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Food Habits of Key Groundfish Species in the Eastern Bering Sea Slope Region

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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ABSTRACT

The eastern Bering Sea continental slope region contains many groundfish species that are important to the Bering Sea ecosystem. Several studies have described the food habits of these species in the eastern Bering Sea shelf region, however few studies have been conducted for the slope region. Consequently, the food habits of the major groundfish in this region are poorly understood. The focus of this study was to identify the trophic interactions of walleye pollock (Theragra chalcogramma), Pacific cod (Gadus macrocephalus), Greenland turbot (Reinhardtius hippoglossoides), arrowtooth flounder (Atheresthes stomias), and flathead sole (Hippoglossoides elassodon) in the slope region of the eastern Bering Sea. Stomach contents of 1,089 walleye pollock, 311 Pacific cod, 455 Greenland halibut, 282 arrowtooth flounder, and 366 flathead sole were examined. The general diet of each species is described and dietary variation due to predator size, depth, season, and latitude within the slope region are examined. Walleye pollock are known to be the most important prey fish in the eastern Bering Sea shelf region. In the slope region, species from the families Bathylagidae and Myctophidae were found, in addition to pollock, to be important forage fish of groundfish predators

CONTENTS

INTRODUCTION

The eastern Bering Sea supports one of the largest groundfish populations of the world's oceans, which in turn supports a multi-million dollar commercial fishery Species such as walleye pollock (Theragra chalcogramma); Pacific cod (Gadus macrocephalus); Pacific halibut (Hippoglossus stenolepis); and king (Paralithodes spp.); Tanner (Chionoecetes bairdi); and snow crabs (Chionoecetes opilio) are important components of the eastern Bering Sea ecosystem which is managed by state, federal, and international fisheries management organizations. In recent years, managers have been moving toward a multi-species management approach that requires a more thorough understanding of the dynamics of ecosystems than had been previously known. One of the key parameters needed for successful multi-species management is an accurate estimate of the natural mortality pressure exerted on a particular species by other species in the system. Understanding predator-prey relationships is a complex, yet crucial aspect of the natural mortality rates of a population. Quite a body of work has been generated around the food habits of key groundfish predators in the eastern Bering Sea continental shelf where the majority of the groundfish populations are found, and researchers are beginning to look at the multi-species interactions that occur between fish, marine mammals, and birds, However, little work has been done to determine the food habits of these important groundfish species over the eastern Bering Sea continental slope region,

The eastern Bering Sea continental slope region (Fig. 1) is the area which links the eastern Bering Sea continental shelf (<200 m) to the Aleutian basin (>2,000 m); however, most of the important groundfish populations are found between 200 and 500 m. The area covered by the continental slope is small relative to the shelf region due to its steepness. Groundfish populations in the eastern Bering Sea slope region are also small relative to those on the eastern Bering Sea shelf but do represent an important component of the ecosystem. Walleye pollock, Pacific cod, Greenland turbot (Reinhardtius

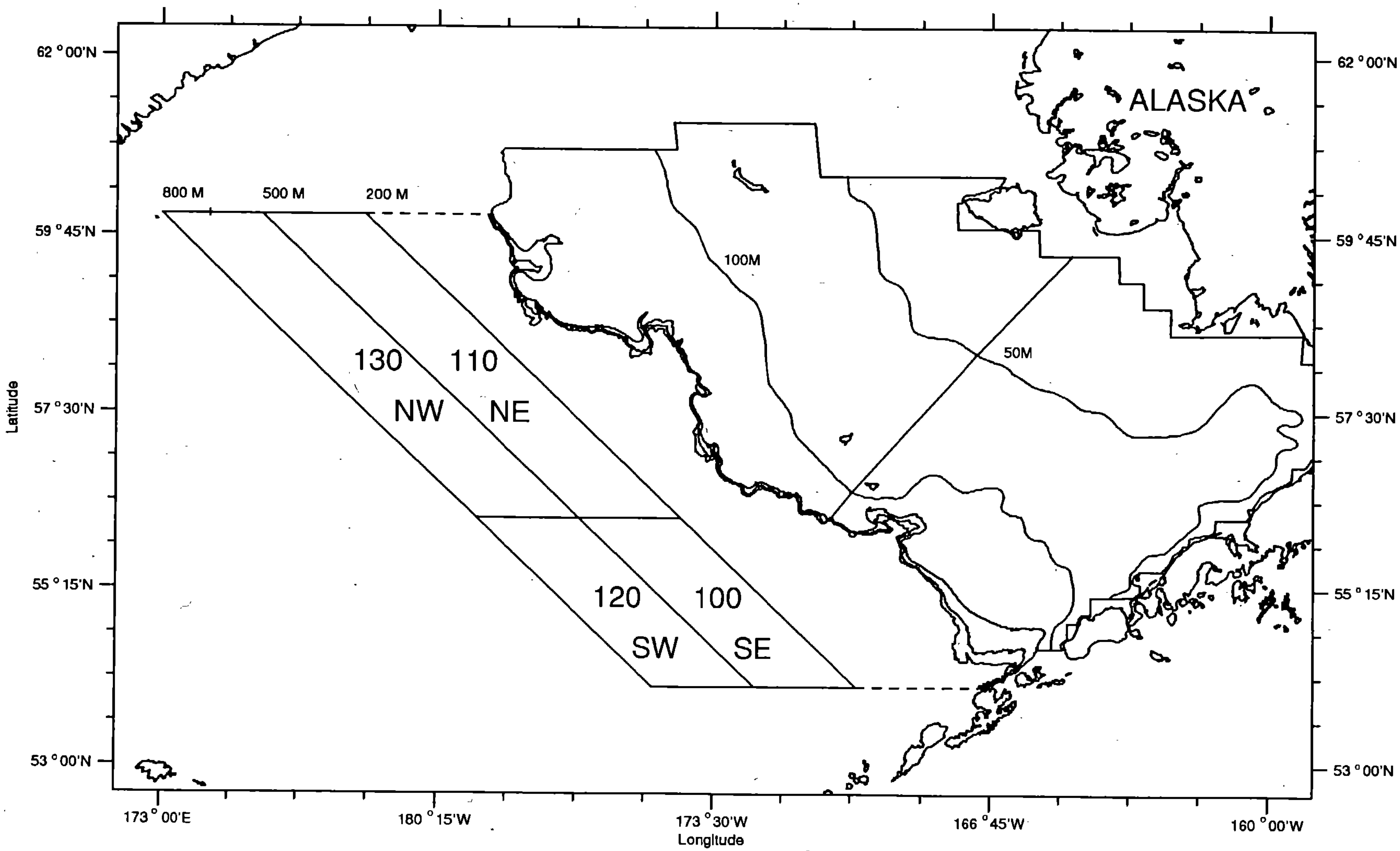

Figure 1.--The eastern Bering Sea slope region expanded to show strata.

hippoglossoides), arrow-tooth flounder (Atheresthes stomias), and flathead sole (Hippoglossoides elassodon) are important predators, prey and competitors in the eastern Bering Sea ecosystem and are commonly found in slope waters.

Walleye pollock is an arctic-circumboreal Pacific Ocean species found at depths to 975 m (Allen and Smith 1988). They are the most abundant groundfish species in the eastern Bering Sea ecosystem (7.7 million metric tons (t)) representing 64 % of the near-bottom biomass (North Pacific Fishery Management Council 1994). Approximately 2% of the walleye pollock biomass and 1% of the population are found over the slope region. The walleye pollock population in the slope region consists of larger; older individuals than those found over the shelf (Bakkala et al. 1992, Goddard and Zimmermann 1993). Most of the walleye pollock over the, slope are located within the 200-500 m depth zone and are relatively evenly distributed north to south (Bakkala et al. .1992, Goddard and Zimmermann 1993).

Pacific cod are a circumboreal Pacific Ocean species found at depths to 875 m (Allen and Smith 1988). Like walleye pollock, the slope portion of the. Pacific cod population represents a relatively small portion (<1% biomass and number) of the Bering Sea population. Pacific cod in the slope region are also larger, older fish than are found over the shelf (Bakkala et al. 1992, Goddard and Zimmermann 1993). Most of the cod found in the slope region of the Bering Sea are found in the 200-500 m depth zone, with a relatively even distribution north to south (Bakkala et al. 1992, Goddard and Zimmermann 1993).

Flathead sole is a Kurile-Aleutian Islands, Bering Sea species found to depths of 1,050 m (Allen and Smith 1988). Flathead sole on the slope represents approximately 2-3% of the population size and biomass of the eastern Bering Sea stock (Bakkala et al. 1992, Goddard and Zimmermann 1993). Flathead sole over the slope are only slightly larger than those over the shelf (Bakkala et al. 1992, Goddard and Zimmermann 1993). Flathead sole over the slope are primarily found in the 200-500 m depth range, and they are slightly more abundant in the southern portion of the slope (Bakkala et al. 1992, Goddard and Zimmermann 1993).

Greenland turbot is an arctic-amphiboreal, deep-water species that is found to depths of 2,000 m (Allen and Smith 1988). In the eastern Bering Sea, they are found most frequently between 50 and 100 m (Allen and Smith 1988). Juvenile Greenland turbot are located primarily on the shelf while the larger adults of the species are found on the slope and beyond (Bakkala et al. 1992, Goddard and Zimmermann 1993). In the 200-500 m depth zone, Greenland turbot are more abundant in the southern strata than in the northern strata. They are also more abundant in the southern region of the 500-800 m depth zone (Bakkala et al. 1992, Goddard and Zimmermann 1993). The slope region of the eastern Bering Sea contains approximately 75% the Greenland turbot biomass and 23% of the population (Bakkala et al. 1992, Goddard and Zimmerman l993).

Arrowtooth flounder is an eastern boreal Pacific Ocean species found down to 900 m. In the eastern Bering Sea, they are primarily found between 50 and 400 m water depth (Allen and Smith 1988). Over the slope region, arrowtooth flounder are most commonly found in the 200-500 m depth zone and are evenly distributed north to south (Bakkala et al. 1992, Goddard and Zimmermann 1993). Arrowtooth flounder on the slope are larger on average than those found on the shelf. Approximately 8% of the biomass and 2% of the arrowtooth flounder population is found over the slope (Bakkala et al. 1992, Goddard and Zimmermann 1993).

Walleye pollock, Pacific cod, Greenland turbot, flathead sole, and arrowtooth flounder represent 5 of the 7 most abundant commercially exploited groundfish species in the eastern Bering Sea; Pacific halibut and sablefish (Anoplopoma fimbria) make up the other two species (North Pacific Fishery Management Council 1994), so knowledge of their trophic ecology is therefore important. The goal of this study is to define the food habits of the former five species in the eastern Bering Sea slope, compare and contrast their diets, and explore spatial and temporal variation in their diets.

METHODS

The eastern Bering Sea slope survey area included all water between 200 and 800 m depth and between 54º and 60º N lat. (Fig. 1). This area is subdivided into four strata: 100, southeast, 200-500 m; 110, northeast, 200-500 m; 120, southwest, 500-800 m; 130, northwest, 500-800 m. Individual stomach samples were collected aboard research vessels by National Marine Fisheries Service (NMFS) personnel in 1985, 1988, and 1991, and aboard commercial ‘fishing vessels by fisheries observers from 1982 to 1992. Samples were collected year-round and throughout the day. Stomachs were only collected from fish which showed no signs of either feeding after capture or regurgitation, as determined by the presence of prey in the buccal cavity, and were preserved in a 10% formalin-sea water mixture. When the stomachs arrived at the laboratory for analysis, they were rinsed in runnning water to remove the formalin and stored in 70% ethyl alcohol. In the laboratory, stomach contents were removed, blotted to remove excess moisture, and weighed to the nearest centigram. Individual prey taxa were then identified to the lowest practical taxa, with emphasis on commercially important prey, enumerated, and weighed to the nearest milligram. Length and sex were recorded for all fish and crab prey,

For the purposes of this diet study, data for arrowtooth flounder and Kamchatka flounder (Atheresthes evermanni) were combined and considered as arrowtooth flounder because of their previously demonstrated dietary similarity (Yang and Livingston 1986), The diet data for flathead sole and Bering flounder (Hippoglossoides robustus) have also been combined in previous studies (Pacunski 1990) due to their morphological and ecological similarity and management status; the same was done in this current study

Qualitative walleye pollock stomach scans were performed in the field by observers aboard commercial fishing vessels from 1982 to 1992. Walleye pollock were checked for signs of feeding after capture and regurgitation and discarded if signs of either were present. The stomach content volumes of selected walleye pollock were then estimated using a graduated cylinder. Prey items were identified by the observers to general taxonomic levels, enumerated, and the percentage of the total content represented by the prey estimated. Length and sex were recorded when possible for fish and crab prey. Examples of common prey identified by the observer were returned to the laboratory for verification by NMFS personnel. While the observers were trained to identify prey to general taxonomic levels, their varied backgrounds and experience resulted in different levels of consistency and thoroughness in prey identifications.

Stomach contents of 1,089 walleye pollock, 282 arrowtooth flounder, 311 Pacific cod, 366 flathead sole, and 455 Greenland turbot were examined. Table 1 presents the number of stomachs, average length, and length range of each predator for each stratum and quarter combination sampled. The standard error of the length of each group was relatively large, indicating that a large size range was sampled. However, the average lengths of most groups were similar for each species.

General diet descriptions were compiled by combining all diet data for a given predator over year, size, quarter, and area. Seasonal diet descriptions were calculated by pooling diet data of a given predator by quarter of collection within each area. Spatial diet comparisons by predator were compiled by area within a given season. Size categories used in the general diet descriptions represent 10 cm size groups shown at the midpoint. Prey size frequencies are derived from all diet data for a given predator. Combining data in this manner is necessary to achieve adequate sample sizes for comparison and to help offset the potentially patchy nature of predator-prey data. However, combined data may exhibit increased variability or noise. All diet data are presented in terms of percentage by weight unless otherwise noted.

To facilitate ease of analysis, predator diet data were pooled into the seven most important, mutually exclusive prey categories (Table 2) and an eighth miscellaneous category that included unidentified prey and prey that were not included in the seven other categories, The deep-sea fish category was comprised of species from the families Bathylagidae and Myctophidae. Offal was considered to be any prey that looked like a fish

Table 1.--Average length (cm), standard error length (SE.), length range (cm), and number of stomachs that contained food of each predator by quarter and stratum.

Predator	Quarter	Stratum	Avg. Length	S.E Length.	Length Range	No. Stomachs
Walleye pollock	1	100	40.56	10.28	23-59	77
	1	110	45.31	10.52	23-79	142
	1	130	45.23	9.10	33-72	53
	2	110	46.13	9.99	32-68	23
	2	130	42.51	7.42	32-62	49
	3	100	49.20	6.06	37-70	429
	3	110	46.03	5.81	23-59	186
	4	100	45.92	8.11	26-67	84
	4	110	45.68	5.28	37-54	40
Walleye pollock scan data	1	100	34.36	1.5	32-37	14
	1	110	51.6	10.06	42-69	10
	2	100	43.14	5.23	36-57	22
	2	110	49.46	7.92	38-64	13
	2	130	45.83	11.84	31-62	47
	3	100	47.74	4.13	40-59	46
	3	110	46.37	5.51	38-61	52
	3	130	46.0	3.12	42-52	23
	4	100	47.97	4.13	39-57	78
	4	110	47.83	4.58	33-67	130
	4	130	47.83	3.58	43-58	49
Pacific cod	3	100	65.28	12.59	21-100	87
	3	110	68.7	12.08	25-103	107
	4	100	66.64	11.36	46-89	25
	4	110	67.87	15.05	44-95	39
Greenland halibut	2	110	57.6	12.63	35-89	35
	2	130	55.5	14.18	37-86	62
	3	110	70.97	11.64	52-96	39
	3	130	67.36	11.51	55-100	22
	4	110	63.63	13.86	42-100	68
	4	130	65.5	13.25	42-96	101
Flathead sole	3	100	37.19	6.35	22-49	123
	3	110	33.06	7.61	10-39	54
	4	100	32.48	8.68	18-49	44
	4	110	32.94	6.96	18-45	84

Table 1. --(continued)

Predator	Quarter	Stratum	Avg. Length	S.E Length.	Length Range	No. Stomachs
Arrowtooth	2	110	50.11	5.86	39-62	45
flounder	2	130	47.21	6.56	38-59	29
	3	100	53.03	12.57	28-82	58
	3	110	47.94	9.59	33-66	52
	4	110	48.40	10.74	22-66	65
	4	130	46.79	6.06	36-63	24

Table 2.--Pooled prey categories used to describe the diets of walleye pollock, Pacific cod, Greenland turbot,

Predator	Walleye pollock	Pacific cod	Greenland turbot	Flathead sole	Arrowtooth flounder
Prey Categories	Euphausiid Pandalid Squid Walleye pollock Deep-sea fish Pacific herring Other fish Miscellaneous	Chionoecetes spp. Pandalid Squid Walleye pollock Offal Pacific herring Other fish Miscellaneous	Squid Walleye pollock Deep-sea fish Pacific herring Snailfish Other fish Offal Miscellaneous	Chionoecetes spp. Pandalid Brittle star Walleye pollock Rockfish Other fish Offal Miscellaneous	Pandalid Squid Walleye pollock Myctophid Pacific herring Other fish Offal Miscellaneous

processing discard from commercial fishing operations, primarily heads and tails of flatfish, walleye pollock heads, and post-fillet remains of walleye pollock.

Schoener's (1970) similarity index was calculated to compare the diets of each species pair so that each species was compared with every other. For these calculations, all twelve common prey (Table 2) were used. The miscellaneous prey category was not used. Schoener's (1970) index C_{Xy} was calculated as

$$1 - 0.5 \sum_{1}^{i} (|p_{xi} - p_{yi}|)$$

where p represents the proportion of prey $\boldsymbol{i}$ in the diet of predator x and y, respectively The result is then multiplied by 100 to represent the percentage dietary overlap.

RESULTS AND DISCUSSION

Walleye Pollock

Results

Walleye pollock were sampled in three of the four strata of the slope region (Fig. 2) with the southwest stratum (120) being the only one from which no walleye pollock were collected. Stomach samples of 1,272 walleye pollock were examined, 1,089 of which contained food representing 119 prey categories (Table 3). Euphausiids were the most important (26%) prey by weight in the diet of walleye pollock in the slope region of the eastern Bering Sea (Fig. 3). Pandahd shrimp (14%) walleye pollock (16%) deep-sea fish (myctophids and bathylagids) (12%) other fish (6%) squid (9%) and Pacific herring (Clupea pallasi) (3%) were also common components of their diet. Fishery discards (offal) were the primary component of the miscellaneous prey in addition to the unidentified prey items. By frequency of occurrence the diet of walleye pollock followed the same trends, with the exception of copepod and hyperiid amphipods being notably more important by frequency of occurrence than by weight (Table 3).

The diet of walleye pollock varied with predator size in the slope region of the eastern Bering Sea (Fig. 4). Euphausiids were the dominant prey (> 19%) for all sizes of pollock but were a smaller component of the diet of larger (>50 cm) fish. Squid (3-7%) pandalids (8-15%) and other fish (6-12%) were found in relatively similar proportions of the diet of all sizes of pollock. Walleye pollock were least prevalent as prey of small (<40 cm) pollock (4%) and were increasingly important to larger pollock (5% and 20%). Pacific herring and deep-sea fish were also more prevalent in the diet of the larger (>50 cm) fish

The diet of walleye pollock varied seasonally when examined by strata (Fig. 5). The greatest variation in the southeast stratum (100) was seen in the consumption of euphausiids, which were more prevalent in the first quarter of the year, and decreased consistently through the third and fourth quarters. Deep-sea fish were seen as prey in the

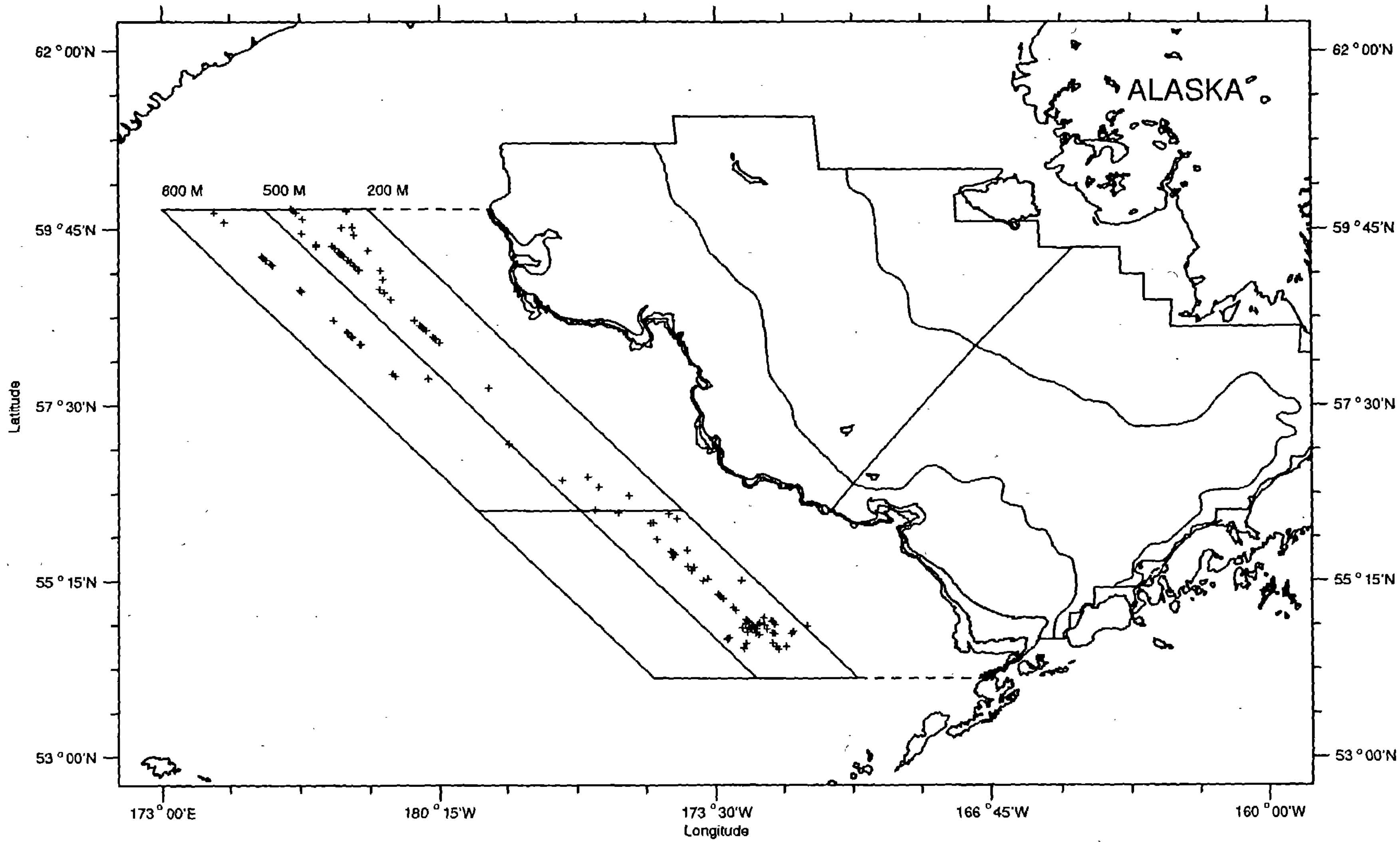

Figure 2.--The location of walleye pollock stomach collections in the eastern Bering Sea slope region.

Table 3.--The diet of walleye pollock, Theragra chalcogramma, from the slope region of the eastern Bering Sea, not including scan data.

Prey Name	% Frequency of Occurrence	% Total Weight
Cnidaria	0.09	0.00
Polychaeta (worm)	1.38	0.04
Alciopidae (polychaete)	0.09	0.00
Gastropoda (snail)	0.18	0.10
Pteropoda	0.37	0.00
Thecosomata (pteropod)	1.01	0.01
Bivalvia (clam)	0.09	0.00
Pectinidae (scallops)	0.09	0.00
Cephalopoda (squid & octopus)	3.41	0.67
Teuthoidea (squid)	2.58	2.08
Teuthoidea Myopsida (squid)	1.66	1.30
Teuthoidea Oegopsida (squid)	2.67	0.46
Gonatidae (squid)	1.20	3.12
Gonatopsis spp. (squid)	0.09	1.06
Berryteuthis spp. (squid)	0.09	0.33
Octopoda (octopus)	0.64	0.85
Crustacea	1.93	0.06
Ostracoda	0.55	0.00
Copepoda	0.09	0.00
Calanoida (copepod)	15.10	0.61
Calanus spp.	7.92	0.90
Neocalanus cristatus	7.00	0.65
Neocalanus plumchrus	0.64	0.00
Eucalanus spp. (copepod)	2.67	0.05
Eucalanus bungii (copepod)	0.09	0.00
Aetideidae (copepod)	0.37	0.00
Euchirella spp. (copepod)	1.01	0.01
Euchaetidae (copepod)	0.09	0.00
Euchaeta spp. (copepod)	2.39	0.01
Euchaeta elongata (copepod)	0.09	0.00
Metridia spp. (copepod)	2.03	0.00
Pleuromamma spp. (copepod)	0.18	0.00
Pleuromamma scutullata (copepod)	0.09	0.00
Candacia spp. (copepod)	1.29	0.00
Candacia columbiae (copepod)	4.14	0.01
Peracarida Mysidacea (mysid)	0.18	0.00
Eucopia spp.	0.09	0.00
Mysidacea Mysida (mysid)	0.74	0.03
Mysidae (mysid)	2.85	0.30

Table 3 .--(continued).

Prey Name	% Frequency of Occurrence	% Total Weight
Holmesiella anomala (mysid)	0.55	0.23
Neomysis czerniawskii (mysid)	0.09	0.00
Pseudomma spp. (mysid)	0.09	0.00
Pseudomma truncatum (mysid)	0.09	0.00
Cumacea (cumacean)	0.18	0.00
Isopoda Microberberidea	0.09	0.00
Amphipoda (amphipod)	0.09	0.00
Gammaridea (amphipod)	3.59	0.25
Ampeliscidae (amphipod)	0.37	0.02
Lysianassidae (amphipod)	0.18	0.01
Cyphocaris spp. (amphipod)	0.28	0.00
Oedicerotidae (amphipod)	0.18	0.00
Amphipoda Hyperiidea (amphipod)	16.21	0.48
Hyperia spp. (amphipod)	0.09	0.00
Themisto spp. (amphipod)	14.27	0.15
Themisto pacifica (amphipod)	0.64	0.00
Primno macropa (amphipod)	0.64	0.00
Caprellidea (amphipod)	0.18	0.00
Euphausiacea (euphausiid)	56.26	19.98
Euphausiidae (euphausiid)	4.24	2.81
Euphausia pacifica (euphausiid)	0.09	0.10
Thysanoessa spp. (euphausiid)	2.95	1.07
Thysanoessa inermis (euphausiid)	5.06	1.46
Thysanoessa longipes (euphausiid)	3.68	0.29
Thysanoessa raschii (euphausiid)	0.37	0.01
Thysanoessa spinifera (euphausiid)	1.66	0.44
Decapoda (shrimp & crab)	0.64	0.09
Reptantia (crab)	0.55	0.00
Caridea (shrimp)	3.87	0.96
Oplophoridae (shrimp)	0.09	0.00
Hymenodora spp. (shrimp)	0.09	0.02
Pasiphaea pacifica (shrimp)	0.18	0.01
Hippolytidae (shrimp)	0.64	0.06
Eualus spp. (shrimp)	0.46	0.08
Eualus biunguis (shrimp)	0.46	0.21
Eualus macrophthalma (shrimp)	0.64	0.13
Eualus avinus (shrimp)	0.09	0.01
Pandalidae (shrimp)	3.87	4.04

Table 3 .--(continued).

Prey Name	% Frequency of Occurrence	% Total Weight
Pandalus spp. (shrimp)	1.57	2.15
Pandalus borealis (shrimp)	3.13	5.31
Pandalus goniurus (shrimp)	0.18	0.42
Pandalopsis spp. (shrimp)	0.55	0.66
Pandalopsis ampla (shrimp)	0.09	1.00
Pandalopsis dispar (shrimp)	0.18	0.79
Crangonidae (shrimp)	0.64	0.16
Crangon spp. (shrimp)	0.28	0.10
Crangon communis (shrimp)	0.55	0.23
Argis lar (shrimp)	0.09	0.03
Argis ovifer (shrimp)	0.09	0.02
Natantia (shrimp)	0.37	0.12
Anomura (crab)	0.18	0.00
Paguridae (hermit crab)	1.84	0.05
Majidae (spider crab)	0.28	0.02
Chionoecetes bairdi (Tanner crab)	0.18	0.00
Echinodermata	0.09	0.00
Ophiuroidea	0.83	0.03
Ophiuroidae Ophiurida	0.28	0.03
Ophiuridae (brittle star)	0.09	0.02
Chaetognatha (arrow worm)	3.87	0.17
Sagitta spp. (arrow worm)	2.67	0.09
Larvacea Copelata	5.80	0.35
Oikopleura spp.	0.83	0.02
Osteichthyes Teleostei	11.14	5.50
Non-gadoid Fish Remains	2.30	1.42
Fish eggs	0.18	0.00
Clupea pallasi (Pacific herring)	0.09	2.54
Bathylagidae (deepsea smelts)	3.78	6.77
Bathylagus stilbius	0.28	0.42
Myctophidae (lanternfish)	2.76	4.96
Theragra chalcogramma (walleye pollock)	0.92	16.14
Sebastes spp. (rockfish)	0.09	0.11
Ammodytes hexapterus (Pacific sandlance)	0.18	0.02
Pleuronectidae (flatfish)	0.09	0.03
Aves (bird part)	0.09	0.01
Unidentified organic material	4.97	0.49
Unidentified eggs	0.64	0.02

Table 3.--(continued).

Prey Name	% Frequency of Occurrence	% Total Weight
Fishery discards	0.46	3.78
Unidentified tube	0.83	0.02
Unidentified algae	0.09	0.28
Unidentified material	0.37	0.15
Total prey weight:	4,090.39g	
Total non-empty stomachs:	1,089	
Total empty stomachs:	183	
Total prey categories:	119	

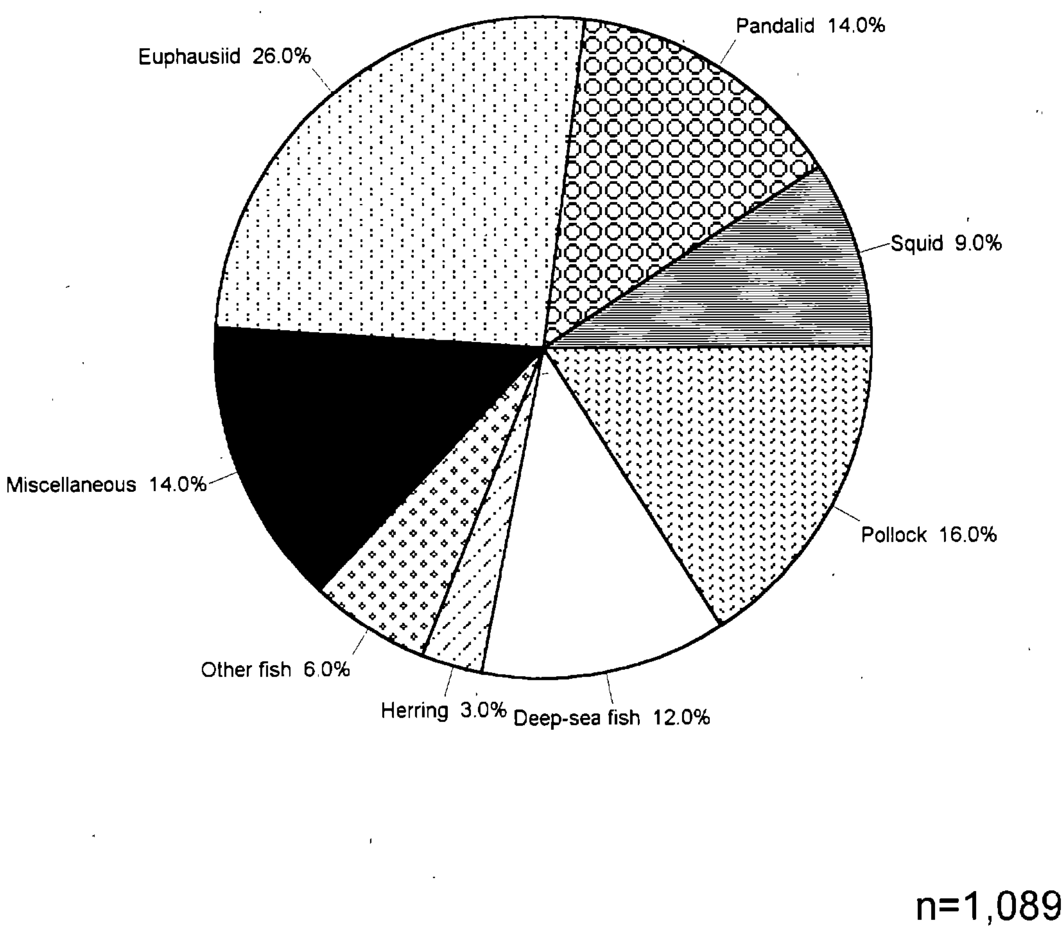

Figure 3.--The diet of walleye pollock by percent weight in the eastern Bering Sea slope region based on quantitative laboratory analysis (n=number of stomachs that contained food).

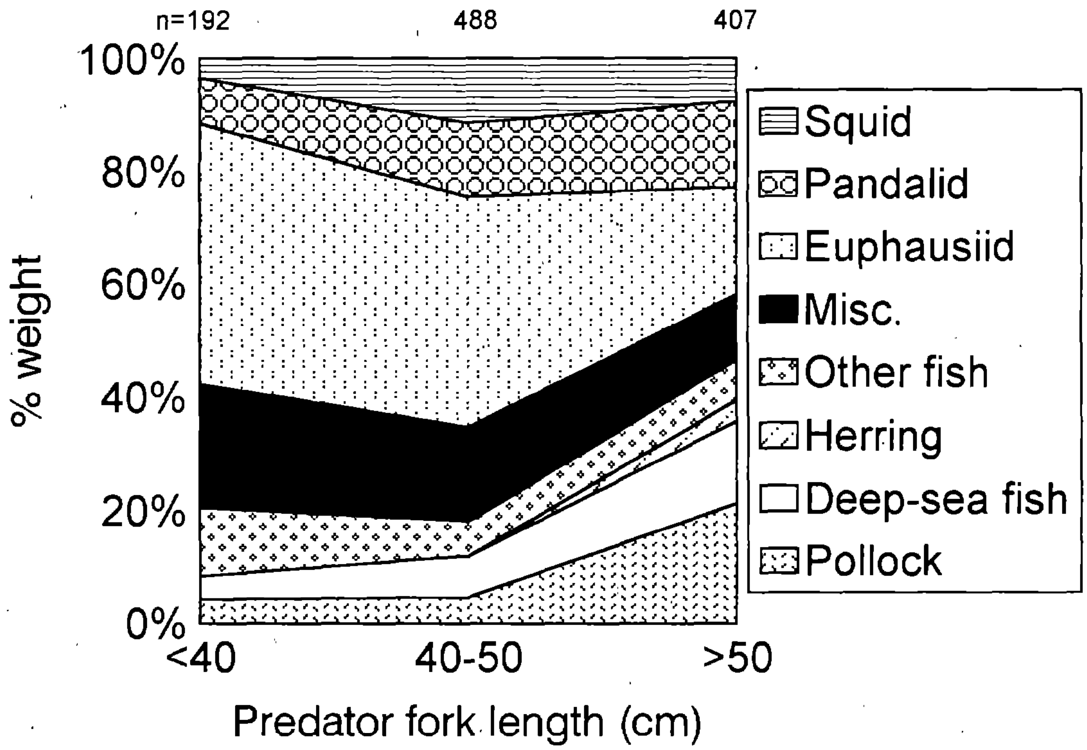

Figure 4.--The diet of walleye pollock by percent weight in the eastern Bering Sea slope region by predator size based on quantitative laboratory analysis (n=number of stomachs that contained food in each size group).

