Consumption of King Crabs

Estimates of total biomass and numbers of king crab consumed by Pacific cod are shown in Tables 15-16. Although in some years and strata, crab were not identified to species; crab found in strata 1, 2, and 3 were probably red king crab. Crab eaten in stratum 4 were probably St. Matthew Island blue king crab, at least in 1985, as seen in Figure 19. Thus, most of the crab consumed in 1984 and 1986 were red king crab while most of the crab consumed in 1985 were blue king crab. As mentioned in the Methods section of this report, it is assumed that these crab were females eaten during their soft-shell stage, which extends about 31 days into the sampling period of May through September. When the biomass of red king crab consumed by cod is expressed as a percentage of the estimated standing stock of female red king crab for the years 1984 to 1986 the removals are 3.3, 5.0, and 48.9%, respectively. Similarly for blue king crab the percent predation removals of female blue king crab biomass are 0.08, 1024, and 0.9% in 1984, 1985, and 1986.

In the case of red king crab, the removals due to cod predation for 1984 and 1985 were fairly low and are similar to those estimated by Livingston (1989b) using the same data but slightly different methodology. The removals for 1986, however, were much higher than the other 2 years and could be an indication of large uncertainty in the estimates of cod consumption and in female red king crab standing stock estimates. Since most crab eaten were less than 100 mm carapace width, trawl surveys estimates of these sizes are likely to be imprecise (Otto 1986). This is certainly part of the problem with the 1986 estimate because 1987 estimates of female red king crab biomass were over three times as large as the previous year, an amount too high to be attributed to a real 1-year increase in population size.

Table 13.--Estimated total biomass (metric tons) of Pacific herring consumed by Pacific cod by cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells where no prey size information was available.

Cod size (cm)	Stratum	Biomass 1984	Biomass 1985	Biomass 1986
<30	2	0	0	(108.4)
30-59	2	0	(91.2)	0
	3	0	3,483.9	0
	4	0	0	600.6
	5	0	0	(186.6)
	6	0	(309.0)	1,237.8
≥60	1	0	0	186.3
	2	0	0	4,834.5
	3	0	2,178.8	(2,911.8)
	4	0	5,374.2	0
	5	0	0	2,644.7
	6	0	7,780.2	(1,284.3)
Total			19,217.3	13,995.0

Table 14.--Estimated numbers (millions) of Pacific herring consumed by Pacific cod by cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. (Numbers in parentheses estimated from an average herring size of 165 mm standard length.)

Cod size (cm)	Stratum	Number 1984	1985	1986
<30	2	0	0	(2.1)
30-59	2	0	(1.8)	0
	3	0	23.3	0
	4	0	0	14.0
	5	0	0	(3.6)
	6	0	(5.9)	9.6
≥60	1	0	0	2.9
	2	0	0	214.2
	3	0	24.3	(56.0)
	4	0	218.1	0
	5	0	0	10.2
	6	0	36.8	(24.7)
Total			310.2	337.3

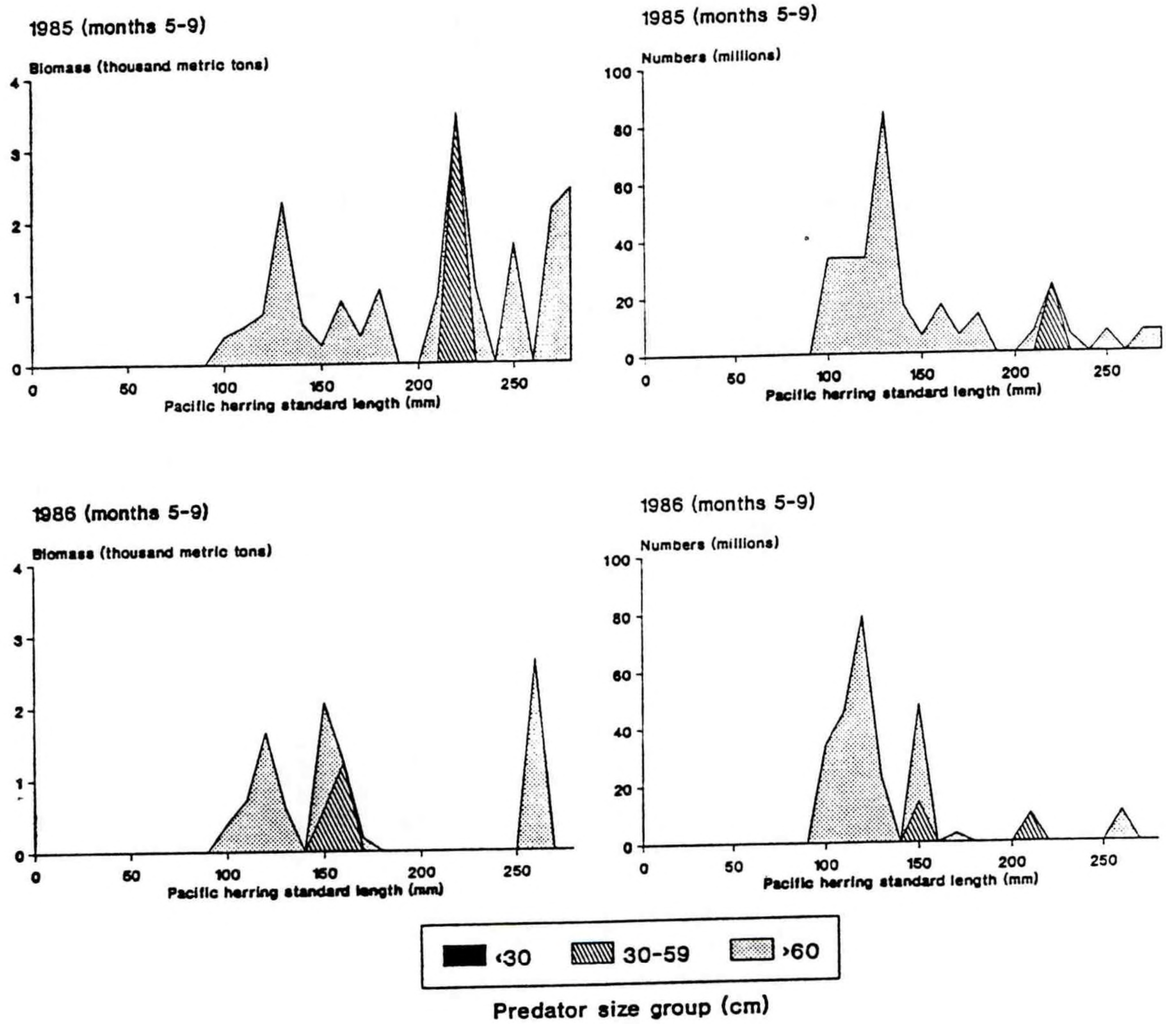


Figure 27.--Biomass and numbers of prey Pacific herring consumed by three size groups of Pacific cod during months 5 to 9 in 1985 and 1986 in the eastern Bering Sea by prey size.

Table 15.--Estimated total biomass (metric tons) of king crabs consumed by Pacific cod by prey species, cod size group, year, and strata for 31 days during months 5 to 6 in the eastern Bering Sea. Values in parentheses indicate cells where no prey size information was available.

Prey	Cod size (cm)	Stratum	Biomass 1984	Biomass 1985	Biomass 1986
Lithodidae	30-59	1	(40.8)	0	(13.3)
	≥60	1	0	(17.8)	(2.0)
		3	0	0	(1.7)
Total			40.8	17.8	17.0
Paralithodes sp.	<30	4	(0.3)	0	0
	30-59	1	0	(15.3)	0
		2	(186.0)	0	0
		4	0	(691.9)	0
	≥60	1	0	(175.7)	0
		2	0	0	(115.7)
		3	386.6	(156.4)	0
		4	0	(78.5)	(1.2)
Total			572.9	1,117.8	116.9
Paralithodes camtschatica (red king crab)	30-59	1	(79.4)	0	(307.5)
	≥60	1	1,777.8	0	774.9
		3	0	0	(1,650.6)
Total			1,857.2		2,733.0

Table 16.--Estimated numbers (millions) of king crabs consumed by Pacific cod by prey species, cod size group, year, and strata for 31 days during months 5 to 9 in the eastern Bering Sea. (Numbers in parentheses estimated from an average king crab size of 97.5 mm carapace length.)

Prey	Cod size (cm)	Stratum	Number 1984	1985	1986
Lithodidae	30-59	1	(0.07)	0	(0.02)
	≥60	1	0	(0.03)	(0.005)
		3	0	0	(0.002)
Total			0.07	0.03	0.027
<u>Paralithodes</u> sp.	≤30	4	(0.001)	0	0
	30-59	1	0	(0.03)	0
		2	(0.29)	0	0
		4	0	(1.09)	0
	≥60	1	0	(0.28)	0
		2	0	0	(0.18)
		3	0.69	(0.25)	0
		4	0	(0.12)	(0.002)
Total			0.981	1.77	0.182
<u>Paralithodes camtschatica</u> (red king crab)	30-59	1	(0.13)	0	(0.48)
	≥60	1	1.67	0	1.37
		3	0	0	(2.60)
Total			1.80		4.45

Estimates of percent removal of blue king crab by cod fluctuated widely for several reasons. First, as mentioned above for red king crab, trawl survey estimates of crab biomass for sizes less than 100 mm are imprecise. Also, blue king crab population estimates as a whole are more imprecise than those for red king crab since blue king crab inhabit rocky bottom areas where trawling is difficult (Otto 1986). Estimates of the amount of blue king crab consumed may depend on the timing of cod stomach sampling near St. Matthew Island relative to the female molting season. Timing of sampling near St. Matthew Island in 1985 and 1986 was about a week earlier than in 1984. Thus, it may be more likely that soft-shell females would still be present when cod stomach samples were taken in 1985 and 1986. Finally, the biennial reproductive cycle of the blue king crab (Jensen and Armstrong 1989) may also be the reason more blue king crab were consumed during 1985. This might be substantiated if 1987 proves to be a year of higher blue king crab consumption relative to 1986.

Pacific cod consumption rates of both species of king crabs should be considered indices of predation rates at this time. Percent removals are meaningless if precise estimates of standing stock are not available. Livingston (1989b) gives a more complete description of possible errors that may arise on calculating total consumption estimates. Total consumption estimates depend on assumptions about the timing and duration of the female king crab molting period. Cod consumption of king crab males and some portion of the female population probably occurs earlier than our sampling is able to detect so total consumption of king crab could be larger than the estimates given here.

Consumption of Snow and Tanner Crabs

Estimated biomass and numbers of snow crab consumed increased during 1984-86 from 80,416 to 147,780 t (Table 17) and from 6,658 to 12,212 million (Table 18), respectively. Mid-sized cod consumed snow crab that were mostly between 10 and 40 mm carapace width (CW) while the largest size group of cod consumed crab between 20 and 60 mm CW (Fig. 28). Mid-sized cod consumed the largest numbers of snow crab. In 1984 and 1985 most snow crabs eaten were from 5 to 24 mm CW (age 1) while those eaten in 1986 were age 1 and age 2 (25-39 mm CW).

Unfortunately, age-1 and age-2 snow crab population sizes are not well estimated in trawl surveys. Tanner and snow crabs are not fully vulnerable to research trawl nets until they are about 40 mm CW (age 3) so trawl survey estimates of abundance at younger ages are not reliable. More recent survey results showing crab size frequencies from 1987 to 1989 (Stevens and MacIntosh 1989) indicate that there was a large increase in the juvenile snow crab population due to new recruitment sometime in the mid-1980s. The increasing amounts of young crab consumed by Pacific cod from 1984 to 1986 also support this conclusion. The

Table 17.--Estimated total biomass (metric tons) of snow (Chionoecetes opilio) and Tanner (C. bairdi) crabs consumed by Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells where no prey size information was available.

Prey	Cod size (cm)		Biomass 1984	Biomass 1985	Biomass 1986
C. opilio	<30	3	0	(137.8)	93.6
		4	0	0	474.5
		6	0	19.5	0
	30-59	1	7,134.6	0	687.9
		2	517.5	3,054.5	(14.5)
		3	3,107.1	12,484.0	3,970.6
		4	4,771.5	32,220.2	53,225.4
		5	0	3.0	402.2
		6	6,157.4	4,083.5	20,230.7
	≥60	1	747.1	0	78.5
		2	2,725.0	15,498.0	5,207.3
		3	993.6	1,969.4	875.2
		4	9,705.1	24,514.7	27,336.0
		5	6,543.7	1,530.0	0
		6	38,013.6	30,658.7	35,183.7
Total			80,416.2	126,173.3	147,780.1
C. bairdi	<30	1	29.6	0	0
		3	799.7	0	36.2
		4	564.9	40.2	43.0
		6	0	16.2	131.1
	30-59	1	1,037.4	920.7	622.4
		2	389.5	0	0
		3	3,338.0	15,140.5	12,224.4
		4	2,390.0	6,951.0	3,762.7
		5	3,678.1	6,111.9	12,435.1
		6	11,027.2	6,747.4	4,165.9
	≥60	1	69.5	2,098.8	431.5
		3	880.7	968.3	147.2
		4	0	5,519.4	497.1
		5	10,629.6	9,165.4	4,504.4
		6	3,821.5	18,332.0	1,047.7
Total			38,655.7	72,011.8	40,048.7

Table 18.--Estimated numbers (millions) of snow (*Chionoecetes opilio*) and Tanner (*C. bairdi*) crabs consumed by Pacific cod by prey species, cod size group, year, and strata during months 5 to 9 in the eastern Bering Sea. (Parentheses indicate cells where no prey size information was available.)

Prey	Cod size (cm)	Stratum	Number 1984	Number 1985	Number 1986
C. opilio	<30	3	0	(0)	106.0
		4	0	0	727.9
		6	0	102.4	0
	30-59	1	644.5	0	132.6
		2	75.5	263.5	(0)
		3	727.9	1,659.2	340.4
		4	1,354.3	5,843.3	5,860.2
		5	0	3.4	356.8
		6	1,187.8	193.6	2,170.9
	≥60	1	52.5	0	5.0
		2	488.5	1,177.7	279.1
		3	140.5	113.4	36.5
		4	283.7	1,044.7	679.1
		5	67.9	15.9	0
		6	1,635.0	583.4	1,520.4
Total			6,658.1	11,000.5	12,214.9
C. bairdi	<30	1	20.7	0	0
		3	560.6	0	25.3
		4	319.0	28.2	47.9
		6	0	776.9	25.4
	30-59	1	405.3	52.9	17.7
		2	146.1	0	0
		3	184.3	1,491.9	2,234.0
		4	469.1	655.2	900.0
		5	1,018.7	1,229.7	2,337.3
		6	1,299.8	1,217.9	503.9
	≥60	1	12.5	76.7	9.8
		3	35.4	52.8	9.6
		4	0	213.4	13.1
		5	279.8	281.8	379.1
		6	228.4	861.5	62.2
Total			4,979.7	6,938.9	6,565.3

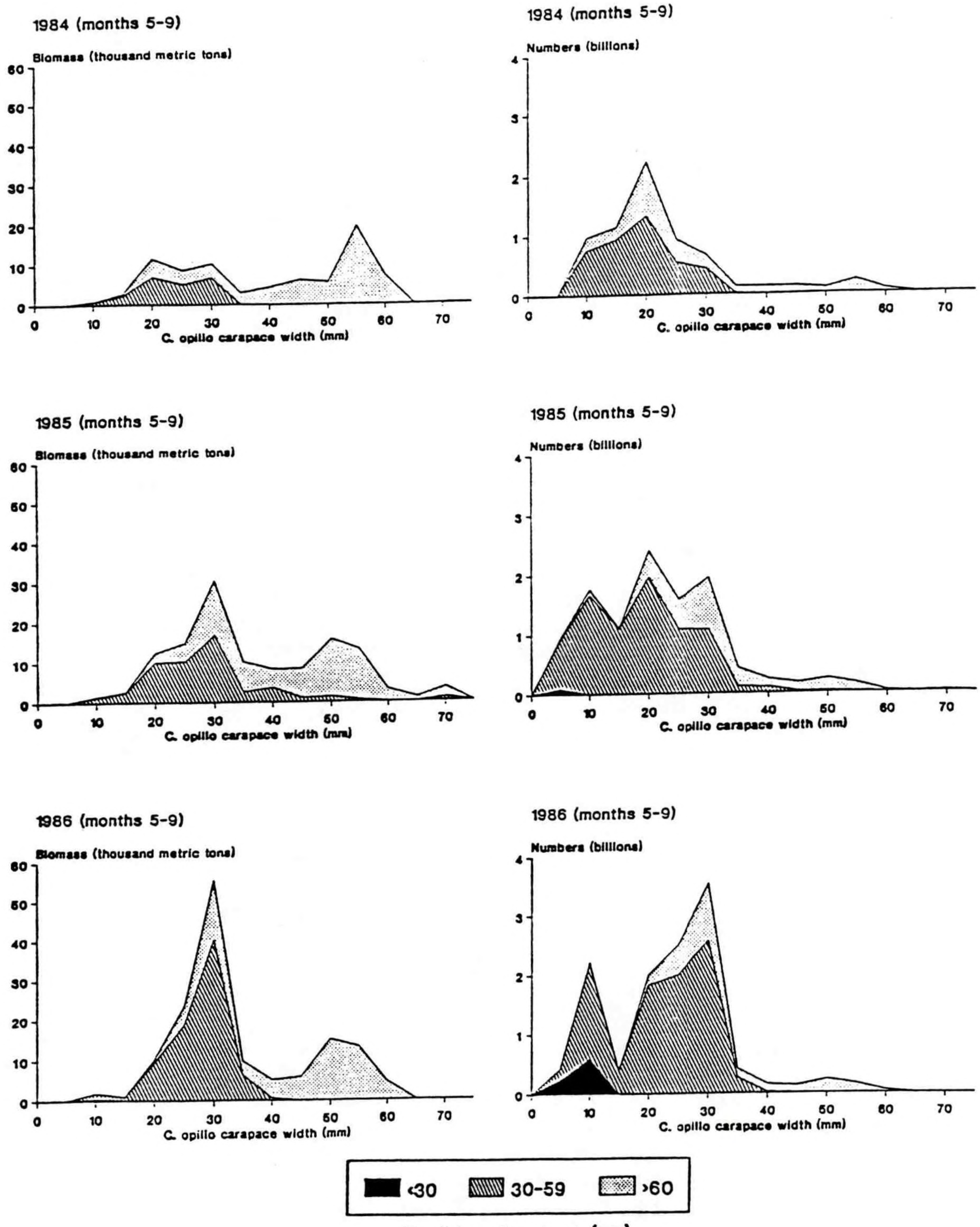


Figure 28.--Biomass and numbers of prey snow crab consumed by three size groups of Pacific cod during months 5 to 9 in the eastern Bering Sea by prey size.

large number of age-1 crab consumed in 1985 and the presence of substantial numbers of age-1 and age-2 snow crab in cod stomachs in 1986 would suggest that a major recruitment event may have occurred in 1984.

Biomass and numbers of Tanner crabs consumed by Pacific cod increased from 1984 (38,656 t, 4,980 million) to 1985 (72,012 t, 6,939 million) but decreased in 1986 (40,049 t, 6,565 million) (Tables 17-18). Mid-sized cod consumed more crab than cod in the other two size ranges (Fig. 29). The largest number of crabs eaten were from 5 to 34 mm CW, which are mainly age-1 crab. The numbers of age-1 Tanner crabs eaten during 1984-86 were 4.4, 5.2, and 5.4 billion, respectively. Estimated population size of these year classes at age 3, when trawl survey estimates are fairly reliable, are 49, 125, and 132 million, respectively. The trend in number present at age 3 is similar to the trend in number consumed by cod at age 1, indicating that cod consumption of Tanner and snow crabs may be an early index of year-class size.

To determine the impact of Pacific cod predation on Tanner and snow crab populations, it is necessary to know the initial size of the crab populations at age 1 before cod predation occurs. Because these estimates are not available they must be reconstructed by using reliable estimates of population size before other sources of mortality (such as fishing) occur. Age-1 population size could be reconstructed by adding the numbers of a year class consumed at younger ages down to age 1, as in Forney (1977). For Tanner and snow crabs, the survey estimates of population size at age 3 would be a reliable estimate; therefore, numbers of crab consumed at ages 2 and 1 would be needed to reconstruct age-1 population size for a year class. There are sufficient predation data here to reconstruct the year-class sizes of Tanner and snow crabs at age 1 for the 1983 and 1984 year classes, assuming cod removals are the main source of mortality for crab between age 1 and age 3. If cod removals of crab, expressed as a percentage of the initial age-1 snow or Tanner crab population size, change across years, then cod exert a density-dependent influence on Tanner and snow crab population size.

The percent removals at age 1 of the 1983 and 1984 Tanner crab population numbers are 89.4 and 94.2%, respectively. Snow crab removals at age 1 of the 1983 and 1984 year classes are 41.6 and 31.0%, respectively. There does not seem to be a strong density-dependent influence of Pacific cod on Tanner crab populations although cod consumption is a large portion of the estimated age-1 population size. There seems to be a stronger density-dependence of cod on snow crab population size even though percent removals are lower than those for Tanner crab. The difference in percent removals of Tanner crab relative to snow crab are due to the estimates of age-3 population size for each species, which differ by an order of magnitude. For example, sizes of the 1983 Tanner and snow crab populations at

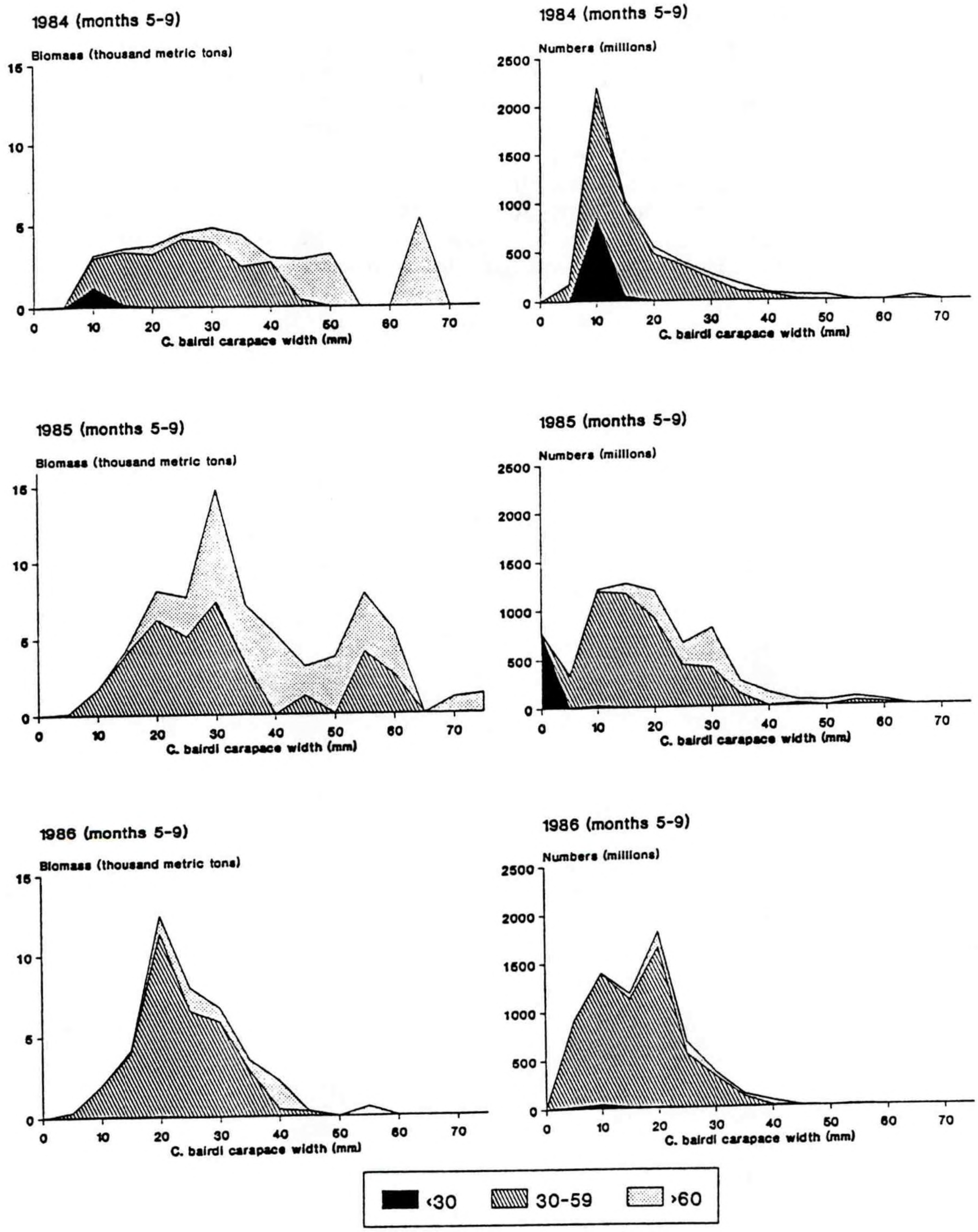


Figure 29.--Biomass and numbers of prey Tanner crab consumed by three size groups of Pacific cod during months 5 to 9 in the eastern Bering Sea by prey size.

age 3 are 125 million and 7.4 billion, respectively, but cod removals at age 1 of the 1983 year classes are similar, amounting to 4.9 billion for Tanner crab and 4.3 billion for snow crab. The lower population size of Tanner crab at age 3 could be due to unaccounted sources of mortality or snow crab populations at age 3 could be artificially high if immigration of snow crab occurs from areas outside the survey area as suggested by Livingston (1989b) and Stevens and MacIntosh (1989). A longer time series of predation data on Tanner and snow crabs will improve our understanding of trends in cod consumption and help to verify the possibility of density-dependent predation mortality.

CITATIONS

Bakkala, R. G., and G. E. Walters. 1986. Other flatfish. In R. G. Bakkala and L-L. Low (editors), Condition of groundfish resources in the eastern Bering Sea and Aleutian Islands region in 1985, p. 77-86. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-104.

Clausen, D. M. 1981. Summer food of Pacific cod, Gadus macrocephalus, in coastal waters of southeastern Alaska. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 78:968-973.

Daan, N. 1987. Multispecies versus single-species assessment of North Sea fish stocks. Can. J. Fish. Aquat. Sci. 44(2):360-370.

Dwyer, D. A., K. M. Bailey, and P. A. Livingston. 1987. Feeding habits and daily ration of walleye pollock (Theragra chalcogramma) in the eastern Bering Sea, with special references to cannibalism. Can. J. Fish. Aquat. Sci. 44: 1972-1984.

Forney, J. L. 1977. Reconstruction of yellow perch (Perca flavescens) cohorts from examination of walleye (Stizostedion vitreum vitreum) stomachs. J. Fish. Res. Board Can. 34:925-932.

Hewett, S. W., and B. L. Johnson. 1987. A generalized bioenergetics model of fish growth for microcomputers. Univ. Wisconsin Sea Grant Tech. Rep. No. WIS-SG-87-245.

Jensen, G. C., and D. A. Armstrong. 1989. Biennial reproductive cycle of blue king crab, Paralithodes platypus, at the Pribilof Islands, Alaska and comparison to a congener, P. camtschatica. Can. J. Fish. Aquat. Sci. 46:932-940.

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

Lebida, R. C. 1987. Age, sex, and size composition of Pacific herring, (Clupea harengus pallasi), from eastern Bering Sea coastal spawning sites, Alaska, 1986. Alaska Dep. Fish Game Tech. Data Rep. No. 216, 64 p.

Livingston, P. A. 1989a. Interannual trends in walleye pollock, Theragra chalcogramma, cannibalism in the eastern Bering Sea. Proceedings of International Symposium on the Biology and Management of Walleye Pollock, Nov. 14-16, 1988, Univ. Alaska, Fairbanks, Alaska Sea Grant Rep. AK-SG-89-01.

Livingston, P. A. 1989b. Interannual trends in Pacific cod, Gadus macrocephalus, predation on three commercially important crab species in the eastern Bering Sea. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 87:807-827.

Livingston, P. A., D. A. Dwyer, D. L. Wencker, M. S. Yang, and G. M. Lang. 1986. Trophic interactions of key fish species in the eastern Bering Sea. Int. North Pac. Fish. Comm. Bull. 47:49-65.

Low, L-L. 1990. Executive summary. In L-L. Low and R. E. Narita (editors). Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 1-18. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Otto, R. S. 1986. Management and assessment of eastern Bering Sea king crab stocks. In G. S. Jamieson and N. Bourne (editors), North Pacific Workshop on stock assessment and management of invertebrates, p. 83-106. Can. Spec. Publ. Fish. Aquat. Sci. 92.

Stevens, B. G., and R. A. MacIntosh. 1989. Report to industry on the 1989 eastern Bering Sea crab survey. NWAFC Processed Rep. 89-18, 47 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE., Seattle, WA 98115.

Thompson, G. G., and A. M. Shimada. 1990. Pacific cod. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 44-66. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Walters, G. E., K. Teshima, J. J. Traynor, R. G. Bakkala, J. A. Sassano, K. L. Halliday, W. A. Karp, K. Mito, N. J. Williamson, and D. M. Smith. 1988. Distribution, abundance, and biological characteristics of groundfish in the eastern Bering Sea based on results of the U.S.-Japan Triennial bottom trawl and hydroacoustic surveys during May-September, 1985. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-154, 401 p.

Wespestad, V. G., and J. J. Traynor. 1990. Walleye pollock. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 19-43. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

YELLOWFIN SOLE

by

Geoffrey M. Lang

INTRODUCTION

Yellowfin sole (Limanda aspera) is the most abundant flounder species in the eastern Bering Sea, and it is the second most abundant fish species behind walleye pollock (Theragra chalcogramma). The estimated biomass in 1988 was 2.9 million t (Bakkala and Wespestad 1990). Yellowfin sole inhabit inner to middle shelf water and is a bottom-oriented feeder primarily preying upon benthic organisms such as polychaetes, echiuroids, bivalves, and amphipods (Wakabayashi 1986; Livingston et al. 1986) although it is known to occasionally prey on pelagic organisms such as walleye pollock and euphausiids (Livingston et al. 1986). Commercially important species such as Pacific cod (Gadus macrocephalus), walleye pollock, and Tanner and snow crab (Chionoecetes spp.) have been found to be prey of yellowfin sole (Haflinger and McRoy 1983; Livingston et al. 1986). Since the biomass of yellowfin sole in the Bering Sea is quite large, there is potential for great impact on the populations of those prey species that are consumed.

GENERAL FOOD HABITS

Diet

A total of 9,467 stomachs have been sampled since 1984, 38.6% (3,653) of which were empty and 61.4% (5,814) of which contained prey items (Table 1). The majority of the prey items were benthic invertebrates and small fish as would be predicted by the feeding morphology and behavior of yellowfin sole. Allen (1984) describes yellowfin sole as a benthopelagivore, a species that preys on both benthic and pelagic organisms. Yellowfin sole has a small, asymmetrical mouth and a relatively long intestine which is characteristic of flatfishes preying on polychaetes and mollusks (DeGroot 1971).

While yellowfin sole preyed on more than 30 different groups of organisms, 4 prey groups accounted for 72.3% of the diet by weight. These main groups included: epibenthic/benthic Polychaeta (worms), benthic bivalves (clams), epibenthic/benthic Gammaridea (amphipods), and benthic Echiura (marine worm). These groups were the top four in terms of percent number and four of the top five groups in terms of percent frequency of occurrence.

Table 1.--Diet of yellowfin sole (Limanda aspera) in the eastern Bering sea, 1984-88, expressed in terms of frequency of occurrence, percent number, and percent total weight.

Prey Name	Freq. Occur.	Number	Total Weight
Polychaeta (worm)	52.84	9.88	18.44
Gastropoda (snail)	4.85	5.98	3.42
Bivalvia (clam)	38.70	7.85	28.07
Crustacea	3.27	0.42	0.18
Cumacea (cumacean)	15.93	2.19	0.14
Amphipoda (amphipod)	2.98	0.32	0.12
Gammaridea (amphipod)	57.52	32.47	7.90
Euphausiacea (euphausiid)	6.11	1.25	2.13
Decapoda (shrimp & crab)	1.46	0.09	0.60
Caridea (shrimp)	1.01	0.05	0.56
Crangonidae (shrimp)	2.49	0.09	1.27
Paguridae (hermit crab)	5.59	1.55	3.19
Paralithodes platypus (blue king crab)	0.14	0.12	0.02
Chionoecetes sp. (snow and Tanner crab)	1.39	0.14	0.69
Chionoecetes opilio (snow crab)	0.22	0.01	0.16
Chionoecetes bairdi (Tanner crab)	0.69	0.04	0.81
Echiura (marine worm)	15.86	23.72	17.88
Echinodermata (sea star, cucumber, urchin)	0.72	0.05	0.13
Ophiuroidae Ophiurida (brittle star)	11.44	4.09	2.20
Echinoidea Clypeasteroida (sand dollar)	9.96	1.37	1.54
Holothuroidea (sea cucumber)	3.03	0.89	1.69
Urochordata (tunicate)	5.99	0.92	1.01
Osteichthyes Teleostei (fish)	2.13	3.14	1.57
Gadidae (gadid fish)	0.05	0.00	0.00
Gadus macrocephalus (Pacific cod)	0.09	0.00	0.07
Theragra chalcogramma (walleye pollock)	0.62	0.04	0.69
Atheresthes stomias (arrowtooth flounder)	0.03	0.00	0.01
Hippoglossoides elassodon (flathead sole)	0.02	0.00	0.00
Lepidopsetta bilineata (rock sole)	0.07	0.01	0.01
Psettichthys melanostictus (sand sole)	0.05	0.10	0.14
Reinhardtius hippoglossoides (Greenland turbot)	0.12	0.02	0.02
Hippoglossus stenolepis (Pacific halibut)	0.02	0.00	0.00
Fishery discards	0.41	0.01	1.13
Miscellaneous and unidentified prey	6.76	3.15	4.21

Total prey count	218,758
Total prey weight	7,895 g
Number of stomachs with food	5,814
Number of empty stomachs	3,653

Commercially important species did not make up a very large portion of the diet of yellowfin sole, but some were consumed. As will be discussed later, some were consumed in large numbers. The largest portions of the diet by weight of commercially important prey for yellowfin sole were Tanner crab (C. bairdi) (0.81%), walleye pollock (0.69%), snow crab (C. opilio) (0.16%), and Pacific cod (0.07%). Several other species, arrowtooth flounder (Atheresthes stomias), flathead sole (Hippoglossoides elassodon), rock sole (Lepidopsetta bilineata), Greenland turbot (Rheinhardtius hippoglossoides), Pacific halibut (Hippoglossus stenolepis), and blue king crab (Paralithodes platypus) were also consumed in small quantities. Fishery discards, usually in the form of fish processor discards, made up 1.13% of the diet by weight.

Seasonal and Annual Changes in Diet

For the analysis of the seasonal and annual changes in the diet of yellowfin sole the diet was consolidated into eight prey categories (Figs. 1-2). These categories represent the seven most common prey items and an eighth catchall category containing the remaining prey groups, including unidentified prey.

The relative importance of the different prey groups varied throughout the year (Fig. 1). In winter, polychaetes, clams, and miscellaneous prey (mainly echiuroids and echinoderms) made up the majority of the diet. Polychaetes made up the largest portion of the diet of the smaller yellowfin sole but were less important to the larger fish. Clams and miscellaneous prey were not as important to the smaller fish, but they became more dominant in the diet of the larger fish.

During spring, clams made up the largest portion of the diet for all sizes, increasing in importance with fish size. Polychaetes and amphipods also contributed a large portion to the diet, particularly for the smaller fish. Miscellaneous prey (mainly gastropods, echinoderms, and echiuroids) also made up a significant portion of the diet in the spring, particularly in the larger fish.

The diet of yellowfin sole in summer was more equally distributed among the various prey categories, with no single dominant prey group. Polychaetes and clams made up a large portion of the diet for all size groups, whereas amphipods were more important to the smaller sizes. The miscellaneous group (mainly echinoderms and echiuroids) made up the greatest portion of the diet for the largest fish but was a smaller portion for the other size groups.

The diet in autumn was dominated by two prey groups, amphipods and miscellaneous prey (mainly gastropods, echiuroids, and echinoderms). Amphipods made up the majority of the diet of smaller fish but became less important in the larger predators.

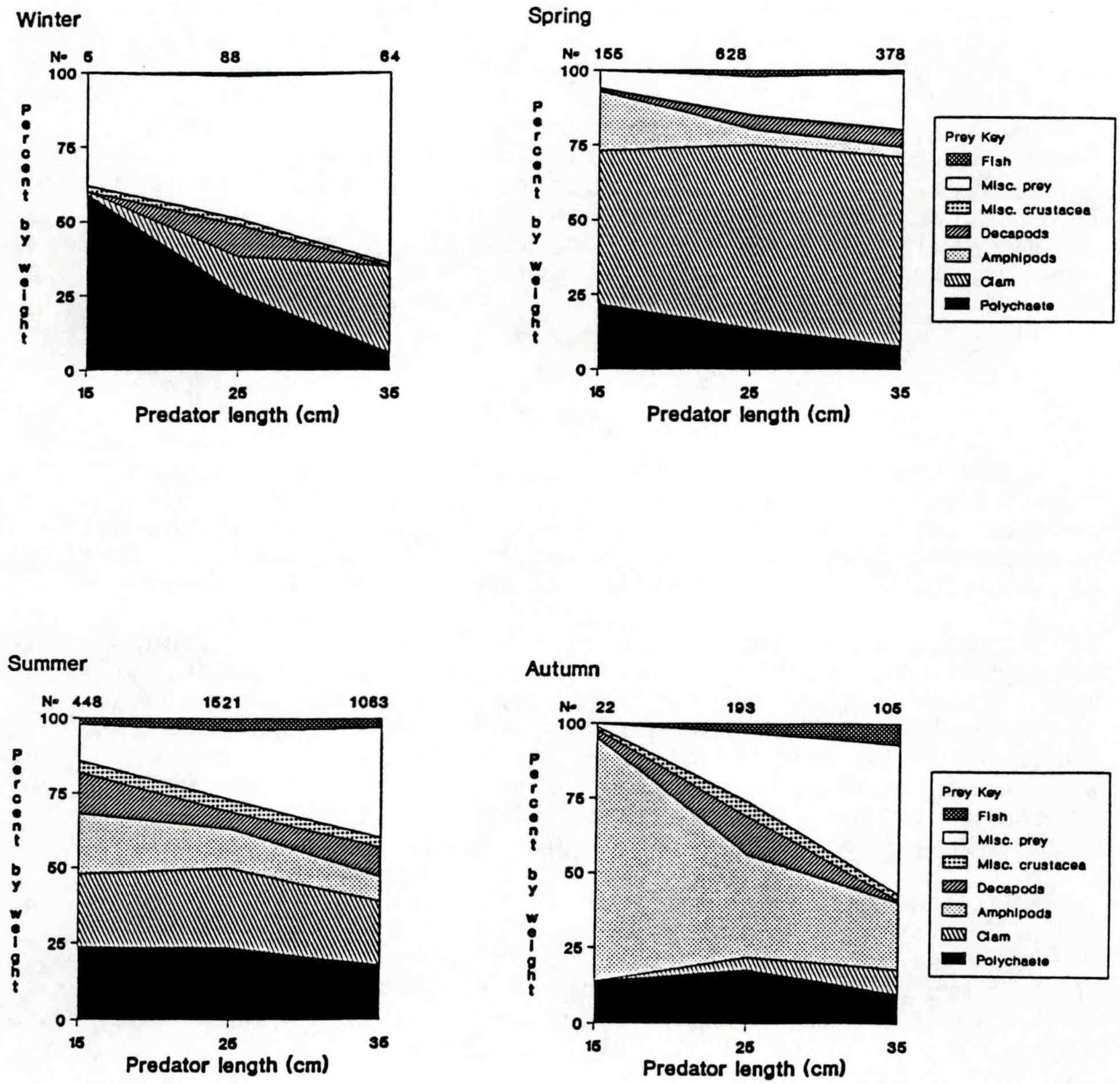


Figure 1.--Diet composition of yellowfin sole, in terms of percent weight, by season and predator fork length (cm) in the eastern Bering Sea, 1984-86. N = number of stomachs.

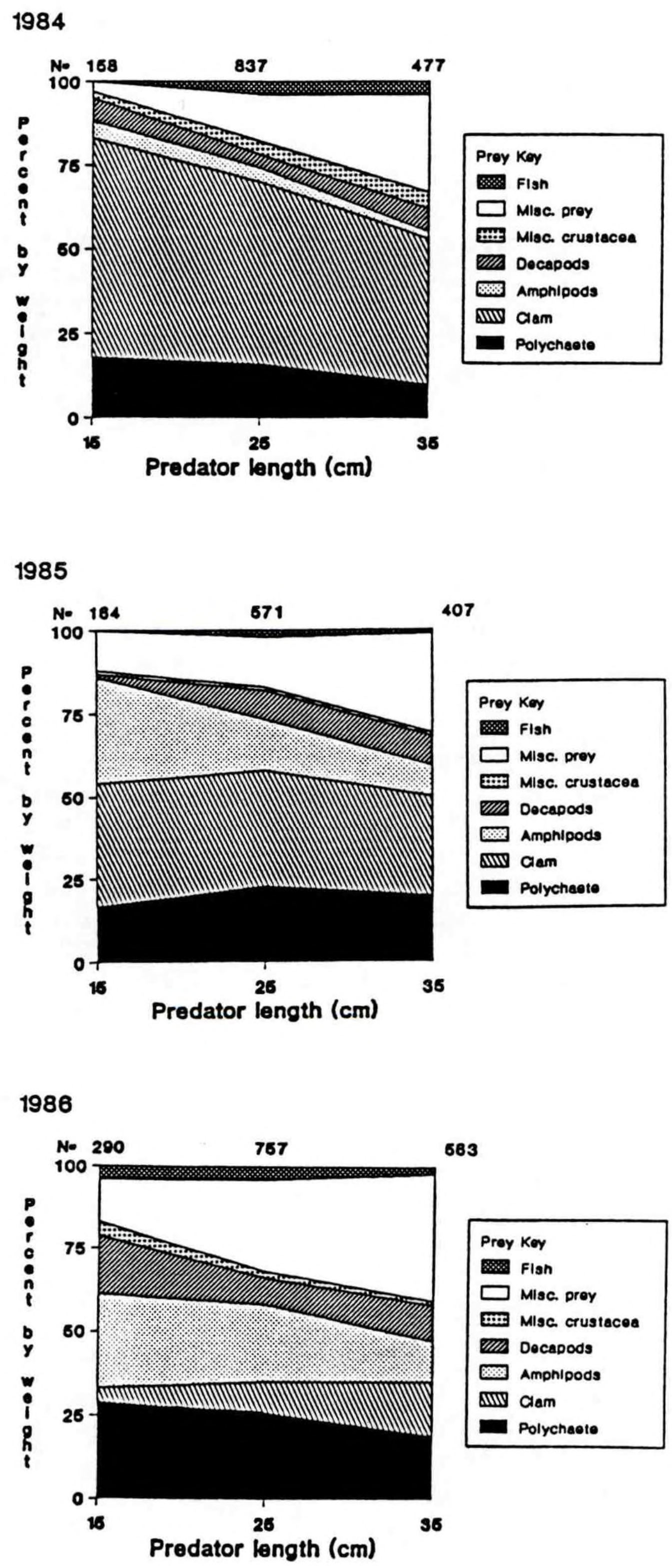


Figure 2.--Diet composition of yellowfin sole, in terms of percent weight, months 5 to 9, by year and predator fork length (cm) in the eastern Bering sea, 1984-86. N = number of stomachs.

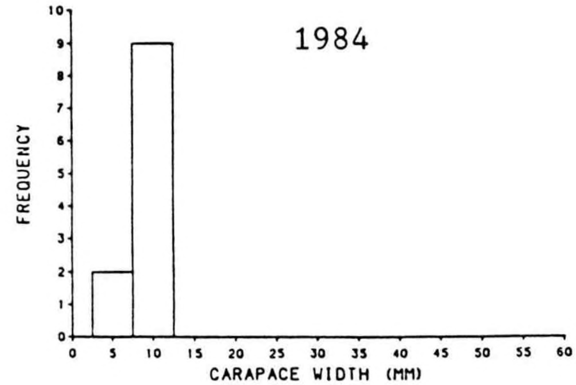
Miscellaneous prey was the greatest contributor to the diet of the larger fish but was less important to the smaller fish. Polychaetes were also a large portion of the diet for all predator categories.

With the exception of the summer diet, which had a fairly even distribution of prey, the seasonal diet of yellowfin sole was dominated by one or two prey categories. Miscellaneous prey dominated the winter diet, clams dominated the spring diet, and amphipods and miscellaneous prey dominated the autumn diet. These shifts in the dominant prey are likely a result of differences in prey availability throughout the year as yellowfin sole migrate from shallow water to deeper water in the winter (Smith and Bakkala 1982; Wakabayashi et al. 1977). Some of the fluctuation in the diet may also have been a result of the small sample sizes for some of the size groups. There was also some change in the diet across predator size within seasons; smaller yellowfin sole relied more heavily upon polychaetes and amphipods, whereas larger fish consumed larger prey such as clams and miscellaneous prey (echinoderms, gastropods, and echiuroids). Fish prey did not make up a significant portion of the diet in any season, although it was a larger portion of the diet of larger fish.

Throughout the 3-year study period the significance of some of the various prey groups in the diet changed (Fig. 2). Fish, miscellaneous crustacea, and general miscellaneous prey were relatively constant over time. Miscellaneous prey was a larger part of the diet of large fish than it was for small fish. The portion of the diet made up by clams showed the greatest change over the 3 years, decreasing substantially each year. As the clam portion of the diet decreased, the portion made up by polychaetes, amphipods, and decapods increased. Shifts such as this could possibly be the result of decreased clam populations, or increased populations of the other organisms, or both. However, Haflinger (1981) shows that the benthic community of the Bering Sea is relatively stable; therefore, it is more likely that the observed changes in the prevalence of certain prey categories is a reflection of spatial and temporal differences in the sampling between years.

Sizes of Commercially Important Prey Consumed

Snow crabs consumed by yellowfin sole were primarily less than 35 mm carapace width (CW). Most of the predation took place on the 10 mm CW group, which corresponds to age-1 and younger crab (Fig. 3). Predation on snow crabs in 1984 was focused on smaller animals than in 1985. The same general relationship holds true for Tanner crab predation in 1985 and 1986 (Fig. 4). Most of the Tanner crabs eaten by yellowfin sole were less than 10 mm CW, corresponding to age-1 and younger crab, but some predation did take place on larger crabs. Predation on walleye pollock in 1984-86 was focused on fish less than 65 mm standard length (age 0) although some larger pollock were consumed



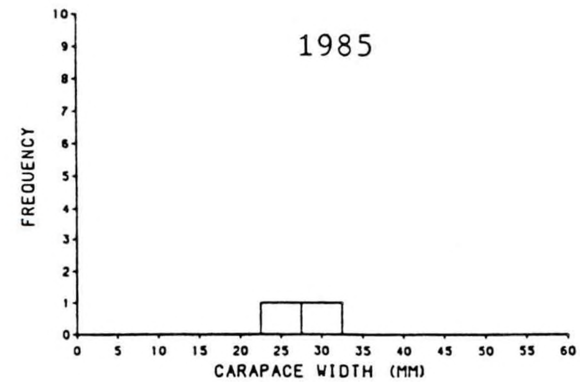


Figure 3.--Size frequency of snow crabs found in yellowfin sole in 1984 and 1985 in the eastern Bering Sea.

