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Part II, Biological Characteristics in **the Extended Region**

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March 1985

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STUDIES OF THE DISTRIBUTION AND ABUNDANCE OF JUVENILE GROUNDFISH IN THE NORTHWESTERN GULF OF ALASKA, 1980-82: PART II, BIOLOGICAL CHARACTERISTICS IN THE EXTENDED REGION

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ABSTRACT

Juvenile groundfish were studied in the northwestern Gulf of Alaska to determine interannual variations in distribution and abundance, evaluate the feasibility of measuring year-class strengths, and obtain other information on this poorly understood life history stage. Bottom trawl data were collected at a total of 749 stations during three surveys conducted in the late summer periods of 1980-82.

This report describes results from the entire sampling coverage in each of the 3 yr, including information on the juvenile biology of fishes not discussed in our first report, and from other data collections and analyses. Bay and nearshore regions were surveyed between long. 152-168°W, from the west end of Unalaska Island to the east end of Afognak Island.

The inshore waters of the study area supported rich fish and shrimp faunas. A total of 100 fish taxa, representing 21 families, and 74 invertebrate taxa were taken during the 3 yr. A large number of fish species were present in the juvenile life history stage.

Walleye pollock, Theragra chalcogramma, was present as young of the year and 1-yr-olds. In 1980, O-group fish were principally found in the northeast; but in 1981, young of the year were abundant both in the Kodiak Island region and south along the Alaska Peninsula to Pavlof Bay. One-yr-olds were also widely distributed and particularly abundant in the lower Alaska Peninsula region in 1980-81.

Other principal groundfish and age groups were as follows: Pacific cod, Gadus macrocephalus, 0-group and 1-yr-olds; sablefish, Anoplopoma fimbria, 1-yr-olds; arrowtooth flounder, Atheresthes stomias, 1- and 2-yr-olds; and flathead sole, Hippoglossoides elassodon, 1-yr-olds.

Additional studies included analyses of regional and between-year variations in the size distributions of O-group and 1-yr-old walleye pollock, classification analyses of faunal associations, and. analyses of the stomach contents of 1-yr-old walleye pollock.

CONTENTS

INTRODUCTION

This study, the second paper in a series of three reports, describes additional results from three shrimp and juvenile fish surveys conducted in the northwestern Gulf of Alaska during the late summer periods of 1980-82. In those years, surveys were made by the Alaska Department of Fish and Game (ADF&G) and National Marine Fisheries Service (NMFS) to assess the abundance of shrimp populations in bays and nearshore waters of Unalaska Island, the Alaska Peninsula, and the Kodiak Island-Afognak Island archipelago. The extensive geographical coverage provided opportunities for studying other aspects of inshore ecology on a regional scale. We participated in the surveys to collect information on the distribution, relative abundance, and other ecological characteristics of the juvenile and adult groundfish that occurred in the catch.

Goals of our investigations were to: 1) describe the geographical distribution and abundance of juvenile age groups of the major fish species and their annual variations; 2) evaluate the feasibility of measuring year-class strengths; and 3) relate our results to other research in the region, providing recommendations for further work.

The study area, the northwestern Gulf of Alaska from Unalaska Island eastward to Afognak Island, is a large geographical area with complex topography (Fig. 1). The coast is rugged and irregular, with numerous bays and islands. The continental shelf varies in width from about 100-200 km in the northeast to 30 km near Unalaska Island; the shelf is crossed by numerous troughs and valleys and is characterized by a variety of types of sediments (Sharma 1979).

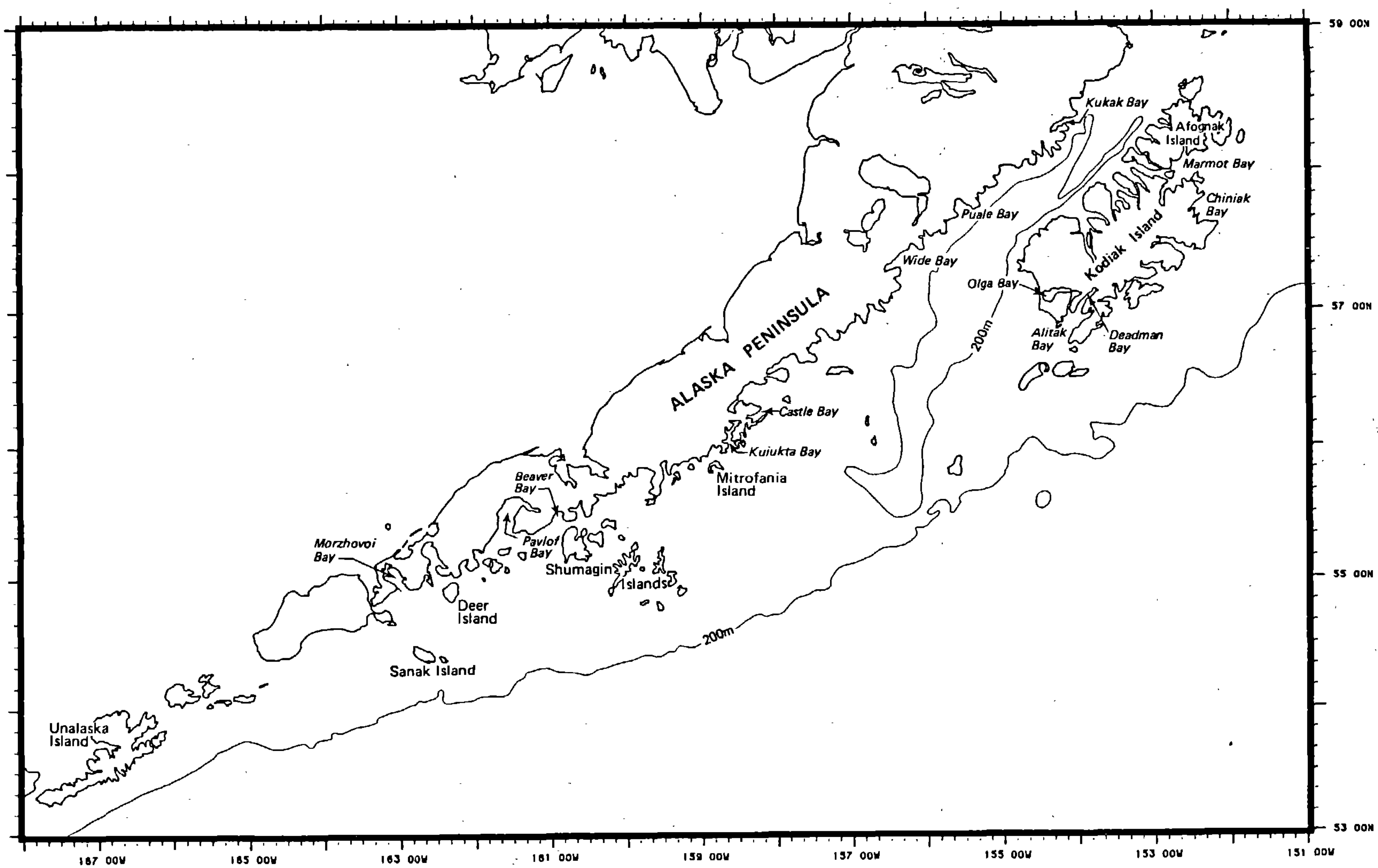

Figure 1. --Map of the entire study area in the northwestern Gulf of Alaska where shrimp and juvenile fish surveys were conducted during late summer periods of 1980-82.

Our preceding report (Smith et al. 1984) emphasized the following species: walleye pollock, *Theragra chalcogramma*; Pacific cod, *Gadus macrocephalus*; and sablefish, *Anoplopoma fimbria*. These were present in those parts of the study area that received comparable sampling coverage over all 3 yr. Such coverage was available for 12 major inlets along the central Alaska Peninsula and Kodiak Island. A principal purpose of the first report was to evaluate the feasibility of early detection of strong year classes by sampling juvenile fish.

Objectives for the present study were to add the additional data from areas surveyed in only 1 or 2 yr (approximately 51% of the total data) and to describe: 1) results from the complete sampling coverage in each of the 3 yr; 2) results on the juvenile biology of additional fishes that were studied; and 3) results from other data collections and analyses. Additional species emphasized were arrowtooth flounder, *Atheresthes stomias*, and flathead sole, *Hippoglossoides elassodon*. Other studies included analyses of length distributions and growth, faunal associations, and feeding relationships.

MATERIALS & METHODS

Most of the survey and analytical methods were described in our first report (Smith et al. 1984). We restate these briefly, but mainly emphasize aspects of the approach that were new or different.

Experimental Design

This study used the data available from the complete sampling coverage of ADF&G and NMFS shrimp surveys in each year, 1980-82, which included 749 total stations occupied between long. 152-168°W (Table 1). Areas surveyed during 1980 and 1981 extended from Unalaska Island to Afognak Island. In 1982, stations were sampled from Castle Bay on the Alaska Peninsula to Kodiak Island.

Survey Methods

As mentioned in our first report, many aspects of each year's survey--e.g., sampling design, timing, and field methods--were beyond our control. due to the nature of our involvement as guest observers. The sampling technique followed a form of stratified random sampling. Although most sampling was done in September, the timing of survey activities ranged from approximately mid-August to early October (Table 1).

Five of the six stern-trawling vessels used in the surveys were similar in size and power, approximately 25-30 m in length and 500-600 hp. The vessel Chapman, however, has a length of about 39 m and 1165 hp.

All the surveys used identical, high-opening, small mesh 61-foot shrimp trawls (Wathne 1977). This trawl was constructed primarily of 32 mm mesh netting and was equipped with a 16.8 m tickler chain rigged to make the net sample approximately 30 cm off the bottom. Mensuration testing (Wathne 1977) indicates an effective path width (i.e., net spread)

-Table 1.--Characteristics of the sampling coverage used from shrimp surveys conducted in the northwestern Gulf of Alaska, 1980-82.

year	Vessel	Number of tows	Region surveyed	Time period
1980	Oregon[a]	89	Alaska Peninsula from Unalaska Island to Mitrofania Island	12 Aug. - 16 Sep.
	Commander[b]	126	Alaska Peninsula from Deer Island to Puale Bay	23 Aug. - 16 Sep.
	Royal Baron[b]	66	Eastern Kodiak Island and Alitak Bay	23 Aug. - 5 Sep.
	Resolution[b]	23	Western Kodiak Island and Chiniak Bay	9 Sep. - 15 Sep.
	Subtotal	304		
1981	Chapman[c]	55	Alaska Peninsula from Unalaska Island to the Shumagin Islands	31 Aug. - 14 Sep.
	Alaska[b]	112	Alaska Peninsula from the Shumagin Island to Wide Bay and outer Marmot Bay on Kodiak Island	2 Sep. - 23 Sep.
	Resolution[b]	134	Eastern and western Kodiak Island and Kukak and Puale Bays on the Alaska Peninsula	3 Sep. - 3 Oct.
	Subtotal	301		
1982	Royal Baron [b]	144	Eastern and western Kodiak Island and the Alaska Peninsula from Castle Bay to Kukak Bay	24 Aug. - 23 Sep.
	Subtotal	144		
	Total	749		

[a] National Marine Fisheries Service.
[b] Alaska Department of Fish and Game.
[c] National Marine Fisheries Service; data provided courtesy of Paul Anderson, National Marine Fisheries Service, Kodiak Laboratory, P.O. Box 1638, Kodiak, AK 99615.

of 9.8 m and a vertical opening of 3.5 to 4.1 m.

Resource survey methods were used as described by Smith and Bakkala (1982). Bottom tows ranged from 10 to 30 min duration. Distances towed, determined by Loran C or radar fixes, ranged from 0.2 to 3.7 km. The-area of bottom "swept" by the trawl was estimated from the distance towed multiplied by the path width.

Trawl catches were processed using the shipboard procedures of Hughes (1976). The catch was sorted and identified by taxa, weighed, and counted. Length-frequency measurements, recorded to the nearest centimeter, were made from random subsamples of selected species. Walleye pollock, Pacific cod, sablefish, and arrowtooth flounder were measured by fork length; flathead sole were measured by total length. Due to time constraints, not all species of interest could be measured from every haul in which they occurred. Saccular otoliths were collected from walleye pollock, sablefish, arrowtooth flounder, and flathead sole, and scale scrape samples were taken from Pacific cod, for age determinations.

Sea surface temperature was measured with a bucket thermometer at a total of 746 stations. In addition, bottom water temperatures were obtained from expendable bathythermograph (XBT) profiles at 461 stations.

Analytical Procedures

Distribution patterns were demonstrated by making maps showing relative abundance. Relative densities of fish were calculated, for each species, as the ratio of the number caught and the estimate of bottom area "swept" by the trawl at each station;. these were standardized to units of number per 10,000 m^2. Distributions of juveniles were estimated by first selecting nonoverlapping length intervals to represent specific age groups.

Length intervals were selected by referencing age-length keys built from data collected on the surveys; and from inspection of the length-. frequency distributions. At each station, the density, of fish in a particular age group was estimated from the fraction that the corresponding size group represented in the length-frequency measurements.

Size distributions of walleye pollock were examined for regional and between-year variations. For these analyses, the study area was subdivided into seven geographical strata on a southwest to northeast basis (Table 2; Fig. 1). The available length-frequency data were combined, unweighted by catch densities, over all stations within each stratum.

Associations of the fish and invertebrate species and specific age groups of the major species taken on the surveys were examined by analyzing the similarity in their geographic distribution patterns. Numerical classification, or "cluster" analysis, techniques were used to measure and describe degrees of statistical relationship. The actual methods employed were similar to those described by Walters and McPhail (1982) and Walters (1983), except that binary data were used instead of quantitative data and only species groups were examined. Initial steps of these analyses were done using computer programs in the CLUSPAK package available in the resource survey data-base system available at the Northwest and Alaska Fisheries Center (Mintel and Smith 1981).

For each year's survey, a data matrix was prepared consisting of the catch data for m taxonomic categories ("entities") among the total set of n sampling sites. The taxonomic categories used were mainly species, although to improve standardization, some taxa were grouped into higher classifications. To remove rare species, we required that

Table 2.--Subregions of the northwestern Gulf of Alaska used for comparisons of the size distributions of walleye pollock, 1980-82.

Stratum	Area'
1	Unalaska Island
2	Morzhovoi Bay and the Sanak Islands
3	Pavlov Bay
4	Shumagin Islands and the Alaska Peninsula from Beaver Bay to Kuiukta Bay
5	Alaska Peninsula from Castle Bay to Kukak Bay
6	Western Kodiak Island (including Alitak Bay)
7	Eastern Kodiak Island

the taxa used in each analysis occur in at least 5% of the samples. In addition, walleye pollock, Pacific cod, and sablefish were subdivided into three age groups (young of the year, 1-yr-olds, and >2 yr) on the basis of length intervals, and treated as separate entities. The number of entities used in analyses were: 1980, 51; 1981, 48; and 1982, 30. For each trawl sample, each entity was scored as either present or absent.

The resemblance between entities was measured using the Czekanowski coefficient of similarity (Clifford and Stephenson 1975). For a set of samples, the coefficient is computed:

$$S = \frac{2\underline{a}}{2\underline{a} + \underline{b} + \underline{c}}$$

where S is a value of similarity ranging from 0 (no similarity) to 1 (complete similarity), and for a pair of entities A and B, a is the number of joint occurrences of A and B, b the number of occurrences of only A, and c the number of occurrences of only B.

Following determination of the matrix of coefficients of similarity between all entities, the entities were-clustered using the group average agglomerative method (Boesch 1977). Program P1M of the University of California Biomedical Computer Program Series (Dixon and Brown 1979) was used to perform the actual classifications.

Feeding Relationships

In 1980, studies were made of the stomach contents of 1yr-old walleye pollock. During surveys in that year, a subsample of 10 walleye pollock in the size range 14-25 an was collected from most trawl samples in which fish of that size occurred, and preserved with 10% formalin.

Samples were processed in the laboratory by dissecting the foregut from each fish, transferring the foregut and contents to 95% ethanol, and identifying and counting the stomach contents using a binocular microscope at 6-30X magnification. Contents were classified to 13 general categories of food items. The stomach contents from all fish within a subsample were pooled by food category, then the alcohol wet weight was determined for each category. A total of 439 walleye pollock were examined from 44 collection sites spread throughout the study area.

After processing, the food items from all samples were pooled by general food categories. At the end of the study, samples were taken from these composite collections for determining more detailed identifications and dry/wet weight ratios.

RESULTS

Data Coverage

The geographical distribution of sampling effort was similar in 1980 and 1981, with coverage from Unalaska Island to Afognak Island (Table 1; Fig. 1). The number of trawl tows was also similar, with 304 in 1980 and 301 in 1981. The 1982 survey coverage was limited to Kodiak and Afognak Islands, and the Alaska Peninsula from Castle Bay to Wide Pay. During that survey, 144 trawl tows were completed.

The survey coverage described for 1980 includes all of the stations from the study area described in our preceding report (Smith et al. 1984), as well as 20 additional stations in that area, and 170 samples from areas to the west. In 1981, 48 additional samples were used from the prior study area and 123 samples were included from the west. In 1982, 22 additional samples were used from the previous study area.

The depth distribution of sampling in 1980 (range 18-274 m) was relatively narrow with nearly half the samples collected from 80 to 120 m (Fig. 2). The sampling effort in 1981 (range 35-278 m) and 1982 (range 33-203 m) was more evenly distributed among depth intervals.

Collections of biological data included 164,971 length measurements for the 5 principal fish species as well as 7,410 measurements from 28 additional species. Otoliths or scales were taken from 2,103 fish of the five major species and 153 fish of other species.

Descriptions of the distribution and abundance of walleye pollock and Pacific cod age groups were based on the entire set of 749 samples. However, in 1981, length-frequency data for sablefish, arrowtooth flounder, and flathead sole were collected only from Beaver Ray on the Alaska

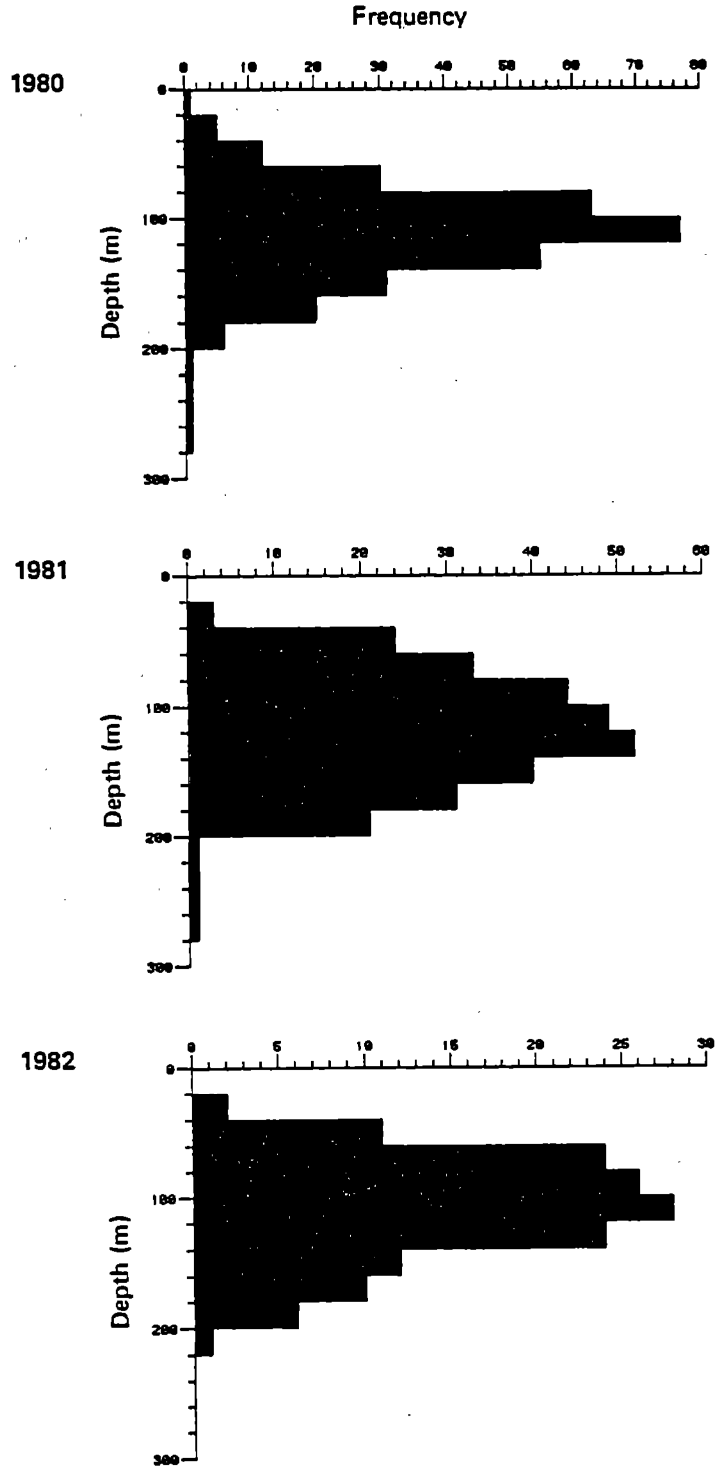

Figure 2. --Sampling depths of shrimp trawl tows taken during the 3 yr of investigations in the northwestern Gulf of Alaska, 1980-82, based on the complete survey coverage.

Peninsula, eastward through Kodiak and Afognak Islands. This reduced the effective 1981 sampling coverage for size and age analyses from 301 stations to 246 stations (i.e., 694 total stations for the 3 yr).

Temperature Conditions

Sea surface temperatures (SST) were similar in 1980 and 1982, but averaged nearly 1°C warmer in 1981 (Fig. 3). During August-September 1980; mean SST was 10.3°C (range 7.4 to 12.5°C); in September-October 1981, mean SST was 11.2°C (8.8 to 13.2°C); and during August-September 1982, mean SST was 10.5°C (range 5.9 to 12.6°C). In 1980, there was a general increase in SST across the study area from west to east (Fig. 4). In 1981, highest temperatures were found along the central Alaska Peninsula with lower values to the east and west. No regional trends were apparent in 1982.

Bottom water temperatures (BWT) were also warmest in 1981 (Fig. 5). Due to failures of the XBT equipment, measurements of BWT were not taken around Kodiak Island in 1980. At other locations, primarily along the Alaska Peninsula, mean BWT was 6.4°C (range 4.7 to 10.5°C). In 1981, mean BWT was 7.8°C (3.6 to 14.6°C); and in 1982, mean BWT was 6.8°C (range 1.5 to 10.3°C). The group of 1982 BWT values near 2°C (Fig. 5) were from the nearly enclosed Olga and Deadman Bays on the southwest end of Kodiak Island. The BWT observations available from 1980 displayed the same west-to-east trend of increasing values shown by the SST (Fig. 6). The distribution of BWT in 1981 was also similar to SST, with highest values near the central Alaska Peninsula and lower values to the east and west.