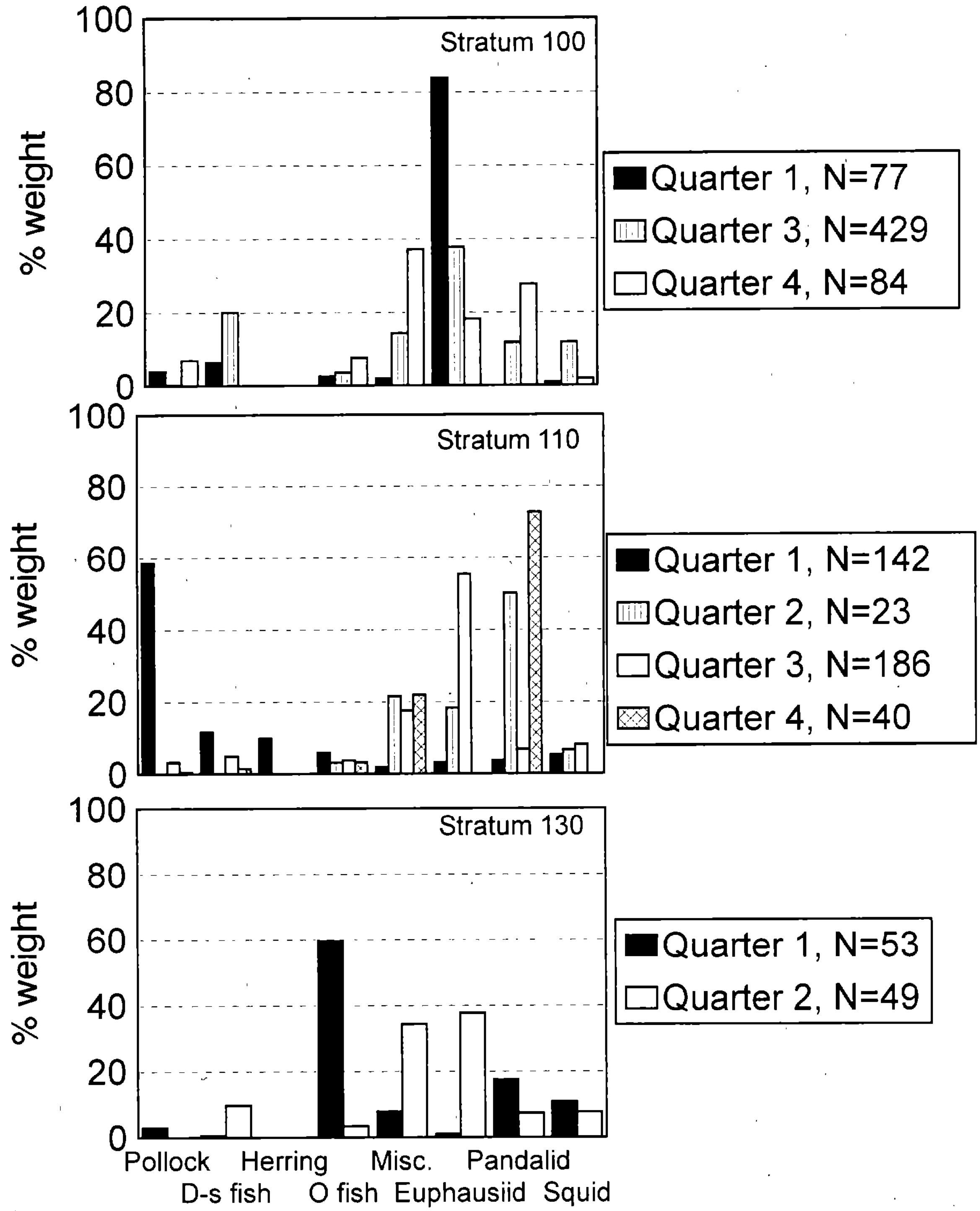

Figure 5.--Seasonal dietary variation of walleye pollock by percent weight from strata 100, 110, and 130 in the eastern Bering Sea slope region. N=number of stomachs that contained food.
D-s fish=deep-sea fish (Myctophidae and Bathylagidae).
O fish= other fish.

first and third quarters but were most prevalent in the third quarter. Pandalids were not seen in the diet of walleye pollock in the first quarter and were most prevalent in the fourth quarter. Seasonal variation was much greater in the northeast stratum (110). Pollock as prey dominated the diet in the first quarter but they were a negligible portion of the diet during the remaining quarters. The percentage by weight contribution of euphausiids to the diet increased from the first through the third quarters and decreased in the fourth quarter. During the first and third quarters pandalids were a relatively small portion of the diet, while in the second and fourth quarters, they were the dominant prey of pollock. The other prey groups represented a smaller portion of the diet. Only the first and second quarters were adequately sampled in the northwest stratum (130) to allow diet comparison. The primary difference between the two quarters was that other fish were the dominant prey category in the first quarter, while euphausiid and miscellaneous prey made up the bulk of the diet in the second quarter.

The diet of pollock varied somewhat with depth within a given quarter (Fig. 6). In the first quarter, pollock were the primary prey in the shallower stations (stratum 110) while other fish were the primary prey in the deeper water (stratum 130). Dietary variation with depth was less pronounced in the second quarter.

The magnitude of latitudinal variation in the diet of pollock varied by quarter (Fig. 7). In the first quarter, euphausiid prey dominated the diet in the southeastern stratum (100) while pollock was the primary prey in the northeast (stratum 110). Most other prey were found to be a small portion of the diet. Dietary variation was less pronounced in the third quarter with most prey being found in similar proportions in both strata. In the fourth quarter, pandalids were the primary prey in the northeast stratum whereas euphausiids, pandalids, and miscellaneous prey were the most prevalent prey in the southeast stratum Fish prey (pollock, deep-sea fish, and other fish) were much more common in the southeastern stratum

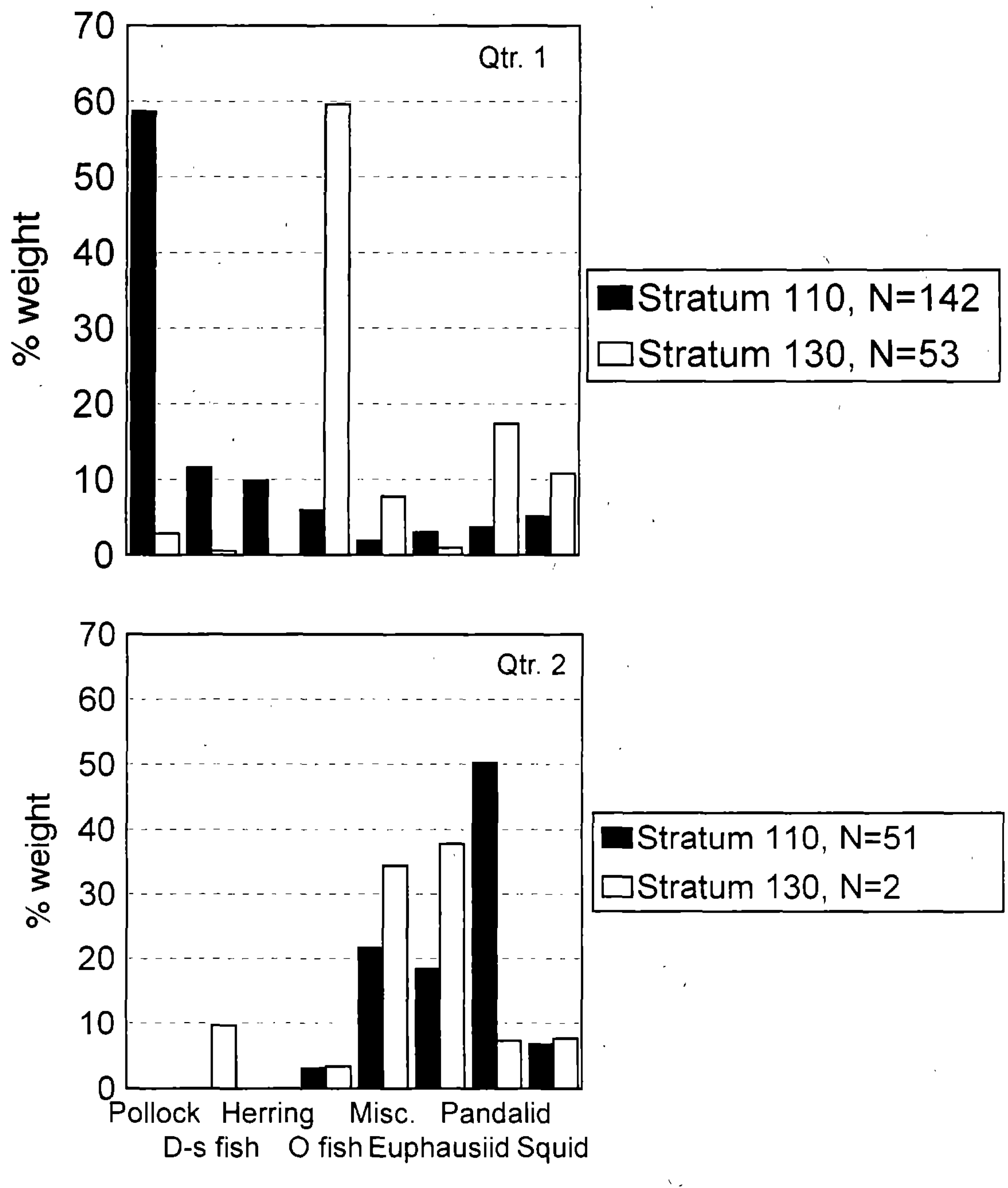

Figure 6.--Depth-related variation of walleye pollock by percent weight in the eastern Bering Sea slope region during the first and second quarters. N=number of stomachs that contained food. D-s fish= deep-sea fish (Myctophidae and Bathylagidae) O fish= Other fish.

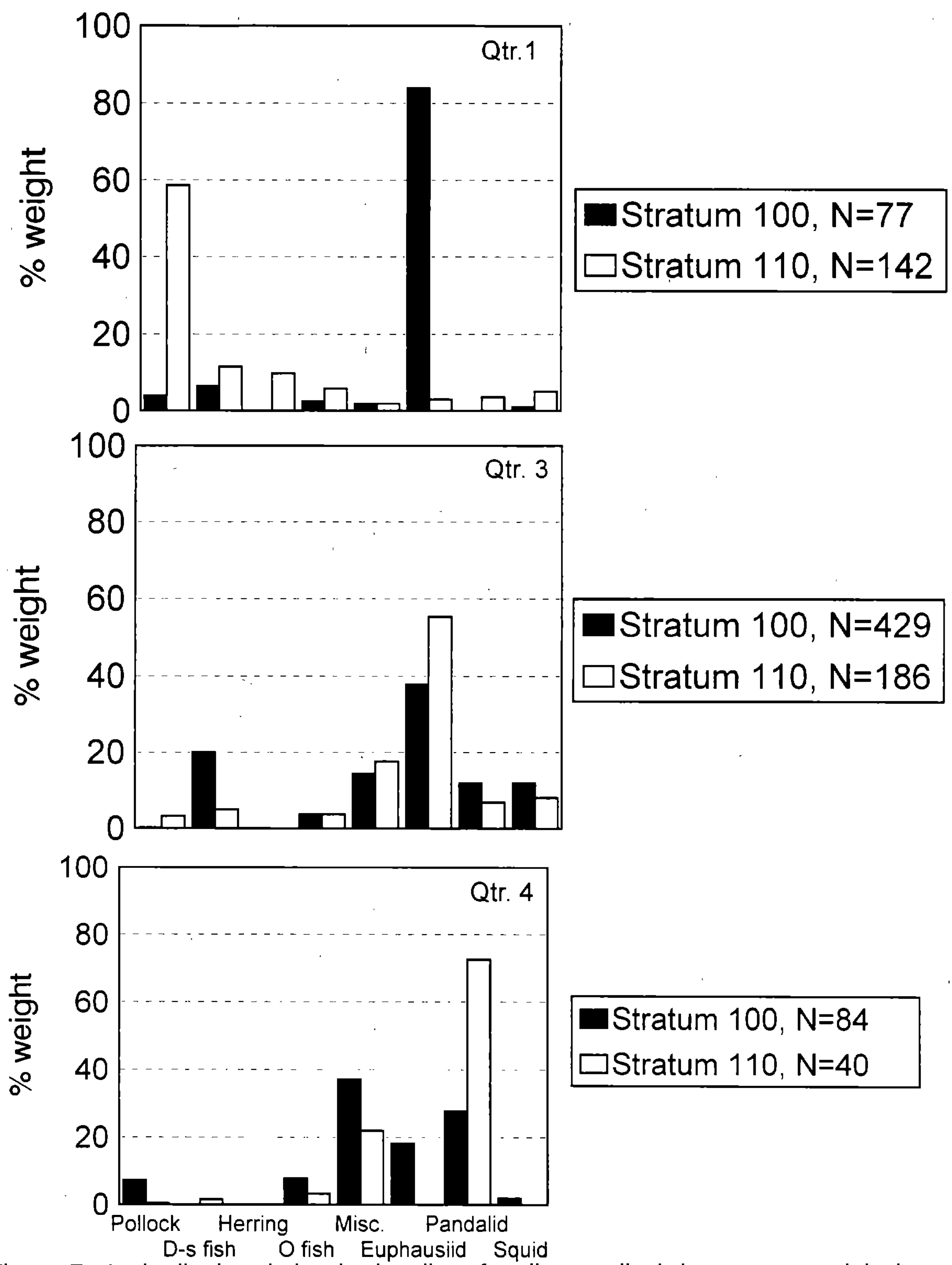

Figure 7.--Latitudinal variation in the diet of walleye pollock by percent weight in the eastern Bering Sea slope region during the first, third, and fourth quarters. N=number of stomachs that contained food.
D-s fish =deep-sea fish (Myctophidae and Bathylagidae).
O fish=other fish.

Comprehensive stomach collections taken during scientific surveys of the slope region in 1988 and 1991 allowed comparison of walleye pollock diets from those 2 years in stratum 100 (southeast) and 110 (northeast) during the third quarter (Fig. 8). Euphausiids were most important in 1991, northeast stratum, and were of lesser, but similar importance in the other samples, Variation was seen in the importance of deep-sea fish, squid, and to a lesser degree, pandalids by year and strata. All other prey were of limited importance or did not vary between years and strata.

Pollock cannibalism occurred most extensively in the northeast stratum (110) and to a lesser degree in the southeast stratum (100) (Fig. 9a). Pollock represented at least 50 % of the diet of pollock at several stations in the northeast stratum. Pollock cannibalism was concentrated in the northern section of the stratum. Squid were found in the diet of pollock in all three strata that were sampled (Fig. 9b). Squid made up the highest percentage of the diet and were found in the highest proportion of samples in the two northern strata. Deep-sea fish were found in relatively high proportion in some stations in all three strata that were sampled with little spatial pattern being evident (Fig. 9c). Pacific herring were found in a high proportion of the diet of pollock in only one station (Fig. 9d). Euphausiids were found in the stomachs of walleye pollock taken from every station sampled (Fig. 9e). Euphausiids were a larger constituent of the pollock diet in the southern stations and the northeastern stations and were less important in the northwestern stations,

Pollock primarily cannibalized juvenile pollock that were less than 120 mm, representing age-0 fish, although a few larger age-1 pollock were also consumed (Fig. 10) Larger adults consumed the larger juveniles, but some of the smallest juveniles were also consumed by relatively large adults. There was positive correlation (r^2=0.28, P<.00l) between prey size with predator size. Walleye pollock length was poorly correlated (r^2=0,001, P=0.85) with the length of bathylagids consumed (Fig. 10). Myctophid length was moderately correlated (r^2=0.09, P=0.014) with walleye pollock length (Fig. 10).

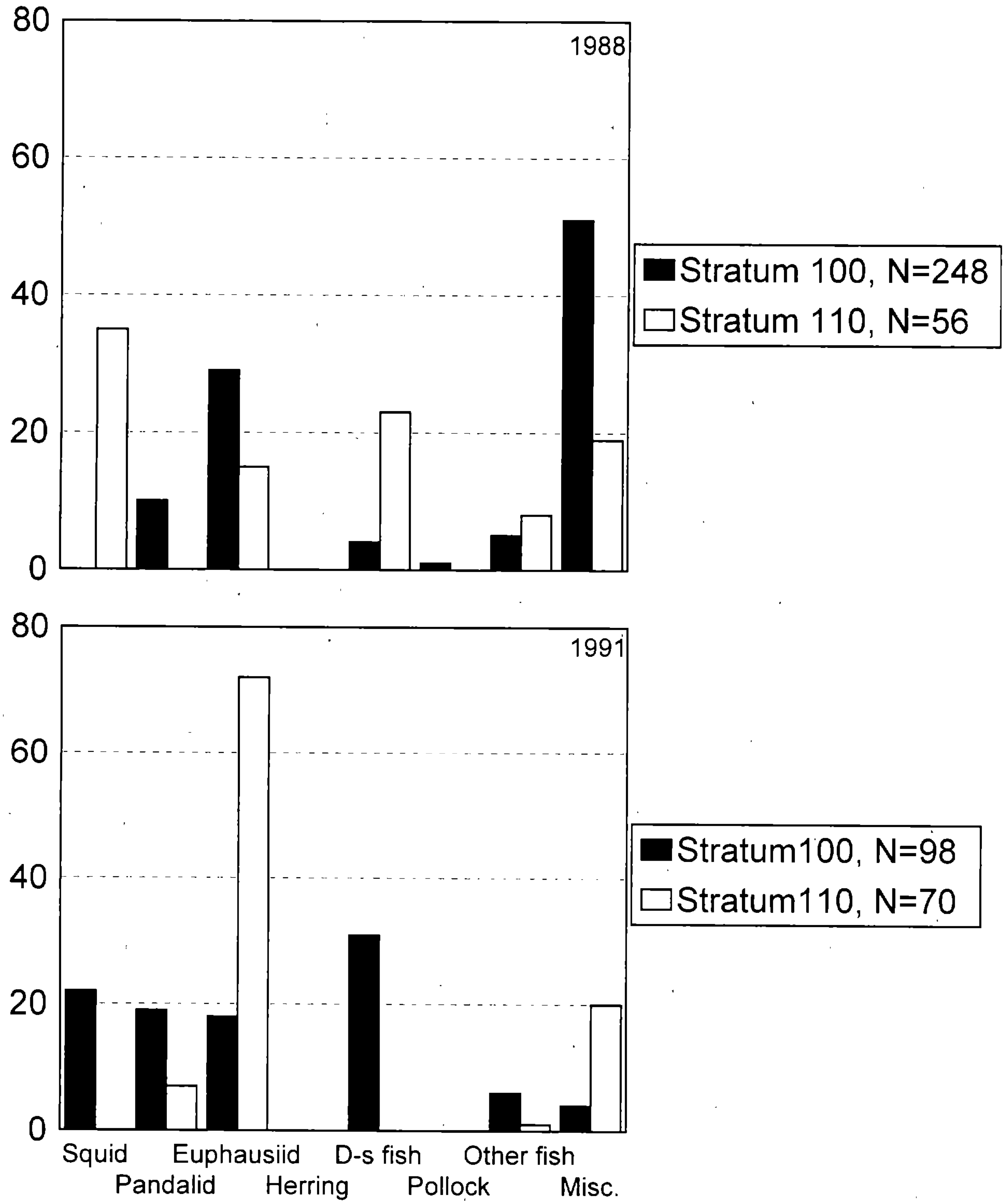

Figure 8.--Dietary comparison of walleye pollock in the eastern Bering Sea slope region during the third quarter of 1988 and 1991 from strata 100 and 110. N=number of stomachs that contained food. D-s fish=Myctophidae and Bathylagidae.

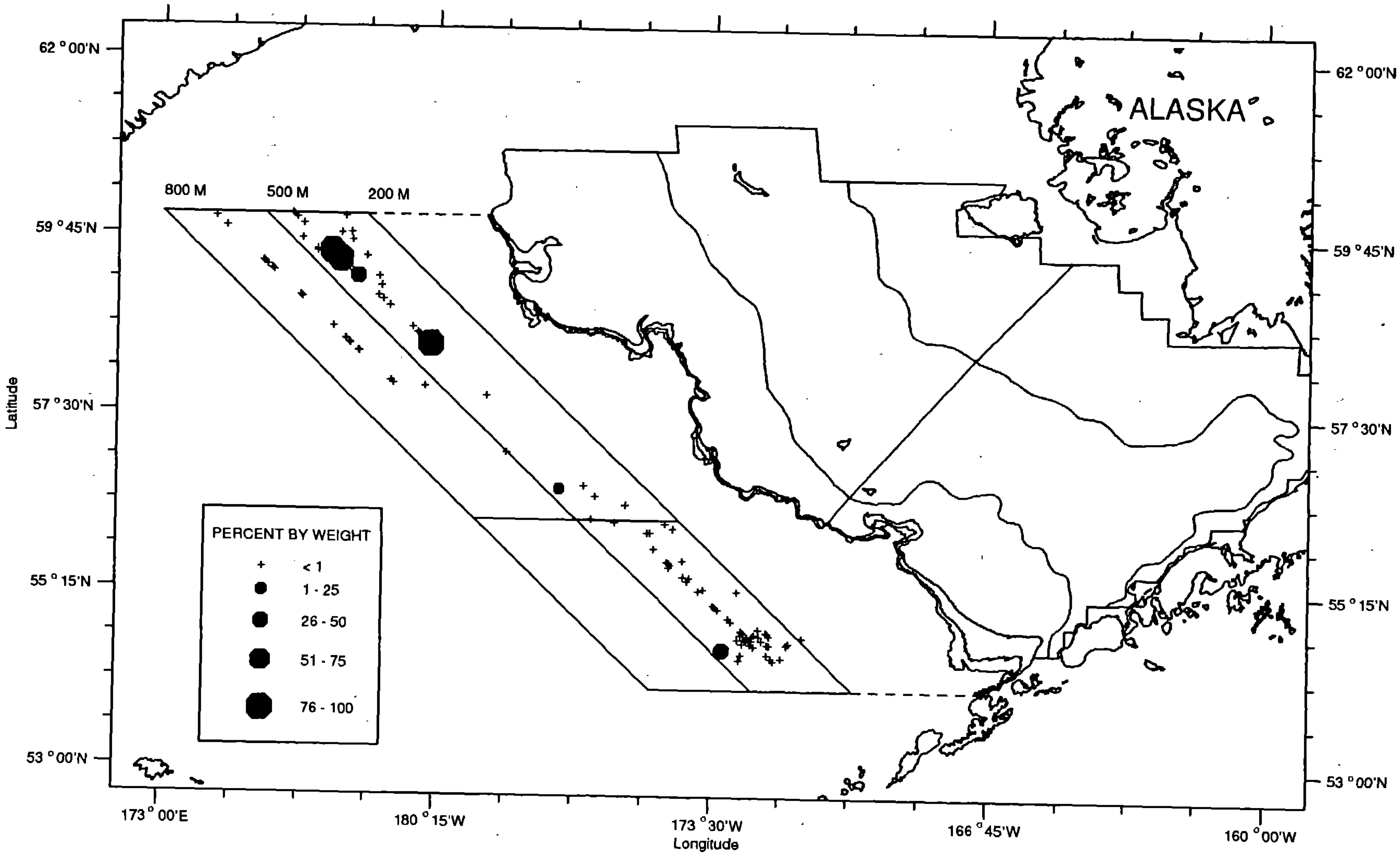

Figure 9a.--The location and magnitude of walleye pollock predation on walleye pollock in the eastern Bering Sea slope region.

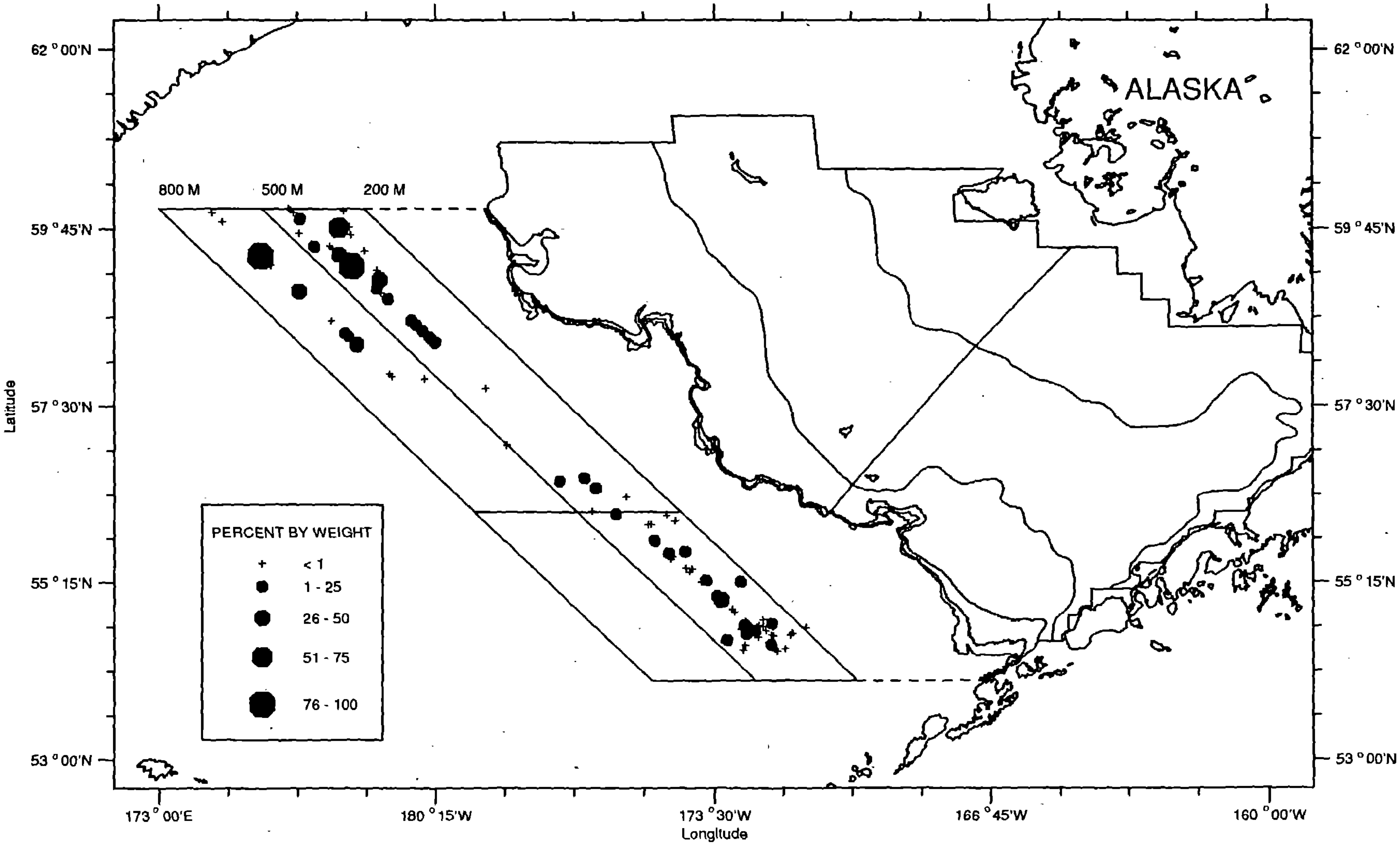

Figure 9b.--The location and magnitude of walleye pollock predation on squid in the eastern Bering Sea slope region.

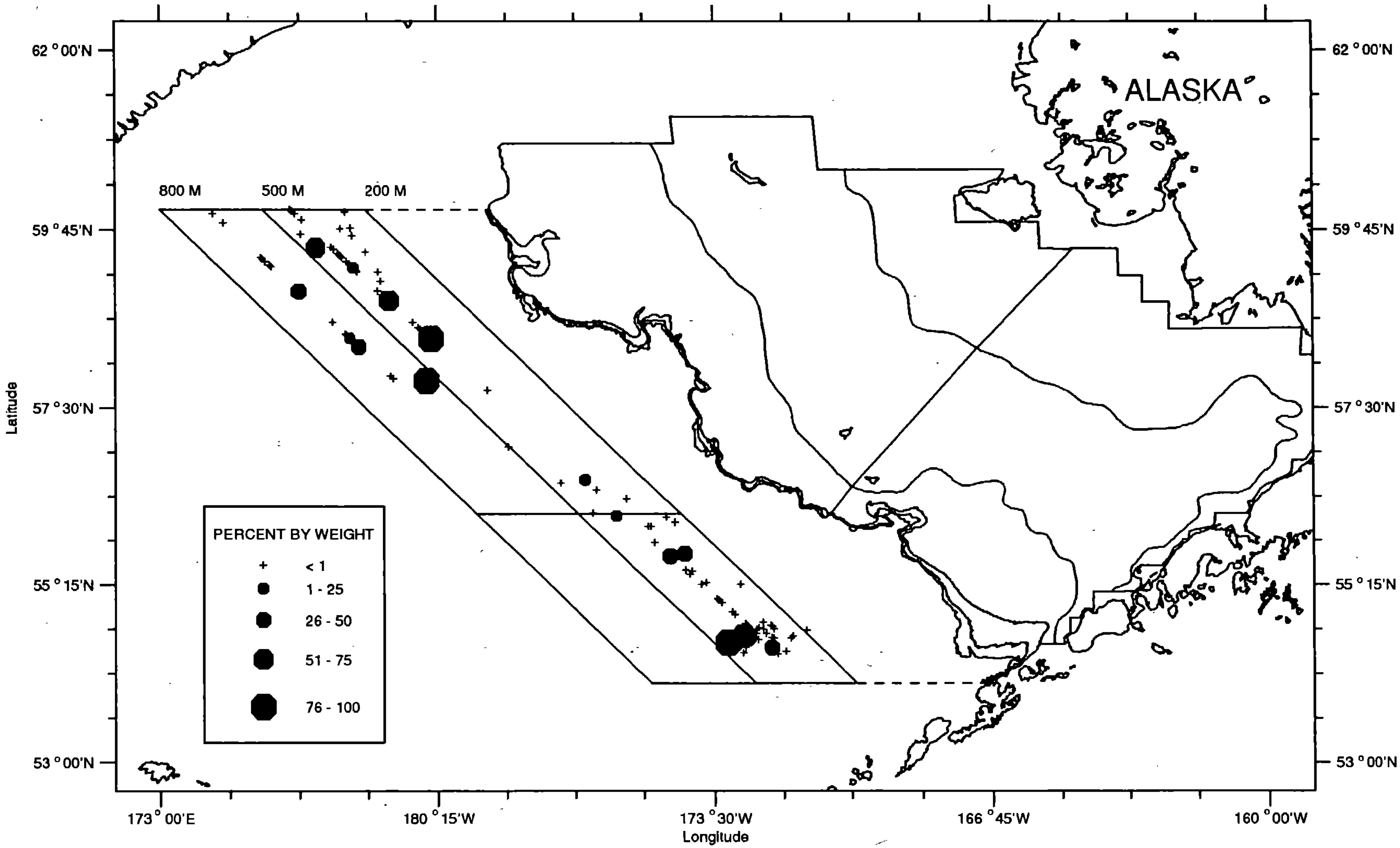

Figure 9c.--The location and magnitude of walleye pollock predation on deep-sea fishes (Myctophide and Bathylagidae) in the eastern Bering Sea slope region.

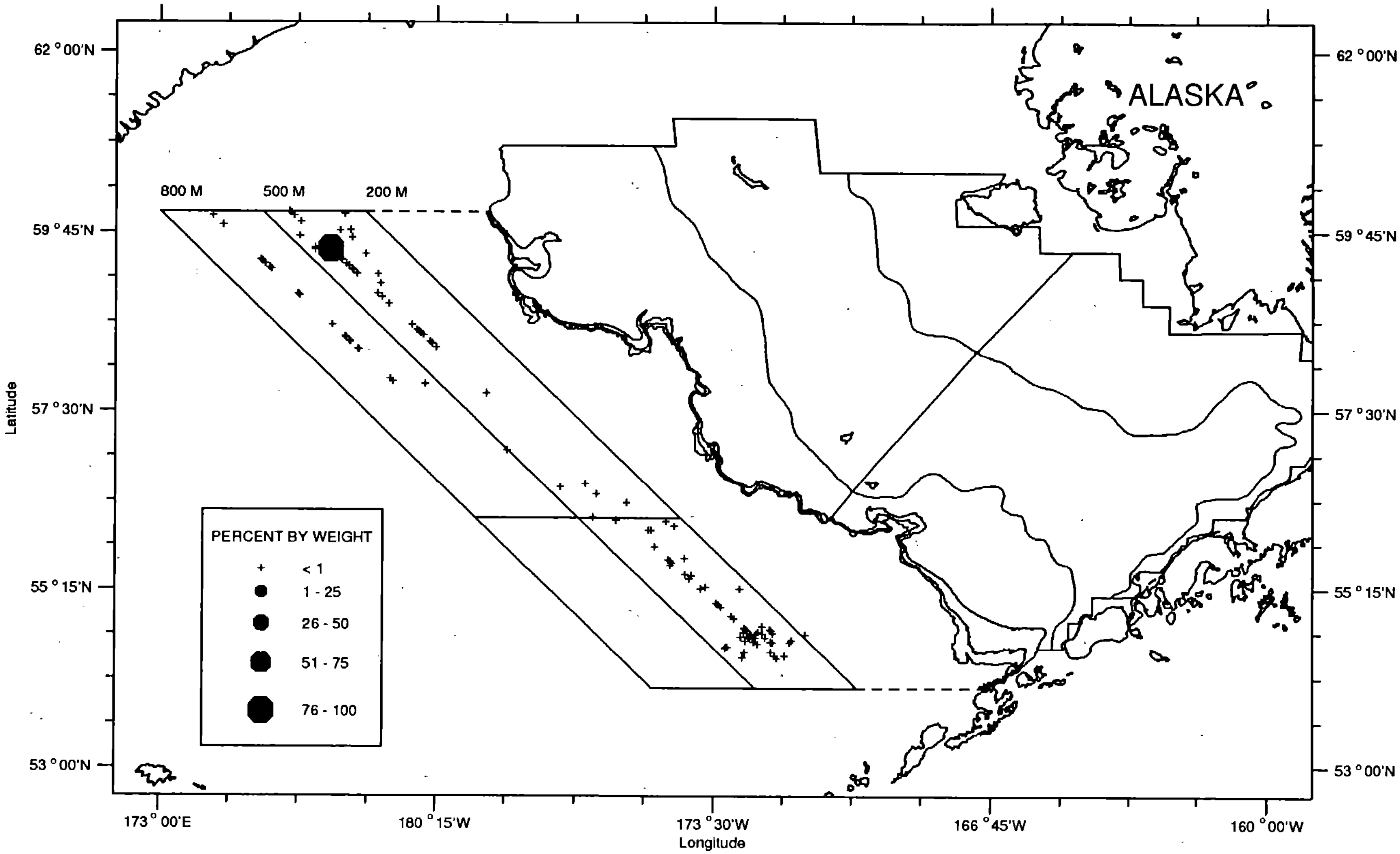

Figure 9d.--The location and magnitude of walleye pollock predation on Pacific herring in the eastern Bering Sea slope region.