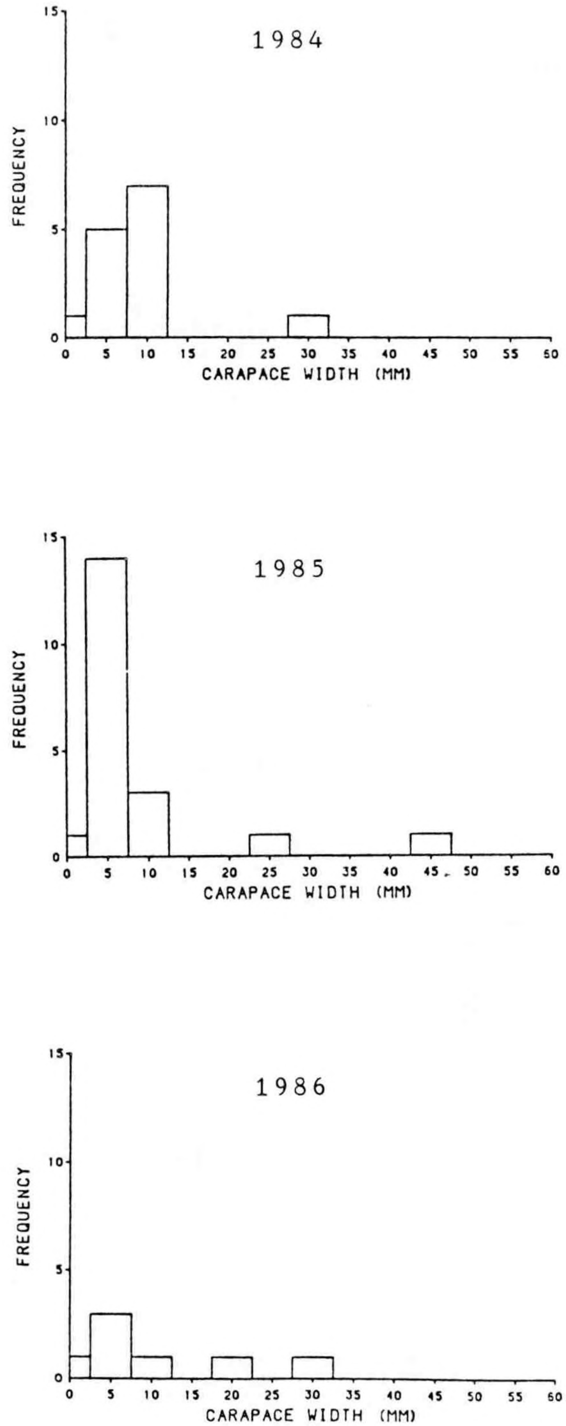


Figure 4.--Size frequency of Tanner crabs found in yellowfin sole in 1984, 1985, and 1986 in the eastern Bering Sea.

(Fig.5). Rock sole and Greenland turbot consumed by yellowfin sole in 1984 were much smaller than the pollock consumed. Most were 15 mm standard length or less, corresponding to age-0 fish (Fig. 6). The relationship between predator size and prey size for these five species is shown as a scatterplot in Figure 7. Although the r^2 values were relatively low, and the P-values were not significant ($P > 0.05$), based on standard linear regression, except for Greenland turbot, (snow crab, $r^2 = 0.092$, $P = 0.323$; Tanner crab, $r^2 = 0.049$, $P = 0.146$; rock sole, $r^2 = 0.164$, $P = 0.097$; Greenland turbot, $r^2 = 0.552$, $P < 0.001$; pollock, $r^2 = 0.005$, $P = 0.634$) there was a size-related relationship present. In general, as yellowfin sole get larger they are able to consume fish and crab prey that are larger and more mobile than their main prey of relatively immobile benthic invertebrates. Thus, yellowfin sole must reach approximately 25 cm before they are able to consume the more mobile prey. However, because of the relatively small mouth size of yellowfin sole their prey must be relatively small in order to be consumed. Because of this prey size limitation, yellowfin sole are confined to age-0 and age-1 prey and are not able to continue preying upon a strong year class as it gets larger.

PREDATOR POPULATION CONSUMPTION OF COMMERCIALLY IMPORTANT PREY

Geographic Trends in Consumption

Consumption trends varied geographically among the more frequently preyed upon commercially important prey. The location of snow crab predation during 1984 and 1985 was very similar with consumption taking place northeast of the Pribilof Islands near the 50 m bottom depth contour (Fig. 8); none were observed in stomach contents in 1986. Tanner crab consumption was also similar in 1984 and 1985, mainly occurring north, but also to some extent east, of the Pribilof Islands in water 50-100 m deep (Fig. 9). In 1986, they were consumed farther inshore in shallower water along the 50 m bottom depth contour. The distribution of pollock consumption did not show much variation through the 3 years (Fig. 10). In 1984, pollock consumption was more prevalent in shallower water than in the other years, and in deeper water in 1986. However, because the overall distribution is quite similar, this patchiness in the observed consumption is probably an artifact of the sampling locations between years.

Greenland turbot, blue king crab, and Pacific cod were consumed by yellowfin sole in 1984 (Fig. 11), but were not observed as prey in 1985 or 1986. Greenland turbot consumption took place on the middle shelf area, east of the Pribilof Islands, between 50 and 100 m bottom depth. Pacific cod predation took place in shallower water, around the 50 m depth contour, east of the Pribilof Islands. Blue king crab

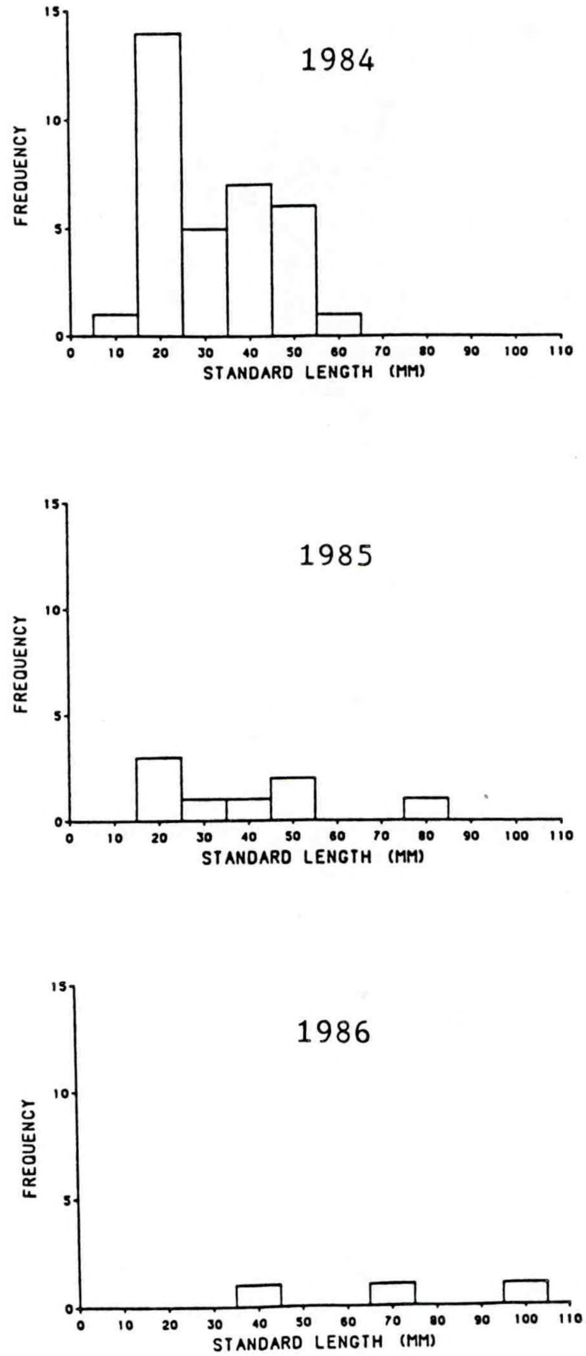


Figure 5.--Size frequency of walleye pollock found in yellowfin sole in 1984, 1985, and 1986 in the eastern Bering Sea.

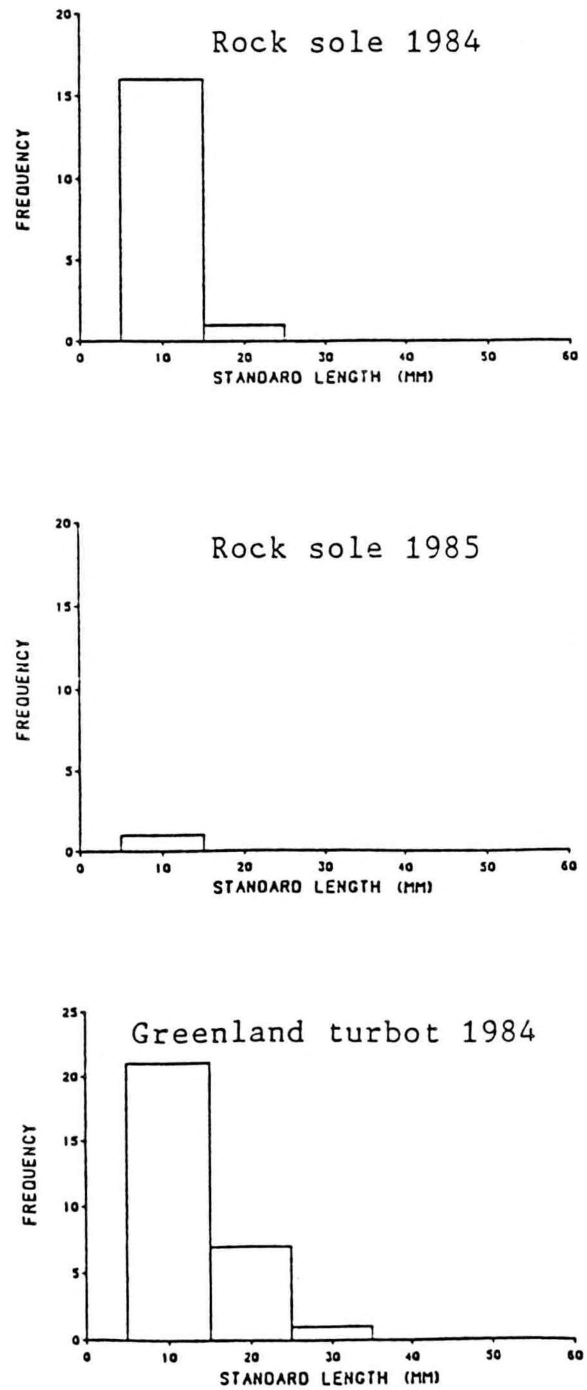


Figure 6.--Size frequency of rock sole found in yellowfin sole in 1984 and 1985 and Greenland turbot found in yellowfin sole in 1984 in the eastern Bering Sea.

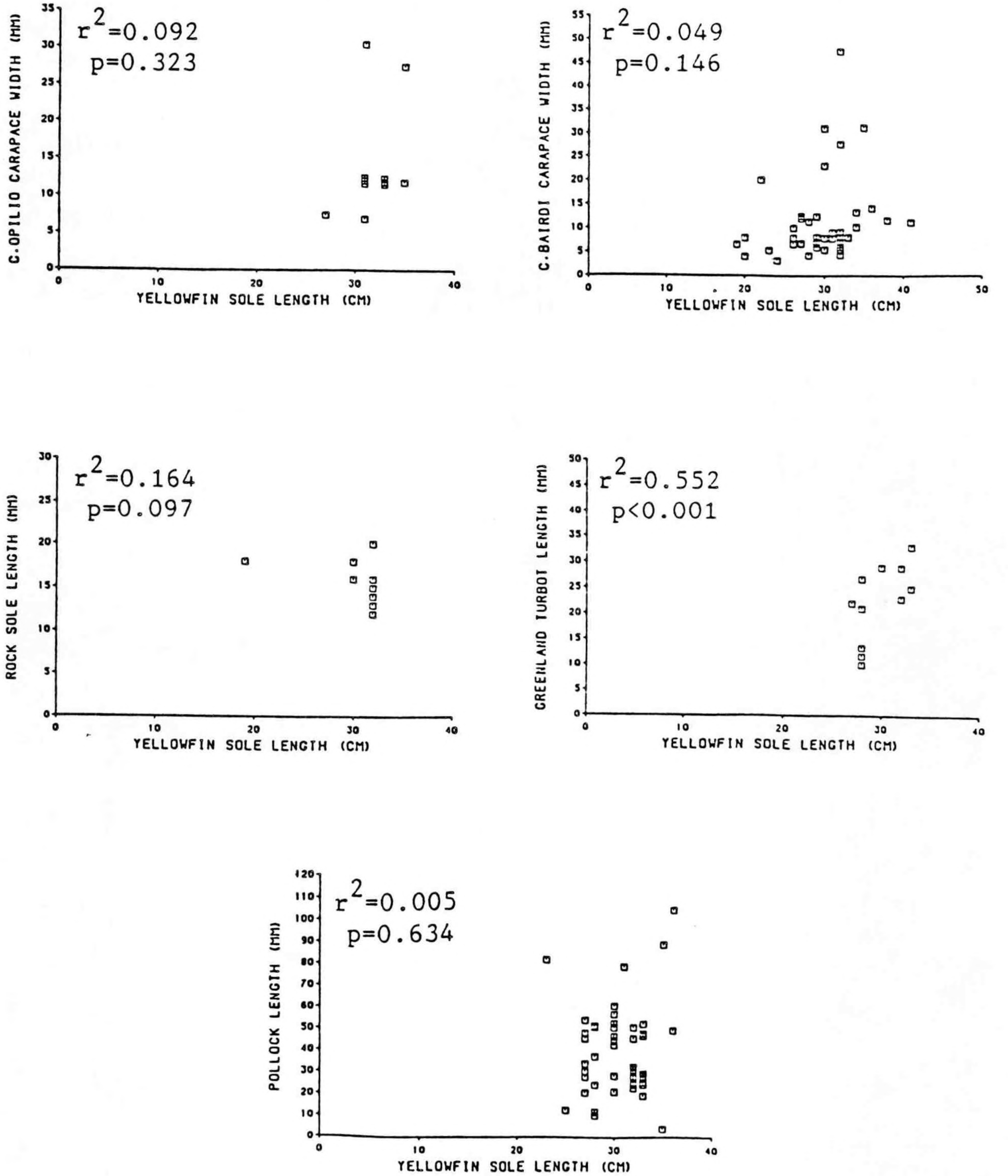


Figure 7.--Scattergrams of yellowfin sole fork length (cm) versus Tanner crab carapace width (mm), snow crab carapace width (mm), rock sole standard length (mm), Greenland turbot standard length (mm), and walleye pollock standard length (mm).

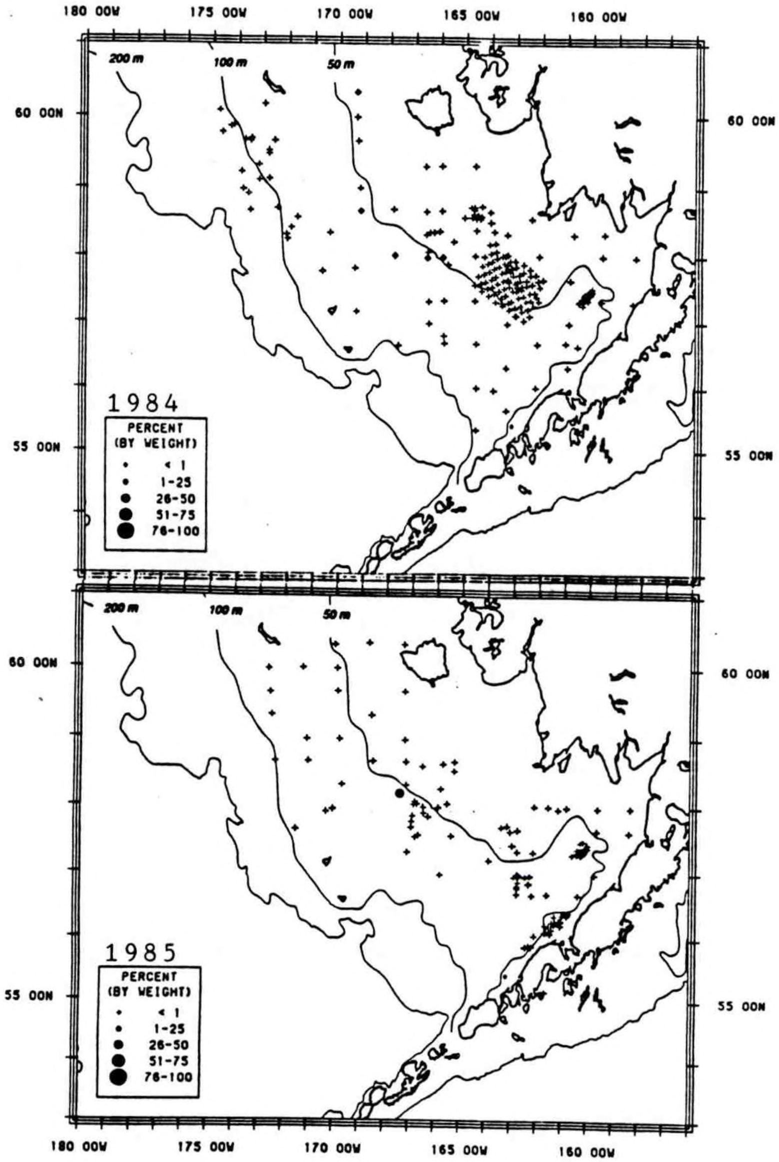


Figure 8.--Percent by weight of snow crab in the diet of yellowfin sole by sampling station during months 5-9 in 1984 and 1985.

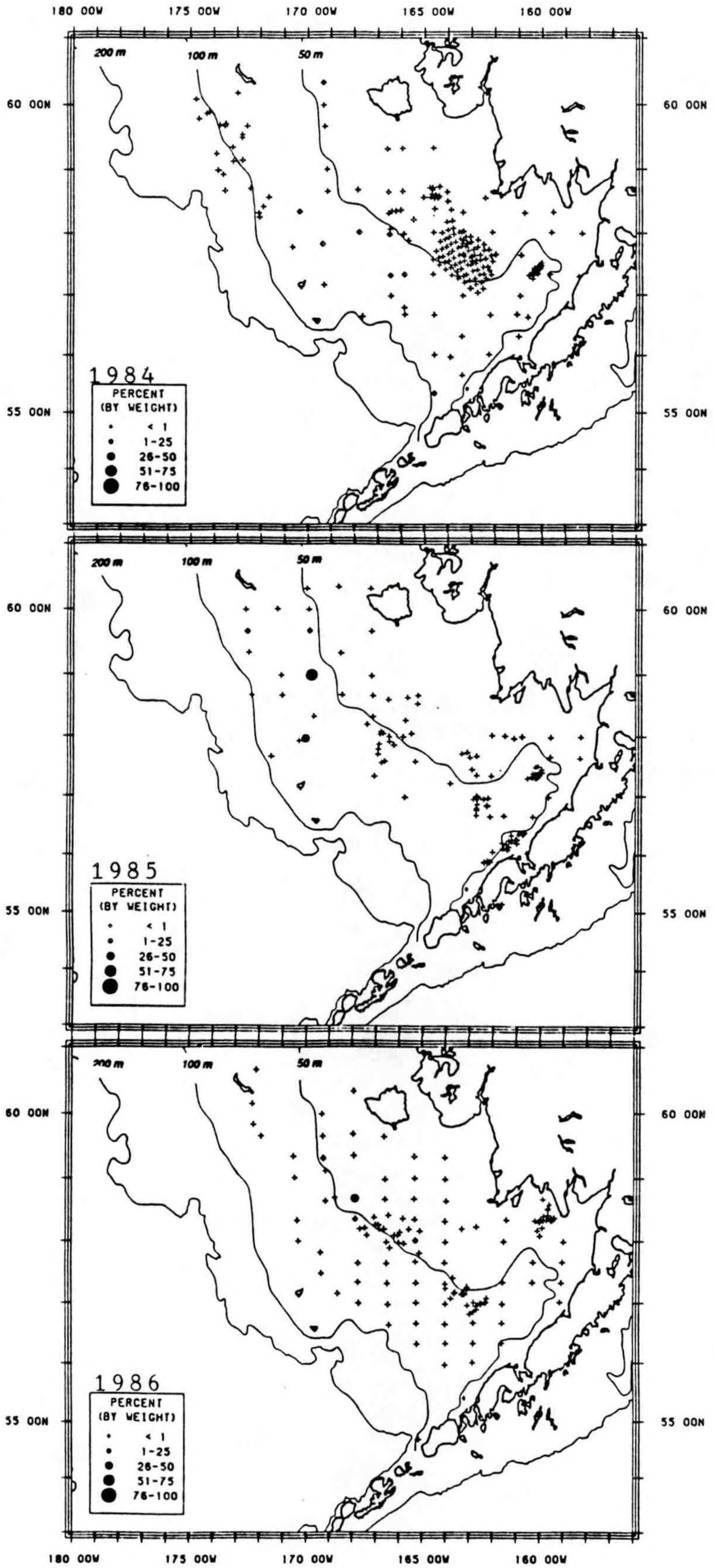


Figure 9.--Percent by weight of Tanner crab in the diet of yellowfin sole by sampling station during months 5-9 in 1984, 1985, and 1986.

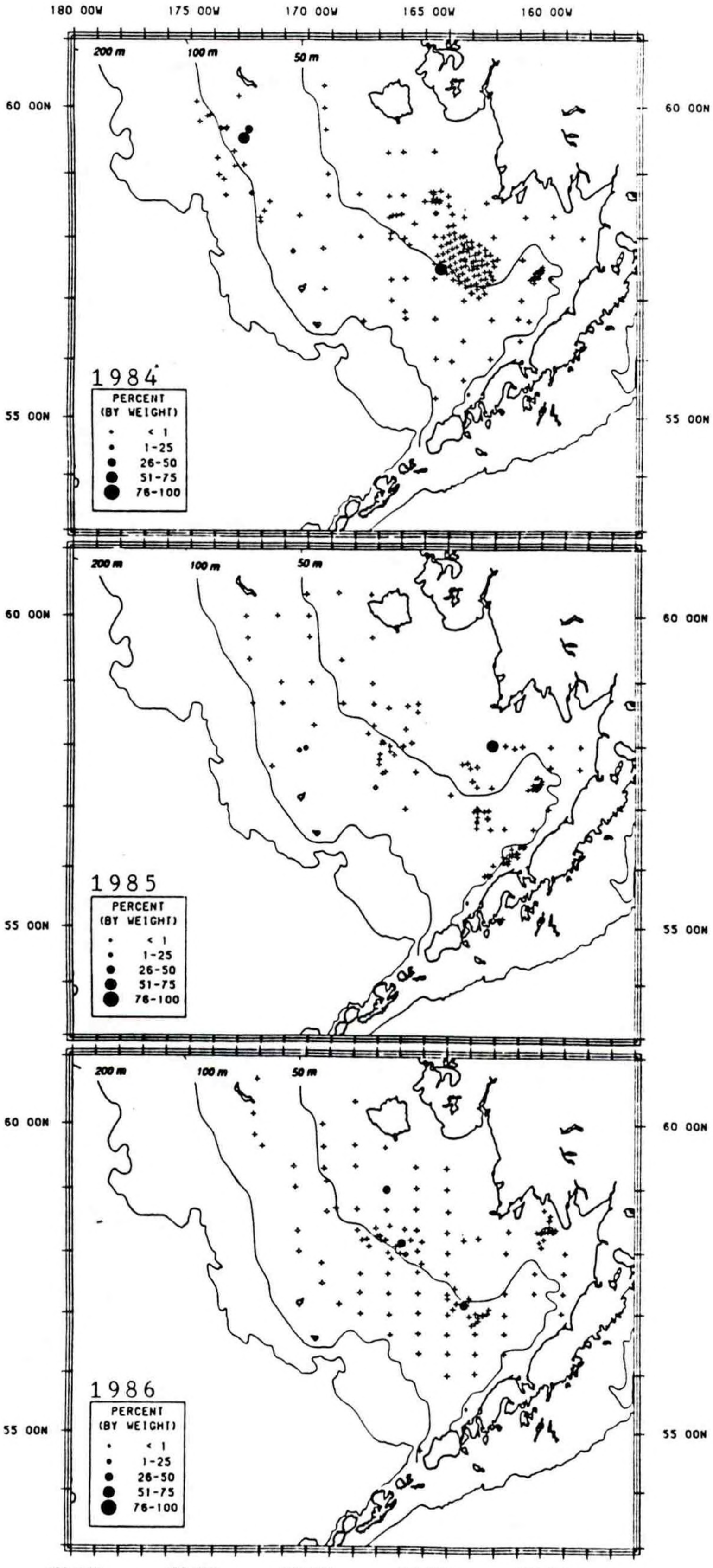


Figure 10.--Percent by weight of walleye pollock in the diet of yellowfin sole by sampling station during months 5-9 in 1984, 1985, and 1986.

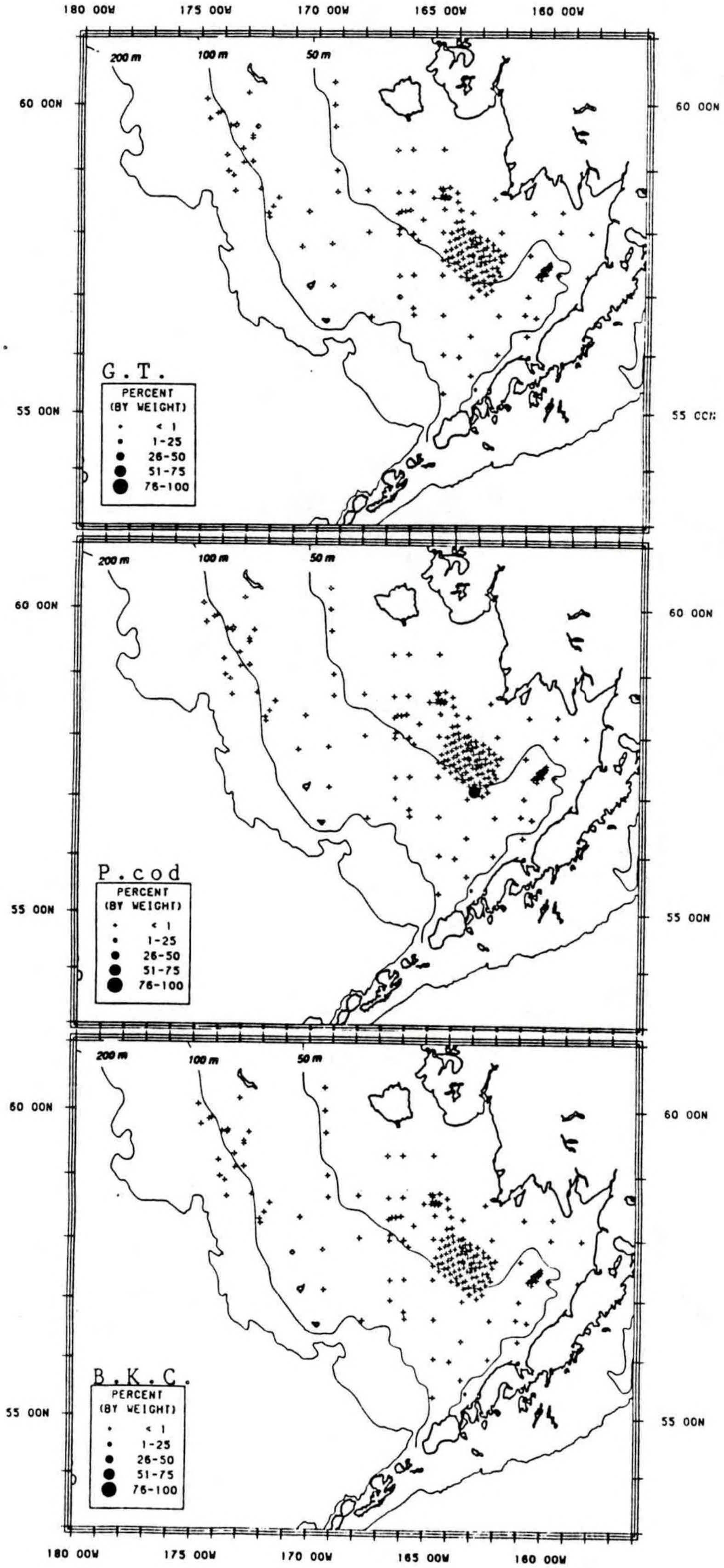


Figure 11.--Percent by weight of Greenland turbot, Pacific cod, and blue king crab in the diet of yellowfin sole by sampling station during months 5-9 in 1984.

consumption took place at one location north of the Pribilof Islands in 50-100 m of water.

Rock sole and Pacific halibut were consumed by yellowfin sole during the study period, but the data was sparse and distribution maps are not included here. Rock sole consumption in 1984 took place south of St. Matthew Island in water 50-100 m deep. In 1985, consumption took place farther southeast, near Bristol Bay, at the same depths. Pacific halibut consumption occurred north of the Pribilof Islands in water depths ranging from 50 to 100 m.

Total Consumption Parameters

Yellowfin sole estimated biomass was the highest in 1984 (3.2 million t) and decreased slightly each successive year to 2.8 million t in 1986 (Table 2). These biomass estimates were determined through cohort analysis for the greater than or equal to 7-year-old fish (Bakkala and Wilderbuer 1990a) and through survey estimates for the 0-6 year olds (Bakkala and Wespestad 1990). The daily ration estimate for yellowfin sole in the eastern Bering Sea, as calculated by bioenergetic considerations outlined in the Methods section of this report, is 0.4% body weight per day.

Table 2.--Yellowfin sole biomass, in metric tons, by year and strata. Biomass estimates are based on cohort analysis of fish age 7 and older, and survey data of 0-6 year olds.

	Biomass		
Strata	1984	1985	1986
1	1,310,692	1,308,580	1,268,924
2	476,449	336,432	348,317
3	878,830	1,057,499	961,418
4	524,377	306,352	187,827
5	13,925	3,970	1,875
6	1,779	1,705	7
Total	3,206,052	3,014,538	2,768,368

Snow crabs, Tanner crabs, and walleye pollock were consumed in more strata in 1984 than in other years, probably due to the larger yellowfin sole biomass, large prey year classes, and more thorough sampling in 1984 (Tables 3-5). Strata where yellowfin sole were not sampled are indicated by dashes (--) in the tables.

Snow crab were consumed in strata 1-4 in 1984, stratum 2 in 1985, and were not observed in yellowfin sole stomachs in 1986. Tanner crabs were consumed in strata 2-4 in 1984, but in 1985 and 1986 they were consumed in strata 2 and 4 only. Walleye pollock were consumed in strata 1, 3, 4, and 6 in 1984. In 1985 they were consumed in the same strata with the exception of stratum 6, and in 1986 they were consumed in strata 1-3. Other commercially important species found as prey did not form a consistent or large portion of the diet.

Table 3.--Mean percent by weight (%W) and standard error (SE) of snow crab in the diet of yellowfin sole by year and stratum, months 5-9. Dashes (--) indicate strata where yellowfin sole were not sampled.

	1984		1985		1986	
Strata	%W	SE	%W	SE	%W	SE
1	0.14	0.14	0.00	0.00	0.00	0.00
2	0.45	0.32	2.65	2.65	0.00	0.00
3	0.30	0.30	0.00	0.00	0.00	0.00
4	2.60	1.39	0.00	0.00	0.00	0.00
5	--	--	--	--	--	--
6	0.00	0.00	--	--	--	--

Table 4.--Mean percent by weight (%W) and standard error (SE) of Tanner crab in the diet of yellowfin sole by year and stratum, months 5-9. Dashes (--) indicate strata where yellowfin sole were not sampled.

	1984		1985		1986	
Strata	%W	SE	%W	SE	%W	SE
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.97	0.97	0.11	0.07	2.46	2.35
3	0.51	0.28	0.00	0.00	0.00	0.00
4	2.04	1.56	6.97	4.72	0.07	0.07
5	--	--	--	--	--	--
6	0.00	0.00	--	--	--	--

Table 5.--Mean percent by weight (%W) and standard error (SE) of walleye pollock in the diet of yellowfin sole by year and stratum, months 5-9. Dashes (--) indicate strata where yellowfin sole were not sampled.

Strata	1984		1985		1986	
	%W	SE	%W	SE	%W	SE
1	0.53	0.53	2.53	2.53	0.26	0.26
2	0.00	0.00	0.00	0.00	3.58	3.58
3	0.93	0.92	0.06	0.06	1.02	1.02
4	3.06	2.29	0.74	0.74	0.00	0.00
5	--	--	--	--	--	--
6	1.97	1.81	--	--	--	--

Total Consumption Estimates

In general, total consumption was relatively constant over the 3-year period, as was the yellowfin sole biomass. The areas of highest predation, by stratum, do not necessarily correspond to the areas of highest yellowfin sole abundance, suggesting that the prey population density is a factor in determining the level at which yellowfin sole consume their prey, as would be expected for a species exhibiting general opportunist feeding behavior.

Estimated snow crab consumption was highest in 1984, decreased in 1985, and was not observed in 1986 (Tables 6 and 7, Fig. 12). Snow crab biomass consumed decreased by approximately 48% from 1984 to 1985, while the numbers consumed decreased nearly 98% due to consumption of larger individuals in 1985 (Fig. 3). While yellowfin sole consumed 17 billion age-0 and age-1 snow crabs in 1984, it is difficult to determine the effects of this predation upon the population since the bottom trawl surveys do not estimate the abundance of crabs this small. However, when considering the number of spawners and their fecundity, it is likely that this predation is relatively trivial, particularly since this predation takes place on the smaller, more abundant life-history stages.

Tanner crab predation was highest in 1984 and decreased in subsequent years (Tables 8 and 9, Fig. 13). In 1984, an estimated 141 billion Tanner crabs were consumed, with a biomass of 12,000 t, which is an average weight of 0.085 g per crab. In 1985, consumption was larger in terms of estimated biomass consumed, but the estimated number consumed was much smaller due to the slightly larger size of the crab consumed. While the number of juvenile Tanner crab consumed is an order of magnitude larger than the number of snow crab consumed by yellowfin sole, it is unlikely that this predation pressure has a very

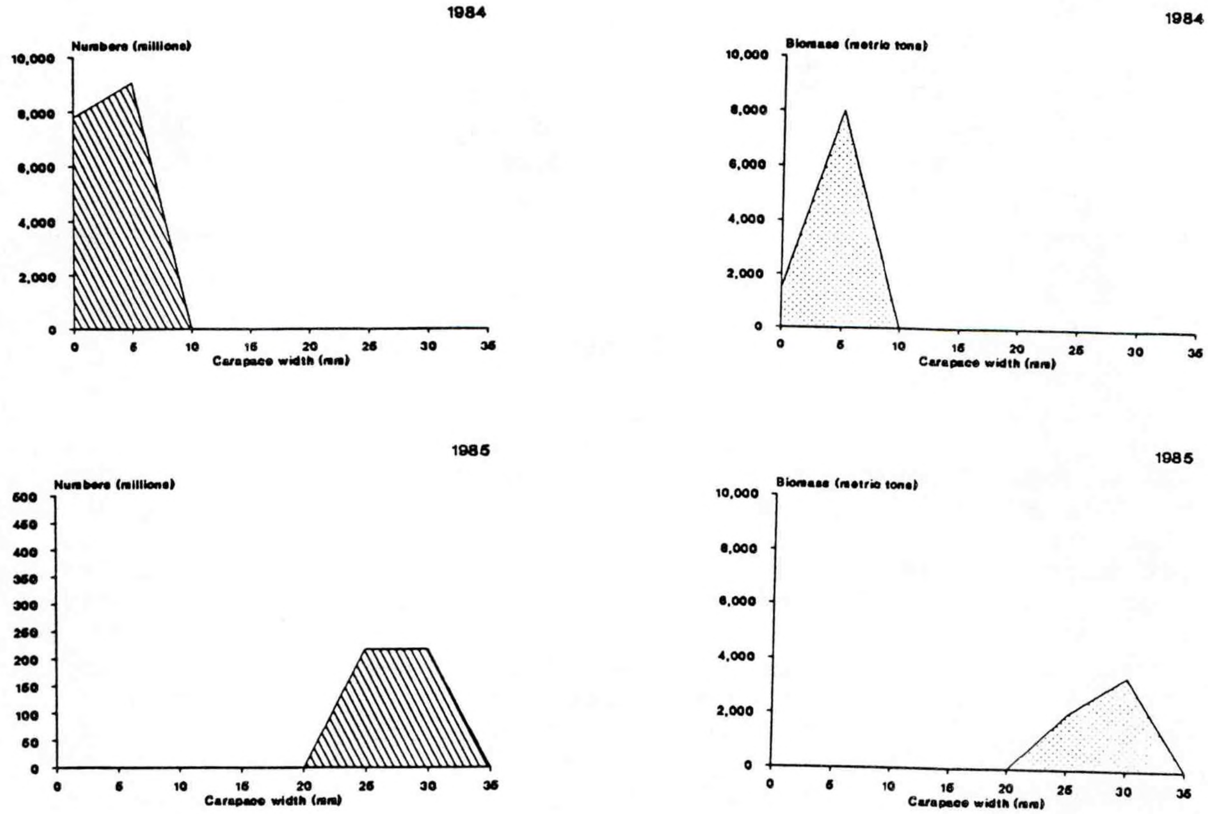


Figure 12.--Estimated biomass (metric tons) and numbers (millions) of snow crab consumed by yellowfin sole, by prey size, during months 5 to 9 in 1984 and 1985. Note different y-axis scale on numbers figure.

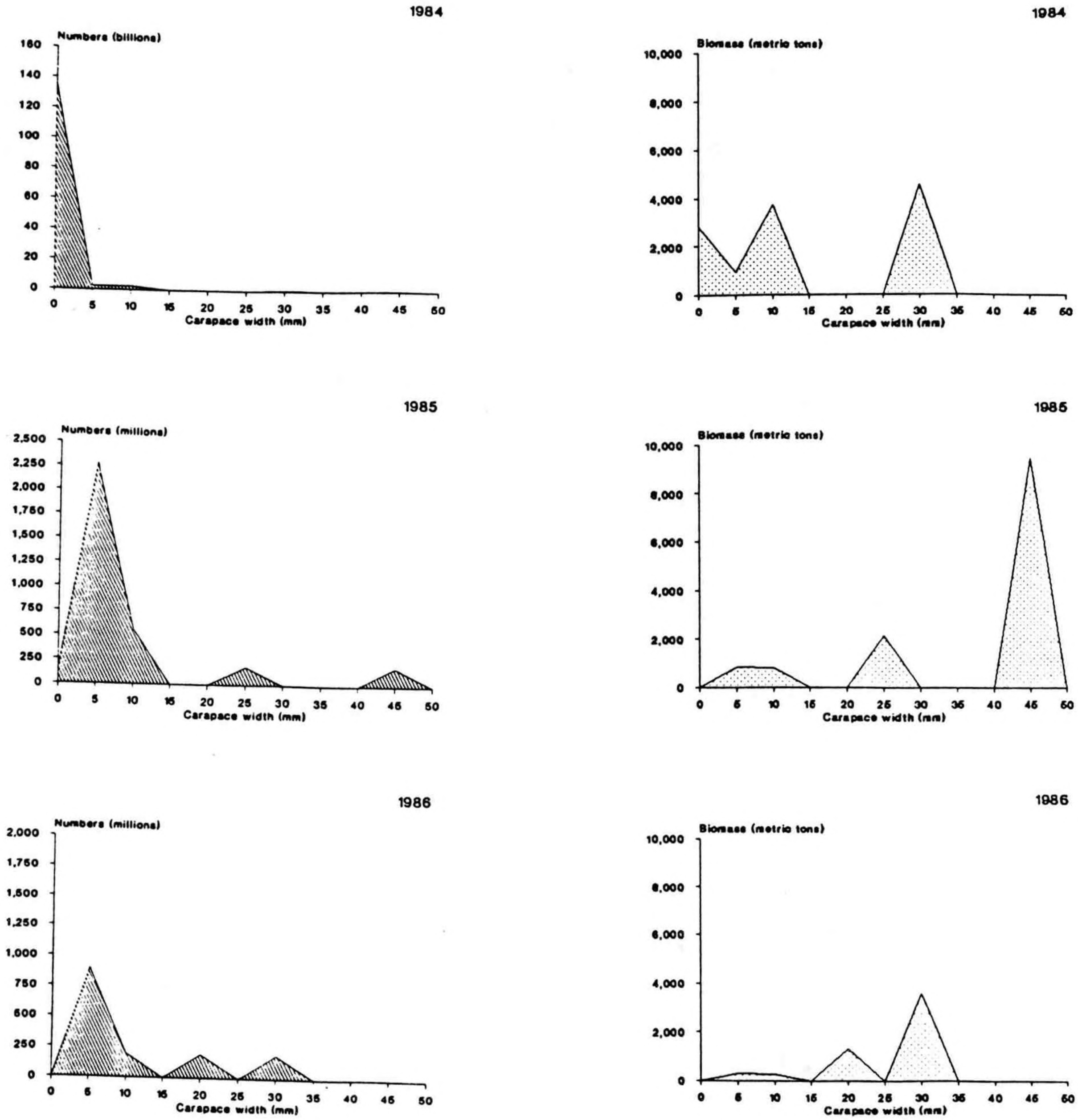


Figure 13.--Estimated biomass (metric tons) and numbers (millions) of Tanner crab consumed by yellowfin sole, by prey size, during months 5 to 9 in 1984, 1985, and 1986. Note different y-axis scale on 1984 numbers figure.

significant effect on the Tanner crab population in the eastern Bering Sea. Stevens and MacIntosh (1990) show strong recruitment and stock growth of both Tanner and snow crab in the late 1980s and suggest that there were several strong year classes in the mid-1980s that have brought about this stock growth. In light of these factors, the magnitude of the yellowfin sole predation on these crabs is probably a reflection of the large numbers of individuals present during those years.

Table 6.--Estimated snow crab biomass (metric tons) consumed by yellowfin sole by year and strata, months 5-9. Numbers in parentheses correspond to year-stratum combinations where number consumed could not be calculated. Dashes (--) indicate strata where yellowfin sole were not sampled.

Strata	1984	1985	1986
1	(1,095.03)	0.00	0.00
2	1,312.25	5,457.35	0.00
3	1,591.38	0.00	0.00
4	6,595.26	0.00	0.00
5	--	--	--
6	0.00	--	--
Total	10,593.92	5,457.35	0.00

Table 7.--Estimated snow crab numbers (millions) consumed by yellowfin sole by year and strata, months 5-9. Parentheses represent year-stratum combinations where number consumed could not be calculated. Dashes (--) indicate strata where yellowfin sole were not sampled.

Strata	1984	1985	1986
1	(0)	0.00	0.00
2	6,906.52	433.14	0.00
3	1,802.64	0.00	0.00
4	8,184.50	0.00	0.00
5	--	--	--
6	0.00	--	--
Total	16,893.66	433.14	0.00

Table 8.--Estimated Tanner crab biomass (metric tons) consumed by yellowfin sole by year and stratum, months 5-9. Dashes (--) indicate strata where yellowfin sole were not sampled.

Strata	1984	1985	1986
1	0.00	0.00	184.59
2	2,822.82	229.91	5,240.95
3	2,754.28	0.00	0.00
4	6,540.06	13,061.85	75.05
5	--	--	--
6	0.00	--	--
Total	12,117.16	13,291.76	5,500.59

Table 9.--Estimated Tanner crab numbers (millions) consumed by yellowfin sole by stratum and year, months 5-9. Dashes (--) indicate strata where yellowfin sole were not sampled.

Strata	1984	1985	1986
1	0.00	0.00	184.59
2	135,676.94	766.65	776.34
3	3,475.74	0.00	0.00
4	1,993.66	2,587.64	203.02
5	--	--	--
6	0.00	--	--
Total	141,146.34	3,354.29	1,163.95

The estimated consumption of pollock by yellowfin sole was highest in 1985, was slightly lower in 1984, and was substantially lower in 1986 (Tables 10 and 11, Fig. 14). The numbers of pollock consumed declined through the 3 years of the study; however, numbers consumed could not be calculated for all strata in 1985, so direct comparison of numbers is difficult. It appears that there were fewer pollock consumed in 1985 than in 1984, but the difference is not quantifiable. In 1984, yellowfin sole consumed approximately 31 billion age-0 pollock, which is in the same range as the adult population for that year. While this

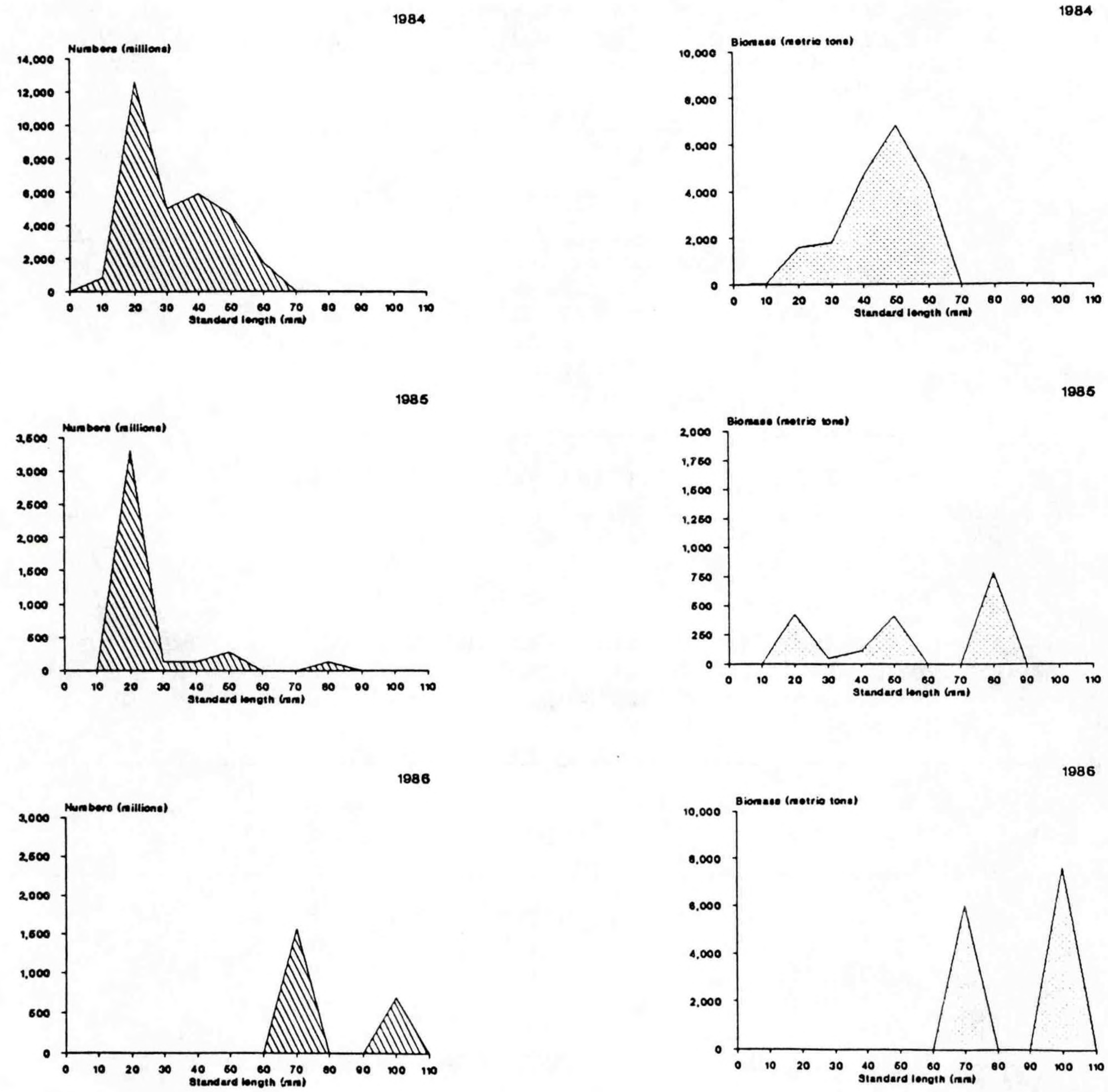


Figure 14.--Estimated biomass (metric tons) and numbers (millions) of walleye pollock consumed by yellowfin sole, by prey size, during months 5 to 9 in 1984, 1985, and 1986. Note different y-axis scale on 1985 biomass and 1984 number figure.

predation appears to remove a large number of juveniles from the population, it is an order of magnitude less than those removed by the adult pollock population by cannibalism in 1984 as shown in the Walleye Pollock section of this report.