Faunal Characteristics

A total of 100 fish taxa, representing 21 families, were collected during the 3 yr (Table 3). These included 91 species and 9 taxa

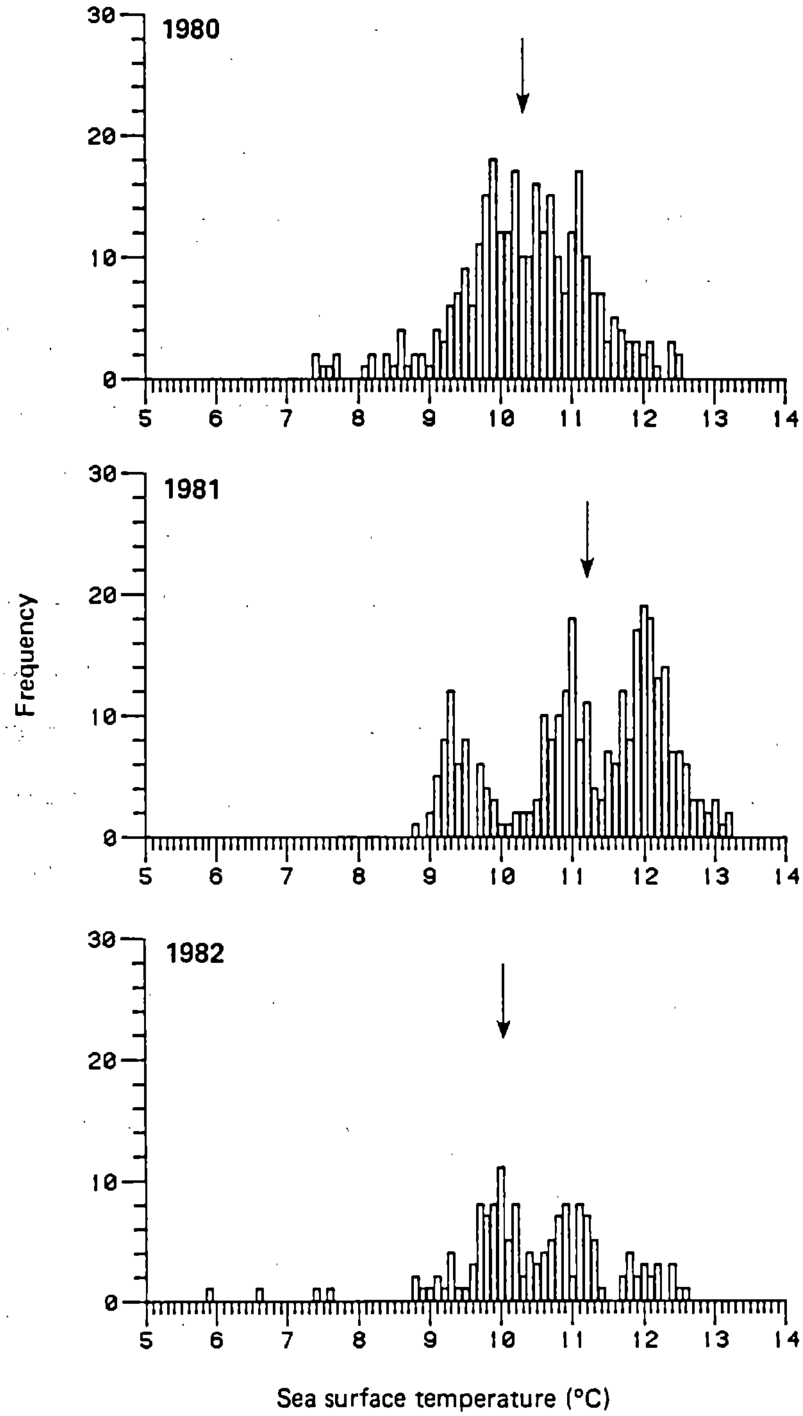

Figure 3.--Sea. surface temperatures observed during the 3 yr of investigations in the northwestern Gulf of Alaska, 1980-82, based on the complete survey coverage; Arrows show mean values.

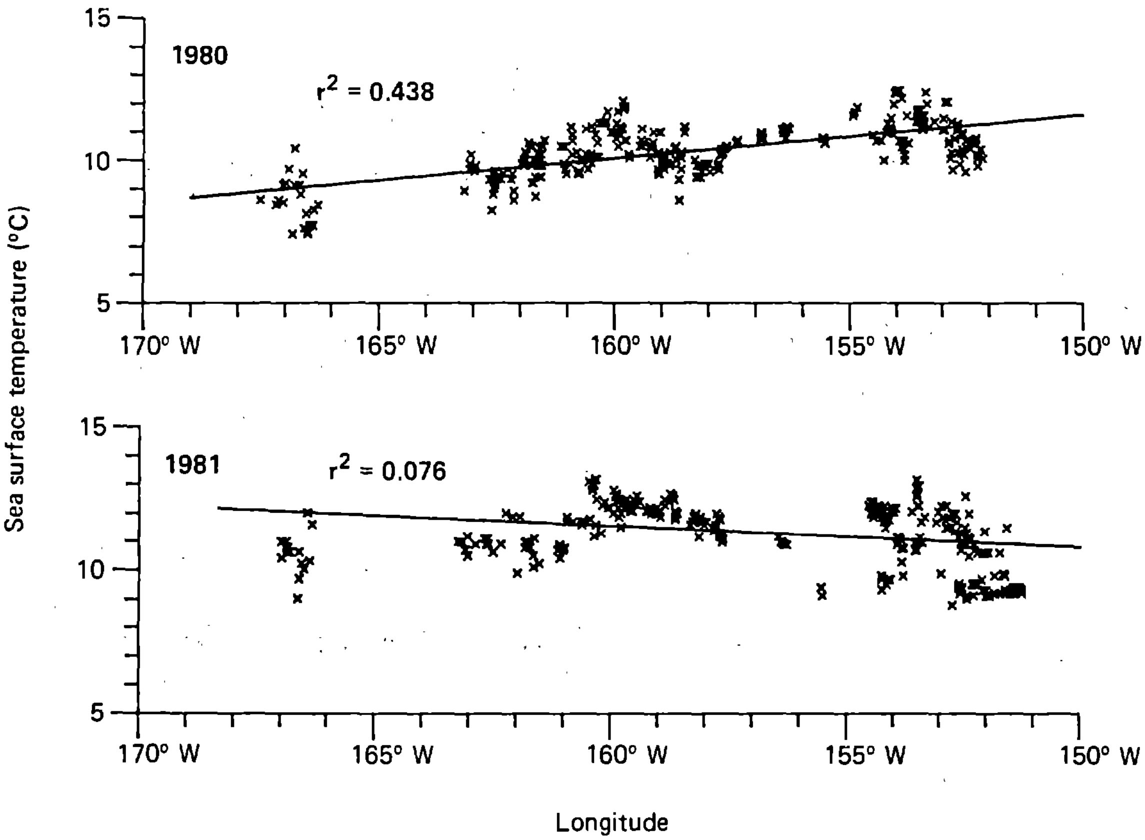

Figure 4.--Scatter diagrams of the relationships observed between sea surface temperature measured at sampling stations and geographic longitude, based on the complete coverage of the 1980-81 surveys in the northwestern Gulf of Alaska. Least-squares linear regression lines (shown) were fitted to the two sets of data; both lines had slopes significantly different from zero.

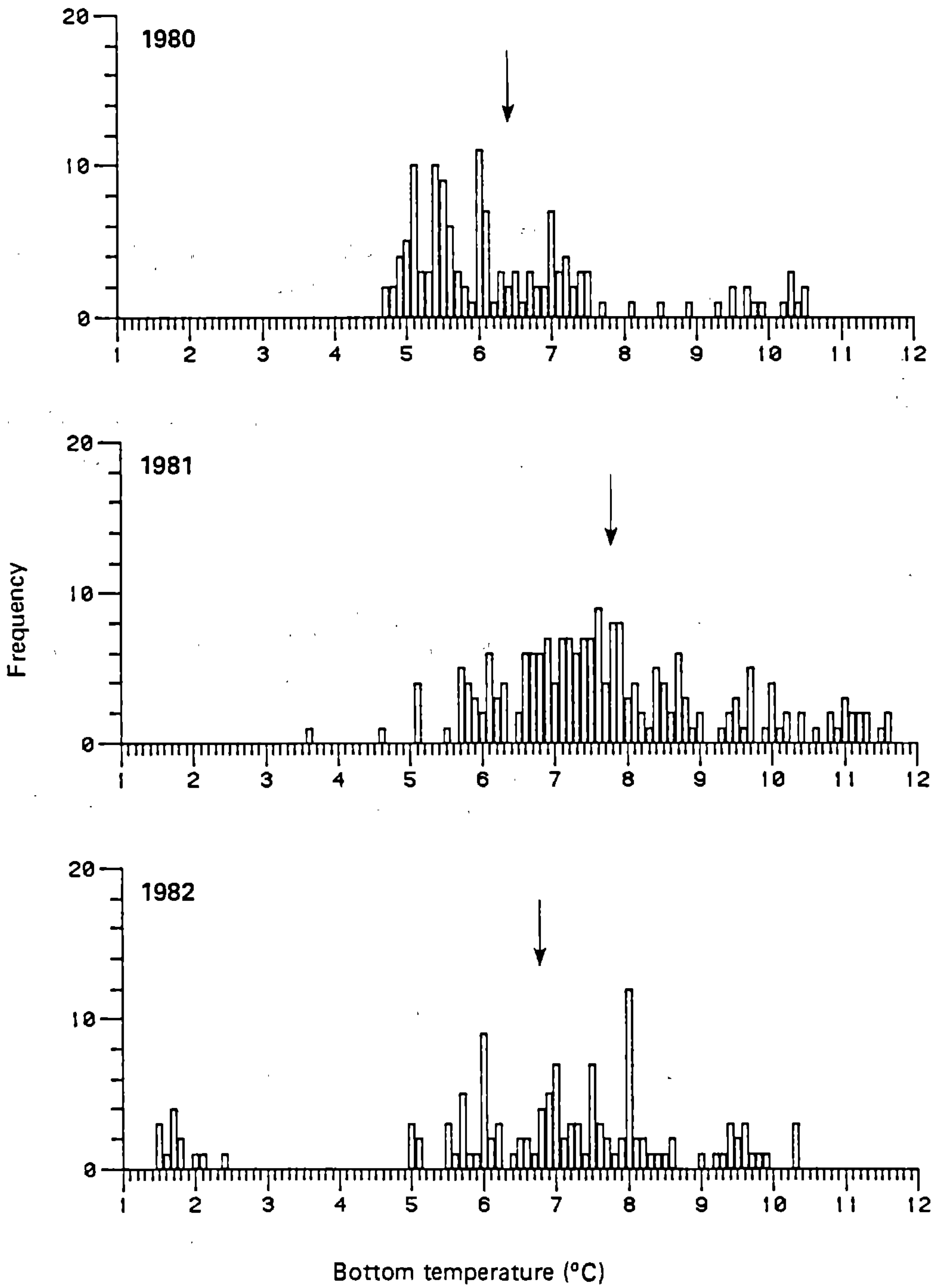

Figure 5. --Bottom water temperatures observed during the 3 yr of investigations in the northwestern Gulf of Alaska, 1980-82, based on the complete survey coverage. Arrows show mean values.

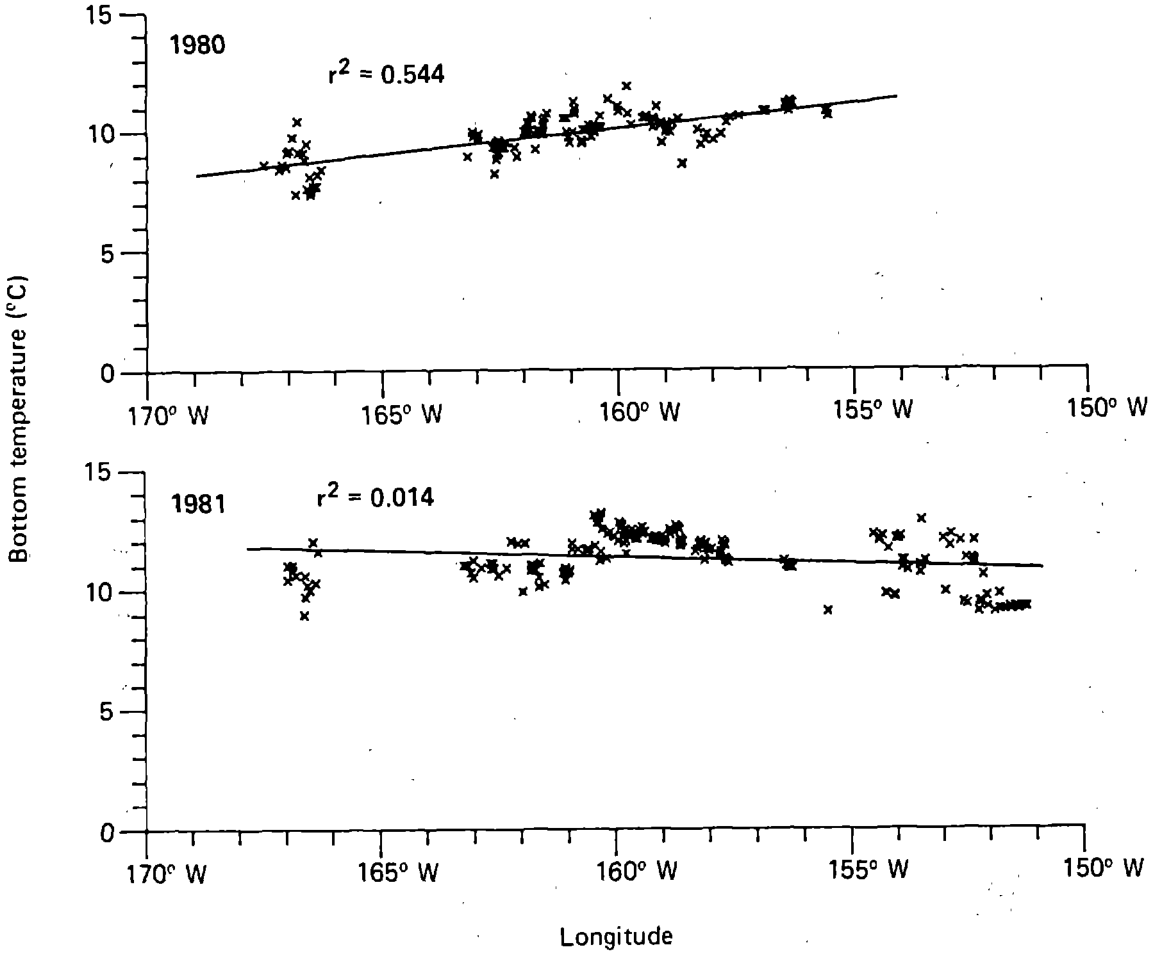

Figure 6. --Scatter diagrams of the relationships observed between bottom water temperature measured at sampling stations and geographic longitude, based on the complete coverage of the 1980-81 surveys in the northwestern Gulf of Alaska. Least-squares linear regression lines (shown) were fitted to the two sets of data; only the line fitted to the 1980 data had a slope significantly different from zero.

Table 3 .--Fishes recorded during the 1980-82 shrimp surveys in the northwestern Gulf of Alaska.

Taxon	Common name	Year[a] 80	81	82
Agonidae				
Podothecus acidpenserinus	Sturgeon poacher	X	X	X
Aspidophoroides bartoni	Aleutian alligatorfish	X	X	-
Bathyagonus alascanus	Gray starsnout	X	X	-
Odontopyxis trispinosa	Pygmy poacher	X	X	X
Pallasina barbata	Tubenose poacher	X	X	-
Percis japonicus	Dragon poacher	-	X	-
Ammodytidae				
Ammodytes hexapterus	Pacific sand lance	-	-	X
Anoplopomatidae				
Anoplopoma fimbria	Sablefish	X	X	X
Aulorhynchidae				
Aulorhynchus flavidus	Tube-snout	-	X	-
Bathymasteridae				
Bathymaster caeruleofasciatus	Alaskan ronquil	X	-	-
Bathymaster signatus	Searcher	X	X	X
Ronquilus jordani	Northern ronquil	X	-	-
Clupeidae				
Clupea pallasi	Pacific herring	X	X	X
Cottidae				
Artediellus sp.	Sculpin	-	-	X
Blepsias bilobus	Crested sculpin	-	X	X
B. cirrhosus	Silverspotted sculpin	X	-	-
Gymnocanthus galeatus	Armorhead sculpin	X	X	X
G. pistilliger	Threaded sculpin	X	X	-
G. sp.	Sculpin	X	-	X
Hemilepidotus jordani	Yellow Irish lord	X	X	X
H. sp.	Irish lord	X	X	-
Hemitripterus bolini	Bigmouth sculpin	X	X	X
Icelinus borealis	Northern sculpin	X	-	-
Icelus spiniger	Thorny sculpin	X	X	-
I. sp.	Sculpin	X	X	-
Leptocottus armatus	Pacific staghorn sculpin	X	X	-
Myoxocephalus jaok	Plain sculpin	X	X	-
M. polyacanthocephalus	Great sculpin	X	X	-
M. sp.	Sculpin	X	X	X
Triglops forficata	Scissortail sculpin	X	X	-
T. pingeli	Ribbed sculpin	X	X	X
T. scepticus	Spectacled sculpin	X	X	-
T. sp.	Sculpin	X	X	-

Table 3--Continued.

Taxon	Common name	Year[a] 80	81	82
Cryptacanthodidae				
Delolepis gigantea	Giant Wrymouth	X	X	-
Lyconectes aleutensis	Dwarf Wrymouth	X	X	-
Cyclopteridae				
Aptocyclus ventricosus	Smooth lumpsucker	X	X	X
Careproctus melanurus	Blacktail snailfish	X	-	-
C. rastrinus	Snailfish	X	X	X
Eumicrotremus derjugini	Leatherfin lumpsucker	X	-	-
E. orbis	Pacific spiny lumpsucker	X	-	-
Liparis dennyi	Marbled snailfish	X	X	-
Paraliparis sp.	Snailfish	-	X	-
Gadidae				
Gadus macrocephalus	Pacific cod	X	X	X
Microgadus proximus	Pacific tomcod	X	X	X
Theragra chalcogramma	Walleye pollock	X	X	X
Hexagrammidae				
Hexagrammos decagrammus	Kelp greenling	X	X	-
H. lagocephalus	Rock greenling		X	
H. stelleri	Whitespotted greenling	X	X	-
Pleurogrammus monopterygius	Atka mackerel	X	X	-
Lamnidae				
Lamna ditropis	Salmon shark	X	-	-
Osmeridae				
Osmerus mordax	Rainbow smelt	-	-	X
Mallotus villosus	Capelin	X	X	X
Spirinchus starksi	Night smelt	X	-	-
S. thaleichthys	Longfin smelt	-	X	-
Thaleichthys pacificus	Eulachon	X	X	X
Pleuronectidae				
Atheresthes evermanni	Kamchatka flounder	X	-	-
A. stomias	Arrowtooth flounder	X	X	X
Glyptocephalus zachirus	Rex sole	X	X	X
Hippoglossoides elassodon	Flathead sole	X	X	X
Hippoglossus stenolepis	Pacific halibut	X	X	X
Isopsetta isolepis	Butter sole	X	X	X
Lepidopsetta bilineata	Rock sole	X	X	X
Limanda aspera	Yellowfin sole	X	X	X
Microstomus pacificus	Dover sole	X	X	X
Parophrys vetulus	English sole	X	-	-
Platichthys stellatus	Starry flounder	X	X	X
Pleuronectes quadrituberculatus	Alaska plaice	X	X	X
Psettichthys melanostictus	Sand sole	X	X	X
Reinhardtius hippoglossoides	Greenland turbot	X	X	-

Table 3. --continued

Taxon	Common name	Year[a] 80	81	82
Psychrolutidae				
Dasycottus setiger	Spinyhead sculpin	X	X	X
Malacocottus kincaidi	Blackfin sculpin	X	-	-
Psychrolutes paradoxus	Tadpole sculpin	X	-	-
P. sigalutes	Soft sculpin	X	-	X
Rajidae				
Raja binoculata	Big skate	X	X	-
R. rhina	Longnose skate	-	X	-
R. stellulata	Starry skate	-	X	-
R. sp.	Skate	X	X	X
Salmonidae				
Oncorhynchus kisutch	Coho salmon	X	-	-
O. tshawytscha	Chinook salmon	X	-	-
Scorpaenidae				
Sebastes aleutianus	Rougheye rockfish	X	X	X
S. alutus	Pacific Ocean perch	-	X	-
S. babcocki	Redbanded rockfish	-	X	-
S. borealis	Shortraker rockfish	X	X	-
S. ciliatus	Dusky rockfish	X	X	X
S. crameri	Darkblotched rockfish	X	X	-
S. flavidus	Yellowtail rockfish	X	X	-
S. melanops	Black rockfish	-	X	-
S. polyspinis	Northern rockfish	X	X	-
S. ruberrimus	Yelloweye rockfish	X	X	X
Squalidae				
Squalus acanthias	Spiny dogfish	X	X	X
Stichaeidae				
Chirolophis decoratus	Decorated warbonnet	-	X	-
Lumpenella longirostris	Longsnout prickleback	X	X	X
Lumpenus maculatus	Daubed shanny	X	X	-
L. sagitta	Snake prickleback	X	X	X
Trichodontidae				
Trichodon trichodon	Pacific sandfish	X	X	X
Zaproridae				
Zaprora silenus	Prowfish	X	X	X
Zoarcidae				
Bothrocara molle	Soft eelpout	X	X	X
Lycodes brevipes	Shortfin eelpout	X	X	X
L. palearis	Wattled eelpout	X	X	X

[a] An "X" indicates occurrence.

identified to the genus level. The more extensive survey coverage described by this report, over that of Smith et al. (1984), provided 20 additional taxa including 3 pleuronectids, 3 scorpaenids, and 4 cottids. The lists of fish taxa taken in 1980 and 1981 were similar, while the list of fish taken in 1982 was much smaller due to the more limited sampling coverage.

Seventy-four invertebrate taxa were collected and identified to taxonomic levels ranging from species to phyla (Table 4). Echinoderms, caridean shrimp, and crabs made up over half the-list.

Despite the long taxonomic lists, relatively few species dominated the catches in every year. Variations in the catch composition between years and between areas were primarily due to shifts in the relative abundance of these few species. For example, catches at the western end of the study area near Unalaska Island were dominated on a weight basis by pink shrimp, _Pandalus borealis_, and walleye pollock. Along the lower Alaska Peninsula, catches were dominated primarily by walleye pollock, flathead sole, and Pacific cod. Around Kodiak Island, the dominant species were pink shrimp, walleye pollock, flathead sole, and jellyfish. Other large components of the catches included: yellowfin sole, _Limanda aspera_; capelin, _Mallotus villosus_; eulachon, _Thaleichthys pacificus_; arrowtooth flounder; and other shrimp species.

Virtually all the fishes that were prominent in the catches were present in the juvenile life history stage. Some species, such as sablefish, were represented almost exclusively by juveniles. Others, such as walleye pollock, Pacific cod, and arrowtooth flounder, were primarily represented as juveniles, with some adults present. Flathead sole were more common as adults, but there were also juveniles present.

Table 4.--Invertebrates recorded during the 1980-82 shrimp surveys in the northwestern Gulf of Alaska.

Taxon	Common name	Year[a] 80	81	82
Phylum Porifera	Sponges	X	X	X
Phylum Cnidaria				
Class Scyphozoa	Jellyfish	X	X	X
Class Anthozoa				
Pennatulacea	Sea pens	X	X	X
Virgularia sp.	Smoothstem seawhip	X	-	-
Actiniaria	Sea anemones	X	X	X
Metridium sp.	*Metridium* sea anemone	X	X	-
Tealia sp.	*Tealia* sea anemone	-	X	-
Phylum Nemertea	Nemertean worms	X	X	-
Phylum Mollusca				
Class Amphineura	Chitons	X	-	-
Class Gastropoda				
Nudibranchia	Nudibranchs	X	X	-
Fusitriton oregonensis	Oregon triton	X	X	X
Neptunea lyrata	Common northwest neptune	X	X	X
N. sp.		X	X	X
Class Bivalvia				
Anomiidae	Rock jingles	X	X	-
Pododesmus macroschisma	False Pacific jingles	X	X	-
Clinocardium sp.	Cockles	X	X	-
Modiolus modiolus	Northern horse mussel	X	-	-
Mytilus sp.	Mussel	X	X	-
Yoldia sp.		X	X	X
Chlamys rubida	Hind's scallop	X	X	-
C. sp.	Scallop	X	X	-
Pecten caurinus	Weathervane scallop	X	X	-
Class Cephalopoda				
Octopoda	Octopus	X	X	-
Decapoda	Squid	X	X	X
Phylum Annelida				
Class Polychaeta	Polychaete worms	X	-	-
Aphroditidae	Sea mouse	X	-	-
Phylum Sipuncula	Sipunculid worms	X	X	-
Phylum Echiura	Echiuroid worms	X	X	-
Phylum Arthropoda				
Class Crustacea				
Balanus sp.	Barnacles	-	X	-
Amphipoda	Amphipods	X	X	-
Euphausiacea	Euphausiids	X	X	-
Argis sp.	*Argis* shrimp	X	X	-
Crangon sp.	*Crangon* shrimp	X	X	X
Eualus sp.	*Eualus* shrimp	X	X	-
Lebbeus groenlandicus	Candy stripe shrimp	X	X	-

Table 4.--Continued.