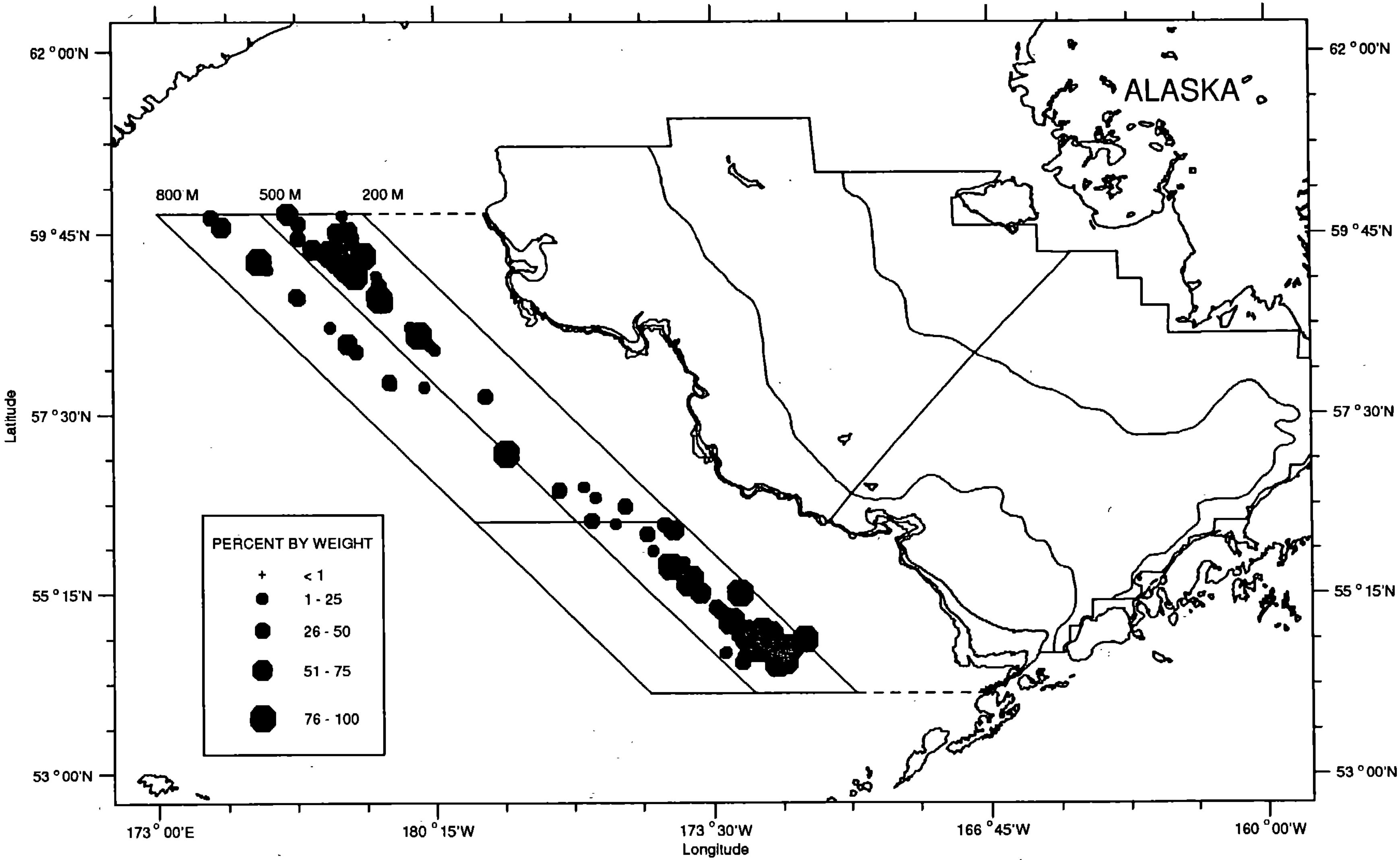

Figure 9e--The location and magnitude of walleye pollock predation on euphausiids in the eastern Bering Sea slope region.

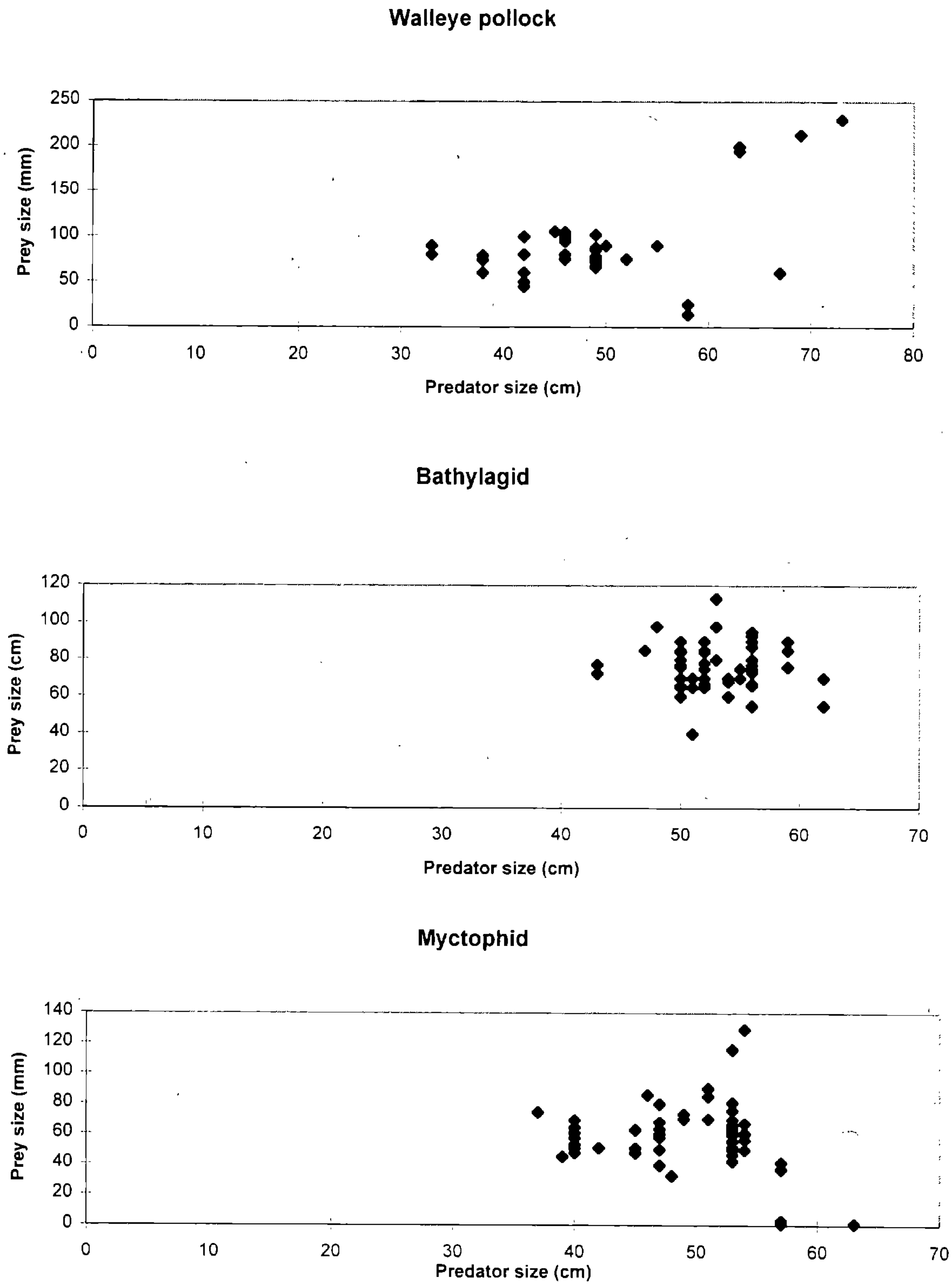

Figure 10--Walleye pollock (predator) size, prey size scatter plots for walleye pollock, bathylagid, and myctophid prey in the eastern Bering Sea slope region.

Discussion

The general diet of walleye pollock has been described for many areas of the Bering Sea. On the eastern Bering Sea shelf the diet of walleye pollock has been shown to primarily consist of walleye pollock, fish, euphausiids, and copepods (Dwyer et al. 1987, Livingston et al. 1986, Mito 1974, Mito 1990, Yoshida 1994, Livingston et al. 1993, Livingston 1991 a) in varying proportions depending on the season, year, or predator size. In the deeper water of the Aleutian Basin, the diet of walleye pollock has been shown to consist primarily of copepods, amphipods, euphausiids, squid, and larvaceans (Dwyer et al. 1987, Yoshida 1994, Mito 1990). In the slope region, the diet of walleye pollock has been described by Mito (1974) to consist of walleye pollock, euphausiids, and squid during the fall. The diet of the walleye pollock sampled in our study had features similar to both the shelf and basin, perhaps indicative of the close geographic proximity to these areas. The greatest dietary differences between our study of the slope and those conducted in other areas were in the presence of deep-sea fish, Pacific herring, and pandalid shrimp in the diet of walleye pollock. A partial explanation is that these prey may not have been specifically mentioned in the previous studies. Deep-sea fish (myctophids and bathylagids) and Pacific herring have typically been grouped into miscellaneous fish categories, as they were not recognized as important ecosystem components. However, recent studies have shown them to be prey of marine mammals in the eastern Bering Sea and therefore warrant individual consideration. Pandalid prey were likely not prevalent enough in previous studies to be considered an important prey group. However, in our study, pandalids represented a large enough portion of the diet to be considered seperately. Copepods were not a significant portion of the diet by weight in the eastern Bering Sea slope, which is in marked contrast to the diets of walleye pollock in the Aleutian Basin and the shelf. On the eastern Bering Sea shelf, copepods are the most important prey of smaller walleye pollock (Dwyer et al. 1987, Livingston 1991a, Livingston et al. 1993, Mito 1974,). On the slope, however, the walleye pollock population consists of larger fish (Goddard and Zimmermann, 1993): which is reflected in our samples and, consequently, in the copepod component of the diet. In the deeper Aleutian Basin area, copepods are very important in the diet of the primarily large walleye pollock (Dwyer et al. 1987, Mito 1990, Yoshida 1994). In that area, other prey such as juvenile walleye pollock and benthic prey are not as readily available. Squid were not found to be important in the diet of walleye pollock on the eastern Bering Sea shelf (Dwyer et al. 1987, Livingston 1991 a, Livingston et al. 1993); however, Mito (1974) found them to be prevalent over the slope, as they were in our study. Gonatid squids, those most commonly identified from walleye pollock stomachs, are primarily distributed in deep water in the Bering Sea (Okutani et al. 1988), which accounts for their greater prevalence in the diet of walleye pollock in deeper slope waters.

Previous researchers have shown that size-re1ated dietary variation exists for walleye pollock; increased cannibalism concurrent with decreased invertebrate zooplankton consumption with increasing predator size is the primary feature of the variation (Dwyer et al. 1987, Mito 1974, Mito 1990, Livingston 1991 a, Livingston et al. 1993). The same general trend was seen in this study, although the magnitude of the change in the diet from the smallest to the largest was relatively small due to the narrow size range and relatively large size of the walleye pollock sampled.

Cannibalism by larger walleye pollock has been shown to be higher in the autumn and winter months on the eastern Bering Sea shelf (Dwyer et al. 1987, Mito 1990, Livingston et al. 1986, Livingston, 1991 a). The results of the current study show the same trend although the dietary differences are more notable in the northeast stratum where cannibalism accounted for nearly 60% of the diet by weight than in either the northwest or southeast strata. Cooney (198 1) showed that the average zooplankton biomass in the slope region of the southeastern Bering Sea decreases through the fall and reaches its lowest levels in winter. Decreasing zooplankton abundance likely results in higher consumption of alternate prey, such as walleye pollock. Conversely, zooplankton such as euphausiids and copepods have been shown to be most important in the diet of walleye pollock in the spring and summer months on the shelf (Dwyer et al. 1987, Livingston et al. 1986), and the same is generally true on the slope. Zooplankton are most abundant during this time of year (Cooney 1981) due to the beginning ‘of the spring phytoplankton bloom which occurs in April (Goering and Iverson 1981). The diet of walleye pollock in the southeast stratum (100) did not follow these trends: euphausiids were most important in the winter and fall (there were no spring samples). One possible factor in this trend may be that walleye pollock in these samples were the smallest on average of all strata sampled; smaller pollock tend to rely more heavily upon euphausiids in the winter than do the larger ones (Livingston 1991 a).

Dwyer et al. (1987) showed that the primary winter forage fish of walleye pollock on the eastern Bering Sea continental shelf was walleye pollock and that it was fish other than walleye pollock in the Aleutian Basin area. More specifically, they showed that walleye pollock cannibalism is non-existent in the Aleutian Basin, while other fish are very prevalent in the diet. The results of the current study are in agreement with this trend. Walleye pollock cannibalism accounted for nearly 60% of the diet by weight in the shallow strata, while it was less than 5% by weight in the diet of walleye pollock in the deep strata. The contribution of other fish to the diet of walleye pollock in deep strata showed an opposite trend; other fish were the most important prey of walleye pollock in the deep strata while cannibalism was less important. Walleye pollock in the shallower strata fed more similarly to walleye pollock on the shelf, while walleye pollock in the deeper strata fed more similarly to those in the Aleutian Basin. During spring quarter the same notion holds true, although the similarities are not as striking. Decapods were present in the diet of shelf walleye pollock (Dwyer et al. 1987, Livingston 1991a), but on the slope, pandalids were the most important prey in the shallow strata; euphausiids were the most important prey in the deeper strata.

Fish, especially walleye pollock, were important prey of larger walleye pollock during winter on the eastern Bering Sea shelf (Dwyer et al. 1987). Walleye pollock cannibalism in the northeastern stratum of the slope during winter was important, however other fish prey were the primary prey in the northwestern stratum. Euphausiids were the primary prey in the diet of walleye pollock in the southeastern stratum during winter rather than fish prey. However, euphausiids were more common in the diet of smaller walleye pollock, even during the winter, on the shelf (Livingston 1991 a). Samples from our study did come from somewhat smaller walleye pollock when compared with the other slope strata sampled. During‘ summer, euphausiids were the dominant prey for walleye pollock in both strata, which is more similar to the diet of walleye pollock on the shelf than in the Aleutian Basin (Dwyer et al. 1987). During the fall, pandalids were more important in the northeastern stratum, which is also consistent with the diet of walleye pollock in the northwest shelf region of the Bering Sea (Dwyer et al. 1987).

Considerable dietary variability existed in the diet of walleye pollock in the two shallow strata between the years 1988 and 1991. This variability is likely due to slight changes in the timing or location of samples between years or inadequate sample sizes rather than representing true changes in the diets of walleye pollock during these 2 years. The presence of similar, relatively high values of some prey (i.e., squid and deep-sea fish) from opposite strata between years is difficult to explain; however, it is likely that it is a reflection of prey availability due to patchy distributions or movement of prey on a diurnal basis.

Walleye pollock cannibalism was most prevalent in the northeast strata, which is consistent with the distribution of juvenile walleye pollock in the eastern Bering Sea (Fadeyev 1988, Kihara 1990). Squid are found throughout the deep waters of the Bering Sea (Okutani et al. 1988) and were consumed by walleye pollock in relatively equal amounts throughout all strata. Walleye pollock consumed deep-sea fishes equally in all strata. However, it is difficult to associate this pattern with prey availability since little is known about the distribution of deep-sea fishes in the Bering Sea. Pacific herring were only consumed in the northeastern strata, which is likely due to their tendency to migrate to this area in winter (Wespestad and Barton 1981). Euphausiids were consumed by walleye pollock at every station sampled, reflecting their importance in the diet of walleye pollock and their ubiquitous distribution (Cooney 1981).

The maximum size of prey consumed by walleye pollock appears to be a function of predator size rather than prey availability. Most of the walleye pollock cannibalism was focused on age-0 fish, although a few larger individuals were consumed. A significant correlation between predator size and prey size indicates that larger predators are consuming larger prey. Prey selection is not simply a matter of prey abundance, but also of predator size preference. While the relationship between predator and prey size was not as clear for the deep-sea fish prey, the maximum size consumed was consistent with the range of the juvenile walleye pollock that were consumed. Livingston (1991 a) presented similar results for walleye pollock cannibalism on the eastern Bering Sea shelf. Yoshida (1994) presented similar results of fish prey size of walleye pollock in the Aleutian Basin. Mito (1974) also demonstrated similar trends of walleye pollock cannibalism in the shelf break and upper slope region of the eastern Bering Sea. This indicates that walleye pollock have exhibited some prey size preferences that should be analyzed in more detail.

Walleye Pollock Scan Data

Results

Walleye pollock field scan data collected in the southeastern stratum (100) show that euphausiids were the primary prey of walleye pollock during all quarters (Fig. 11), Other fish were of some importance in the first, third, and fourth quarters. Squid were important to walleye pollock in the third quarter and walleye pollock cannibalism was only seen in the third quarter. The diet of walleye pollock collected in the northeastern stratum (110) indicates that euphausiids were the primary prey in the third quarter (Fig. 11). Squid were the most important prey in the first quarter; euphausiids and deep-sea fish were of secondary importance. In the second quarter, walleye pollock was the most important prey with other fish and miscellaneous prey constituting the remainder of the diet. Walleye pollock collected in the fourth quarter from stratum 110 (northwest) had the most diverse diet; squid, euphausiids, miscellaneous prey, other fish, and pollock were all relatively important in the diet. The diets of walleye pollock collected in the northwestern stratum (130) revealed very different diets for each of the three quarters sampled (Fig. 11). In the second quarter, euphausiids were the primary prey, while miscellaneous prey and other fish were of secondary importance. In the third quarter, other fish comprised 99% of the diet by weight. In the fourth quarter, squid were the primary prey, with miscellaneous prey, other fish, and euphausiids being of secondary importance.

Discussion

Walleye pollock field scan data shows somewhat greater seasonal and strata dietary variation than seen in the results of the laboratory analysis presented here. Field scan data should be considered qualitative in nature. Some of the sample sizes were relatively small, and observers who performed these scans were given only limited training. Observers were trained to identify, without the aid of magnification, only the most distinguishable and most common prey such as walleye pollock, copepods, euphausiids, fish, and squid.,

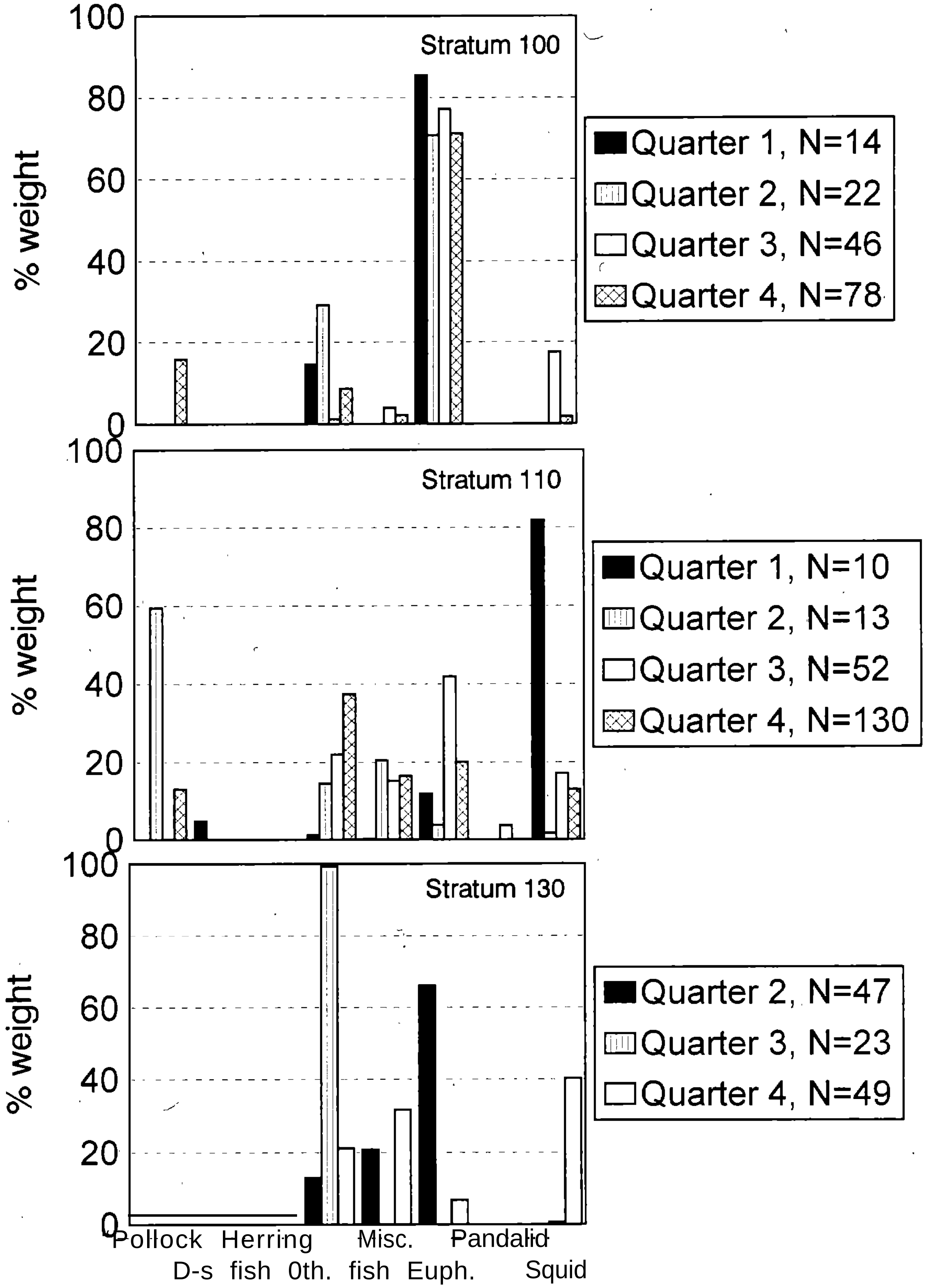

Figure 11 .--Seasonal variation in the diet of walleye pollock by percent weight in the eastern Bering Sea region in strata 100, 110, and 130 as determined from qualitative field scans. N=number of stomachs that contained food. D-s=deep-sea fish (Myctophidae and Bathylagidae).

Some similarities between the field stomach scan data and lab stomach data do exist, particularly for the data for the southeastern stratum (100) and northwestern stratum (130). The data for the northeastern stratum (110) are different, primarily due to the large presence of pandalids in the lab stomach data that might be difficult to identify in the field.

Pacific Cod

Results

Sampling locations for Pacific cod were fairly evenly distributed within each of the two shallow strata (100 and 110) (Fig. 12). Stomach samples from 314 Pacific cod were analyzed, of which 311 contained food representing 112 prey categories (Table 4). Walleye pollock dominated the diet (52%) of Pacific cod in the slope region of the eastern Bering Sea (Fig. 13). Other fish (13%) offal (10%) and pandalids (8%) were also important components of the Pacific cod diet. Chionoecetes spp.(6%), Pacific herring (4%) and squid (2%) were of lesser importance in the cod diet. The miscellaneous prey category was primarily made up of unidentified prey. Frequency of occurrence data suggest the same trend in diet composition with the exception that gammarid amphipods and polychaetes represented a greater portion of the diet than the percentage by weight figures indicated (Table 4).

Walleye pollock became more important (19-59%) in the diet of Pacific cod with increasing predator size (Fig. 14). Offal also became more important with size (8-12%) although the overall importance of offal in the diet was less. The percentage by weight of most other prey items remained relatively constant through all predator sizes, with the exception of pandalids (25-l%) and miscellaneous prey (19-2%) which declined with size. Pollock was the dominant prey for all sizes of Pacific cod.

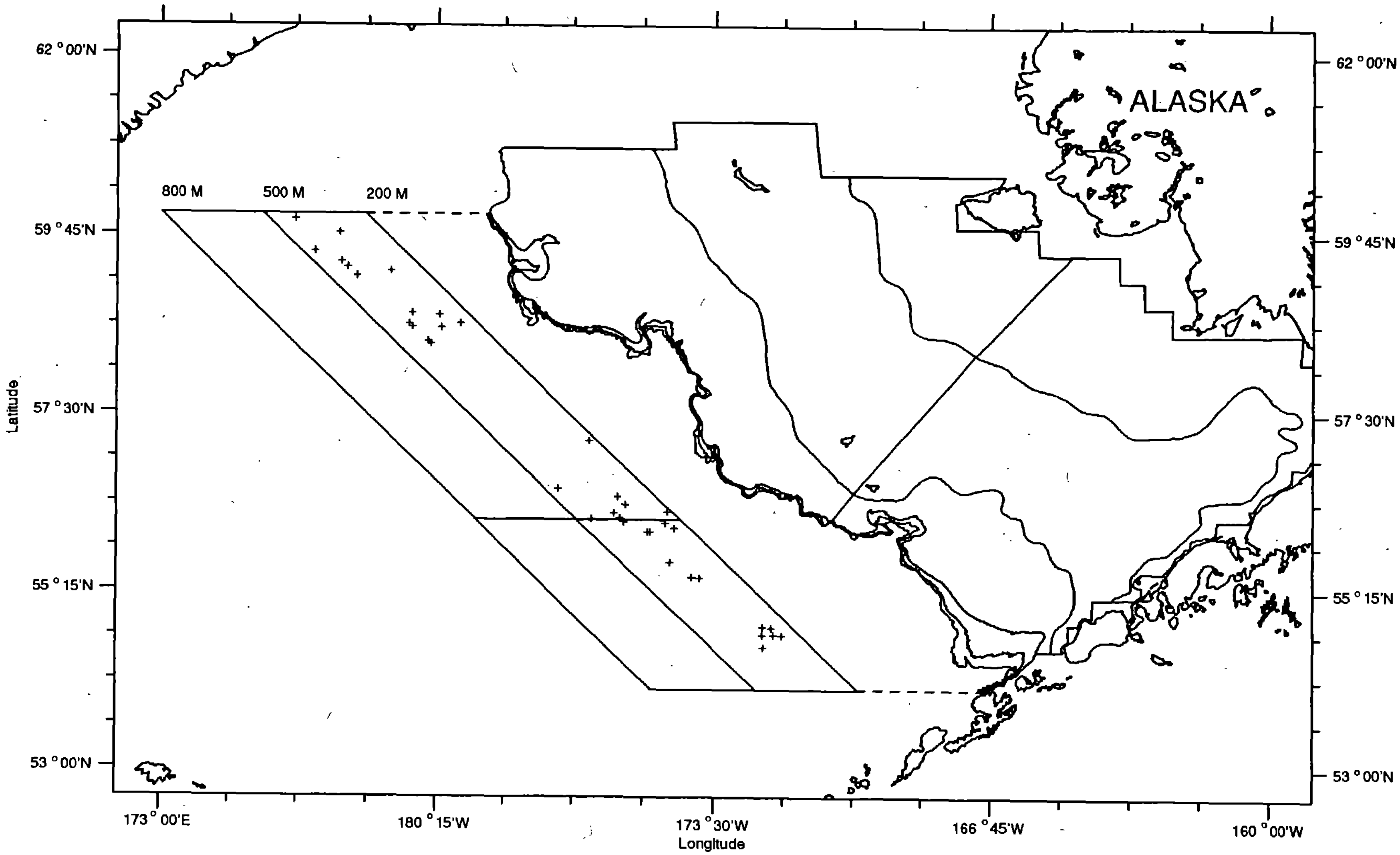

Figure 12.--The location of Pacific cod stomach collections in the eastern Bering Sea slope region.

Table 4.--The diet of Pacific cod, Gadus macrocephalus, from the slope region of the eastern Bering Sea.

Prey Name	% Frequency of Occurrence	% Total Weight
Anthozoa (anemome)	0.64	0.39
Polychaeta (worm)	27.33	0.45
Aphroditidae (sea mouse)	6.11	0.45
Phyllodocidae (polychaete)	0.64	0.00
Onuphidae (polychaete)	0.32	0.00
Gastropoda (snail)	6.75	0.09
Fusitriton oregonensis (snail)	0.32	0.02
Buccinum spp. (snail)	3.22	0.67
Neptuneidae (snail)	0.64	0.01
Beringius spp. (snail)	0.64	0.00
Colus halli (snail)	0.32	0.02
Neptunea spp. (snail)	2.25	0.00
Bivalvia (clam)	0.96	0.01
Cephalopoda (squid & octopus)	11.90	0.26
Teuthoidea (squid)	0.32	0.12
Teuthoidea Myopsida (squid)	0.32	0.25
Teuthoidea Oegopsida (squid)	3.22	0.34
Berryteuthis magister (squid)	0.96	1.15
Octopoda (octopus)	4.82	0.35
Octopodidae (octopus)	0.32	0.00
Crustacea	0.32	0.00
Calanoida (copepod)	0.32	0.00
Mysidacea Mysida (mysid)	1.29	0.01
Acanthomysis spp. (mysid)	0.32	0.00
Holmesiella anomala (mysid)	0.32	0.00
Pseudomma spp. (mysid)	0.32	0.00
Isopoda (isopod)	0.32	0.01
Flabellifera (isopod)	0.32	0.00
Amphipoda (amphipod)	0.96	0.00
Gammaridea (amphipod)	20.58	0.09
Ampeliscidae (amphipod)	0.64	0.00
Ampelisca spp. (amphipod)	0.32	0.01
Eusiridae (amphipod)	1.29	0.00
Lysianassidae (amphipod)	3.22	0.00
Anonyx spp. (amphipod)	0.96	0.00
Caprellidea (amphipod)	0.32	0.00
Eucarida	0.64	0.02
Euphausiacea (euphausiid)	3.22	0.00
Thysanoessa inermis (euphausiid)	0.32	0.00

Table 4.--(continued).

Prey Name	% Frequency of Occurrence	% Total Weight
Decapoda (shrimp & crab)	1.29	0.06
Reptantia (crab)	1.29	0.03
Caridea (shrimp)	14.47	0.34
Hippolytidae (shrimp)	14.79	0.10
Lebbeus spp. (shrimp)	0.32	0.00
Eualus spp. (shrimp)	1.61	0.01
Eualus biunguis (shrimp)	0.32	0.00
Eualus macrophthalma (shrimp)	0.96	0.01
Eualus pusiolus (shrimp)	0.32	0.00
Eualus avinus (shrimp)	6.11	0.04
Pandalidae (shrimp)	31.51	4.43
Pandalus spp. (shrimp)	11.58	1.26
Pandalus borealis (shrimp)	10.29	1.29
Pandalus jordani (shrimp)	2.57	0.09
Pandalus montagui tridens (shrimp)	0.64	0.06
Pandalopsis spp. (shrimp)	2.89	0.35
Pandalopsis ampla (shrimp)	0.32	0.17
Pandalopsis dispar (sidestripe shrimp)	0.32	0.05
Crangonidae (shrimp)	14.15	0.15
Crangon spp. (shrimp)	5.47	0.07
Crangon dalli (shrimp)	3.22	0.02
Crangon communis (shrimp)	4.50	0.08
Argis ovifer (shrimp)	0.32	0.08
Natantia (shrimp)	1.93	0.02
Anomura (crab)	2.25	0.02
Paguridae (hermit crab)	8.36	0.46
Paralithodes camtschatica (red king crab)	0.32	0.10
Decapoda brachyura (crab)	0.64	0.01
Majidae (spider crab)	1.93	0.04
Hyas spp. (lyre crab)	0.64	0.09
Hyas lyratus (lyre crab)	0.32	0.01
Chionoecetes spp. (snow and Tanner crab)	12.86	1.88
Chionoecetes opilio (snow crab)	8.68	0.66
Chionoecetes bairdi (Tanner crab)	15.43	3.45
Erimacrus isenbeckii (Korean horse-hair crab)	0.96	0.04
Sipuncula (marine worm)	0.32	0.00
Echiura (marine worm)	0.64	0.09
Echiurus spp. (marine worm)	0.64	0.04

Table 4.--(continued).

Prey Name	% Frequency of Occurrence	% Total Weight
Ophiuroidae Ophiurida (brittlestar)	0.64	0.01
Ophiuridae (brittle star)	0.32	0.00
Echinacea spp. (sea urchin)	0.32	0.00
Holothuroidea (sea cucumber)	0.32	0.01
Urochordata (tunicate)	0.32	0.00
Rajidae (skate)	0.64	0.35
Osteichthyes Teleostei (bony fish)	34.73	5.74
Non-gadoid Fish Remains	5.47	0.25
Alosa sapidissima (American shad)	0.32	0.68
Clupea pallasi (Pacific herring)	1.29	3.50
Bathylagidae (deepsea smelts)	0.32	0.00
Gadus macrocephalus (Pacific cod)	0.32	1.01
Theragra chalcogramma (walleye pollock)	21.54	51.62
Zoarcidae (eelpout)	0.64	0.21
Lycodes spp. (eelpout unid)	0.32	0.06
Sebastes crameri (darkblotched rockfish)	0.32	0.13
Icelus spiniger (thorny sculpin)	1.61	0.06
Cottidae (sculpin)	4.18	1.09
Dasycottus setiger (spinyhead sculpin)	1.29	0.58
Malacocottus kincaidi (blackfin sculpin)	0.32	0.10
Agonidae (poacher)	1.61	0.11
Asterotheca spp. (poacher)	0.32	0.00
Asterotheca pentacanthus (bigeye poacher)	0.64	0.05
Stichaeidae (prickleback)	0.96	0.07
Lumpenus maculatus (daubed shanny)	0.64	0.00
Pleuronectidae (flatfish)	0.96	2.51
Hippoglossus stenolepis (Pacific halibut)	0.32	1.57
Unidentified organic material	1.93	0.04
Unidentified eggs	0.32	0.00
Fishery discards	4.50	9.74
Unidentified tube	6.43	0.05
Overboard material (non-fishery)	0.32	0.01
Unidentified algae	0.32	0.00
Rocks	1.29	0.11
Unidentified material	1.93	0.01

Table 4.--(continued).

Total prey weight:	38,731.14g
Total non-empty stomachs:	311
‘Total empty stomachs:	3
Total prey categories:	112

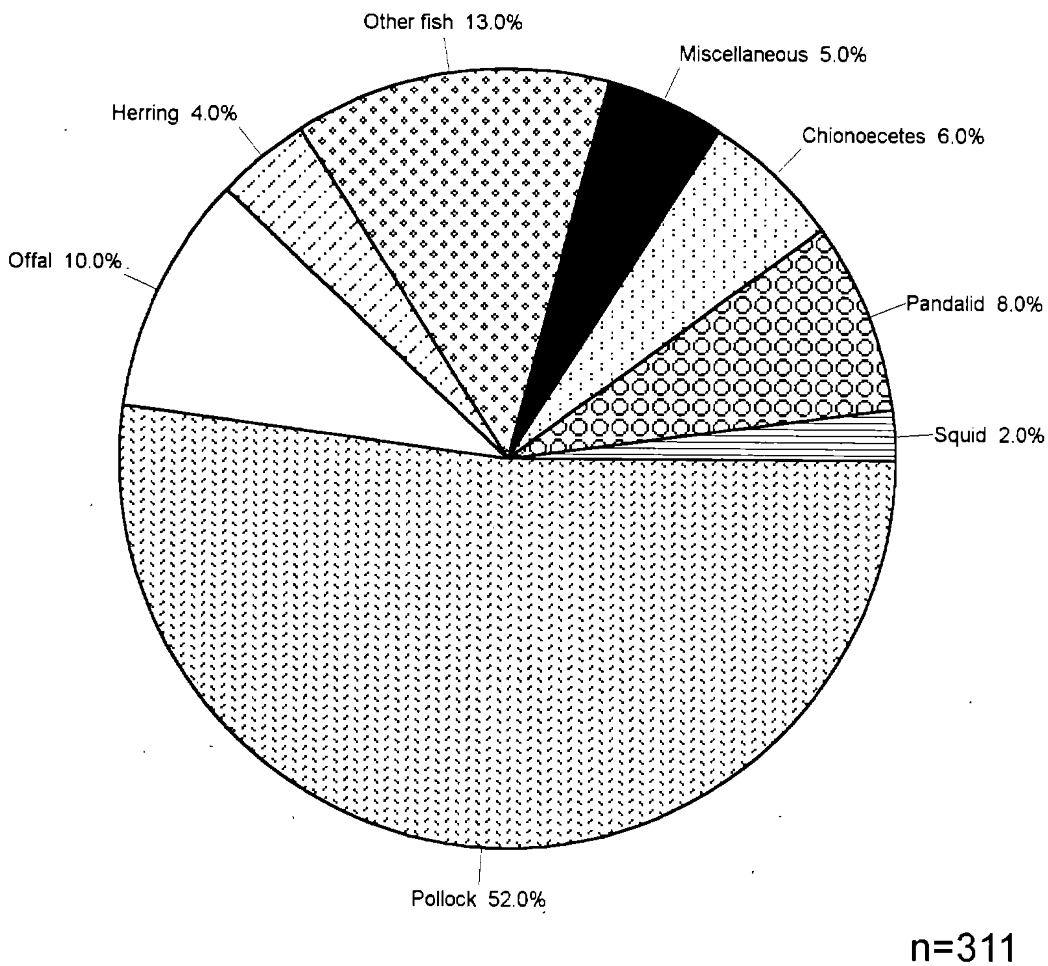

Figure 13.--The diet of Pacific cod by percent weight in the eastern Bering Sea slope region based on quantitative laboratory analysis (n=number of stomachs that contained food).