Table 10.--Estimated walleye pollock biomass (metric tons) consumed by yellowfin sole by year and strata, months 5-9. Numbers in parentheses correspond to year-stratum combinations where number consumed could not be calculated. Dashes (--) indicate strata where yellowfin sole were not sampled.

Strata	1984	1985	1986
1	4,275.19	(20,300.81)	(2,019.94)
2	0.00	0.00	7,638.86
3	4,982.72	385.37	6,010.25
4	9,818.36	1,389.18	0.00
5	--	--	--
6	19.66	--	--
Total	19,095.93	22,075.36	15,669.05

Table 11.--Estimated walleye pollock numbers (millions) consumed by yellowfin sole by year and strata, months 5-9. Parentheses correspond to year-strata combinations where number consumed could not be calculated. Dashes (--) indicate strata where yellowfin were not sampled.

Strata	1984	1985	1986
1	1,738.09	(0)	(0)
2	0.00	702.25	0.00
3	8,686.77	3,029.79	1,568.02
4	20,236.73	974.08	0.00
5	--	--	--
6	14.65	--	--
Total	30,676.24	4,706.12	1,568.02

Most of the other prey species were found in limited areas or years (Tables 12 and 13). As a result, the consumption of these species was a very small portion (<1.0%) of the population with the exception of Greenland turbot. In 1984, an estimated 3,918 t of age-0 Greenland turbot, accounting for 81.78 billion fish, were consumed by yellowfin sole (Fig. 15). Predation on Greenland turbot was not observed in 1985 or 1986 probably due to the decreased abundance of Greenland turbot (Bakkala and Wilderbuer 1990b) and the fact that the distributions of these two species do not overlap much.

Table 12.--Estimated biomass (metric tons) of miscellaneous species consumed by yellowfin sole by year and strata, months 5-9. Numbers in parentheses correspond to year-stratum combinations where number consumed could not be calculated using conventional methods.

	Strata	1984	1985	1986
Rock sole	1	0.00	147.60	0.00
	4	1,043.63	0.00	0.00
Greenland turbot	2	355.99	0.00	0.00
	3	2,622.11	0.00	0.00
	4	940.67	0.00	0.00
Blue king crab	4	(213.38)	0.00	0.00
Pacific cod	3	(9,220.18)	0.00	0.00
Arrowtooth flounder	4	871.10	0.00	0.00
Pacific halibut	4	89.41	0.00	0.00

Consumption of rock sole in 1984 and 1985 was relatively small, 1,043.63 and 147.60 t estimated biomass and 23,462 and 4,173 million individuals, respectively, likely representing trivial mortality for the rock sole population (Fig 16). Arrowtooth flounder and Pacific halibut were also consumed in small quantities in 1984 (Fig. 17). An estimated 871.10 t of arrowtooth flounder were consumed, representing 1,868 million fish. Yellowfin sole consumed an estimated 89.41 t and 727.76 million Pacific halibut in 1984 as well. It is unlikely that this predation placed any significant pressure on the stocks of either of these species.

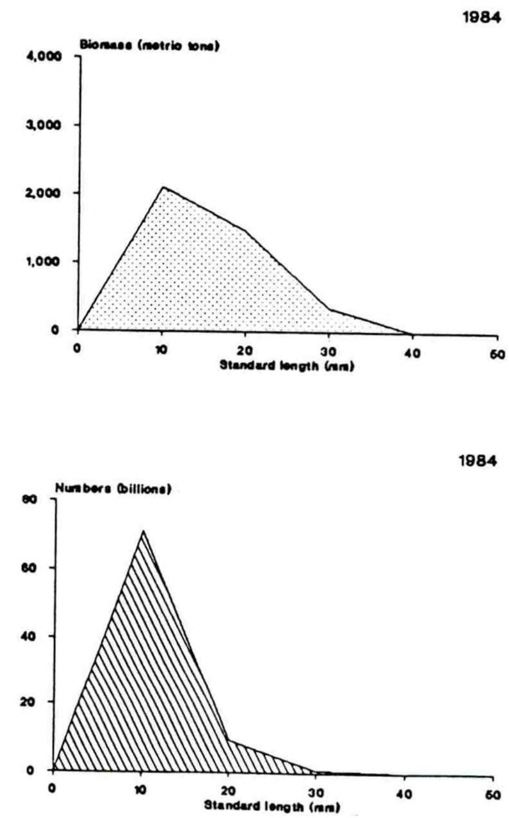


Figure 15.--Biomass (metric tons) and numbers (millions) of Greenland turbot consumed by yellowfin sole, by prey size, during months 5 to 9 in 1984.

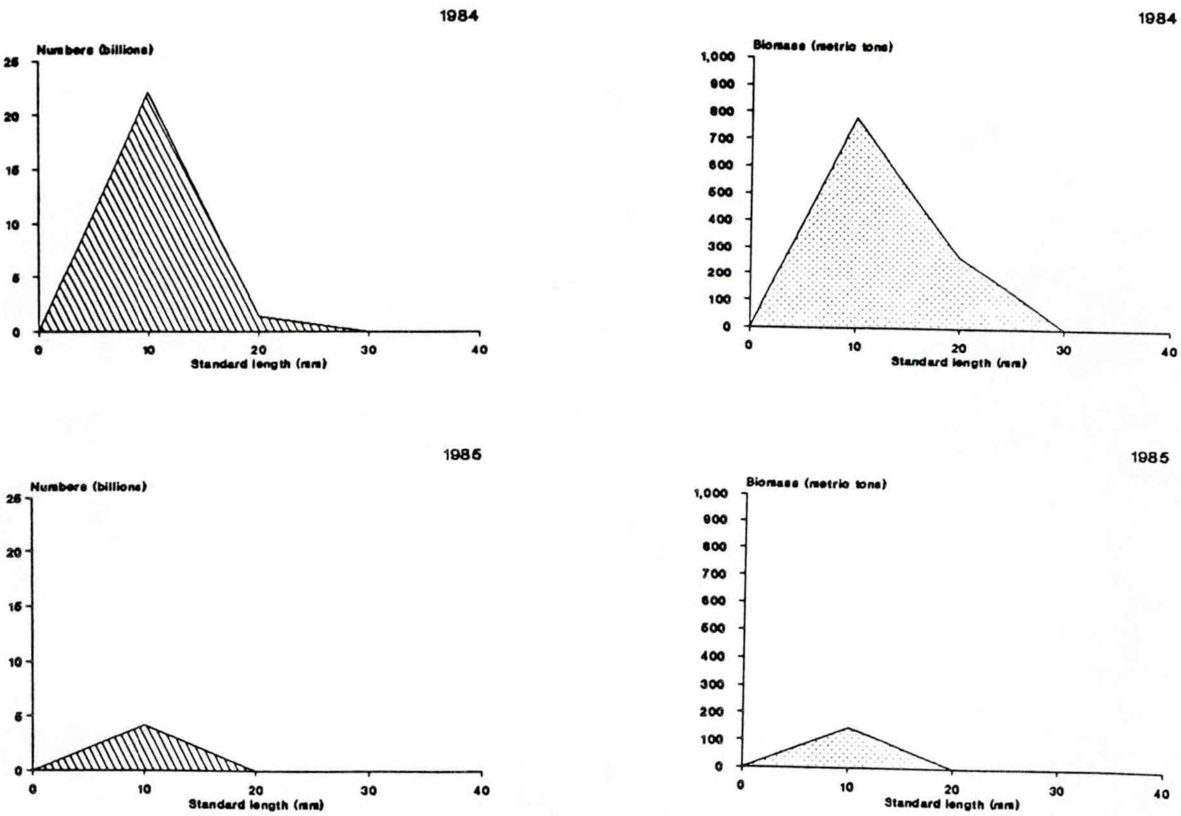


Figure 16.--Estimated biomass (metric tons) and numbers (millions) of rock sole consumed by yellowfin sole, by prey size, during months 5 to 9 in 1984 and 1985.

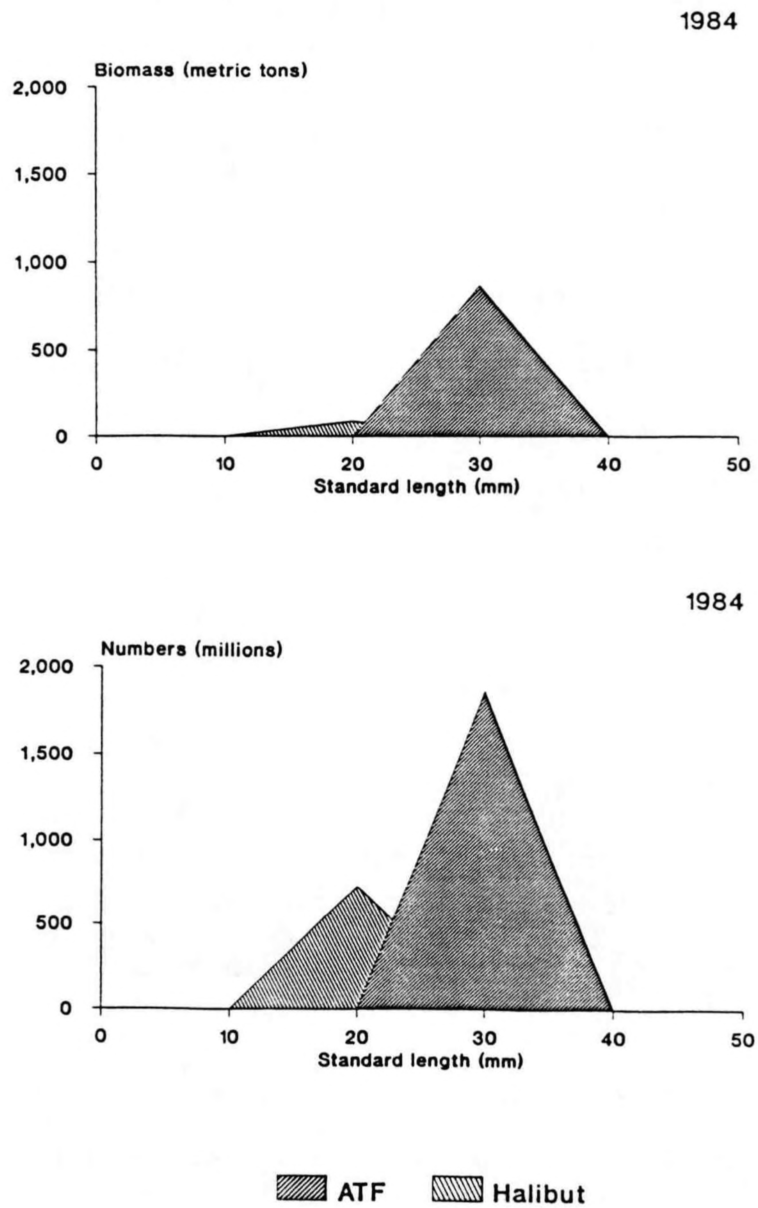


Figure 17.--Estimated biomass (metric tons) and numbers (millions) of arrowtooth (ATF) flounder and Pacific halibut consumed by yellowfin sole, by prey size, during months 5 to 9 in 1984.

Table 13.--Estimated numbers (millions) of miscellaneous species consumed by yellowfin sole by year and strata, months 5-9. Parentheses correspond to year-stratum combinations where number consumed could not be calculated using conventional methods.

	Strata	1984	1985	1986
Rock sole	1	0.00	4,173.95	0.00
	4	23,462.63	0.00	0.00
Greenland turbot	2	2,333.37	0.00	0.00
	3	74,525.95	0.00	0.00
	4	4,861.33	0.00	0.00
Blue king crab	4	(35,563.43)[a]	0.00	0.00
Pacific cod	3	(0)	0.00	0.00
Arrowtooth flounder	4	1,867.75	0.00	0.00
Pacific halibut	4	727.76	0.00	0.00

[a] Estimate of number consumed was calculated by dividing the estimated blue king crab biomass consumed by the average weight of blue king crab megalopa larvae found in yellowfin sole stomachs (0.006 g).

Blue king crab were consumed as megalopa larvae; therefore, their size was not measured as part of the standard analysis. As a result, numbers consumed could not be estimated using the conventional method. An estimate of the number consumed was arrived at by dividing the total estimated biomass consumed (213.38 t) by the average weight of blue king crab megalopa larvae found in yellowfin sole stomachs (0.006 g). Therefore, it is estimated that approximately 36 billion blue king crab megalopa larvae were consumed by yellowfin sole in 1984. When calculating the biomass and number of blue king crab consumed by yellowfin sole, 31 days was used in Equation (1) in the Methods section of this report, rather than 151 days as was used for other species, since blue king crab larvae are only in the megalopa stage for 31 days on the average (Jensen and Armstrong 1989). Since there is no estimate of the number of blue king crab larvae in the eastern Bering Sea, it is difficult to quantify the effect yellowfin sole predation might have on the blue king crab population. However, Jensen and Armstrong (1989) report blue king crab zoea larval densities of up to 18,000 per 100 m^2 surface area in the Pribilof Island region. With densities as high as this, it is likely that yellowfin sole predation does not represent a significant source of mortality for the blue king crab population.

Overall, yellowfin sole did not rely heavily upon commercially important prey as a major part of it diet; less than 1.0% for any given species. Despite the small percent of its diet made up by commercially important prey, the large yellowfin sole biomass did consume a large number of commercially important prey juveniles in its diet. While these numbers are not the most significant factor in the fitness of these prey populations, yellowfin sole is certainly an integral part of the Bering Sea ecosystem.

CITATIONS

Allen, M. J. 1984. Functional organization of demersal fish communities of the eastern Bering Sea. Unpubl. manuscr., 266 p. Alaska Fish. Sci. Cent., 7600 Sand Point Way NE, Bin C15700, Seattle, WA 98115.

Bakkala, R. G., and V. G. Wespestad. 1990. Yellowfin sole. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 67-85. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Bakkala, R. G., and T. K. Wilderbuer. 1990a. Yellowfin sole. In Stock assessment and fisheries evaluation document for groundfish resources in the eastern Bering Sea/Aleutian Islands region as projected for 1991. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Bakkala, R. G., and T. K. Wilderbuer. 1990b. Greenland turbot. In L-L. Low, and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 86-101. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

DeGroot, S. J. 1971. On the interrelationships between morphology and the alimentary tract, food and feeding behaviour in flatfishes (Pisces: Plueronecteformes). Neth. J. Sea Res. 5:121-196.

Haflinger, K. 1981. A survey of benthic infaunal communities of the southeastern Bering Sea shelf. In D.W. Hood, and J. A. Calder (editors), The eastern Bering Sea shelf: Oceanography and resources Vol. 2, p. 1091-1103. U.S. Dept. Commer., Natl. Oceanic Atmos. Admin., Off. Mar. Pollut. Assess., U.S. Gov. Print. Off., Washington, D.C.

Haflinger, K. E., and C. P. McRoy. 1983. Yellowfin sole (Limanda aspera) predation on three commercial crab species (Chionoecetes opilio, C. bairdi and Paralithodes camtschatica) in the southeastern Bering Sea. Final report to the U.S. Natl. Mar. Fish. Serv., Contract 82-ABC-00202, 28 p. Inst. Mar. Sci. Univ. Alaska, Fairbanks, AK 99701.

Jensen, G. C., and D. A. Armstrong. 1989. Biennial reproductive cycle of blue king crab (Paralithodes platypus) at the Pribilof Islands, Alaska and comparison to a congener (P. camtschatica). Can. J. Fish. Aquat. Sci. 46:932-940.

Livingston, P. A., D. A. Dwyer, D. L. Wencker, M. S. Yang, and G. M. Lang. 1986. Trophic interactions of key fish species in the eastern Bering Sea. Int. North Pac. Fish. Comm. Bull. 47:49-65.

Smith, D. B., and R. G. Bakkala. 1982. Demersal fish resources of the eastern Bering Sea: Spring 1976. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-754, 129 p.

Stevens, B.G., and R.A. MacIntosh. 1990. Report to the industry on the 1990 eastern Bering Sea crab survey. Alaska Fish. Sci. Cent. processed report 90-09, 50 p. Natl. Mar. Fish. Serv., Alaska Fish. Sci. Cent., Kodiak Facility, P.O. Box 1638, Kodiak, AK 99615.

Wakabayashi, K. 1986. Interspecific feeding relationships on the continental shelf of the eastern Bering Sea, with special references to yellowfin sole. Int. North Pac. Fish. Comm. Bull. 47:3-30.

Wakabayashi, K., R. Bakkala, and L. Low. 1977. Status of the yellowfin sole resource in the eastern Bering Sea through 1976. Intl. North Pac. Fish. Comm. Doc 2016. Unpubl. manuscr., 45 p. Alaska Fish. Sci. Cent., 7600 Sand Point Way NE, Bin C15700, Seattle WA 98115.

GREENLAND TURBOT

by

Mei-Sun Yang

INTRODUCTION

Greenland turbot (Reinhardtius hippoglossoides) is one of the larger sized flatfish species in the eastern Bering Sea. Because of decline in recruitment, commercial catch has been less than 10,000 t since 1986 (Bakkala and Wilderbuer 1990). The estimated total exploitable biomass in 1989 was 375,800 t (Low 1990), about 2.7% of the total groundfish complex. Earlier studies on the diet of Greenland turbot (Mito 1974; Smith et al. 1978; Yang and Livingston 1988) have shown that Greenland turbot is mainly a fish feeder, and walleye pollock (Theragra chalcogramma) is the most important prey of Greenland turbot in the eastern Bering Sea area. Therefore, it is especially important to study the impact of Greenland turbot on walleye pollock as well as other commercially important prey. However, due to a lack of information of food habits data from the continental slope area, all estimates in this study are for the shelf portion of the population only.

GENERAL FOOD HABITS

Diet

A total of 1,291 stomachs have been sampled since 1984, 44.6% (576) of which were empty and 55.4% (715) of which contained prey. Fish (75% by weight) was the most important prey item of Greenland turbot (Table 1). Walleye pollock constituted the highest proportion of the diet (30% by frequency of occurrence, 25% by number, and 56% by total weight). Squid (mainly Berryteuthis spp.) was the second most important prey of Greenland turbot (29% by frequency of occurrence, 20% by number, and 22% by weight of the diet). Greenland turbot also consumed other commercially important and commercially unimportant prey. The commercially important prey included: king crab (Paralithodes spp., legs only), snow crab (Chionoecetes opilio), Pacific herring (Clupea harengus pallasi), flathead sole (Hippoglossoides elassodon), and juvenile Greenland turbot. Some of the commercially unimportant fish were bathylagids, myctophids, zoarcids, macrourids, cyclopterids, cottids, and stichaeids. All of these species were not important in terms of the three feeding

Table 1.--Prey items (expressed in percent frequency of occurrence, numerical percentage, and percent total weight) of Greenland turbot (Reinhardtius hippoglossoides) collected in the eastern Bering Sea from 1984 through 1986.

Prey Name	Freq. occur	Number	Total weight
Gastropoda (snail)	0.84	5.24	0.17
Teuthoidea Oegopsida (squid)	20.00	12.78	9.48
Gonatidae (squid)	1.40	0.98	0.88
Gonatopsis spp. (squid)	1.82	1.06	2.74
Gonatus spp. (squid)	0.84	0.82	0.26
Berryteuthis spp. (squid)	6.15	4.42	8.33
Octopoda (octopus)	0.14	0.08	0.61
Crustacea	5.59	8.60	0.01
Caridea (shrimp)	2.66	3.60	0.18
Paralithodes spp. (king crabs)	0.14	0.08	0.17
Chionoecetes opilio (snow crab)	0.14	0.08	0.04
Osteichthyes Teleostei (fish)	18.46	10.89	4.32
Clupea harengus pallasi (Pacific herring)	0.28	0.16	0.88
Bathylagidae (deep sea smelts)	6.57	6.96	0.53
Myctophidae (lanternfish)	4.06	5.81	0.67
Stenobrachius leucopsarus (northern lampfish)	0.14	0.08	0.00
Gadidae (gadid fish)	6.43	4.01	3.19
Theragra chalcogramma (walleye pollock)	30.49	24.49	55.81
Zoarcidae (eelpout)	4.76	3.77	4.02
Lycodes diapterus (black eelpout)	0.14	0.08	0.06
Lycodes palearis (wattled eelpout)	0.14	0.08	0.13
Macrouridae (rattail)	1.54	0.98	1.41
Icelus spiniger (thorny sculpin)	0.14	0.08	0.03
Dasycottus setiger (spinyhead sculpin)	0.14	0.08	0.24
Hemitripterus bolini (bigmouth sculpin)	0.14	0.08	0.01
Cyclopteridae (snailfish)	0.28	0.16	0.44
Aptocyclus ventricosus (smooth lumpsucker)	0.14	0.08	0.66
Careproctus cypselurus (blackfinned red snailfish)	0.14	0.08	0.98
Stichaeidae (prickleback)	0.14	0.08	0.04
Lumpenus maculatus (daubed shanny)	0.28	0.16	0.05
Hippoglossoides elassodon (flathead sole)	0.14	0.08	0.07
Reinhardtius hippoglossoides (Greenland turbot)	0.42	0.25	1.40
Fishery discards	0.70	0.66	2.15
Miscellaneous and unidentified prey	1.96	2.62	0.00

Total prey count	1,221
Total prey weight	39,809 g
Number of stomachs with food	715
Number of empty stomachs	576

indices (percent of frequency of occurrence, numerical percentage, and percent total weight of diet). These results indicate that Greenland turbot is primarily a pelagic feeder that mainly feeds on fish and squid.

Seasonal and Annual Changes in Diet

The seasonal variations in the main food items of Greenland turbot are shown in Figure 1. Because no winter samples were collected, only spring, summer, and autumn samples were compared. Walleye pollock dominated the diet of all size groups of Greenland turbot in summer and all turbot 65 cm and greater in spring and autumn, whereas cephalopods were the predominant prey of Greenland turbot less than 65 cm in spring and autumn. Yang and Livingston (1988) found the feeding habits of Greenland turbot are strongly correlated with sampling depth and fish length. Shuntov (1970) and Mikawa (1963) reported the seasonal depth migrations of Greenland turbot. They hypothesized that Greenland turbot migrate into shallower waters to feed on walleye pollock. The seasonal variations of the walleye pollock and cephalopods in the diet of Greenland turbot are consistent with this hypothesis. In spring and autumn, juvenile walleye pollock (age 0 and age 1) of the appropriate size for smaller sized (35-64 cm) Greenland turbot were not available in the deeper area (>200 m). Therefore, the smaller sized Greenland turbot consumed cephalopods and deepwater fishes, while turbot 65 cm and greater consumed mostly larger walleye pollock and other fish in all seasons and all different depth areas.

The interannual variations of Greenland turbot diet are shown in Figure 2. With some variation, walleye pollock was the predominant prey of Greenland turbot in every year. The variations of the amount of different prey items between 1984 and 1985 were interrelated with sampling depth, season, and fish size. In 1986, Greenland turbot consumed almost exclusively walleye pollock and other gadids. This is because in 1986, samples were only collected in the continental shelf (<200 m) area in summer (Fig. 3), and the sample size (n = 71) was relatively small.

Sizes of Commercially Important Prey Consumed

Walleye pollock was the only prey consumed by Greenland turbot that had an adequate number for size analysis. The size of the walleye pollock consumed by Greenland turbot increased dramatically with predator size (Fig. 4). The relationship is linear with an r-squared value of 0.776. Based on the age-length conversion table used in this study, the walleye pollock eaten by Greenland turbot were approximately age-0 and age-1 for fish less than 50 cm long. Greenland turbot 50 cm long and greater consumed mainly age-1 and age-2 walleye pollock but also fed on some age-3 and age-4 walleye pollock (Fig. 5). This trend

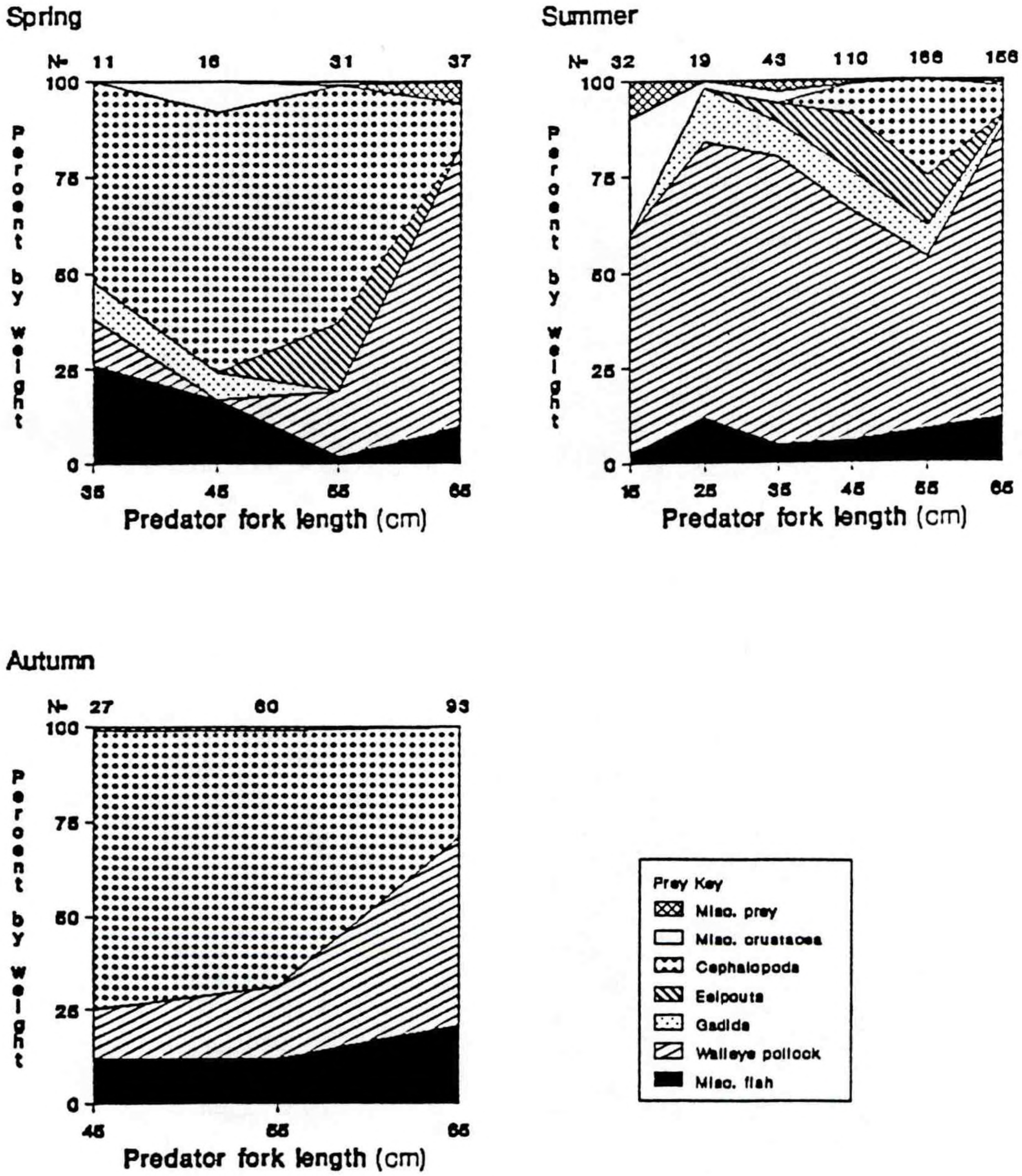


Figure 1.--Seasonal variations in the main food items of Greenland turbot in the eastern Bering Sea by year, 1984-86. N = sample size.

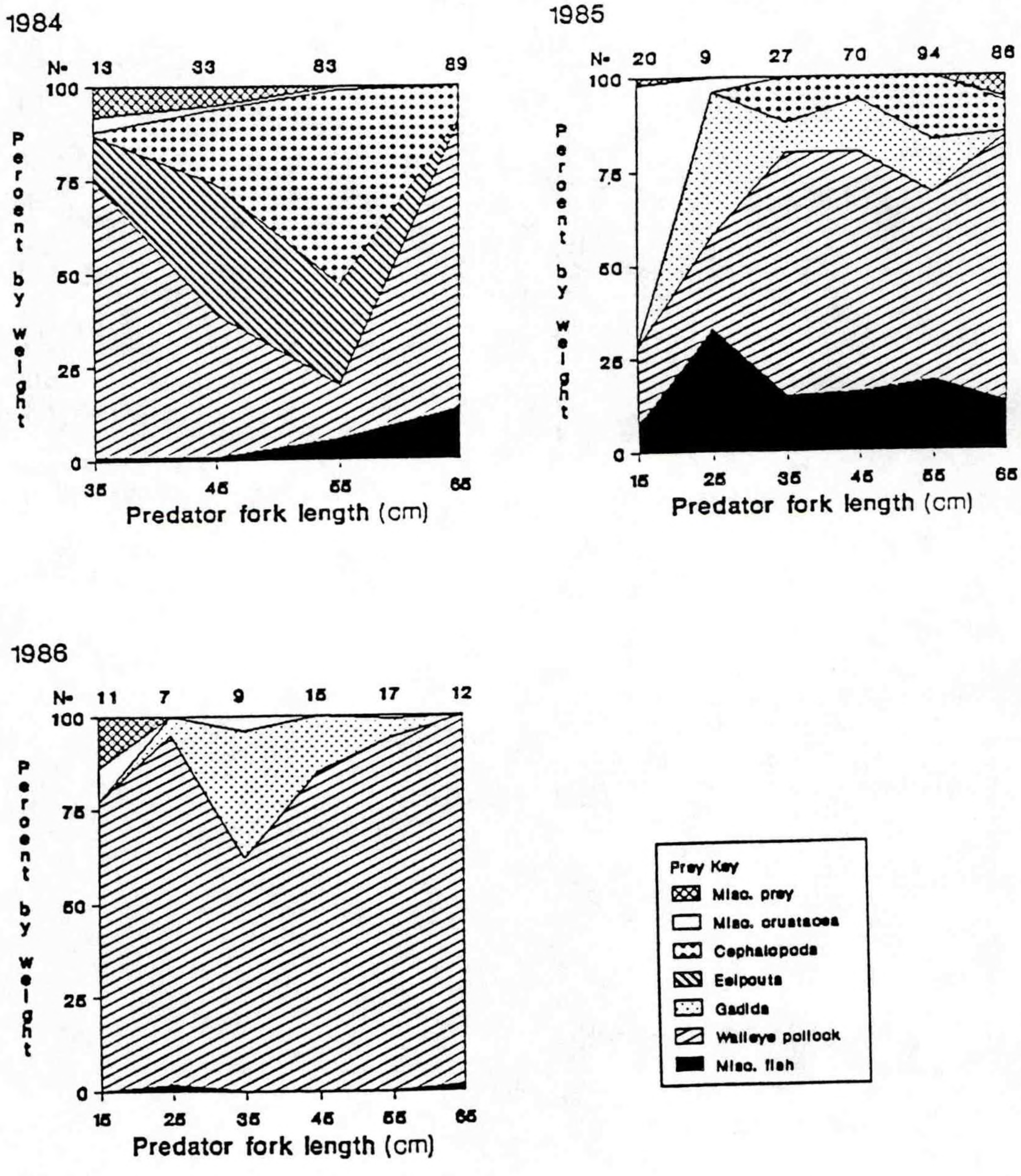


Figure 2.--Annual variations in the main food items of Greenland turbot in the eastern Bering Sea by year, 1984-86 (months 5 to 9). N = sample size.

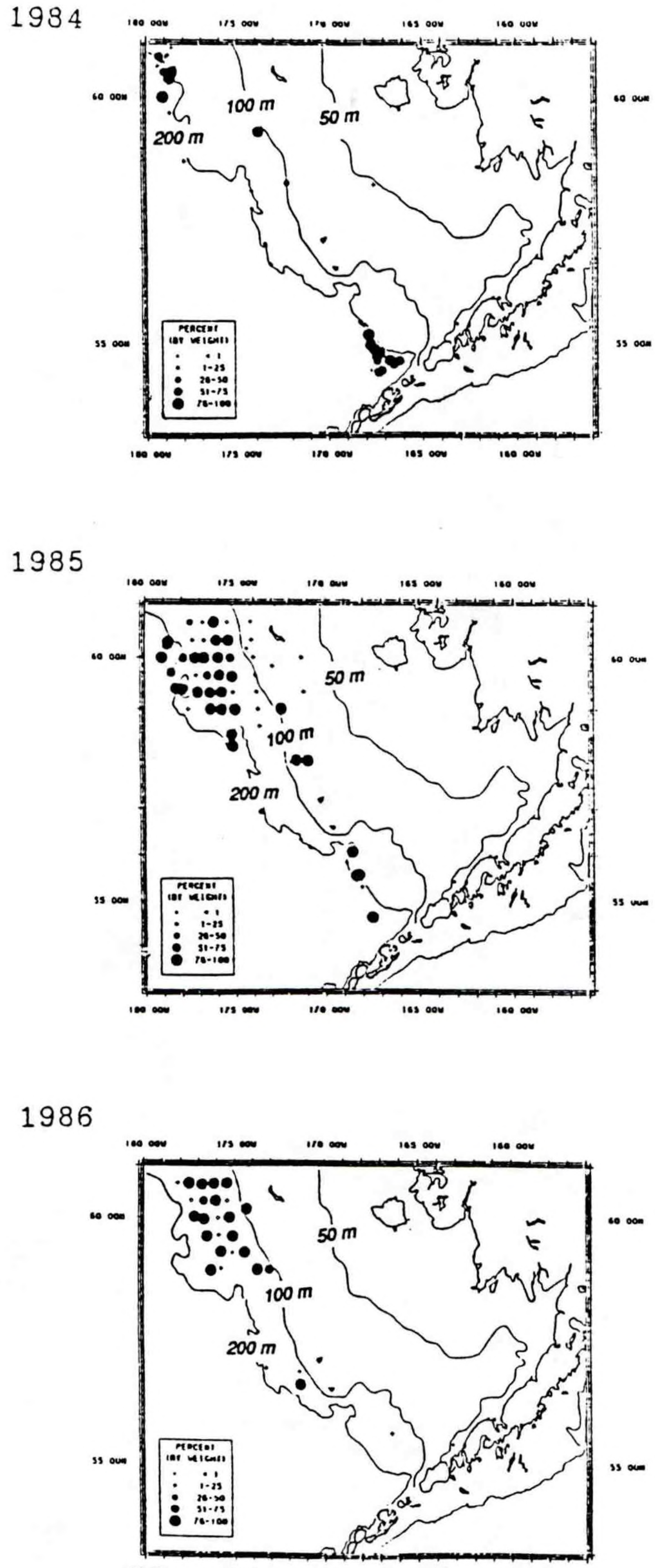


Figure 3.--Geographic variations of walleye pollock consumed by Greenland turbot in the eastern Bering Sea, 1984-86 (months 5 to 9).

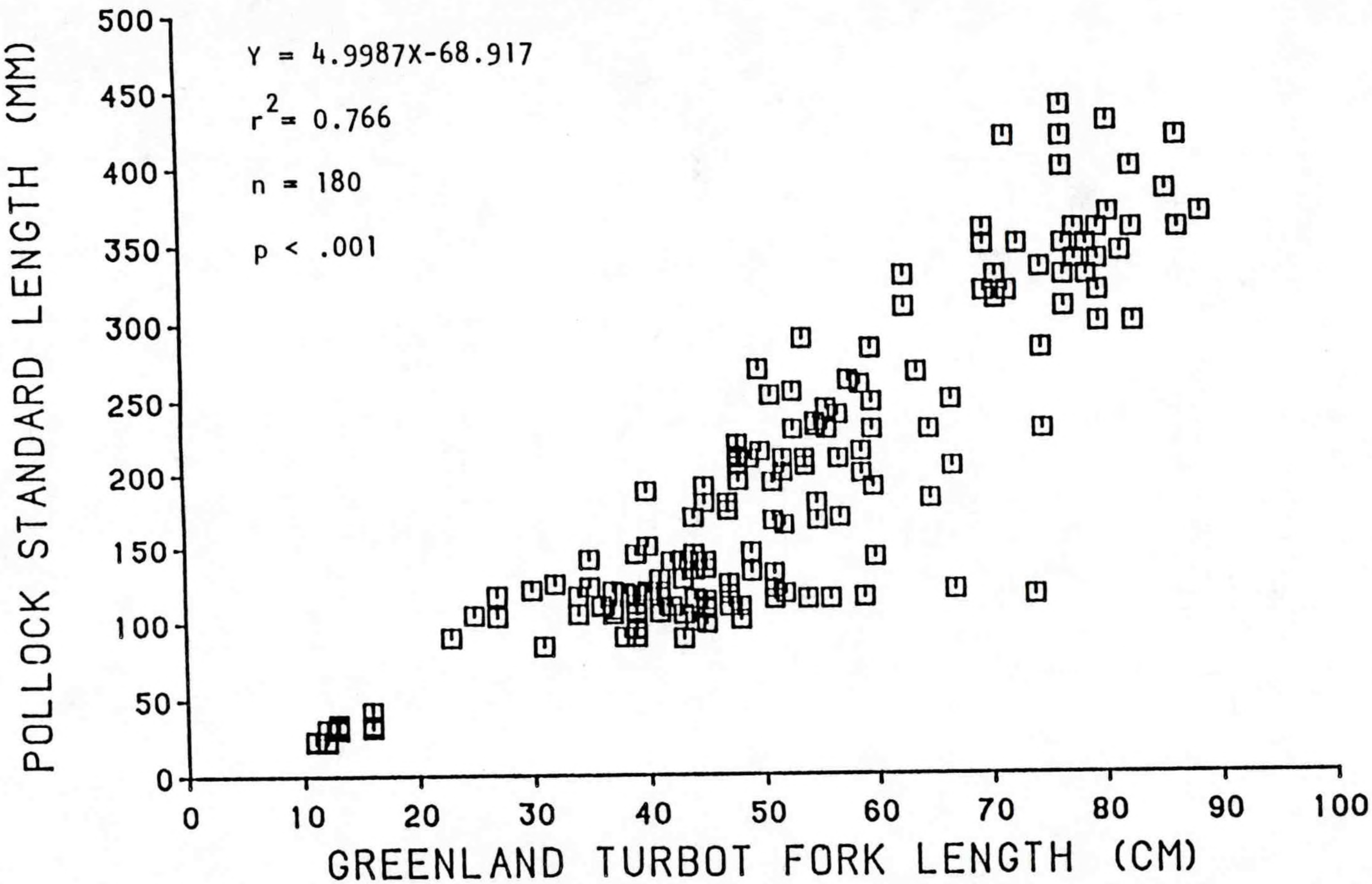


Figure 4.--Scatterplot of walleye pollock prey size versus Greenland turbot size in the eastern Bering Sea.

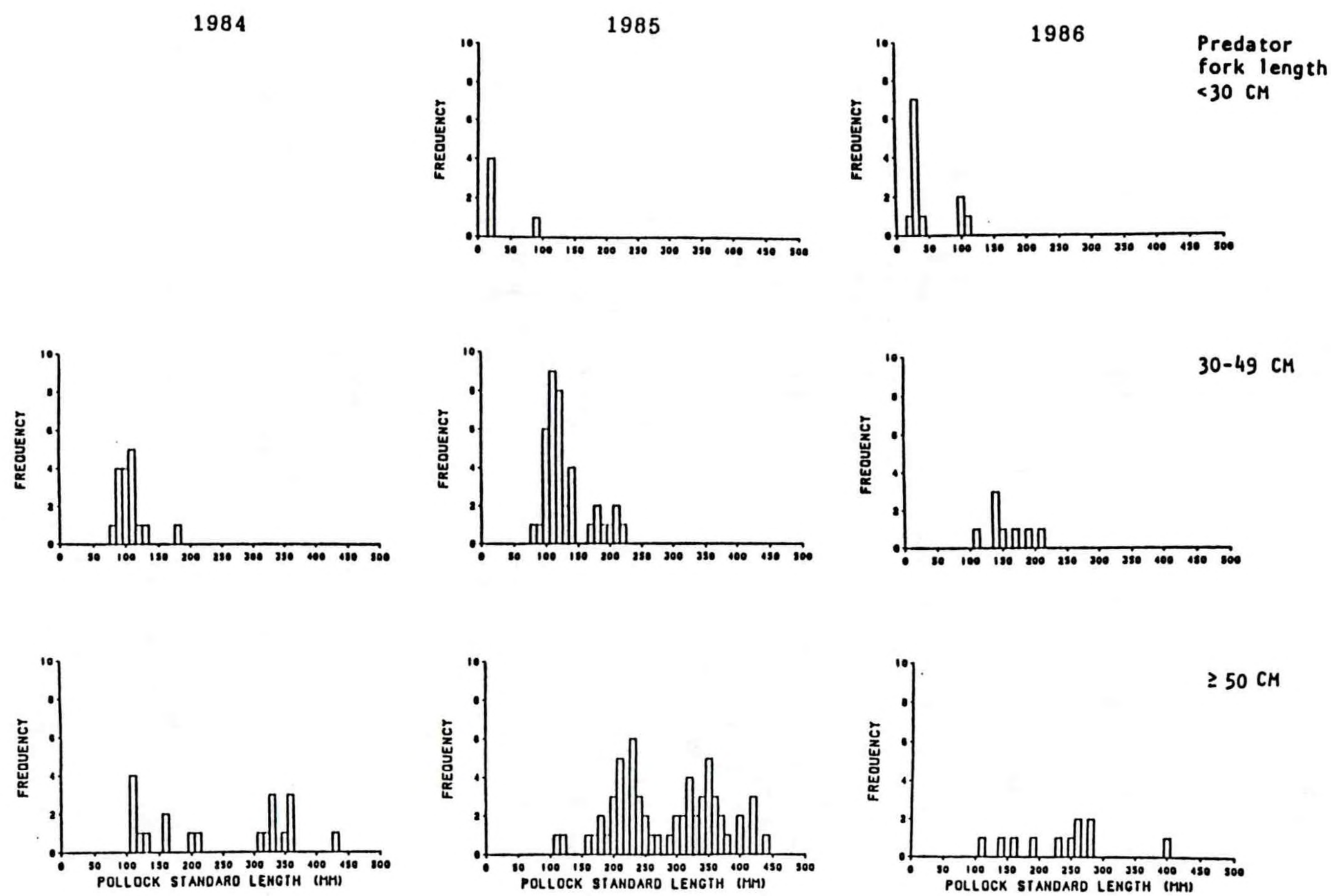


Figure 5.--Size frequency distributions of walleye pollock consumed by Greenland turbot in the eastern Bering Sea by year, 1984-86.

occurred in all 3 years, but it was more obvious in 1985 when a large number of walleye pollock were consumed by Greenland turbot.

The available size measurements of other commercially important prey are Pacific herring, 210 mm average standard length (SL); flathead sole, 150 mm average SL; snow crab, 35 mm average carapace width.

PREDATOR POPULATION CONSUMPTION OF COMMERCIALLY IMPORTANT PREY

Geographic Trends in Consumption

As in the prey size analysis, walleye pollock was the only commercially important prey consumed by Greenland turbot for which adequate data existed for detailed consumption analysis. Figure 3 shows the percent by weight of walleye pollock consumed by Greenland turbot at different locations (sampled in months 5 to 9) from 1984 to 1986. In all years, most walleye pollock were consumed in the outer shelf area, especially northwest of the Pribilof Islands. In those areas, walleye pollock usually constituted at least 50% of the diet by weight.

No specific geographic trends were analyzed in other commercially important prey because of the inadequate data of these prey. However, in summer 1985, king crab (Paralithodes spp.) legs were consumed in stratum 5 (see Fig. 1 in the Methods section of this report) and snow crab were consumed in stratum 6, and Pacific herring were consumed in stratum 6. In June 1986, flathead sole were consumed in stratum 5.

Total Consumption Parameters

The input parameters used to estimate the biomass of a particular prey item consumed by a predator was described in the Methods section of this report. The estimated biomass (based on the bottom trawl survey conducted by the Resource Assessment and Conservation Engineering Division of the Alaska Fisheries Science Center, National Marine Fisheries Service) of Greenland turbot in the eastern Bering Sea shelf area decreased dramatically from 1984 (17,500 t) to 1986 (5,600 t) (Table 2). The mid-sized group (30-49 cm) of Greenland turbot constituted the greatest portion of turbot biomass in 1984 (61%), whereas the larger size group (≥50 cm) contributed the greatest portion of biomass in both 1985 (55%) and 1986 (82%). The biomass of the young recruits (<30 cm) was low (<3% of each of those 3 years). In terms of the biomass in each stratum, it appears that stratum 6 constituted the largest portion (>86%) of Greenland turbot biomass for every size group in every year (except fish <30 cm in 1986 (36%)).

Table 2.--Biomass (by fish size, stratum, and year) of Greenland turbot in the eastern Bering Sea from 1984 through 1986 (data based on the bottom trawl survey of the Alaska Fisheries Science Center, NMFS).

		Biomass (metric tons)		
Fish size	Stratum	1984	1985	1986
<30 cm				
	1	0	0	0
	2	0	0	0
	3	0	1	0
	4	0	8	47
	5	4	0	0
	6	124	169	27
	Subtotal	128	178	74
30-49 cm				
	1	0	0	0
	2	0	0	0
	3	7	25	0
	4	885	319	43
	5	602	0	0
	6	9,170	2,893	880
	Subtotal	10,664	3,237	923
≥50 cm				
	1	0	0	0
	2	0	0	0
	3	4	4	184
	4	493	53	0
	5	360	513	104
	6	5,860	3,547	4,299
	Subtotal	6,717	4,117	4,587
Total		17,509	7,532	5,584

The percentages by weight of walleye pollock in the diet of Greenland turbot are listed in Table 3. Most walleye pollock were consumed in stratum 6 in all years. The percentage by weight of walleye pollock in the diet of Greenland turbot in stratum 6 generally increased from 1984 to 1986 for all size groups of Greenland turbot.

Other commercially important prey usually did not constitute large proportions of the diet of Greenland turbot (Table 4). Also, the occurrence of these prey were not consistent. Pacific herring, Paralithodes spp. legs, and snow crab each constituted less than 5% of the stomach content weight of Greenland turbot. Flathead sole constituted a high percent of the stomach content weight because only one station was sampled in that area. The daily rations of different size Greenland turbot estimated using the parameters described in the Methods section of this report were as follows:

Fish size (cm)	Daily ration (Fraction body weight daily)
<30	0.011
30-49	0.013
≥50	0.005

Total Consumption Estimates

The total biomass of the commercially important prey consumed by Greenland turbot population were estimated by using Equation (1) in the Methods section of this report and the parameters given above. Consumption of king crab legs was not considered in the total consumption estimates since it probably does not contribute directly to mortality of king crab. The total numbers of prey consumed were also calculated using prey size information in strata where it was available.

Walleye pollock was the main commercially important prey species consumed by Greenland turbot. Other commercially important prey (Pacific herring, snow crabs, and flathead sole) constituted only small portions of the diet and were not consumed in all years.