Taxon	Common name	Year[a] 80	81	82
Spirontocaris sp.	Shrimp	X	X	-
Pandalopsis dispar	Sidestripe shrimp	X	X	X
Pandalus borealis	Pink shrimp	X	X	X
P. danae	Dock shrimp	X	X	X
P. goniurus	Humpy shrimp	X	X	X
P. hypsinotus	Coonstripe shrimp	X	X	X
P. platyceros	Spot shrimp	X	X	X
P. tridens	Yellow-leg shrimp	X	X	-
Erimacrus isenbeckii	Korean horsehair crab	X	X	-
Hyas sp.	*Hyas* crab	X	X	-
Lopholithodes foraminatus	Box crab	-	X	-
Paguridae	Hermit crabs	X	X	X
Paralithodes camtschatica	Red king crab	X	X	X
P. platypus	Blue king crab	-	X	-
Pugettia sp.	Kelp crab	X	-	-
Cancer magister	Dungeness crab	X	X	X
C. oregonensis	Oregon *Cancer* crab	-	X	-
Chionoecetes bairdi	Snow (Tanner) crab	X	X	X
Oregonia gracilis	Decorator crab	X	X	X
Placetron wosnesenskii	Scaled crab	X	-	-
Telmessus sp.	*Telmessus* crab	X	-	-
Phylum Brachiopoda	Brachiopods	X	X	-
Phylum Echinodermata				
Class Ophiuroidea				
Gorgonocephalus eucnemis	Basket star	X	X	X
Class Asteroidea				
Asterias amurensis	Purple-orange sea star	X	X	-
Crossaster sp.		X	X	-
Ctenodiscus sp.	Mud star	X	-	-
Evasterias echinosoma		-	X	-
E. sp.		X	X	
Henricia sp.		-	X	-
Lethasterias nanimensis		X	-	-
Pisaster sp.		X	-	-
Pteraster sp.		X	X	-
Pycnopodia helianthoides	Sunflower star	X	X	-
Solaster endeca	Northern sun star	-	X	-
S. sp.		-	X	X
Class Echinoidea				
Clypeastroida	Sand dollars	X	X	-
Strongylocentrotus droebachiensis	Green sea urchin	X	X	X
Class Holothuroidea	Sea cucumbers	X	X	X
Phylum Chordata				
Class Ascidiacea				
Boltenia villosa		X	X	-

[a] An "X" indicates occurrence.

Species Distributions and Abundance

walleye Pollock--Walleye pollock was found in 715 (95%) of the 749 trawl samples collected in 1980-82. Length-frequency measurements were made at 700 of those stations, distributed as follows: 1980, 279/281; 1981, 289/297; and 1982, 132/137. Length intervals used to represent age groups were chosen after examination of the age-length keys (Tables A-l to A-3) and length-frequency distributions (Fig. 7). Due to variations in size with geographical area and year class, discussed later, slightly different intervals were chosen for this study than those used before (Smith et al. 1984). In order to be consistent over all areas and years, the intervals 5-13 cm and 14-28 cm were used to represent O-group walleye pollock and 1-yr-olds, respectively.

O-Group-Young-of-the-year walleye pollock were found at 31% of the stations in 1980 (Fig. 8); however, their distribution was not continuous across the range of the survey. Young of the year were moderately abundant around' Unalaska Island, but were not found near the lower end of the Alaska Peninsula or in the Sanak Islands area. Highest densities in 1980 were found in bays along the central Alaska Peninsula and on the eastern and southeastern sides of Kodiak Island.

In 1981, the distribution and abundance of O-group walleye pollock were greatly increased over 1980 (Fig. 9). Young of the year were found at 76% of the stations. Although only low abundances were observed at the lower end of the Alaska Peninsula, O-group fish were found at 83% of the stations from Pavlof Bay to the east. Abundances along the south-central and central Alaska Peninsula and around Kodiak Island were

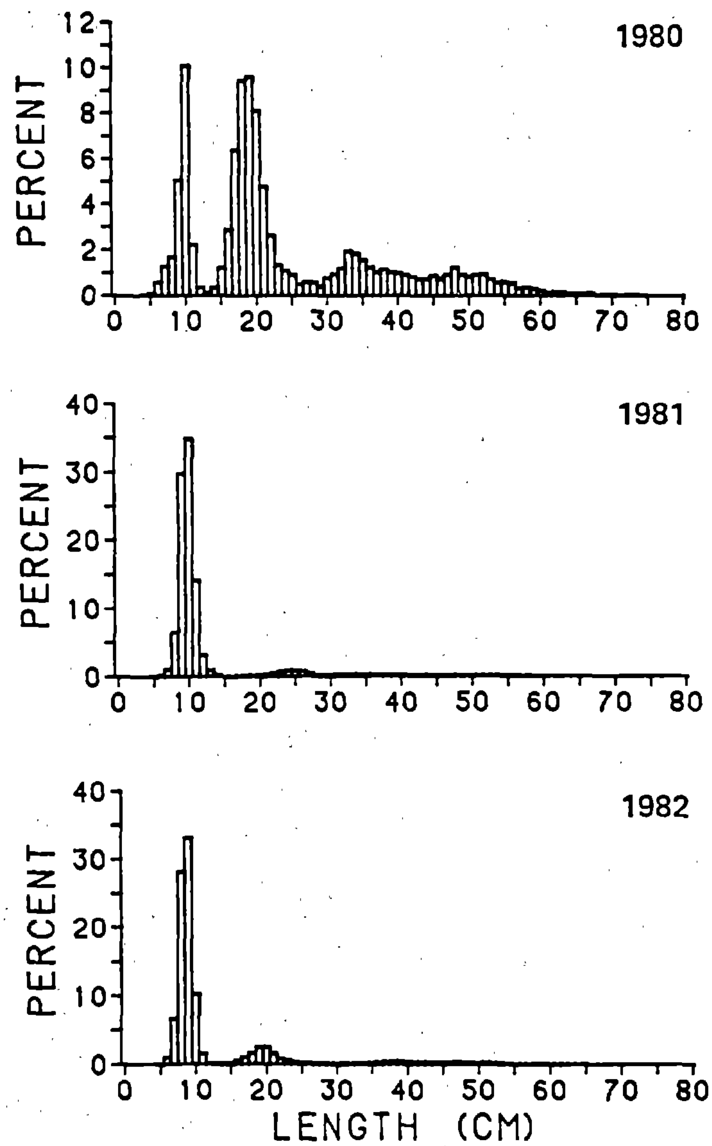

Figure 7.--Length-frequency distributions of walleye pollock taken in the 'northwestern Gulf of Alaska, 1980-82, based on the complete survey coverage. The data shown are simple sums, unweighted by catch sizes or sampling areas.

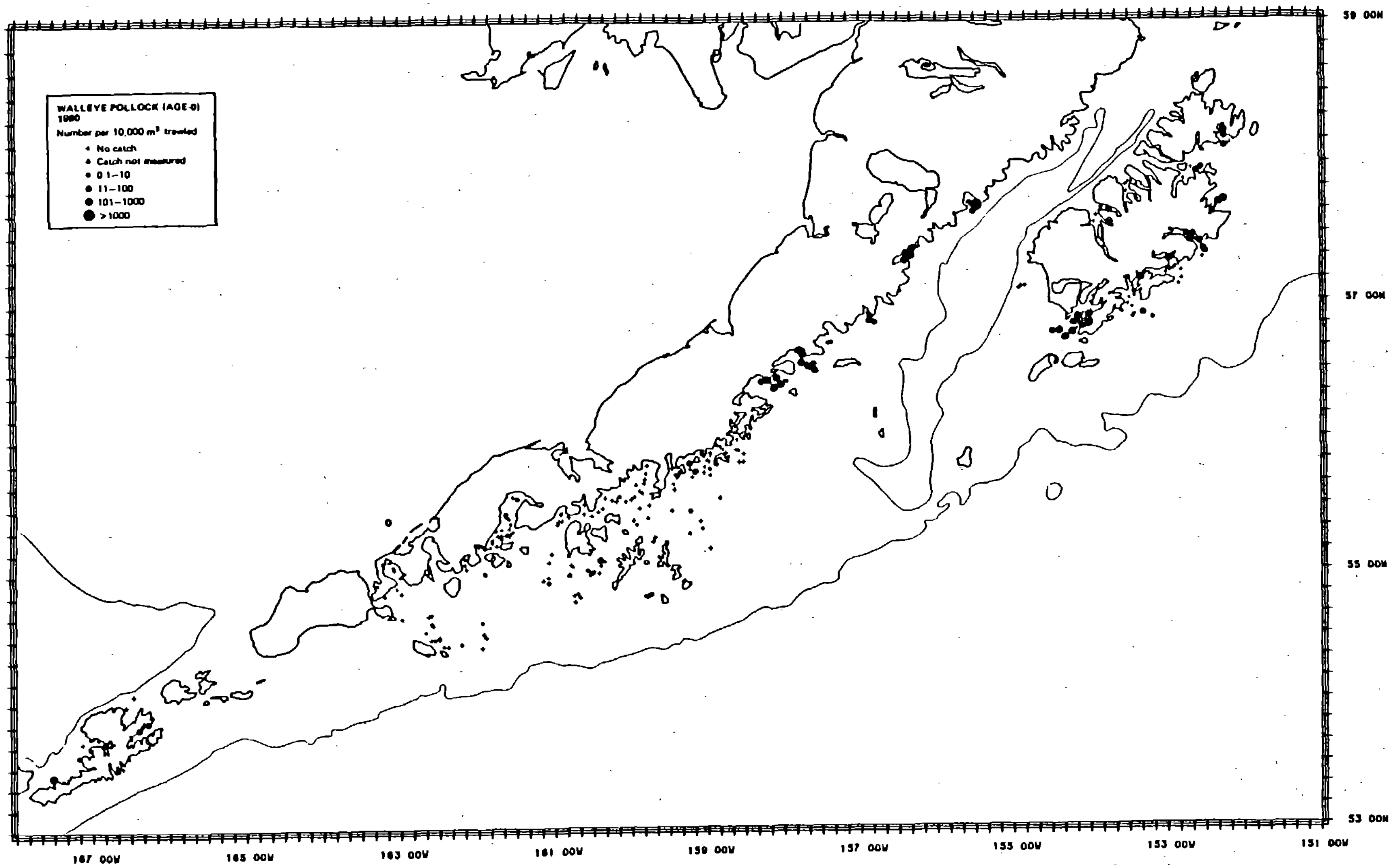

Figure 8.--Distribution and relative abundance of O-group walleye pollock in the northwestern Gulf of Alaska in 1980, based on the complete survey coverage.

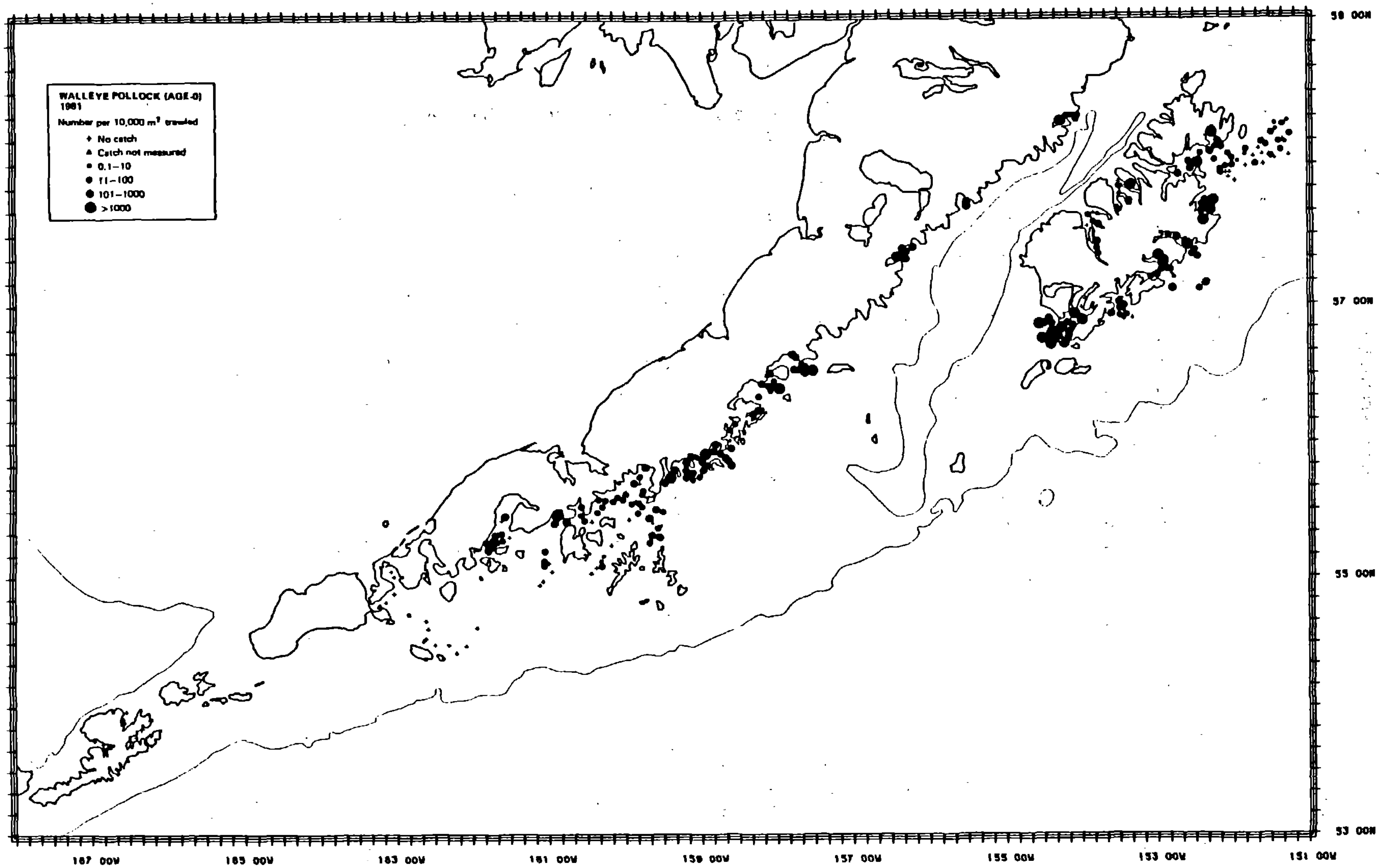

Figure 9.--Distribution and relative abundance of O-group walleye pollock in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

relatively high. The mean abundance around Kodiak Island exceeded 1,300 fish per 10,000 m^2 trawled.

The distribution of O-group walleye pollock in 1982 was similar to the previous years for the same general area (Fig. 10). within this area, they were found at 61% of the stations compared to 54% and 85% in 1980 and 1981, respectively. Abundances were similar to the values observed in 1980.

Young-of-the-year walleye pollock were found throughout most of the depth range sampled in every year (Fig. 11). However, highest densities were found at depths less than 140 m.

Age-l --One-yr-old walleye pollock were found at 68% of the stations in 1980 (Fig. 12). Unlike the O-group fish, the distribution was relatively continuous throughout the survey. Highest densities were found in Pavlof Bay and along the central Alaska Peninsula, while lowest densities occurred on the eastern side. of Kodiak Island where the abundance of O-group fish was very high in 1980.

The distribution of 1-yr-olds in 1981 was similar to 1980 (Fig. 13). They were found at 70% of the stations. In the study area as a whole, densities were generally lower in 1981; however, values on the east side of Kodiak Island were greater than in 1980.

In 1982, 1-yr-old walleye pollock were found at 61% of the stations (Fig. 14). The distribution was similar to the previous years for the same general area. Relative densities observed in 1982 were intermediate between those of 1980 and 1981, except in Alitak Bay where densities were much higher..

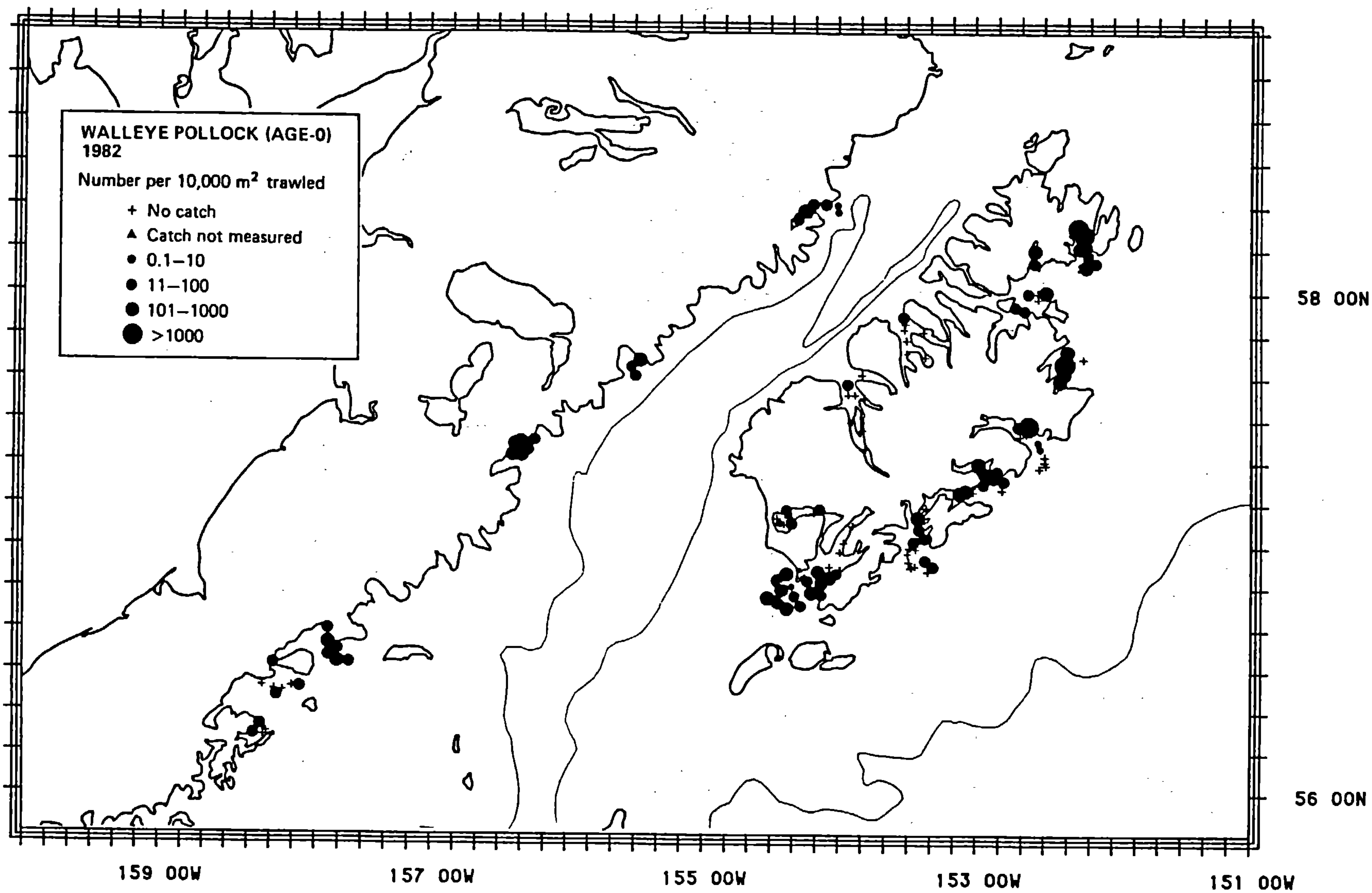

Figure 10.--Distribution and relative abundance of 0-group walley pollock in the northwestern Gulf of Alaska in 1982, based on the complete survey coverage.

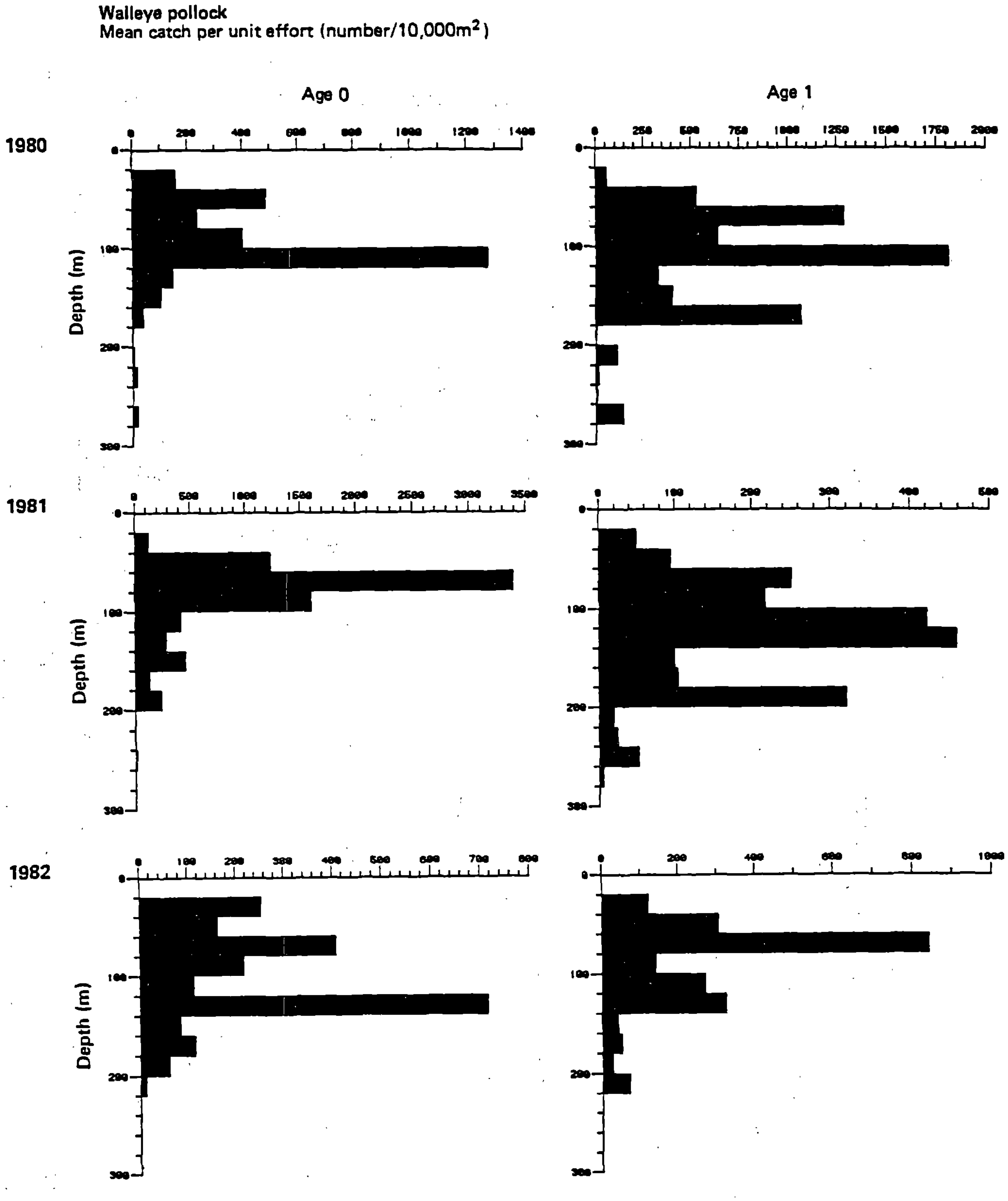

Figure 11. --Variations of walleye pollock densities with sampling depth, ages 0-1 yr, based on the complete coverage of surveys in the northwestern Gulf of Alaska, during 1980-82.