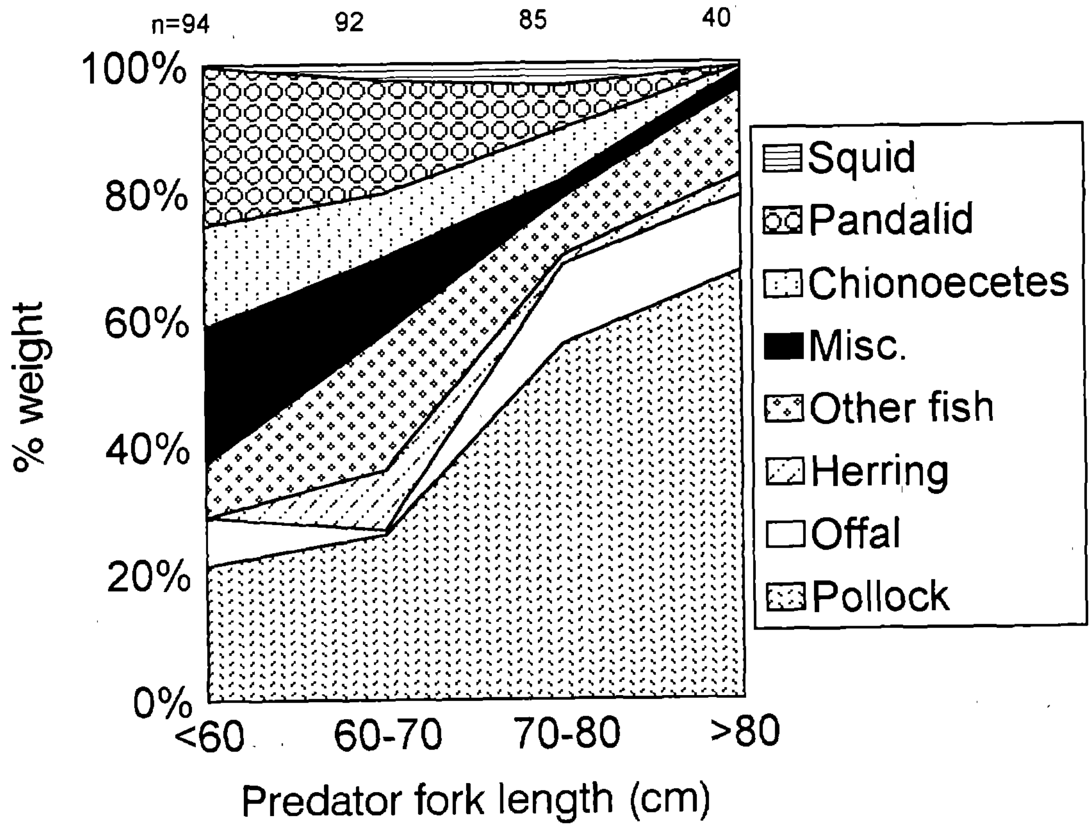

Figure 14.--The diet of Pacific cod by percent weight in the eastern Bering Sea slope region by predator size based on quantitative laboratory analysis (n=number of stomachs that contained food in each size group).

Seasonal data for Pacific cod were only available for third and fourth quarters (Fig. 15). In the southeastern stratum (l00), pollock was the primary prey of Pacific cod in both quarters. Other fish were of secondary importance in the fourth quarter. Chionoecetes spp. and pandalids were of secondary importance during the third quarter in the southeastern stratum (100). Pollock were also the primary prey of cod of both quarters in stratum 110. Herring were of secondary importance and only found in cod from the fourth quarter. Offal, other fish, and pandalids were secondary prey in the third quarter.

Latitudinal variation in the diet of Pacific cod in the slope region of the eastern Bering Sea was most prevalent in the fish prey categories (Fig. 16). Pollock were the primary prey in both strata during the third quarter, although they were a larger proportion of the diet in the southeastern stratum (100). Offal and other fish were more important in the northeastern stratum. Little variation was seen between the two strata for the other prey. During the fourth quarter, pollock were also the most important prey in both strata and were equally important in both areas. Offal and Pacific herring were only seen from stratum 110 and represented the second and third most important prey. Other fish were the secondary prey in the southeastern stratum (100). The four remaining prey types were of limited importance to Pacific cod during the fourth quarter.

Pollock were found in the diet of Pacific cod at approximately one-half of the stations sampled (Fig. 17a). Predation on pollock was more common in the northeastern stratum than in the southeastern stratum and represented a larger portion of the diet. Pacific herring were only found in the diet of Pacific cod in significant proportion at a relatively small number of stations in the northeastern stratum (Fig. 17b). Chionoecetes spp. prey were found in moderately large proportion of the diet of Pacific cod from stations in both strata (Fig. 17c). Offal was found in a relatively small portion of the diet of Pacific cod in less than one-half of the stations sampled (Fig. 17d). Offal represented >76% of the diet by weight of Pacific cod at only one station.

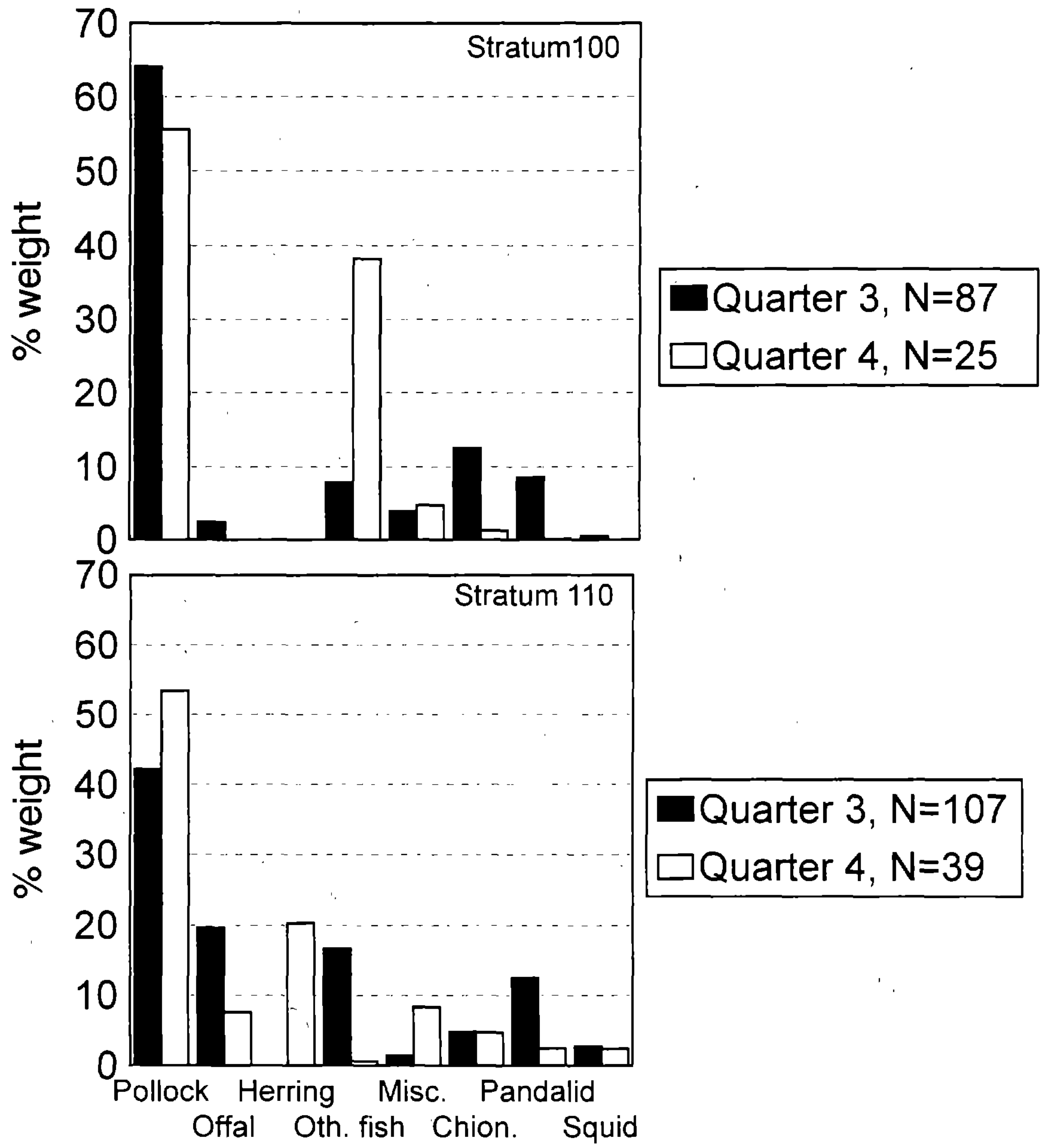

Figure 15.--Seasonal dietary variation in the diet of Pacific cod by weight in the eastern Bering Sea slope region from strata 100 and 110. N=number of stomachs that contained food. Chion.=Chionoecetes spp.

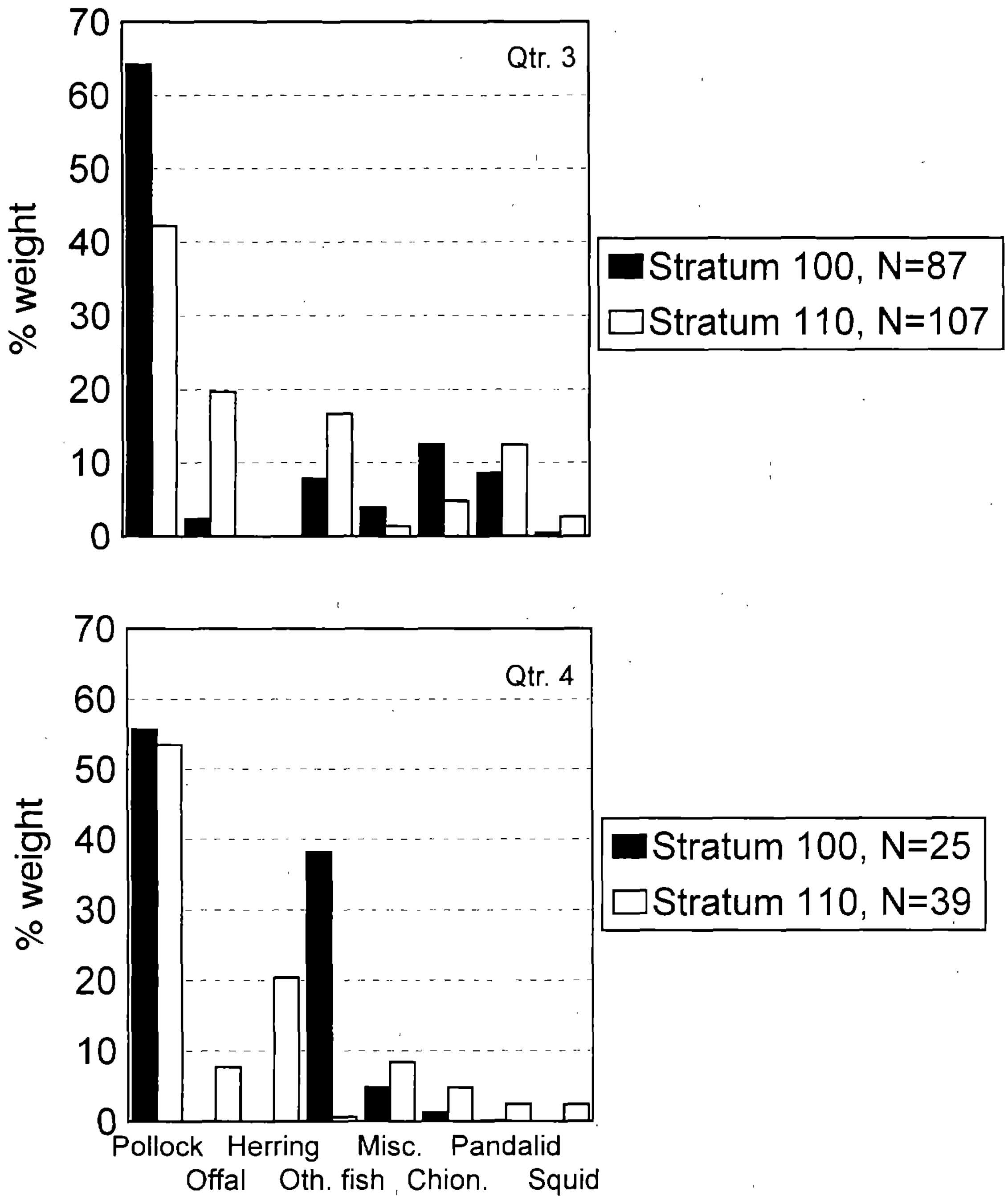

Figure 16.--Latitudinal variation in the diet of Pacific cod by percent weight in the eastern Bering Sea slope region from the third and fourth quarters. N=number of stomachs that contained food. Chion=Chionoecetes spp.

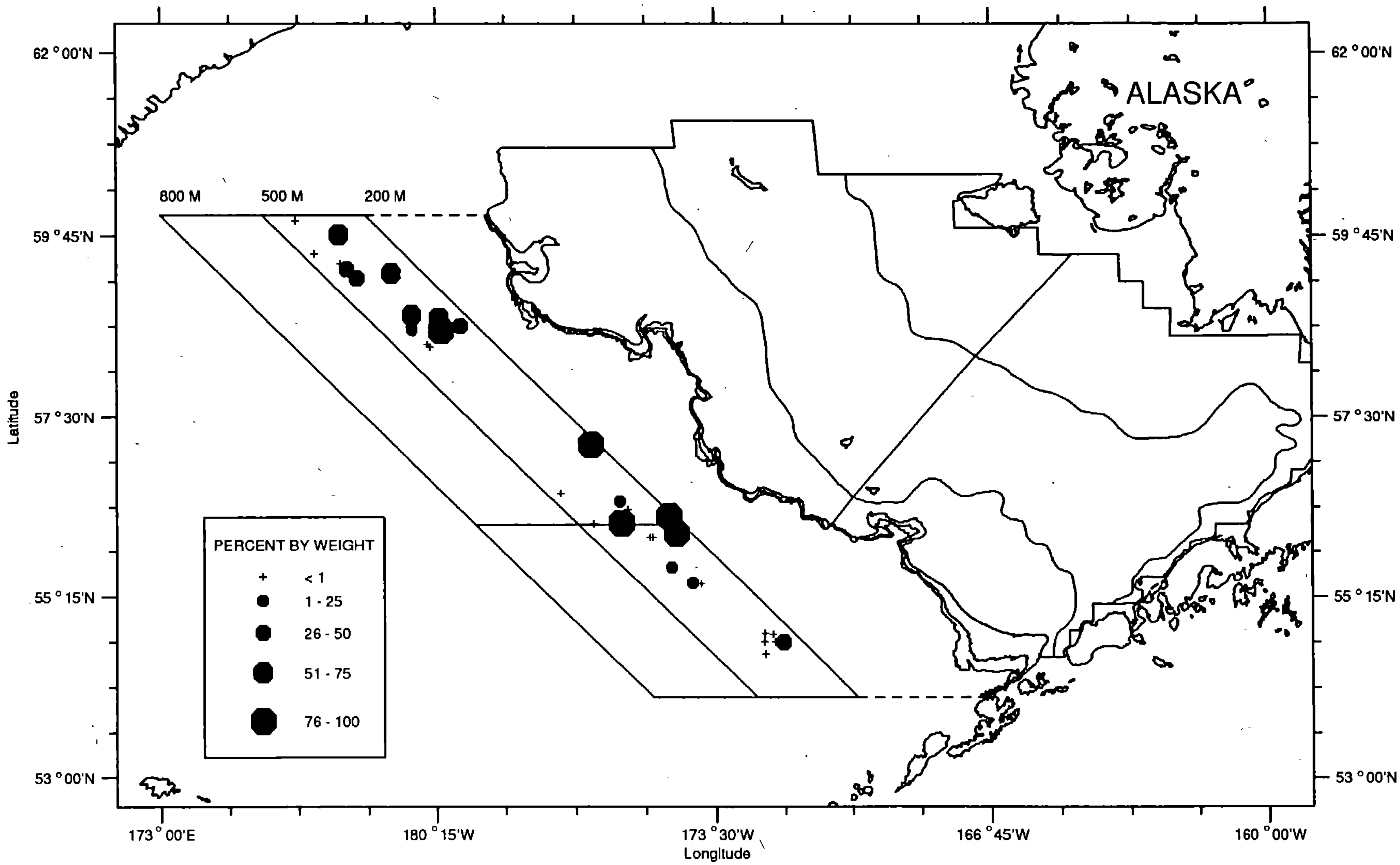

Figure 17a--The location and magnitude of Pacific cod predation on walleye pollock in the eastern Bering Sea slope region.

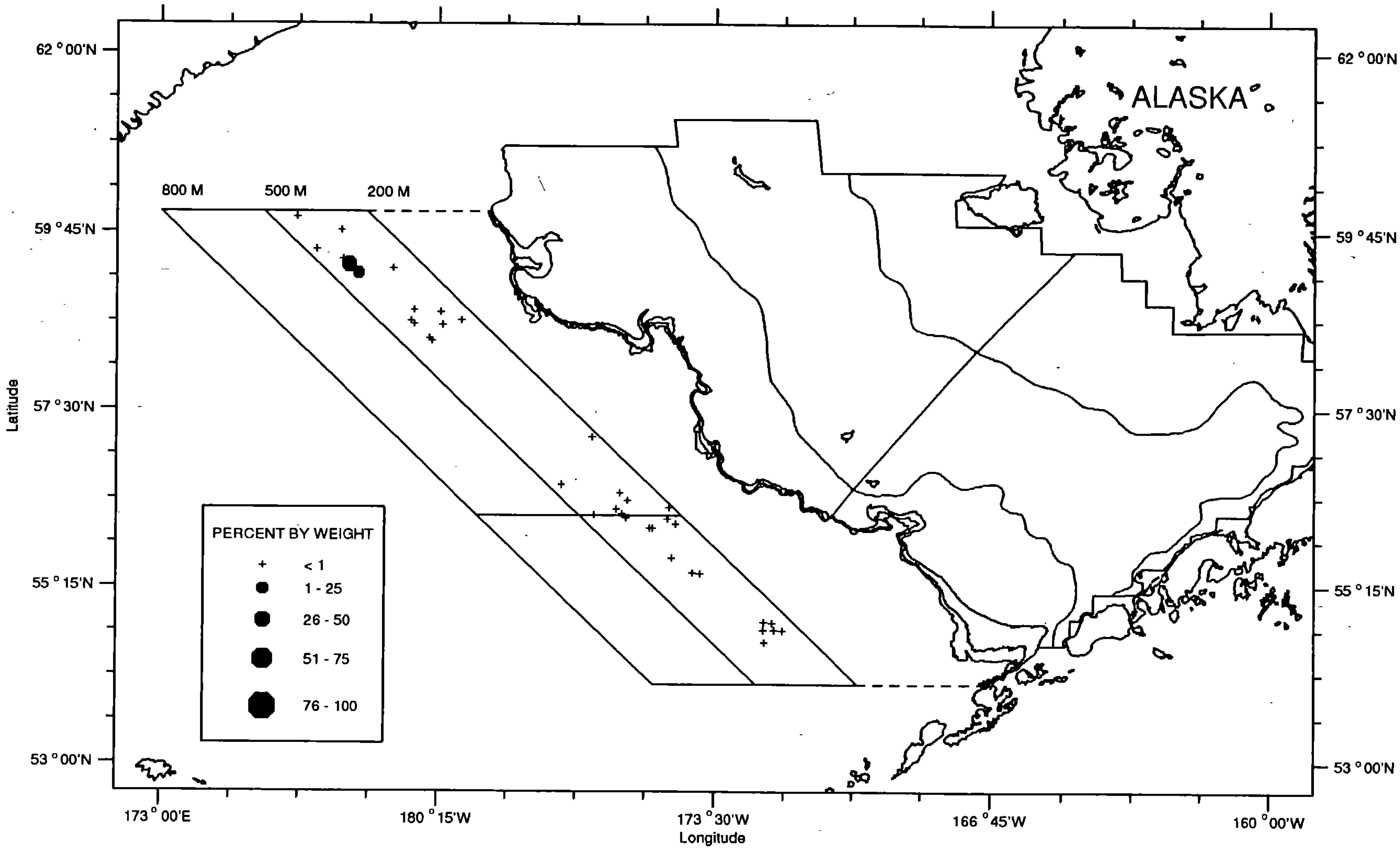

Figure 17b.--The location and magnitude of Pacific cod predation on Pacific herring in the eastern Bering Sea slope region.

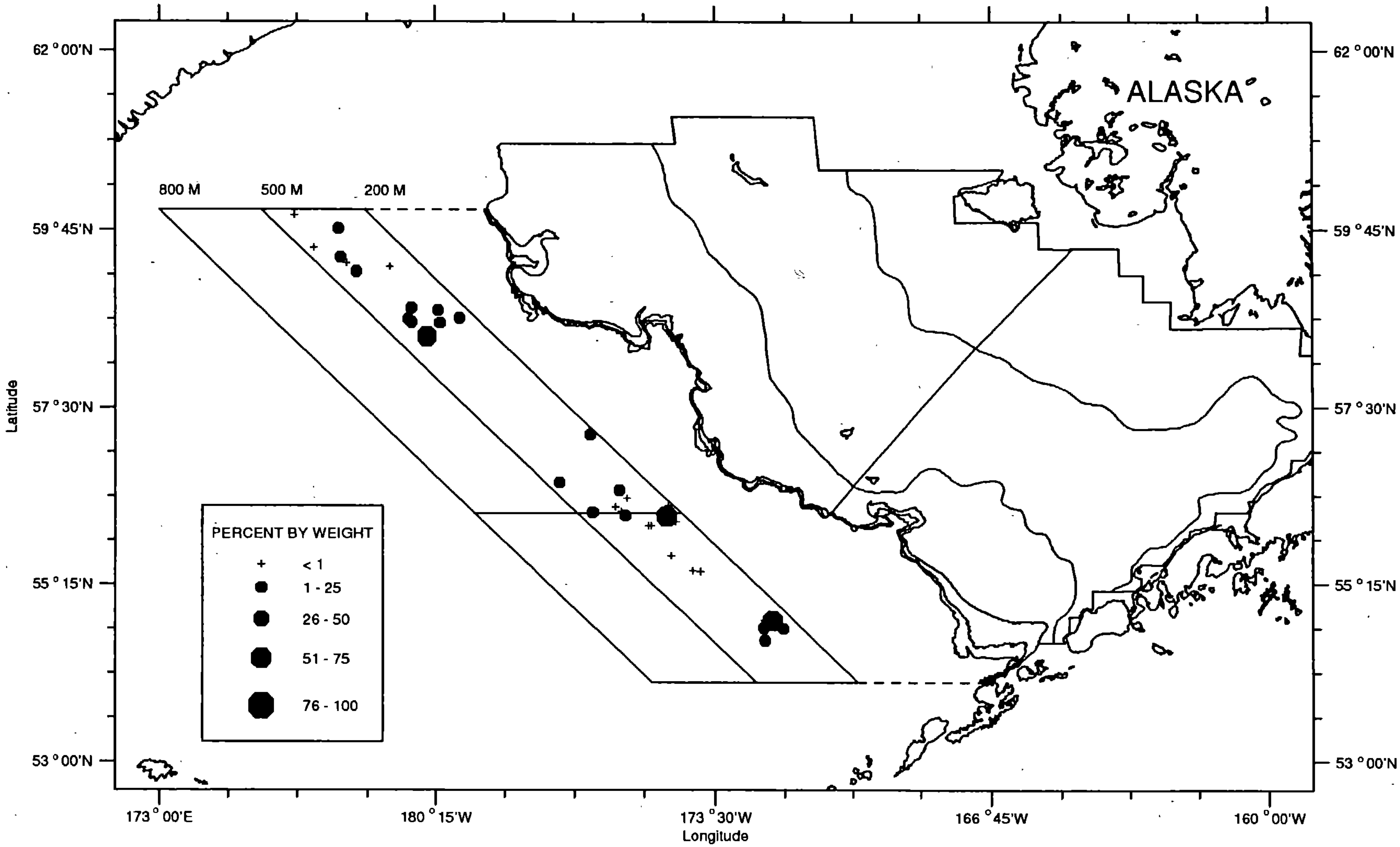

Figure 17c.--The location and magnitude of Pacific cod predation on Chionoecetes spp. in the eastern Bering Sea slope region.

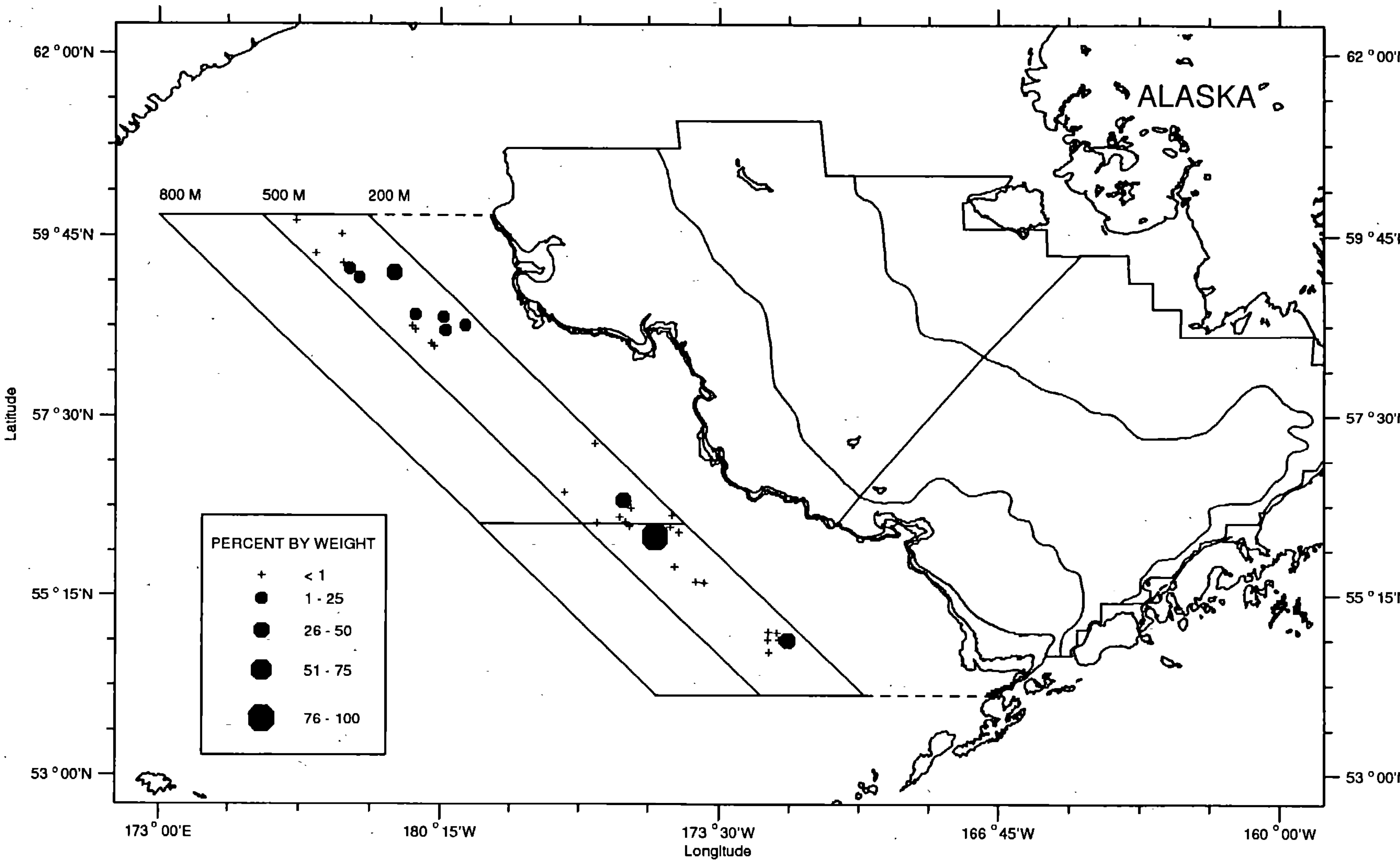

Figure 17d.--The location and magnitude of Pacific cod predation on offal in the eastern Bering Sea slope region.

Cod consumed primarily larger pollock, representing age-l and older fish (Fig. 18). Some small pollock were consumed, however there was no correlation between predator size and prey size (r^2=0.03, 0.l5>P>0. 10). Consumption of Chionoecetes bairdi and C. opilio by Pacific cod was primarily focused on relatively small individuals (Fig. 18). In both cases, prey size was positively correlated with predator size (r^2=0.23, 0.05>P>0.01, r^2=0. 16 , P<0.00l, respectively).

Discussion

In the eastern Bering Sea, Pacific cod are rare in waters deeper than 300 m (Allen and Smith 1988) and our sample locations reflect that distribution. The diet of Pacific cod in western Bering Sea coastal areas has been described to consist primarily of walleye pollock, Pacific sand lance (Ammodytes hexapterus), other fish, and crab (Tokranov and Vinnikov 1991). In the Gulf of Alaska, the diet of Pacific cod consisted of walleye pollock, capelin, other fish, and shrimp (Albers and Anderson 1985, Yang 1993). In the eastern Bering Sea, walleye pollock, other fish, and crab were the primary prey of Pacific cod (Livingston 1991b, Livingston et al 1993). Previous research in the slope region during fall showed the-diet of Pacific cod to consist of polychaete worms, decapods, and walleye pollock (Mito 1974). In the current study of the slope region of the eastern Bering Sea, walleye pollock were the dominant component of the diet of Pacific cod. The diet of Pacific cod over the slope is similar to that seen in other areas likely due to the relatively shallow distribution of Pacific cod over the slope region. The large contribution of walleye pollock seen in the slope region compared to previous studies is likely due to the larger size of Pacific cod sampled in our study. In our study,, walleye pollock were increasingly important in the diet with increasing predator size, which is consistent with, previous work (Livingston 1991b, Livingston et al. 1993, Mito 1974, Yang 1993). These studies primarily used somewhat smaller predators and showed the beginning of the relationship

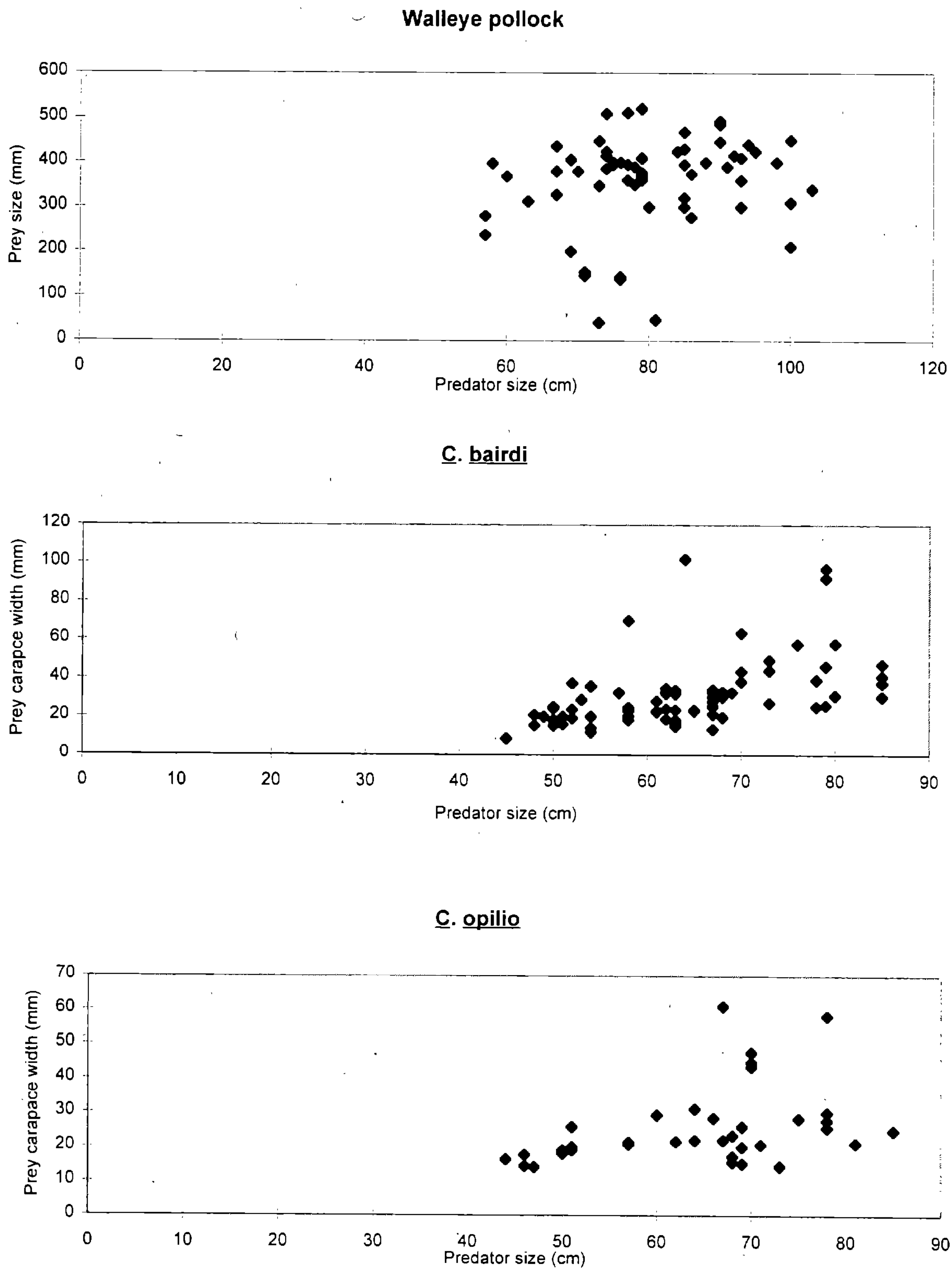

Figure 18.--Pacific cod (predator) size, prey size scatter plot of walleye pollock, C. bairdi, and C. opilio in the eastern Bering Sea slope region.

of increased importance of walleye pollock in the diet of Pacific cod with increasing predator size that is evident here. The relatively large presence of offal in the diet compared to other areas is likely due to the fact that this prey category was separated out in this study while it was lumped as miscellaneous prey or not counted as prey in some previous studies. Yang (1993) and Livingston et al. (1993) show offal as being of minor importance in the diet of Pacific cod in other areas, but that its importance increases with predator size. Our results also show an increase in the importance of offal in the diet with size, which confirms the size relationship seen in the previous works. Squid were more common in the diet of Pacific cod over the slope due to their higher abundance in deeper water (Okutani et al. 1988).

The presence of Pacific herring in the diet of Pacific cod in the northeastern stratum during the fourth quarter is likely a reflection of the seasonal return of Pacific herring to their over-wintering grounds located in the northwest section of the eastern Bering Sea (Wespestad and Barton 1981). Spatial variation in the offal component in the diet is difficult to explain based on these data. Offal would be expected to be highest in prevelence in stomachs of predators collected near at-sea processing commercial fishing operations, and most (64%) of the collections that contained offal were collected aboard commercial vessels by observers. Variation in the other fish category can result from variation in prey availability (i.e., changes in prey abundance and size) with season or area However, data on these aspects are lacking for most of the prey considered here such as juvenile walleye pollock and other small pelagic or mesopelagic fish. Changes in the relative composition of the other fish category can also result from factors, such as level of digestion, which prevent complete identification of prey fish and increases the proportion of unidentified fish within this category.

Pacific cod have been shown to exhibit a significant relationship between predator size and prey size in Alaska waters; bigger fish eat bigger prey (Livingston 1991b, Mito 1974, Yang 1993). The results of this study show a positive, significant relationship between

Pacific cod standard length and carapace width of Chionoecetes bairdi and C. opilio, but not for walleye pollock prey. Pacific cod over the slope region were relatively large, and consequently consumed primarily large walleye pollock. The lack of small Pacific cod and therefore small walleye pollock prey prohibited the development of the lower end of the relationship

Greenland Turbot

Results

Greenland turbot samples were collected from each of the four strata in the slope region (Fig. 19). Samples were collected from more stations in the outer, deeper strata than in the inner, shallower two; however, spatial coverage was similar in all four strata. Stomach samples from 858 Greenland turbot were analyzed, 45.5 of which contained prey items representing 50 categories (Table 5). Walleye pollock (58%) dominated the general diet of Greenland turbot by weight. Squid (19%) and offal (12%) were the second and third most important prey by weight (Fig. 20). These three prey accounted for 89% of the diet of Greenland turbot. Other fish (6%) snailfish (3%) Pacific herring (<l%) and deep-sea fish (1%) made up the rest of the diet. By frequency of occurrence, squid (41%) other fish (23%) and walleye pollock (23%) were the most important prey (Table 5).

Squid (up to 76%) were the most important, prey by weight of smaller (<70 cm) Greenland turbot (Fig. 21); however, the importance of squid in the diet decreased with size for fish larger than 70 cm. Squid became less important with increasing predator size and walleye pollock became more important. Walleye pollock prey were most important to the larger (>70 cm) Greenland turbot and least important to the smaller sizes. Most of the other prey were found in relatively constant proportion throughout the range of predator sizes.