Walleye Pollock as Prey

The estimated total biomasses of walleye pollock consumed by Greenland turbot from 1984 to 1986 were 6,989, 5,312, and 3,862 t, respectively (Table 5). In 1984, 89% by weight (6,192 t) of the pollock consumed by Greenland turbot were age-0 and age-1 fishes. Because no total biomass estimates of age-0 and age-1 pollock are available, the impact of the consumption of age-0 and age-1 pollock to the pollock population is not known. Greenland turbot also consumed 792 t of age-2, -3, and -4 pollock on the Bering Sea shelf. This consumption is about 0.02% of the

Table 3.--Mean percent by weight and standard error (%W ± S.E.) of walleye pollock in the diet of Greenland turbot by predator size, stratum, and year in the eastern Bering Sea (sampled in months 5 to 9). (-) = no samples taken.

Pred. size	Stratum	%W ± S. E. 1984	1985	1986
<30 cm				
	4	(-)	0	44.5 ± 44.5
	5	(-)	(-)	(-)
	6	(-)	19.0 ± 11.3	74.8 ± 24.9
30-49 cm				
	4	(-)	93.0 ± 6.5	(-)
	5	0	0	(-)
	6	33.3 ± 21.0	55.3 ± 9.4	51.0 ± 15.0
≥50 cm				
	4	0	89.6 ± 0.0*	(-)
	5	1.6 ± 1.6	45.0 ± 26.1	0
	6	20.3 ± 12.5	47.0 ± 8.6	88.2 ± 7.8

* Only one station sampled.

Table 4.--Mean percent by weight and standard error (%W ± S.E.) of miscellaneous commercial prey consumed by Greenland turbot (sampled in months 5-9) by prey item, predator size group, year, and stratum.

Prey	Pred. size (cm)	Year	Stratum	%W ± S.E.
Pacific herring	≥50	1985	6	3.85 ± 3.85
Paralithodes spp. (legs only)	≥50	1985	5	3.64 ± 3.64
Flathead sole	≥50	1986	5	98.04 ± 0.00*
Chionoecetes opilio	≥50	1985	6	1.24 ± 1.24

* Only one station was sampled.

Table 5.--Estimated biomass of walleye pollock consumed by Greenland turbot in the eastern Bering Sea (by predator size, stratum, and year). (-) = no samples taken.

		Biomass (metric tons)		
Pred. size	Stratum	1984	1985	1986
<30 cm				
	4	(-)	0	35
	5	(-)	(-)	(-)
	6	(-)	54	34
	Subtotal	(-)	54	69
30-49 cm				
	4	(-)	590	(-)
	5	0	(-)	(-)
	6	6,073	3,180	893
	Subtotal	6,073	3,770	893
≥50 cm				
	4	0	36	(-)
	5	(5)*	177	0
	6	911	1,275	2,900
	Subtotal	916	1,488	2,900
Total		6,989	5,312	3,862

* Values in the parentheses are biomass estimated from consumption of walleye pollock with no prey size information.

estimated biomass of the same age groups of pollock from cohort analysis (Wespestad, Bakkala, and Dawson 1990).

In 1985, about 52% by weight (2,737 t) of the pollock consumed by Greenland turbot were age-0 and age-1 fishes. The rest, 48% by weight (2,576 t), of the pollock consumed by Greenland turbot were age-2, -3, -4, -5, and -6 fishes. This consumption is about 0.04% of the estimated biomass of the same age groups of pollock from cohort analysis.

In 1986, only 25% by weight (918 t) of the pollock consumed by Greenland turbot were age-0 and age-1 fishes. Seventy-five percent by weight (2,881 t) of pollock consumed by Greenland turbot were age-2, -3, -4, and -5 fishes. This is about 0.05% of the pollock biomass of the same age groups estimated in 1986 using cohort analysis.

The decline of the consumption of walleye pollock from 1984 to 1986 was consistent with the decline in Greenland turbot biomass (Table 2). The numbers of walleye pollock consumed by Greenland turbot also indicate a declining trend from 1984 (414 million) to 1986 (65 million) (Table 6).

The estimated biomass and numbers of walleye pollock (by 10-mm size categories) consumed by Greenland turbot were shown in Figure 6. Greenland turbot with size range 30 to 49 cm had the greatest impact on the consumption of walleye pollock. They consumed a large amount of walleye pollock between 100 and 230 mm long. The largest size group (≥50 cm) of Greenland turbot consumed the larger sized (150-450 mm) walleye pollock, and the smallest size group (<30 cm) consumed the smallest sized (<100 mm) walleye pollock. Also, the largest size group consumed more biomass but fewer numbers of walleye pollock, and the smallest size group consumed less biomass but higher numbers of walleye pollock. From 1984 to 1986 the annual consumption of walleye pollock by the mid-sized group (30-49 cm) decreased from 6,073 t to 893 t and the consumption by the largest size group (≥50 cm) increased from 916 t to 2,900 t. The decrease in walleye pollock consumption by the mid-sized group is probable due to the reduction of recruitment of Greenland turbot into that group. Though the biomass of walleye pollock (mainly <100 mm) consumed by Greenland turbot less than 30 cm was low (54 t, 1985; 69 t, 1986), the estimated numbers consumed were relatively high (32 million and 25 million, respectively).

Other Commercially Important Prey

The estimated biomass and numbers of the miscellaneous commercial prey are listed in Table 7. The biomass of Pacific herring consumed by Greenland turbot was 104 t in 1985. It is about 0.02% of the total biomass of Pacific herring estimated from cohort analysis (V. G. Wespestad, Fishery Biologist, Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115-0070. Pers. commun., November 1990). The average size of

Table 6.--Estimated numbers (millions) of walleye pollock consumed by Greenland turbot in the eastern Bering Sea (by predator size, stratum, and year). (-) = no samples taken.

Pred. size	Stratum	Numbers (millions) 1984	1985	1986
<30 cm				
	4	(-)	(-)	17
	5	(-)	(-)	(-)
	6	(-)	32	8
	Subtotal	(-)	32	25
30-49 cm				
	4	(-)	27	(-)
	5	(-)	(-)	(-)
	6	407	107	21
	Subtotal	407	134	21
≥50 cm				
	4	(-)	1	(-)
	5	(-)*	0.4	(-)
	6	7	5	19
	Subtotal	7	6.4	19
Total		414	172.4	65

* No prey size information was available to calculate number consumed.

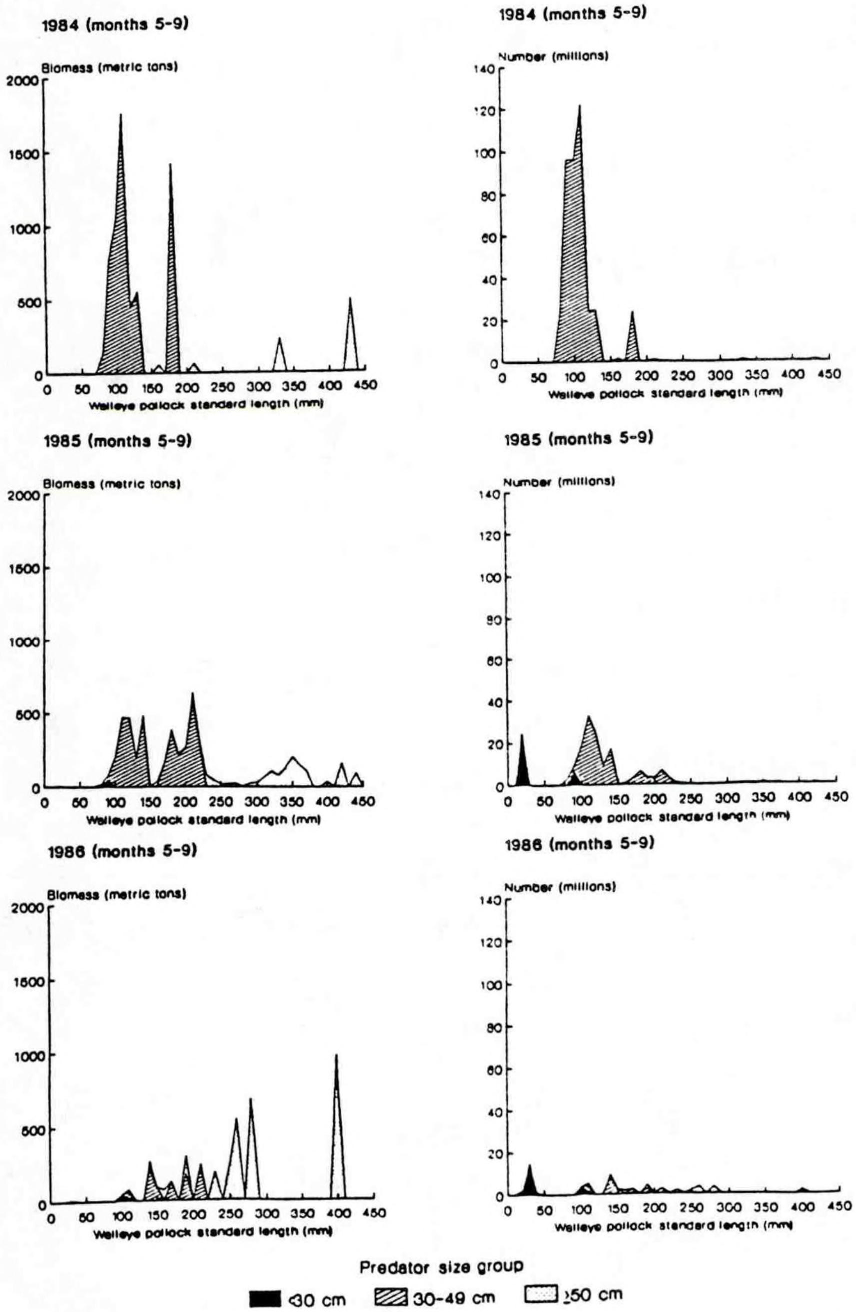


Figure 6.--Estimated biomass and numbers of walleye pollock consumed by Greenland turbot in the eastern Bering Sea by year, 1984-86 (months 5 to 9).

Table 7.--Estimated biomass and numbers of miscellaneous commercial prey consumed by Greenland turbot (sampled in months 5-9) by prey item, predator size group, year, and stratum.

Prey	Pred. size (cm)	Year	Stratum	Biomass (metric tons)	Numbers (millions)
Pacific herring	≥50	1985	6	104.4	0.812
Flathead sole	≥50	1986	5	78.0	1.581
Chionoecetes opilio	≥50	1985	6	33.8	1.396

the Pacific herring consumed was 210 mm SL and approximately age-4 in the central Bering Sea area.

Greenland turbot also consumed about 1.4 million snow crab in the stratum 6 area in 1985. The biomass consumed was about 34 t; it was about 0.05% of the total snow crab biomass in the northern district (strata 5 and 6) in 1985.

In 1986, Greenland turbot consumed an estimated 78 t of flathead sole, which is about 0.02% of the total flathead sole biomass (based on bottom trawl survey data, Walters and Wilderbuer 1990). Since size compositions of the flathead sole were not available from the survey, no impact of Greenland turbot on the different size groups of flathead sole was analyzed.

CITATIONS

Bakkala, R. G., and T. K. Wilderbuer. 1990. Greenland turbot. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 86-101. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Low, L-L. 1990. Executive summary. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 1-18. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Mikawa, M. 1963, Ecology of the lesser halibut, Reinhardtius hippoglossoides Matsuurae Jordan and Snyder. Bull. Tohoku Reg. Fish. Lab. 29:1-41.

Mito, K. 1974. Food relationships among benthic fish populations in the Bering Sea. M.S. Thesis, Hokkaido Univ., Hokkaido, Japan.

Shuntov, V. P. 1970. Sezonnoe respredelenie chernogo i strlozubykh patusov v Beringovum more [Seasonal distribution of black and arrow-tooth halibut in the Bering Sea]. [In Russ.] Tr. Vses. Nauchno-Issled. Inst. Morsk. Rybn. Khoz, Okeanogr. 70 [Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 72]:391-401. (Transl. by Israel Program Sci. Transl., Jerusalem) 1972, in P. A. Moiseev (editor), Soviet fisheries investigations in the northeastern Pacific, Part 5, p. 397-408. Available Natl. Tech. Inf. Serv., Springfield, VA, as TT71-501271.)

Smith, R. L., A. C. Paulson, and J. R. Rose. 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. In Environmental assessment of the Alaskan continental shelf, Final Rep., Biol. Stud. Vol 1, p. 33-107. U.S. Dep. Commer., NOAA, Environ. Res. Lab. Available Arctic Environ. Assess. Cent., 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

Walters, G. E., and T. K. Wilderbuer. 1990. Other flatfish. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 123-141. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Wespestad, V. G., R. G. Bakkala, and P. Dawson. 1990. Walleye pollock. In Stock assessment fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1991. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 9510.

Yang, M. S., and P. A. Livingston. 1988. Food habits and daily ration of Greenland halibut, Reinhardtius hippoglossoides, in the eastern Bering Sea. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 86:675-690.

ARROWTOOTH FLOUNDER

by

Mei-Sun Yang

INTRODUCTION

Arrowtooth flounder (Atheresthes stomias) is one of the larger sized flatfish species in the eastern Bering Sea. Though the annual catch has been less than 10,000 t since 1983, the relative abundance of arrowtooth flounder has increased substantially in the eastern Bering Sea area (Bakkala and Wilderbuer 1990). The total exploitable biomass of arrowtooth flounder for the eastern Bering Sea and Aleutian Islands area in 1990 was 590,400 t (Sample and Wilderbuer 1990). It is about 4% of the total groundfish complex. Early study on the diet of arrowtooth flounder in the eastern Bering Sea (Yang and Livingston 1986) showed that arrowtooth flounder feeds in the water column and preys mainly on walleye pollock (Theragra chalcogramma). Therefore, it is especially important to study the impact of arrowtooth flounder on walleye pollock as well as other commercially important prey. However, due to lack of information of food habits data from the continental slope area, all estimates in this study are for the shelf portion of the population only.

Since the diets of arrowtooth flounder and its congeneric species, Kamchatka flounder (A. evermanni), are very similar (Yang and Livingston 1986), stomach contents data of both species were lumped together in this study.

GENERAL FOOD HABITS

Diet

A total of 3,608 stomachs were sampled, of which 39.6% (1,427) were empty and 60.4% (2,181) contained food. Fish was the main food of arrowtooth flounder. Walleye pollock constituted the highest proportion of the diet; 32% by frequency of occurrence and 56% by total weight (Table 1). Other commercially important species consumed by arrowtooth flounder were Pacific herring (Clupea harengus pallasi), arrowtooth flounder, flathead sole (Hippoglossoides elassodon), and Tanner or snow crabs (Chionoecetes spp.). These species constituted only a small portion of the diet. Arrowtooth flounder also consumed small portions of noncommercially important fish (zoarcids, stichaeids, and macrourids). Important invertebrate

Table 1.--Prey items (expressed in percent frequency of occurrence, numerical percentage, and percent total weight) of arrowtooth flounder (Atheresthes stomias) collected in the eastern Bering Sea from 1984 through 1986.

Prey Name*	Freq. occur	Number	Total weight
Polychaeta (worm)	1.24	0.19	0.02
Bivalvia (clam)	0.64	0.17	0.01
Cephalopoda (squid and octopus)	2.80	0.39	6.03
Crustacea	0.64	0.29	0.00
Peracarida Mysidacea (mysid)	2.20	0.44	0.02
Amphipoda (amphipod)	4.08	2.02	0.03
Euphausiacea (euphausiid)	18.84	79.84	1.65
Decapoda (shrimp and crab)	1.15	0.18	0.01
Caridea (shrimp)	2.25	0.38	0.15
Hippolytidae (shrimp)	0.69	0.10	0.03
Pandalidae (shrimp)	7.15	1.15	1.64
Crangonidae (shrimp)	11.69	2.18	0.37
Paguridae (hermit crabs)	0.50	0.07	0.05
Chionoecetes spp. (Tanner and snow crab)	0.09	0.02	0.00
Chionoecetes bairdi (Tanner crab)	0.05	0.01	0.00
Osteichthyes Teleostei (fish)	28.84	4.13	10.76
Clupea harengus pallasi (Pacific herring)	0.37	0.05	3.11
Osmeridae (smelts)	0.05	0.01	0.08
Gadidae (gadid fish)	3.35	0.48	4.63
Theragra chalcogramma (walleye pollock)	31.55	6.02	56.08
Zoarcidae (eelpout)	1.38	0.21	2.87
Bothrocara brunneum (twoline eelpout)	0.05	0.01	0.01
Lycodes spp. (eelpout)	2.20	0.36	6.05
Lycodes brevipes (shortfin eelpout)	0.23	0.04	0.43
Lycodes diapterus (black eelpout)	0.14	0.02	0.69
Lycodes palearis (wattled eelpout)	0.05	0.01	0.09
Macrouridae (rattail)	0.32	0.05	2.26
Scorpaeniformes Cottoidei (fish)	0.60	0.09	0.41
Agonidae (poacher)	0.23	0.03	0.16
Stichaeidae (prickleback)	0.87	0.12	0.28
Ammodytes hexapterus (Pacific sandlance)	0.09	0.02	0.03
Pleuronectidae (flatfish)	0.37	0.05	0.18
Atheresthes stomias (arrowtooth flounder)	0.18	0.02	0.11
Hippoglossoides elassodon (flathead sole)	0.14	0.02	0.11
Fishery discards	0.96	0.16	1.49
Miscellaneous and unidentified prey	2.34	0.67	0.17
Total prey count		16,327	
Total prey weight		29,712 g	
Number of stomachs with food		2,181	
Number of empty stomachs		1,427	

* Prey name indicates highest level of identification possible for that catagory.

prey included cephalopods, euphausiids, and shrimps. Cephalopods constituted 6% by weight of the stomach contents. Euphausiids constituted the highest proportion (80%) of the number of prey consumed by arrowtooth flounder, but only constituted about 2% by weight. Pandalids and crangonids were the main shrimps in the diet. Based on the food described above, arrowtooth flounder is mainly piscivorous and feeds primarily in the water column.

Seasonal and Annual Changes in Diet

Walleye pollock were the dominant prey of arrowtooth flounder in all seasons. They constituted more than 50% by weight of the diet in all seasons except spring (Fig. 1). In spring, though the percent by weight of walleye pollock was lower than in the other seasons, the percentages of the miscellaneous fish (mainly unidentifiable fish remains, probably walleye pollock) were high. The main variations between seasons were attributed to the small size (<25 cm in length) of the arrowtooth flounder sampled in spring. They consumed much more euphausiids than those in the other seasons. However, the small sample sizes of some size groups in different seasons might also have contributed to some of the variations. The overall trend was that arrowtooth flounder became more piscivorous as they grew larger, and they ate more zooplankton in spring and summer than in autumn and winter. In winter, arrowtooth flounder (especially fish >45 cm) ate mostly fish.

The annual diet compositions of arrowtooth flounder were very similar for fish 25 cm or greater in length (Fig. 2). About 75% by weight of the diet were walleye pollock and miscellaneous fish for arrowtooth flounder in every year. Cephalopods, euphausiids, decapods, and miscellaneous crustaceans constituted the remaining 25% of the diet. For the smallest size group (<25 cm), little difference in the diets between 1985 and 1986 were found; about 50% of the diets were walleye pollock and miscellaneous fish, and 50% were euphausiids and decapods. However, in 1984, approximately 75% of the diet was euphausiids and decapods, and only 25% was walleye pollock and miscellaneous fish. Overall, the annual variations of the diet of arrowtooth flounder were small and, like the seasonal variations, were mainly related to the size of the predator.

Sizes of Commercially Important Prey Consumed

The size of walleye pollock consumed by arrowtooth flounder increased with increasing predator size (Fig. 3). The relationship appears linear with an r-squared value equal to 0.304. Figure 4 shows that smaller size (<40 cm) arrowtooth flounder consumed mostly age-0 and age-1 walleye pollock (<190 mm) while the larger size ($\geq$40 cm) fish consumed mostly age-1 and age-2 walleye pollock (100-270 mm).

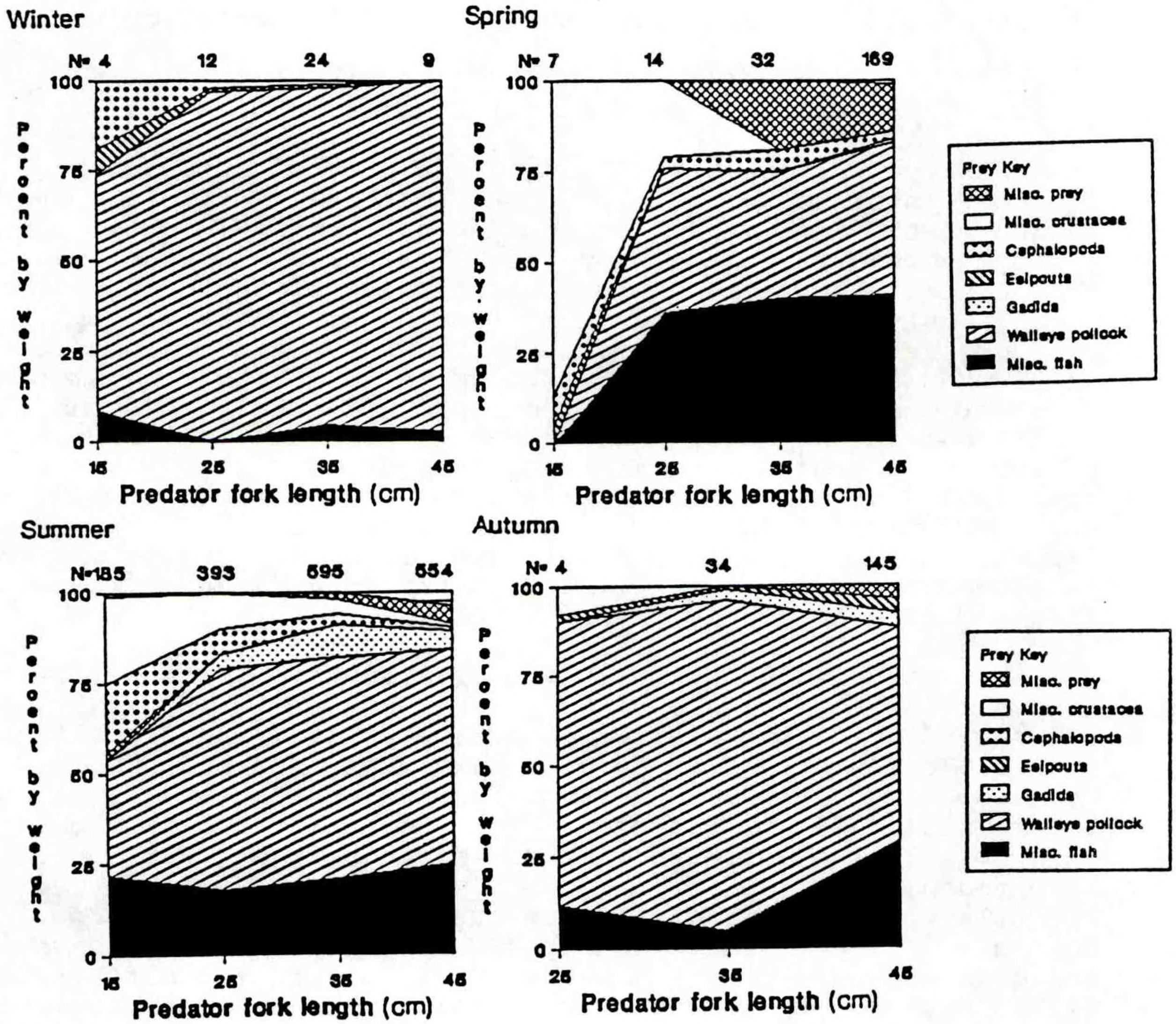


Figure 1.--Seasonal variations in the main food items of arrowtooth flounder in the eastern Bering Sea by year, 1984-86. N = sample size.

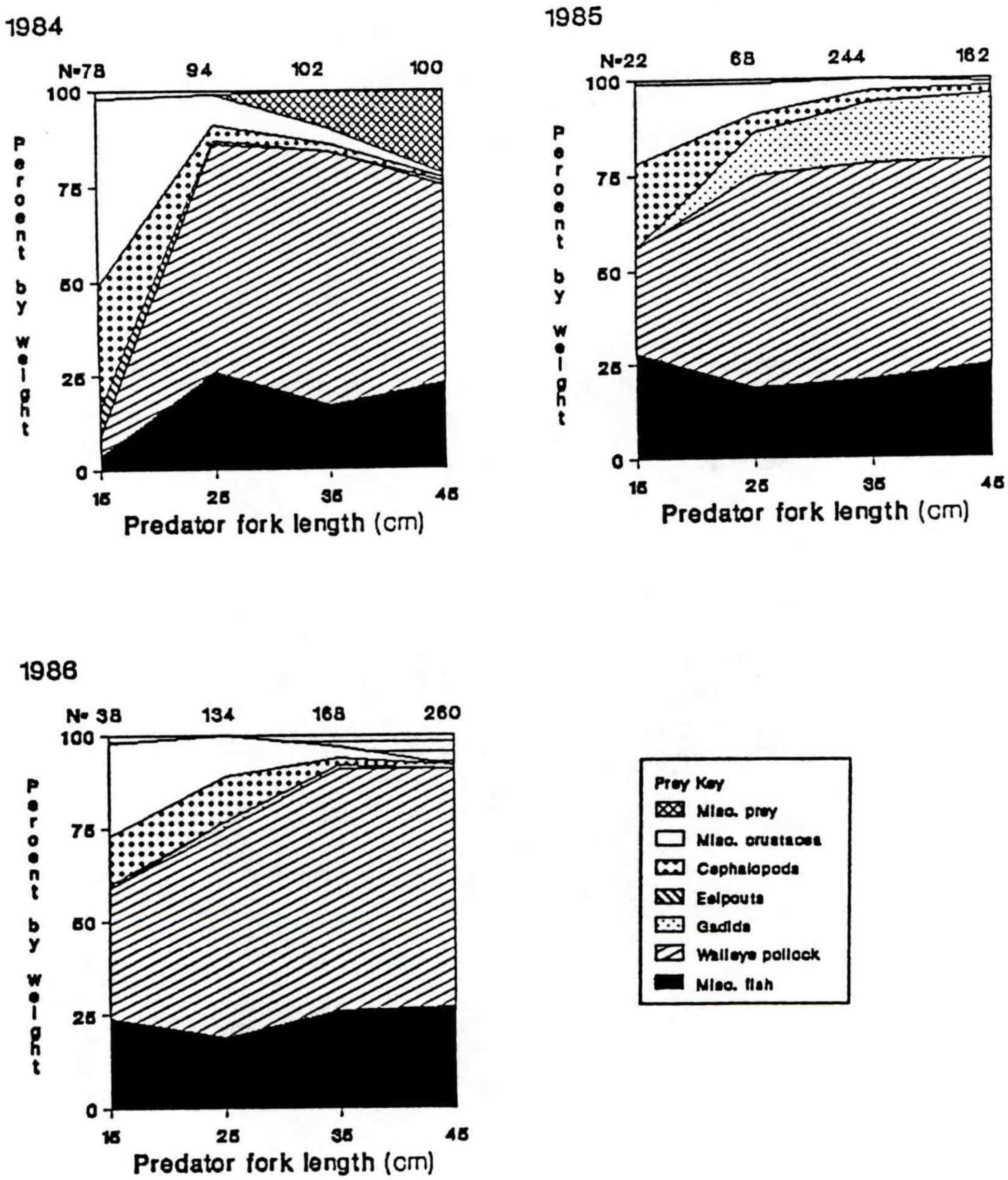


Figure 2.--Annual variations in the main food items of arrowtooth flounder in the eastern Bering Sea by year, 1984-86 (months 5 to 9). N = sample size.

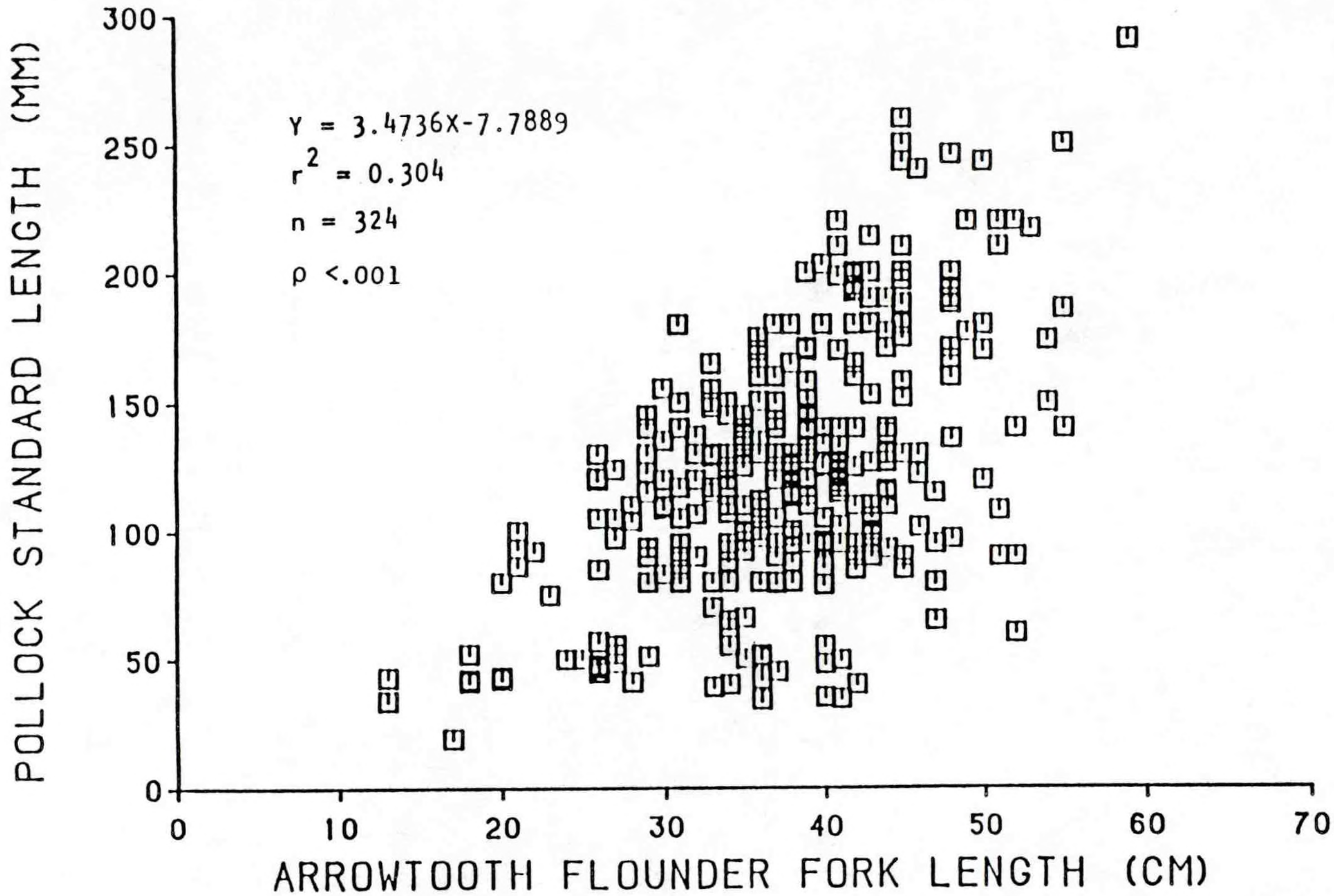


Figure 3.--Scatterplot of walleye pollock prey size versus arrowtooth flounder in the eastern Bering Sea.

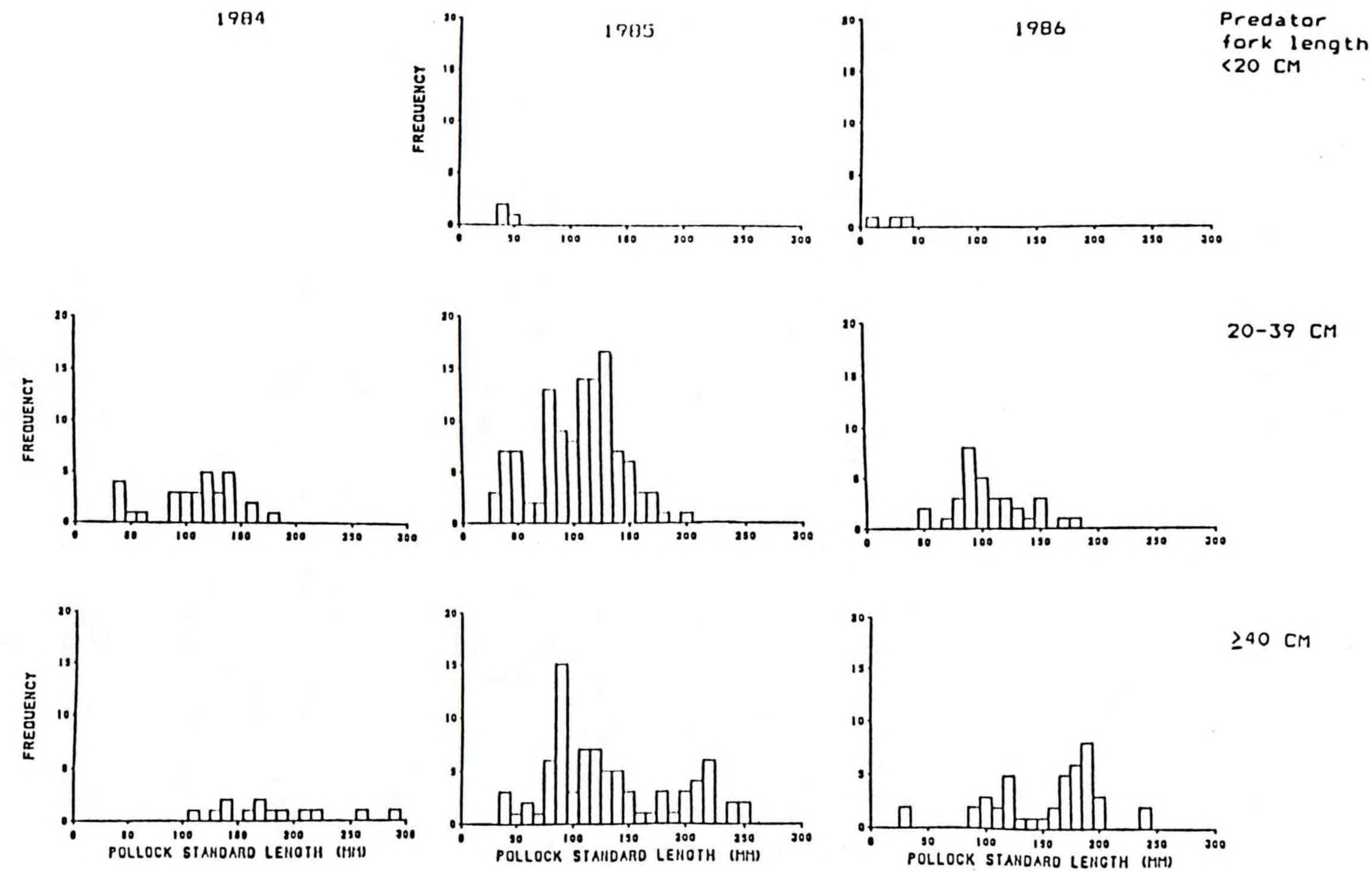


Figure 4.--Size frequency distributions of walleye pollock consumed by three size groups of arrowtooth flounder in the eastern Bering Sea by year, 1984-86.

Though arrowtooth flounder also consumed some other commercially important prey, their numbers were not adequate for detailed analysis. Some of the available length measurements are as follows: Pacific herring, 280 mm average standard length (SL); arrowtooth flounder, 150 mm average SL; and flathead sole with a range between 40 and 160 mm SL.

PREDATOR POPULATION CONSUMPTION OF COMMERCIALLY IMPORTANT PREY

Geographic Trends in Consumption

Walleye pollock were consumed by arrowtooth flounder at different locations from 1984 to 1986--mainly in the outer shelf area (100-200 m) (Fig. 5). In most stations, walleye pollock constituted more than 50% of the diet by weight. Some earlier studies (Gotshall 1969; Smith et al. 1978; Yang and Livingston 1986) show that arrowtooth flounder is an opportunistic feeder (they feed on the most abundant prey). Therefore, the high percentages of walleye pollock in the diet seen in Figure 5 are probably due to the overlap of the distributions of walleye pollock prey and predatory arrowtooth flounder.

Total Consumption Parameters

Table 2 lists the estimated biomass (data based on the bottom trawl survey conducted by the Resource Assessment and Conservation Engineering Division of the Alaska Fisheries Science Center, National Marine Fisheries Service) of arrowtooth flounder from 1984 to 1986. The total biomass in 1986 (232,090 t) was the highest among those 3 years, followed by 187,621 t in 1984 and 163,572 t in 1985. The 20-39 cm size group constituted the highest proportion of biomass in 1984 and 1985; however, the largest portion of biomass in 1986 was contributed by fish 40 cm or greater in length. Fish smaller than 20 cm constituted the smallest proportion of the biomass in all 3 years. In terms of the biomass in different strata, in general, strata 3, 5, and 6 constituted higher proportions of biomass in every year (Table 2).

It seems that arrowtooth flounder consumed higher percentages of walleye pollock in strata 3 and 4 (where the bottom depth is between 50 and 100 m) than in other strata (Table 3). However, the variations were high both interannually and between different strata.

Other commercially important prey usually do not constitute large proportions of the diet of arrowtooth flounder (Table 4). The occurrence of these prey were not consistent either. Pacific herring and flathead sole each constituted less than 10% of the

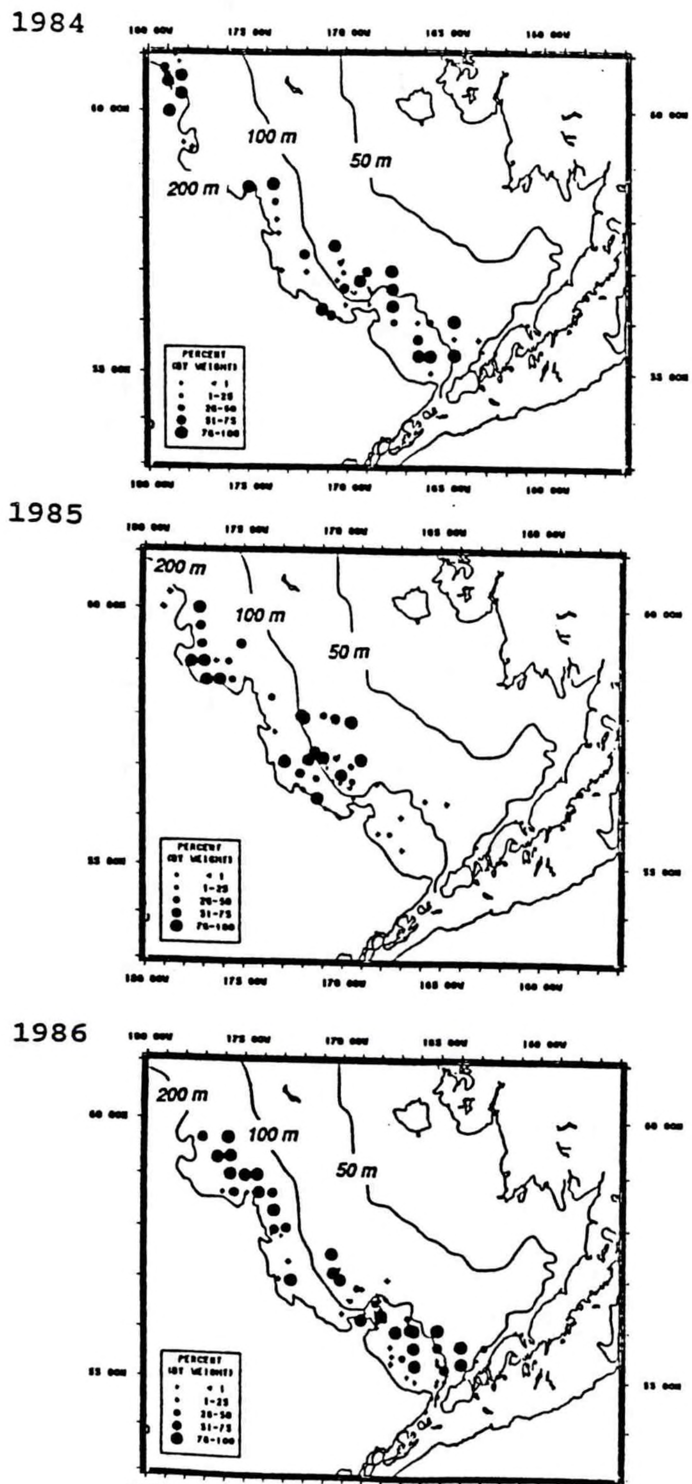


Figure 5.--Geographic variations of walleye pollock consumed by arrowtooth flounder in the eastern Bering Sea by year, 1984-86 (months 5 to 9).

Table 2.--Biomass (by fish size, stratum, and year) of arrowtooth flounder in the eastern Bering Sea from 1984 through 1986 (data based on the bottom trawl survey of the Alaska Fisheries Science Center, NMFS).

		Biomass (metric tons)		
Size (cm)	Stratum	1984	1985	1986
<20	1	0	30	36
	2	0	0	0
	3	399	199	1,197
	4	558	54	588
	5	252	224	946
	6	514	463	577
	Subtotal	1,723	970	3,344
20-39	1	44	608	254
	2	0	0	0
	3	30,303	29,850	18,056
	4	5,205	8,020	1,953
	5	49,173	32,209	46,143
	6	31,798	32,407	22,218
	Subtotal	116,523	103,094	88,624
≥40	1	17	109	0
	2	0	0	0
	3	11,598	8,499	17,702
	4	29	2,266	1,046
	5	26,942	23,380	46,563
	6	30,789	25,254	74,811
	Subtotal	69,375	59,508	140,122
Total		187,621	163,572	232,090

Table 3.--Mean percent by weight and standard error (%W ± S.E.) of walleye pollock in the diet of arrowtooth flounder by predator size, stratum, and year in the eastern Bering Sea (sampled in months 5 to 9). (-) = no samples taken.

Pred. size	Stratum	%W ± S. E. 1984	1985	1986
<20 cm				
	1	(-)	(-)	0
	2	(-)	(-)	(-)
	3	0	71.5 ± 28.6	0
	4	0	26.2 ± 15.2	60.8 ± 0.6
	5	0	9.9 ± 0.0*	0
	6	26.1 ± 26.1	21.9 ± 21.9	13.4 ± 13.4
20-39 cm				
	1	(-)	(-)	45.9 ± 0.0*
	2	(-)	(-)	(-)
	3	50.3 ± 16.1	32.0 ± 18.3	37.0 ± 14.7
	4	58.9 ± 22.8	63.9 ± 13.5	85.0 ± 1.9
	5	39.8 ± 16.0	7.9 ± 4.2	19.3 ± 8.4
	6	31.7 ± 12.0	35.7 ± 7.2	40.8 ± 9.8
≥40 cm				
	1	(-)	(-)	(-)
	2	(-)	(-)	(-)
	3	57.0 ± 23.4	50.0 ± 28.9	41.3 ± 14.0
	4	(-)	45.6 ± 17.2	49.9 ± 49.9
	5	48.1 ± 16.6	12.2 ± 12.2	31.6 ± 10.2
	6	37.0 ± 12.7	50.5 ± 9.3	62.1 ± 9.3

* Only one station was sampled.

Table 4.--Mean percent by weight and standard error (%W ± S.E.) of miscellaneous commercial prey consumed by arrowtooth flounder (sampled in months 5-9) by prey item, predator size group, year, and stratum.

Prey	Pred. size (cm)	Year	Stratum	%W ± S.E.
Pacific herring	≥40	1986	3	7.75 ± 7.75
		1986	5	4.78 ± 4.78
Arrowtooth flounder	20-39	1985	6	0.01 ± 0.01
	≥40	1984	3	20.00 ± 20.00
		1986	5	0.12 ± 0.12
Flathead sole	<20	1984	5	9.23 ± 9.23
	≥40	1984	6	9.08 ± 9.08
		1986	5	0.21 ± 0.21
Chionoecetes bairdi	20-39	1984	6	0.01 ± 0.01

stomach content weight of arrowtooth flounder. Cannibalism (eating their young) among arrowtooth flounder occurred mainly in 1984 at stratum 3 for fish 40 cm or greater in length.

Daily rations (fractions of body weight daily) of different-sized arrowtooth flounder estimated using the parameters described in the Methods section of this report were as follows:

Fish size (cm)	Daily ration (fraction body weight daily)
<20	0.009
20-39	0.009
≥40	0.007

Total Consumption Estimates

The total biomass of commercially important prey consumed by the arrowtooth flounder population were estimated by using Equation (1) in the Methods section of this report and parameters given above. The total numbers of each prey consumed were also calculated when prey size information was available.

Walleye Pollock as Prey

The estimated biomass of walleye pollock consumed by arrowtooth flounder in 1986 was the highest (110,893 t) among the 3 years, followed by 99,383 t in 1984 and 62,409 t in 1985 (Table 5). In 1984, 79% by weight (78,436 t) of the pollock consumed by arrowtooth flounder were age-0 and age-1 fishes. Since no total biomass estimates of age-0 and age-1 pollock are available, the impact of the consumption of age-0 and age-1 fish to the pollock population is not known. Arrowtooth flounder also consumed 20,947 t of age-2 and age-3 pollock on the Bering Sea shelf. This consumption is about 0.79% of the estimated biomass of the same age groups of pollock from cohort analysis (Wespestad et al. 1990).

In 1985, 94% by weight (58,841 out of 62,409) of the pollock consumed by arrowtooth flounder were measurable (i.e., these were the pollock with prey size information; Table 5). Within this group, 82% by weight (48,337 t) of the pollock consumed were age-0 and age-1 fishes. The rest, 18% by weight (10,504 t) of pollock consumed, were age-2 fishes. This consumption is about 1.94% of the estimated biomass of age-2 pollock from cohort analysis.

In 1986, 83% by weight (92,136 t) of the pollock consumed by arrowtooth flounder were age-0 and age-1 fishes. The rest, 17% by weight (18,757 t) of pollock consumed by arrowtooth flounder, were age-2 fishes. This is about 1.25% of the age-2 pollock biomass estimated in 1986 using cohort analysis.

Table 5.--Estimated biomass (metric tons) of walleye pollock consumed by arrowtooth flounder in the eastern Bering Sea (by predator size, stratum, and year). (-) = no samples taken.

		Biomass (metric tons)		
Pred. size	Stratum	1984	1985	1986
<20 cm				
	1	(-)	(-)	0
	2	(-)	(-)	(-)
	3	0	196	0
	4	0	(20)*	492
	5	0	(31)*	0
	6	(185)*	139	106
	Subtotal	(185)*	386	598
20-39 cm				
	1	(-)	(-)	160
	2	(-)	(-)	(-)
	3	20,968	13,135	9,200
	4	4,221	7,060	2,287
	5	26,938	(3,517)*	12,258
	6	13,891	15,935	12,484
	Subtotal	66,018	39,647	36,389
≥40 cm				
	1	(-)	(-)	(-)
	2	(-)	(-)	(-)
	3	7,081	4,551	7,838
	4	(-)	1,108	559
	5	13,890	3,052	15,736
	6	12,209	13,665	49,773
	Subtotal	33,180	22,376	73,906
Total		99,383	62,409	110,893

* Values in parentheses are biomass estimated from consumption of walleye pollock with no prey size information.

Although the total biomass of walleye pollock consumed by arrowtooth flounder in 1985 was low, the estimated total number consumed (20.6 billion) was relatively high, compared with 1984 (4.6 billion, Table 6). The highest number of pollock were consumed (22.8 billion) in 1986. Fluctuations in biomass of walleye pollock consumed were mainly determined by fluctuations in the biomass of different size groups of arrowtooth flounder across years and not by the percentage of walleye pollock in the diet or the daily ration of arrowtooth flounder.