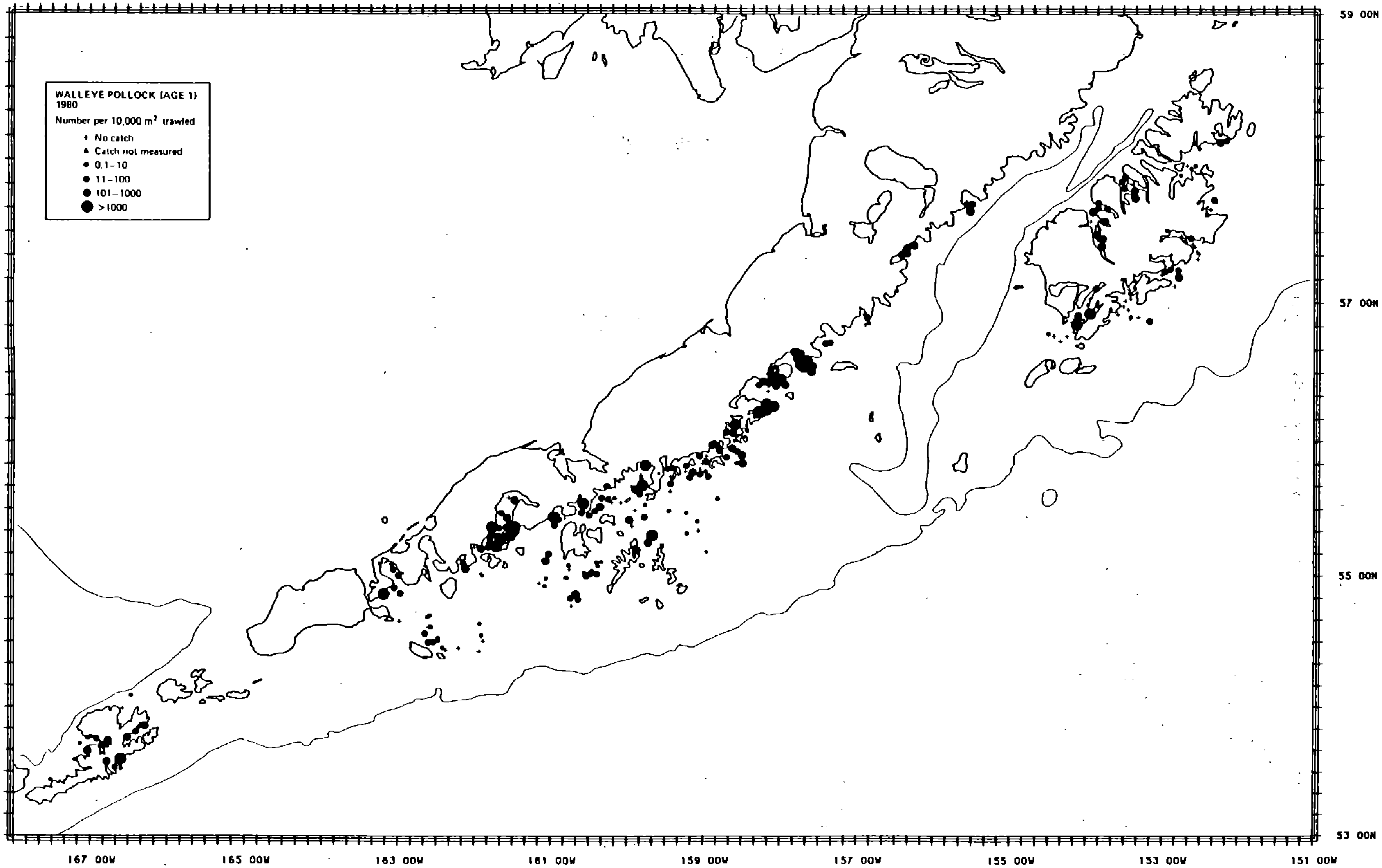

Figure 12. --Distribution and relative abundance of 1-yr-old walleye pollock in the northwestern Gulf of Alaska in 1980, based on the complete survey coverage.

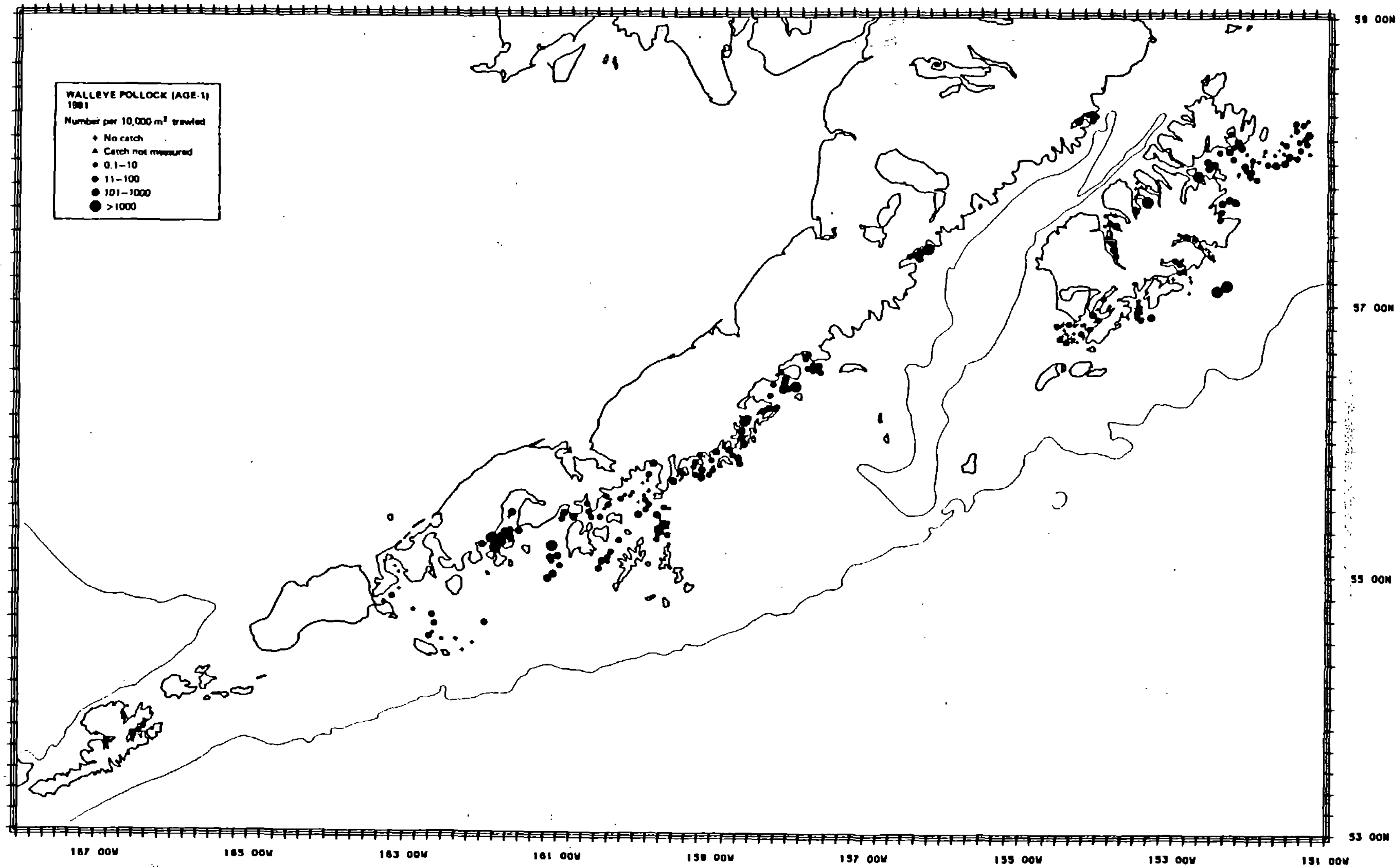

Figure 13.--Distribution and relative abundance of 1-yr-old walleye pollock in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

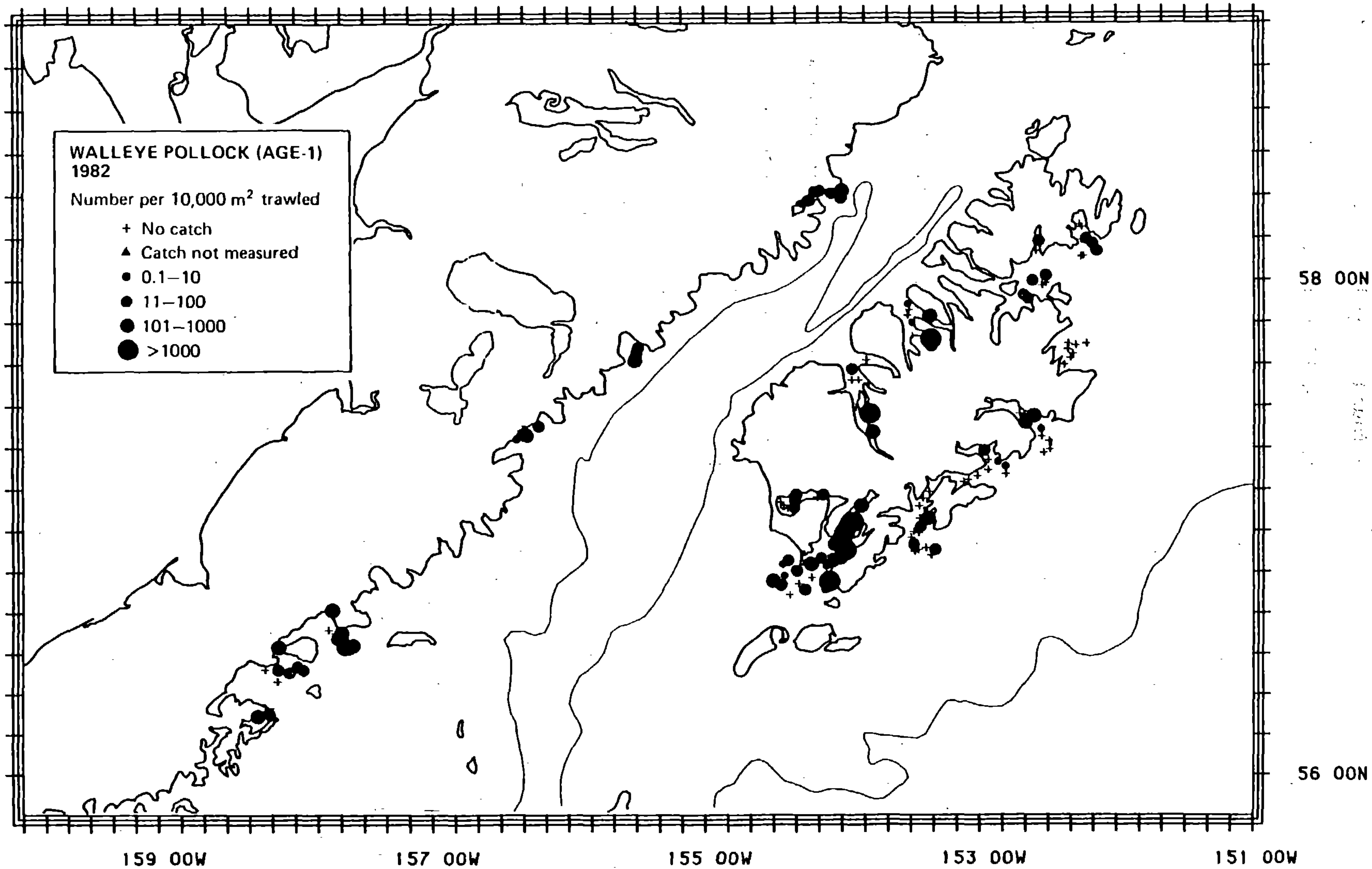

Figure 14.--Distribution and relative abundance of 1-yr-old walleye pollock in the northwestern Gulf of Alaska in 1982, based on the complete survey coverage.

One-yr-old walleye pollock were found throughout most of the depth range sampled in every year (Fig. 11). In 1980 and 1981, highest densities were found in samples from 40 to 200 m, extending somewhat deeper than the young of the year. In 1982, the depth distributions of O-group and 1-yr-old fish were similar.

Pacific Cod

Pacific cod was found in 495 (66%) of the 749 trawl samples. Length-frequency measurements were taken at 478 of those stations, distributed as follows: 1980, 205/210; 1981; 200/207; 1982, 73/78. The size intervals used to represent age groups were chosen after examination of the length-frequency distributions (Fig. 15). Age-length keys were not available for Pacific cod. The intervals chosen were 5-15 cm and 16-30 cm for D-group fish and 1-yr-olds, respectively.

O-Group-Young-of-the-year Pacific cod were found at only seven stations in three areas in 1980 (Fig. 16). They were taken near Unalaska Island, in Pavlof Bay, and in Wide Bay. All of these stations, except one, were located in waters less than 60 m depth (Fig. 17).

In 1981, O-group Pacific cod were found at 11% of the stations, ranging from the lower-Alaska Peninsula to Chiniak Bay on the east side of Kodiak Island (Fig. 18). They were particularly abundant in Alitak Bay. Depths of occurrences in trawl samples ranged from 20 to 120 m.

The distribution of O-group Pacific cod in 1982 was similar to the pattern observed in 1981 for the comparable areas (Fig. 19). However,, in 1982 they were not found in any of the bays on the east side of Kodiak

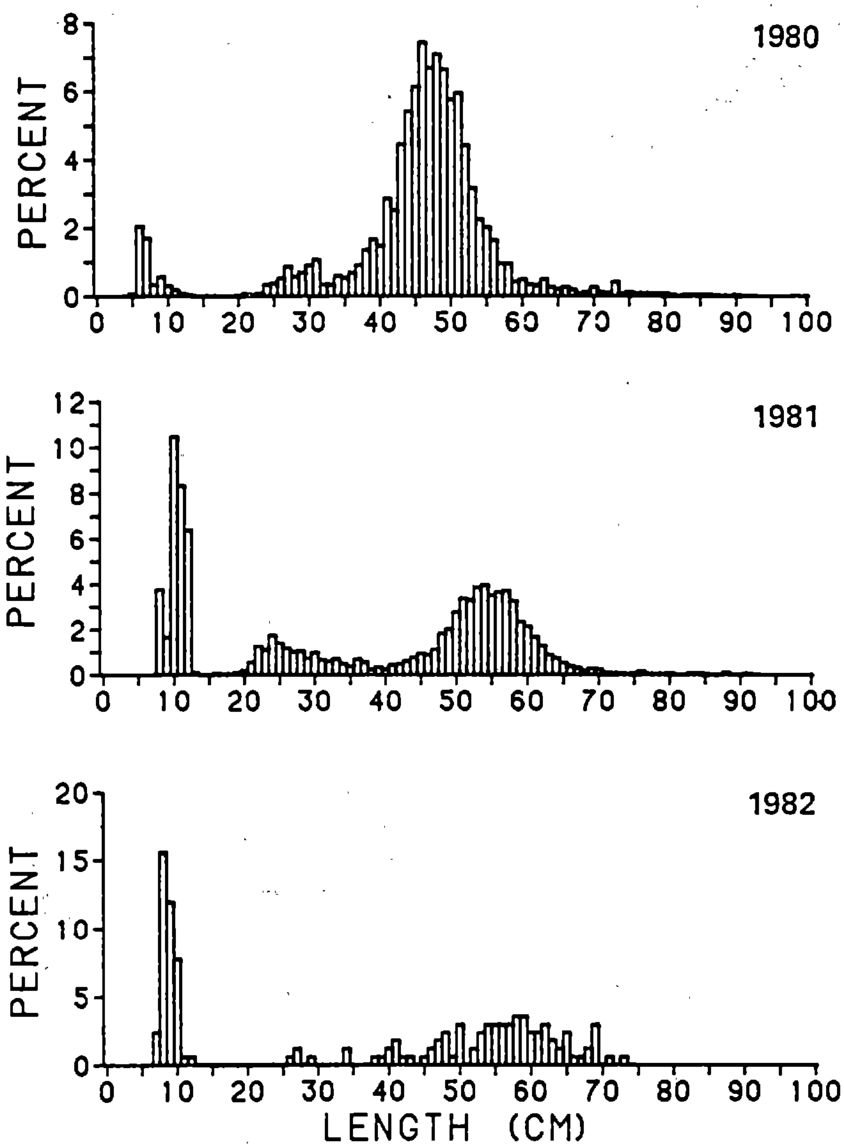

Figure 15. --Length-frequency distributions of Pacific cod taken in the northwestern Gulf of Alaska, 1980-82, based on the complete survey coverage. The data shown are simple sums, unweighted by catch sizes or sampling areas.

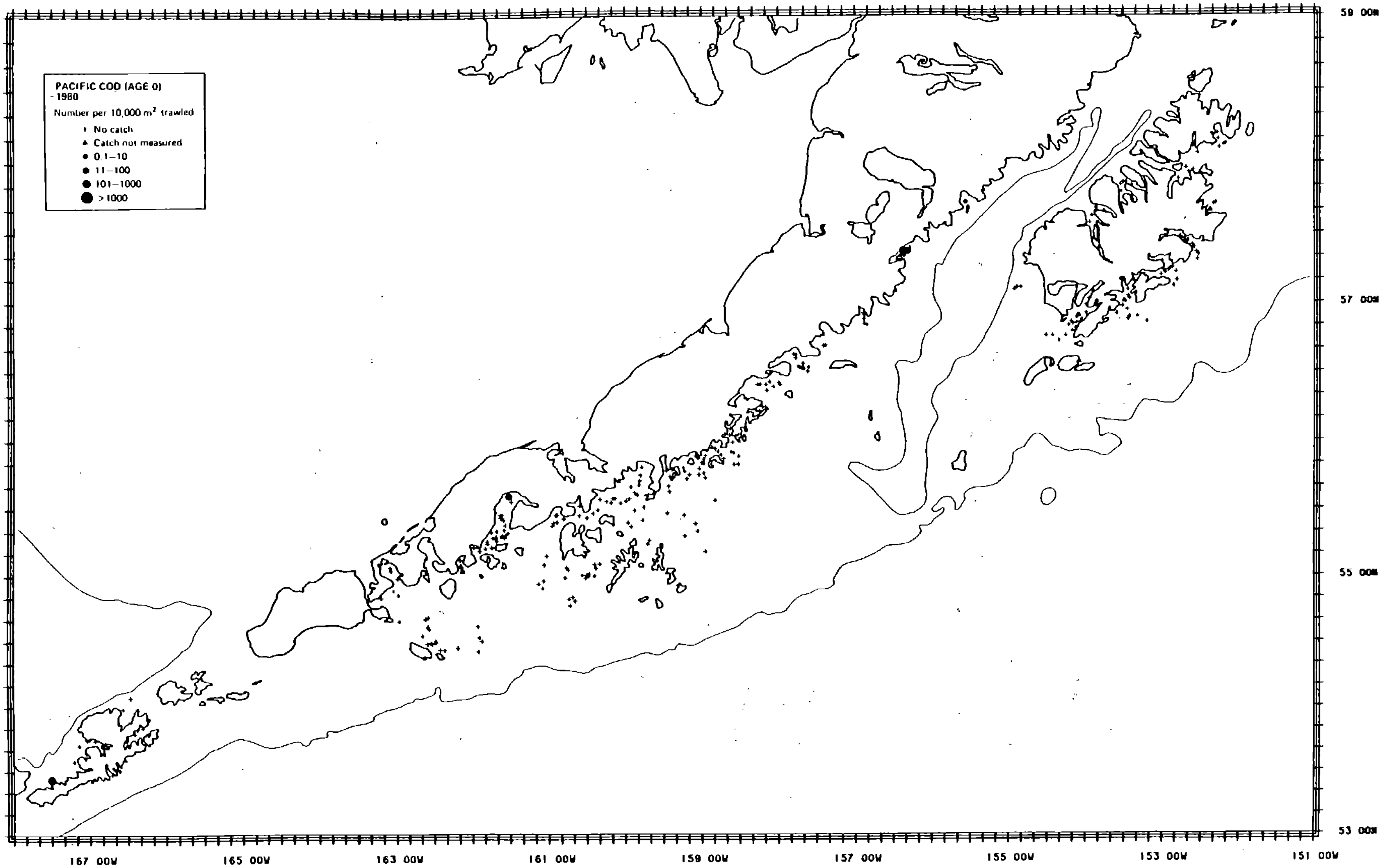

Figure 16.--Distribution and relative abundance of O-group Pacific cod in the northwestern Gulf of Alaska in 1980, based on the complete survey coverage.

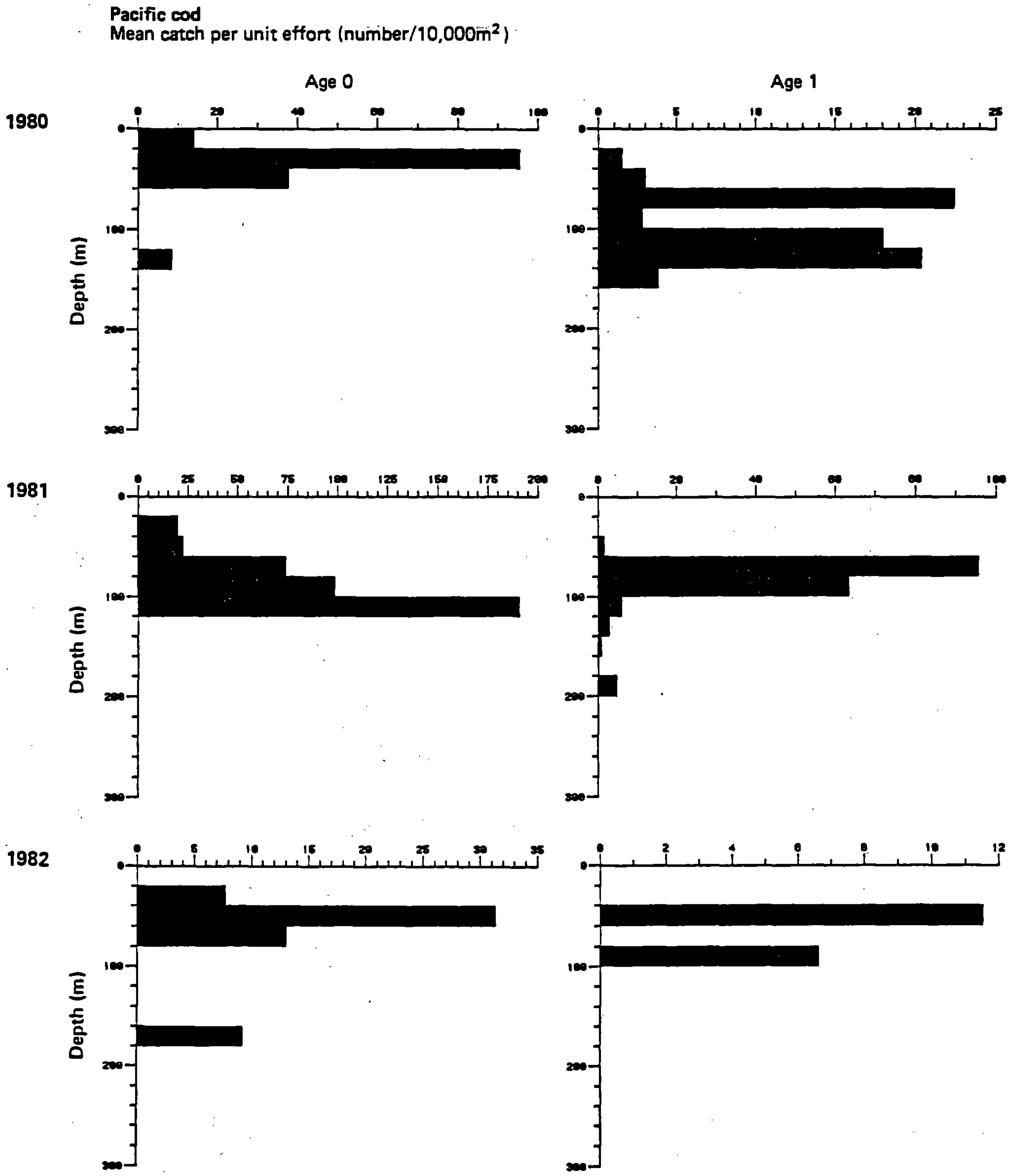

Figure 17.--Variations of Pacific cod densities with sampling depth, ages 0-1 yr, based on the complete coverage of surveys in the northwestern Gulf of Alaska during 1980-82.