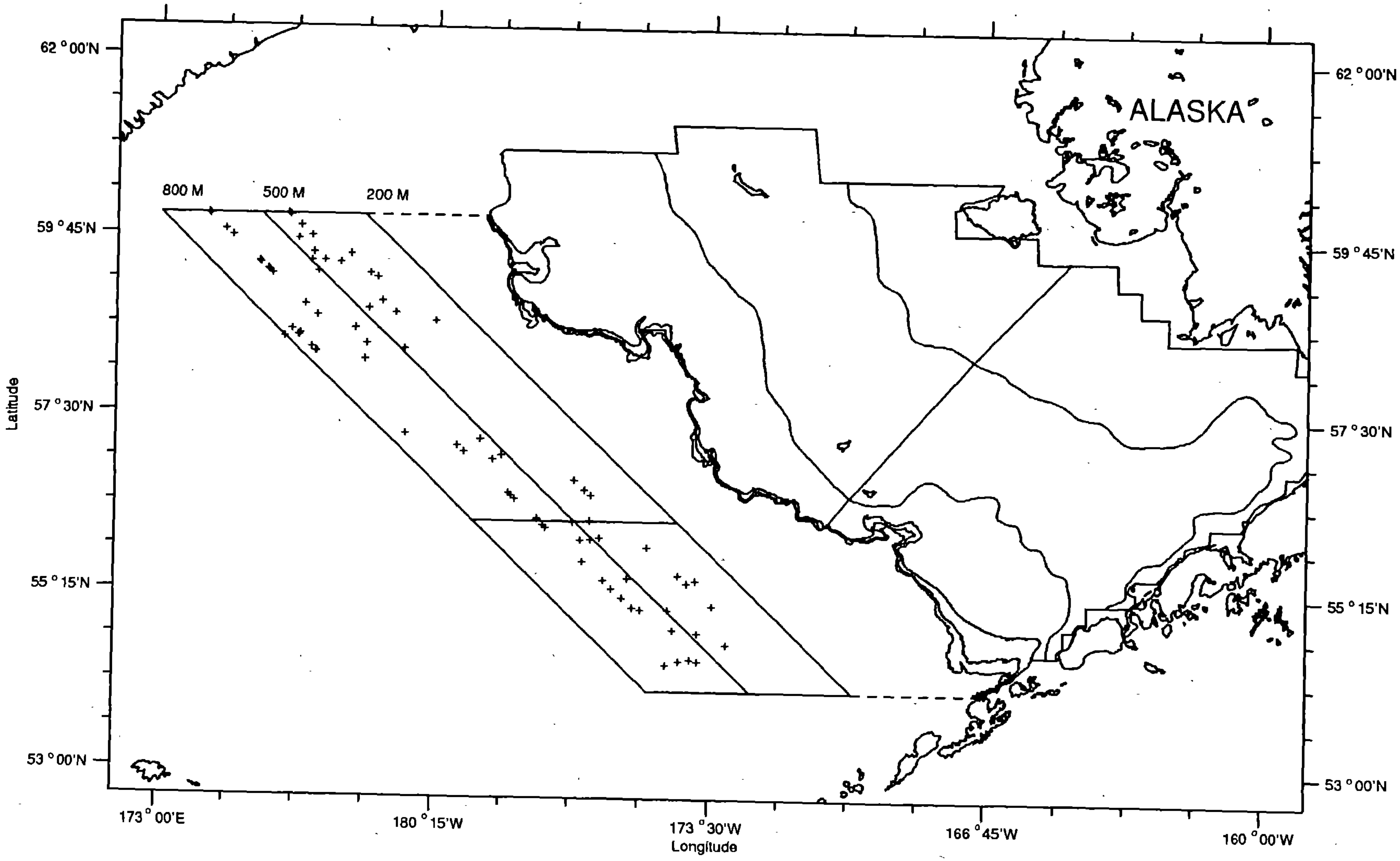

Figure 19.--The location of Greenland turbot stomach collections in the eastern Bering Sea slope region.

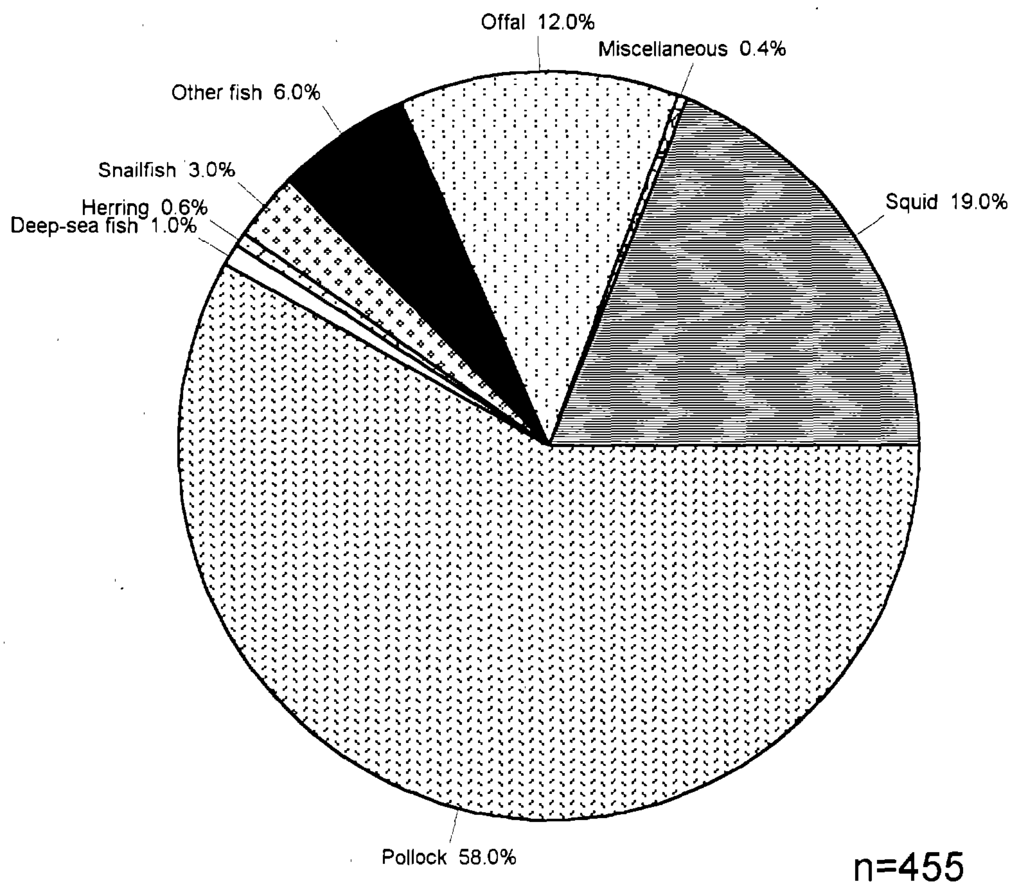

Figure 20. --The diet of Greenland turbot by percent weight in the eastern Bering Sea slope region based on quantitative laboratory analysis (n=number of stomachs that contained food).

Table 5.--The diet of Greenland turbot, Reinhardtius hippoglossoides, from the slope region of the eastern Bering Sea.

Prey Name	of Occurrence	Weight
Polychaeta (worm)	0.22	0.01
Cephalopoda (squid & octopus)	2.20	0.56
Teuthoidea (squid)	16.04	3.90
Teuthoidea Myopsida (squid)	0.22	0.00
Teuthoidea Oegopsida (squid)	8.13	2.52
Gonatidae (squid)	3.08	1.45
Gonatopsis spp. (squid)	2.42	3.05
Gonatus spp. (squid)	2.20	1.26
Gonatus magister (squid)	0.22	0.09
Berryteuthis spp. (squid)	4.40	2.08
Berryteuthis magister (squid)	4.18	4.16
Octopoda (octopus)	0.88	0.72
Crustacea	0.22	0.00
Holmesiella anomala (mysid)	0.88	0.00
Gammaridea (amphipod)	0.44	0.00
Hippolytidae (shrimp)	0.22	0.00
Pandalus spp. (shrimp)	1.10	0.02
Pandalus borealis (shrimp)	0.22	0.00
Crangonidae (shrimp)	0.22	0.00
Crangon spp. (shrimp)	0.22	0.00
Lithodidae (king crabs - legs only)	0.22	0.14
Chionoecetes opilio (snow crab)	0.22	0.03
Ophiuroidea Euryalina (basket star)	0.22	0.00
Ophiuroidae Ophiurida (brittle star)	1.54	0.01
Osteichthyes Teleostei (bony fish)	17.80	2.03
Non-gadoid Fish Remains	0.88	0.70
Clupea pallasi (Pacific herring)	0.22	0.59
Bathylagidae (deepsea smelts)	8.35	0.34
Bathylagus stilbius	1.10	0.06
Myctophidae (lanternfish)	5.93	0.43
Stenobrachius leucopsarus (n. lampfish)	0.22	0.00
Theragra chalcogramma (walleye pollock)	22.86	58.31
Zoarcidae (eelpout)	0.88	0.46
Lycodes spp. (eelpout unid)	0.88	0.31
Lycodes brevipes (shortfin eelpout)	0.22	0.09
Lycodes diapterus (black eelpout)	0.22	0.05
Macrouridae (rattail)	0.66	0.68
Coryphaenoides spp. (rattail)	0.66	0.14
Coryphaenoides acrolepis (Pacific rattail)	0.22	0.16
Coryphaenoides filifer (rattail)	0.22	0.04

Table 5.--(continued).

Prey Name	% Frequency of Occurrence	% Total Weight
Sebastolobus alascanus (shortspine thornyhead)	0.22	0.00
Dasycottus setiger (spinyhead sculpin)	0.22	0.20
Cyclopteridae (snailfish)	0.66	1.34
Aptocyclus ventricosus (smooth lumpsucker)	0.22	0.55
Careproctus cypselurus (blackfinned red snailfish)	0.22	0.82
Stichaeidae (prickleback)	0.22	0.03
Reinhardtius hippoglossoides (Greenland turbot)	0.44	0.75
Unidentified organic material	0.66	0.02
Fishery discards	5.71	11.86
Total prey weight:	47,804.28g	
Total non-empty stomachs:	455	
Total empty stomachs:	303	
Total prey categories:	50	

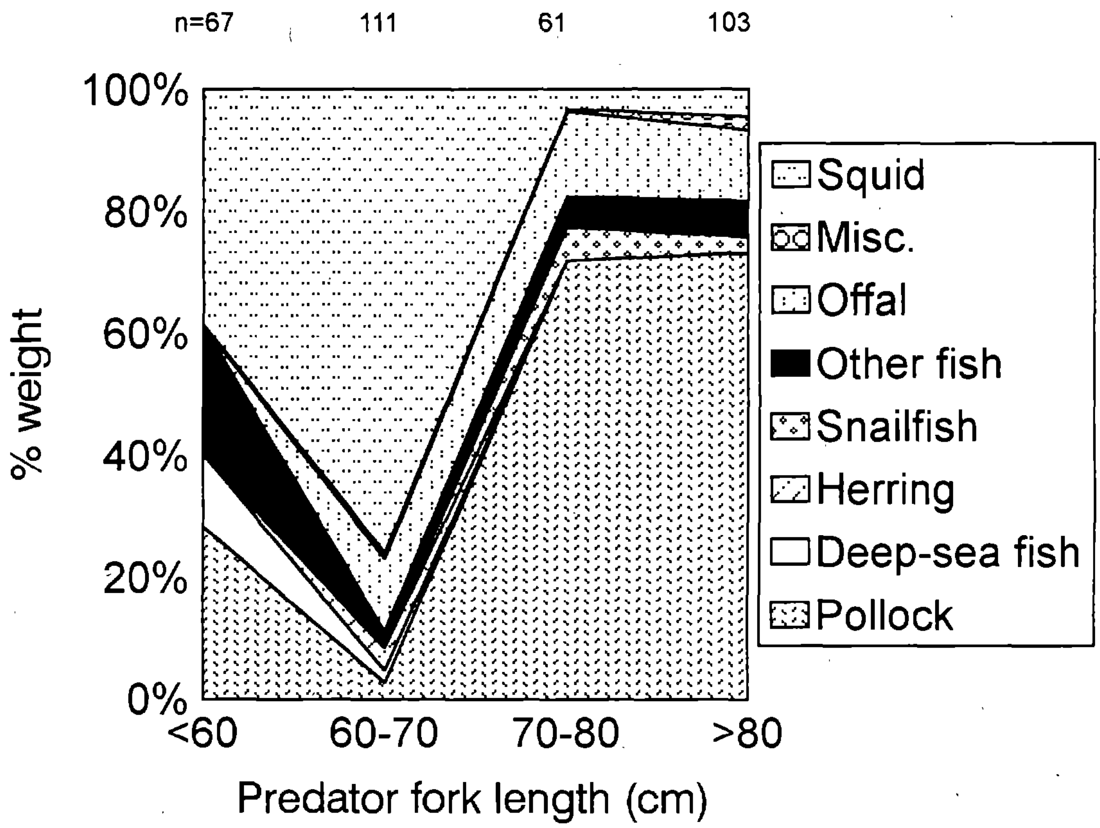

Figure 21 .--The diet of Greenland turbot by percent weight in the eastern Bering Sea slope region by predator size based on quantitative laboratory analysis (n=number of stomachs that contained food in each size group).

Adequate sample sizes were collected to allow dietary comparisons in second, third, and fourth quarters from strata 110 and 130 only (Fig. 22). In the shallower stratum (110), seasonal variation in the diet was present, although not as prevalent as was seen in other species. Walleye pollock were an important prey item in all seasons, although they were more important in the third quarter than the others. Offal was most prevalent (40%) in the diet of Greenland turbot in the fourth quarter and was not very important in the other two. Squid were of equal importance (30%) in the second and fourth quarters and much less important in the third. The other prey types were found in relatively equal proportions in the other strata. In the deeper stratum (130) seasonal variation was somewhat less pronounced. Walleye pollock were the most important portion of the diet of Greenland turbot during all seasons. Squid were important in the fourth quarter but were not as important in the other quarters. Offal was found in its highest contribution in the third quarter, somewhat less in the fourth quarter and of negligible importance in the second quarter. All other prey were found in relatively similar proportions in all quarters.

With the exception of walleye pollock and squid, depth-related variation in the diet of Greenland turbot was relatively small in the second quarter (Fig. 23). Pollock were more important in the diet from deeper water, while squid were more important in the shallower water. In the third quarter, dietary variation was even more limited, and most prey were of similar importance in both depth zones. Walleye pollock were more important in the shallower depth, while offal was more important in the deeper water. In the fourth quarter, offal was substantially more important in the shallow stratum while walleye pollock, squid, and other fish were most important in the deeper water.

Pollock were found to be a large portion (>25%) of the diet of Greenland turbot in most stations sampled (Fig. 24a). Significant (>50%) amounts of pollock in the diet were found in higher proportion of the stations in the northern strata than in the southern strata, Squid were also found in relatively high proportions in the diet of Greenland turbot in stations from all strata and were more prevalent in the inner strata (Fig. 24b).

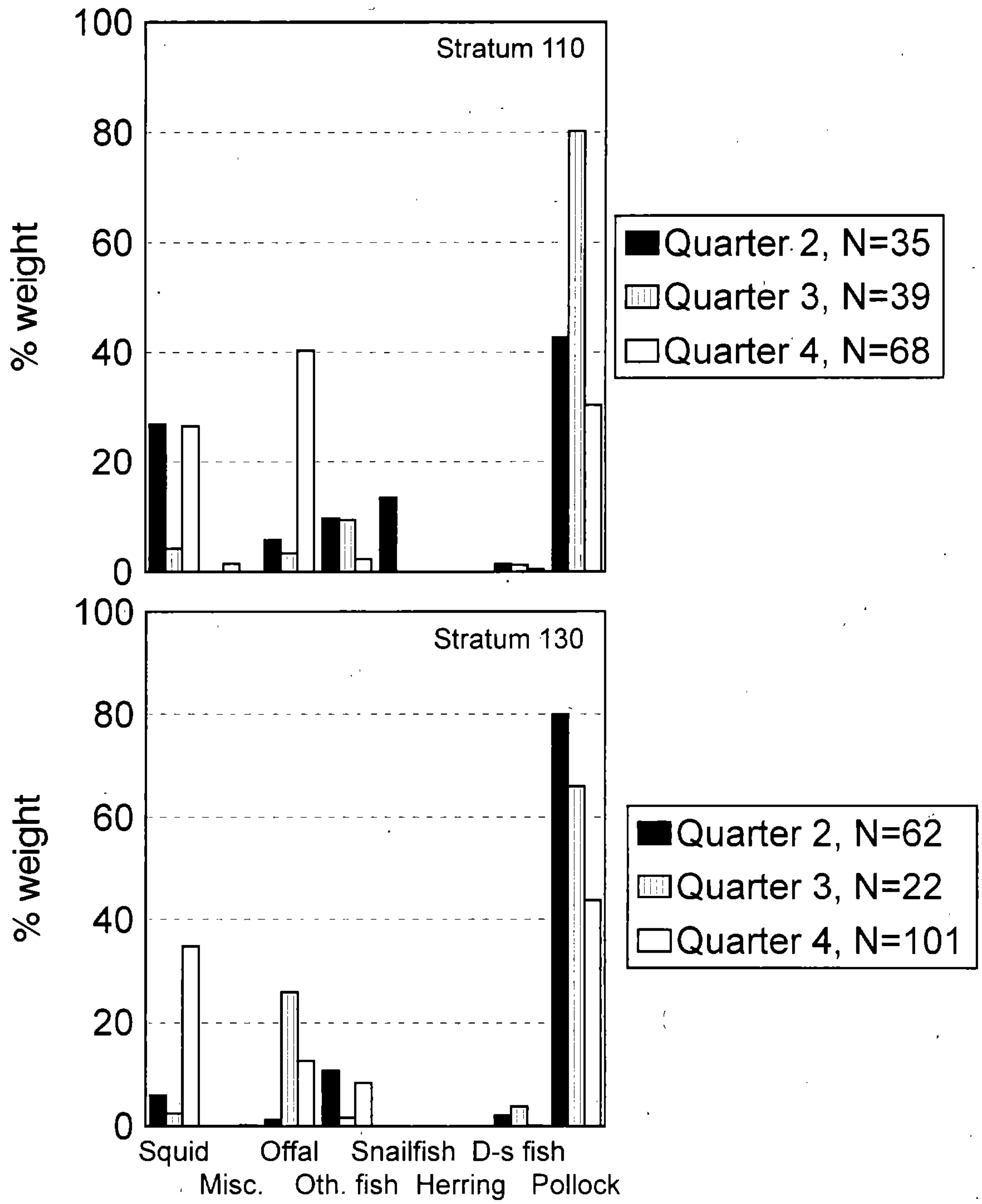

Figure 22.--Seasonal variation in the diet of Greenland turbot by percent weight in the eastern Bering Sea slope region from strata 110 and 130. N=number of stomachs that contained food. D-s fish=deep-sea fish (Myctophidae and Bathylagidae).

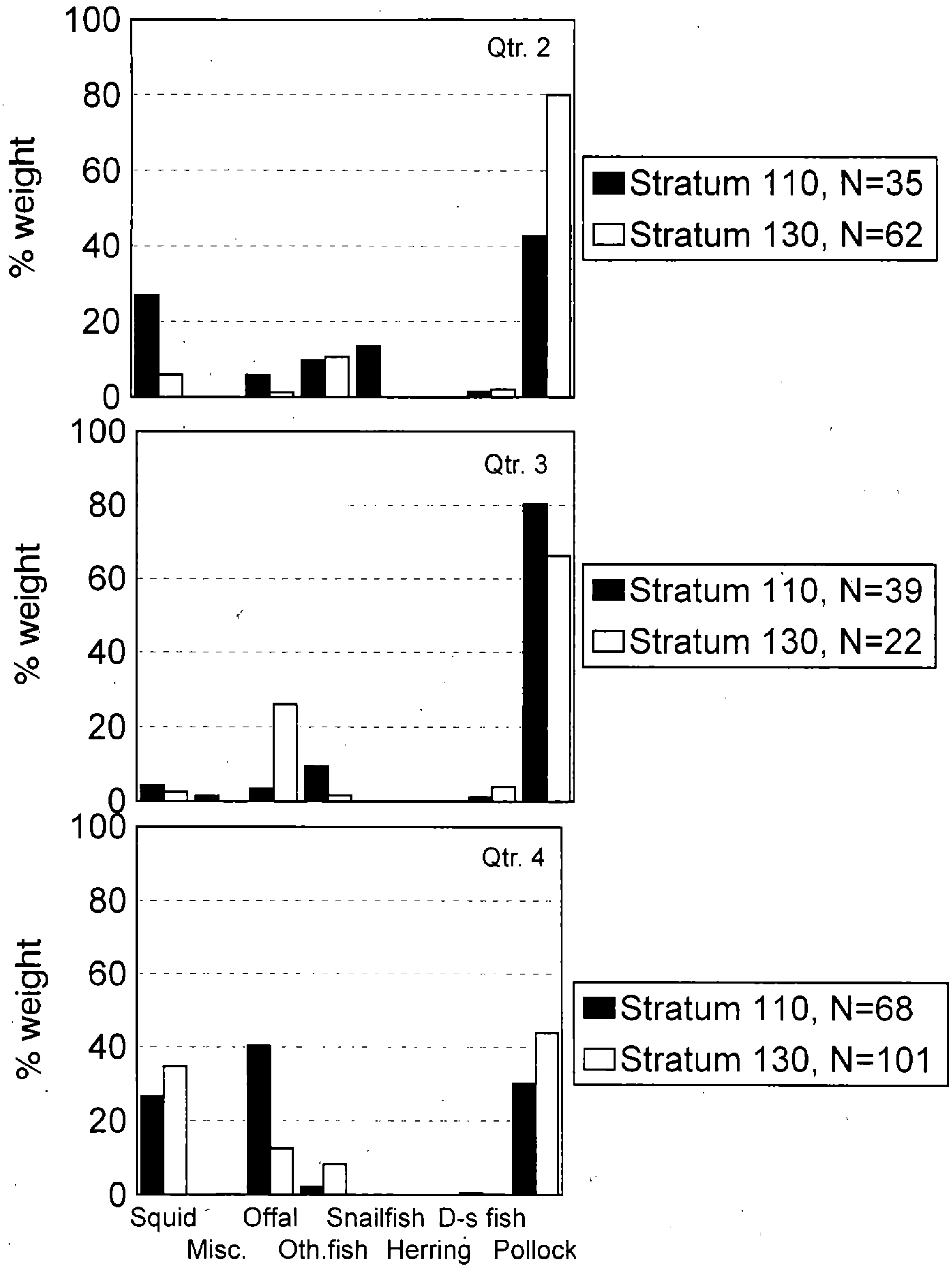

Figure 23.--Depth related variation in the diet of Greenland turbot by percent weight in the eastern Bering Sea slope region from the second, third, and fourth quarters. N=number of stomachs that contained food. D-s fish=deep-sea fish (Myctophidae and Bathylagidae).

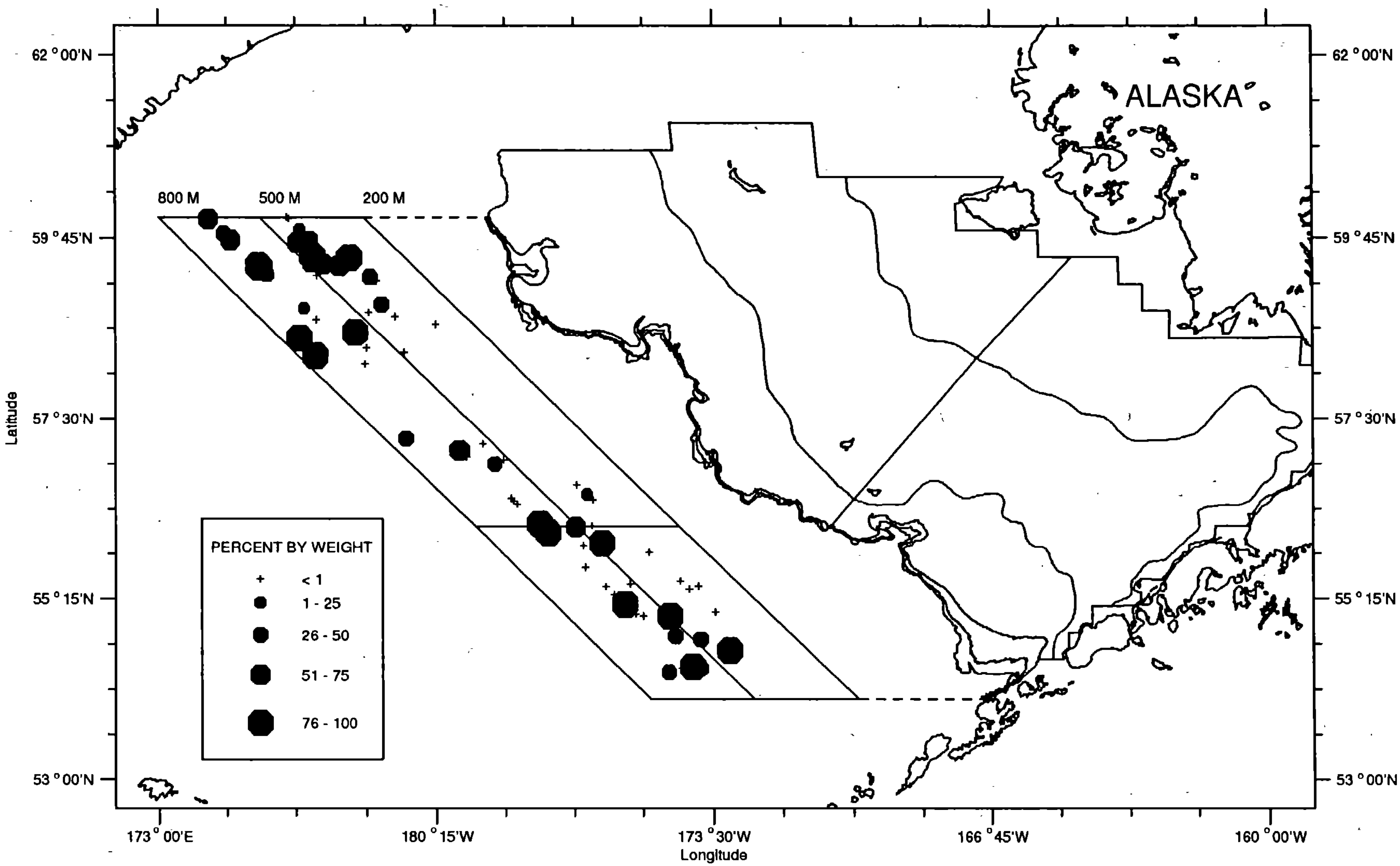

Figure 24a.--The location and magnitude of Greenland turbot predation on walleye pollock in the eastern Bering Sea slope region.

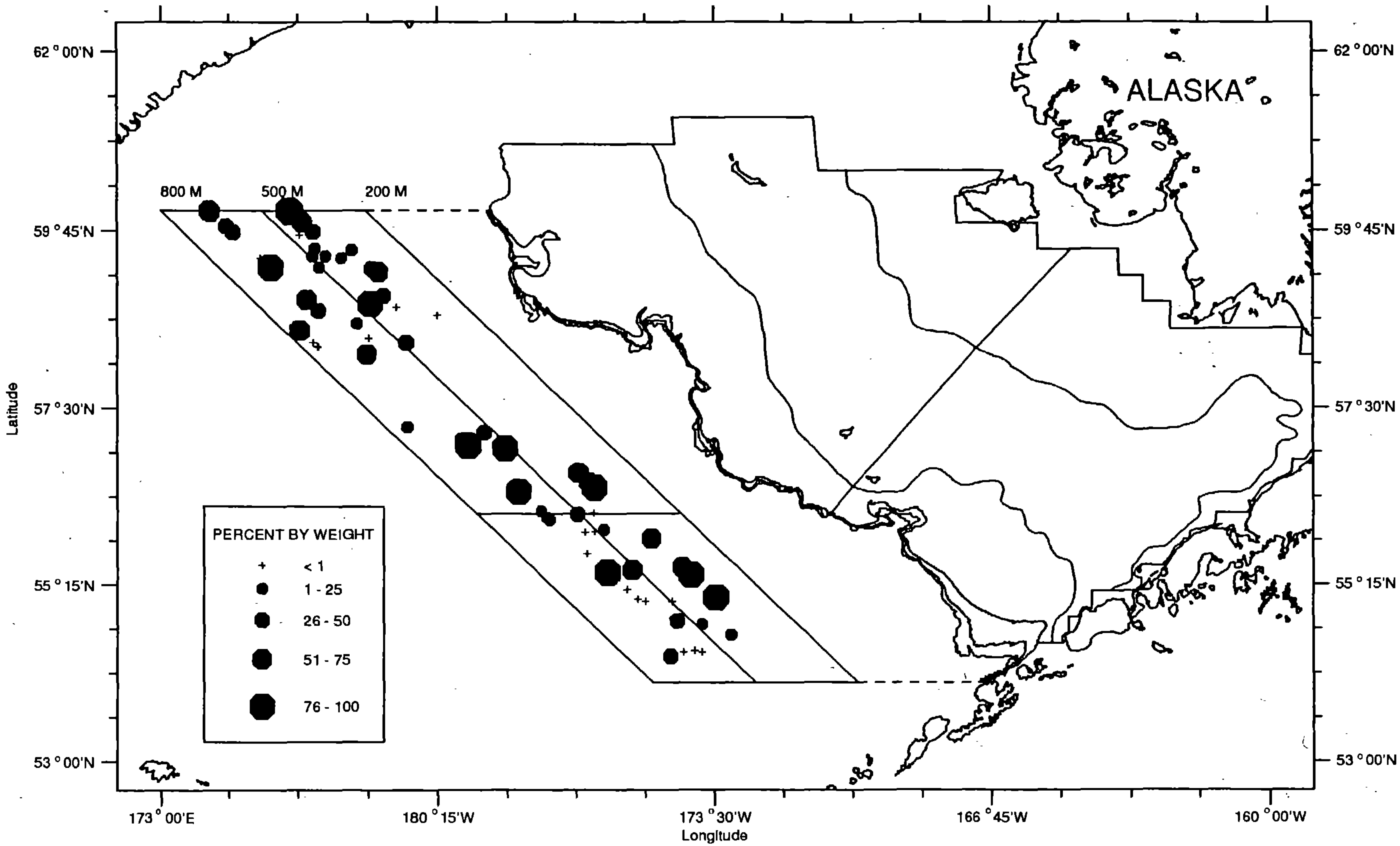

Figure 24b.--The location and magnitude of Greenland turbot predation on squid in the eastern Bering Sea slope region.

Consumption of offal by Greenland turbot was relatively sparse, although it was somewhat more common in samples collected in the northern strata (Fig. 24c).

Greenland turbot consumed all size groups of pollock; however, the smaller (age-O) fish were primarily consumed in the northern strata (Fig. 25). Smaller prey were also generally consumed by the smaller predators and there was a significant correlation between predator size and prey size (r^2=0.41, P<0.00l). Myctophid predation was focused on individuals less than 100 mm fork length with a positive correlation (r^2= 0.22, 0.05>P>0.01) between predator size and prey size (Fig. 25). Bathylagid prey consumed by Greenland turbot were primarily between 60 and 110 mm fork length (Fig. 25). There was not ‘a significant relationship (r^2=0.006, P=O.63) between predator length and prey length.

Discussion

Greenland turbot are primarily found in depths less than 600 m (Allen and Smith 1988). Our sample locations reflect this distribution as Greenland turbot stomachs were sampled in all strata in the slope region of the eastern Bering Sea. Yang and Livingston (1988) described the diet of Greenland turbot in the eastern Bering Sea slope region to primarily consist of gadids (primarily walleye pollock), cephalopods, and other fish. Mito (1974) described the diet of Greenland turbot over the slope during the fall to consist primarily of walleye pollock, with Pacific herring and arrowtooth flounder as secondary fish prey. On the eastern Bering Sea shelf, the Greenland turbot diet has been described as consisting of gadids, cephalopods, and euphausiids (at smaller predator sizes) as the primary prey, and that bathylagids and myctophids (deep-sea fish in the current study) became increasingly important with depth (Yang and Livingston 1988, Yang 1991a, Livingston et al. 1993). The diet of Greenland turbot over the slope described here is in general agreement with these studies although the importance of some fish (bathylagids and zoarcids) is less than what might have been expected given the trends on the shelf,

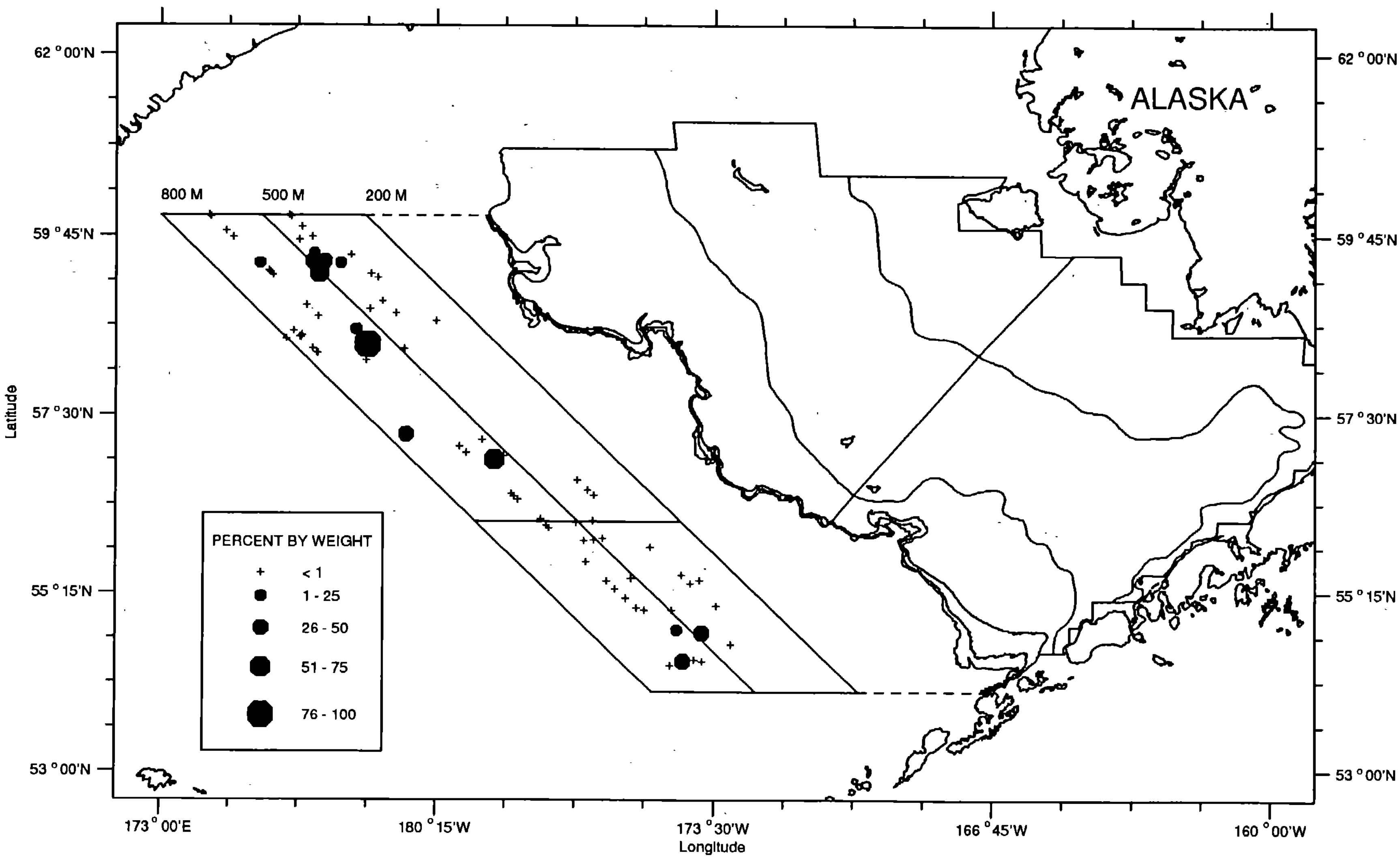

Figure 24c.--The location and magnitude of Greenland turbot predation on offal in the eastern Bering Sea slope region.