The estimated number and biomass of walleye pollock (by 10 mm size categories) consumed by arrowtooth flounder are shown in Figure 6. The two larger size groups (20-39 cm and ≥40 cm) of arrowtooth flounder consumed the main proportion of the walleye pollock biomass, whereas the smallest size group (<20 cm) consumed very small amounts in terms of biomass. The impact of arrowtooth flounder on walleye pollock numbers was mainly caused by the predation of arrowtooth flounder less than 40 cm long. In 1984, the largest number of walleye pollock consumed by arrowtooth flounder ranged between 80 and 150 mm in length. These walleye pollock also constituted the largest proportion of the biomass consumed by arrowtooth flounder. In 1985, walleye pollock less than 50 mm long (age-0) constituted the largest proportion of both biomass and number of walleye pollock consumed by arrowtooth flounder 20-39 cm long. The situation in 1986 was different. A large number of small (<50 mm or age-0) walleye pollock were consumed by arrowtooth flounder less than 20 cm long; however, they constituted only a small amount of the total biomass consumed. Instead, walleye pollock between 150 and 200 mm constituted the largest proportion of biomass consumed by arrowtooth flounder.

<u>Other Commercially Important Prey</u>

Estimated biomass and numbers of the miscellaneous commercial prey consumed by arrowtooth flounder are listed in Table 7. The biomass of Pacific herring consumed by arrowtooth flounder was about 4,000 t in 1986. It was about 1% of the total Pacific herring biomass in the eastern Bering Sea, according to V. G. Wespestad (Fishery Biologist, Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115-0070. Pers. commun., November 1990). The average size of the Pacific herring consumed was 280 mm SL--approximately 8-year-old fish. According to Wespestad, age classes 7, 8, and 9 were the predominant age groups in 1986; they constituted two-thirds of the total biomass in that year. The locations (strata 3 and 5) of the Pacific herring consumed by arrowtooth flounder indicate that these Pacific herring probably belong to the stock in the Togiak area.

About 2,500 t of small (≤15 cm) arrowtooth flounder were consumed by large (≥40 cm) arrowtooth flounder in the stratum 3 area in 1984. This figure is greater than the biomass (399 t) of arrowtooth flounder less than 20 cm estimated from the trawl survey data. It is possible that the biomass of small arrowtooth

Table 6.--Estimated numbers of walleye pollock consumed by arrowtooth flounder in the eastern Bering Sea (by predator size, stratum, and year). (-) = no samples taken.

		Numbers (millions)		
Pred. size	Stratum	1984	1985	1986
<20 cm				
	1	(-)	(-)	0
	2	(-)	(-)	(-)
	3	0	249	0
	4	0	(-)*	18,856
	5	0	(-)*	0
	6	(-)*	95	185
	Subtotal	(-)	344	19,041
20-39 cm				
	1	(-)	(-)	20
	2	(-)	(-)	(-)
	3	1,823	16,697	489
	4	173	762	274
	5	1,414	(-)*	766
	6	790	761	569
	Subtotal	4,200	18,320	2,118
≥40 cm				
	1	(-)	(-)	(-)
	2	(-)	(-)	(-)
	3	44	632	180
	4	(-)	71	42
	5	220	949	354
	6	182	272	1,030
	Subtotal	446	1,924	1,606
Total		4,646	20,588	22,765

* No prey size information was available to calculate number consumed.

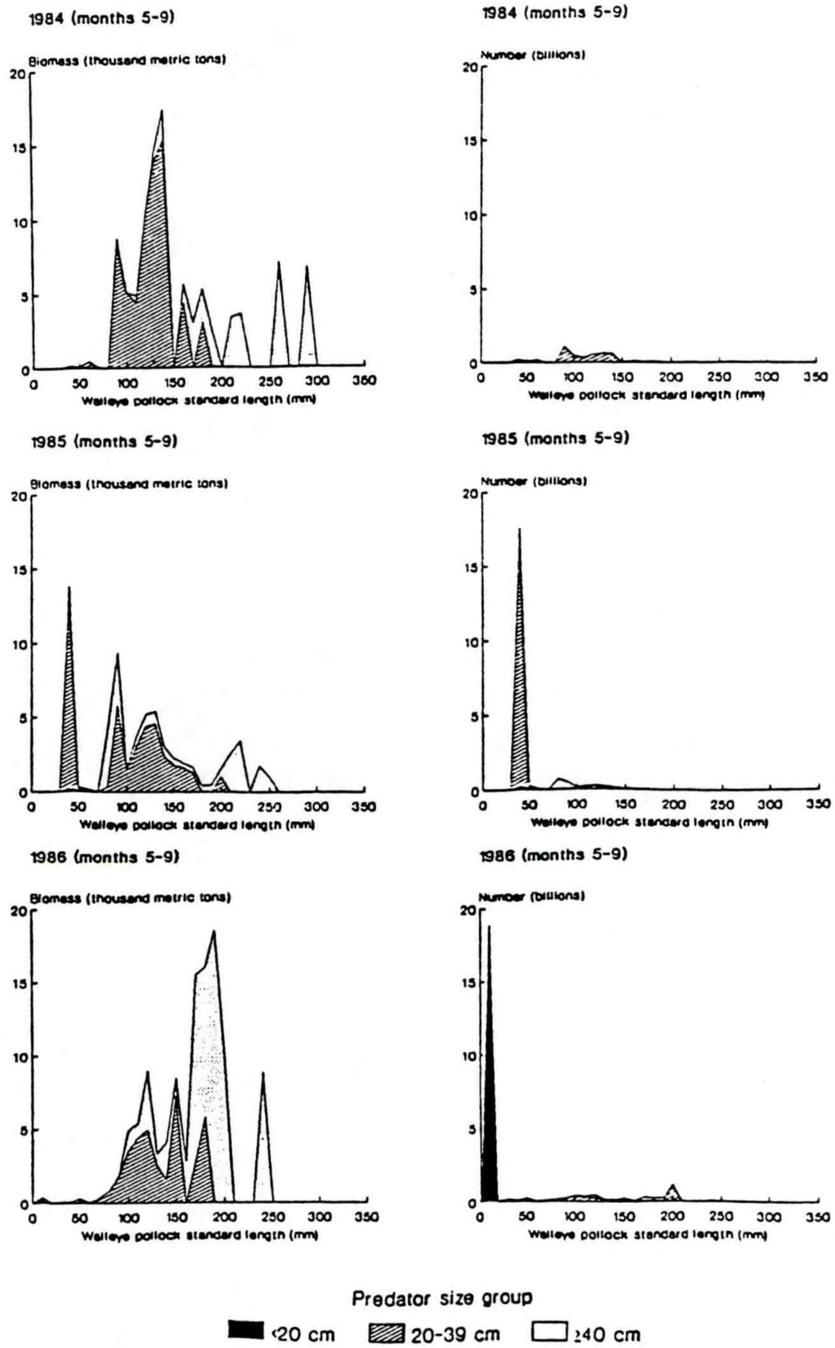


Figure 6.--Estimated biomass and numbers of walleye pollock consumed by three size groups of arrowtooth flounder in the eastern Bering Sea by year, 1984-86 (months 5 to 9).

Table 7.--Estimated biomass (metric tons) and numbers (millions) of miscellaneous commercial prey consumed by arrowtooth flounder (sampled in months 5-9) by prey item, predator size group, year, and stratum.

Prey	Pred. size (cm)	Year	Stratum	Biomass (metric tons)	Numbers (millions)
Pacific herring	≥40	1986	3	(1,470)*	(-)
		1986	5	2,382	7.2
Arrowtooth flounder	20-39	1985	6	(2)	(-)
	≥40	1984	3	2,484	46.4
		1986	5	(62)	(-)
Flathead sole	<20	1984	5	32	38.0
	≥40	1984	6	2,996	49.5
		1986	5	104	36.1
Chionoecetes bairdi	20-39	1984	6	(120)	(-)

* Parentheses indicate strata where prey size information was not available to convert biomass into numbers consumed.

flounder was underestimated by the trawl survey because of mesh selectivity or other reasons.

Arrowtooth flounder consumed an estimated 3,028 t of flathead sole (with size range 40-160 mm SL) in 1984. It is about 0.9% of the total flathead sole biomass based on the survey data (Walters and Wilderbuer 1990). Arrowtooth flounder also consumed 104 t of flathead sole in 1986 (about 0.03% of the total biomass). Because size compositions of the flathead sole consumed by arrowtooth flounder were not available, we do not know the exact impact of arrowtooth flounder predation on different size groups of flathead sole.

In 1984, there were an estimated 120 t (about 0.2% of the survey biomass) of Tanner crabs (C. bairdi) consumed by arrowtooth flounder. Size compositions of the Tanner crabs consumed by arrowtooth flounder were not available. This low biomass indicates that arrowtooth flounder have little affect on the mortality of Tanner and snow crabs.

CITATIONS

Bakkala, R. G., and T. K. Wilderbuer. 1990. Arrowtooth flounder. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 102-111. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Gotshall, D. W. 1969. Stomach contents of Pacific hake and arrowtooth flounder from northern California. Calif. Fish Game 55:75-82.

Sample, T. M., and T. K. Wilderbuer. 1990. Arrowtooth flounder. In Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1991. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Smith, R. L., A. C. Paulson, and J. R. Rose. 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. In Environmental assessment of the Alaskan continental shelf, Final rep., Biol. Stud. Vol. 1, p.33-107. U.S. Dep. Commer., NOAA, Environ. Res. Lab. Available Arctic Environ. Assess. Center, 222 W. 8th Ave., No.56, Anchorage, AK 99513.

Walters, G. E., and T. K. Wilderbuer. 1990. Other flatfish. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 123-139. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Wespestad, V. G., R. G. Bakkala, and P. Dawson. 1990. Walleye pollock. In Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Island region as projected for 1991. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Yang, M. S., and P. A. Livingston. 1986. Food habits and diet overlap of two congeneric species, Atheresthes stomias and Atheresthes evermanni, in the eastern Bering Sea. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 84:222-226.

FLATHEAD SOLE

by

Robert E. Pacunski

INTRODUCTION

Flathead sole, Hippoglossoides elassodon, is a small-sized member of the family Pleuronectidae and one of the most abundant flatfishes in the northeast Pacific Ocean. In the eastern Bering Sea, abundance is greatest over the middle and outer continental shelf and along the continental slope between bottom depths of 100 and 250 m (Allen and Smith 1989). In 1990, flathead sole (and the morphologically similar Bering flounder, Hippoglossoides robustus) comprised 12% of the eastern Bering Sea flatfish complex with an estimated biomass of 632,300 t (Walters and Wilderbuer 1990a). Generally taken as incidental bycatch in target fisheries on other groundfish species, flathead sole are of limited commercial importance, and no directed fishery exists for the species in the eastern Bering Sea. Flathead sole are benthopelagivores, feeding mainly on epibenthic invertebrates, pelagic crustaceans, and demersal fishes. In the Gulf of Alaska and eastern Bering Sea, feeding shifts from crustaceans to brittlestars as predator size increases (Smith et al. 1978; Pacunski 1990). Several commercially important fish and crab species, including walleye pollock (Theragra chalcogramma), Tanner crabs (Chionoecetes bairdi), and snow crabs (C. opilio), have been documented as prey of flathead sole in the eastern Bering Sea (Mito 1974; Livingston et al. 1986; Pacunski 1990).

GENERAL FOOD HABITS

Diet

A total of 5,361 flathead sole stomachs have been examined since 1984, of which 21.4% (1,145) have been empty. Stomach-content analysis of the remaining stomachs has revealed a variety of benthic and benthopelagic organisms in the diet (Table 1). Overall, brittlestars (family Ophiuridae) are the main food in terms of weight (37%) and are the dominant prey items by frequency of occurrence (43% FO). Walleye pollock and other fish accounted for 30% of the diet by weight and occurred in 20% of stomachs containing food. Decapod crustaceans, mainly shrimps (families Crangonidae and Pandalidae) and hermit crabs (family Paguridae), comprised 12% of the diet, and, as a group, were the second most common prey items (31% FO). Mysids and gammarid amphipods were also frequently consumed as prey (29% and 24% FO, respectively), but constituted only a small fraction of the diet by weight (<3%). This appears to be due to the importance of these small crustaceans as prey of flathead sole less than 20 cm

Table 1. Summary of the diet of flathead sole, *Hippoglossoides elassodon*, collected in the eastern Bering Sea from 1984 to 1988, in terms of percent frequency of occurrence, percent number, and percent total weight of diet.

Prey name	Freq. occur.	Number	Total weight
Polychaeta (worm)	17.46	1.15	2.25
Mollusca	0.71	0.03	0.03
Bivalve (clam)	7.04	0.89	2.67
Crustacean	10.18	1.92	0.08
Mysidacea Mysida (mysid)	19.47	6.70	1.87
Amphipoda (amphipod)	0.74	0.03	0.01
Gammaridea (amphipod)	23.43	4.14	0.87
Euphausiacea (euphausiid)	8.11	4.19	3.49
Decapoda (shrimp & crabs)	2.68	0.15	0.16
Caridea (shrimp)	6.26	0.51	0.66
Pandalidae (shrimp)	5.79	0.47	2.98
Crangonidae (shrimp)	16.32	1.56	5.14
Paguridae (hermit crab)	5.19	0.36	1.91
Chionoecetes sp.	1.92	1.51	1.09
Chionoecetes opilio (snow crab)	0.64	0.04	0.34
Chionoecetes bairdi (Tanner crab)	2.89	0.86	0.85
Chionoecetes hybrid (hybrid crab)	0.05	0.00	0.02
Echiura (marine worm)	3.56	0.78	1.40
Echinodermata (sea star, cucumber, urchin)	2.70	5.92	2.47
Ophiuroidae Ophiurida (brittle star)	42.81	66.68	36.69
Osteichthyes Teleostei (fish)	7.90	0.34	4.46
Gadidae (gadid fish)	0.36	0.02	0.57
Gadus macrocephalus (Pacific cod)	0.26	0.01	0.37
Theragra chalcogramma (walleye pollock)	7.83	0.52	21.77
Zoarcidae (eelpout)	0.40	0.02	0.14
Sebastes sp. (rockfish)	0.81	0.11	1.87
Cottidae (sculpin)	0.26	0.01	0.12
Agonidae (poacher)	0.09	0.00	0.02
Stichaeidae (prickleback)	0.43	0.02	0.54
Pleuronectidae (flatfish)	0.38	0.01	0.19
Hippoglossoides elassodon (flathead sole)	0.02	0.00	0.02
Lepidopsetta bilineata (rock sole)	0.19	0.01	0.21
Pleuronectes quadrituberculatus (Alaska plaice)	0.02	0.00	0.00
Reinhardtius hippoglossoides (Greenland turbot)	0.02	0.00	0.00
Fishery discards	1.14	0.04	3.62
Miscellaneous and unidentified prey	8.80	1.02	0.91

Total prey count	139,506
Total prey weight	9,687 g
Total number of stomachs with food	4,216
Total number of empty stomachs	1,145

in length (Pacunski 1990). Commercially important fish and crabs identified in stomach contents were walleye pollock, Pacific cod (Gadus macrocephalus), rock sole (Lepidopsetta bilineata), Tanner crab and snow crab. Of these, only walleye pollock made up a significant portion of the flathead sole diet.

Previous food habit studies confirm the benthopelagic feeding behavior of flathead sole in the eastern Bering Sea. In order of frequency, Mineva (1964) reported ophiuroids, shrimps, and amphipods as the main foods of flathead sole. Mito (1974) studied flathead sole along the continental slope and found brittlestars and shrimps to be the dominant prey items by weight. Pacunski (1990) found brittlestars, decapods, and amphipods to be the most common prey items, with brittlestars, fish (mainly walleye pollock), and decapods as the main foods by weight.

The food habits of flathead sole are consistent with the species morphology. Flathead sole possess a large, nearly symmetrical mouth, with a row of well-developed teeth in each jaw (Allen 1984). The stomach is medium-sized and the intestinal loop is of moderate length and complication (DeGroot 1971; Allen 1984). These characteristics are typical of flatfish that feed on benthopelagic prey (DeGroot 1971). Moiseev (1953) concluded that a large mouth was advantageous for capturing large mobile prey items, and Allen (1984) found that flatfish with large, nearly symmetrical mouths feed primarily on benthic and nektonic benthopelagic prey. Based on digestive tract morphology, Moiseev (1953) characterized the genus Hippoglossoides as fish of mixed feeding habits, consuming both benthic and pelagic prey.

The foraging behavior of flathead sole can be inferred from its morphology and the types of prey consumed. The large eyes with an upwardly directed field of vision indicates that flathead sole are primarily visual feeders (Miller 1970; Allen 1984). This condition appears to be advantageous for detecting and capturing nektobenthic prey in the water column. Consumption of highly mobile prey items (e.g., fish and shrimp) implies the use of ambush or pursuit for capturing prey. The presence of sedentary benthic organisms in the diet (e.g., brittlestars) suggests that flathead sole also utilize a searcher-grazer feeding strategy. Based on similar food habits results, Allen (1984) concluded that these were the primary foraging behaviors of flathead sole in the eastern Bering Sea.

Seasonal and Annual Changes in the Diet

To facilitate seasonal and annual description of the diet, prey items were grouped into eight major food categories. Seasonal variation occurred in the diet of the four predator length groups examined (Fig. 1). In winter, the diet of small flathead sole (<20 cm) was composed almost entirely of mysids and brittlestars. Other decapods (i.e., decapods other than Tanner and snow crabs), mysids, and miscellaneous prey were the main foods of fish in the 20-29 cm length group, while the largest fish (≥30 cm) consumed mainly walleye pollock and miscellaneous prey in winter.

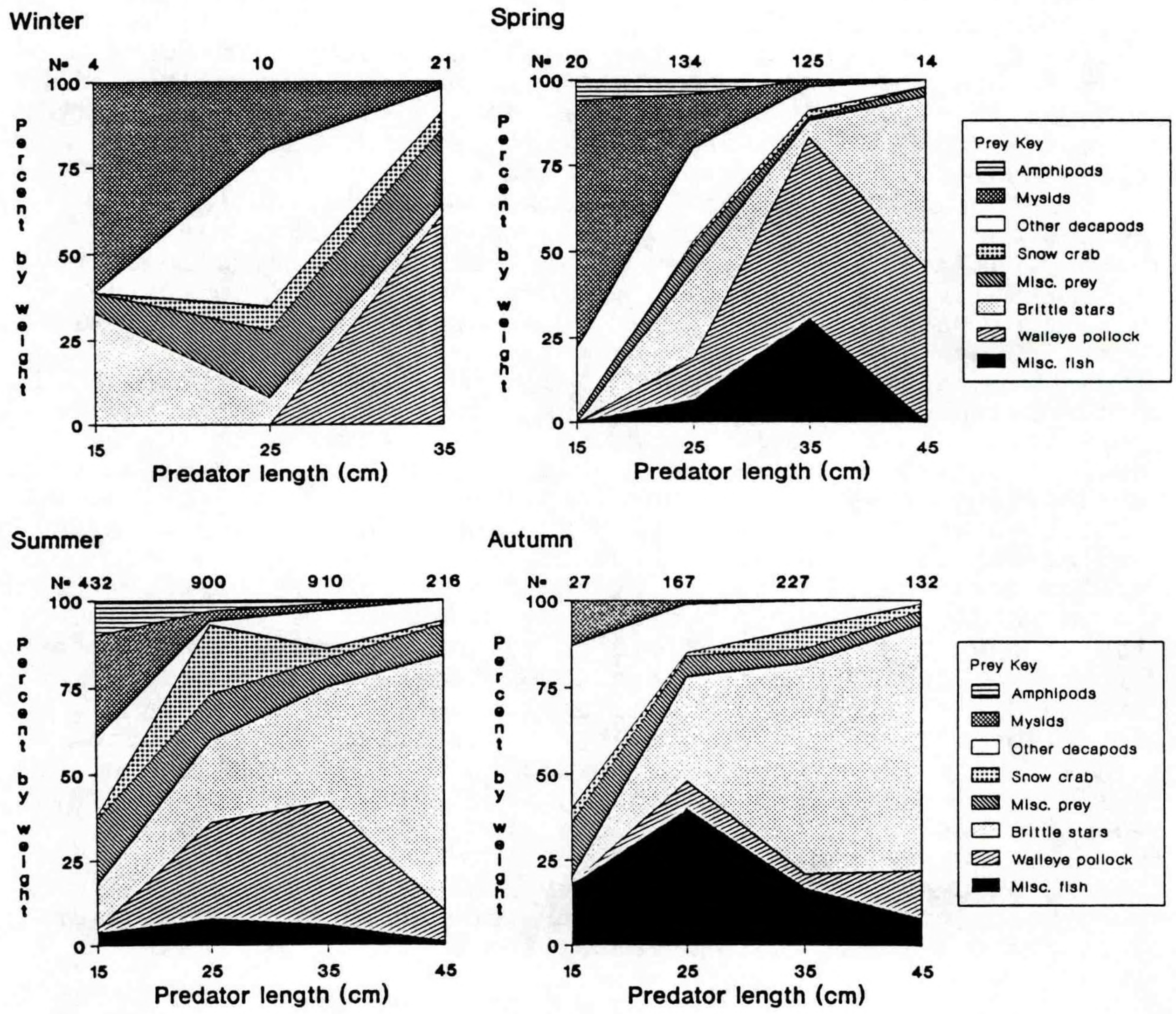


Figure 1.--Diet composition of flathead sole in the eastern Bering Sea, in terms of percent weight, by season and predator size (fork length).

Mysids dominated the diet of flathead sole less then 20 cm in spring, although other decapods were of moderate importance. The diet of flathead sole in the 20-29 cm length group included brittlestars, mysids, other decapods, and fish. Fish were the dominant prey of flathead sole 30-39 cm in length, while the diet of large fish ($\geq$40 cm) consisted almost exclusively of walleye pollock and brittlestars.

The summer diet of small flathead sole (<20 cm) consisted of mysids, other decapods, miscellaneous prey, and amphipods. Walleye pollock, brittlestars, snow crabs, and Tanner crabs were the major prey items of flathead sole 20-29 cm in length. The diet of fish in the 30-39 cm length group was composed primarily of walleye pollock and brittlestars. Large flathead sole ate mostly brittlestars in summer but also consumed a small amount of walleye pollock.

Other decapods were the most important prey of small flathead sole in autumn, followed by miscellaneous fish, miscellaneous prey, and amphipods. Miscellaneous fish, brittlestars, and other decapods were the main foods of fish 20-29 cm in length. The diet of flathead sole in the 30-39 cm length group was composed mainly of brittlestars, although miscellaneous fish were also of some importance. Brittlestars were the most important prey of large flathead sole in autumn, with small amounts of walleye pollock and miscellaneous fish also being consumed.

Based on data from stomachs collected during months 5 to 9, the basic diet of flathead sole was found to be rather similar in all years, although all prey types showed varying degrees of interannual variation (Fig. 2). Amphipods, mysids, and shrimp made up the majority of the diet of small flathead sole (<20 cm) in all 3 years. Equal proportions of these organisms were consumed in 1984, with mysids being dominant in 1985 and shrimps in 1986. Brittlestars were of limited importance to small fish except in 1986. The diet of flathead sole in the 20-29 cm length group was composed mainly of brittlestars, other decapods, and fish. Walleye pollock and brittlestars were the dominant prey items of flathead sole 30-39 cm in all years, with walleye pollock consumption being greatest in 1985. Brittlestars were the main food of large flathead sole in all years.

Moiseev (1953) concluded that seasonal changes in diet composition are the result of differences in prey assemblages encountered by the fish as they pass between feeding zones during their spring and fall migrations. Pacunski (1990) suggested that seasonal differences in the diet may be the result of variations in prey distribution and abundance combined with an uneven sampling distribution between seasons. In the present study, sample sizes in winter, spring, and autumn were small and may not accurately reflect the food habits of flathead sole in these seasons, making comparisons of the food habits between seasons difficult. Annual changes in the diet of each size group were relatively limited, suggesting that prey resources utilized by flathead sole remain fairly stable over time.

Size-related trends in prey consumption were seen both seasonally and annually. In all seasons and years, predation on crustaceans was greatest by small flathead sole, then decreased

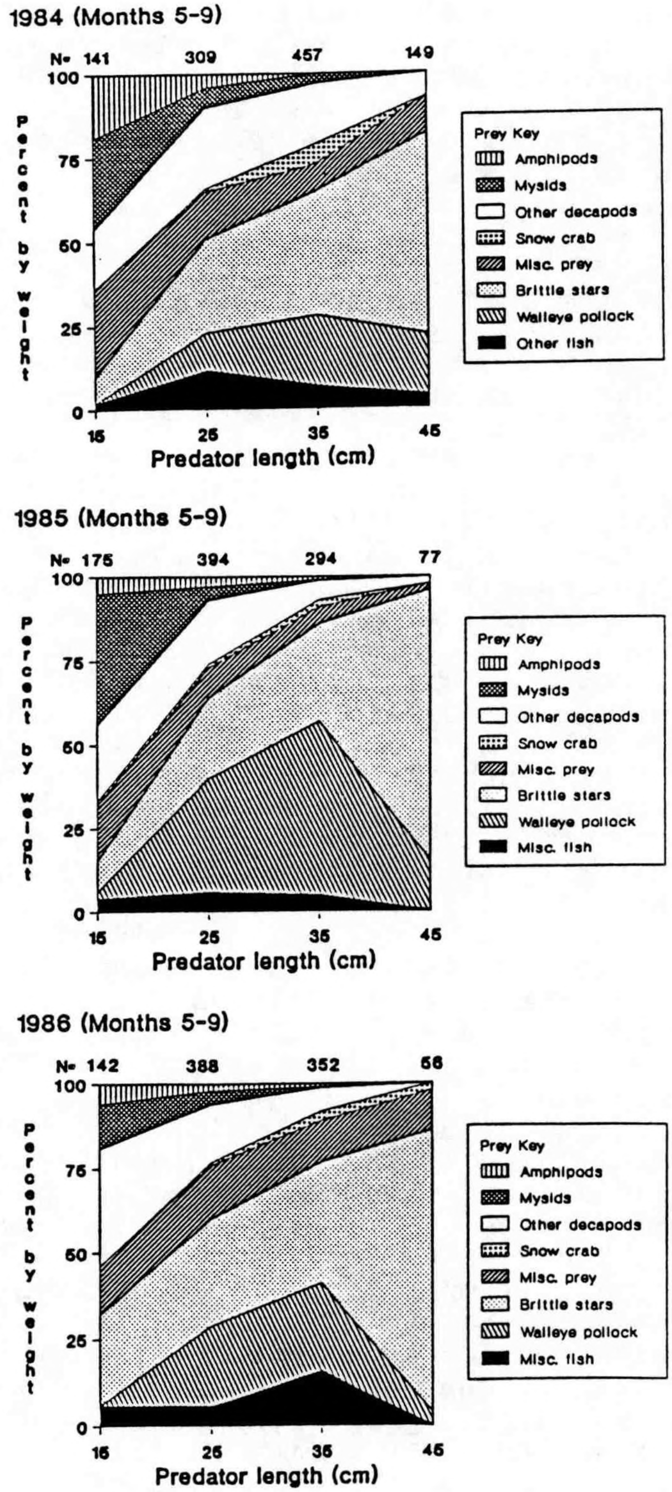


Figure 2.--Diet composition of flathead sole in the eastern Bering Sea, in terms of percent weight, during months 5 to 9, by predator size (fork length) and year. (N = sample size)

substantially as predator size increased. In summer and autumn, and in all years, brittlestars increased in importance with predator size, and dominated the diet of the largest flathead sole. The ontogenetic shift in gross feeding habits from crustaceans to brittlestars appears to involve a transition from an active to a more sedentary existence (Pacunski 1990); however, the factors controlling this shift are unclear.

Sizes of Commercially Important Prey Consumed

In general, the size range of commercially important fish and crabs consumed by flathead sole increased with predator size (Fig. 3). Significant predator-prey size relationships were seen for Pacific cod ($p = 0.026$) and Tanner crab ($p < 0.001$) but not for walleye pollock ($p = 0.068$) or snow crab ($p=0.254$). The r-squared values were rather low in all cases. Although the maximum size of prey increased with predator size, smaller sized prey were also consumed, suggesting that predation of these organisms is not prey-size selective.

The majority of walleye pollock consumed in all years were less than or equal to 100 mm standard length (SL) (Fig. 4), while all Pacific cod consumed were less than 100 mm SL (Fig. 5). The size range of prey walleye pollock and Pacific cod indicates that predation occurs mainly on age-0 and small age-1 fish. Sampled flathead sole consumed one 40 mm SL (age-0) rock sole in 1984 and one 70 mm SL (age-1) rock sole in 1985. Predation on Tanner and snow crabs in all years was greatest on crabs of around 15 mm carapace width (CW) or less (Figs. 6 and 7), which corresponds to age-1 and younger crabs (Adams 1979, Donaldson et al. 1980).

Interannual differences in the size-frequency distribution of prey walleye pollock were apparent (Fig. 4). A large mode of age-0 walleye pollock is seen in 1984 and then again as age-1 fish in 1985. Following the large mode of age-1 fish in 1985 is a smaller mode of age-0 fish. In 1986, age-0 fish from the previous year appear as age-1 fish, followed by a small mode of age-0 fish. This pattern strongly resembles changes in walleye pollock year-class strength reported for these years. Wespestad et al. (1990) report a strong year class of walleye pollock spawned in 1984, followed by successively smaller year classes in 1985 and 1986. Although other factors may be relevant, the available data suggest that flathead sole predation of walleye pollock may be a function of prey year-class size.

The emphasis on predation of age-0 and small age-1 walleye pollock and Pacific cod implies that flathead sole cannot capture fish beyond a certain size. Two of the most likely factors controlling flathead sole predation of juvenile gadids are 1) a limited mouth size relative to prey size, and 2) an increased predator avoidance response by juveniles as a result of development.

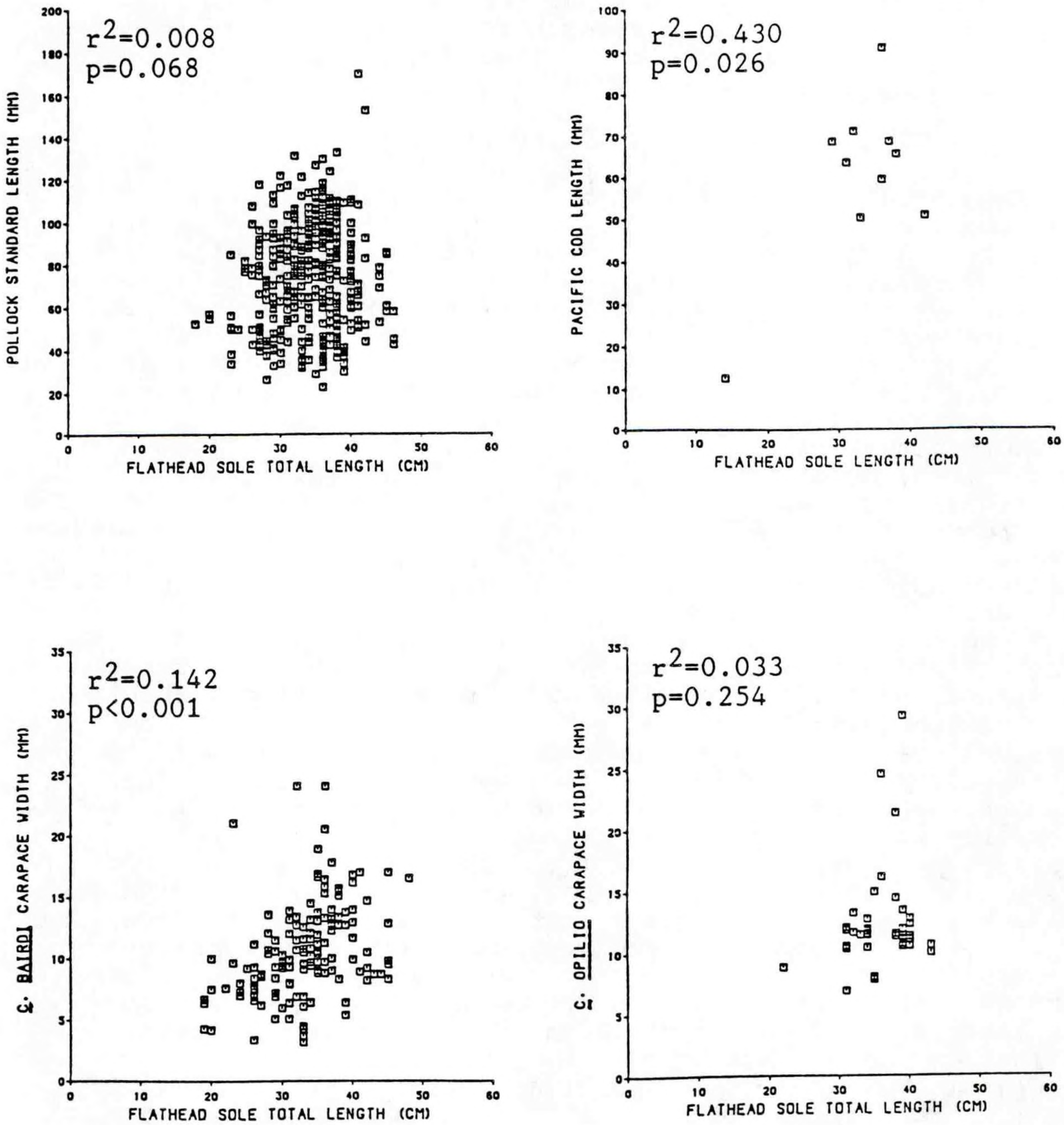


Figure 3.--Scatterplot of predator flathead sole fork length (cm) versus prey walleye pollock standard length (mm), Pacific cod standard length (mm), Tanner crab carapace width (mm) and snow crab carapace width (mm).

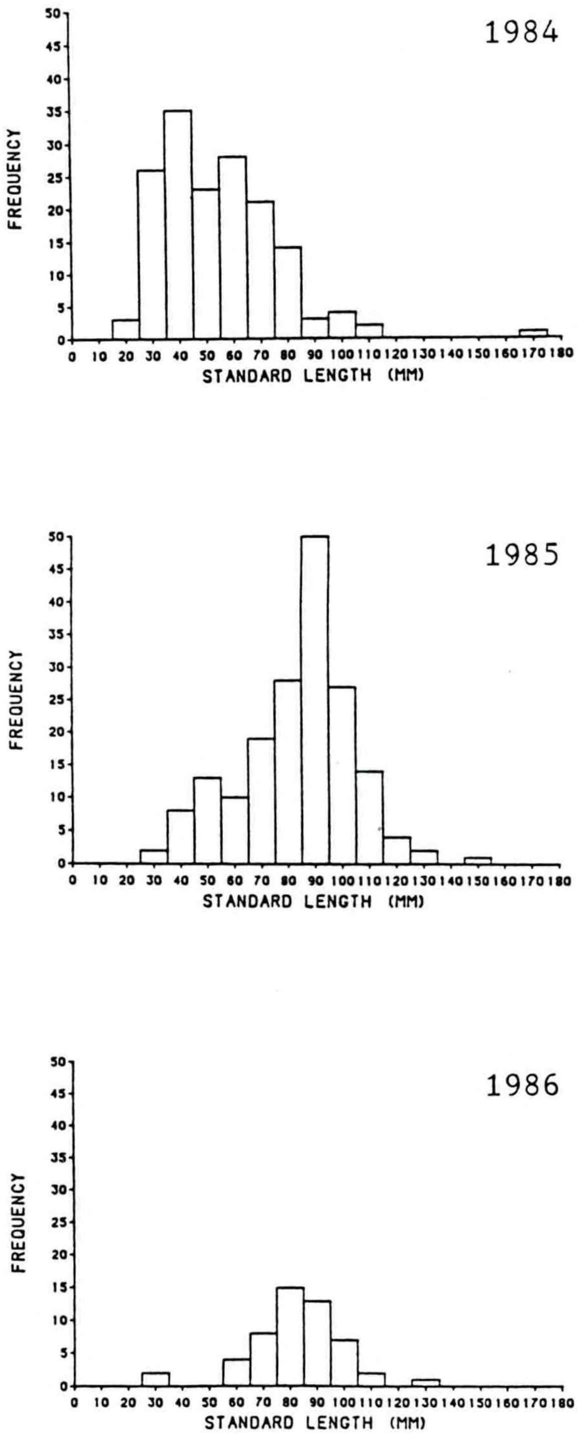
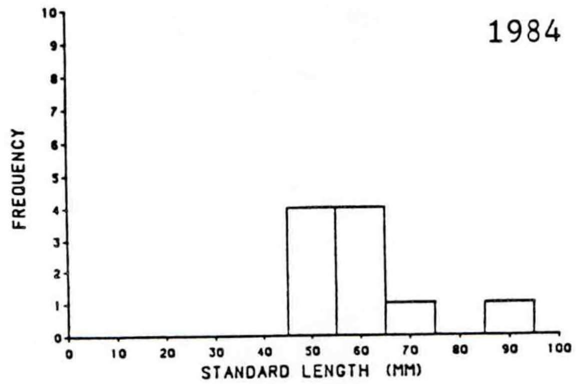


Figure 4.--Size frequency distribution of prey walleye pollock consumed by flathead sole during months 5 to 9, by year.



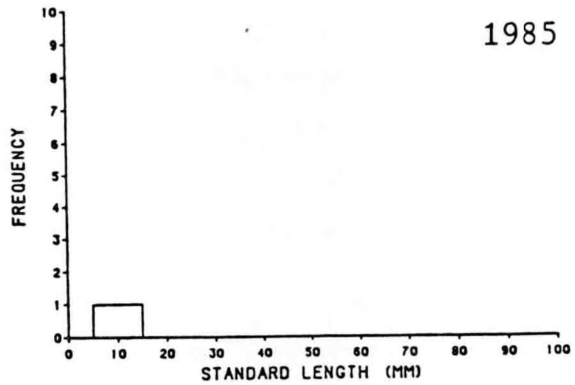


Figure 5.--Size frequency distribution of prey Pacific cod consumed by flathead sole during months 5 to 9, by year.

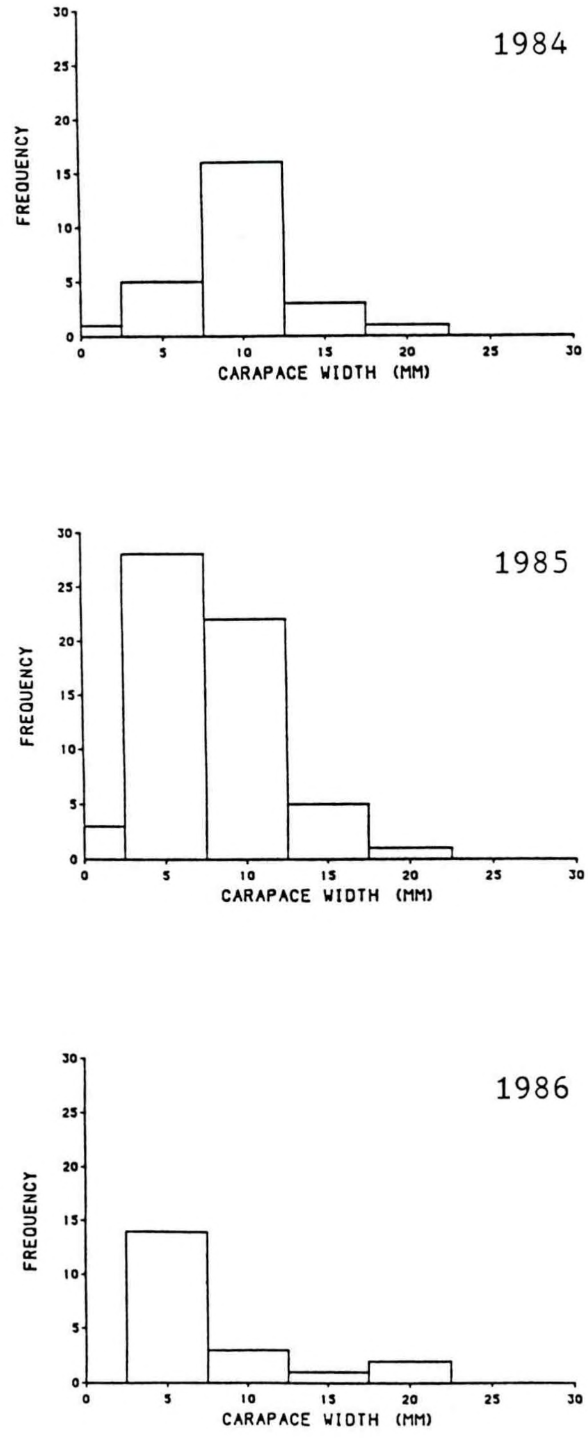


Figure 6.--Size frequency distribution of prey Tanner crab consumed by flathead sole during months 5 to 9, by year.

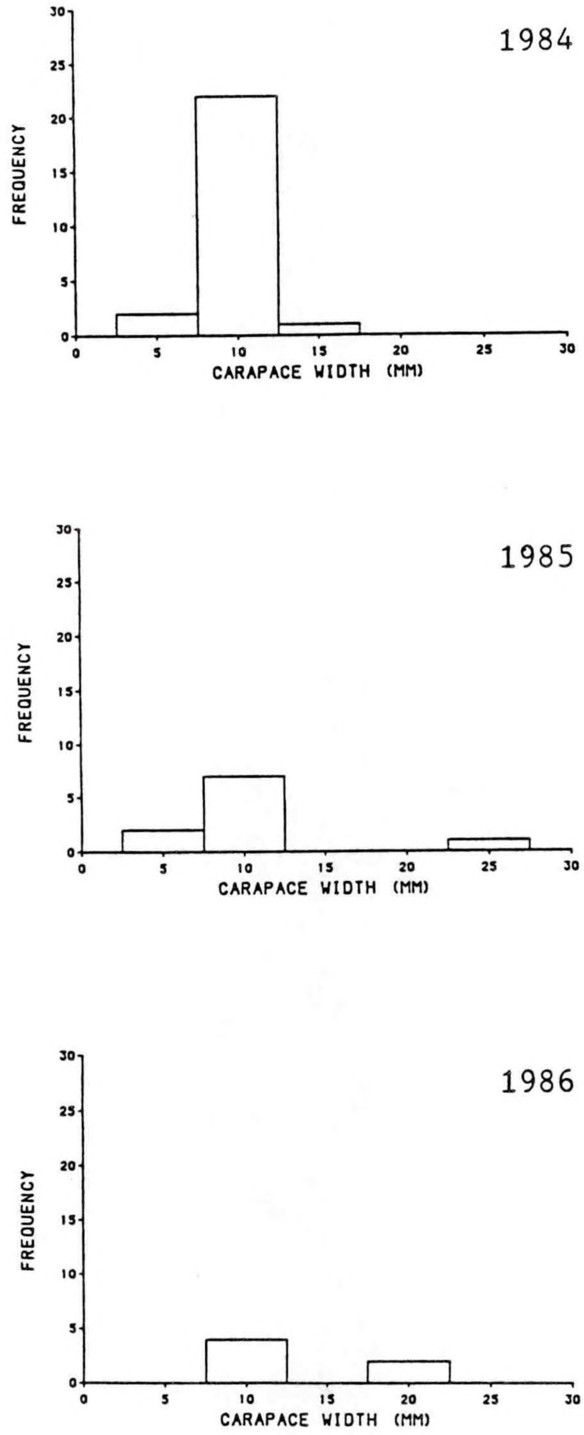


Figure 7.--Size frequency distribution of prey snow crab consumed by flathead sole during months 5 to 9, by year.

PREDATOR POPULATION CONSUMPTION OF COMMERCIALLY IMPORTANT PREY

Geographic Trends in Consumption

In 1984, walleye pollock made up a large portion of the diet (by weight) of flathead sole collected from the southeastern inner (≤50 m depth) and middle (51-100 m depth) continental shelf areas, and along the 100 m isobath northwest of the Pribilof Islands (Fig. 8). Walleye pollock consumption in 1985 was greatest over the middle and outer (101-200 m depth) shelf areas north and northwest of the Pribilof Islands, although walleye pollock also made up a large portion of the diet of fish collected at three stations in the southeastern middle shelf area. In 1986, walleye pollock were consumed over the middle and inner shelf areas east of the Pribilof Islands, and over the middle and outer shelf areas northwest of the Pribilofs. The locations of walleye pollock consumption in 1984 and 1985 appear to correspond to areas of relatively high age-0 walleye pollock densities as determined by hydroacoustic surveys (Walters et al. 1988), although in both years walleye pollock made up a significant portion of the diet of some flathead sole collected in areas of low pollock density. A similar comparison could not be made for 1986 since no hydroacoustic data were available.

In 1984, consumption of Pacific cod was centered primarily around the 50 m isobath in the southeastern part of the continental shelf in the inner and middle shelf areas, but also occurred at one location due west of St. George Island near the 200 m isobath (Fig. 9). In 1985, Pacific cod were only consumed at one station northwest of St. Paul Island over the middle shelf area (lat. 58°20'N, long. 171°01'W), but made up less than 1% of the diet of flathead sole collected at this location. A single occurrence of rock sole predation was observed near the 50 m isobath in 1984 at 57°35'N lat. 162°24'W long., and in 1985 at 57°40'N lat. 160°15'W long (Fig. 10).

In 1984, predation on Tanner crabs occurred over the inner shelf area (lat. 57°30'N), the southeastern middle shelf area north of Unimak Island (lat. 55°20'N), and along the 100 m isobath northwest of the Pribilof Islands (Fig. 11). In 1985, Tanner crabs were only found in the diet of flathead sole collected west and northwest of the Pribilof Islands, while predation in 1986 occurred at a few stations southeast and northwest of the Pribilof Islands. Consumption of snow crabs was greatest in 1984, with predation centered near the Pribilof Islands (Fig. 12). In 1985 and 1986, predation on snow crabs was low, occurring primarily northwest of the Pribilof Islands.

In all years, the locations of flathead sole predation on Tanner and snow crabs showed little geographical overlap, except near the Pribilof Islands. Livingston (1989) reported similar results for Pacific cod feeding on Tanner and snow crab in 1981, 1984, and 1985, and suggested that bottom temperature was the main factor controlling the geographic distribution of juvenile snow crab in the eastern Bering Sea.