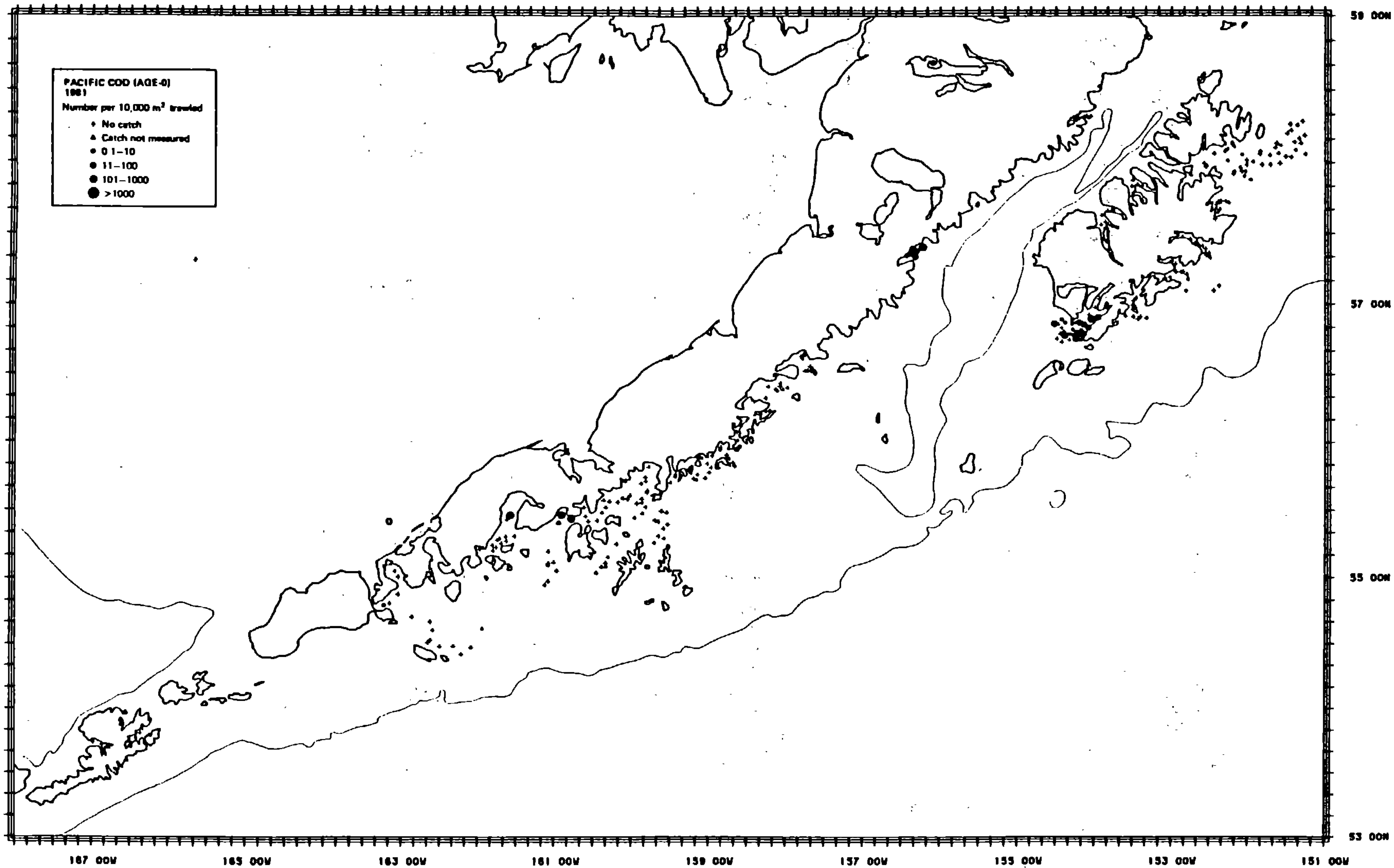

Figure 18.--Distribution and relative abundance of O-group Pacific cod in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

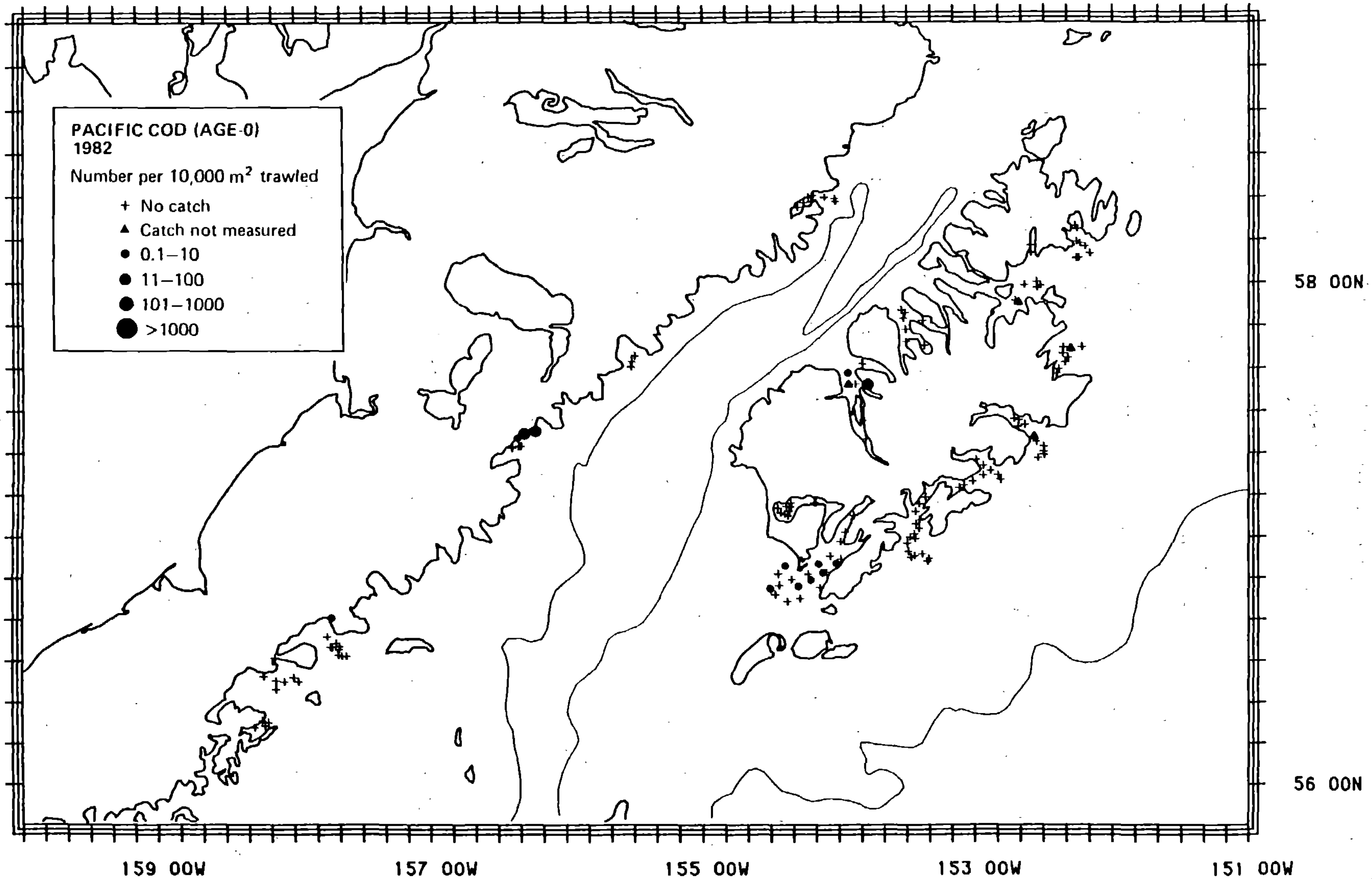

Figure lg.--Distribution and relative abundance of O-group Pacific cod in the northwestern Gulf of Alaska in 1982, based on the complete survey coverage.

Island and densities were generally lower than in 1981. The depth distribution of O-group fish was similar to previous years with most catches in shallow waters (Fig. 17).

Age-l --In 1980 and 1981, relatively low numbers of 1-yr-old Pacific cod were taken at several locations near Unalaska Island and along the Alaska Peninsula (Figs. 20, 21). They were also found in two bays on the Alaska Peninsula in 1982 (Fig. 22). Low concentrations were found on the west side of Kodiak Island in 1980 and 1981, and on the east side of Kodiak Island in 1981. One-yr-olds were not present in catches from the Kodiak Island area in 1982. The depth distributions of 1-yr-old Pacific cod were somewhat deeper than those of the O-group fish in 1980 and 1981 (Fig. 17).

Sablefish

Sablefish were present at 183 (26%) of the 694 stations used for analyses. Length-frequency measurements were made at 172 of those stations, distributed as follows: 1980, 91/93; 1981, 50/56; 1982, 31/34. Size intervals used to represent age groups were chosen based on an age-length key (Smith et al. 1984:table 7) and the length-frequency distributions (Fig. 23). The intervals selected were 18-26 cm and 27-42 cm for O-group fish and 1-yr-olds, respectively.

O-Group-- Young-of-the-year sablefish were found only in 1981, in two bays on the Alaska Peninsula and two bays of Kodiak Island (Fig. 24). Most O-group fish were taken at depths less than 80 m (Fig. 25).

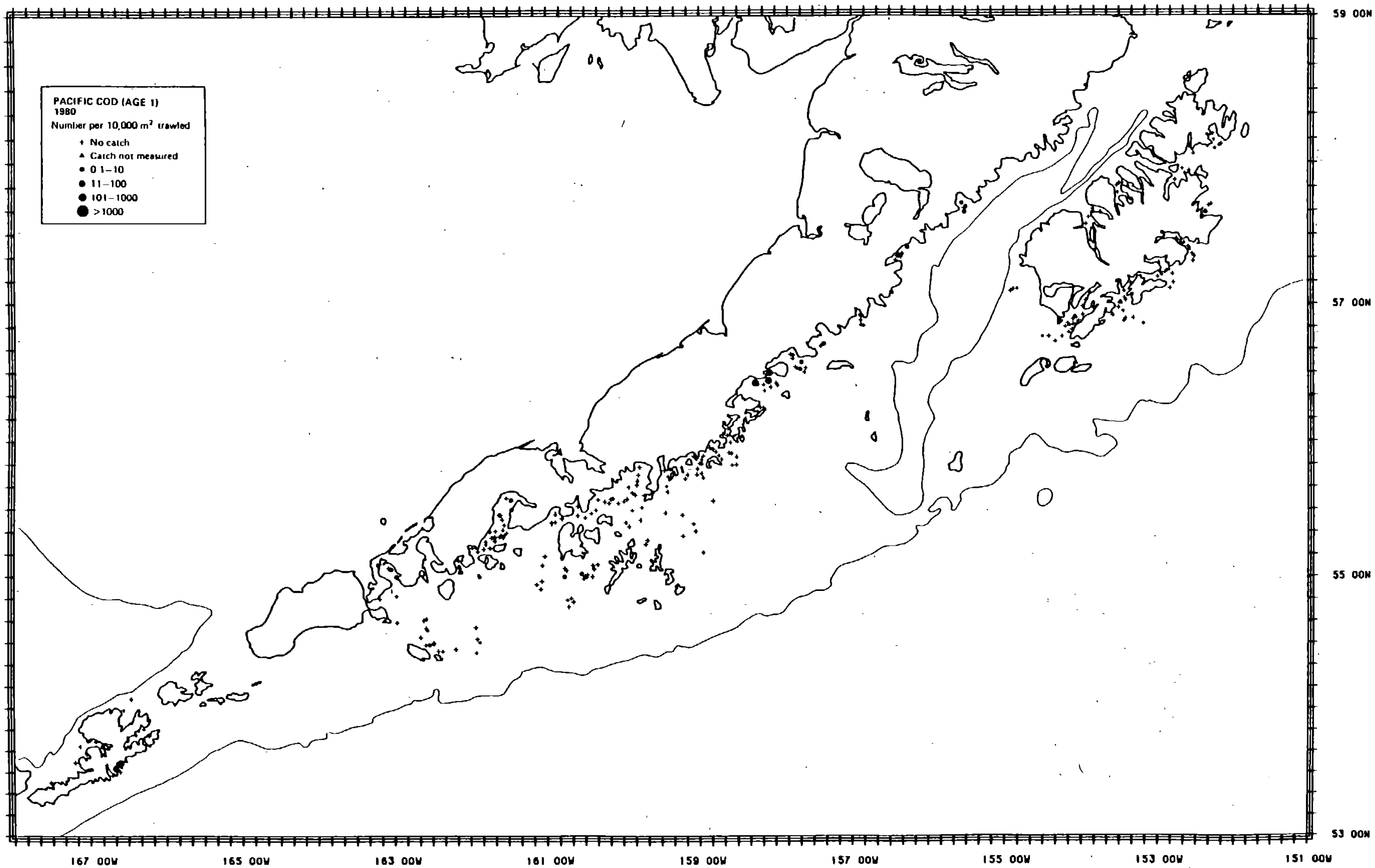

Figure 20.--Distribution and relative abundance of 1-yr-old Pacific cod in the northwestern Gulf of Alaska in 1980, based on the complete survey coverage.

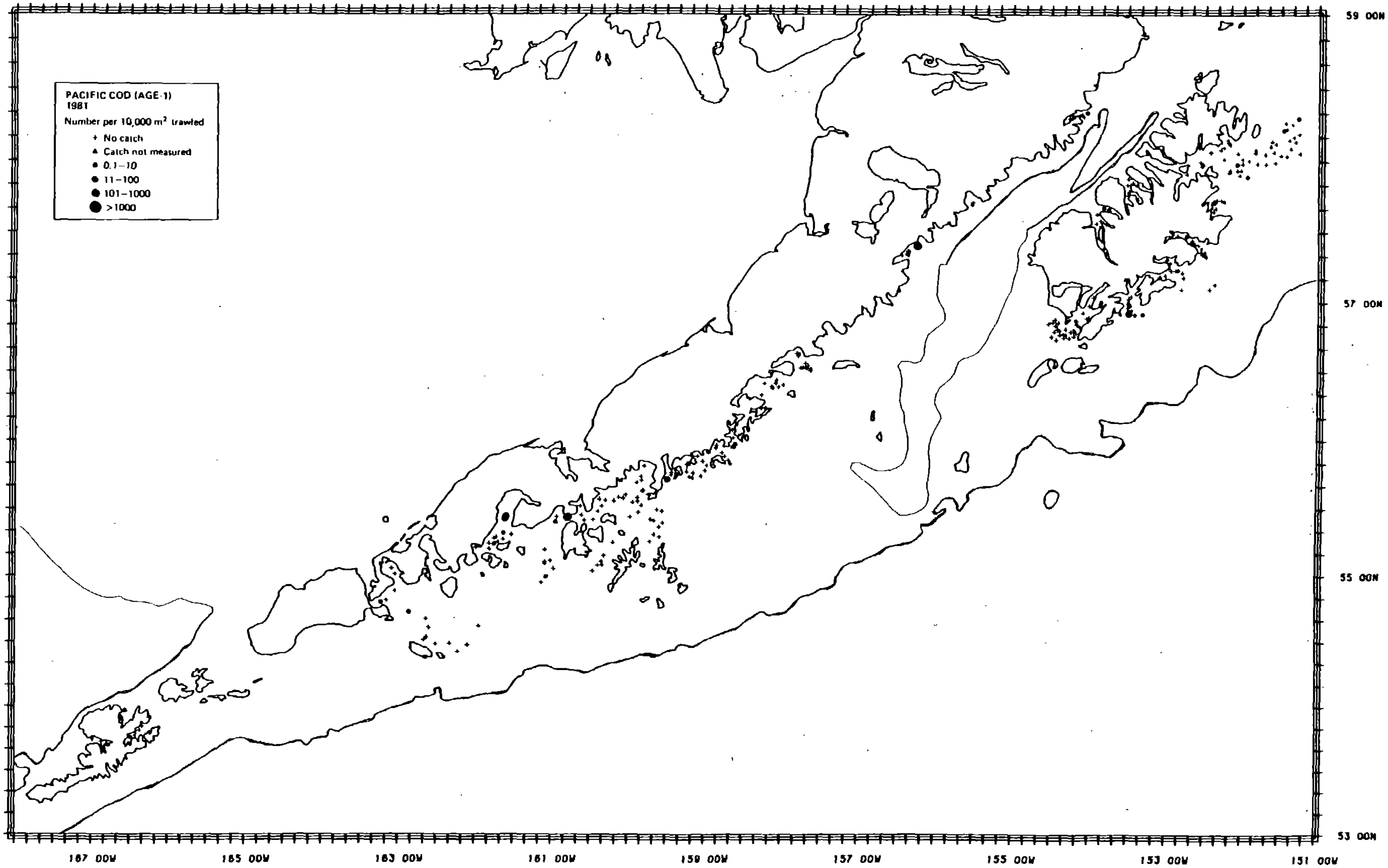

Figure 21.--Distribution and relative abundance of 1-yr-old Pacific cod in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

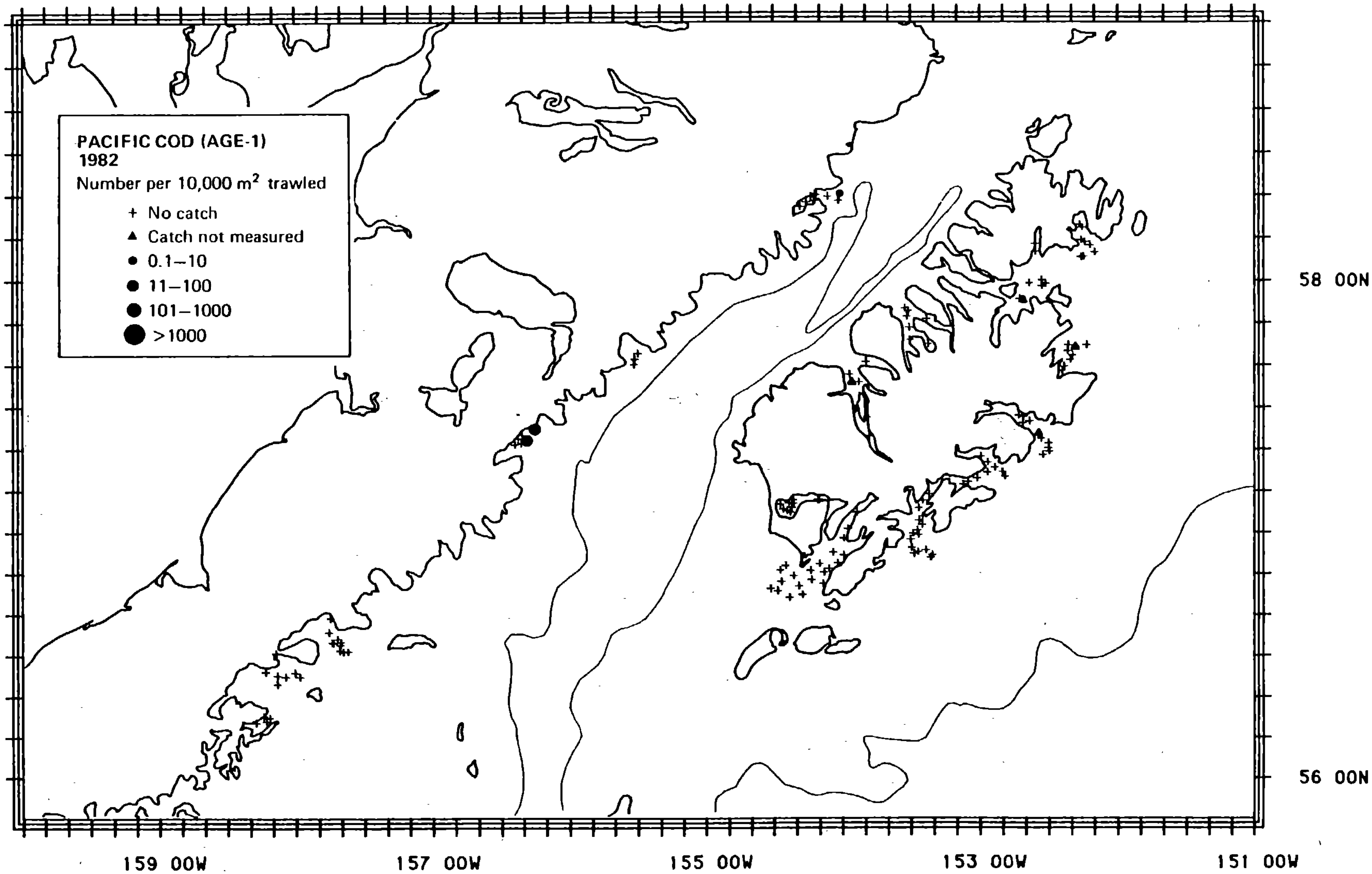

Figure 22.--Distribution and relative abundance of 1-yr-old Pacific cod in the northwestern Gulf of Alaska in 1982, based on the complete survey coverage.

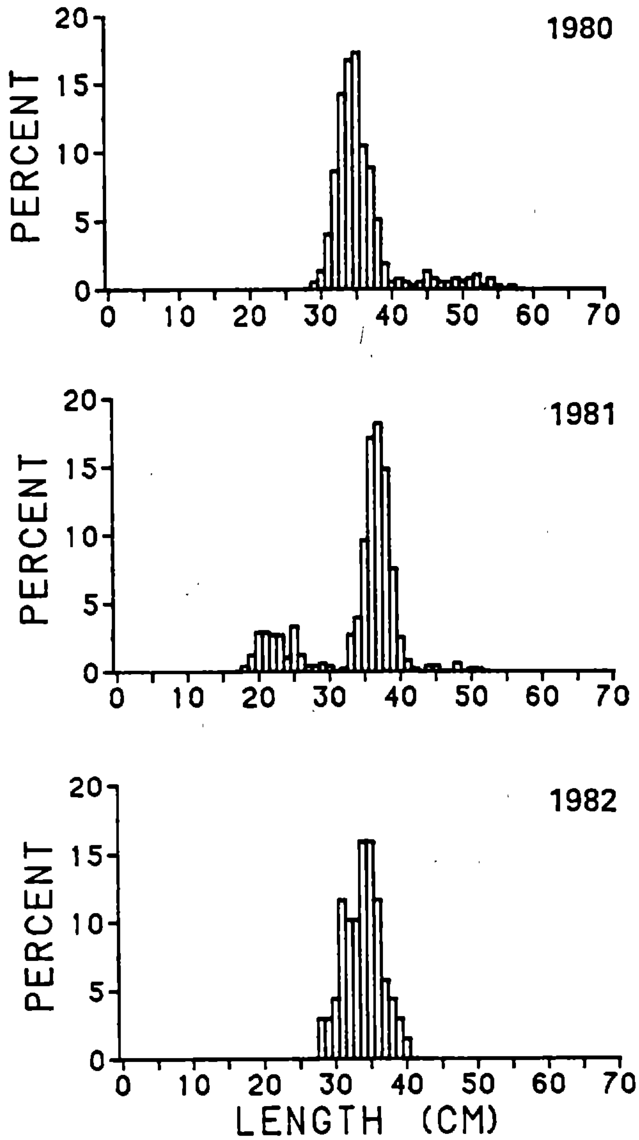

Figure 23.--Length-frequency distributions of sablefish taken in the northwestern Gulf of Alaska, 1980-82, based on the complete survey coverage. The data shown are simple sums, unweighted by catch sizes or sampling areas.