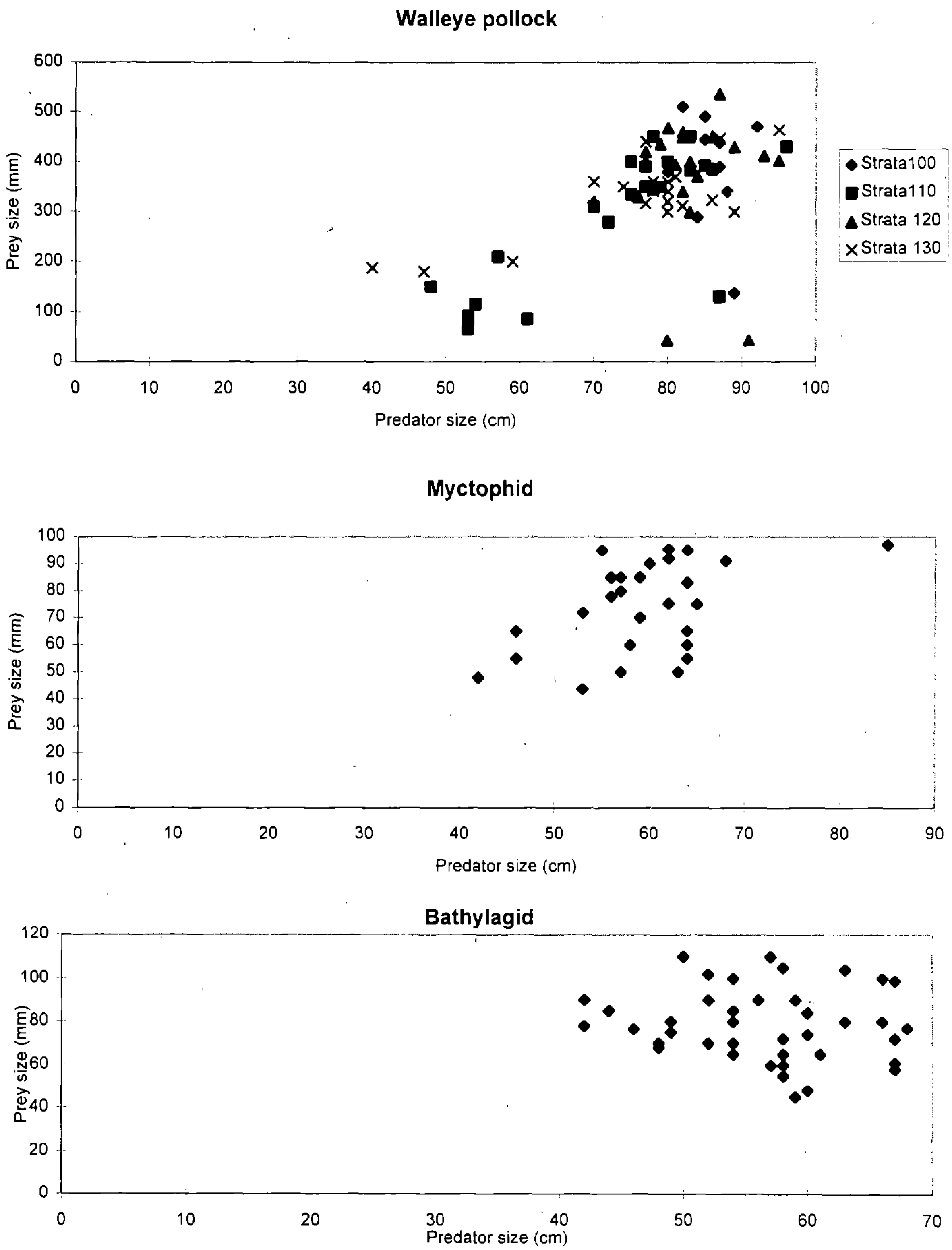

Figure 25.--Greenland turbot (predator) size, prey size scatter plots of walleye pollock, myctophid, and bathylagid prey in the eastern Bering Sea slope region.

A higher dependence upon squid by smaller Greenland turbot in slope areas was also seen by Yang and Livingston (1988) with a switch to walleye pollock at larger sizes. Other work (Yang 1991a, Livingston et al. 1993) on the shelf, and Mito (1974) on the slope did not show such a strong relationship. The reasons for this diet pattern and the differences between the shelf and slope seen here are likely due to a lower abundance of squid and higher abundance of juvenile walleye pollock in shallow water (Goddard and Zimmermann 1993, Okutani et al. 1988). Greenland turbot exhibited a positive, significant relationship between predator size and walleye pollock prey size in previous work on the shelf (Yang and Livingston 1988, Yang 1991a, Livingston et al. 1993) and in the current study indicating the availability of small walleye pollock as prey. Therefore it is likely that the relative lack of juvenile walleye pollock over the slope contributes to their decreased importance in the diet of small Greenland turbot. In this study,. the majority of the smaller walleye pollock were consumed in the northern strata, which is where juvenile walleye pollock are thought to be most abundant (Fadeyev 1988, Kihara 1990). A significant relationship did not exist between Greenland turbot size and bathylagid size. Although there was a significant relationship between myctophid length and Greenland turbot length, there was not a large variation in the size of myctophids consumed (40-100 mm) and the number of myctophids measured was low.

Seasonal variation in the diet of Greenland turbot on the slope is consistent with that seen on the shelf by Yang (1991a), although the proportion of walleye pollock in the diet was generally larger on the slope due to larger predator sizes sampled. The most striking variation lies in the importance of squid and offal in the diet. Differences in squid predation may be a result of seasonal movement of squid in response to reproduction or predation behavior. This variation may also be due to changes in the availability of alternate prey; walleye pollock, in this case, varied inversely with squid in the diet, Variation in the prevalence of offal in the diet likely lies in its availability to the predator. Offal is an anthropogenic contribution to the prey pool; it can only be consumed within a relatively close proximity to fishing operations. Offal consumption was primarily (85% of the occurrences) seen in samples collected aboard commercial fishing vessels.

The location of stations where Greenland turbot consumed walleye pollock and squid were fairly evenly distributed throughout all strata over the year. The relative importance of these prey was also evenly distributed, indicating "a relative consistency of prey availability in a strata. The results do not, however, shed light on the seasonal abundance of prey. The location of stations where offal was important in the diet of Greenland turbot primarily reflects areas where samples were collected aboard commercial processing vessels.

Flathead Sole

Results

Flathead sole were primarily sampled in the two inner strata (100 and 110), although a few stations were sampled in the outer strata (Fig. 26). Stomach samples from 528 flathead sole were analyzed, of which 366 contained prey representing 75 categories (Table 6). Brittle stars were the most important prey by weight (50%) of flathead sole in the slope region of the eastern Bering Sea (Fig. 27). Offal (24%) rockfish (10%) other fish (4%) and walleye pollock (3%) also contributed to the diet of flathead sole over the slope region of the eastern Bering Sea. The miscellaneous prey category (5% by weight) was primarily unidentified material. By frequency of occurrence the diet of flathead sole is very similar; brittle stars were the primary prey. However, small prey such as gammarid amphipods and polychaetes which were not important by weight were more important by frequency (Table 6).

Brittle stars were the dominant prey for all sizes of flathead sole collected in this study (Fig. 28). Brittle stars and offal were of greater importance with increasing predator size: Walleye pollock and rockfish prey were found to be less important in the diet of flathead

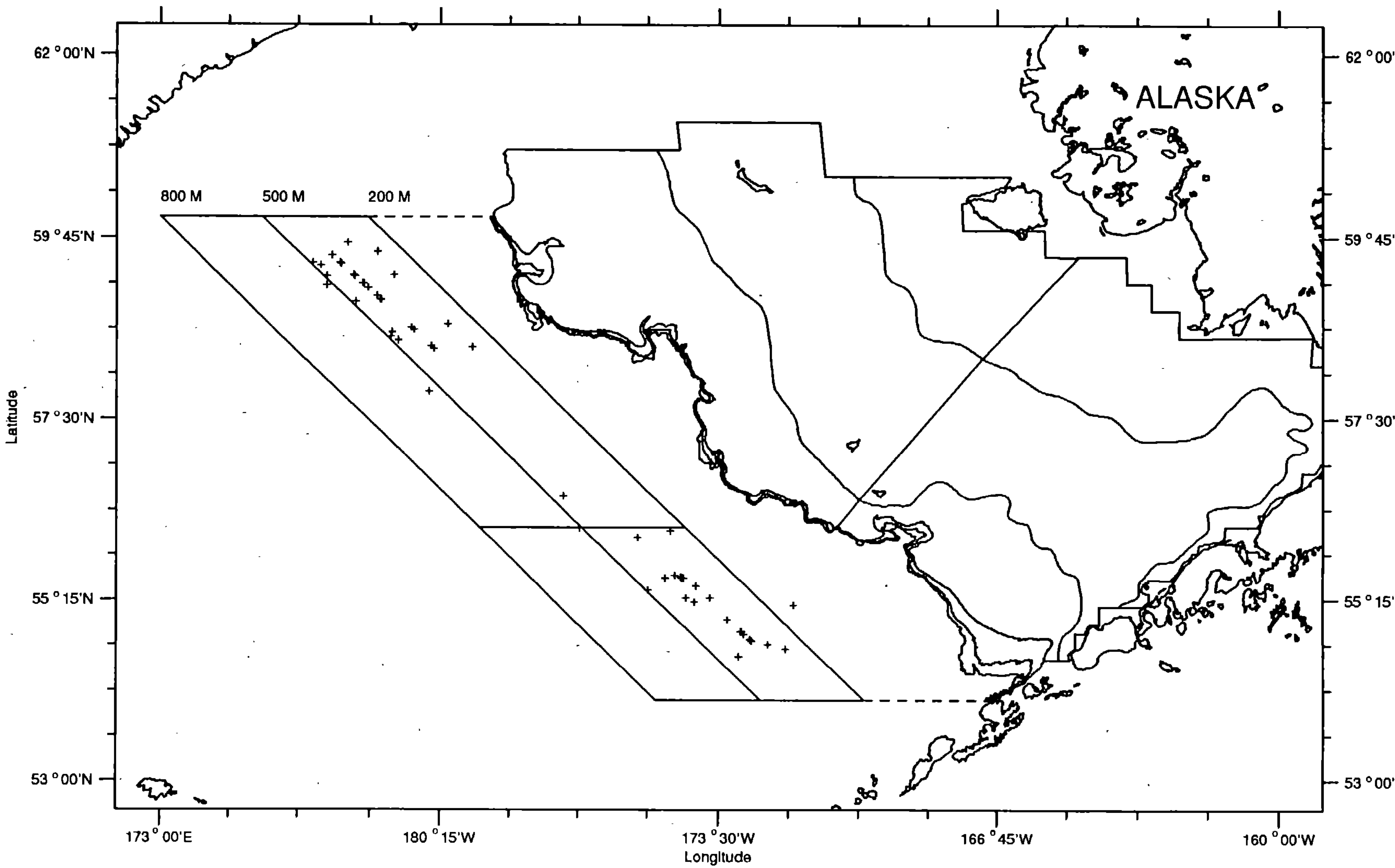

Figure 26 --The location of flathead sole stomach collections in the eastern Bering Sea slope region.

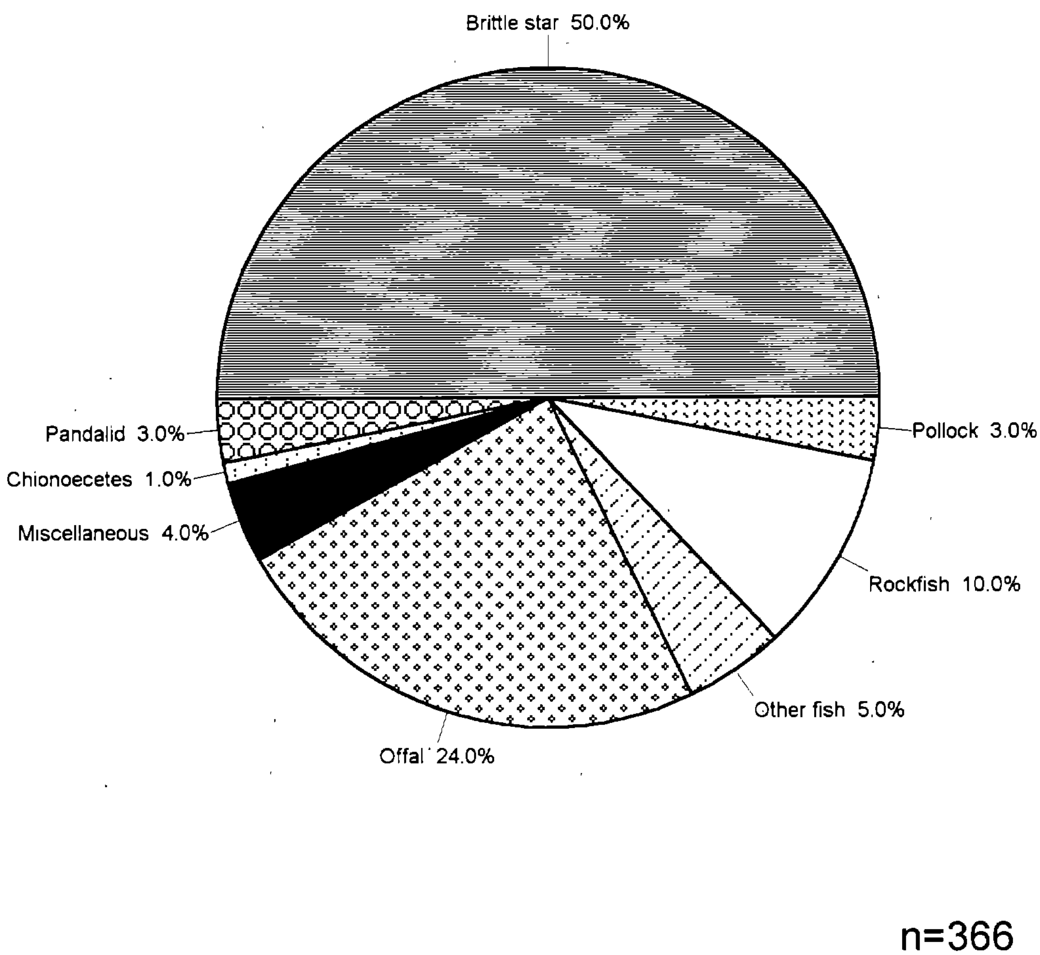

Figure 27.--The diet of flathead sole by percent weight in the eastern Bering Sea slope region based on quantitative laboratory analysis (n=number of stomachs that contained food).

Table 6.--The diet of flathead sole, Hippoglossoides elassodon, from the slope region of the eastern Bering sea.

Prey Name	% Frequency of Occurrence	% Total Weight
Polychaeta (worm)	17.76	1.03
Aphroditidae (sea mouse)	0.55	0.60
Hirudinea (leech)	0.27	0.08
Mollusca	0.27	0.00
Gastropoda (snail)	2.19	0.04
Bivalvia (clam)	2.73	0.02
Nucula spp. (clam)	0.27	0.01
Nuculana spp. (clam)	1.09	0.00
Cyclopecten spp. (scallop)	0.55	0.06
Cephalopoda (squid & octopus)	0.55	0.00
Teuthoidea (squid)	0.27	0.14
Gonatidae (squid)	0.27	0.30
Arachnida	0.82	0.00
Arthropoda Pycnogonida (sea spider)	0.27	0.00
Crustacea	0.82	0.02
Ostracoda	0.27	0.00
Calanoida (copepod)	0.27	0.00
Calanus spp.	0.27	0.00
Neocalanus cristatus	0.27	0.00
Malacostraca	0.27	0.01
Mysidacea Mysida (mysid)	2.46	0.02
Mysidae (mysid)	1.64	0.36
Holmesiella anomala (mysid)	0.27	0.00
Pseudomma truncatum (mysid)	0.55	0.00
Cumacea (cumacean)	4.64	0.01
Isopoda (isopod)	2.19	0.01
Flabellifera (isopod)	0.82	0.07
Amphipoda (amphipod)	1.64	0.02
Gammaridea (amphipod)	11.48	0.07
Lysianassidae (amphipod)	0.55	0.01
Amphipoda Hyperiidea (amphipod)	0.55	0.00
Euphausiacea (euphausiid)	2.73	0.12
Euphausiidae (euphausiid)	0.27	0.01
Thysanoessa spp. (euphausiid)	0.55	0.06
Decapoda (shrimp & crab)	0.27	0.07
Reptantia (crab)	0.27	0.00
Caridea (shrimp)	1.91	0.48
Eualus spp. (shrimp)	0.27	0.00
Eualus avinus (shrimp)	1.09	0.05

Table 6.--(continued).

Prey Name	% Frequency of Occurrence	% Total Weight
Pandalidae (shrimp)	2.46	0.90
Pandalus spp. (shrimp)	0.82	1.17
Pandalus borealis (shrimp)	1.91	1.06
Pandalus goniurus (shrimp)	0.27	0.01
Pandalus jordani (shrimp)	0.27	0.00
Crangonidae (shrimp)	0.82	0.06
Crangon spp. (shrimp)	0.55	0.01
Crangon dalli (shrimp)	0.55	0.03
Crangon communis (shrimp)	1.37	0.23
Argis dentata (shrimp)	0.27	0.17
Natantia (shrimp)	0.55	0.01
Paguridae (hermit crab)	5.19	0.24
Decapoda brachyura (crab)	0.27	0.00
Majidae (spider crab)	2.19	0.20
Hyas lyratus (lyre crab)	0.55	0.01
Chionoecetes spp. (snow and Tanner crab)	1.09	1.01
Chionoecetes opilio (snow crab)	0.27	0.01
Chionoecetes bairdi (Tannercrab)	0.82	0.16
Echiurus echiurus (marine worm)	0.27	0.09
Ophiuroidea (basket & brittle star)	12.02	5.96
Ophiuroidae Ophiurida (brittle star)	33.61	27.64
Ophiuridae (brittle star)	10.66	4.69
Ophiura spp. (brittle star)	12.84	10.78
Ophiura sarsi (brittle star)	1.37	0.50
Osteichthyes Teleostei (bony fish)	14.21	3.65
Non-gadoid Fish Remains	0.27	0.03
Bathylagidae (deepsea smelts)	0.27	0.12
Myctophidae (lanternfish)	0.27	0.26
Theragra chalcogramma (walleye pollock)	2.73	2.87
Sebastes spp. (rockfish)	7.65	10.06
Cottidae (sculpin)	0.27	0.08
Paraliparis spp. (snailfish)	0.27	0.23
Unidentified organic material	1.64	0.06
Fishery discards	5.74	23.74
Unidentified tube	12.84	0.29
Wood	2.19	0.00

Table 6.--(continued).

Total prey weight:	1,641.14g
Total non-empty stomachs:	366
Total empty stomachs:	162
Total prey categories:	75

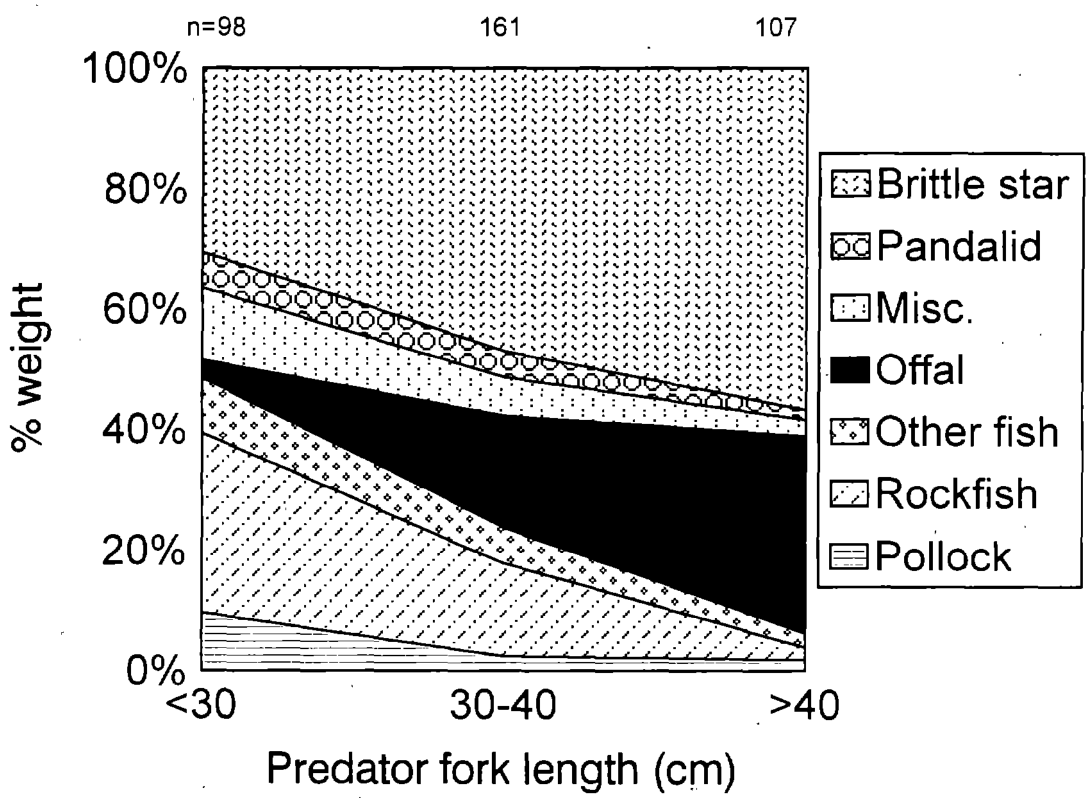

Figure 28.--The diet of flathead sole by percent weight in the eastern Bering Sea slope region by predator size based on quantitative laboratory analysis (n=number of stomachs that contained food in each size group).

sole with increasing predator size. Pandalid shrimp, miscellaneous prey, and other fish were found in similar proportions in the diet of all predator sizes.

For seasonal comparisons, adequate samples sizes were only obtained from strata 100 and 110 for the third and fourth quarters. In the southeastern stratum (100) variation between the two quarters was pronounced (Fig. 29). In the third quarter, offal was the predominant prey of flathead sole (almost SO,% by weight), while in the fourth quarter brittle stars comprised over 80% of the diet by weight. With the exception of the one dominant prey, all other prey were found to be a small proportion of the diet. In the northeastern stratum (110), brittle stars were also the most prevalent prey in the diet of flathead sole in the fourth quarter, representing over 90% of the diet by weight. All other prey were found in negligible amounts. During the third quarter, rockfish were the predominant prey by weight,, but brittle stars were also relatively important. Walleye pollock, other fish, and offal were of minor importance as well.

Latitudinal variation within a given quarter was more pronounced in the third quarter than in the fourth (Fig. 30). In the third quarter, offal was the dominant prey item in the diet of flathead sole in the southeastern stratum (100); all other, prey were only of minor importance. In the northeastern stratum (110), rockfish and brittle stars were the most important prey, however walleye pollock and other fish were also of minor importance. In the fourth quarter, there was little variation in the diet between strata, and brittle stars were the most important prey of both areas with little else showing up in the diet.

Brittle stars were found in a high proportion of the diet of flathead sole in most of the stations sampled; with little difference between the northern and southern strata (Fig. 3la) Offal was only found at a few, primarily southern stations, but was very important in the few stations at which it was found (Fig. 3 lb). Rockfish represented a moderate proportion of the diet of flathead sole at a few stations in the northern stratum (Fig. 31 c). All rockfish prey were 30-60 mm fork length and flathead sole that consumed them were

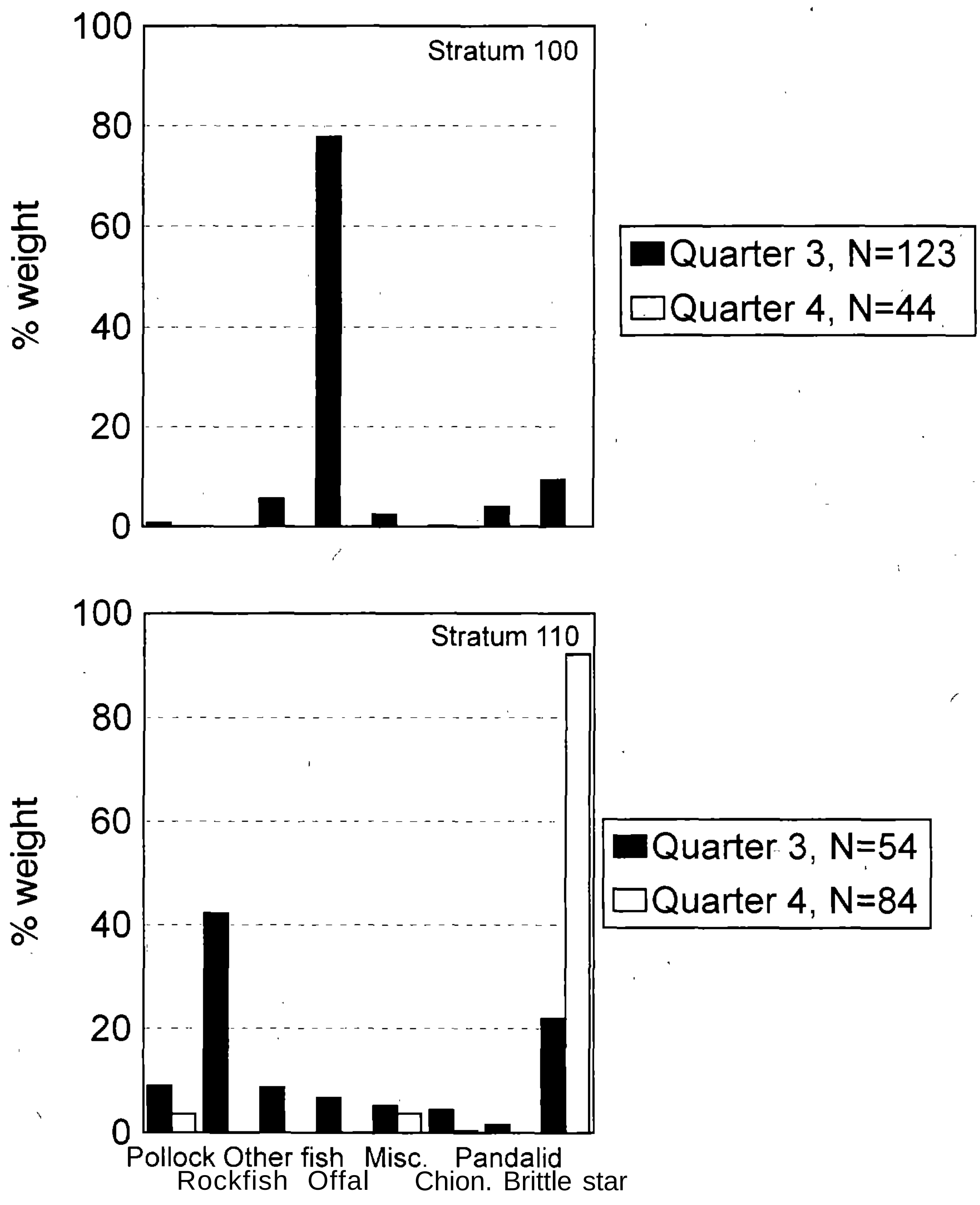

Figure 29.--Seasonal dietary variation of flathead sole by percent weight in the eastern Bering Sea slope region from strata 100 and 110. N=number of stomachs that contained food. Chion.=Chionoecetes spp.

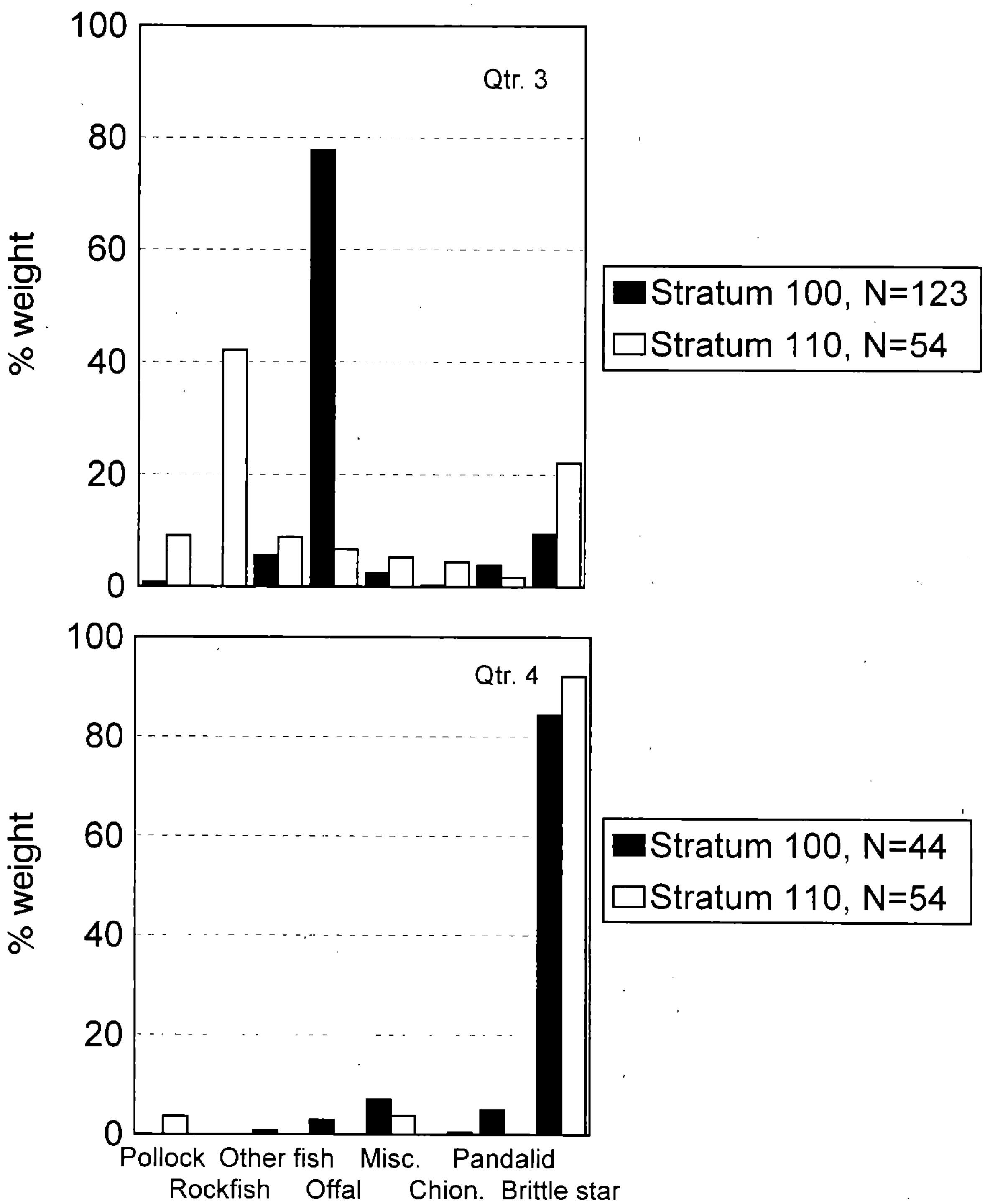

Figure 30.--Latitudinal dietary variation of flathead sole by percent weight in the eastern Bering Sea slope region from strata 100 and 110. N=number of stomachs that contained food. Chion.=Chionoecetes spp.

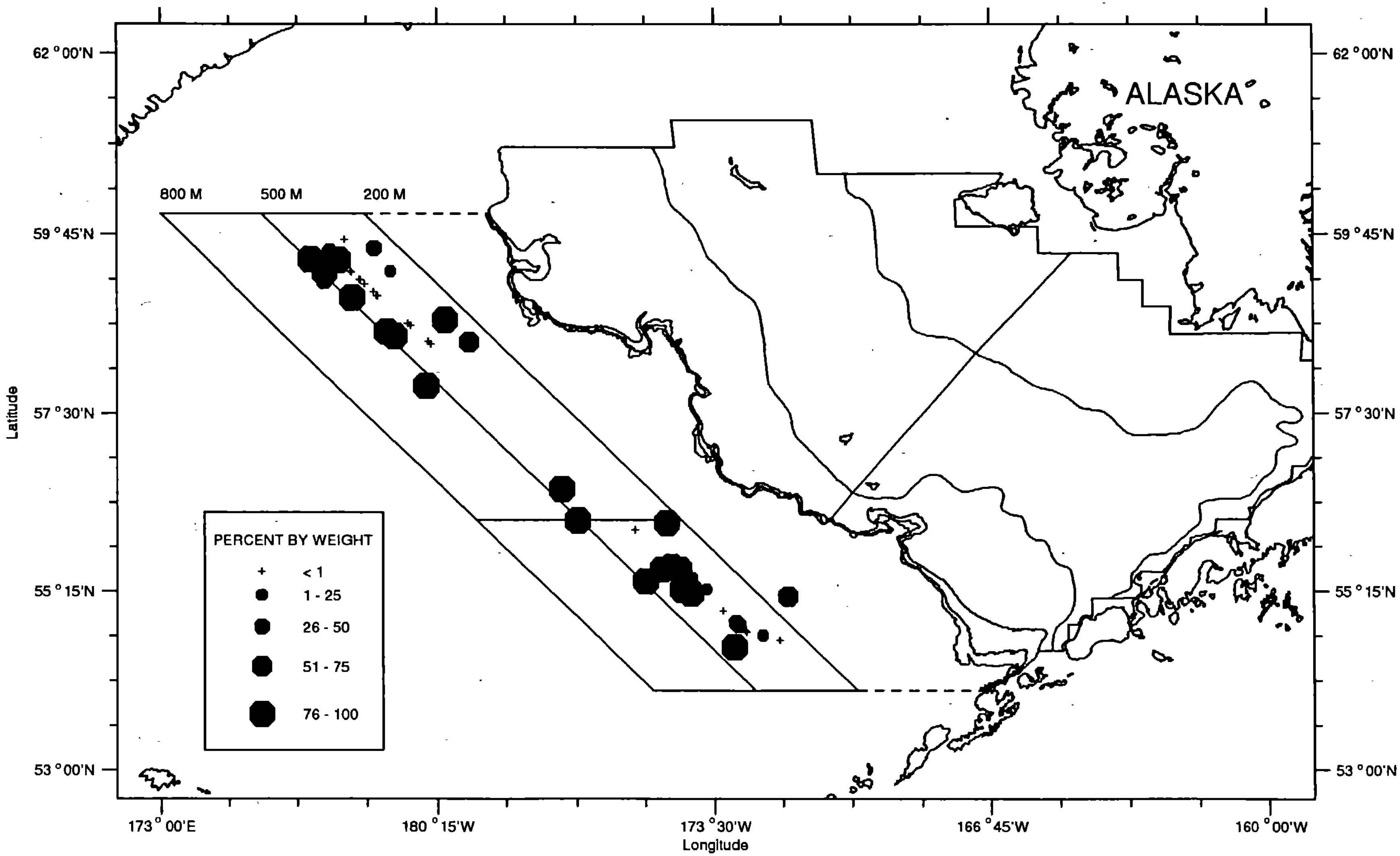

Figure 31a.--The location and magnitude of flathead sole predation on brittle stars in the eastern Bering Sea slope region.