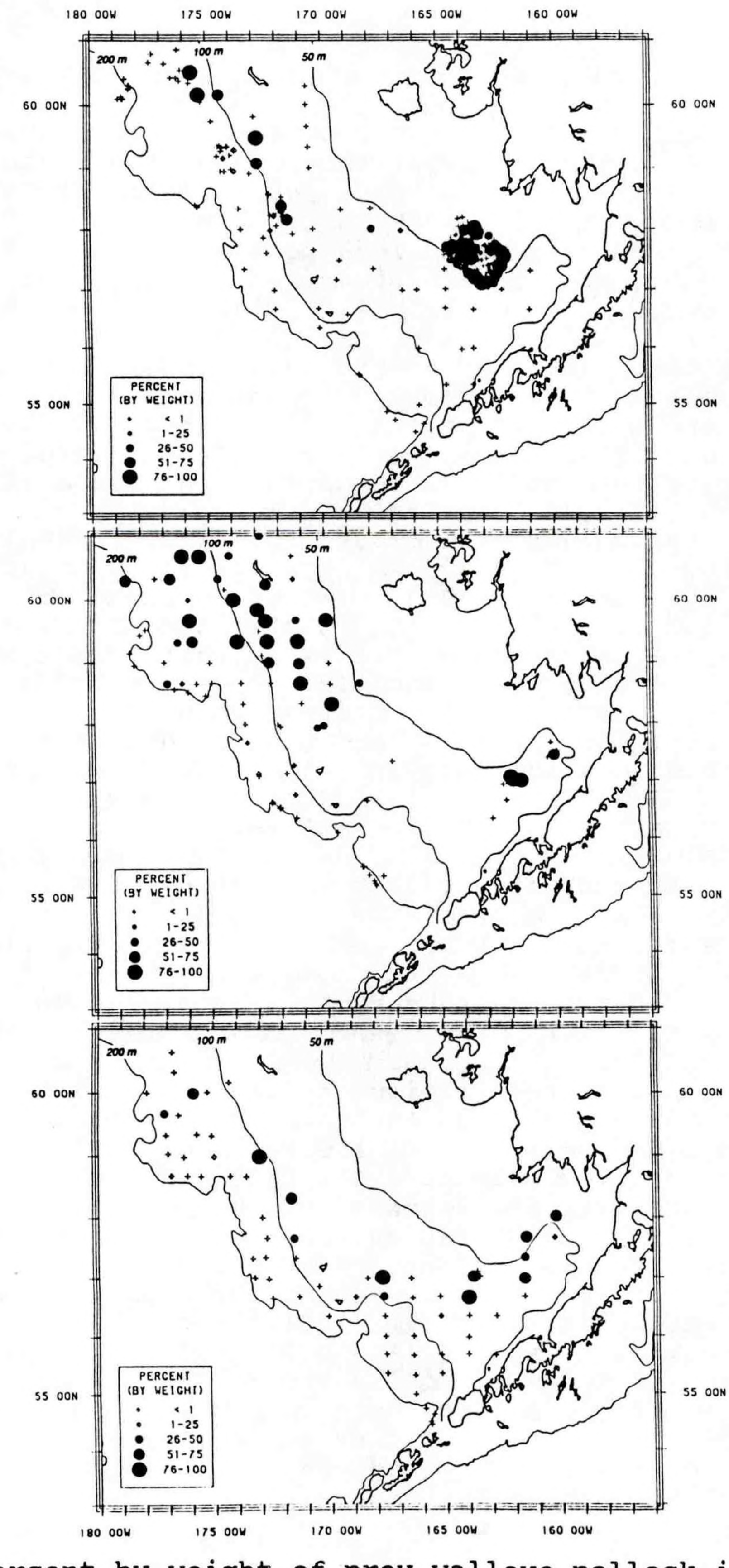


Figure 8.--Percent by weight of prey walleye pollock in the diet of flathead sole, months 5-9, by geographic location and year.

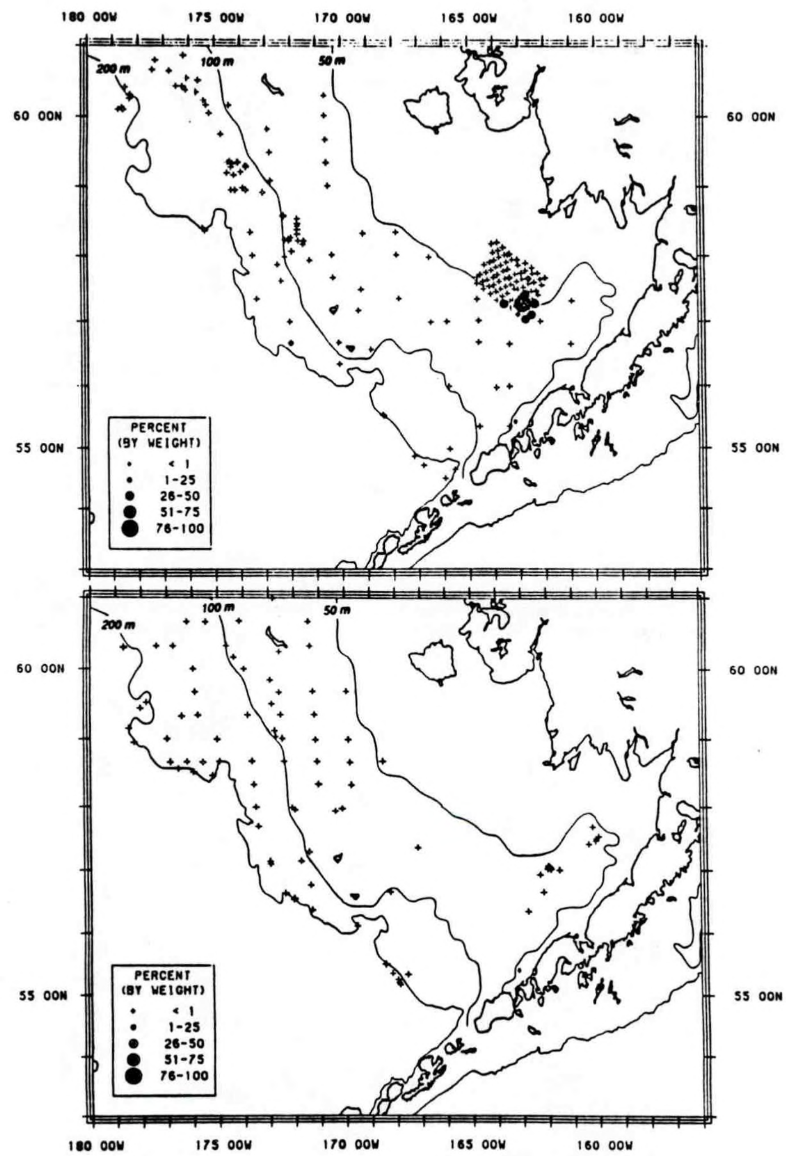


Figure 9.--Percent by weight of prey Pacific cod in the diet of flathead sole, months 5-9, by geographic location and year.

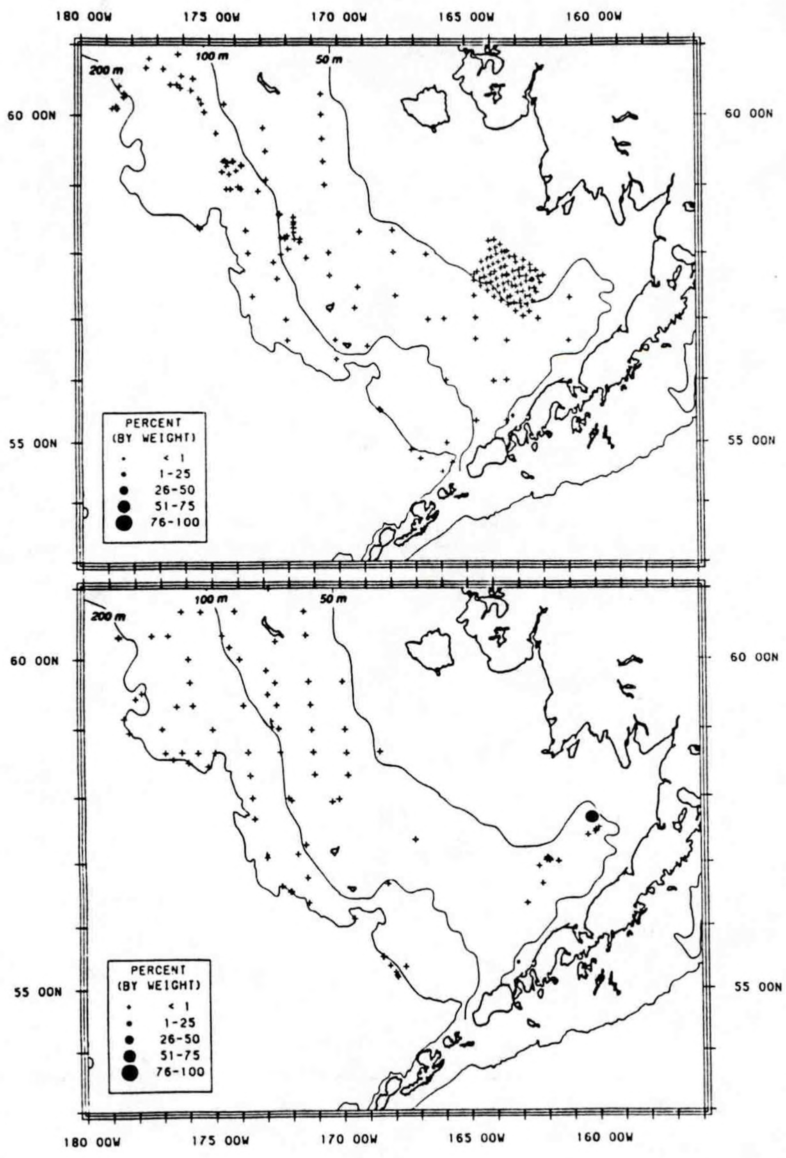


Figure 10.--Percent by weight of prey rock sole in the diet of flathead sole, months 5-9, by geographic location and year.

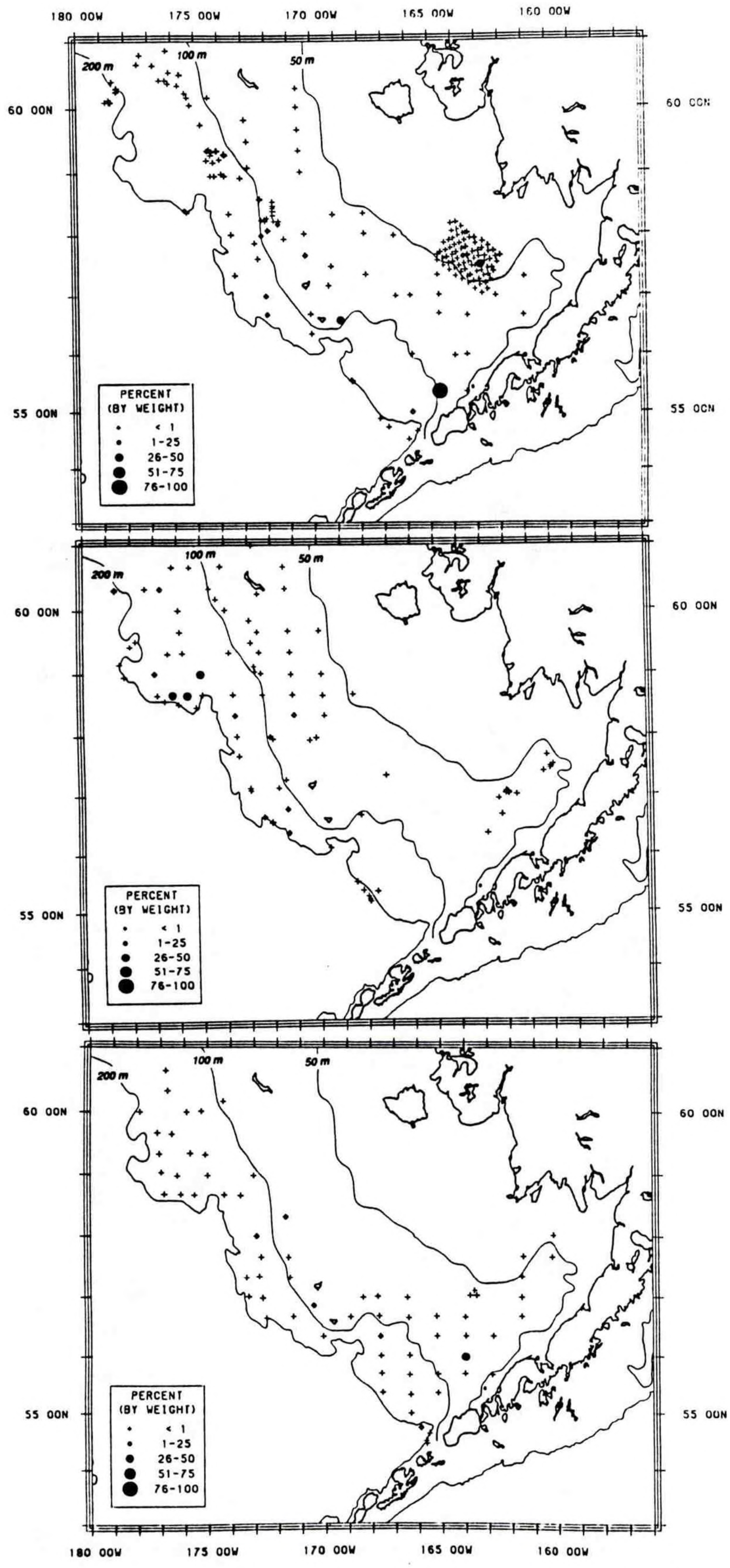


Figure 11.--Percent by weight of prey Tanner crab in the diet of flathead sole, months 5-9, by geographic location and year.

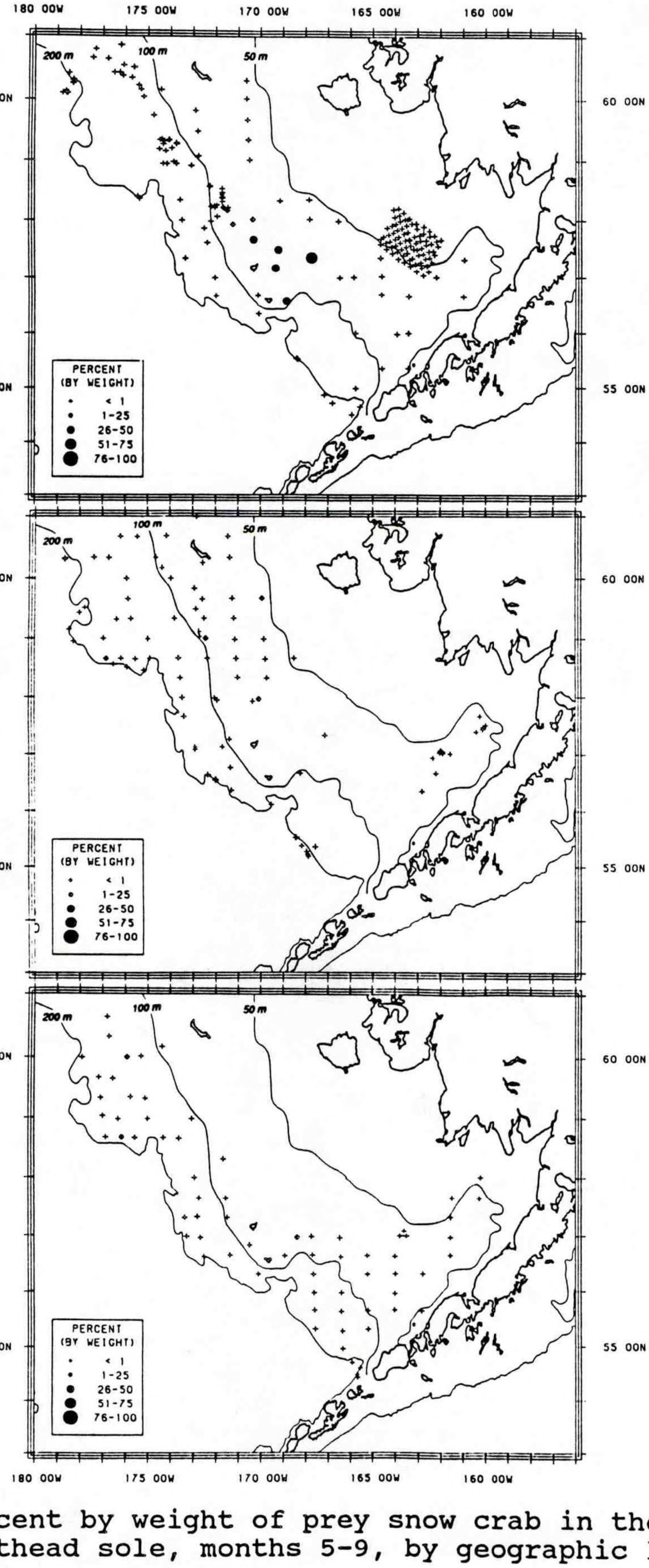


Figure 12.--Percent by weight of prey snow crab in the diet of flathead sole, months 5-9, by geographic location and year.

No geographic trends in the predation of commercially important fish and crabs were apparent. The rather inconsistent pattern of sampling between years might explain some of the variablility in prey consumption between years. In areas that received similar sampling coverage between years, changes in the amount of predation may be the result of annual fluctuations in prey distribution and abundance. However, without accurate information concerning the distribution patterns and abundance of juvenile fish and crabs in the eastern Bering Sea, the mechanisms controlling flathead sole predation on these species remain poorly understood.

Total Consumption Parameters

Parameters used to estimate the total population consumption (see Equation 1 in the Methods section of this report) of commercially important species by flathead sole during the main feeding period (months 5-9) are presented in Tables 2-7. Biomass estimates for flathead sole by stratum and year (Table 2) were derived from RACE groundfish surveys.

The daily ration estimate as a fraction of body weight daily (BWD) was 0.007.

Considerable variation was seen in the mean percent weight of walleye pollock in the flathead sole diet between strata and years (Table 3). In 1984, walleye pollock made up nearly 40% of the diet of flathead sole collected in stratum 1 and between 7% and 11% of the diet in strata 3, 4, and 6 (see Fig. 1 in the Methods section of this report for strata locations). In 1985, walleye pollock accounted for nearly 50% of the diet in strata 2 and 4, over 30% in stratum 3, and over 20% in stratum 6. Walleye pollock made up almost 40% of the diet of flathead sole collected from stratum 1 in 1986, and around 20% of the diet of flathead sole in strata 3 and 4. Stratum 5 was the only area in all 3 years where predation on walleye pollock was not observed.

Table 2.--Biomass estimates (metric tons) of flathead sole in the eastern Bering Sea by strata and year.

Stratum	Biomass		
	1984	1985	1986
1	17,827	12,356	14,652
2	2,043	799	1,000
3	108,655	111,816	127,595
4	40,527	49,139	30,724
5	80,764	52,000	69,575
6	94,976	106,808	125,807
Total	344,792	332,918	369,352

Table 3.--Mean percent weight (%W) and standard error (SE) of walleye pollock, Theragra chalcogramma, in the diet of flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken; * = no standard error estimate since sampling occurred at only one station.)

Stratum	1984		1985		1986	
	%W	SE	%W	SE	%W	SE
1	38.85	6.62	-	-	38.82	19.49
2	-	-	46.09	*	-	-
3	7.40	3.88	31.57	15.18	19.78	6.40
4	10.61	5.35	45.63	8.46	22.06	13.68
5	0	0	0	0	0	0
6	9.52	4.21	20.99	5.48	7.11	4.15

Other commercially important prey of flathead sole were Pacific cod, rock sole, Tanner crab, and snow crab; however, these species never formed a consistent or large portion of the diet. Predation on Pacific cod was observed in strata 1, 3, and 6 in 1984, and only in stratum 4 in 1985 (Table 4). Rock sole occurred in the diet of sampled flathead sole in stratum 1 in 1984 and stratum 3 in 1985 (Table 5).

Table 4.--Mean percent weight (%W) and standard error (SE) of Pacific cod, Gadus macrocephalus, in the diet of flathead sole in the eastern Bering Sea during months 5 to 9, by strata and year. (- = no samples taken.)

Stratum	1984		1985		1986	
	%W	SE	%W	SE	%W	SE
1	3.90	1.87	-	-	0	0
2	-	-	0	0	-	-
3	1.78	1.78	0	0	0	0
4	0	0	0.01	0.01	0	0
5	0	0	0	0	0	0
6	0.64	0.58	0	0	0	0

Table 5.--Mean percent weight (%W) and standard error (SE) of rock sole, Lepidopsetta bilineata, in the diet of flathead sole in the eastern Bering Sea during months 5 to 9, by strata and year. (- = no samples taken.)

Stratum	1984		1985		1986	
	%W	SE	%W	SE	%W	SE
1	0.14	0.14	-	-	0	0
2	-	-	0	0	-	-
3	0	0	3.26	3.26	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0

Tanner crabs were consumed by flathead sole in all areas except stratum 2 in 1984, with consumption being greatest in strata 3 and 5 (Table 6). In 1985, Tanner crabs were consumed only in strata 4 and 6, and in strata 3, 4, 5, and 6 in 1986.

Snow crab consumption was highest in 1984, but was only recorded in strata 3 and 4 (Table 7). Snow crab occurred in the diet of flathead sole collected in strata 4 and 6 in 1985, and in strata 3 and 6 in 1986, but made up less than 1% of the diet in these areas in both years.

Table 6.--Mean percent weight (%W) and standard error (SE) of Tanner crab, Chionoecetes bairdi, in the diet of flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken.)

Stratum	1984		1985		1986	
	%W	SE	%W	SE	%W	SE
1	0.22	0.16	-	-	0	0
2	-	-	0	0	-	-
3	5.56	4.35	0	0	1.69	1.68
4	0.80	0.66	0.66	0.66	1.93	1.47
5	5.45	5.45	0	0	0.12	0.12
6	0.71	0.38	3.80	1.45	0.18	0.15

Table 7.--Mean percent weight (%W) and standard error (SE) of snow crab, Chionoecetes opilio, in the diet of flathead sole in the eastern Bering Sea during months 5 to 9, by strata and year. (- = no samples taken.)

Stratum	1984		1985		1986	
	%W	SE	%W	SE	%W	SE
1	0	0	-	-	0	0
2	-	-	0	0	-	-
3	4.30	3.09	0	0	0.32	0.32
4	6.45	2.90	0.27	0.20	0	0
5	0	0	0	0	0	0
6	0	0	0.58	0.58	0.64	0.45

As discussed in the previous section, the lack of any geographical trends in predation may be due to the uneven sampling distribution between years. Differences in the percent weight of commercially important prey consumed between years and strata may reflect variations in prey abundance and distribution, although small sample sizes may also have affected the results.

Total Consumption Estimates

Commercially Important Fish

The total estimated biomass of walleye pollock consumed by flathead sole in 1985 (86,329 t) was substantially higher than consumption estimates for 1984 (29,299 t) and 1986 (49,928 t) (Table 8, Fig. 13), a direct result of the greater proportion of these fish in the diet in 1985. Although the estimated biomass of walleye pollock consumed was lowest in 1984, the estimate of total numbers consumed (9.9 billion) was greater than in 1985 (9.6 billion) and 1986 (7.1 billion) (Table 9) due to the smaller sizes of prey walleye pollock eaten in that year (see Fig. 4).

Table 8.--Estimated biomass of walleye pollock, *Theragra chalcogramma*, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken; numbers in parentheses indicate years-strata where prey numbers could not be calculated.)

Stratum	Biomass (metric tons) 1984	1985	1986
1	7,322.0	-	6,055.0
2	-	(394.4)	-
3	8,613.0	37,803.3	27,032.9
4	4,606.3	24,117.6	7,258.5
5	0	0	0
6	9,687.2	24,013.3	9,581.8
Total	30,228.5	86,328.6	49,928.2

Table 9.--Estimated numbers of walleye pollock, *Theragra chalcogramma*, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken; * = no prey size information was available for calculating prey numbers.)

Stratum	Numbers (millions) 1984	1985	1986
1	3,605.0	-	967.1
2	-	*	-
3	2,864.6	4,086.0	4,178.5
4	1,496.5	3,361.3	524.1
5	0	0	0
6	1,890.0	2,108.6	1,408.4
Total	9,856.1	9,555.9	7,078.1

Flathead sole consumption of Pacific cod was estimated at nearly 3,500 t in 1984 and 8 t in 1985 (Table 10, Fig. 14). About 1.1 billion and 308 million Pacific cod were estimated to have been consumed in 1984 and 1985, respectively. The greater ratio of numbers to biomass consumed in 1985 reflects the smaller size of prey Pacific cod utilized by flathead sole in that year.

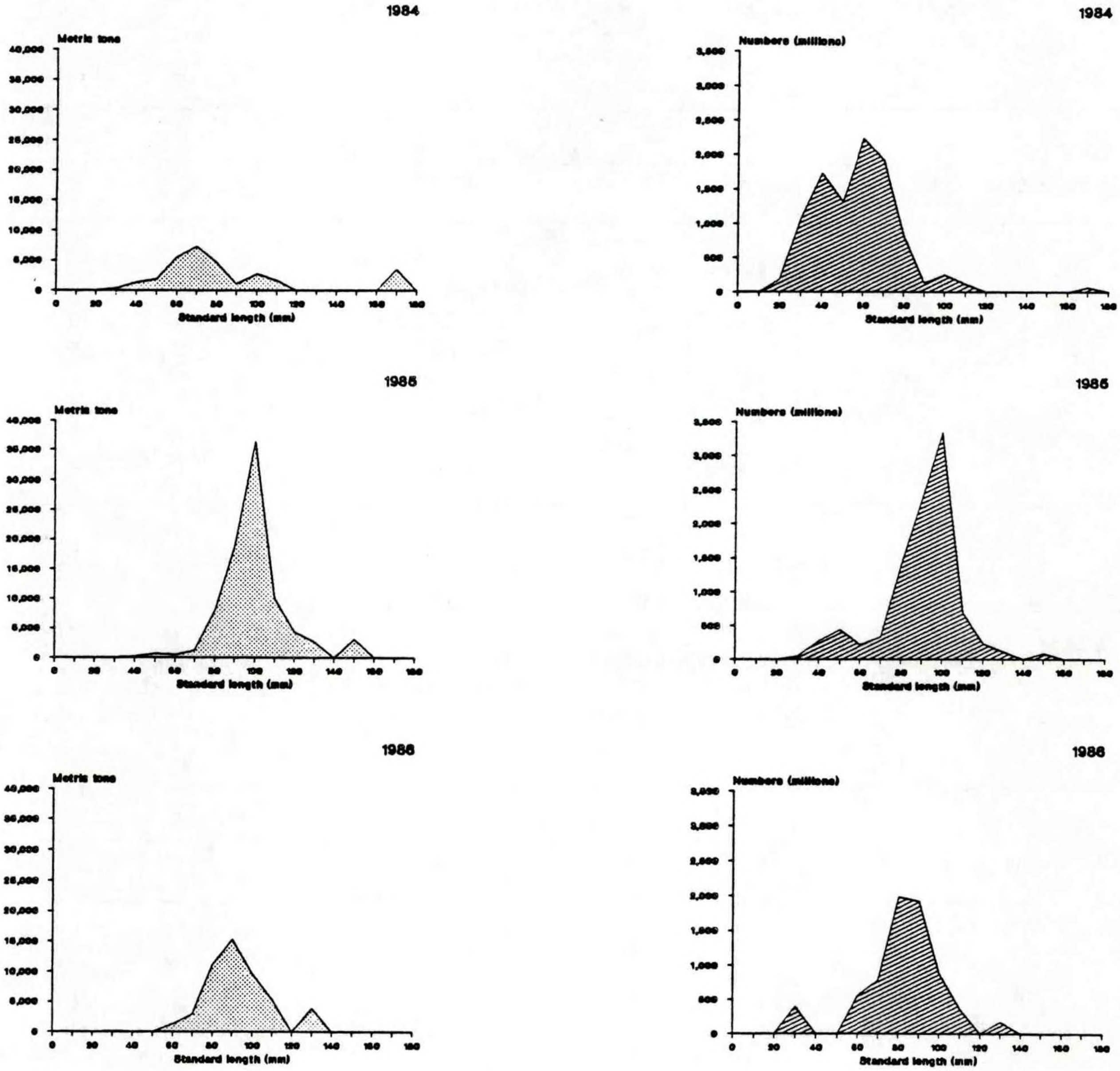


Figure 13.--Estimated biomass (metric tons) and number of walleye pollock consumed by flathead sole during months 5-9 in the eastern Bering Sea by prey size and year.

Table 10.--Estimated biomass of Pacific cod, Gadus macrocephalus, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken.)

Stratum	Biomass (metric tons)		
	1984	1985	1986
1	744.7	-	0
2	-	0	-
3	2,071.0	0	0
4	0	7.7	0
5	0	0	0
6	647.0	0	0
Total	3,462.7	7.7	0

Table 11.--Estimated numbers of Pacific cod, Gadus macrocephalus, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken.)

Stratum	Numbers (millions)		
	1984	1985	1986
1	242.1	-	0
2	-	0	-
3	469.2	0	0
4	0	308.3	0
5	0	0	0
6	409.1	0	0
Total	1,120.4	308.3	0

Approximately 27 t and 3,900 t of rock sole were estimated to have been consumed by flathead sole during 1984 and 1985, respectively (Table 12, Fig. 15). Although the biomass of rock sole consumed by flathead sole in 1985 was over 140 times the amount consumed in 1984, the estimated number of rock sole consumed in 1985 (592 million) was only about 30 times the amount estimated for 1984 (21 million) (Table 13) due to the smaller size of prey rock sole consumed in 1984.

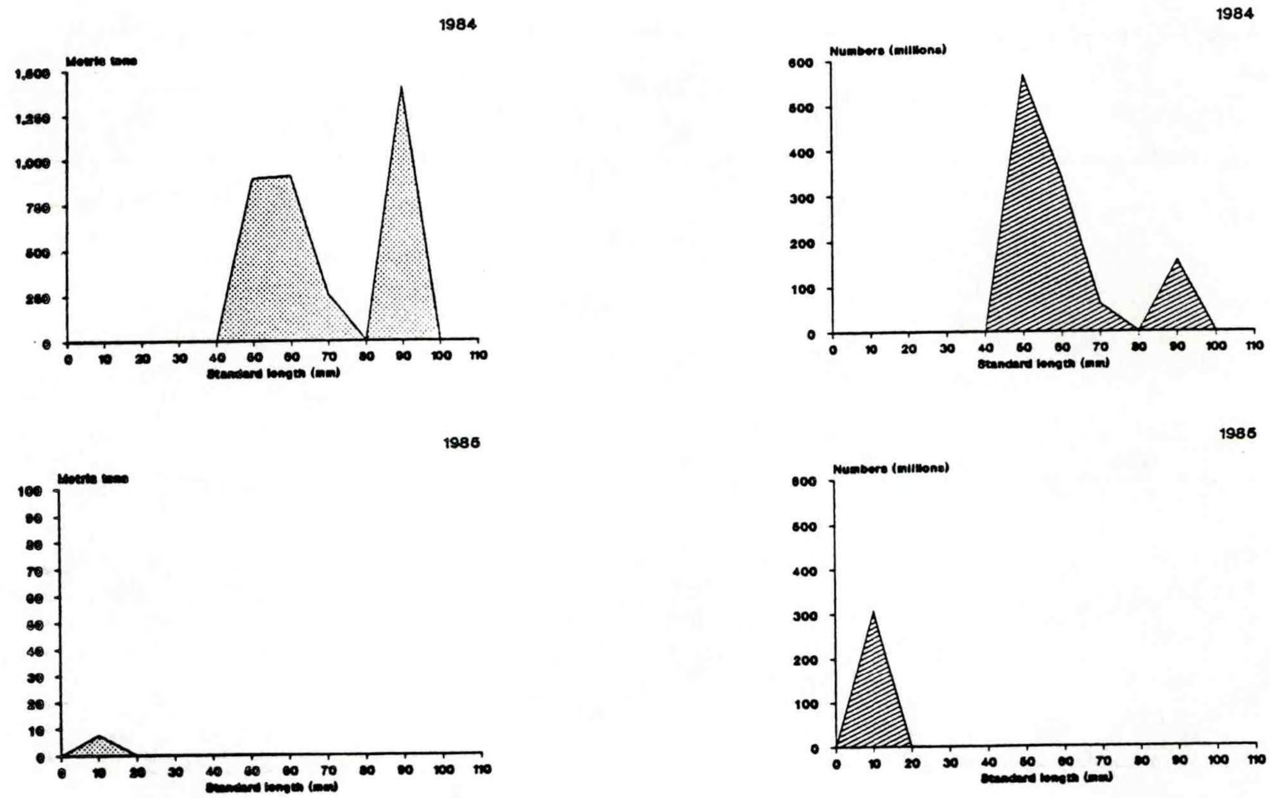


Figure 14.--Estimated biomass (metric tons) and number of Pacific cod consumed by flathead sole during months 5-9 in the eastern Bering Sea by prey size and year.

Table 12.--Estimated biomass of rock sole, *Lepidopsetta bilineata*, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken.)

Stratum	Biomass (metric tons) 1984	1985	1986
1	27.3	-	0
2	-	0	-
3	0	3,903.7	0
4	0	0	0
5	0	0	0
6	0	0	0
Total	27.3	3,903.7	0

Table 13.--Estimated numbers of rock sole, *Lepidopsetta bilineata*, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken.)

Stratum	Numbers (millions) 1984	1985	1986
1	21.3	-	0
2	-	0	-
3	0	591.9	0
4	0	0	0
5	0	0	0
6	0	0	0
Total	21.3	591.9	0

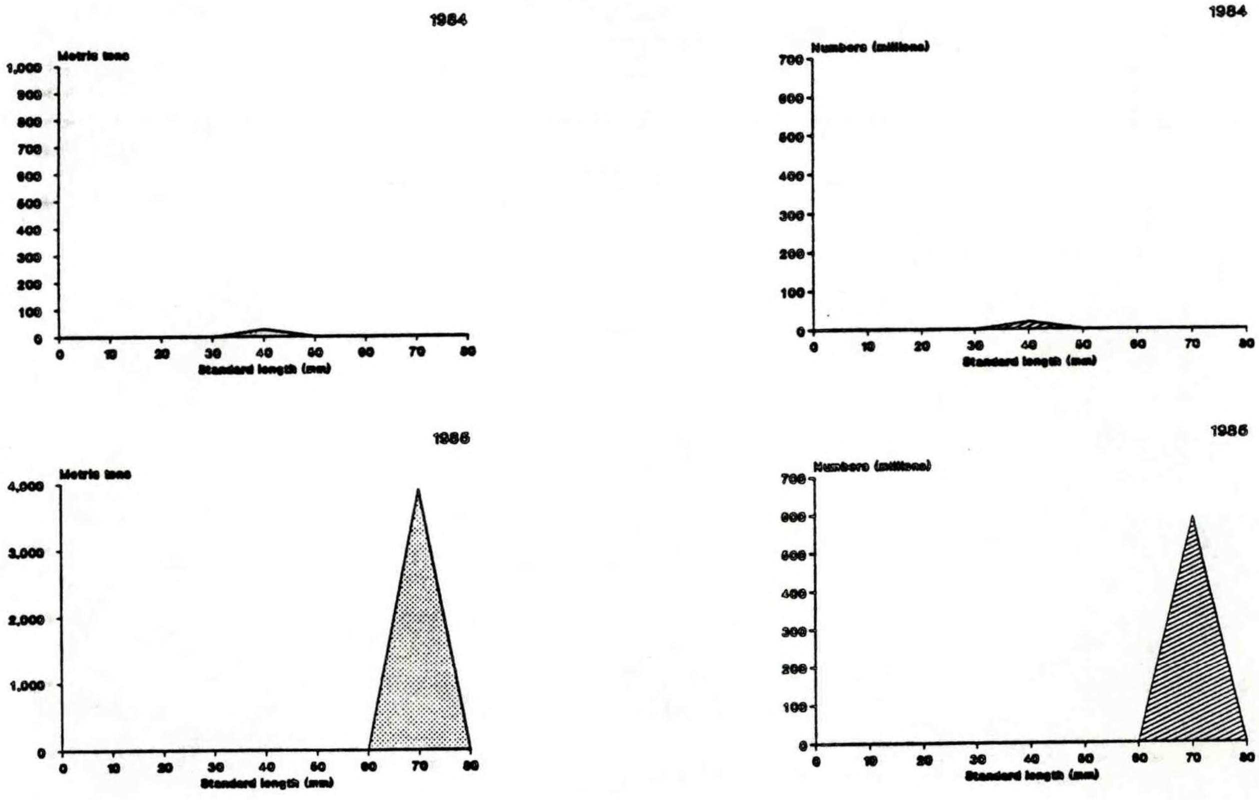


Figure 15.--Estimated biomass (metric tons) and number of rock sole consumed by flathead sole during months 5-9 in the eastern Bering Sea by prey size and year.

Prey size-frequency distributions indicate that flathead sole consume age-0 and small age-1 walleye pollock, as well as age-0 Pacific cod. Limited prey-size information indicates that flathead sole consume age-1 and younger rock sole. Since the estimated age composition of these species from RACE groundfish surveys does not include age-1 and younger fish, the direct impact of flathead sole predation on walleye pollock, Pacific cod and rock sole could not be determined. Therefore, several less direct approaches were utilized to evaluate the extent of flathead sole predation on populations of these species.

It is well documented that walleye pollock are cannibalistic on their young (Dwyer et al. 1987, Livingston et al. 1986, Mito 1974). Dwyer et al. (1987) estimated that adult pollock consumed over 400 billion age-0 pollock annually between 1981 and 1983. Livingston (see Walleye Pollock section of this report) estimated that adult walleye pollock consumed over 1 million t of walleye pollock as prey in 1985 and over 600,000 t in 1986. In contrast, flathead sole consumption of walleye pollock was estimated at about 86,000 t in 1985 and 50,000 t in 1986. Estimates of the number of walleye pollock consumed by walleye pollock were 65 times and 17 times greater than the number of walleye pollock consumed by flathead sole in 1985 and 1986, respectively. Thus, relative to adult walleye pollock, flathead sole appear to have little impact on the population size of juvenile pollock in the eastern Bering Sea.

Sampling for walleye pollock was not conducted in 1984; consequently, flathead sole appear to be responsible for almost 100% of Pacific cod removals (numbers) in the eastern Bering Sea. However, in 1985, walleye pollock account for over 80% of the total Pacific cod removals, whereas flathead sole accounted for only 9% of all Pacific cod consumed in that year. Because it is unlikely that flathead sole were the only predators of Pacific cod in 1984, total consumption estimates for 1985 are considered to be more representative of the relative levels of Pacific cod predation by walleye pollock and flathead sole. Therefore, based on 1985 consumption estimates, flathead sole appear to play only a minor role in the reduction of eastern Bering Sea Pacific cod populations.

Flathead sole accounted for around 10% of the total estimated number of rock sole consumed in both 1984 and 1985, suggesting that they are a minor predator of juvenile rock sole in the eastern Bering Sea. However, based on the relatively limited geographical overlap in the distributions of flathead sole and rock sole, and the steadily increasing biomass of rock sole over the last decade (Walters and Wilderbuer 1990b), it is unlikely that flathead sole predation has any significant effect on the population structure of rock sole in the eastern Bering Sea.

Commercially Important Crabs

The estimated biomass of Tanner crab consumed by flathead sole was highest in 1984 at 12,297 t, then decreased to 4,688 t and 3,273 t in 1985 and 1986, respectively (Table 14, Fig. 16). Similarly, the number of Tanner crabs estimated to have been consumed was greatest in 1984 at 6,732 million, compared with 3,633 million in 1985 and 2,169 million in 1986 (Table 15).

The estimated biomass of snow crab consumed by flathead sole in 1984 (7,808 t) was substantially greater than estimates for 1985 (803 t) and 1986 (1,297 t) (Table 16, Fig. 17). In addition, the number of snow crab estimated to have been consumed was greatest in 1984 at 7,379 million, compared with 800 million in 1985 and 827 million in 1986 (Table 17).

Table 14.--Estimated biomass of Tanner crab, Chionoecetes bairdi, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken; parentheses indicate years-strata where prey numbers could not be calculated.)

Stratum	Biomass (metric tons)		
	1984	1985	1986
1	41.3	-	-
2	-	0	0
3	6,475.4	0	2,312.2
4	346.9	(345.3)	636.1
5	4,713.6	0	86.0
6	719.7	4,342.2	238.5
Total	12,296.9	4,687.5	3,272.8

Table 15.--Estimated numbers of Tanner crab, Chionoecetes bairdi, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken.)

Stratum	Numbers (millions)		
	1984	1985	1986
1	16.8	-	0
2	-	0	-
3	2,575.0	0	915.6
4	141.1	*	926.3
5	3,304.1	0	232.7
6	695.0	3,632.7	94.5
Total	6,732.0	3,632.7	2,169.1

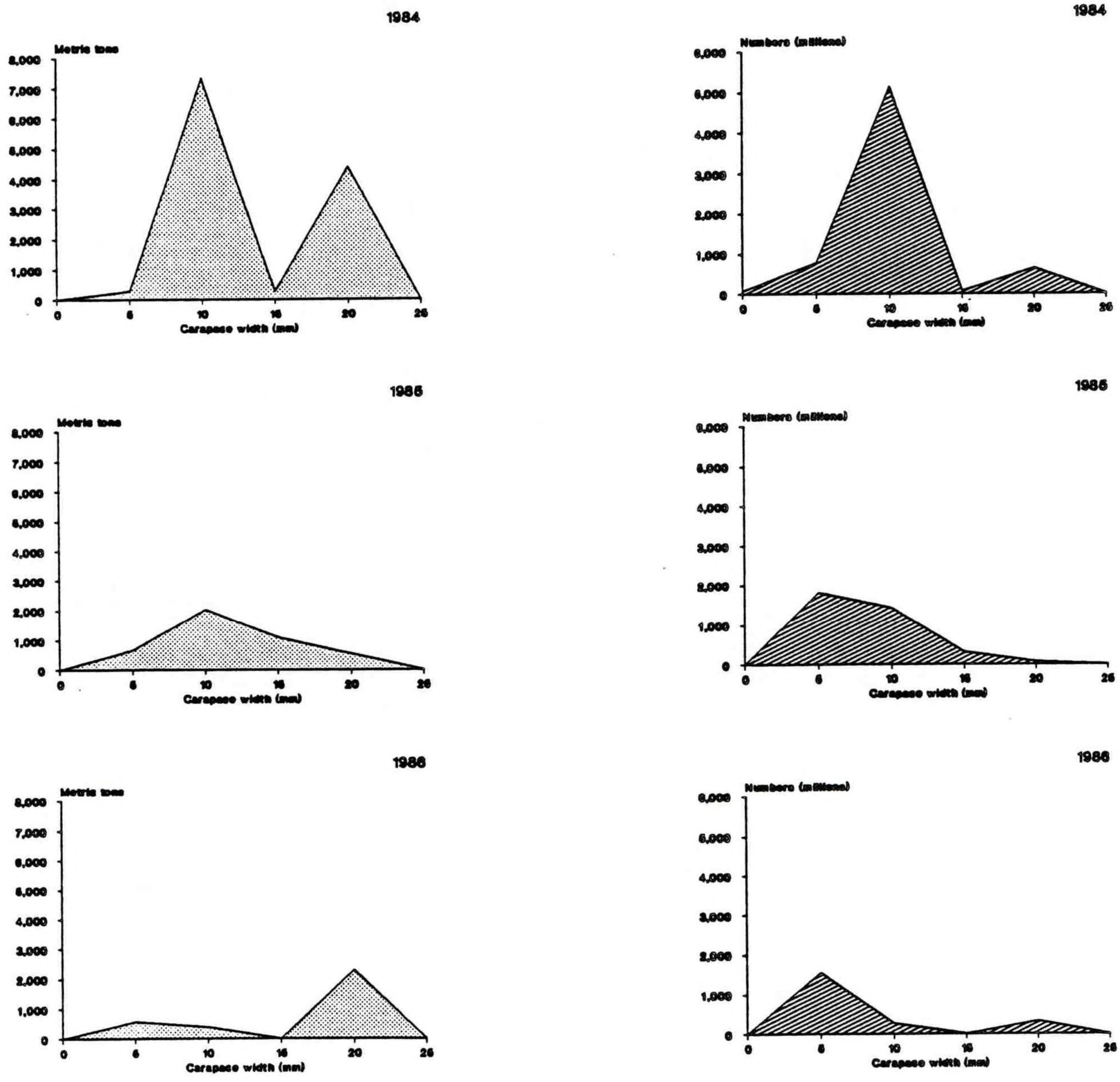


Figure 16.--Estimated biomass (metric tons) and number of Tanner crab consumed by flathead sole during months 5-9 in the eastern Bering Sea by prey size and year.

Table 16.--Estimated biomass of snow crab, <u>Chionoecetes opilio</u>, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken; parentheses indicate strata-years where prey numbers could not be calculated.)

Stratum	Biomass (metric tons)		
	1984	1985	1986
1	0	-	0
2	-	0	-
3	5,008.2	0	438.6
4	2,797.8	143.7	0
5	0	0	0
6	(1.7)	658.9	859.6
Total	7,807.7	802.6	1,297.2

Table 17.--Estimated numbers of snow crab, <u>Chionoecetes opilio</u>, consumed by flathead sole in the eastern Bering Sea during months 5 to 9, by stratum and year. (- = no samples taken; * = no prey size information was available for calculating prey numbers.)

Stratum	Numbers (millions)		
	1984	1985	1986
1	0	-	0
2	-	0	-
3	3,944.0	0	496.8
4	3,425.2	53.4	0
5	0	0	0
6	*	746.4	330.2
Total	7,379.2	799.8	827.0

Because the population age composition of age-1 and younger Tanner and snow crabs in the eastern Bering Sea is not estimated by RACE bottom trawl surveys, a direct comparison of prey abundance to prey consumption is not possible. However, based on substantial recruitment of Tanner and snow crab in the late 1980s from strong year classes in the mid-1980s (Stevens and MacIntosh 1990), it is doubtful that predation mortality by flathead sole

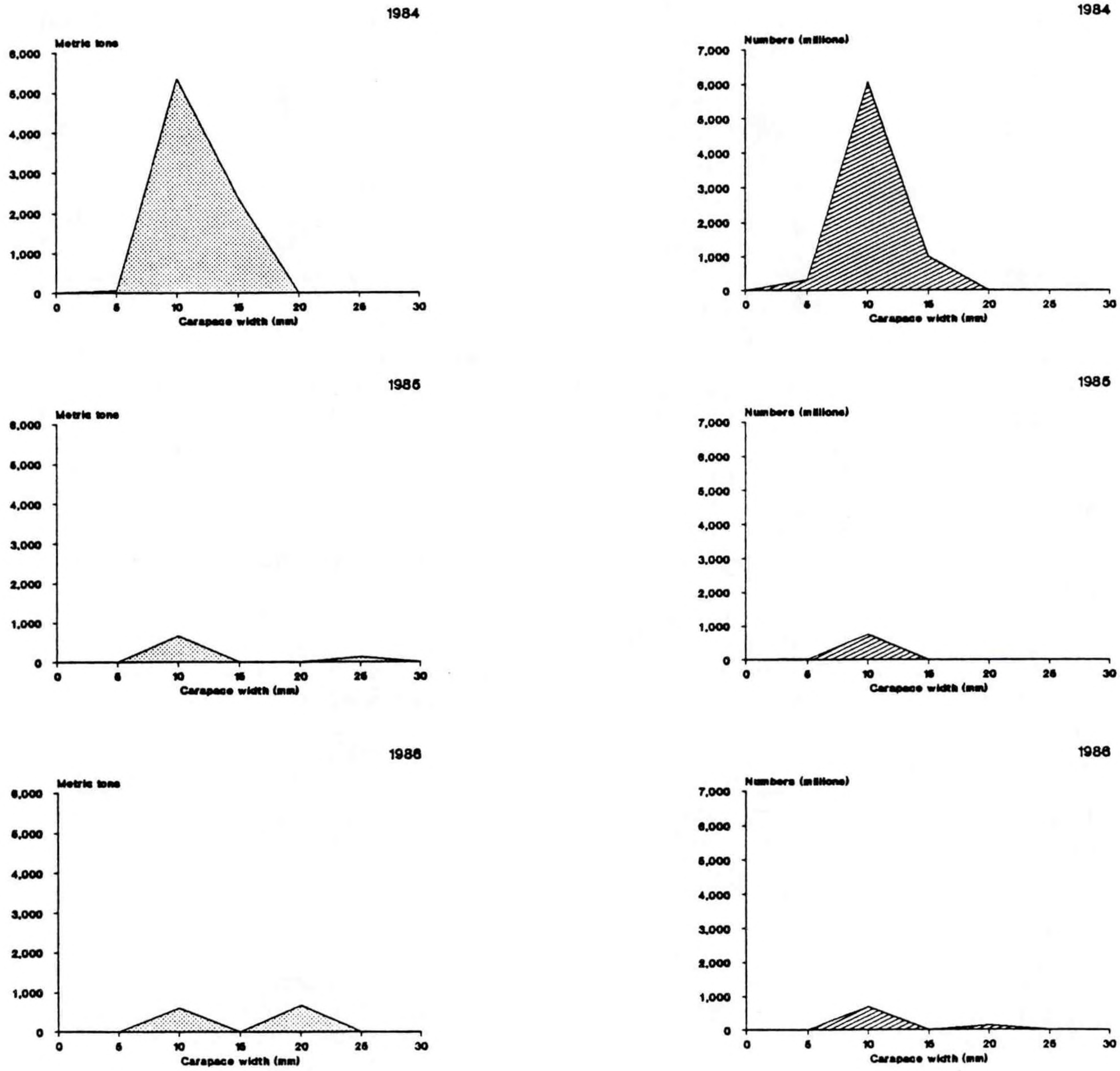


Figure 17.--Estimated biomass (metric tons) and number of snow crab consumed by flathead sole during months 5-9 in the eastern Bering Sea by prey size and year.

significantly effects populations of Tanner and snow crabs in the eastern Bering Sea.