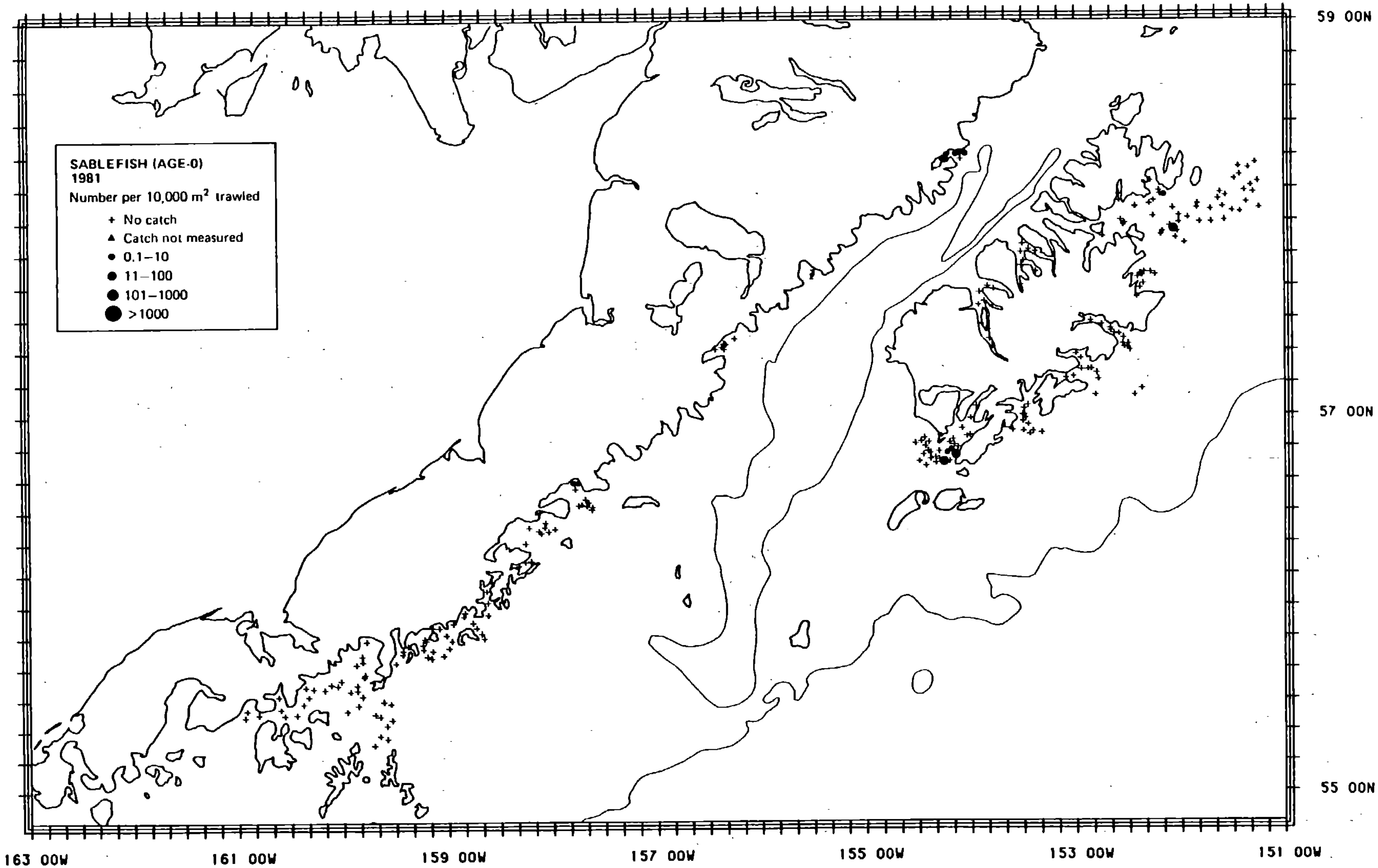

Figure 24.--Distribution and relative abundance of O-group sablefish in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

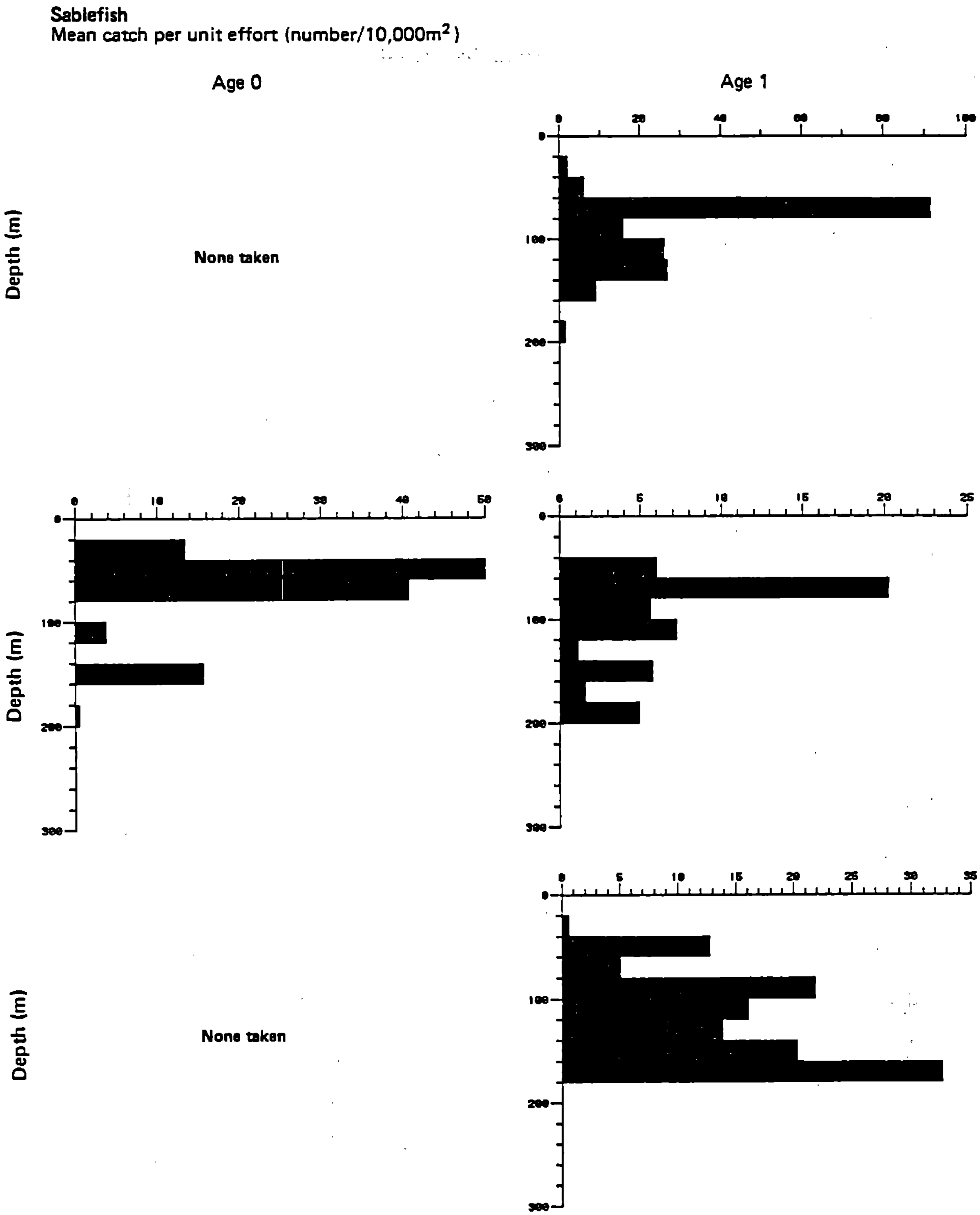

Figure 25. --Variations of sablefish densities with sampling depth, ages 0-1 yr, based on the complete coverage of surveys in the northwestern Gulf of Alaska during 1980-82.

Age-1 --One-yr-old sablefish were distributed over a relatively wide geographic area in 1980 and occurred in over 25% of the catches (Fig. 26). They were particularly abundant along the 'central Alaska Peninsula. In 1981, 1-yr-old sablefish were also relatively widespread (Fig. 27), but less abundant than in 1980. The abundance of 1-yr-olds in 1982 was higher on the east side of Kodiak Island (Fig. 28), but none were found in bays on the west side. Their distribution and abundance along the Alaska Peninsula were similar to 1981.

The depth distribution of 1-yr-old sablefish was somewhat wider than O-group fish, extending primarily from 40 to 180 m (Fig. 25).

Arrowtooth Flounder

Arrowtooth flounder were common in the survey catches, occurring in 493 (71%) of the 694 trawl tows used for analyses. Due to time constraints, length-frequency measurements were made at only 379 (77%) of those stations, distributed as follows: 1980, 132/203; 1981, 175/213; 1982, 72/77. The size intervals used to represent age groups were chosen after examination of an age-length key built from data collected in 1981 (Table A-4), and the length-frequency distributions (Fig. 29). The intervals selected were 10-20 cm and 21-30 cm for ages 1 and 2, respectively> Few, if any, young-of-the-year arrowtooth flounder were taken in the surveys.

Age-l --One-yr-old arrow-tooth flounder were found throughout all areas surveyed in 1980, and were represented in over half the catches where length measurements were taken (Fig. 30). Densities appeared to increase towards the east, and were highest around Kodiak and Afognak Islands.

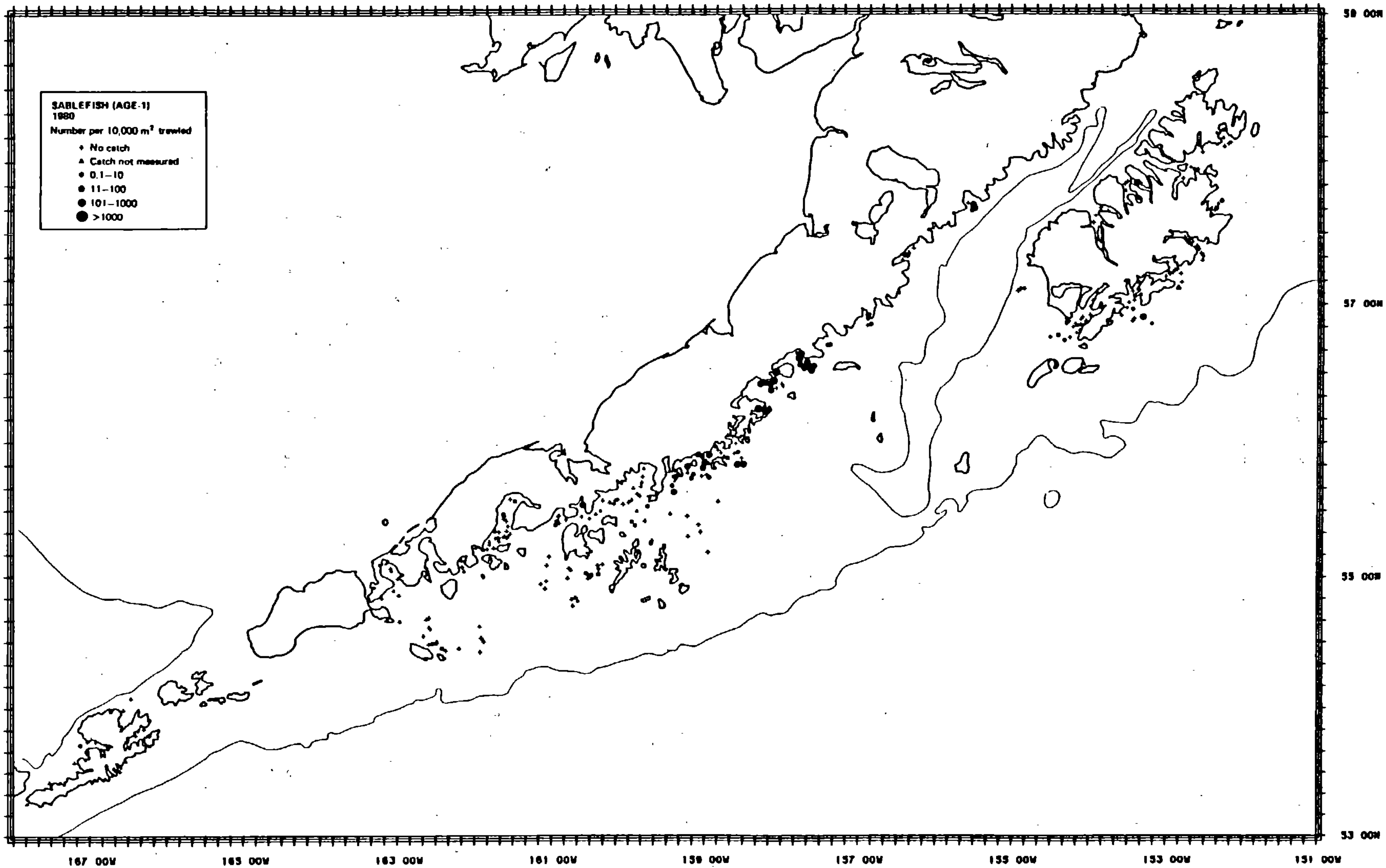

Figure 26. --Distribution and relative abundance of 1-yr-old sablefish in the northwestern Gulf of Alaska in 1980, based on the complete survey coverage.

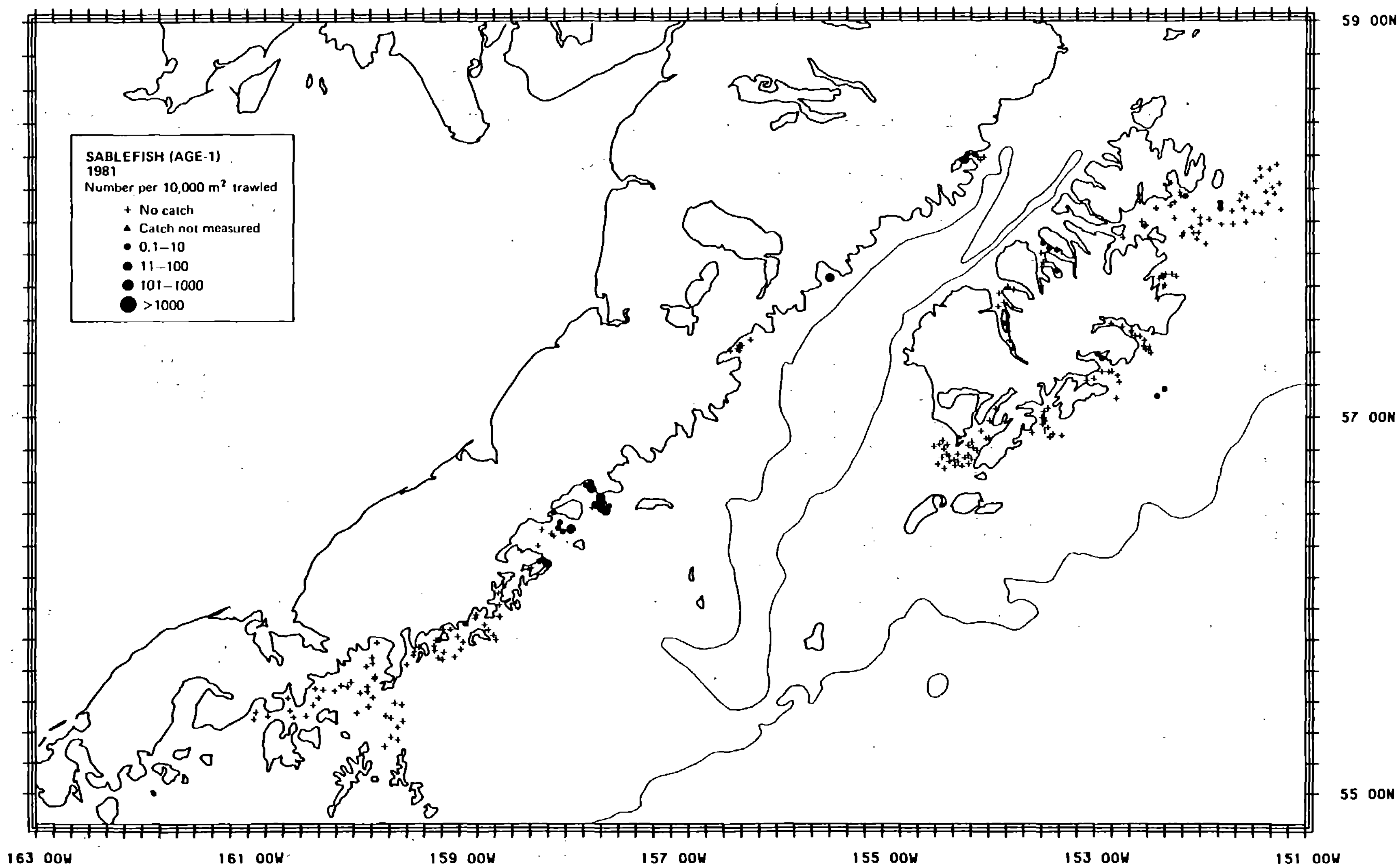

Figure 27.--Distribution and relative abundance of 1-yr-old sablefish in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

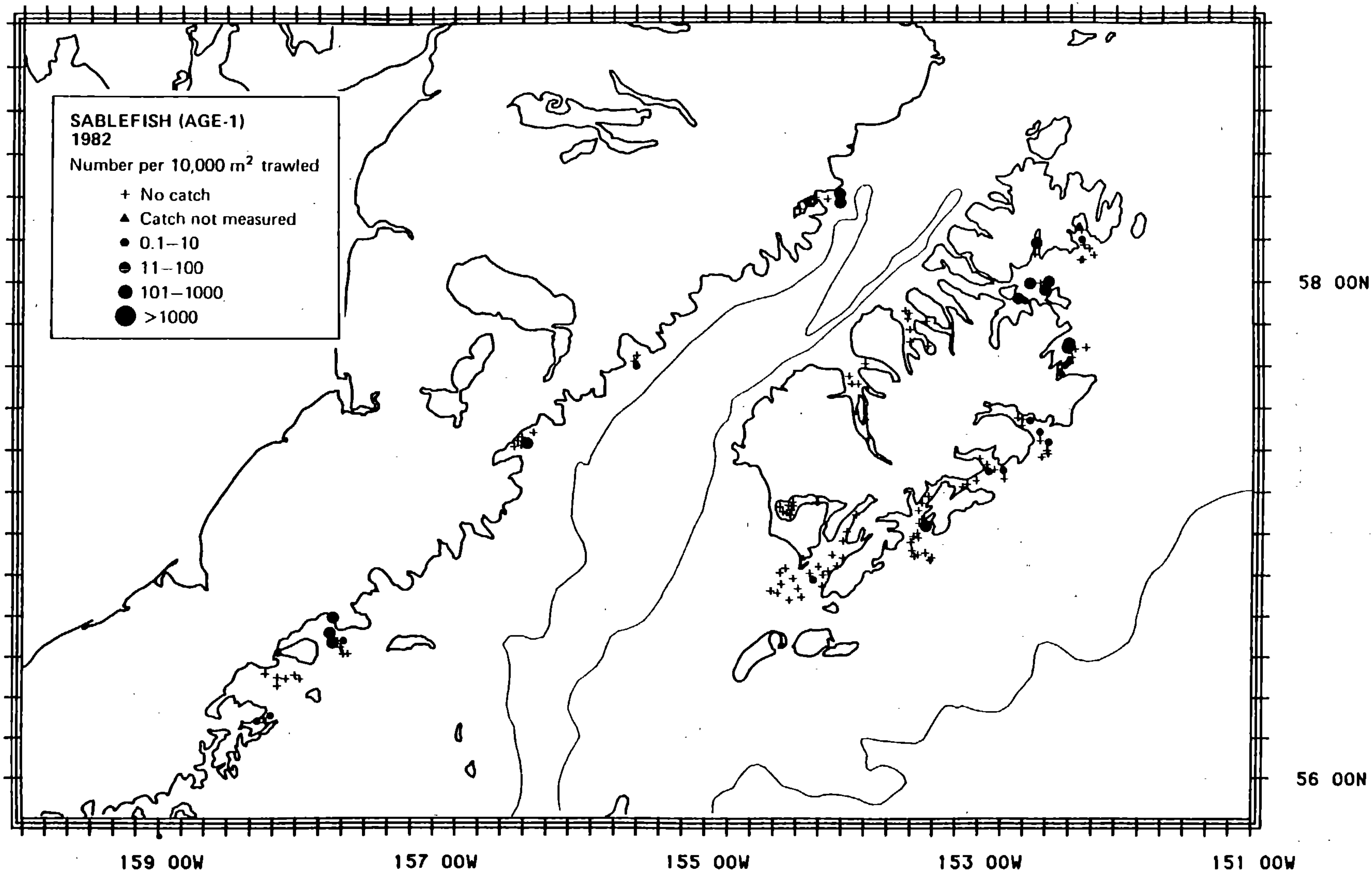

Figure 28.--Distribution and relative abundance of 1-yr-old sablefish in the northwestern Gulf of Alaska in 1982, based on the complete survey coverage.

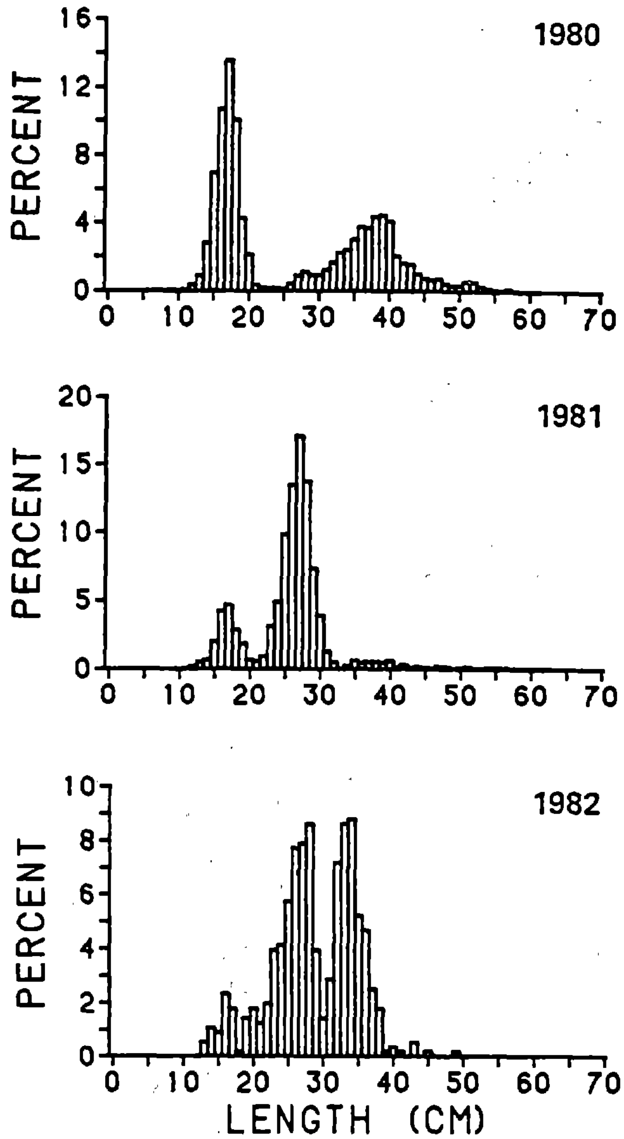

Figure 29. --Length-frequency distributions of arrow-tooth flounder taken in the northwestern Gulf of Alaska, 1980-82, based on the complete survey coverage. The data shown are simple sums, unweighted by catch sizes or sampling areas.