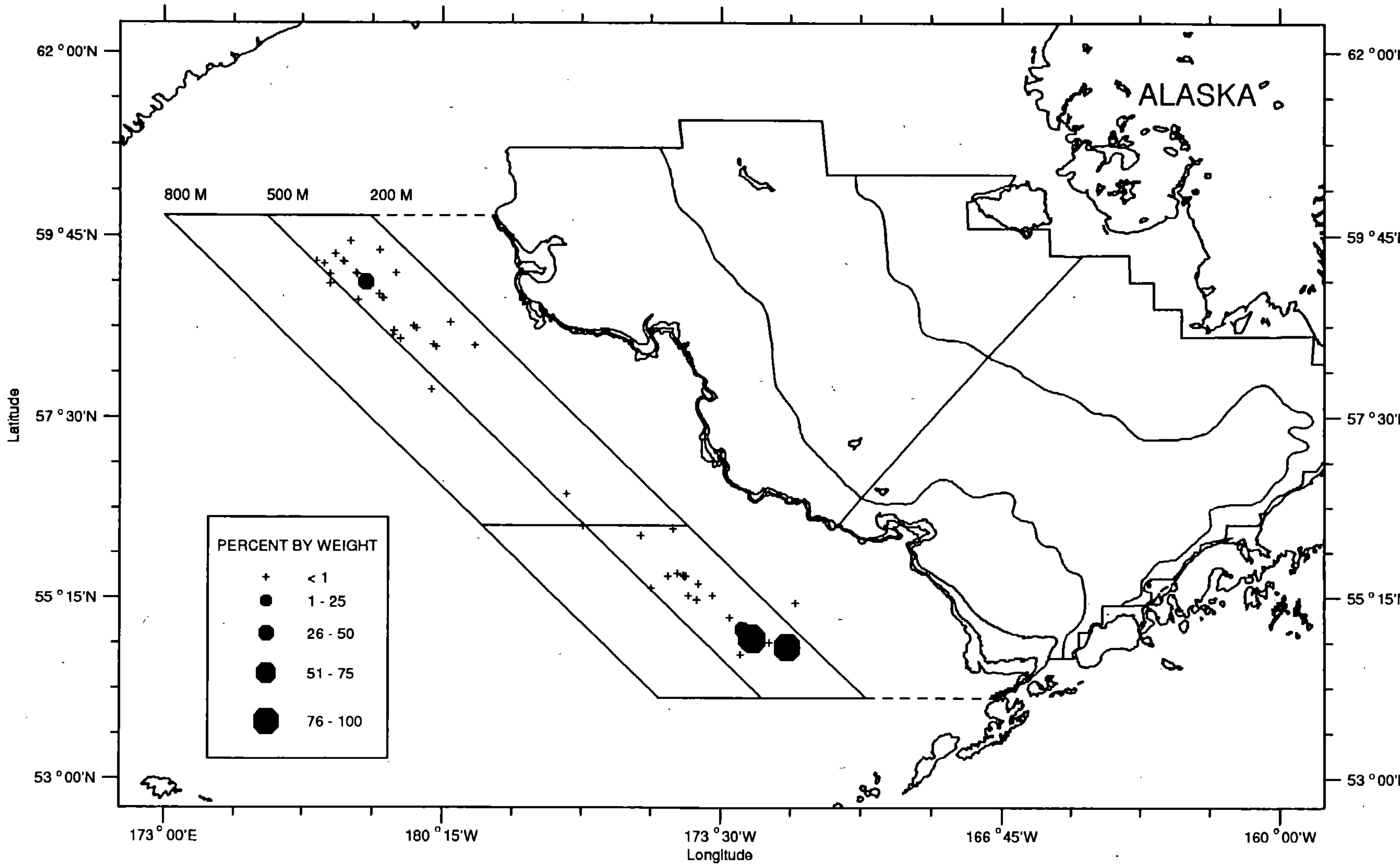

Figure 31b --The location and magnitude of flathead sole predation on offal in the eastern Bering Sea slope region.

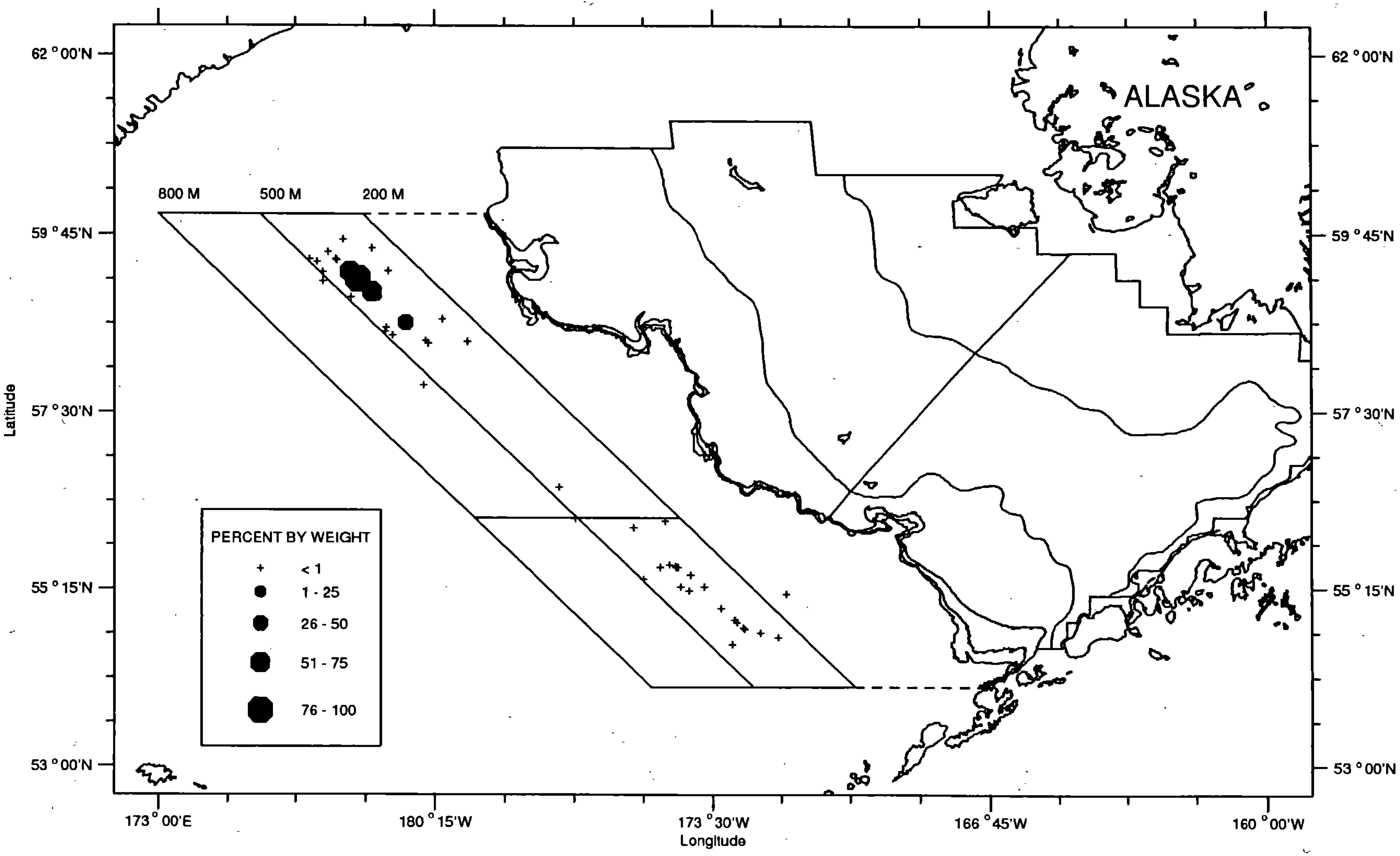

Figure 31c.--The location and magnitude of flathead sole predation on rockfish in the eastern Bering Sea slope region.

> 22 cm standard length (Fig. 32). There was no correlation (r^2=0.002, P=O.665) between predator size and prey size.

Discussion

Most of the flathead sole in the eastern Bering Sea are found in water depths less than 450 m (Allen and Smith 1988) which is reflected in our sample locations. The diet of flathead sole on the shelf generally consists of brittle stars, walleye pollock, and decapod crustaceans (Pacunski 1990, Pacunski 1991, Livingston et al. 1993). With increasing depth and predator size, their diet tends towards brittle stars and decapod crustacea (Pacunski 1990). Over the slope, the diet of flathead sole has been shown to consist of brittle stars, decapods, and zooplankton (Mito 1974). The results of the present work showed brittle stars to be the primary prey throughout the slope area. Decapod crustacea were not important. Offal represented the second most abundant prey item and is again a likely artifact of the sampling vessels. Rockfish were an important prey, but their overall importance is probably overestimated by weight as they were only found in a few hauls, but they were the dominant prey in those samples. Large, heavy prey can be overly influential in the percentage by weight values when they occur in large quantities from a small number of samples. The percentage frequency of occurrence of rockfish prey was 8%, which is another factor to consider in determining the importance of a particular prey in the diet.

Size-related variation in prey consumption was slight due to the lack of small predators in our study. Increased dependence upon brittle stars with size is consistent with previous work (Mito 1974, Pacunski 1990). However, the inverse relationship in the amounts of rockfish and offal in the diet with increasing flathead sole size seen here is not likely due to the decreased abundance of these prey categories. The offal found in flathead sole stomachs (primarily walleye pollock parts) are likely too large for smaller predators to

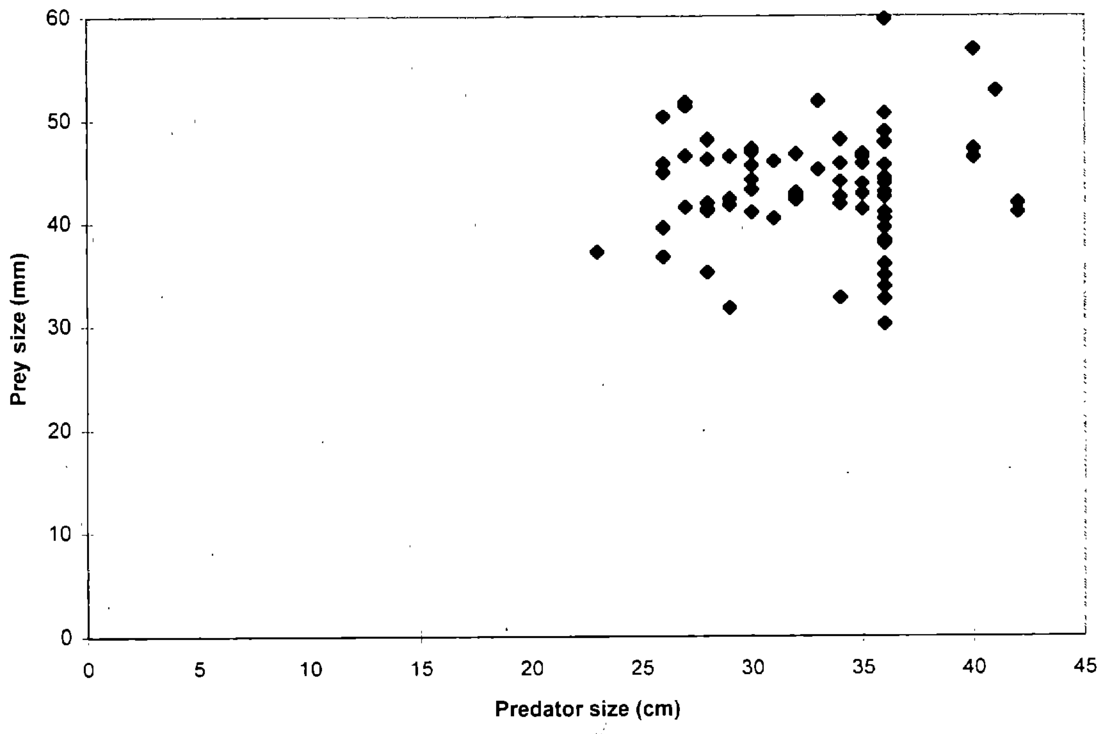

Figure 32.--Flathead sole (predator) size, rockfish (prey) size scatter plot from the eastern Bering Sea slope region.

consume, while the rockfish that were consumed were relatively small (< 60 mm standard length) and could, therefore, be consumed by small predators with relative ease.

The dietary variation seen between the third and fourth quarters in the southeastern stratum (100) could be a result of sampling location rather than changes in prey availability. Most of the samples containing offal were collected in the southern portion of the southeastern strata, an area where extensive walleye pollock fishing takes place. However, the variation between these quarters in the northeastern stratum could be a true reflection of opportunistic feeding on a seasonal abundance of juvenile rockfish.

The north-south comparison of the diet reflects the geographic distinction between an area of higher commercial fishing operations and/or sampling aboard those vessels and the area of seasonally abundant juvenile rockfish. The importance of offal in the diet may be overestimated as the weight of offal in a few stomachs can be very high and may have an exaggerated effect upon the percentage by weight calculations. In the fourth quarter, there were no differences in the diet of flathead sole between strata indicating that the rockfish had migrated, or grown to a size too large for flathead, sole to consume. Additionally, by the fourth quarter, the walleye pollock fishery is generally over (Fritz et al. 1995).

There was no significant relationship between the size of rockfish prey and size of flathead sole due to the limited size range of rockfish eaten. The size range of prey was likely determined by availability rather than the ability of flathead sole to consume them.

Arrowtooth Flounder

Results

Arrow-tooth and Kamchatka flounder were sampled from all four strata in the slope region; however, only one station was sampled in the southwest stratum (120) and the inner, shallower strata were sampled more thoroughly than the outer strata (Fig. 33). Stomach samples from 686 arrowtooth and Kamchatka flounder were analyzed, of which

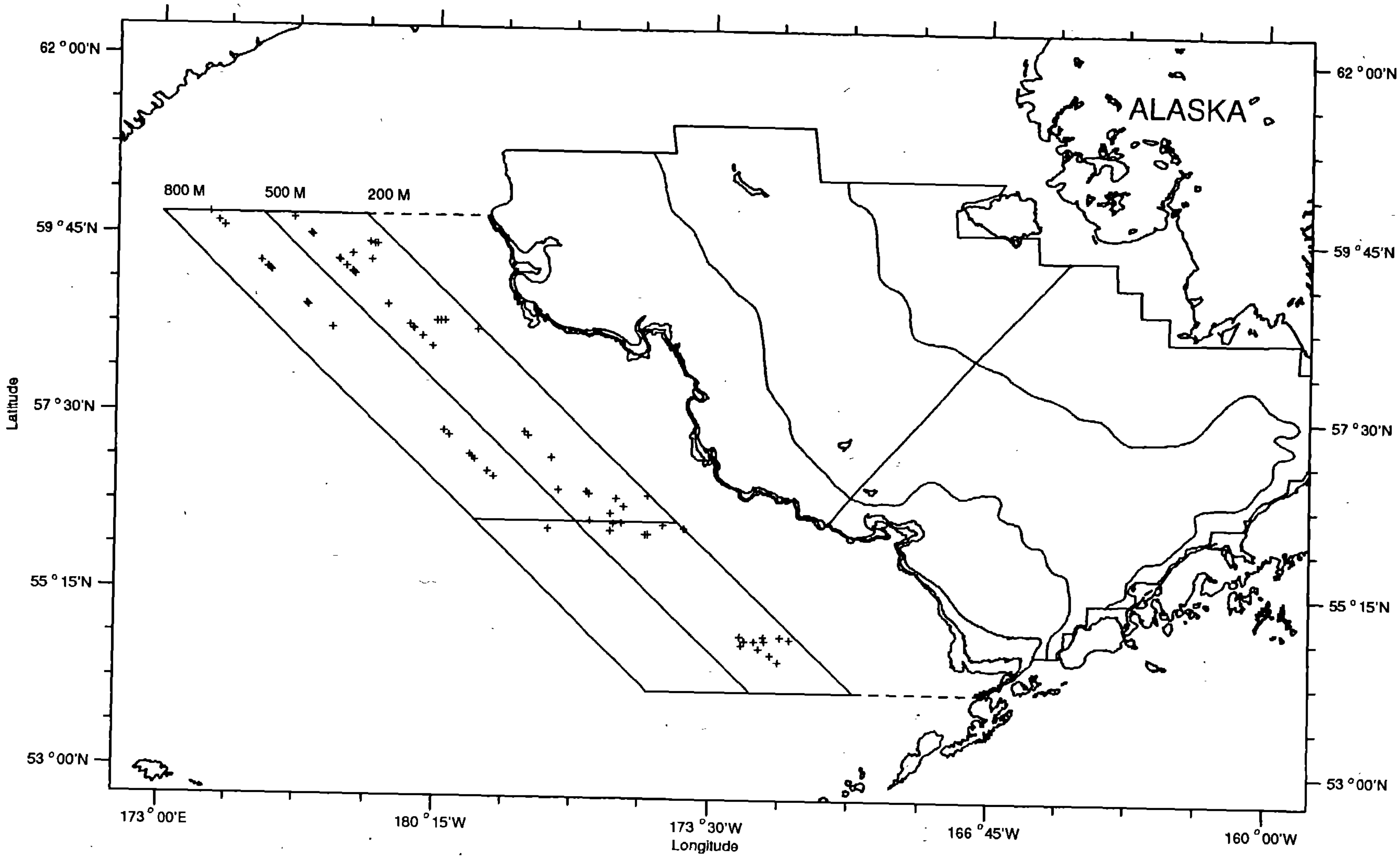

Figure 33.--The location of arrowtooth flounder stomach collections in the eastern Bering Sea slope region.

285 contained food representing 48 prey categories (Table 7). For the purposes of this study, arrow-tooth and Kamchatka flounder diet data were pooled. Walleye pollock was the most important prey by weight (55%) in the diet of arrowtooth flounder. Pacific herring (11%) other fish (16%) and squid (11%) were also relatively important (Fig. 34). By frequency of occurrence, the same prey were important, although some prey (i.e., pandalids and other fish) were more important, while others (i.e., walleye pollock and Pacific herring) appeared to be less important by this measure (Table 7).

With the exception of miscellaneous prey, all prey appeared in different proportions in the diet of arrowtooth flounder depending upon predator size (Fig. 35). Offal was only seen in the diet of 40-50 cm fish, and myctophids were only seen in smaller (<50 cm) fish. The importance of walleye pollock in the diet increased with predator size while other fish and pandalids became less important. Squid and herring were more important to fish in the middle size range (40-60 cm) samples than to those at either end.

Seasonal variation was slight for most prey items in the diet of arrowtooth collected from the northeastern stratum 110 during second, third, and fourth quarters (Fig. 36). Walleye pollock was the primary prey during all quarters, but it was more important in the diet during the third and fourth quarters than in the second quarter. Squid were important in the second quarter, but they were negligible in the others. Pacific herring were only found in the diet of arrowtooth flounder in the fourth quarter, In the northwestern stratum (130), there was less dietary variability (Fig. 36). Squid were the primary prey during both quarters sampled and were found in relatively similar proportions of the diet. Other fish and miscellaneous prey were also found in relatively similar proportions of the diet in both quarters. Walleye pollock were substantially more prevalent in the second quarter diet while pandalids represented a larger portion of the diet in the fourth quarter.

During the third quarter, samples were collected from strata 100 and 110, allowing a latitudinal comparison of the diet of arrowtooth flounder. Walleye pollock was the primary prey of arrowtooth in both strata, representing more than 60% of the diet (Fig. 37).

Table 7.--The diet of arrowtooth flounder, Atheresthes stomias, and Kamchatka flounder, A. evermanni, from the slope region of the eastern Bering Sea.

Prey Name	% Frequency of Occurrence	% Total Weight
Polychaeta (worm)	0.35	0.01
Cephalopoda (squid & octopus)	3.16	0.70
Teuthoidea (squid)	6.67	9.03
Teuthoidea Oegopsida (squid)	1.05	0.10
Gonatopsis spp. (squid)	0.35	0.24
Berryteuthis spp. (squid)	0.35	0.09
Berryteuthis magister (squid)	0.35	1.11
Mysidacea Mysida (mysid)	0.35	0.00
Mysidae (mysid)	0.70	0.01
Holmesiella anomala (mysid)	2.11	0.02
Pseudomma spp. (mysid)	0.35	0.00
Gammaridea (amphipod)	0.70	0.00
Euphausiacea (euphausiid)	2.46	0.16
Euphausiidae (euphausiid)	0.35	0.00
Thysanoessa spp. (euphausiid)	1.05	0.06
Decapoda (shrimp & crab)	0.35	0.00
Caridea (shrimp)	6.67	0.69
Eualus avinus (shrimp)	1.05	0.04
Heptacarpus moseri (shrimp)	0.35	0.04
Pandalidae (shrimp)	6.67	0.51
Pandalus spp. (shrimp)	5.26	0.68
Pandalus borealis (shrimp)	4.56	1.10
Pandalus jordani (shrimp)	2.11	0.24
Pandalopsis dispar (shrimp)	2.81	1.23
Crangonidae (shrimp)	1.05	0.02
Crangon spp. (shrimp)	0.35	0.00
Paguridae (hermit crab)	0.35	0.00
Majidae (spider crab)	0.35	0.01
Asteroidea (starfish)	0.35	0.30
Ophiuroidea (basket & brittle star)	2.46	0.01
Ophiuroidae Ophiurida (brittle star)	1.40	0.00
Osteichthyes Teleostei (bony fish)	35.79	10.64
Non-gadoid Fish Remains	0.70	0.09
Clupea pallasi (Pacific herring)	1.40	11.09
Myctophidae (lanternfish)	0.70	0.20
Theragra chalcogramma (pollock)	13.33	55.43
Zoarcidae (eelpout)	1.40	1.17
Lycodes spp. (eelpout unid)	0.70	0.91
Lycodes diapterus (black eelpout)	0.70	1.36

Table 7.--(continued).

Prey Name	% Frequency of Occurrence	% Total Weight
Icelidae (sculpin)	0.35	0.15
Icelus spiniger (thorny sculpin)	0.35	0.13
Cottidae (sculpin)	0.70	0.33
Dasycottus setiger (sculpin)	0.70	0.10
Malacocottus kincaidi (sculpin)	0.35	0.60
Podothecus acipenserinus (poacher)	0.35	0.33
Stichaeidae (prickleback)	0.35	0.05
Unidentified organic material	2.11	0.32
Fishery discards	0.35	0.67
Total prey weight:	6,412.17g	
Total non-empty stomachs:	285	
Total empty stomachs:	401	
Total prey categories:	48	

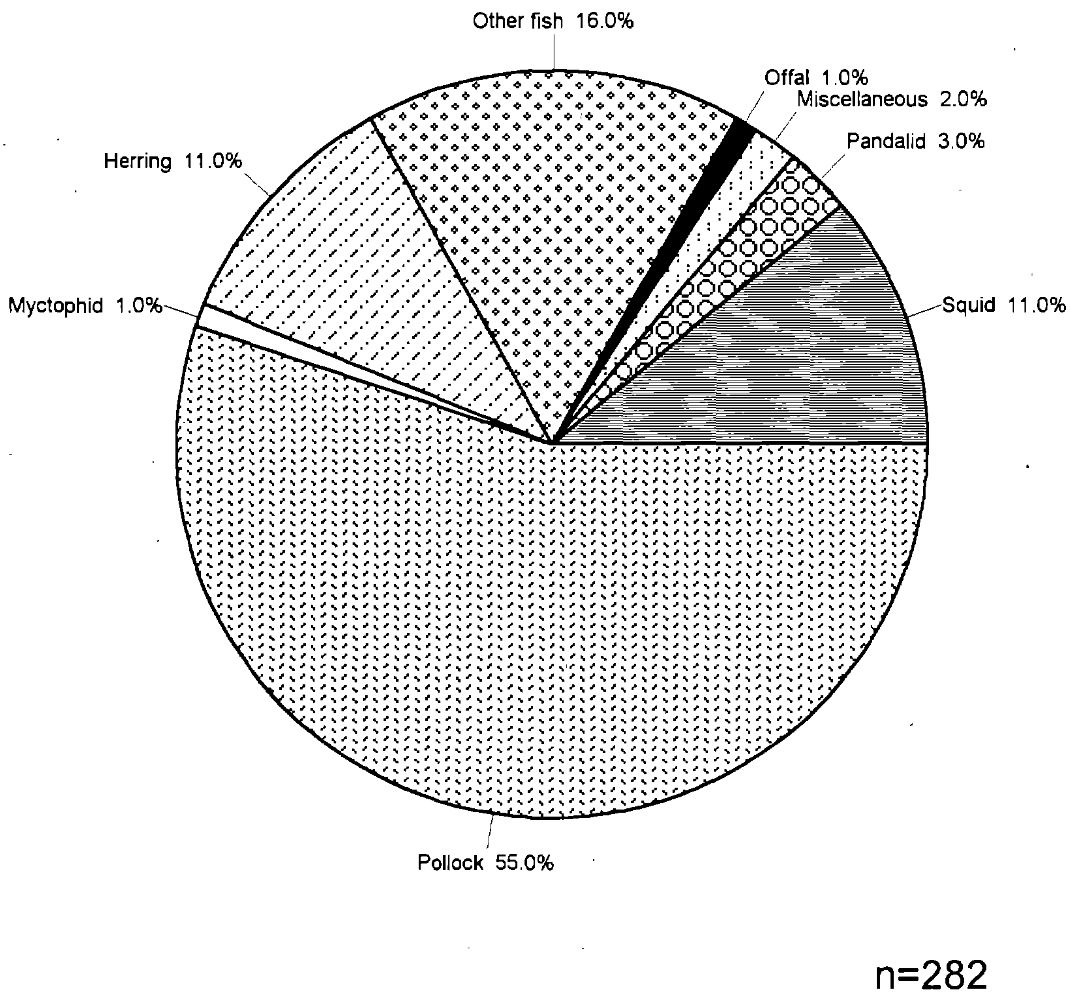

Figure 34.--The diet of arrowtooth flounder by percent weight in the eastern Bering Sea slope region based on quantitative laboratory analysis (n=number of stomachs that contained food).

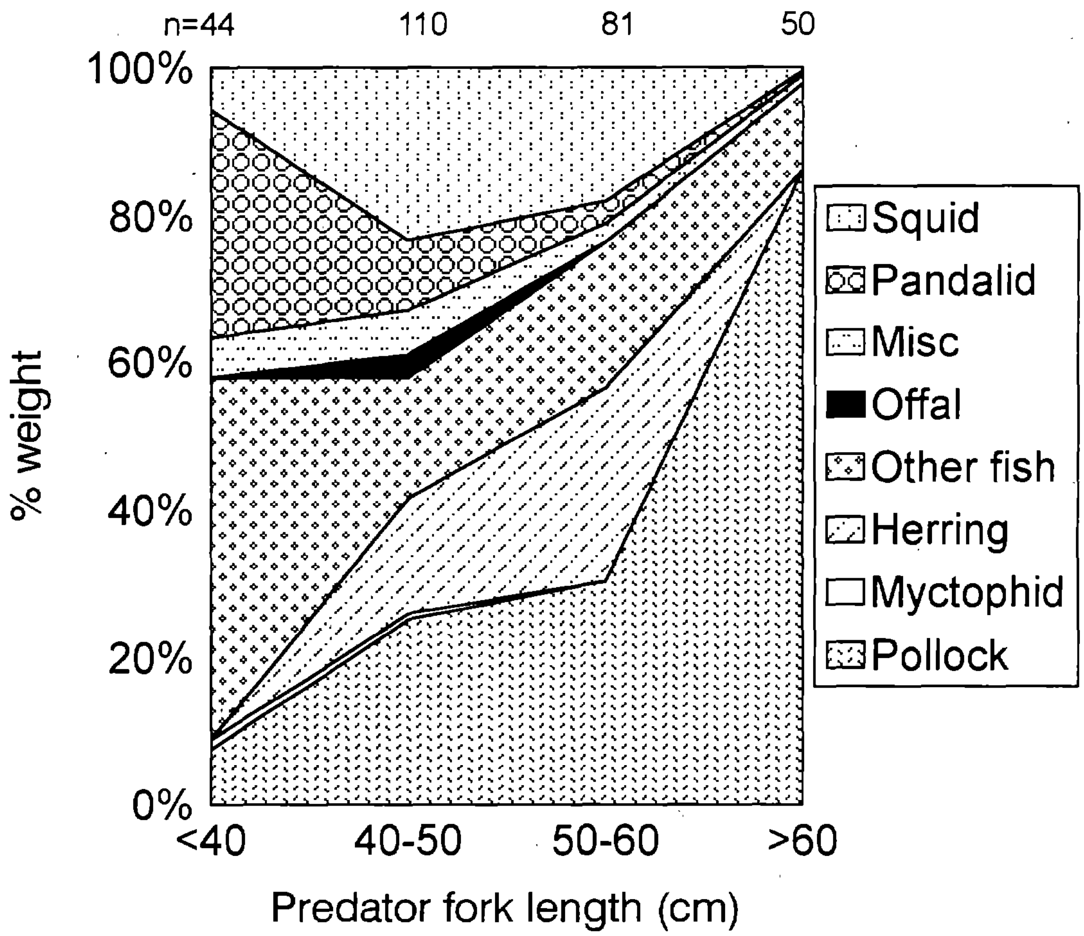

Figure 35.--The diet of arrowtooth flounder by percent weight in the eastern Bering Sea slope region by predator size based on quantitative laboratory analysis (n=number of stomachs that contained food in each size group).

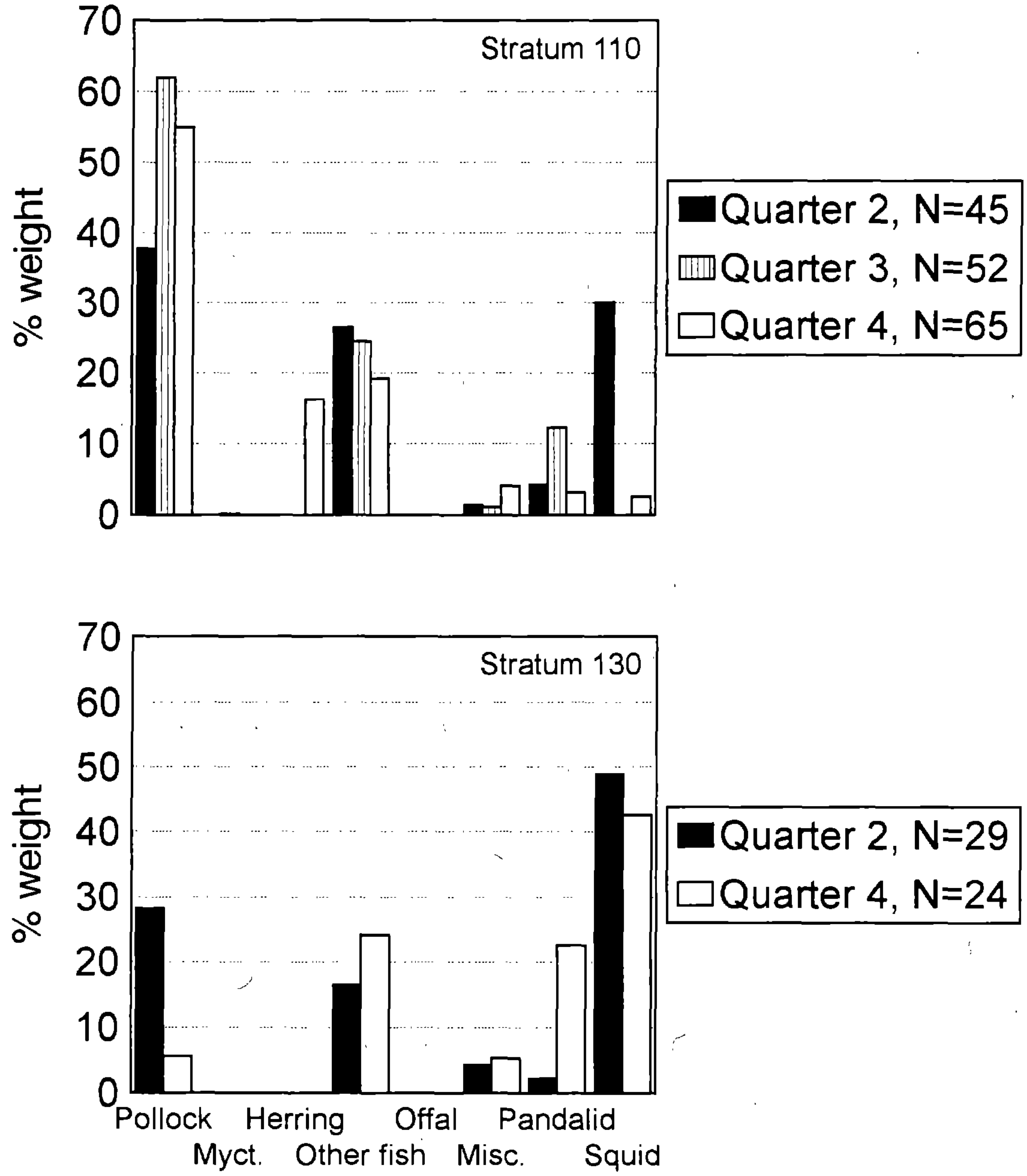

Figure 36.--Seasonal diets of arrowtooth flounder by percent weight in the eastern Bering Sea slope region from strata 110 and 130. N=number of stomachs that contained food. Myct.=Myctophidae.

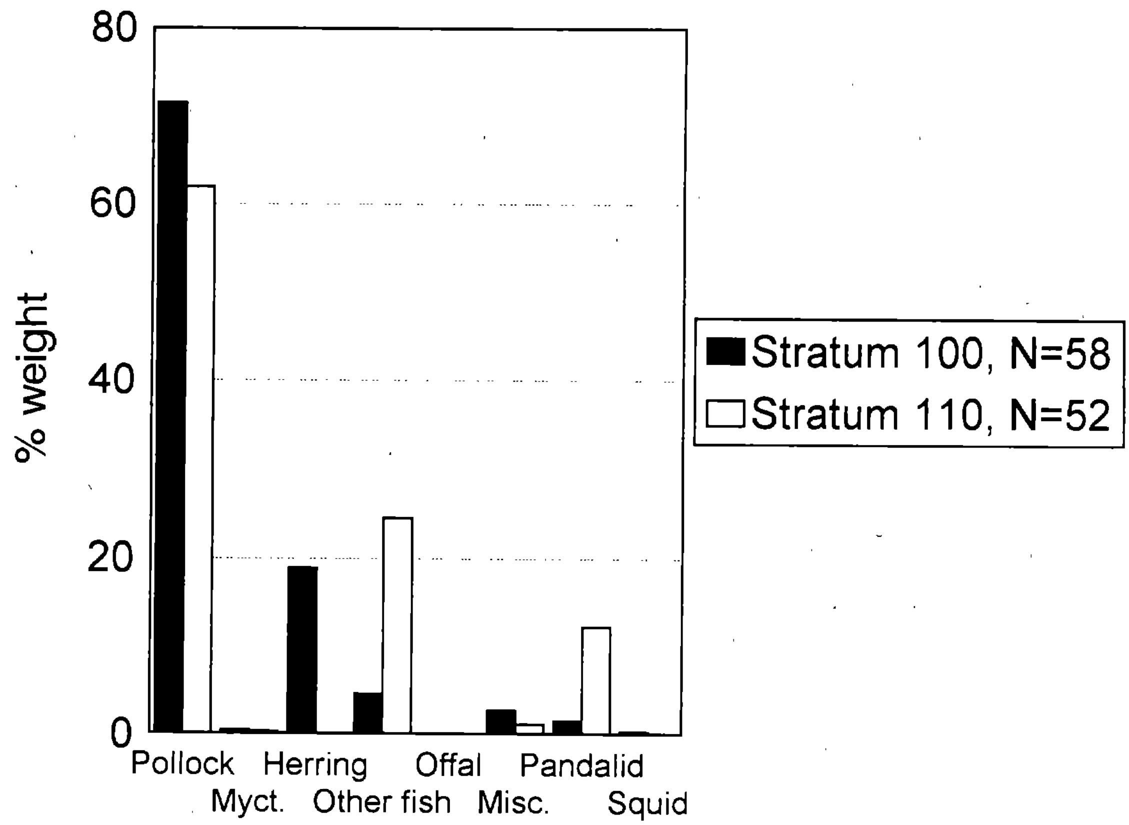

Figure 37.--Latitudinal variation in the diet of arrowtooth flounder by percent weight in the eastern Bering Sea slope region during the third quarter. N=number of stomachs that contained food. Myct.=Myctophidae.

However, Pacific herring was the second most important prey in the southeastern stratum (l00), while other fish and pandalids were of secondary importance in the northeastern stratum (110).

In comparing the diet of arrow-tooth flounder at differing depths within a given season, it is apparent that the magnitude of dietary variability depends upon the season (Fig. 38). In the second quarter, the diets of arrow-tooth flounder in the two strata were similar. Walleye pollock and other fish were more important in the shallower stratum (110), while squid were somewhat important in the deeper stratum (130). Walleye pollock, squid, and other fish were the three most important prey in both regions. In the fourth quarter, however, walleye pollock were of little importance to arrowtooth flounder in deeper water, while they were the primary prey of those in the shallower water. Pacific herring were only found in the diet of arrow-tooth flounder in shallow water. Other fish were relatively important to arrowtooth flounder in both strata. Squid and pandalid shrimp were substantially more important in the diet of arrowtooth flounder collected from the deeper water of stratum 130.

Pollock were found in relatively high proportion in the diet of arrowtooth flounder in stations from all strata sampled, although they were more prevalent in the diet of arrowtooth flounder in the inner strata (Fig. 39a). Squid were only found as a major dietary component of arrowtooth flounder at most stations in the two northern strata and were relatively rare in the southern strata (Fig. 39b). Pacific herring were important in the diet of arrow-tooth flounder primarily in the two northern strata (Fig. 39c). There was a significant, positive relationship (r^2=0.58, P<O.OOl) between arrowtooth flounder size and walleye pollock size (Fig. 40).