Flathead sole in this study consumed some fish and crab that could not be identified to the species level (see Table 1). Also, from seasonal anaylsis, it is apparent that flathead sole consume commercially important fish and crabs throughout the year (see Fig. 1). As a result, predation mortality rates presented above may be underestimated since they only consider predation that occurred from May to September (months 5 to 9), and do not include unidentified fish or crabs in their calculation. Also, due to the advanced digestive state of some prey items, not all of the commercially important fish and crabs recovered from stomach contents were measurable. Consequently, for population consumption estimates calculated based on prey size, it is possible that segments of these fish and crab populations may be over- or underestimated.

It is important to note that some bias is inherent in the population consumption estimates presented above. For example, for estimates based on small sample sizes (e.g., Pacific cod and rock sole, $n \leq 10$), consumption of these prey items may represent rare or isolated incidences of predation, in which case Equation (1) may greatly overestimate the amount of predation occurring in situ. Better laboratory identification of prey fish may help to resolve this problem.

The apparently high predation mortality rates reported here may not be completely unrealistic. Fecundities of commercially important fish and crab species consumed by flathead sole range from the thousands to millions of eggs per individual per spawning event. Considering the population sizes of these species in the eastern Bering Sea, annual egg production reaches into the trillions or more, which is one to several orders of magnitude greater than total consumption estimates presented above. This approach to reproduction, predator satiation (Smith 1980) or "predator swamping," predicts a high predation mortality rate of juveniles, enabling a few offspring to escape predation and survive to reproduce.

Clearly, more data are required in order to accurately assess the overall impact of flathead sole predation on populations of commercially important fish and crabs in the eastern Bering Sea. However, until reliable prey abundance estimates are available, the total consumption estimates presented here are probably more appropriate as indices for comparing predation mortality rates among key fish predators in the eastern Bering Sea.

CITATIONS

Adams, A. E. 1979. The life history of the snow crab, Chionoecetes opilio: A literature review. Alaska Sea Grant Report 78-13, 141 p.

Allen, M. J. 1984. Functional organization of demersal fish communities of the eastern Bering Sea. Unpubl. manuscr., 266 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 66, 151 p.

DeGroot, S. J. 1971. On the interrelationships between morphology and the alimentary tract, food and feeding behaviour in flatfishes (Pisces: Pleuronectiformes). Neth. J. Sea Res. 5:121-196.

Donaldson, W. E., J. R. Hilsinger, and R. T. Cooney. 1980. Growth, age, and size at maturity of Tanner crab, Chionoecetes bairdi, in the northern Gulf of Alaska. Alaska Dep. Fish and Game, Information Leaflet No. 185, 52 p.

Dwyer, D. A., K. M. Bailey, and P. A. Livingston. 1987. Feeding habits and daily ration of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea, with special reference to cannibalism. Can. J. Fish. Aquat. Sci. 44:1972-1984.

Flora, J. D., Jr. 1980. Food habits of yellowfin sole, Limanda aspera, and flathead sole, Hippoglossoides elassodon, in Auke Bay, Stephens Passage, Alaska. M.S. Thesis, Univ. Alaska-Southeast, Juneau, 51 p.

Livingston, P. A. 1989. Interannual trends in Pacific cod, Gadus macrocephalus, predation on three commercially important crab species in the eastern Bering Sea. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 87:807-8027.

Livingston, P. A., D. A. Dwyer, D. L. Wencker, M. S. Yang, and G. M. Lang. 1986. Trophic interactions of key fish species in the eastern Bering Sea. Int. North Pac. Fish. Comm. Bull. 47:49-65.

Miller, B. S. 1970. Food of flathead sole (Hippoglossoides elassodon) in East Sound, Orcas Island, Washington. J. Fish. Res. Board Can. 27:1661-1665.

Mineva, T. A. 1964. On the biology of some flatfishes in the eastern Bering Sea, p. 227-235. In P. A. Moiseev (editor). Soviet fisheries investigations in the Northeast Pacific, Part. II. (Translated from Russian by Israel Program Sci. Trans., Jerusalem, 1968.) Available U.S. Department of Commerce, Clearinghouse for Federal Scientific and Technical Information, Springfield, VA. 22151.

Mito, K. 1974. Food relationships among benthic fish populations in the Bering Sea. M.S. Thesis, Hokkaido Univ., Hokkaido, Japan, 135 p.

Moiseev, P. A. 1953. Cod and flounders of the far-eastern seas. [Treska i kambaly delnovostochnykh morei.] (Translated from Russian by Bureau of Translations, Dep. Sec. State of Canada, 1956.) Available as J. Fish. Res. Board Can. Transl. Ser. 119, 576 p.

Pacunski, R. E. 1990. Food habits of flathead sole, Hippoglossoides elassodon, in the eastern Bering Sea. M.S. Thesis, Univ. Washington, 106 p.

Smith, R. L. 1980. Ecology and field biology. Third edition. Harper and Row, San Francisco, CA, 835 p.

Smith, R. L., A. C. Paulson, and J. R. Rose. 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. In Environmental assessment of the Alaskan continental shelf, Final Rep., Biol. Stud. Vol. 1, p. 33-107. U.S. Dep. Commer., NOAA, Environ. Res. Lab. Available Arctic Environ. Assess. Cent., 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

Stevens, B. G., and R. A. MacIntosh. 1990. Report to industry on the 1990 eastern Bering Sea crab survey. NWAFC Processed Rep. 90-09, 50 p. Natl. Mar. Fish. Serv., Alaska Fish. Sci. Cent., P.O Box 1638, Kodiak, AK 99615.

Walters, G. E., and T. K. Wilderbuer, 1990a. Other Flatfish. In L-L. Low and R. E. Narita (editors), Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands region as Projected for 1991. Available North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Walters, G. E., and T. K. Wilderbuer, 1990b. Rock Sole. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 112-122. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Walters, G. E., K. Teshima, J. J. Traynor, R. G. Bakkala, J. A. Sassano, K. L. Halliday, W. A. Karp, K. Mito, N. J. Williamson, and D. M. Smith. 1988. Distribution, abundance, and biological characteristics of groundfish in the eastern Bering Sea based on results of the U.S.-Japan triennial bottom trawl and hydroacoustic surveys during May-September, 1985. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-154, 401 p.

Wespestad, V. G., R. G. Bakkala, and P. Dawson. 1991. Walleye pollock. In L-L. Low and R. E. Narita (editors), Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1991. Available North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

OTHER SPECIES

by

Jeffrey C. Parkhurst

INTRODUCTION

Total groundfish biomass in the eastern Bering Sea is approximately 11 million metric tons (Halliday and Sassano 1988). The fish species covered in previous sections of this report constitute almost 80% of the fish biomass (Table 1). Other species such as rock sole (Lepidopsetta bilineata), Alaska plaice (Pleuronectes quadrituberculatus), sablefish (Anoplopoma fimbria), Pacific herring (Clupea harengus pallasi), and sculpins make up most of the remaining biomass. With the exception of rock sole and Alaska plaice, these species individually constitute less than 5% of the total biomass.

Because these fish have not been identified as dominant components of the eastern Bering Sea biomass or as major consumers of commercially important fish or crabs, collection of detailed data on their food habits has not been a high priority. However, it is still important to study the food habits of these species because they may become more abundant in the future and because they may play an important role in situations where there is competition with other predators for scarce resources. This supplementary food habits data may help clarify fluctuations in niche separation (i.e., dominant predator versus subdominant predator abundances) and their effect on the Bering Sea ecosystem.

Twenty-five species were examined using the quantitative shipboard scan method, of which 12 species had more than 60 stomachs containing food (Table 2). In addition, detailed laboratory analysis of stomach contents was performed on three species (sablefish, Alaska plaice, and Pacific halibut Hippoglossus stenolepis). Of the 434 stomachs examined, 390 contained prey items. Certain trends in prey use in terms of biomass are apparent, which may be related to functional limits in feeding morphology and habitat use (Allen 1984). A variety of dietary overlap indices have been proposed to help quantify possible similarities in the diets of predators (Cailliet and Barry 1979; Linton et al. 1981; Wallace 1981). Schoener's (1970) index was found to be accurate for a wide range of true overlaps and thus was computed for the predator species mentioned here (Linton et al. 1981).

Table 1.--Biomass estimates (metric tons) for major fish species and fish groups taken during the 1986 bottom trawl survey in the eastern Bering Sea. (Adapted from Halliday and Sassano 1988.)

Taxon	Estimated total fish biomass	Proportion of total fish biomass
Gadidae (cods)		
Walleye pollock	4,977,942	0.457
Pacific cod	1,134,106	0.104
Other cods	1,065	0.000
Total cods	6,113,112	0.561
Pleuronectidae (flatfishes)		
Yellowfin sole	1,866,432	0.171
Rock sole	1,013,741	0.093
Flathead sole	369,273	0.034
Alaska plaice	550,567	0.050
Arrowtooth flounder	232,090	0.021
Greenland turbot	5,584	0.000
Pacific halibut	86,617	0.008
Other flatfish	42,865	0.004
Total flatfish	4,167,169	0.381
Anoplopomatidae		
Sablefish	16,633	0.002
Clupeidae		
Pacific herring	7,790	0.001
Cottidae (sculpins)	305,058	0.028
Zoarcidae (eelpouts)	9,559	0.001
Osmeridae (smelts)	9,541	0.001
Agonidae (poachers)	4,684	0.000
Scorpaenidae (rockfish)		
Pacific ocean perch	138	0.000
Other rockfish	1,109	0.000
Total rockfish	1,247	0.000
Cyclopteridae (snailfish)	1,557	0.000
Rajidae (skates)	258,035	0.024
Other fish	7,754	0.001
Total fish	10,902,146	1.000

Table 2.--Summary of stomachs examined using quantitative shipboard scans (a) and laboratory analysis (b) in 1983-86 in the eastern Bering Sea (empty stomachs in parentheses).

Predator	Number of stomachs
a) Shipboard scans	
Pacific herring	247 (24)
Pacific cod	74 (1)
Atka mackerel	60 (8)
Sablefish	142 (39)
Red Irish lord	71 (1)
Yellow Irish lord	274 (19)
Plain sculpin	106 (15)
Great sculpin	353 (74)
Rex sole	80 (3)
Flathead sole	69 (17)
Rock sole	226 (161)
Alaska plaice	266 (130)
TOTAL	1,968 (492)
b) Laboratory analysis	
Sablefish	31 (3)
Alaska plaice	87 (12)
Pacific halibut	272 (29)
TOTAL	390 (44)

DIET OVERLAP

	PACIFIC HERRING	PACIFIC COD	ATKA MACKEREL	SABLEFISH	YELLOW IRISH LORD	RED IRISH LORD	PLAIN SCULPIN	GREAT SCULPIN	REX SOLE	FLATHEAD SOLE	ROCK SOLE	ALASKA PLAICE
PACIFIC HERRING												
PACIFIC COD	1											
ATKA MACKEREL	26	47										
SABLEFISH	3	43	41									
YELLOW IRISH LORD	4	33	15	45								
RED IRISH LORD	0	25	2	4	54							
PLAIN SCULPIN	1	55	13	38	50	29						
GREAT SCULPIN	1	60	28	34	29	28	63					
REX SOLE	8	4	9	4	5	2	6	4				
FLATHEAD SOLE	12	12	21	20	17	3	13	11	31			
ROCK SOLE	5	23	13	15	21	8	18	16	34	55		
ALASKA PLAICE	4	3	3	2	9	2	3	4	31	30	66	

0 < 30   30 < 60   60 < 100

Figure 1.--Diet overlap among predators for which 60 or more stomachs containing food were examined. Numbers below the diagonal represent the interspecific overlap values and the shading above the diagonal corresponds to the degree (low, medium, high) of overlap (from Brodeur and Livingston 1988).

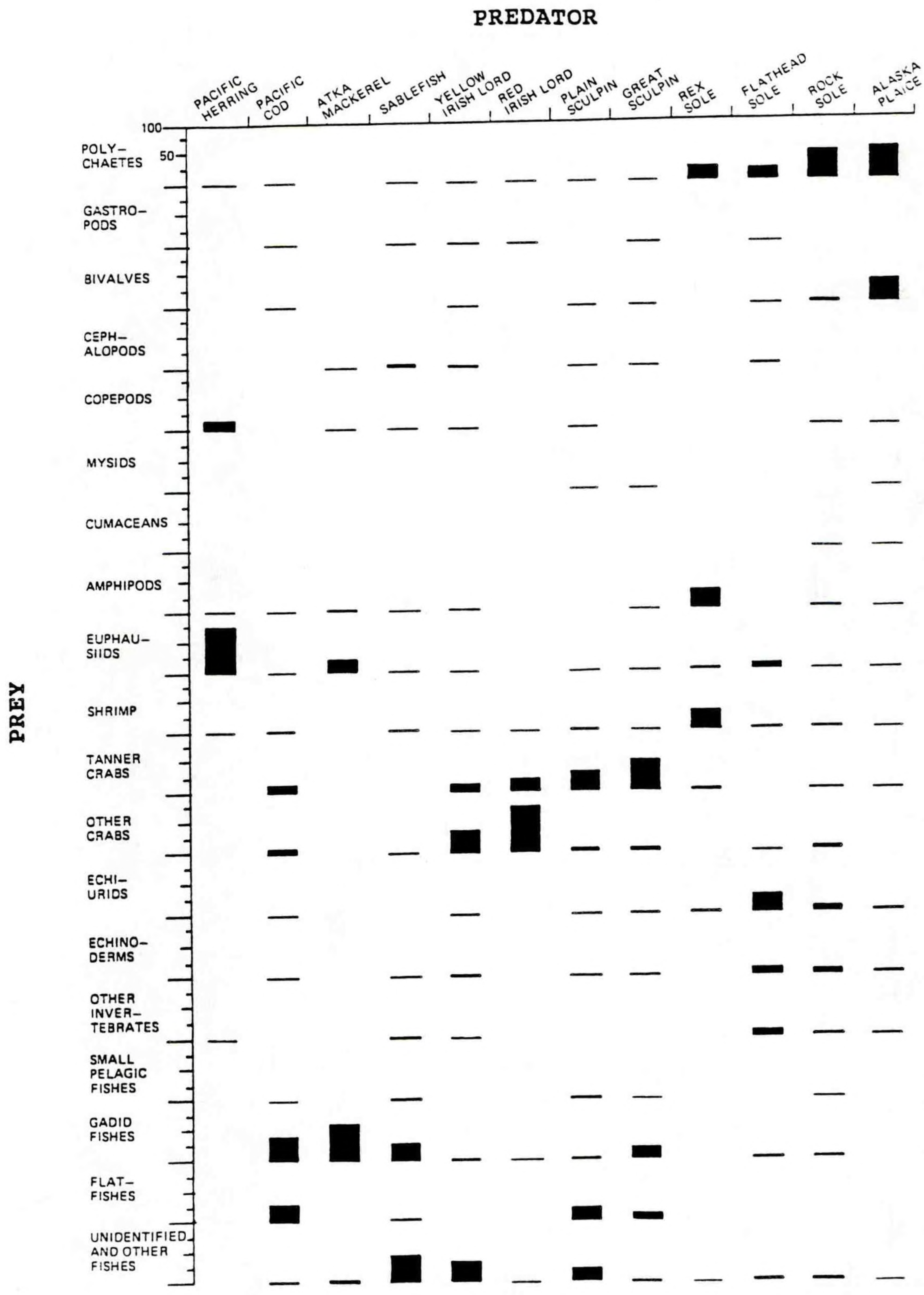


Figure 2.--Consumption of major prey categories by predators for which 60 or more stomachs containing food were examined. Height of bars corresponds to percent of total diet weight (from Brodeur and Livingston 1988).

Schoener's index, C_{xy}, is calculated as:

$$C_{xy}=1.0-0.5\sum_{j=1}^{n}|P_{xj}-P_{yj}|$$

where P_{xj} and P_{yj} are the estimated proportions by weight of prey j in the diets of species x and y, respectively. The index has a minimum of 0 (no overlap of prey) and a maximum of 1 (all items in equal proportions). Overlap values were grouped into three categories to represent low (0 to 30%), intermediate (30 to 60%), and high (60 to 100%) levels of diet overlap (Langton and Bowman 1980). The resulting overlap matrix is shown in Figure 1.

Pacific herring differed from the other key predators in that they consumed mostly small pelagic crustaceans and had low dietary overlap with all other species examined (Figs. 1-2). For the most part, Pacific cod Gadus macrocephalus, Atka mackerel Pleurogrammus monopterygius, and sablefish preyed upon pelagic (mostly gadid) fishes. There was moderate diet overlap between these species with minor differences in prey utilization. Benthopelagic feeders such as the four cottid species examined here (red Irish lord Hemilepidotus hemilepidotus, yellow Irish lord Hemilepidotus jordani, plain sculpin Myoxocephalus jaok, and great sculpin Myoxocephalus polyacanthocephalus) consumed crabs primarily and fishes secondarily. The flatfishes (rex sole Glyptocephalus zachirus, flathead sole Hippoglossoides elassodon, rock sole, and Alaska plaice) exhibited many differences in prey utilization with the exception of shared polychaete consumption. Rex sole consumed similar amounts of amphipods, shrimp, and polychaetes (approximately 25 to 35% by weight). The Alaska plaice diet consisted of a significant amount of bivalve mollusks (40%). Flathead sole and rock sole shared a similar prey spectrum in the consumption of echiurids, echinoderms, other invertebrates, and fishes. Yet diet overlap between these two species was only moderate. The highest overlap values in the entire diet overlap matrix was exhibited between rock sole and Alaska plaice at 66% (Fig. 1).

CONSUMPTION OF COMMERCIALLY IMPORTANT PREY

Consumption of key commercial prey species was studied in order to clarify food web pathways between commercially and noncommercially important Bering Sea fishes. Brodeur and Livingston (1988) have summarized location, number and size distribution of individual prey species in greater detail. The four species treated here include walleye pollock Theragra chalcogramma, yellowfin sole Limanda aspera, and two species of crab (Chionoecetes bairdi and C. opilio), all of which support fairly substantial commercial fisheries. Shipboard scan data permitted species-level analysis based upon weight percentages of the total diet of key predator species. Seven of the 10 species studied consumed walleye pollock (Table 3). Walleye pollock consumption figures for all of these species were less than 50%, with Atka mackerel diet containing the largest amount (46.2% by weight) of pollock. Snow crabs (C. opilio) were of secondary importance to most species but were consumed in large amounts (31 to 39% by weight) by various cottid species (Myoxocephalus spp.). A more detailed study of cottid diets is needed, given the occurrence of such a commercially important prey group in their diet and the fairly large biomass of cottids in the eastern Bering Sea.

Due to limited geographic coverage and insufficient sample sizes in shipboard scans, there was no calculation of population level predation on these key prey species.

DISCUSSION

The results of prey consumption by these predator species concurs with the limited studies describing single-species food habits of various fishes in the Bering Sea (see Livingston and Goiney 1983). Unfortunately, most studies have not examined more than just a few species at one time and thus have been lacking in detailed overlap information. Of the 25 commercially important fishes studied, 12 species had sufficient full stomach samples taken to allow some comment on the significance of resulting diet overlap values and prey consumption.

Given the present prey utilization data and the resulting low overlap values, Pacific herring displays all the characteristics of a midwater planktivore, with its primary consumption of pelagic microcrustaceans; it is most dissimilar to all the other species in this study in terms of its feeding type (Wailes 1936; Brodeur et al. 1987). Pacific cod, Atka mackerel, and sablefish were primarily piscivores that, based upon previous studies, share benthopelagivore attributes (Shubnikov 1963; Allen 1984). The various cottid fishes fed mainly on crabs, and with their large gape width, have a potential for consuming large quantities at one time in areas that are significant to the snow crab life history (high-density larval settling areas). The flatfishes seemed to have the most diverse utilization of the prey spectrum and have been classified as benthivores or benthopelagivores (Allen 1984). Since abundance data are lacking for the benthic invertebrate prey common to these predators, it is difficult to say whether prey choice is an opportunistic consumption of a prey item that is very abundant, or limited by other morphological or behavioral constraints.

Table 3.--Summary of the utilization of several commercially important prey species as determined by quantitative shipboard scans of major predators in the eastern Bering Sea, 1985-86. Data are percentages by weight of the total diet of each predator (from Brodeur and Livingston 1988).

	Prey Species			
Predators	*Theragra chalcogramma*	*Chionoecetes opilio*	*Chionoecetes bairdi*	*Limanda aspera*
Pacific cod	35.0	--	6.2	1.8
Great sculpin	--	38.5	3.2	5.8
Plain sculpin	--	30.7	0.2	6.5
Atka mackerel	46.2	--	--	--
Sablefish	26.0	--	--	--
Red Irish lord	0.2	10.6	2.3	--
Yellow Irish lord	2.9	4.8	3.1	--
Flathead sole	2.5	--	--	--
Rock sole	1.3	0.4	0.1	--
Alaska plaice	--	1.9	--	--

Dietary arrays of these "other species" reflect the distinct spatial and morphological limits of the predators studied. There was quite a large variation in diet among species but certain trends may be attributed to area-specific foraging patterns, feeding types, or foraging guilds (Mito 1974; Allen 1984). Additional analysis of geographic separation, morphology, diel activity, and other niche structure parameters might yield a more precise description of the eastern Bering Sea trophic spectrum. Regular stomach sampling of rock sole, Alaska plaice, and Pacific halibut was initiated in 1988, and more detailed food habits data will be available in future reports.

CITATIONS

Allen, M. J. 1984. Functional organization of demersal fish communities in the eastern Bering Sea. Unpubl. manuscr., 266 p. Alaska Fish. Sci. Cent., 7600 Sand Point Way NE, Bin C15700, Seattle, WA 98115.

Brodeur, R. D., and P. A. Livingston. 1988. Food habits and diet overlap of various eastern Bering sea fishes. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-127, 76 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.

Cailliet, G. M., and J. P. Barry. 1979. Comparison of food array overlap measures useful in fish feeding habits analysis. In S. J. Lipovsky and C. A. Simenstad (editors), Gutshop '78, Fish food habits studies, Proceedings of the Second Pacific Northwest Technical Workshop, p. 67-79. Univ. Washington Division of Marine Resources, Washington Sea Grant WSG-WO-79-1.

Halliday, K. L., and J. A. Sassano. 1988. Data report: 1986 bottom trawl survey of the eastern Bering sea continental shelf. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-147, 159 p.

Langton, R. W., and R. E. Bowman. 1980. Food of fifteen Northwest Atlantic gadiform fishes. U.S. Dep. Commer., NOAA Tech. Rep. NMFS-SSRF-740, 23 p.

Linton, L. R., R. W. Davies, and F. J. Wrona. 1981. Resource utilization indices: An assessment. J. Anim. Ecol. 50:283-292.

Livingston, P. A., and B. J. Goiney, Jr. 1983. Food habits literature of North Pacific marine fishes: A review and selected bibliography. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-54, 81 p.

Mito, K. I. 1974. Food relationships among benthic fish populations in the Bering Sea. M.S. Thesis, Hokkaido Univ., Hakodate, Japan, 135 p.

Schoener, T. W. 1970. Non-synchronous spatial overlap of lizards in patchy habitats. Ecology 51:408-418.

Shubnikov, D. A. 1963. Nekotorye dannye po biologii ugol'noi ryby Beringova morya [Data on the biology of sablefish of the Bering Sea]. Tr. Vses. Nauchno Issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 48 [Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 50]:271-295. In Russ. (Transl. by Isr. Program Sci. Transl., 1968, p. 287-296, In P. A. Moiseev (editor), Soviet fisheries investigations in the northeast Pacific, Part 1, available U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA, as TT 67-51203.

Wailes, G. H. 1936. Food of Clupea pallasii in southern British Columbia waters. J. Biol. Board Can. 1:477-486.

Wallace, R. K. 1981. An assessment of diet overlap indexes. Trans. Am. Fish. Soc. 110:72-76.

TOTAL GROUNDFISH CONSUMPTION OF COMMERCIALLY IMPORTANT PREY

by

Patricia A. Livingston

The total impact of groundfish predation on a particular prey species is estimated in this paper by summing the individual predator removals described in previous sections. Comparison of total fish predation with each individual predator's removals provides an indication of which predator population tends to be the most important source of predation mortality for a prey population. Also, comparison of total predation removals with prey population size demonstrates the relative importance of predation as a source of mortality. Finally, interannual fluctuations in predation on a particular age group of prey may give early indications of changes in abundance of prey age groups before they are vulnerable to assessment by trawl survey. The total consumption of each important prey group is summarized in terms of estimated biomass and numbers removed by groundfish predation in the eastern Bering Sea for segments of the years 1984 to 1986.

TOTAL PREDATION SUMMARIES BY PREY SPECIES

King Crabs

Tables 1-2 show the estimated total biomass and numbers of king crabs consumed by all groundfish predators for 31 days during months 5 to 9 in 1984 through 1986. An average prey size of 97.5 mm carapace length (CL) was used in strata with no prey size information so numbers consumed in Table 2 are estimates of total numbers consumed.

Red King Crab

Pacific cod (*Gadus macrocephalus*) was the main predator of red king crabs (*Paralithodes camtschatica*) and king crabs that could not be identified to the species level. As discussed earlier in the section on Pacific cod predation, most of the king crabs consumed by cod in 1985 were assumed to be blue king crabs (*P. platypus*) based on the geographic location where the crabs were consumed. Most of the crabs consumed by cod in 1984 and 1986 were red king crab (69 and 95%, respectively). Total red king crab consumption decreased from 1984 to 1985 and increased from 1985 to 1986. These crabs were presumed to be soft-shell females based on the timing and location of consumption by predators.

Resource assessment survey data for female red king crab (Stevens and MacIntosh 1990) do not show a similar trend in female red king crab abundance over the 1984 to 1986 time period.

Table 1.--Estimated total biomass (metric tons) of king crabs consumed by groundfish predators by year for 31 days during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells with some missing prey size information.

Prey	Predator	Biomass consumed 1984	1985	1986
Lithodidae				
	Pacific cod	(40.8)	(17.8)	(17.0)
Paralithodes spp.				
	Pacific cod	(572.9)	(1,117.8)	(116.9)
Paralithodes camtschatica (red king crab)				
	Pacific cod	(1,857.2)	0	(2,733.0)
Paralithodes platypus (blue king crab)				
	Yellowfin sole	(213.4)	0	0

Table 2.--Estimated numbers (millions) of king crabs consumed by groundfish predators by year for 31 days during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells with some missing prey size information. Prey size was assumed to be 97.5 mm carapace length for cells without prey size information except for blue king crab, which were consumed as megalops larvae with an average individual weight of 0.006 g.

		Number consumed		
Prey	Predator	1984	1985	1986
Lithodidae				
	Pacific cod	(0.07)	(0.03)	(0.027)
Paralithodes spp.				
	Pacific cod	(0.981)	(1.77)	(0.182)
Paralithodes camtschatica (red king crab)				
	Pacific cod	(1.80)	0	(4.45)
Paralithodes platypus (blue king crab)				
	Yellowfin sole	(35,563.4)	0	0

Those data show a steady decline in abundance. Increases in abundance of juvenile female red king crabs from 1987 to 1989, however, may be an indication that there were similar increases in young female abundance in years immediately before this that were not of sizes fully vulnerable to research trawls.

Using these same predation data but slightly different analysis, Livingston (1989a) concluded that Pacific cod consumption of red king crab during the years 1981, 1984, and 1985 was less than 5% of the crab population and did not show a strong density-dependent trend. A similar result is suggested here for the years 1984 and 1985. However, the increase in predation on red king crab in 1986 despite a possible decline in population size suggests the possibility of depensatory predation mortality in that year. Uncertainties in predation estimates along with uncertainties in trawl survey estimates of juveniles preclude a definite conclusion regarding possible predator control of red king crab population size. Comparison of predation amounts with reconstructed population sizes from cohort analysis may provide a more definitive answer.

Blue King Crab

As mentioned earlier, it was assumed that blue king crab females were consumed mainly by Pacific cod in 1985. The dominance of blue king crab consumption in that year may be the result of the biennial molting and reproductive behavior of blue king crab (Jensen and Armstrong 1989). A longer time series of predation data may verify this result if peaks in blue king crab consumption occur on a biennial cycle. Megalops larvae of blue king crab were consumed only by yellowfin sole in 1984 near the Pribilof Islands. RACE survey data show a peak of 50 mm CL blue king crab in 1988, but with little information about blue king crab growth patterns it is not possible to determine whether these might be from the 1984 year class.

Snow and Tanner Crabs

Total biomass of snow crabs (*Chionoecetes opilio*) and Tanner crabs (*C. bairdi*) consumed by groundfish predators is shown in Table 3. Table 4 shows the estimated number of snow crabs consumed in areas where prey size information was available, so they should be considered the minimum number consumed by groundfish predators. Figures 1 and 2 show the biomass and numbers removed by prey size.

Snow Crabs

The main predator of snow crabs, in terms of estimated biomass removed, was Pacific cod. Cod consumed at least 80% of the total biomass removals of snow crabs in all 3 years. The next most important predators were yellowfin sole (*Limanda aspera*) and flathead sole (*Hippoglossoides elassodon*). While

Table 3.--Estimated total biomass (metric tons) of Tanner crabs (Chionoecetes bairdi) and snow crabs (C. opilio) consumed by groundfish predators by year during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells where some prey size information was not available.

Prey	Predator	Biomass consumed 1984	1985	1986
C. opilio				
	Pacific cod	80,416.1	126,173.2	(147,780.0)
	Flathead sole	(7,807.7)	802.5	1,298.2
	Yellowfin sole	(10,593.9)	5,457.4	0
	Greenland turbot	0	33.8	0
	Total	98,817.7	132,466.9	149,078.2
C. bairdi				
	Pacific cod	38,655.6	72,011.7	40,048.8
	Arrowtooth flounder	(119.7)	0	0
	Flathead sole	12,296.8	(4,687.5)	3,272.7
	Yellowfin sole	12,117.2	13,291.8	5,500.6
	Total	63,189.3	89,991.0	48,822.1

Table 4.--Estimated numbers (millions) of Tanner crabs (Chionoecetes bairdi) and snow crabs (C. opilio) consumed by groundfish predators by year during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells where some prey size information was not available.

Prey	Predator	Number consumed 1984	1985	1986
C. opilio				
	Pacific cod	6,658.0	11,000.5	(12,214.8)
	Flathead sole	(7,369.2)	799.8	827.1
	Yellowfin sole	(16,893.7)	433.1	0
	Greenland turbot	0	1.4	0
	Total	30,920.9	12,234.8	13,041.9
C. bairdi				
	Pacific cod	4,979.8	6,938.7	6,565.2
	Arrowtooth flounder	(0)	0	0
	Flathead sole	6,731.9	(3,632.7)	2,169.1
	Yellowfin sole	141,146.3	3,354.3	1,163.9
	Total	152,850.0	13,925.7	9,898.2

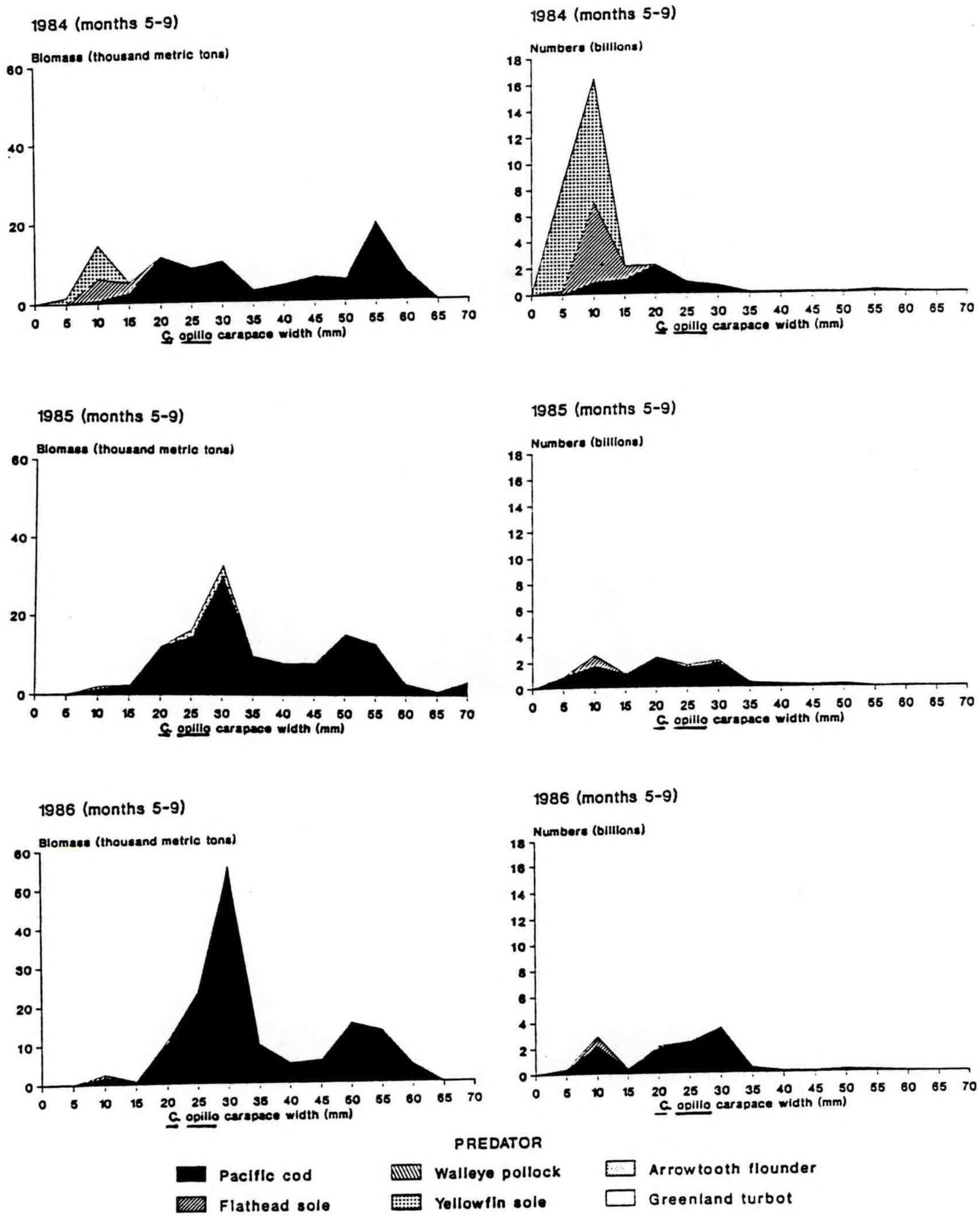


Figure 1.--Estimated biomass and numbers of snow crabs (Chionoecetes opilio) consumed by groundfish predators during months 5 to 9 in 1984, 1985, and 1986 in the eastern Bering Sea by prey size.

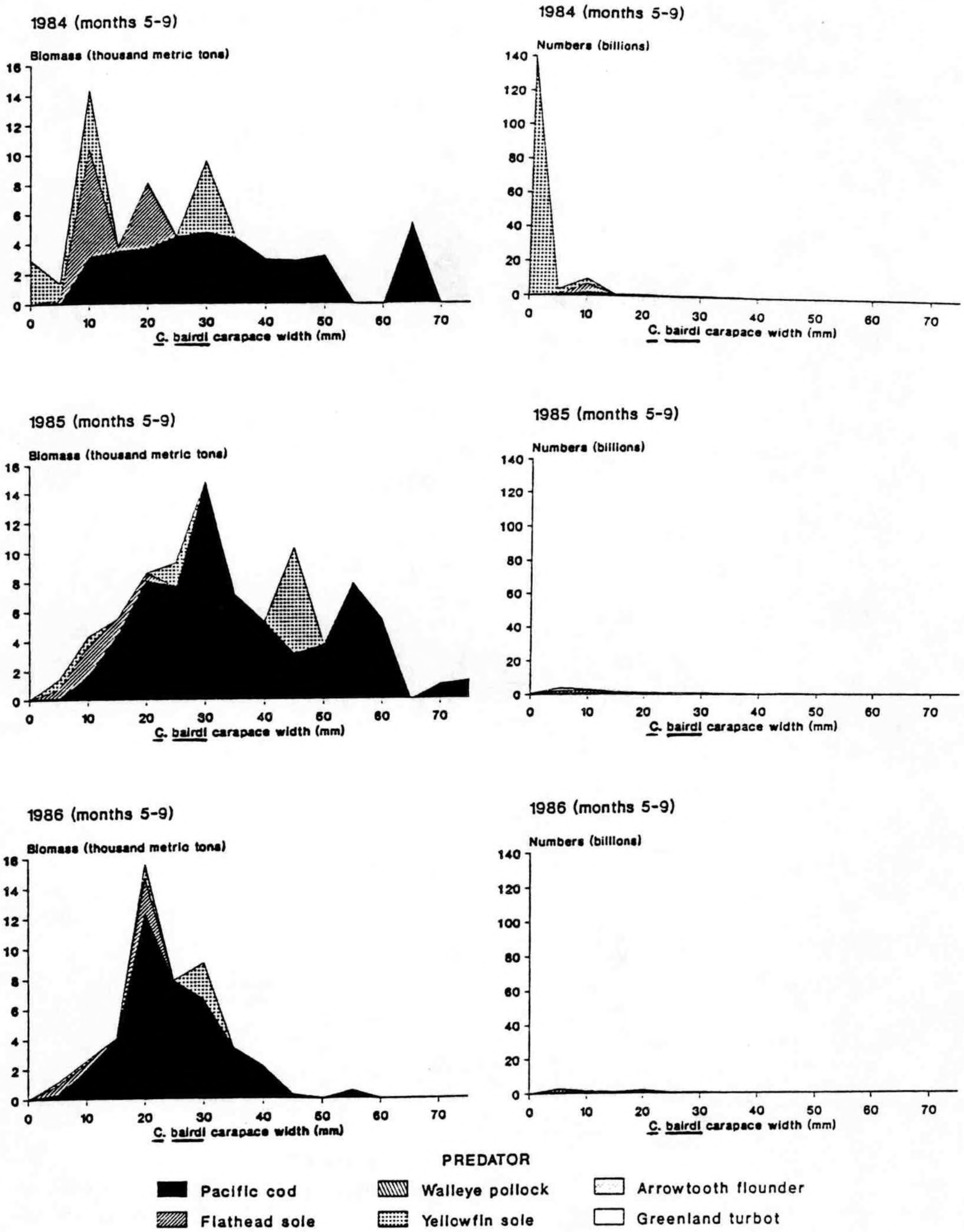


Figure 2.--Estimated biomass and numbers of Tanner crabs (<u>Chionoecetes</u> <u>bairdi</u>) consumed by groundfish predators during months 5 to 9 in 1984, 1985, and 1986 in the eastern Bering Sea by prey size.

biomass of snow crabs consumed by Pacific cod increased from 1984 (80,416 t) to 1986 (147,780 t), biomass consumed by yellowfin sole (10,594 t to 0 t) and flathead sole (7,807 t to 1,298 t) decreased over the time period. Numbers of snow crabs consumed by all predators decreased from 1984 (30.9 billion) to 1986 (13 billion), primarily as a result of the tremendous decrease in numbers consumed by yellowfin sole over the same time period (16.9 billion to 0).

The increase in biomass consumed and decrease in numbers consumed would seem to indicate an increase in the average size of snow crabs consumed by predators. Figure 1 supports this assertion, showing a dominance of crabs less than 15 mm carapace width (CW) (ages 0 to 1) in the numbers consumed during 1984 by yellowfin sole and flathead sole. Pacific cod mainly consumed crabs in the 15-35 mm size category (ages 1 and 2) and the biomass and numbers consumed in that size category increased from 1984 to 1986. This pattern is likely a reflection of a dominant year class of snow crabs increasing in size (age) and becoming vulnerable to a succession of predators that have increasing mouth size and ability to consume larger crabs.

These data suggest an increased recruitment of snow crab in 1984 or possibly 1983. Size at age of snow crabs is uncertain and the size mode of crabs at 10 mm CW observed in 1984 may have been from the 1983 or 1984 year class. RACE survey data support the contention of an increase in snow crab recruitment sometime in the mid-1980s. Increases in numbers of juvenile crabs becoming vulnerable to research trawl nets were observed from 1986 to 1987 (Stevens and MacIntosh 1990). There is about a 2-year time lag between the time young snow crabs become vulnerable to small-mouthed predators like yellowfin sole and flathead sole and the time those crabs become vulnerable to research trawls. Monitoring the amount of predation on small crabs by these predators may provide early indications of the presence of abundant year classes of crabs.

Reconstructing age-1 snow crab population size according to the methods of Forney (1977) could be done for 1984 and 1985 by using trawl estimates of numbers at age 3 and backcalculating age-1 population size assuming predation removals were the main source of mortality between age 1 and age 3. Consumption of age-1 snow crabs by all predators, expressed as a proportion of reconstructed age-1 population size in those years, was 83 and 34% for 1984 and 1985, respectively. These large changes in percent predation removals are an indication that predators may be exerting density-dependent influences on snow crab populations at age 1.

<u>Tanner Crabs</u>

Estimated total biomass of Tanner crabs consumed by all predators increased from 1984 (63,189 t) to 1985 (89,991 t) with a subsequent decrease in 1986 (48,822 t). Like snow crabs, most of the biomass removed was due to Pacific cod predation and most of the numbers removed in 1984 were from yellowfin sole predation. Total numbers consumed decreased from 1984 (153 billion) to 1986 (9.9 billion); however, a large peak of Tanner crabs less than 5 mm CW (age 0) were consumed by yellowfin sole in 1984 (Fig. 2). Trawl survey estimates of juvenile Tanner crab abundance show an increase from 1986 to 1987 (Stevens and MacIntosh 1990), again a reflection of the lag between the time small Tanner and snow crabs become vulnerable to groundfish predation and the time crabs can be assessed by trawl nets.

These results suggest a possible increased recruitment of Tanner crabs in 1984, the same year of possible increased recruitment in snow crab discussed previously. Although this might lead to a suggestion that good year-class production might be synchronous for snow and Tanner crabs, previous research has not supported this conclusion. Incze (1983) found that good year-class production of the two species assessed at the larval stage did not occur in the same years for the 1978 to 1981 time period in the eastern Bering Sea. He linked year-class production in snow and Tanner crabs to different environmental variables for each species. It is possible that 1984 was a year in which favorable environmental conditions were present for both species, especially if larvae of both species were spatially separated. Examination of Incze's hypothesis could be performed if more years of large year-class production of either species are noted in predation data and they correlate with environmental variables in the areas of high crab abundance in the first year of life.

Reconstruction of age-0 population size for 1984 and age-1 population size for 1984 and 1985, using trawl estimates of year-class abundance at age 3 and backcalculating abundance assuming predation removals were the main source of mortality, was done to determine whether predation was a variable proportion of year-class abundance. Changing proportions of predation removals would be an indication that predators were exerting density-dependent control of prey population size. Predation on Tanner crabs as a percent of the reconstructed age-0 population size in 1984 was 95% and the percent predation removals of age-1 crabs in 1984 and 1985 were 95 and 96%, respectively. These are high but stable rates of removal across years, indicating predators may not be exerting a density-dependent influence on Tanner crab population size.

Roundfish

Roundfish, for the purposes of this report, is defined as any groundfish species that is not a flatfish. Total estimated biomass and minimum numbers of the roundfishes Pacific cod, walleye pollock (*Theragra chalcogramma*), and Pacific herring (*Clupea harengus pallasi*) consumed by all groundfish predators are summarized in Tables 5-6 and Figures 3-5.

Table 5.--Estimated total biomass (metric tons) of roundfish consumed by groundfish predators by year during months 5 to 9, including walleye pollock cannibalism during months 10 to 12, in the eastern Bering Sea. Values in parentheses indicate cells with some missing prey size information.

Prey	Predator	Biomass consumed 1984	1985	1986
Pacific cod				
	Pacific cod	747.1	5,488.3	(6,771.7)
	Walleye pollock	-*	4,481.8	(2,530.3)
	Flathead sole	3,462.7	7.6	0
	Yellowfin sole	(9,220.2)	0	0
	Total	13,430.0	9,977.7	9,302.0
Walleye pollock				
	Pacific cod	(159,087.2)	201,615.7	(368,468.2)
	Walleye pollock	-	(3,487,110.1)	(947,890.0)
	Arrowtooth flounder	(99,382.2)	(62,408.3)	110,894.1
	Flathead sole	30,228.5	(86,328.6)	49,928.2
	Yellowfin sole	19,095.9	(22,075.4)	(12,669.0)
	Greenland turbot	(6,989.3)	5,313.0	3,862.3
	Total	314,783.1	3,864,851.1	1,493,711.8
Pacific herring				
	Pacific cod	0	(19,217.2)	(13,995.1)
	Walleye pollock	-	0	(26,592.0)
	Arrowtooth flounder	0	0	(3,852.5)
	Greenland turbot	0	104.4	0
	Total		19,321.6	44,439.6

*No walleye pollock stomach samples were taken in 1984.

Table 6.--Estimated numbers (millions) of roundfish consumed by groundfish predators by year during months 5 to 9, including pollock cannibalism during months 10 to 12, in the eastern Bering Sea. Values in parentheses indicate cells with some missing prey size information.

		Number consumed		
Prey	Predator	1984	1985	1986
Pacific cod				
	Pacific cod	3.6	274.1	(75.5)
	Walleye pollock	-*	2,681.0	(0)
	Flathead sole	1,120.4	308.3	0
	Yellowfin sole	(0)	0	0
	Total	1,124.0	3,263.4	75.5
Walleye pollock				
	Pacific cod	(2,239.4)	6,136.1	(10,413.3)
	Walleye pollock	-	(1,009,260.0)	(189,050.0)
	Arrowtooth flounder	(4,646.7)	(20,488.4)	22,765.7
	Flathead sole	9,856.2	(9,555.9)	7,078.1
	Yellowfin sole	30,676.2	(4,003.9)	(2,270.3)
	Greenland turbot	(413.9)	172.4	63.7
	Total	47,832.4	1,049,616.7	231,641.1
Pacific herring				
	Pacific cod	0	(302.5)	(250.9)
	Walleye pollock	-	0	(295.8)
	Arrowtooth flounder	0	0	(7.2)
	Greenland turbot	0	0.8	0
	Total	0	303.3	553.9

*No walleye pollock stomach samples were taken in 1984.