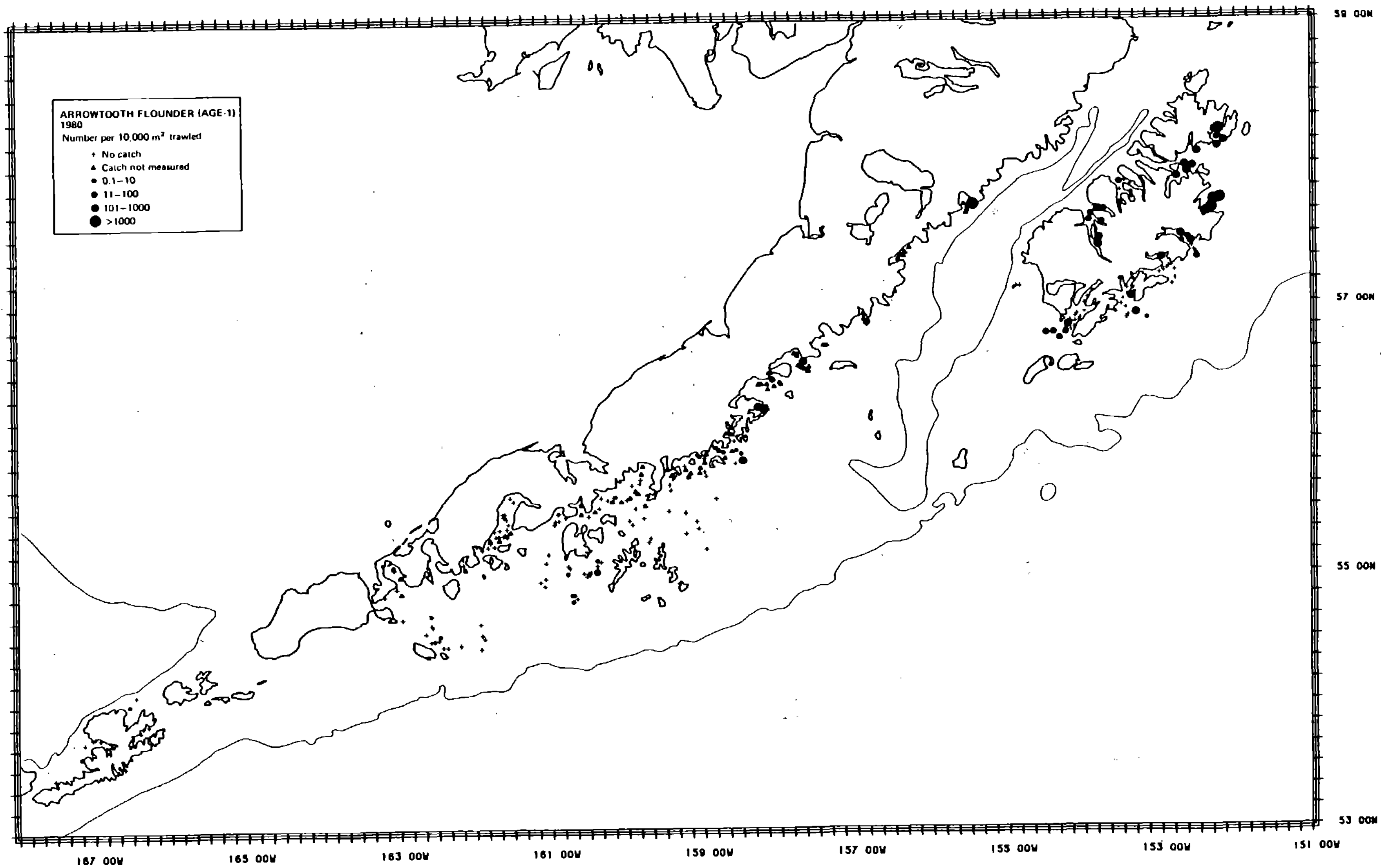

Figure 30.--Distribution and relative abundance of 1-yr-old arrowtooth flounder in the northwestern Gulf of Alaska in 1980, based on the complete survey coverage.

The distribution in 1981 was similar;-but densities were generally lower (Fig. 31"). Inner and outer areas of Marmot Bay were regions of relatively high abundance.

Densities also appeared to be lower in 1982 for the areas surveyed, but the general distribution pattern of 1-yr-olds was similar to the previous years (Fig. 32). The depth distributions of 1-yr-old arrowtooth flounder indicated a wide range of habitat,. from 20 to 200 m (Fig. 33). The apparent vertical distribution pattern was similar to the overall pattern of sampling depths (Fig. 2).

Age-2--Two-yr-old arrowtooth flounder were even more common than 1-yr-olds. In 1981 and 1982, they appeared in approximately twice as many samples as the younger fish. In general, 2-yr-old arrowtooth flounder occurred throughout the study area in all years (Figs. 34-36), but their densities tended to be distributed differently than 1-yr-olds. Two-yr-olds were more common in nearshore continental shelf areas and near the mouths of bays. By comparison, 1-yr-olds were most common in inside waters. The depth distributions of 2-yr-olds, particularly in 1981 and 1982, showed a tendency toward deeper water (Fig. 33).

Abundances of 2-yr-old arrowtooth flounder were highest in 1981, perhaps reflecting the high abundance of 1-yr-old fish observed in 1980. Densities in 1982 were intermediate to those of 1980 and 1981.

Flathead Sole

Flathead sole were as common in the survey samples as walleye pollock, occurring in 659 (95%) of the 694 trawl samples used in the analyses. Length-frequency measurements were taken at 513 (74%) of the 694 trawl

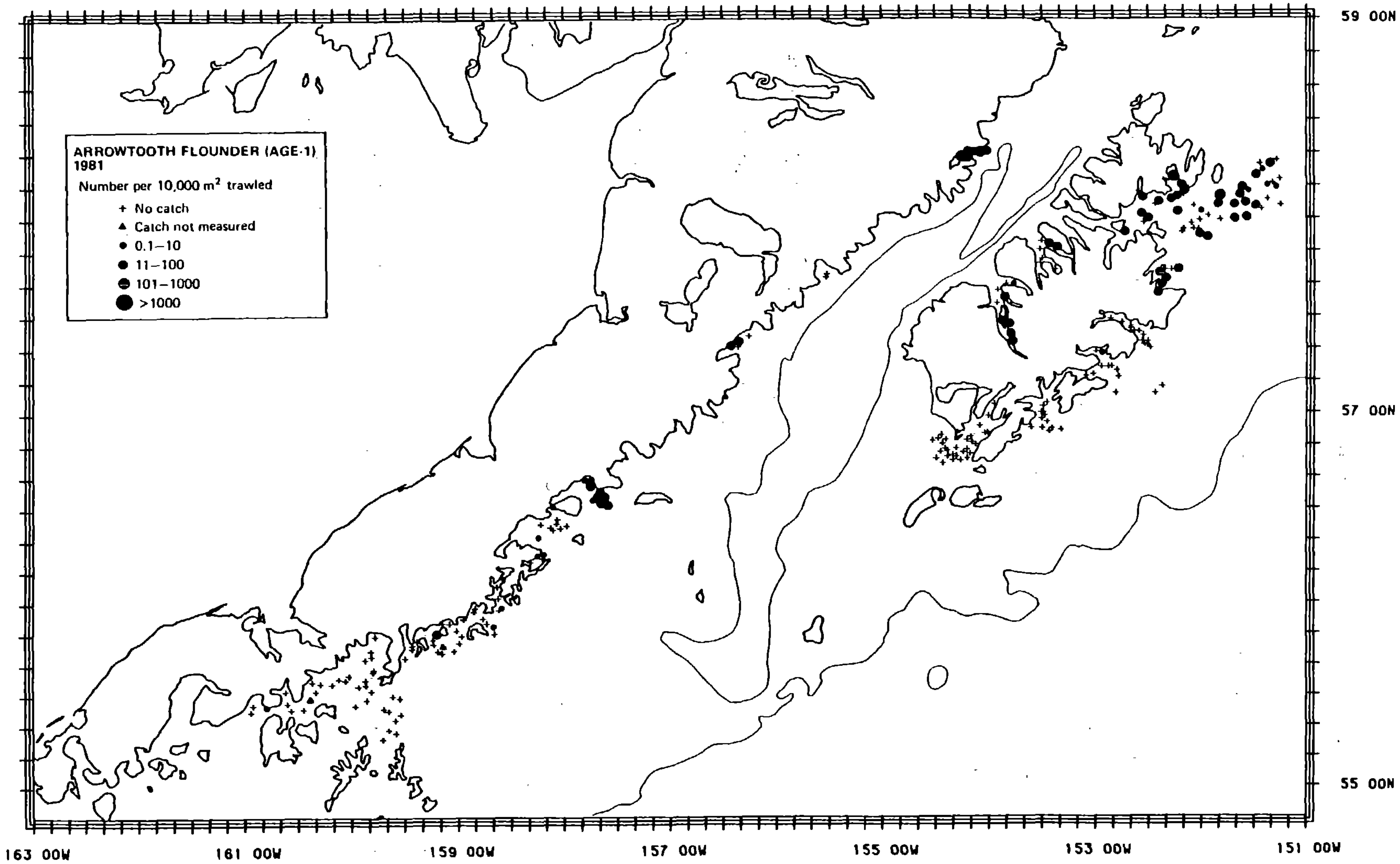

Figure 31.--Distribution and relative abundance of 1-yr-old arrowtooth flounder in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

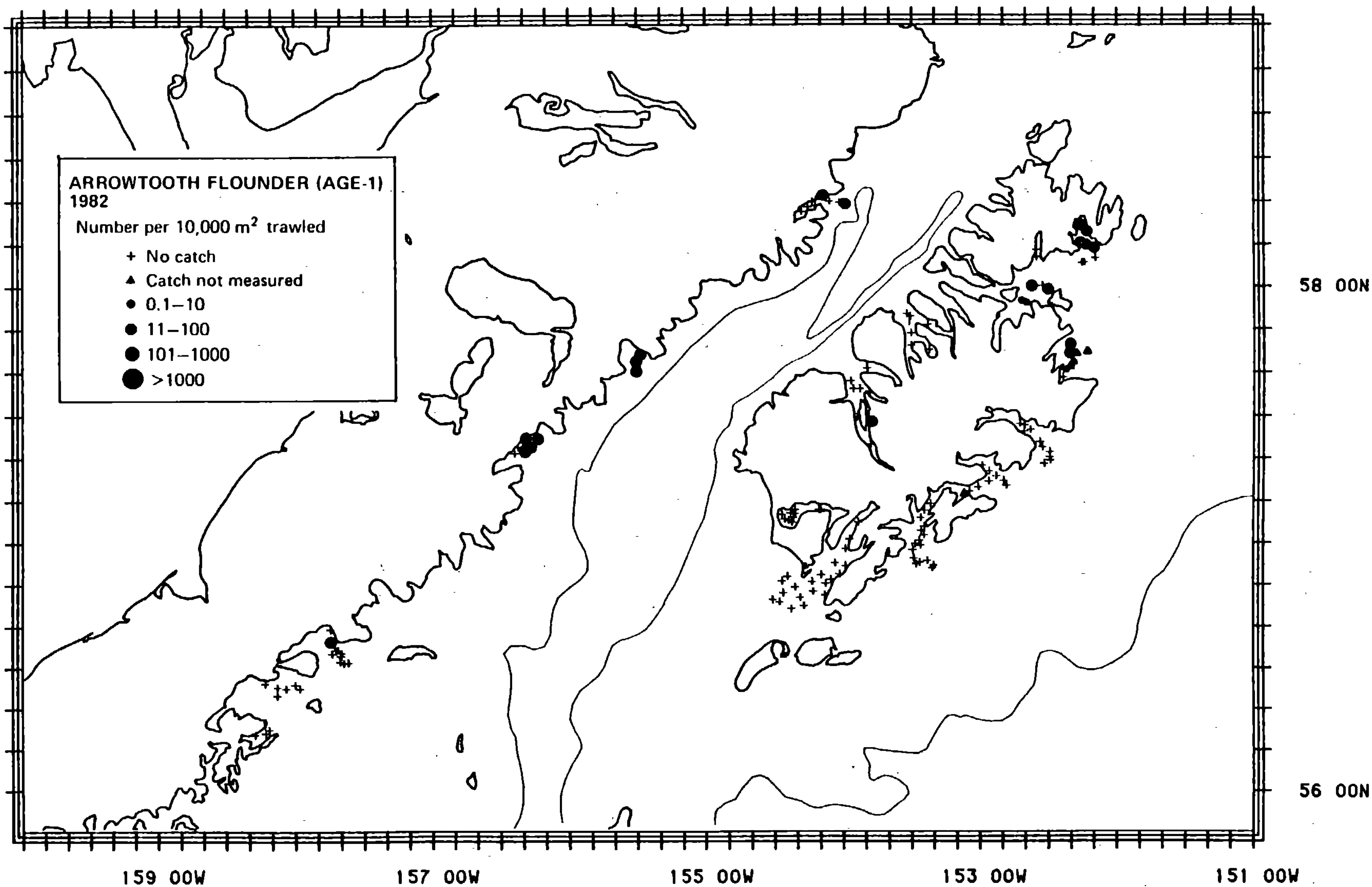

Figure 32.--Distribution and relative abundance of 1-yr-old arrowtooth flounder in the northwestern Fulg of Alaska in 1982, based on the complete survey coverage.

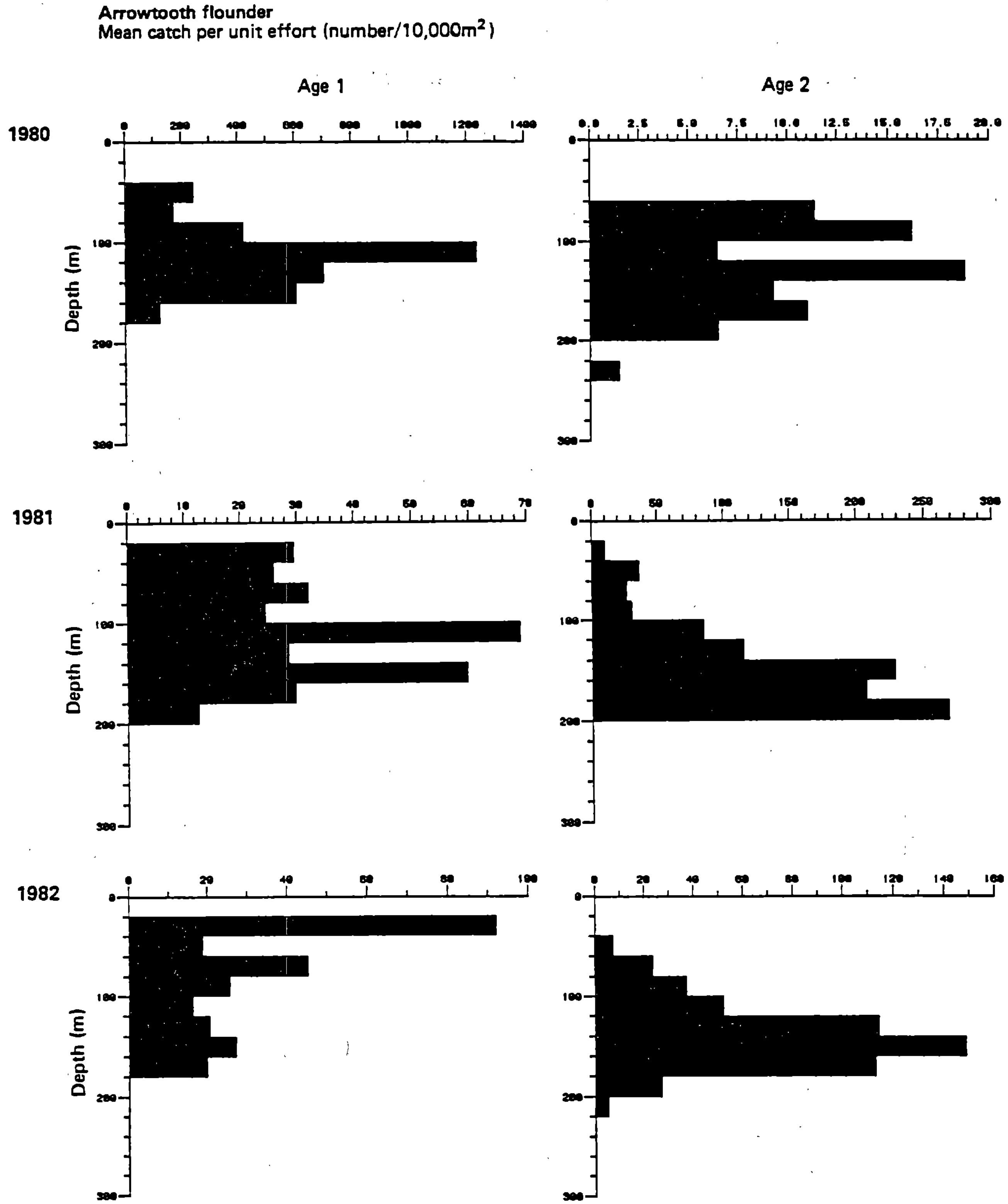

Figure 33. --Variations of arrowtooth flounder densities with sampling depth, ages 1-2 yr, based on the complete coverage of surveys in the northwestern Gulf of Alaska during 1980-82.

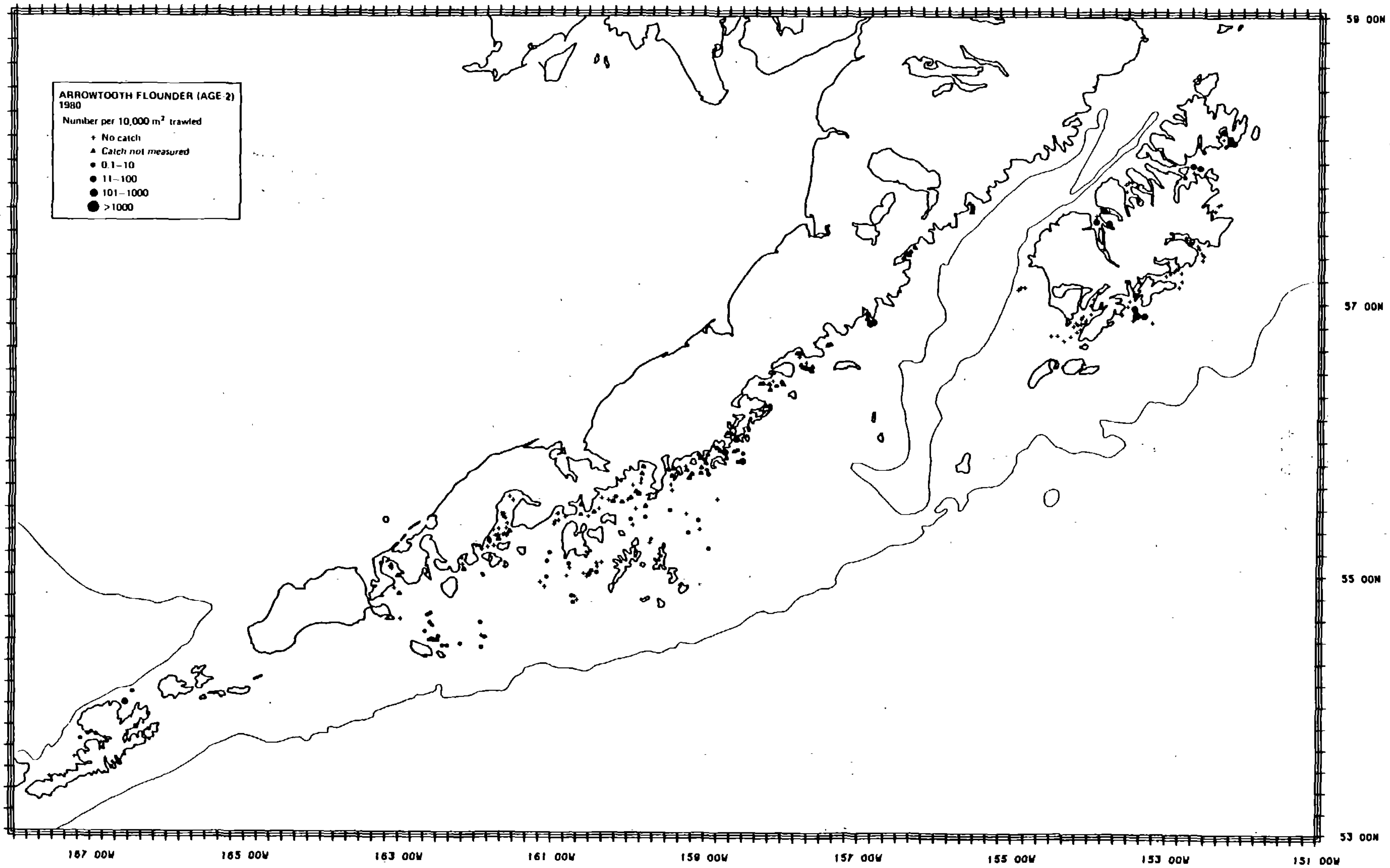

Figure 34.--Distribution and relative abundance of 2-yr-old arrowtooth flounder-in the northwestern Gulf of Alaska in 1980, based on the complete survey coverage.