Discussion

Arrow-tooth flounder are found to depths of 900 m, however most are found in water depths less than 400 m (Allen and Smith 1988). Our sample locations reflect this

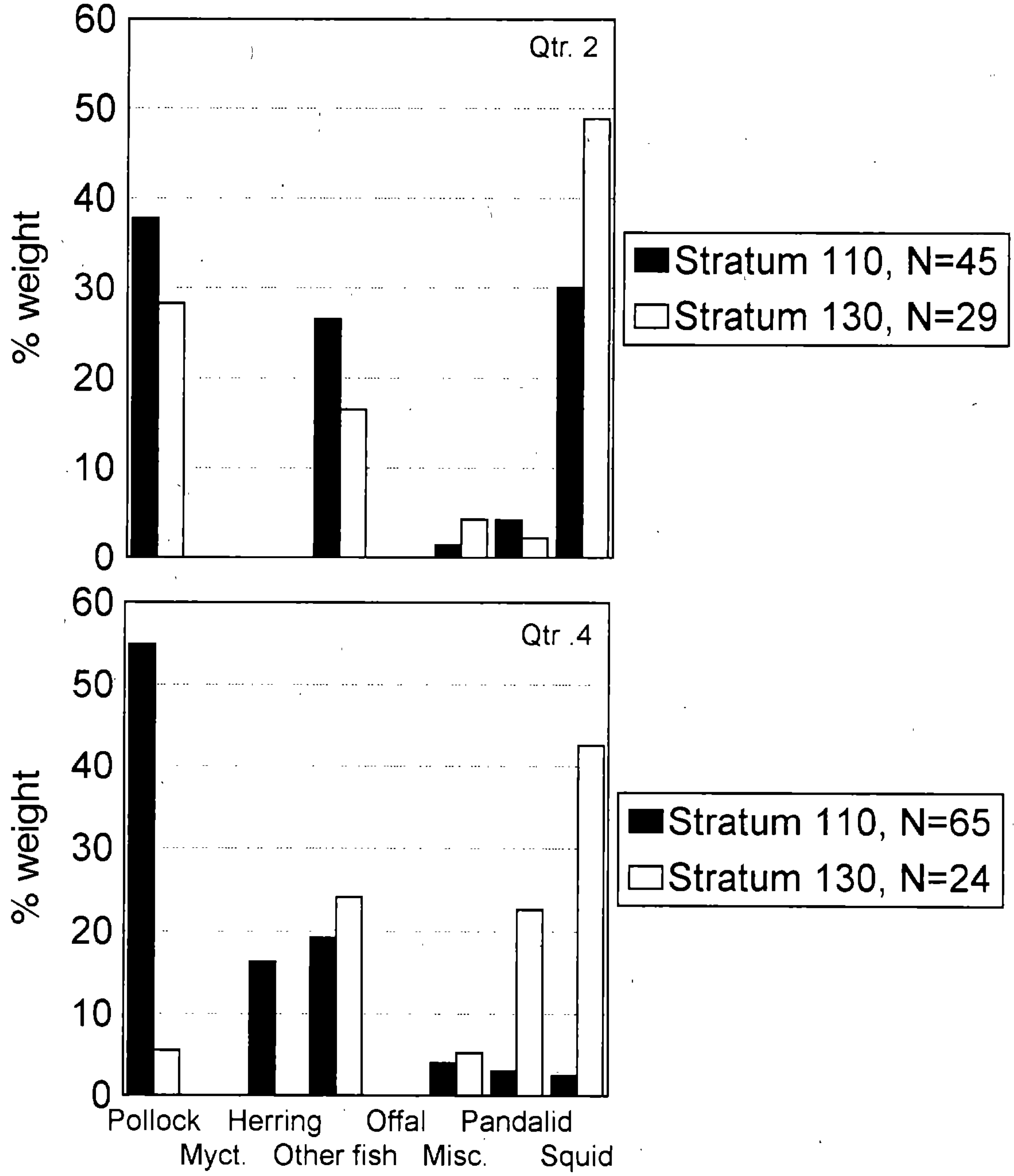

Figure 38.--Depth-related variation in the diet of arrowtooth flounder by percent weight in the eastern Bering Sea slope region. N=number of stomachs that contained food. Myct=Myctophidae.

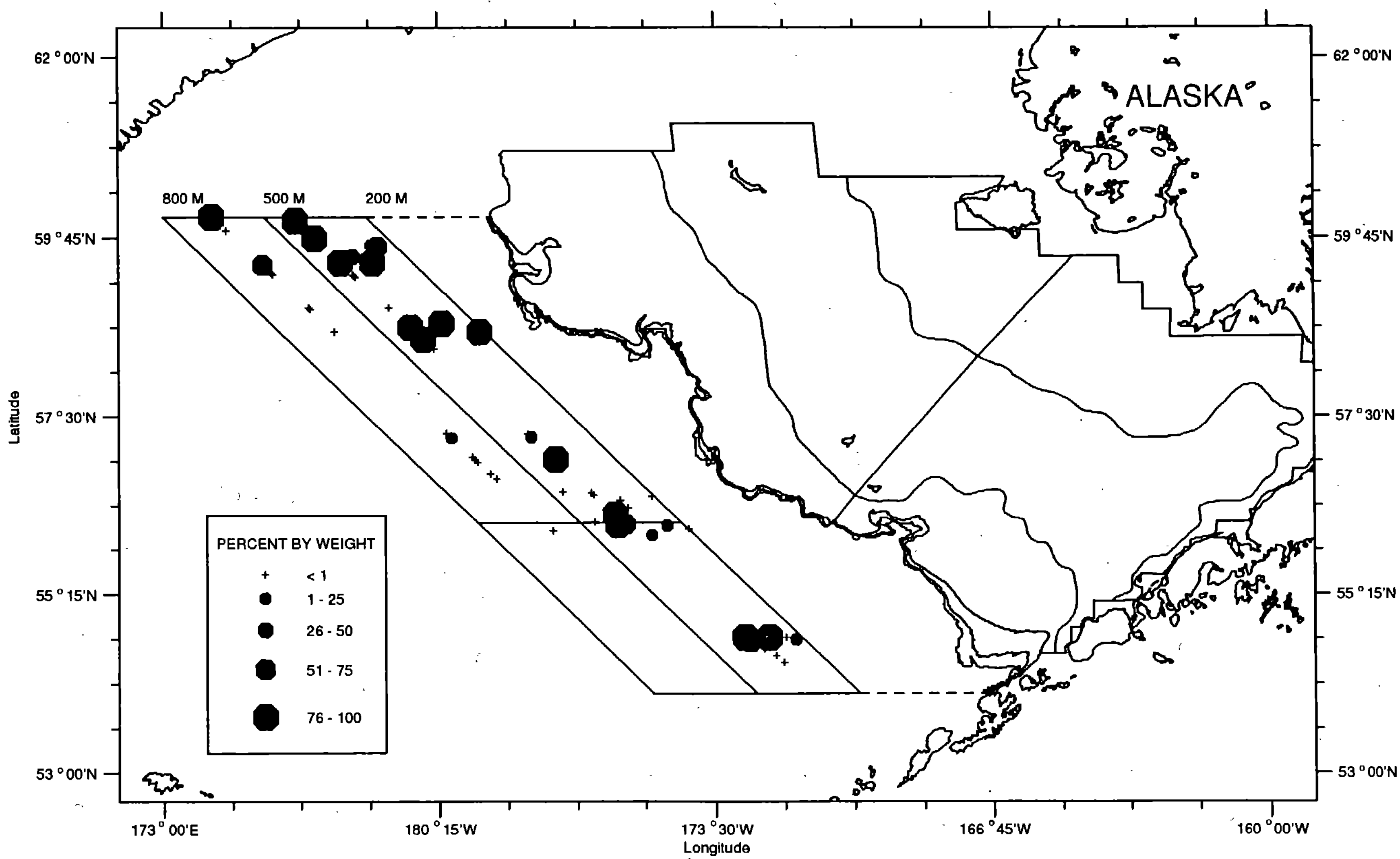

Figure 39a.--The location and magnitude of arrowtooth Hounder predation on walleye pollock in the eastern Bering Sea slope region.

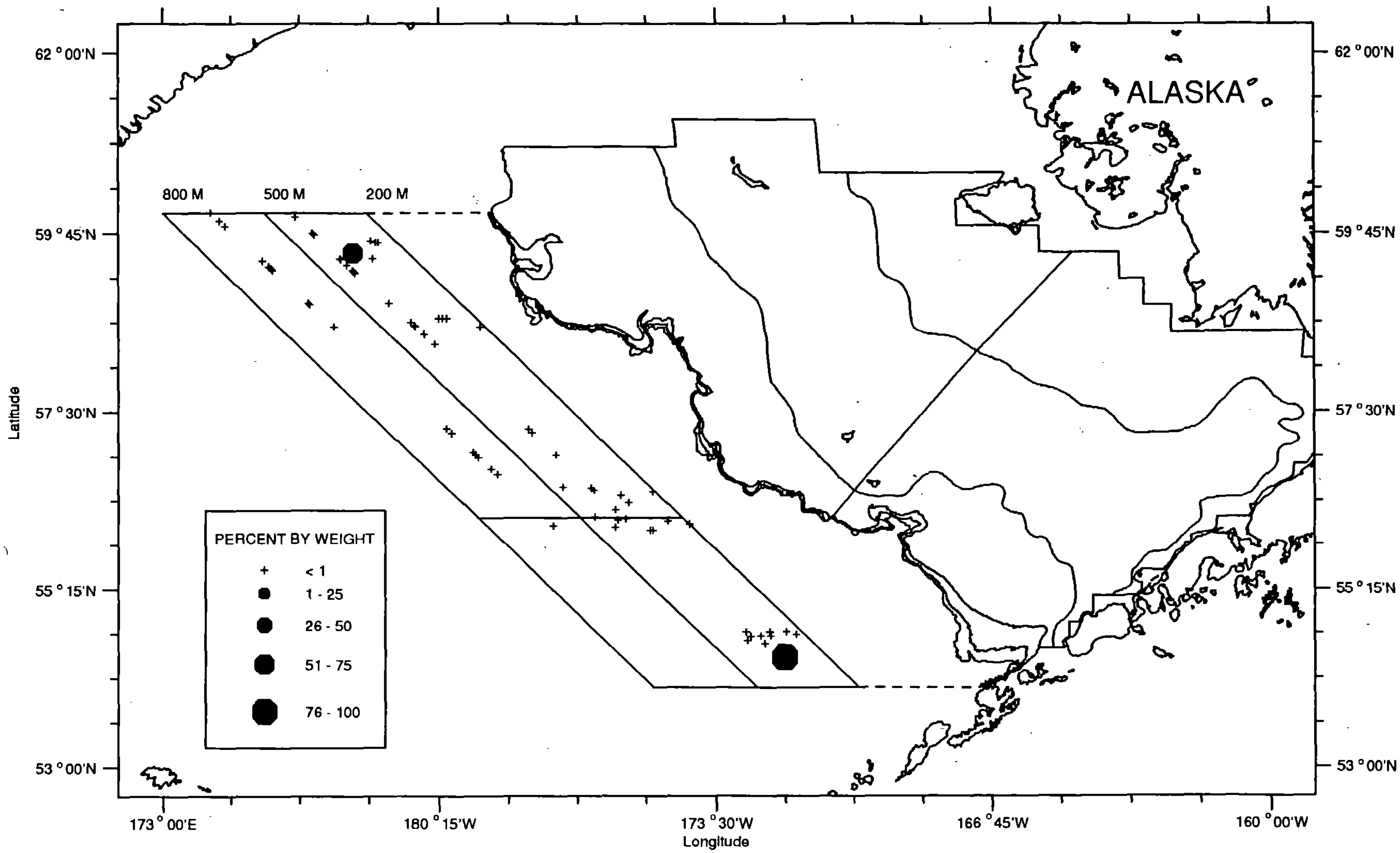

Figure 39b.--The location and magnitude of arrowtooth flounder predation on squid in the eastern Bering Sea slope region.

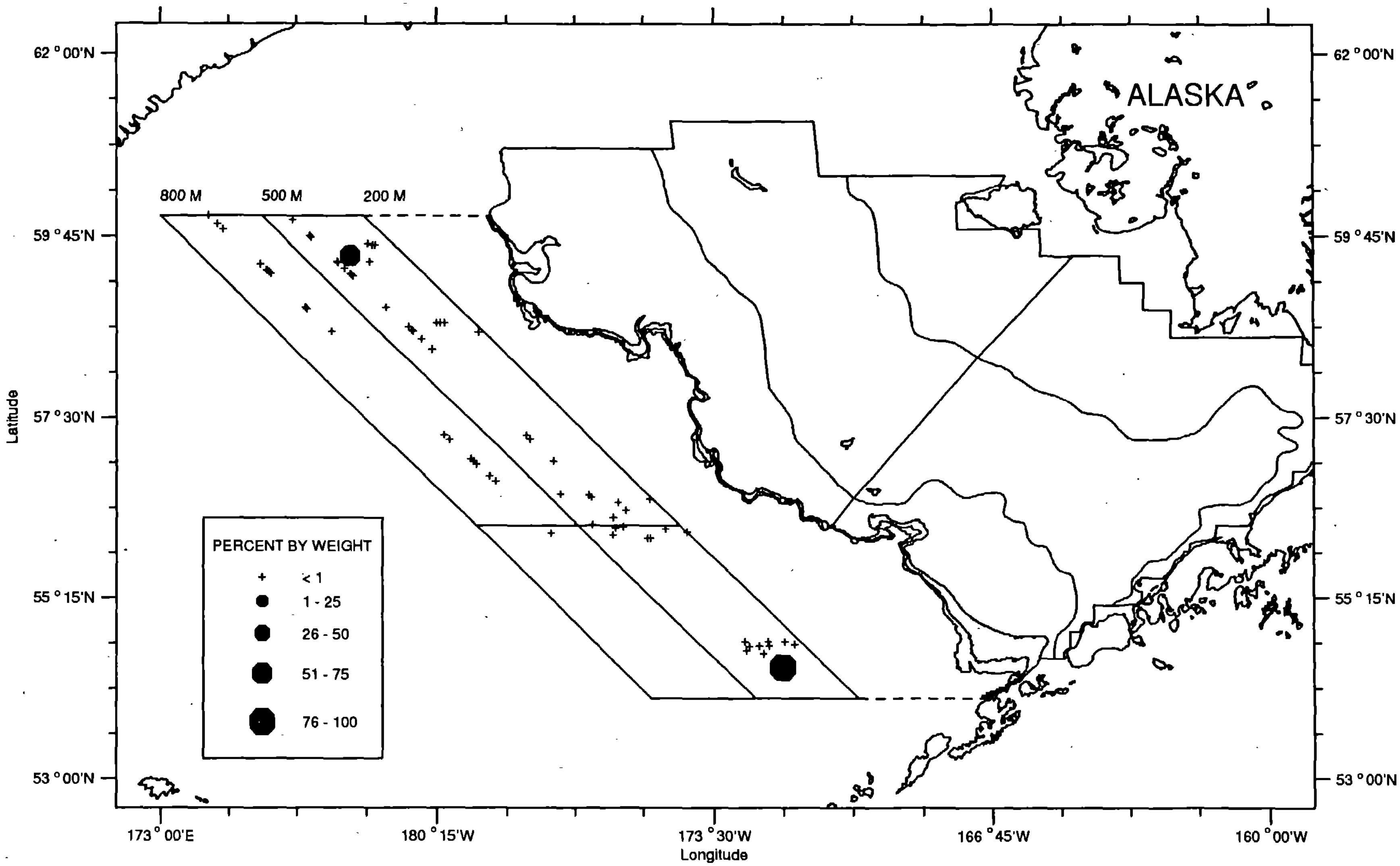

Figure 39c.--The location and magnitude of arrowtooth flounder predation on Pacific herring in the eastern Bering Sea slope region.

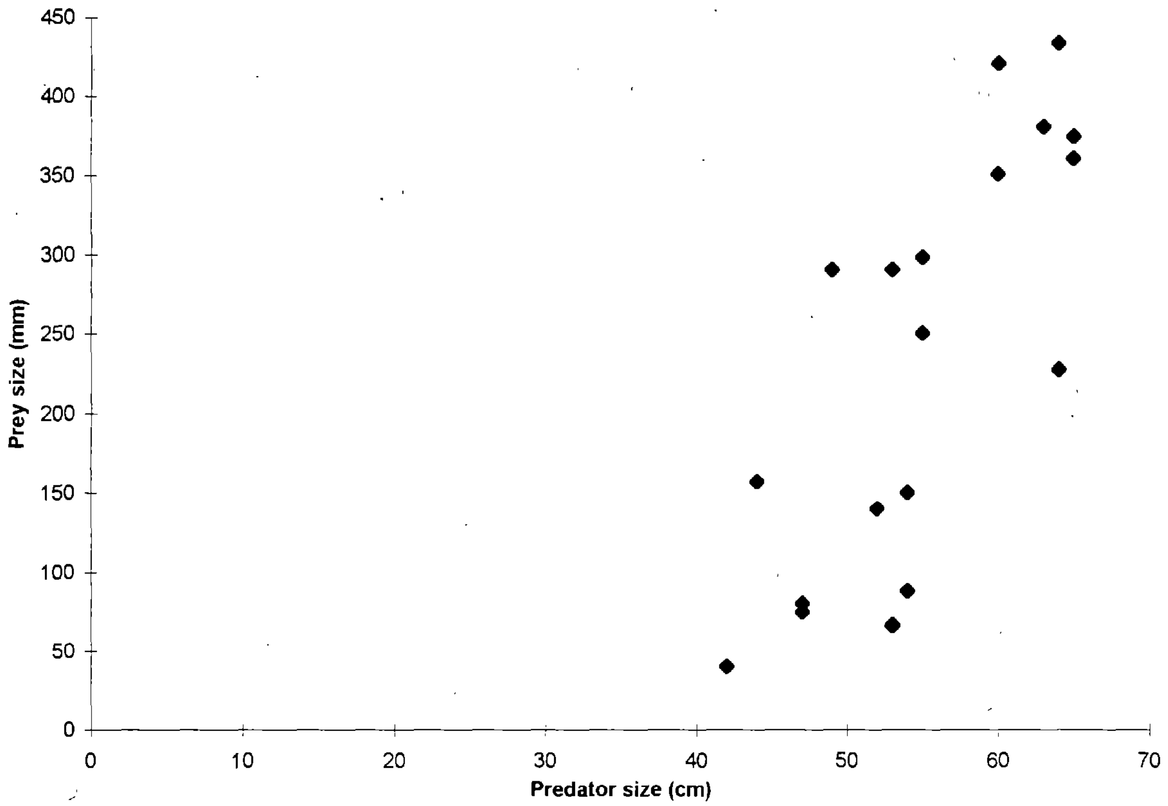

Figure 40.--Arrowtooth flounder (predator) size, walleye pollock (prey) size scatter plot for the eastern Bering Sea slope region

distribution with most samples coming from the shallower strata. In Alaska waters, the diet of arrowtooth flounder consists primarily of walleye pollock, other fish (especially Pacific herring and capelin), and crustaceans (Mito 1974, Yang 1991b, Yang and Livingston 1986, Livingston et al. 1993, Yang 1993). In these studies, the importance of fish prey increased with increasing predator size. The present study shows that walleye pollock was the main prey of arrow-tooth flounder in the slope region of the eastern Bering Sea; Pacific herring, squid, and other fish were of secondary importance. The differences seen in the present study are likely a reflection of differences in prey composition and larger predator size composition on the slope.

Seasonal variation in the diet of arrow-tooth flounder has been shown to consist of changes in the percentage composition of some of the secondary prey (euphausiids, shrimp, and cephalopods [Yang, 1991b]) but walleye pollock remained as the primary prey. Our study found the same results for the northeastern stratum. Pacific herring are found in higher abundance in the fourth quarter, probably reflecting their return to over; wintering areas (Wespestad and Barton 1981). The seasonal variation in squid is also likely a reflection of their seasonal migrations associated with spawning and growth (Okutani 1988). In the northwest stratum, walleye pollock and pandalids in the diet were inversely related.

Latitudinal variation in the diet of arrow-tooth flounder during the third quarter in the shallow strata indicates that the primary difference in the diets is the large presence of Pacific herring in the southeastern stratum while not being consumed in the northeastern stratum. Other fish were more common in the diet in the northeastern stratum. It is possible that Pacific herring were consumed in the northeastern strata, but they were not identified as such (due to digestion) and were consequently recorded as unidentified fish. It is also possible that Pacific herring were more common in the southeastern stratum because they were more available as prey in that stratum. Pacific herring are generally inshore for spawning during the spring and summer months, but begin migrating toward their overwintering grounds in late summer via the Alaska Peninsula and Aleutian Basin (Wespestad and Barton 1981, Wespestad 1994) and therefore become available only to predators in the southeastern stratum during the third quarter..

Depth-related variation in the second quarter was slight; however, during the fourth quarter, it was substantial. The variation seen in the diet of arrow-tooth flounder in the fourth quarter by depth is inconsistent with dietary variation seen for the same prey, quarter, and stratum for Greenland turbot. It is most likely that this variation is an artifact of the sampling scheme. There were relatively few. samples from the deep stratum, which likely came from only a few hauls, representing a smaller spatial scale. This leads to a higher likelihood of patchy prey distributions being reflected in the diet.

The spatial distribution in the consumption of walleye pollock and Pacific herring by arrowtooth flounder reflects their distribution throughout the year in the slope region of the eastern Bering Sea. Walleye pollock are found throughout the region and were consumed by arrowtooth flounder throughout the region as well. Pacific herring are seasonally variable in their availability and are most common over the slope in the northern section (Wespestad and Barton 1981) which is where they were most commonly consumed by arrowtooth flounder. Gonatid squids, those most commonly identified from arrow-tooth flounder stomachs, are thought to be distributed throughout the deeper waters of the eastern Bering Sea (Okutani et al. 1988). However, arrow-tooth flounder preyed more heavily upon squid in the northern strata. The cause of this relationship is not clear due to our poor understanding of the seasonal variation in abundance of squid along the north-south gradient on the eastern Bering Sea.

The significance of the relationship of predator length with prey length for arrow-tooth flounder and walleye pollock is consistent with previous work (Yang and Livingston 1986, Yang 1991 b, Yang 1993) in Alaska waters, Our study, however, predicts a much steeper regression line due to the lack of smaller predators, and the presence of relatively small walleye pollock in predator stomachs, despite the larger predator size.

Dietary Comparisons

The overall diets of all five predator species are summarized in Figure 41. Fish, especially walleye pollock, were the primary prey of Greenland turbot, arrowtooth flounder, and Pacific cod. The diet of walleye pollock was the most general in terms of number of significant prey types. The diet of flathead sole was restricted to a few prey types: brittle stars, fish, and offal. Dietary similarity was greatest between the piscivorous predators Greenland turbot, arrowtooth flounder, and Pacific cod (Table 8). Walleye pollock and flathead sole had relatively low dietary similarity with the other predators studied.

The high dietary overlap values calculated for Greenland turbot, arrowtooth flounder, and Pacific cod are primarily the result of the significance of walleye pollock in their diets. The low dietary overlap of flathead sole with all other predators was the result of their dependence upon brittle stars as their primary prey, while the other species rarely consumed brittle stars. Walleye pollock did-not have high dietary overlap with any other predator despite the presence of common prey due to the relatively equal importance of several prey in their diet. Mito (1974) presented results of dietary similarity during the fall over the slope region which also indicated the prevalence of walleye pollock in the diet increased the extent of dietary similarity,

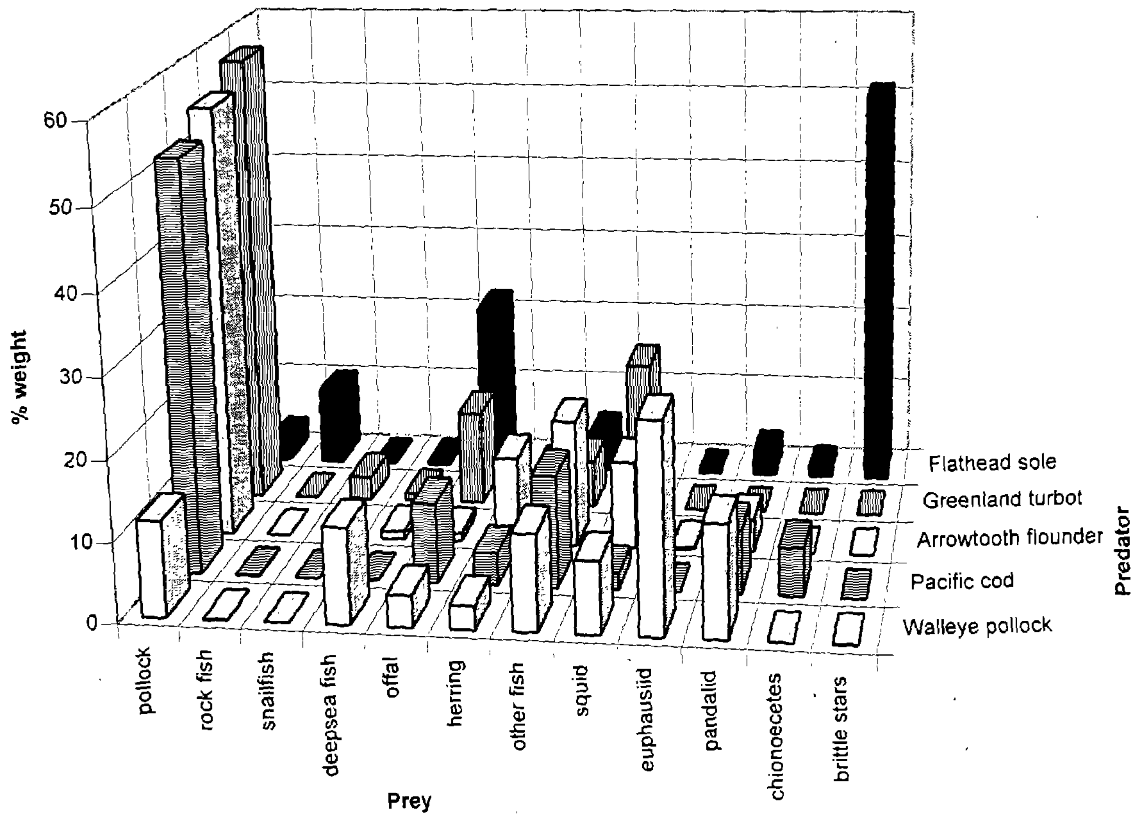

Figure 41 .--Diets of walleye pollock, Pacific cod, arrowtooth flounder, Greenland halibut, and flathead sole in the eastern Bering Sea slope region.

Table 8.--Schoener's (1970) index of dietary overlap of Pacific cod, walleye pollock, arrow-tooth flounder, flathead sole, and Greenland turbot in the eastern Bering Sea slope region. Low overlap = O-33, moderate overlap = 34-66, high overlap = 67-100.

Predator	Pacific cod	Walleye pollock	Arrowtooth flounder	Flathead sole	Greenland halibut
Pacific cod		moderate	high	low	high
Walleye pollock	47		moderate	low	moderate
Arrowtooth flounder	79	46		low	high
Flathead sole	25	22	15		low
Greenland halibut	73	37	75	23	

SUMMARY

As seen in previous studies of groundfish diets on the eastern Bering Sea shelf, walleye pollock were generally the primary prey of most piscivorous fish in the eastern Bering Sea slope region. In the slope region, however, myctophids, bathylagids, and rockfish were also found to be important. The importance of rockfish, found primarily in the diet of flathead sole, is likely overestimated by the percentage by weight contribution in the diet. Nonetheless, rockfish were found in 8% of the flathead sole stomachs that contained food and could still be considered an important prey. The prevalence of deep-sea fish (myctophids and bathylagids) in the diet of walleye pollock is indicative of a different species composition in the pelagic food web than is seen over the shelf region. Walleye pollock over the slope are generally larger, and therefore more piscivorous. Juvenile walleye pollock are less abundant, leading to a greater dependence upon other fish prey. Myctophids, bathylagids, and squid are generally not available over the shelf region, and therefore are not a significant part of the shelf food web. The predators studied in the slope region of the eastern Bering Sea were larger on average, which resulted in higher piscivory in the diets.

Walleye pollock, myctophids, bathylagids, and squid are not only important prey of fish in the eastern Bering Sea, but they also are important prey to marine mammals and birds. Lowry et al. (1988) report that walleye pollock are consumed by 15 of the 31 species of marine mammals that occur in the eastern Bering Sea. ‘Sinclair (1988) also presented information detailing the importance of bathylagids and gonatid squids in the diet of northern fur seals (Callorhinus ursinus) in the eastern Bering Sea. Hunt et al. (198 1) reported myctophids as an important prey of red-legged kittiwakes (Rissa brevirostris) in the eastern Bering Sea. Population level estimates of the impact of predation by key fish in the region were not calculated in the current study due to the relatively small portion of the groundfish populations that are found over the slope, Nevertheless the complexity of the eastern Bering Sea slope food web warrants further investigation,

Dietary differences betweeen predators on the slope and shelf region of the eastern Bering Sea increased with distance from the shelf, Diets of fish from the outer strata were generally less similar to those in the shallow strata, depicting a transition from the shelf environment to the bathypelagic environment. A lack of adequate sample sizes in our study precluded a thorough analysis of the seasonal variation of the diets of most predators. The paucity of detailed life history information for many of the invertebrate prey seen in the diets of these fish limited the interpretation of some dietary variation. Further food habits studies in this area should focus on more detailed dietary analyses achieved through larger sample sizes with greater spatial resolution, food web analyses, and possible dietary variation associated with canyons.

CITATIONS

Albers, W. D., and P. J. Anderson. 1985. Diet of Pacific cod, Gadus macrocephalus, and predation on the northern pink shrimp, Pandalus borealis in Pavlof Bay, Alaska. Fish. Bull. U.S. 83(4):601-610.

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

Bakkala, R. G., W. A. Karp, G. F. Walters, T. Sasaki, M. T. Wilson, T. M. Sample, A. M. Shimada, D. Adams, and C. E. Armistead. 1992. Distribution, abundance, and biological characteristics of groundfish in the eastern Bering Sea based on results of U.S. - Japan bottom trawl and midwater surveys during June-September, 1988. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-213, 372 p.

Cooney, T. R. 1981. Bering Sea zooplankton and micronekton communities with emphasis on annual production. P. 947-974, In Hood, D. W. and J. A. Calder (eds.), The eastern Bering Sea shelf Oceanography and resources, vol. II. Univ. Washington Press, Seattle, WA 98105.

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(11):1972-1984.

Fadeyev, N. S. 1988. Spatial and temporal variability of the eastern Bering Sea walleye pollock size composition in relation to its migrations. P 497-508, In Proceedings of the International Symposium on the Biology and Management of Walleye Pollock, Anchorage, Alaska, USA, November 14-16, 1988, Univ. Alaska, Fairbanks. Sea Grant Rep. AK-SG-89-01,

Fritz, L. W., C. E. Armistead, and N. J. Williamson. 1995. Effect of catcher vessel operational area on walleye pollock fisheries and marine mammals in the eastern Bering Sea, 1990-94. AFSC Processed Rep. 95-04, 114 p. Alaska Fish, Sci. Cent,, Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE., Seattle WA 98115-0070

Goddard, P., and M. Zimmermann. 1993. Distribution, abundance, and biological characteristics of groundfish in the eastern Bering Sea based on results of the U.S. bottom trawl survey during June - September 1991. AFSC Processed Rep. 93-l5, 324 p, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE., Seattle WA 98115-0070

a

Goerinig, J. J., and R. L. Iverson. 1981. Phytoplankton distribution on the southeastern Bering Sea shelf. P. 933-947 In Hood, D. W. and J. A. Calder (eds.), The eastern Bering Sea shelf Oceanography and resources, vol II. Univ. Washington Press, Seattle, WA 98105.

Hunt, G. L. Jr., B. Burgeson, and G. A. Sanger. 1981. Feeding ecology of seabirds of the eastern Bering Sea. P. 629-648, In Hood, D. W. and J. A. Calder (eds.), The eastern Bering Sea shelf Oceanography and resources, vol. II. Univ. Washington Press, Seattle, WA 98105.

Kihara, K. 1990. Distributions of recurrent groups and predators of walleye pollock Theragra chalcogramma. J. Tokyo Univ. Fish. 77(2):263-273.

Lowry, L. F., K. J. Frost, and T. R. Loughlin. 1988. Importance of walleye pollock in the diets of marine mammals in the Gulf of Alaska and Bering Sea, and implications for fishery management. P.701:726, In Proceedings of the International Symposium on the Biology and Management of Walleye Pollock, Anchorage, Alaska, USA, November 14-16, 1988, Univ. Alaska, Fairbanks. Sea Grant Rep. AK-SG-89-01.

Livingston, P. A. 1991a. Walleye pollock, P. 9-30, In Livingston, P. A. (ed.), Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea, 1984-1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-207.

Livingston, P. A. 1991b. Pacific cod. P. 3l-88, In Livingston, P. A. (ed.), Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea, 1984-1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-207.

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.

Livingston, P. A., A. Ward, G. M. Lang, and M-S. Yang. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-11, 192 p.

Mito, K. 1974. Food relationships among benthic fish populations in the Bering Sea on the Theragra chalcogramma fishing grounds in October and November of 1972. M. S. Thesis, Hokkaido University Graduate School. 135 p.

Mito, K. 1990. Differences in the weight and composition of stomach contents of pollock between areas of the Bering Sea. (Document submitted to the Annual Meeting of the North Pacific Fisheries Commision, Vancouver, Canada, 1990, October) 17 p. Fisheries Agency of Japan, National Research Institute of Far Seas Fisheries, 7-1 Orido 5, Chome, Shimizu, Shizuoka, Japan 424.

North Pacific Fishery Management Council. 1994. Stock Assessment and Fishery Evaluation Report for the groundfish resources of the Bering Sea/Aleutian Islands regions as projected for 1995. North Pac. Fish. Manage. Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 995 10-2252.

Okutani, T. 1988. Evidence of spawning of Berryteuthis magister in the northeast Pacific (Cephalopoda:Gonatidae). Bull. Ocean Res. Inst., Univ. Tokyo. No. 26 (Part II): 193-200.

Okutani, T., T. Kubodera, and K. Jefferts. 1988: Diversity, distribution and ecology of Gonatid squids in the subarctic Pacific: A review. Bull. Ocean Res. Inst., Univ. Tokyo. No. 26 (Part 1):159-192.

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

Pacunski, R. E. 1991. Flathead sole. P. 163-199, In Livingston, P. A. (ed.), Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea, 1984-1986.. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-FNWC-207.

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

Sinclair, E. H. 1988. Feeding habits of northern fur seals (Callorhinus ursinus) in the eastern Bering Sea. M. S. Thesis, Oregon State University. 94 p.

Tokranov, A. M., and A. B. Vinnikov. 1991. Diet of the Pacific cod, Gadus macrocephalus, and its position in the food chain in Kamchatkan coastal waters J. Ichthyol. 31(5):84-98.

Wespestad, V. G. 1994. Pacific herring population dynamics, early life history, and recruitment variation relative to eastern Bering Sea oceanographic factors. Ph. D. dissertation, University of Washington, 237 p.

Wespestad, V. G. 1994. Walleye pollock. P. 1-2 to l-29, In Stock Assessment and Fishery Evaluation Report for the groundfish resources of the Bering Sea/Aleutian Islands regions as projected for 1995. North Pac. Fish. Manage. Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99510-2252.

Wespestad, V. G., and L. H. Barton. 1981. Distribution, migration and status of Pacific Herring. P. 509-526, In Hood, D. W. and J. A. Calder (eds.), The eastern Bering Sea shelf Oceanography and resources, vol. II. Univer. Washington Press, Seattle, WA 98105.

Yang, M-S. 1991a. Greenland turbot. P. 122-142, In Livingston, P. A. (ed.), Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea, 1984-1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-207.

Yang, M-S. 1991b. Arrowtooth flounder. P. 143-162, In Livingston, P. A. (ed.), Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea, 1984-1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-207.

Yang, M-S. 1993. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-22, 150 p.

Yang, M-S., and P. A. Livingston. 1986. Food habits and diet overlap of two congeneric species, Atherestes stomias and Atherestes evermanni, in the eastern Bering, Sea. Fish. Bull, U.S. 82(3):615-623.

Yang, M-S., and P. A. Livingston. 1988. Food habits and daily ration of Greenland halibut, Reinhardtius hippoglossoides, in the eastern Bering Sea. Fish. Bull. U.S. 86(4):675-690.

Yoshida, H. 1994. Food and feeding habits of pelagic walleye pollock in the central Bering Sea in summer, 1976-1980. Sci. Rep. Hokkaido Fish. Exp. Stn. 45: 1-35

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