Pacific Cod

Total estimated biomass of Pacific cod consumed by groundfish predators (Table 5) decreased from 1984 (13,430 t) to 1985 (9,978 t) and remained stable from 1985 to 1986 (9,302 t). Since walleye pollock were not sampled during 1984, consumption of cod by pollock during that year was not estimated. This implies that consumption of Pacific cod in 1984 would be higher than shown here if pollock predation were taken into account. Other predators on Pacific cod include flathead sole and yellowfin sole. Although Pacific cod was responsible for most of the Pacific cod predation during 1985 and 1986 (55 and 73% of biomass, respectively), yellowfin sole consumed the highest biomass of cod in 1984 (69%).

The estimated numbers consumed (Table 6) are difficult to interpret given the lack of walleye pollock data during 1984 and the absence of prey size information necessary to compute numbers consumed by yellowfin sole during 1984 or by pollock during 1986. Presumably, numbers consumed in 1984 would be much higher than the other 2 years if sizes of Pacific cod consumed by yellowfin sole were available because yellowfin sole consumed such a large biomass of cod, and cod sizes consumed by sole would most likely be less than 10 cm (age 0). Cod cannibalism included cod ranging in size from 5 to 35 cm standard length (SL) (ages 0 to 3). Pollock and flathead sole consumed only age-0 cod (Fig. 3).

In 1984, the smaller-mouthed yellowfin sole and flathead sole consumed Pacific cod that were presumably age 0, suggesting that abundance of age-0 Pacific cod was higher during that year or that they were more available to these predators. Thompson and Shimada (1990) show that the 1984 cod year-class size (assessed at age 3) was twice as high as the 1985 year-class size. This implies that yellowfin sole and flathead sole responded to an increase in abundance of age-0 cod in 1984 by increasing their consumption of that species. It is possible that the diet of these predators might be used as an early indicator of cod year-class abundance. More prey size composition data and more years of predation data need to be examined to determine the feasibility of this suggestion.

Walleye Pollock

Walleye pollock was consumed by all the major groundfish predators considered here. Since walleye pollock as predators were not sampled during 1984, the total estimated biomass and number consumed in that year are large underestimates of the totals if pollock cannibalism had been taken into account. In 1985 and 1986, pollock cannibalism dominated pollock removals in terms of biomass and numbers. Pacific cod was the next most important predator in terms of biomass removals while yellowfin sole consumed the most in terms of numbers in 1984. Incomplete prey size information on the pollock prey of many predators made

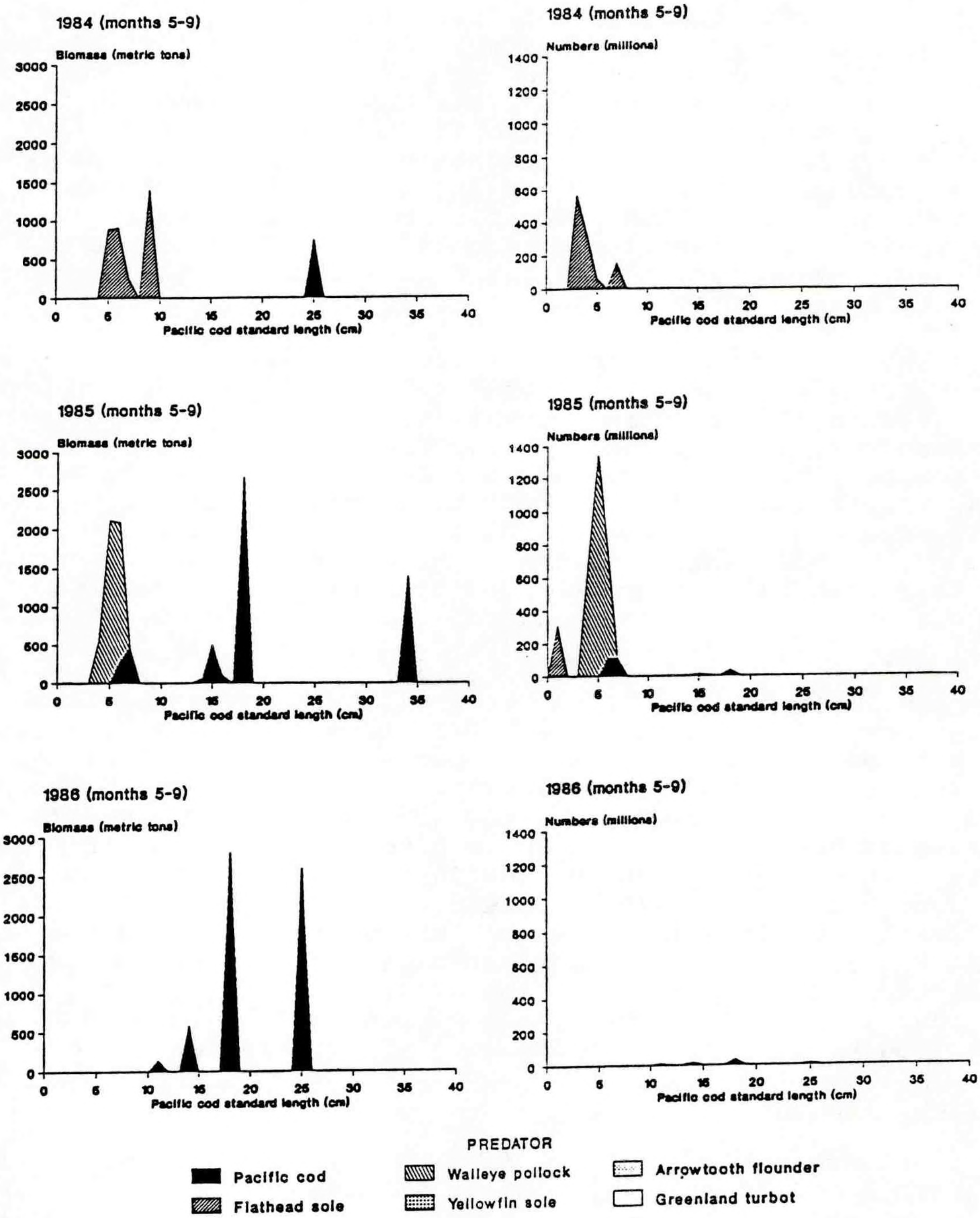


Figure 3.--Estimated biomass and numbers of Pacific cod consumed by groundfish predators during months 5 to 9 in 1984, 1985, and 1986 in the eastern Bering Sea by prey size.

it impossible to use changes in numbers consumed across years to reliably indicate changes in prey abundance because variable proportions of the biomass consumed were converted to numbers depending on availability of prey size information.

Sizes of walleye pollock consumed by predators indicate most were age-0 pollock (less than 14 cm SL) in all years (Fig. 4). Pacific cod tended to consume a wide range of pollock sizes, mainly from 5 to 45 cm SL. Most age-1 pollock (approximately 14-22 cm SL) were consumed by cod, pollock, and arrowtooth flounder (Atheresthes stomias). It appears that more age-0 pollock were consumed in 1985 than in 1986, with both years consisting mainly of pollock cannibalism. Wespestad and Traynor (1990) show that the 1985 pollock year class was larger than the 1986 year class, both as age-1 fish caught in survey trawls and as age-3 fish estimated from cohort analysis. It seem likely, since predation occurs mainly on age-0 fish, that the larger amount of pollock consumed in 1985 is the result of increased density of age-0 pollock available to groundfish predators relative to 1986.

Livingston (1989b) evaluated cannibalism data on walleye pollock in the eastern Bering Sea from 1981 to 1987, using some of the same data used here but slightly different analysis methods. She concluded that pollock cannibalism, particularly of age-0 pollock, was always large relative to the number of pollock remaining from a year class at age 3. An attempt to reconstruct age-0 population sizes and determine whether cannibalism was a density-dependent factor controlling pollock population size was performed but was inconclusive. Due to the method of reconstruction, cannibalism always constituted over 90% of the mortality of age-0 pollock and only minor changes in percent mortality across years occurred. Use of better reconstruction methods, which include pollock removals by other predators with more complete pollock prey size information, might provide a more definitive conclusion about density-dependent predation effects. The number of years of data presented in this report are only sufficient to reconstruct age-0 pollock for 1984, which would be inappropriate given no pollock stomach data were collected in that year and would thus produce a severe underestimate of age-0 pollock predation and reconstructed age-0 population size. Analysis of more years of predation data will give a time series of reconstructed age-0 population numbers and percent predation, from which better conclusions about density-dependent predation can be made.

Pacific Herring

The consumption of Pacific herring was observed only in 1985 and 1986, with both total estimated biomass and numbers consumed increasing from 1985 (19,322 t, 303 million) to 1986 (44,439 t, 554 million) (Tables 5-6). The major consumers of herring in both years were Pacific cod and walleye pollock. These values do not include some very small fish that were identified as herring in walleye pollock stomach samples during months 10-12, since it

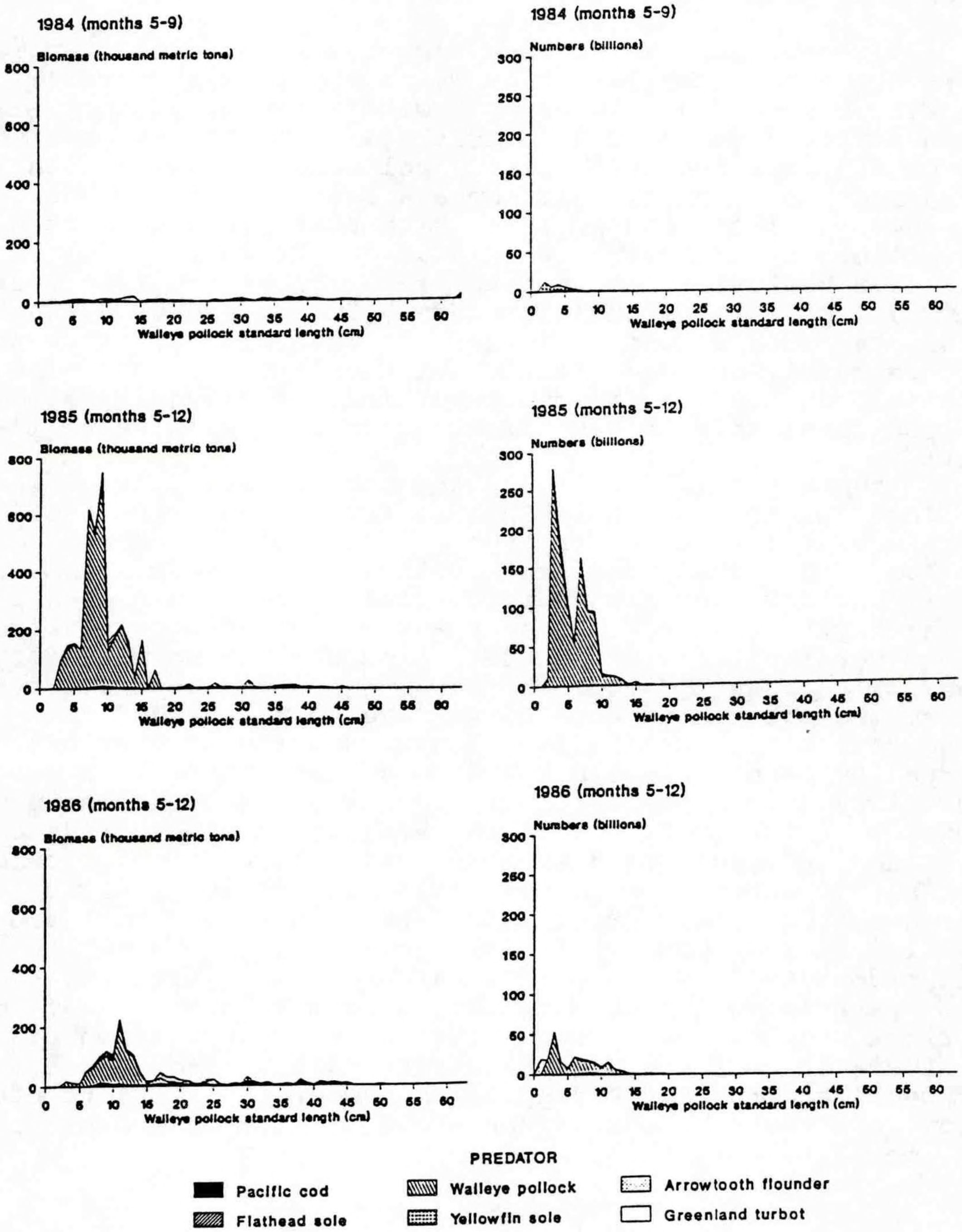


Figure 4.--Estimated biomass and numbers of walleye pollock consumed by groundfish predators other than walleye pollock during months 5 to 9 in 1984 and by groundfish predators including walleye pollock during months 5 to 9 plus cannibalism by walleye pollock during months 10 to 12 in 1985 and 1986 in the eastern Bering Sea by prey size.

is likely these fish were actually juvenile walleye pollock that had been identified incorrectly. Refer to the section on walleye pollock predation to see those data.

A wide size range of Pacific herring was consumed, ranging from 10 to 30 cm (Fig. 5), or about age 1 to age 9+. Cohort analysis estimates of herring biomass in 1985 and 1986 are 487,481 t and 396,711 t, respectively (V. Wespestad, Alaska Fisheries Science Center, Pers. commun., November 1990). Groundfish predation in those years, expressed as a percentage of the available herring biomass, is 4% in 1985 and 11% in 1986. Predators did not decrease consumption in 1986 when apparent biomass of herring was lower, thus producing a higher predation removal rate in 1986. Herring consumption by these predators tended to be sporadic in time and space and may depend on encounter rates of herring schools rather than overall biomass.

Flatfish

Arrowtooth Flounder

Consumption of arrowtooth flounder by all predators was variable across years (Tables 7-8). Estimated total biomass consumed in 1985 (15,436 t) was 3 times greater than the previous year and biomass consumed in 1986 (781 t) was over 15 times less than that in 1985. The high consumption observed in 1985 was due mainly (99%) to walleye pollock predation. None of the arrowtooth flounder consumed by pollock in that year were measurable so no information on numbers consumed by pollock are available. Arrowtooth flounder cannibalism was responsible for most of the biomass consumed during 1984. The fish consumed by flounder in that year were about 15 cm SL and totalled 46 million in terms of numbers consumed. The highest estimated numbers consumed were for predation by yellowfin sole in 1984, where almost 2 billion arrowtooth flounder of about 3 cm SL (possibly age 0) were consumed.

Total biomass consumed in each year can be compared with the estimated standing stock of arrowtooth flounder to determine the relative importance of predation on the arrowtooth flounder population. Total consumption in each year, expressed as a percentage of trawl estimated biomass of arrowtooth flounder from Bakkala and Wilderbuer (1990a), is 2.3, 9.6, and 0.3% for 1984, 1985, and 1986, respectively. These are variable but mostly small percentages of the arrowtooth flounder population, indicating predation is probably not a major source of mortality in the size ranges of arrowtooth flounder consumed by groundfish predators. The one exception is the 2 billion small arrowtooth flounder consumed by yellowfin sole in 1984, which might be a significant portion of the unassessed part of the juvenile arrowtooth flounder population. Examination of possible predation impact on this part of the population requires more information about juvenile arrowtooth flounder population size.

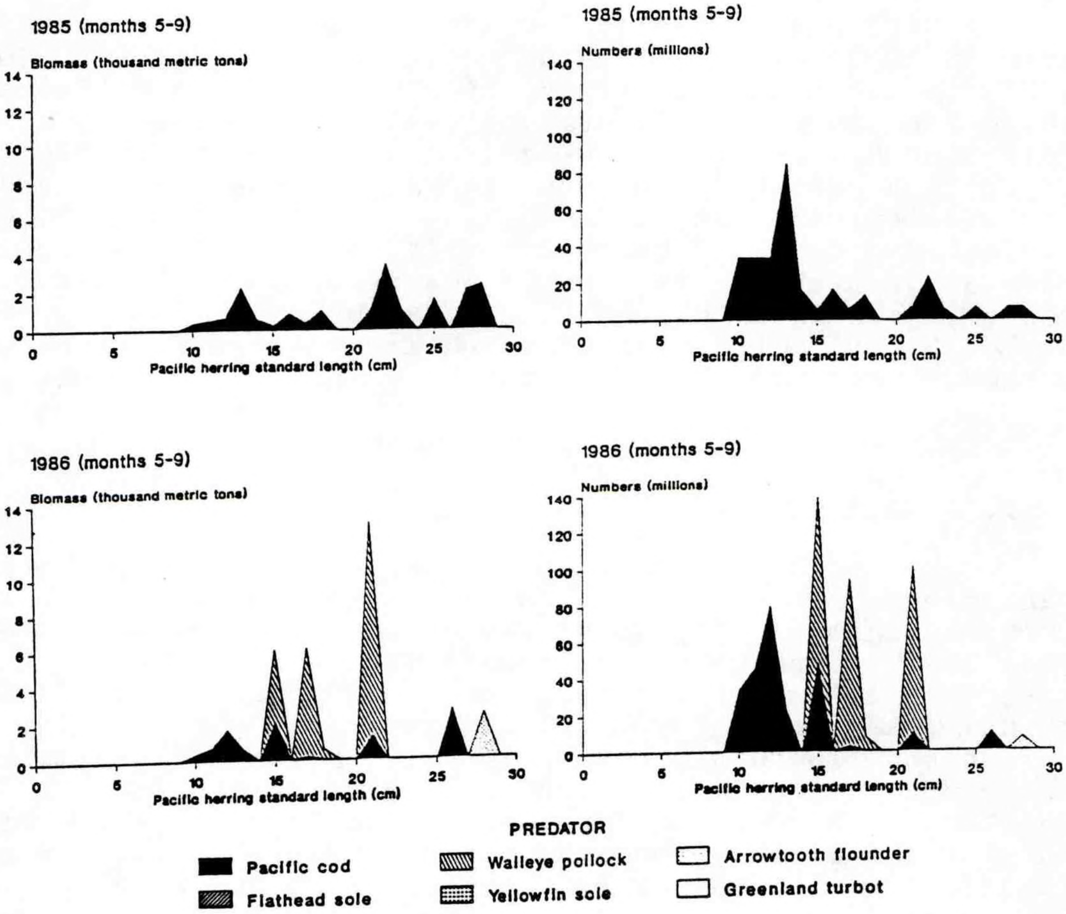


Figure 5.--Estimated biomass and numbers of Pacific herring consumed by groundfish predators during months 5 to 9 in 1984, 1985, and 1986 in the eastern Bering Sea by prey size.

Table 7.--Estimated total biomass (metric tons) of flatfish consumed by groundfish predators by year during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells where some prey size information was not available.

Prey	Predator	Biomass consumed 1984	1985	1986
Arrowtooth flounder				
	Pacific cod	972.1	100.2	718.8
	Walleye pollock	-*	(15,334.0)	0
	Arrowtooth flounder	2,484.3	(1.9)	(61.8)
	Yellowfin sole	871.1	0	0
	Total	4,327.5	15,436.1	780.6
Flathead sole				
	Pacific cod	6,759.2	4,281.4	13,812.7
	Walleye pollock	-	1,647.8	0
	Arrowtooth flounder	3,027.6	0	102.6
	Greenland turbot	0	0	78.0
	Total	9,786.8	5,929.2	13,993.3
Rock sole				
	Pacific cod	6,949.0	15,780.0	34,955.5
	Walleye pollock	-	1,012.2	3,848.1
	Flathead sole	27.3	3,903.7	0
	Yellowfin sole	1,043.6	147.6	0
	Total	8,019.9	20,843.5	38,803.6
Yellowfin sole				
	Pacific cod	56,290.8	28,359.2	42,330.3
Greenland turbot				
	Yellowfin sole	3,918.8	0	0
Pacific halibut				
	Yellowfin sole	89.4	0	0

*No walleye pollock stomach samples were taken in 1984.

Table 8.--Estimated numbers (millions) of flatfish consumed by groundfish predators by year during months 5 to 9 in the eastern Bering Sea. Values in parentheses indicate cells where some prey size information was not available.

Prey	Predator	Number consumed 1984	1985	1986
Arrowtooth flounder				
	Pacific cod	6.4	2.9	39.9
	Walleye pollock	-*	(0)	0
	Arrowtooth flounder	46.4	(0)	(0)
	Yellowfin sole	1,867.7	0	0
	Total	1,920.5	2.9	39.9
Flathead sole				
	Pacific cod	275.7	175.0	343.2
	Walleye pollock	-	1,952.6	0
	Arrowtooth flounder	87.4	0	36.1
	Greenland turbot	0	0	1.6
	Total	363.1	2,127.6	380.9
Rock sole				
	Pacific cod	126.9	412.2	1,546.3
	Walleye pollock	-	335.6	141.4
	Flathead sole	21.3	591.9	0
	Yellowfin sole	23,462.6	4,173.9	0
	Total	23,610.8	5,513.6	1,687.7
Yellowfin sole				
	Pacific cod	480.4	313.0	651.1
Greenland turbot				
	Yellowfin sole	81,720.6	0	0
Pacific halibut				
	Yellowfin sole	727.8	0	0

*No walleye pollock stomach samples were taken in 1984.

Flathead Sole

Estimated total biomass of flathead sole consumed by groundfish predators ranged from 5,929 t in 1985 to 13,993 t in 1986 (Table 7). Biomass consumed in 1984 was intermediate between the other 2 years. Although 1985 had the lowest value for biomass consumed, it was the year that most flathead sole in terms of numbers were consumed (2,128 million) (Table 8). This was due to the large number of very small (<5 cm SL or possibly age 0) flathead sole consumed by walleye pollock in that year (Fig. 6). Pacific cod was the most important predator of flathead sole in all years if biomass consumed is considered and cod was also most important in terms of numbers removed except for 1985. Other predators on flathead sole included arrowtooth flounder and Greenland turbot (Reinhardtius hippoglossoides).

Most of the flathead sole consumed were less than 20 cm SL (Fig. 6) or less than age 3. Walters and Wilderbuer (1990a) report that flathead sole do not recruit to trawl fisheries until age 3 and although some age-2 fish are caught in research trawls they are probably not fully recruited. This precludes a relevant comparison of predator removals of juveniles with the juvenile flathead sole population size. However, total biomass removals by predators expressed as a percentage of trawl survey estimates of biomass for 1984, 1985, and 1986 are 2.8, 1.8, and 3.8%, respectively. These are fairly small proportions, at least of the adult portion of the population, indicating predation may not be a significant source of mortality for flathead sole.

In all 3 years, predators consumed some flathead sole that were age 0, but total numbers of age-0 flathead sole consumed in 1985 were much higher than the other 2 years (Fig. 6). This might be an indication of an abundant year class produced in 1985. These fish would be fully recruited to the trawl survey in 1988. Biomass estimates of flathead sole in 1988 showed a 37% increase from the previous year, possibly indicating an influx of newly recruited fish to the trawl survey. Size composition of the flathead sole population over that time period is needed for verification.

Rock Sole

Total estimated biomass of rock sole (Lepidopsetta bilineata) consumed by groundfish predators increased from 1984 (8,019 t) to 1986 (38,803 t) (Table 7), while total numbers consumed decreased over the time period (23.6 billion to 1.7 billion) (Table 8). Biomass removals over all 3 years were mainly due to Pacific cod predation while the most in numbers were consumed by yellowfin sole. Size composition of rock sole consumed in all 3 years tended to consist of fish mainly between 10 and 20 cm SL (Fig. 7), sizes that are probably not fully vulnerable to trawl surveys.

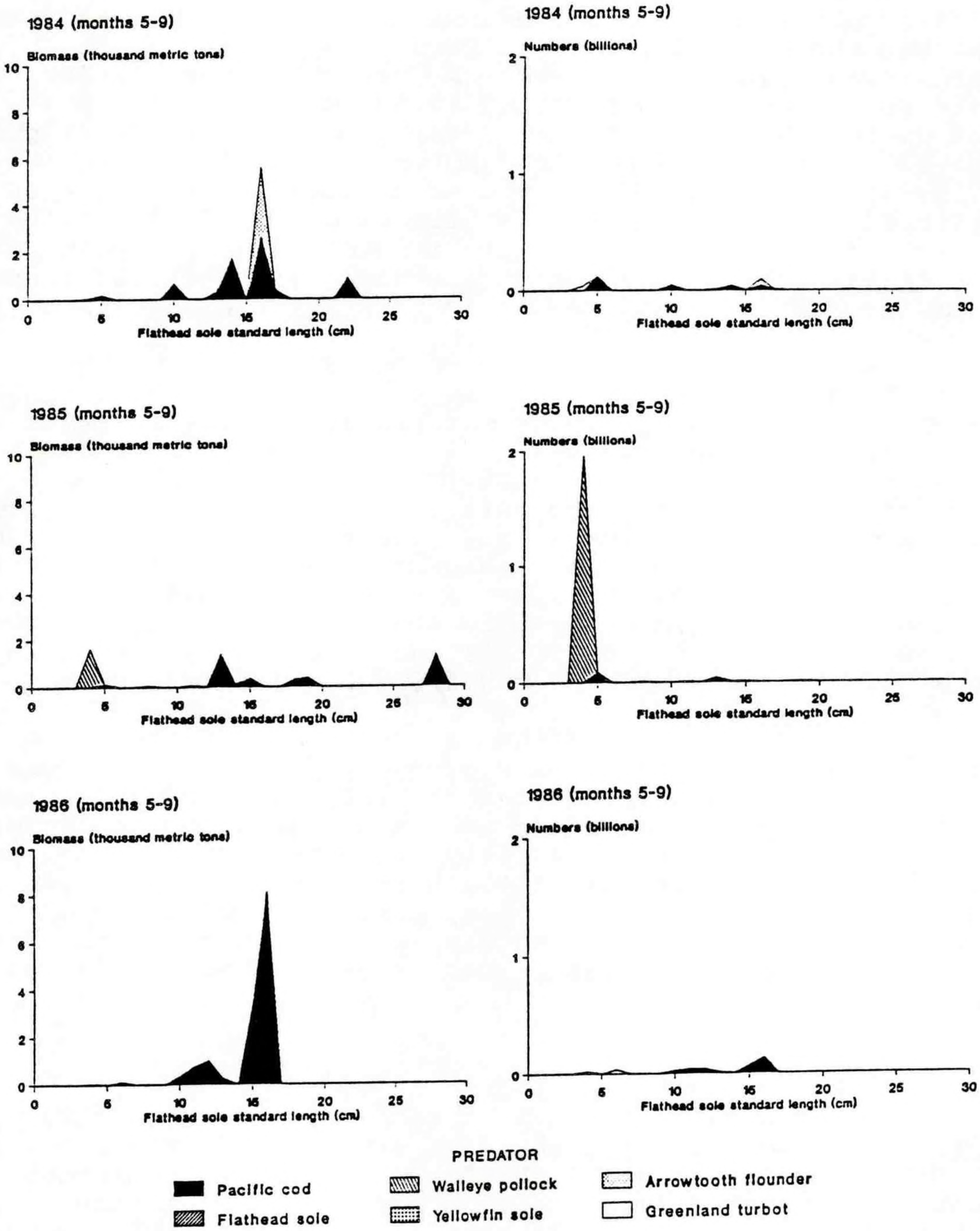


Figure 6.--Estimated biomass and numbers of flathead sole consumed by groundfish predators during months 5 to 9 in 1984, 1985, and 1986 in the eastern Bering Sea by prey size.

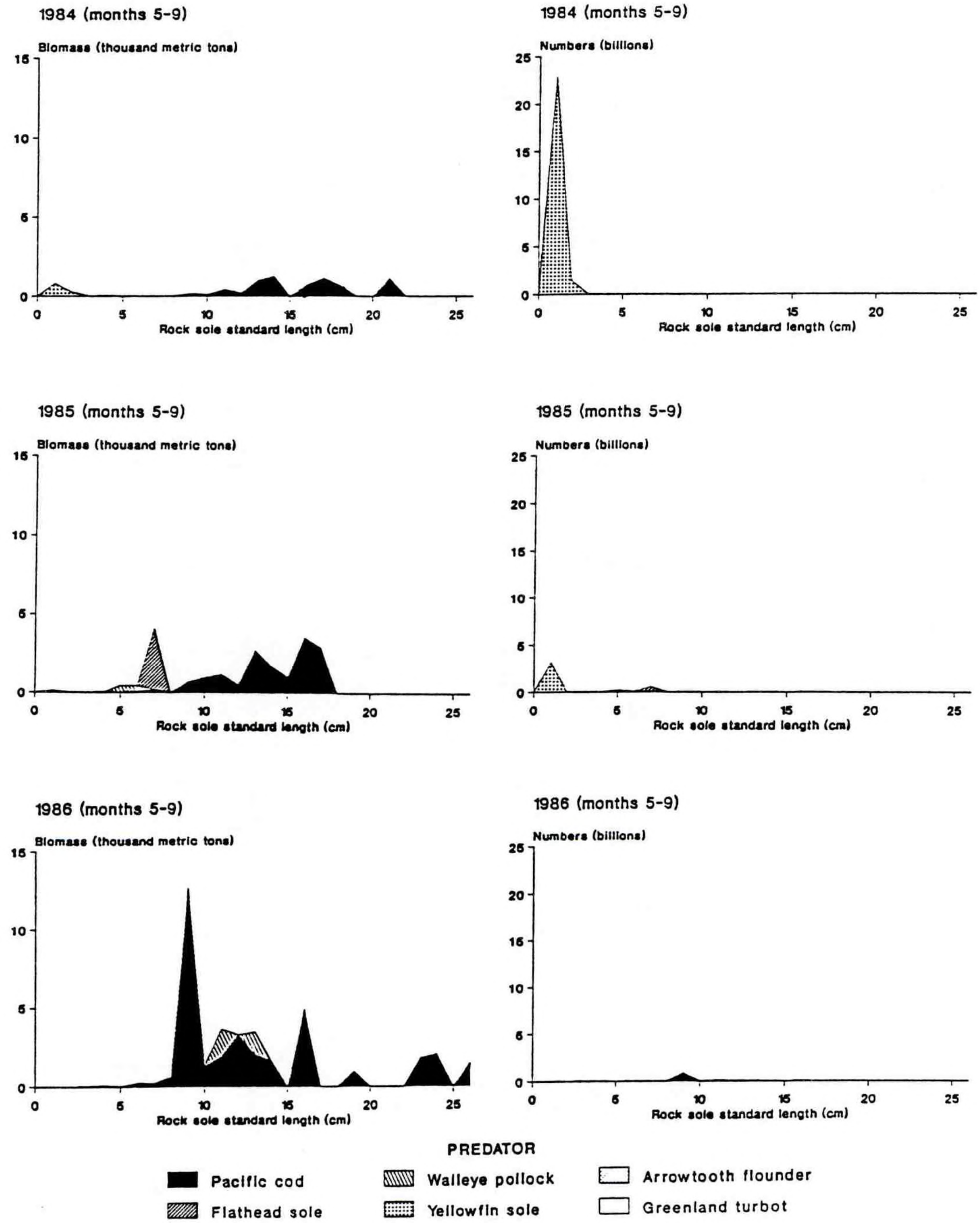


Figure 7.--Estimated biomass and numbers of rock sole consumed by groundfish predators during months 5 to 9 in 1984, 1985, and 1986 in the eastern Bering Sea by prey size.

Yellowfin sole consumed large numbers of age-0 rock sole in 1984 (23.4 billion), which might indicate an abundant 1984 year class of rock sole. However, comparison with survey estimates of abundance between 1987 and 1988 (Walters and Wilderbuer 1990b), which might show whether this year class was more abundant than adjacent ones when it became fully vulnerable to the trawl survey, does not show that the 1984 year class was extraordinary in size. Trawl survey estimates of abundance of the 1984 year class increased fourfold from 1987 to 1988 but so did adjacent year classes, indicating either a change in trawl efficiency over the 2 years or some overall change in rock sole availability. Total biomass consumed, expressed as a percentage of survey estimates of biomass in the 3 years, were 0.8, 2.9, and 3.8% for 1984, 1985, and 1986, respectively.

Yellowfin Sole

Pacific cod was the only groundfish that consumed yellowfin sole (Tables 7-8, Fig. 8). Estimated total biomass consumed was highest in 1984 (56,291 t), while estimated total numbers consumed was highest in 1986. Most yellowfin sole eaten in 1984 and 1985 were between 10 and 25 cm SL (ages 3-10), while in 1986 cod consumed large numbers of yellowfin sole between 5 and 10 cm SL (less than age 3). Survey and cohort analysis estimates of yellowfin sole abundance (Bakkala and Wespestad 1990) indicate a decrease in the biomass of yellowfin sole between 10 and 25 cm SL from 1984 to 1986. The decline in cod consumption of yellowfin sole in that size range over the same time period may be a reflection of the changing yellowfin sole population size. Cod consumption, expressed as a percentage of cohort analysis estimates of yellowfin sole biomass for ages 7 to 10, is 5.5, 3.1, and 4.7% for 1984, 1985, and 1986, respectively.

Greenland Turbot

Yellowfin sole was the only groundfish that consumed Greenland turbot (Tables 7-8) and predation on turbot occurred only in 1984. Four thousand metric tons of turbot were consumed at sizes between 1 and 3 cm SL (probably age 0), amounting to 82 billion fish in terms of numbers. Trawl survey estimates of juvenile Greenland turbot biomass decreased from 17,900 t in 1984 to 5,600 t in 1986 (Bakkala and Wilderbuer 1990b) and do not show any indication of an abundant 1984 year class.

Pacific Halibut

Pacific halibut (Hippoglossus stenolepis) was consumed only by yellowfin sole during 1984 (Tables 7-8). Consumed halibut were 2 cm SL (age 0). Total estimated consumption by yellowfin sole was 89 t or 728 million halibut. Trawl surveys could not sample halibut of this size (2 cm SL); however, the survey estimated the biomass of adult halibut in the Bering Sea during 1985 to be 79,932 t. Yellowfin sole consumption was only 0.1% of the halibut standing stock value. The small size of halibut

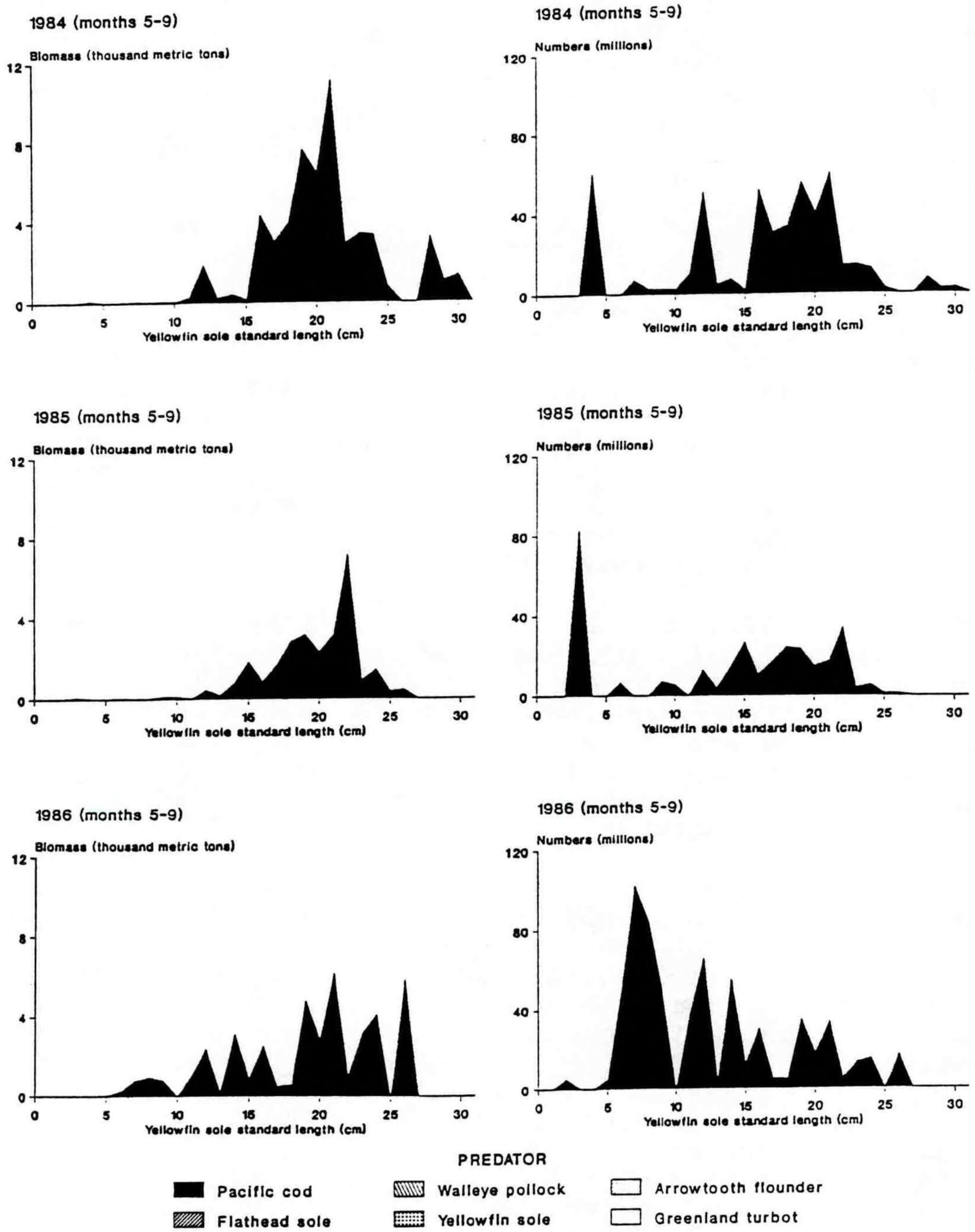


Figure 8.--Estimated biomass and numbers of yellowfin sole consumed by groundfish predators during months 5 to 9 in 1984, 1985, and 1986 in the eastern Bering Sea by prey size.

consumed implies they were postlarvae that had not yet settled to the bottom. Deriso (1987) suggests that these fish may be transported into the Bering Sea from the Gulf of Alaska. It is possible that yellowfin consumption of halibut is a transitory phenomenon, occurring during restricted time periods when postlarvae are swept into shallow waters and start settling to the bottom. The total consumption estimates assume that predation is occurring throughout the month 5 to 9 period, whereas the vulnerability of young halibut to yellowfin sole may be of shorter duration, implying that consumption estimates are probably high.

CONCLUSIONS

Predation by Pacific cod and yellowfin sole on Tanner and snow crabs appears to include a large portion of the juvenile Tanner and snow crab population and may be a density-dependent factor. Walleye pollock cannibalism was the most important source of groundfish predation on age-0 pollock and may also prove to be a density-dependent factor. Figure 9 shows a breakdown of total numbers consumed of the two species of Chionoecetes crabs and of pollock by age. These numbers indicate large recruitment of snow crab in 1983-84, Tanner crab in 1984, and walleye pollock in 1985. (However, pollock stomachs were not sampled in 1984 so pollock predation in that year is a severe underestimate.) A longer time series of predation data is needed to determine whether these data can be used as early indicators of year-class abundance. A better understanding of Tanner and snow crab size at age and of the juvenile abundances of both these crabs as well as walleye pollock are needed to determine whether predation is a density-dependent factor controlling population size.

In many cases, yellowfin sole appeared to be an early sampler of Tanner and snow crabs, blue king crabs, and several flatfish species. Again, a longer time series of predation data by yellowfin sole and correlation with juvenile abundance estimates of these prey species may determine whether this predation is an early indicator of the presence of abundant year classes.

Consumption estimates for all prey should be viewed at the present time more as indices of consumption rather than actual consumption for several reasons. First, most of the calculations (except for walleye pollock as predators) consider only the time period from May through September in each year. Although this is the main feeding period for most fishes in the Bering Sea, consumption of prey certainly occurs during other parts of the year. Inadequate numbers and spatial distribution of stomach samples during other parts of the year combined with gaps in knowledge about the seasonal migrations of groundfish predators

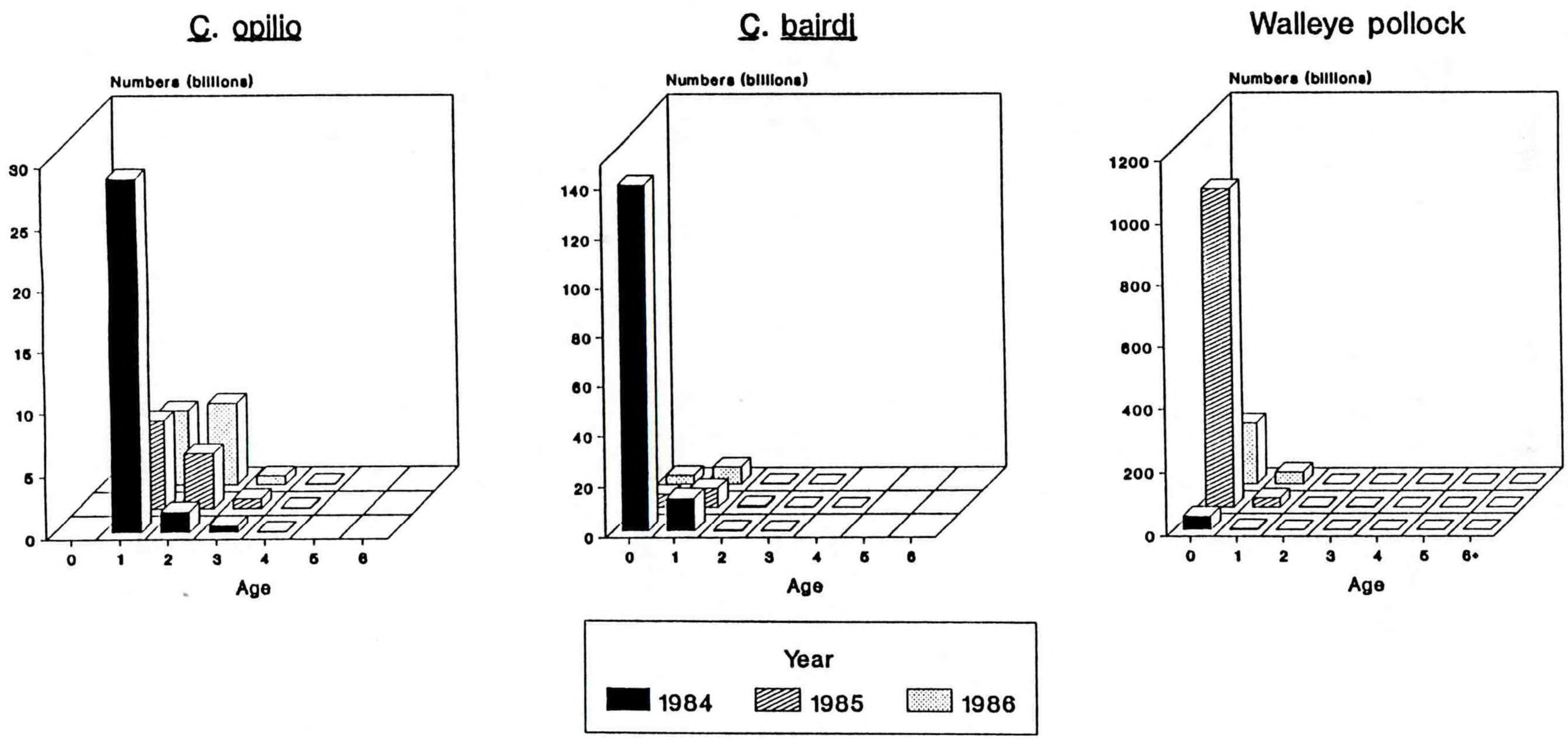


Figure 9.--Estimated numbers at age of snow crabs (<u>Chionoecetes opilio</u>), Tanner crabs (<u>C</u>. <u>bairdi</u>), and walleye pollock consumed by groundfish predators during months 5 to 9 in 1984, 1985, and 1986 in the eastern Bering Sea.

make calculation of predation in other parts of the year difficult without seasonal resource assessment surveys in the area.

Predation estimates during the time period considered here may be underestimates for prey that are consumed year-round, such as Tanner and snow crabs that are consumed by Pacific cod. Predation estimates for yellowfin sole predation on newly settling stages of crabs and flatfishes may be overestimates if the prey species are not available to the predator during the whole time period. Also, for prey that have a very limited spatial distribution within a stratum, such as red and blue king crabs, inadequate stomach sampling throughout the whole stratum can provide biased estimates of consumption. For these prey, consumption estimates would be biased upwards if sampling was concentrated more in areas where king crab occur and estimates would be biased downwards if stomach sampling was not performed in king crab areas. Stomach sampling density was doubled beginning in 1989 so problems such as this will be minimized. Different treatment of the data can also remove the bias by weighting consumption at each station within a stratum by the predator biomass at that station.

Estimates of total numbers consumed are underestimates for most prey since prey size data were not available for all predator-stratum combinations to convert biomass consumed to numbers consumed. Additional assumptions about prey sizes consumed by each predator need to be made before converting biomass to numbers in strata lacking prey size information. Future reports may use the overall prey size distribution over all strata to compute numbers consumed in one or more strata without size information.

Total consumption estimates in terms of biomass are underestimates of total groundfish predation if important groundfish predators of a particular prey have not been sampled. Rock sole and Alaska plaice (*Pleuronectes quadrituberculatus*) are growing parts of the groundfish biomass in the eastern Bering Sea and consideration of their predation is becoming important. Similarly, Pacific halibut is a predator that consumes many commercially important prey and, although it is not a dominant component of the Bering Sea groundfish biomass, needs to be considered. Stomach sampling of rock sole, Alaska plaice, and Pacific halibut is now a regular part of the Food Habits Program.

CITATIONS

Bakkala, R. G., and V. G. Wespestad. 1990. Yellowfin sole. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 67-85. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Bakkala, R. G., and T. K. Wilderbuer. 1990a. Arrowtooth flounder. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea Aleutian Islands region as assessed in 1988, p. 102-111. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Bakkala, R. G., and T. K. Wilderbuer. 1990b. Greenland turbot. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea Aleutian Islands region as assessed in 1988, p. 86-101. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Deriso, R. B. 1987. Pacific halibut: Biology, fishery, and management. Northwest Env. J. 3:129-144.

Forney, J. L. 1977. Reconstruction of yellow perch (Perca flavescens) cohorts from examination of walleye (Stizostedion vitreum vitreum) stomachs. J. Fish. Res. Board Can. 34:925-932.

Incze, L. S. 1983. Larval life history of Tanner crabs, Chionoecetes bairdi and C. opilio, in the southeastern Bering Sea and relationships to regional oceanography. Ph.D. Thesis, Univ. Washington, Seattle, 191 p.

Jensen, G. C., and D. A. Armstrong. 1989. Biennial reproductive cycle of blue king crab, Paralithodes platypus, at the Pribilof Islands, Alaska and comparison to a congener, P. camtschatica. Can. J. Fish. Aquat. Sci. 46:932-940.

Livingston, P. A. 1989a. Interannual trends in Pacific cod, Gadus macrocephalus, predation on three commercially important crab species in the eastern Bering Sea. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 87:807-827.

Livingston, P. A. 1989b. Interannual trends in walleye pollock, Theragra chalcogramma, cannibalism in the eastern Bering Sea. Proceedings of International Symposium on the Biology and Management of Walleye Pollock, Nov. 14-16, 1988, Anchorage, Alaska. Alaska Sea Grant Rep. No. 89-1.

Stevens, B. G., and R. A. MacIntosh. 1990. Report to industry on the 1990 eastern Bering Sea crab survey. NWAFC Processed Rep. 90-09, 50 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE., Seattle, WA 98115.

Thompson, G. G., and A. M. Shimada. 1990. Pacific cod. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 44-66. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Walters, G. E., and T. K. Wilderbuer. 1990a. Other flatfish. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 123-141. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Walters, G. E., and T. K. Wilderbuer. 1990b. Rock sole. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 112-122. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Wespestad, V. G., and J. J. Traynor. 1990. Walleye pollock. In L-L. Low and R. E. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988, p. 19-43. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.