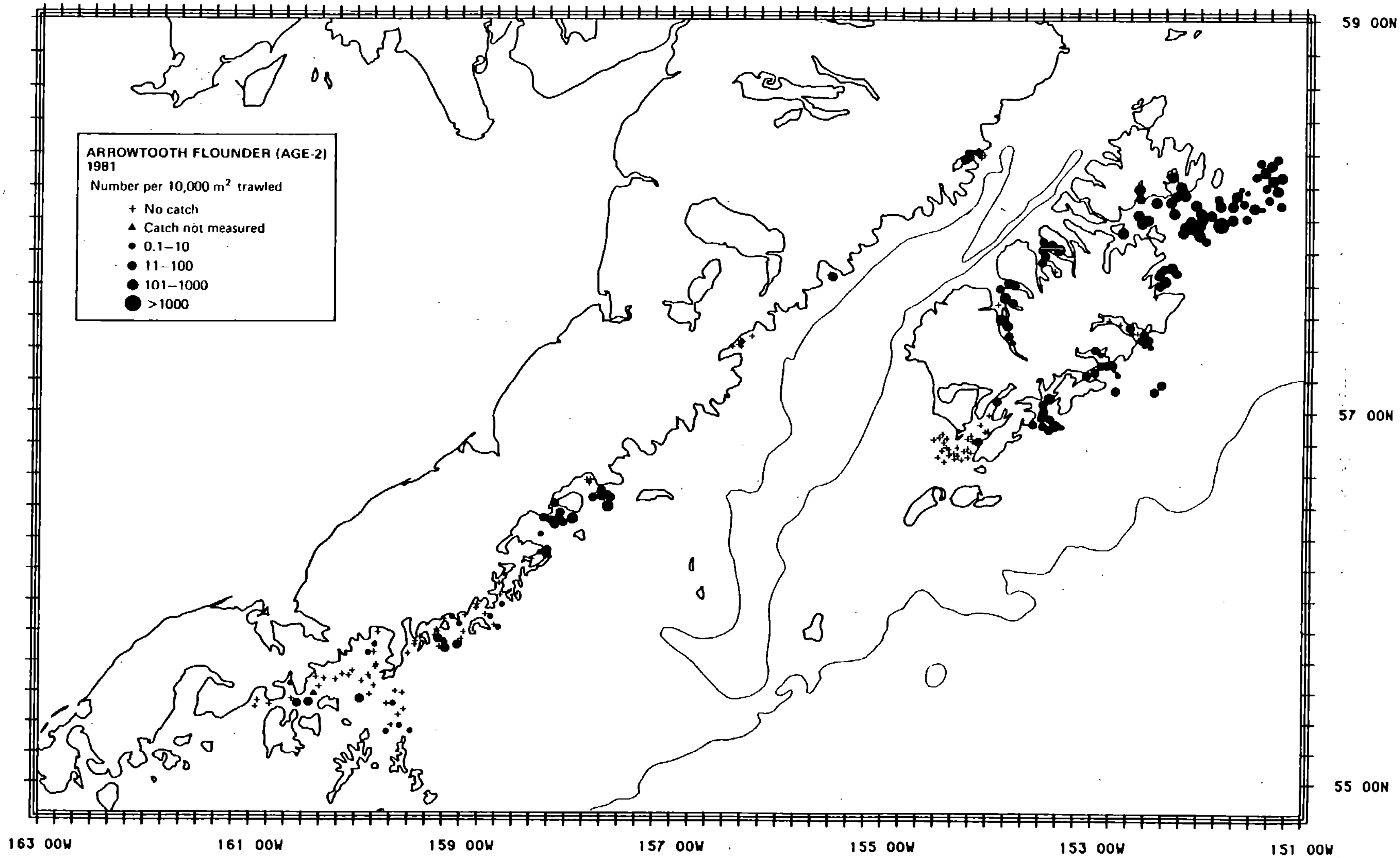

Figure 35.--Distribution and relative abundance of 2-yr-old arrowtooth flounder in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

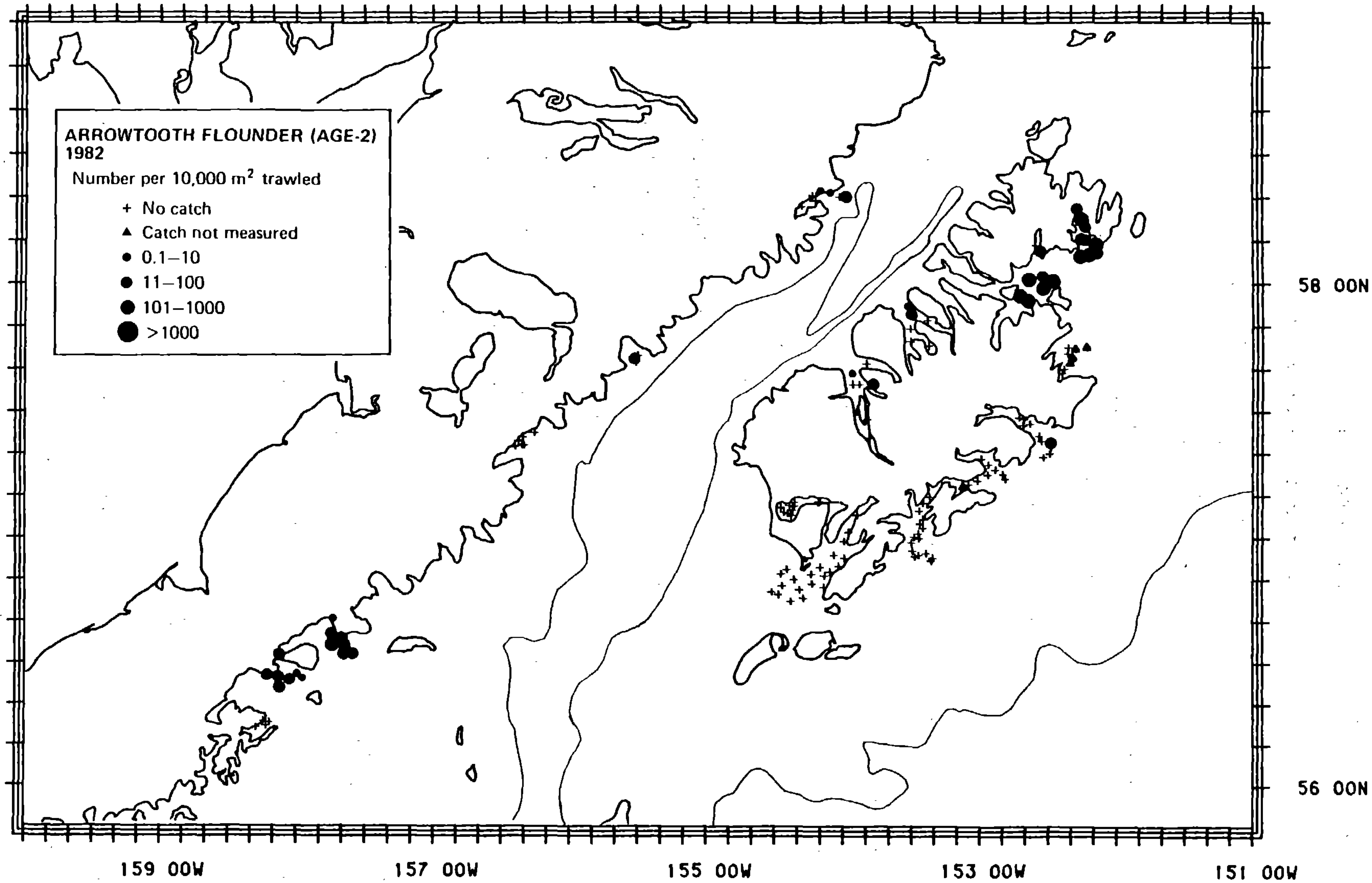

Figure 36.--Distribution and relative abundance of 2-yr-old arrowtooth flounder in the northwestern Gulf of Alaska in 1982, based on the complete survey coverage.

stations, distributed as follows: 1980, 195/295; 1981, 194/236; 1982, 124/128. Unlike the other species reported here, flathead sole were represented by a large number of relatively abundant age groups, ranging from juveniles to adults. In addition, their slower growth rate and small adult size resulted in considerable overlapping of the length distributions associated with the different ages. After examination of the age-length keys (Tables A-5 to A-7) and the length-frequency distributions (Fig. 37), we decided that only 1-yr-olds could be distinguished with reliability. These were represented by the length interval 6-10 cm. Only a few young of the year, at lengths of approximately 3 cm, were found in the surveys.

Age-l --In 1980, 1-yr-old flathead sole were widely distributed around Unalaska Island, the lower Alaska Peninsula, and Kodiak Island (Fig. 38). Since few length measurements were taken along the central Alaska Peninsula during that survey, the distribution of fish in the area was uncertain. However, the distribution patterns observed in 1981 and 1982 indicated that none were found along the Alaska Peninsula east of Wide Bay (Figs. 39,40). Relative densities around Kodiak Island were high in 1980 and 1981, and low in 1982. Depth distributions in 1980 and 1981 show that highest densities occurred in samples from less than 100 m (Fig. 41). There was no clear pattern in 1982.

Length and Growth Analyses

All of the major fish species emphasized in this report showed variations in their length characteristics at different ages. Changes occurred in the shape, range, or central value of the length-frequency

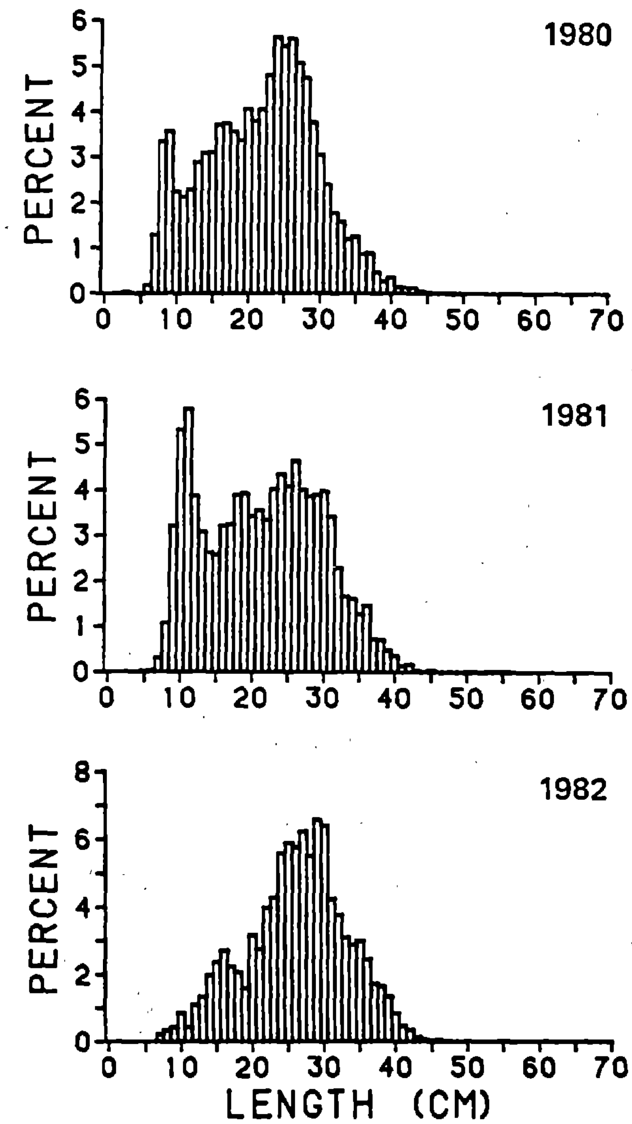

Figure 37.--Length-frequency distributions of flathead sole taken in the northwestern Gulf of Alaska, 1980-82, based on the complete survey coverage. The data shown are simple sums, unweighted by catch sizes or sampling areas.

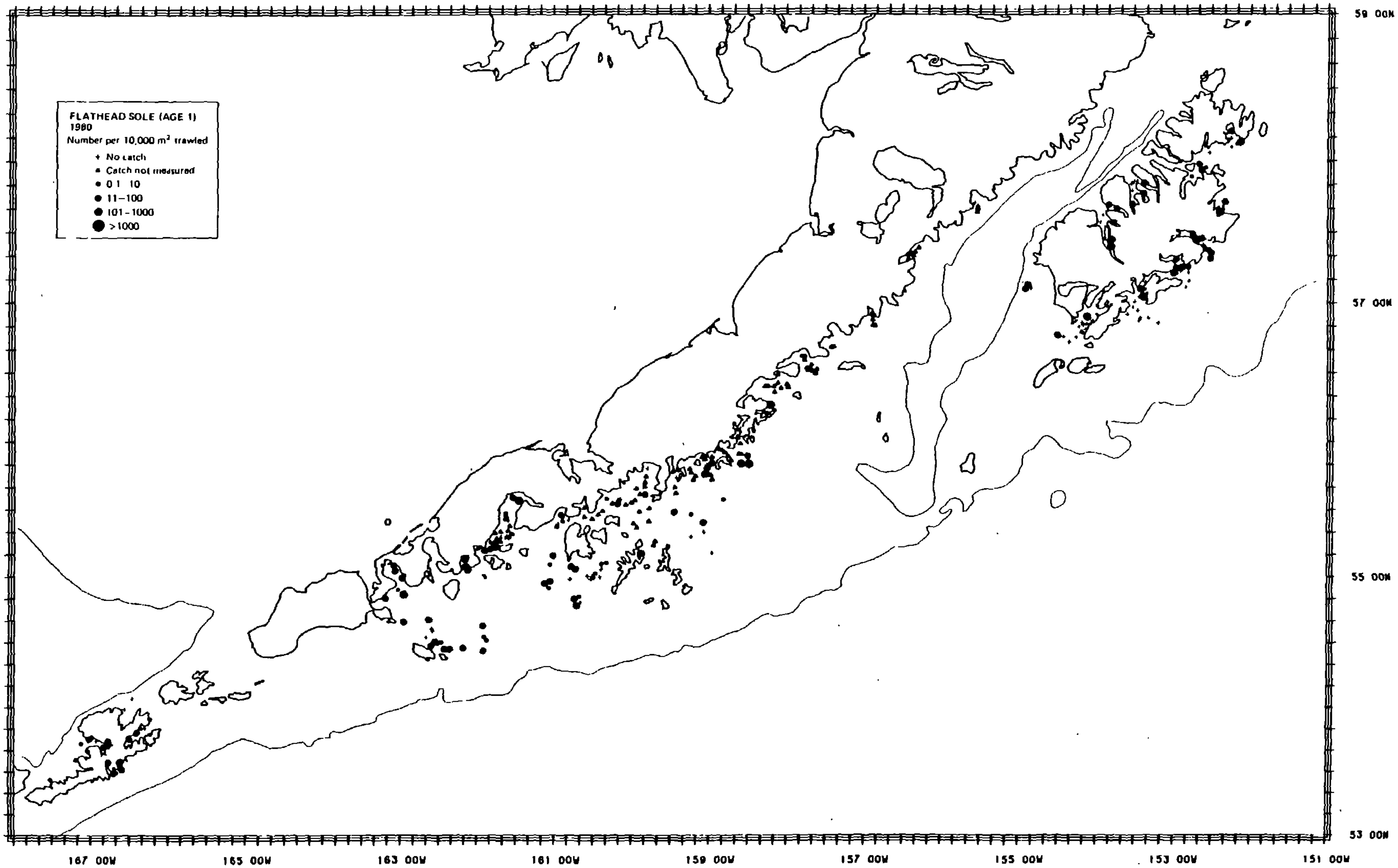

Figure 38.--Distribution and relative abundance of 1-yr-old flathead sole in the northwestern Gulf of Alaska in 1980, based on the complete survey coverage.

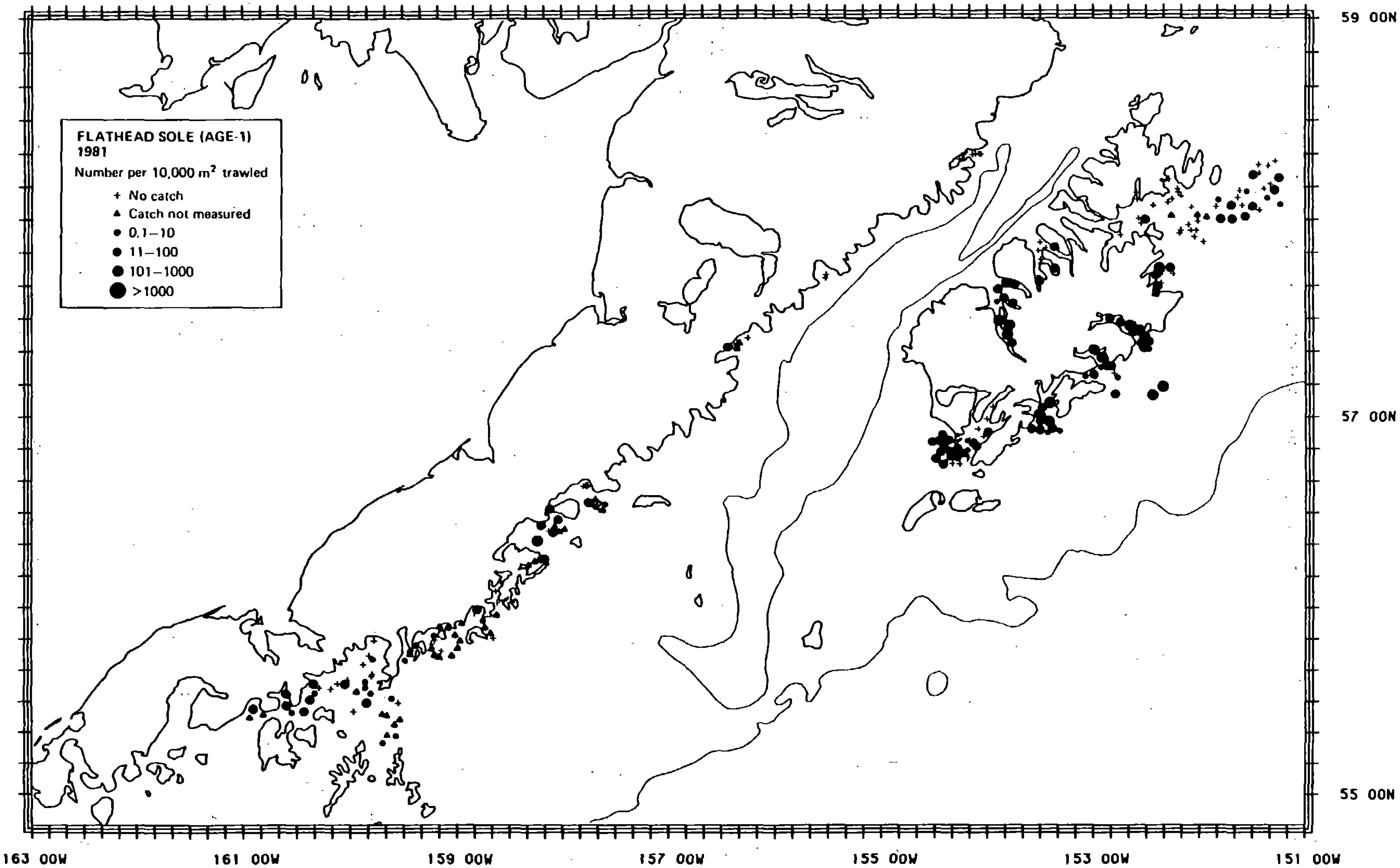

Figure 39.--Distribution and relative abundance of 1-yr-old flathead sole in the northwestern Gulf of Alaska in 1981, based on the complete survey coverage.

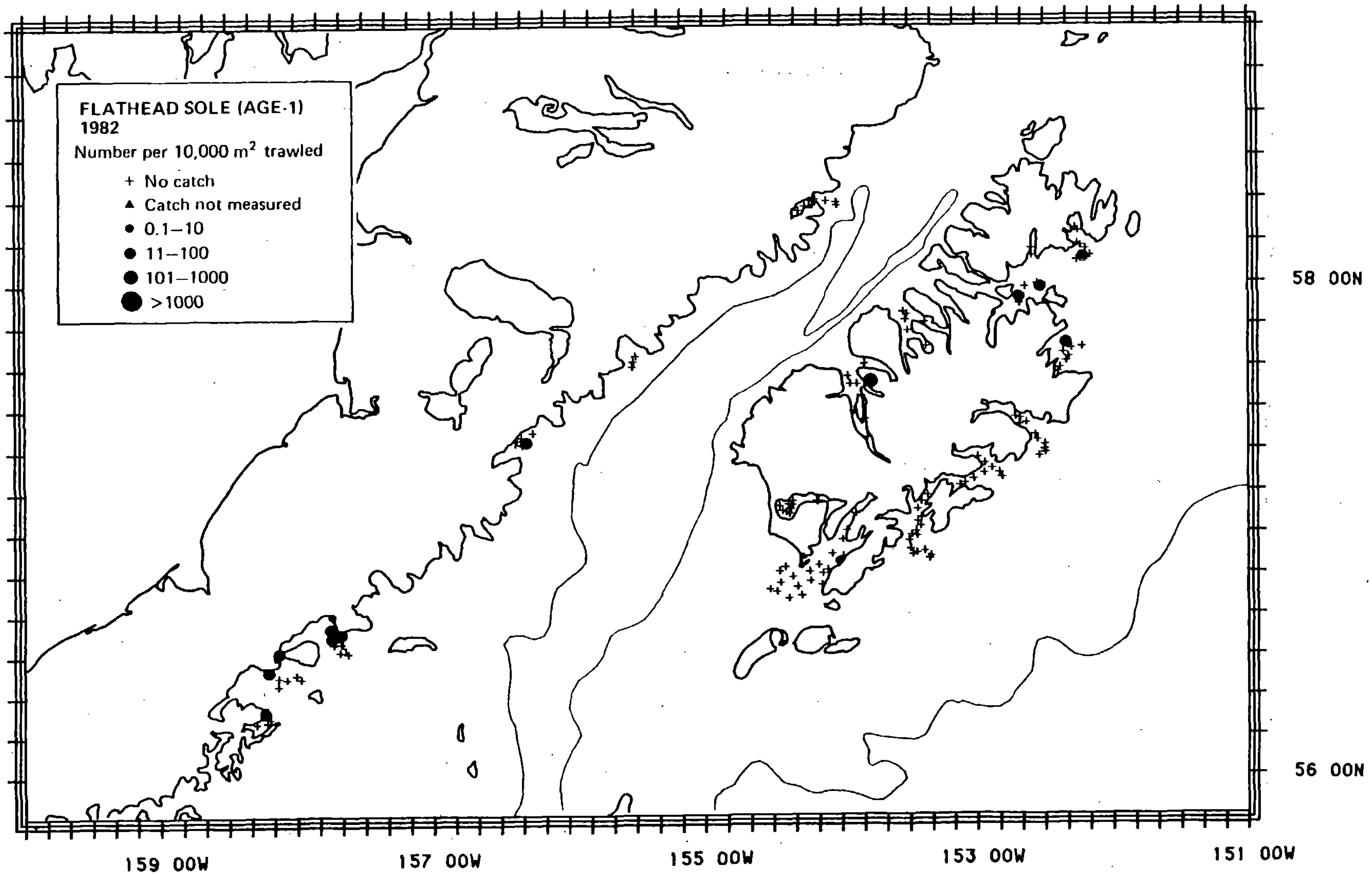

Figure 40.--Distribution and relative abundance of 1-yr-old flathead sole in the northwestern Gulf of Alaska in 1982, based on the complete survey coverage.

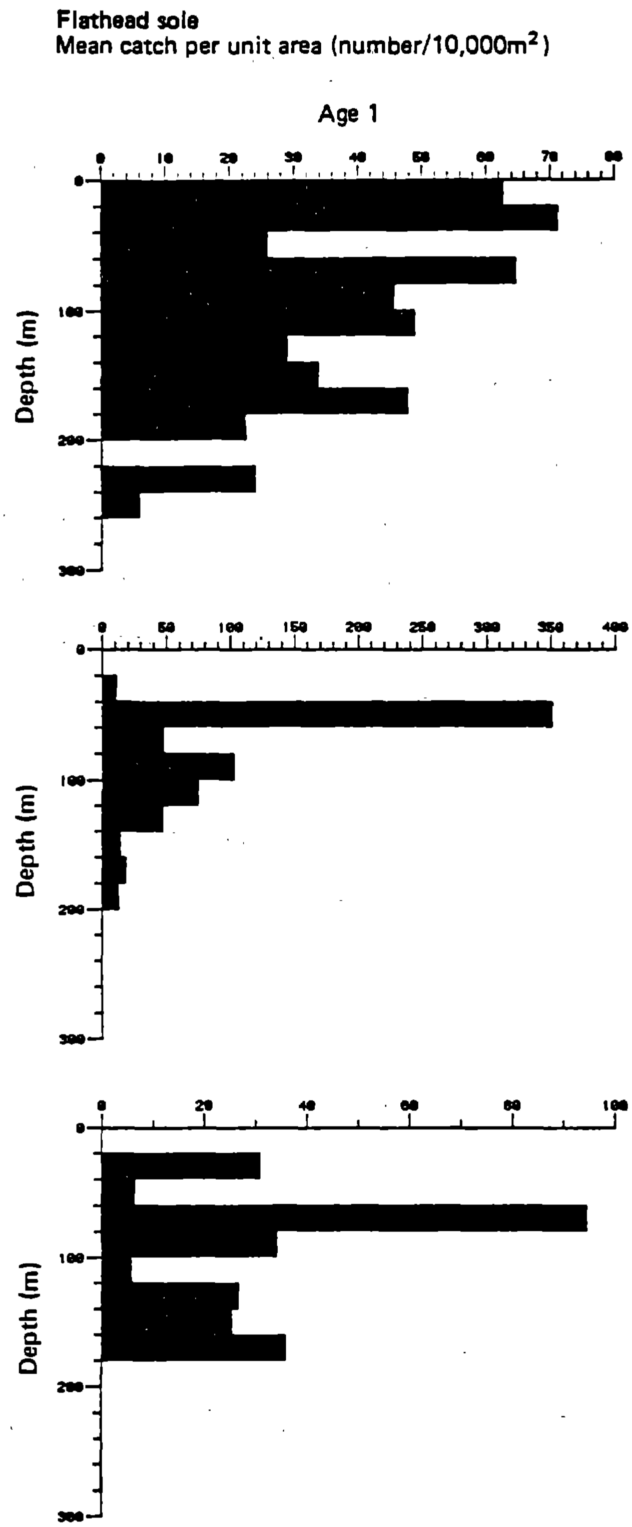

Figure 41. --Variations of the densities of 1-yr-old flathead sole with sampling depth, based on the complete coverage of surveys in the northwestern Gulf of Alaska during 1980-82.

distributions corresponding to particular age groups. For example, variations of this type occurred more or less from year to year, as shown by the summary statistics for population length-frequency distributions (Figs. 7, 15, 23, 29, 37). In addition, similar variations were observed within years, among different geographic regions. However, for most species except walleye pollock, the extent of geographic variation of length characteristics was relatively small and there were no clear patterns.

In the case of walleye pollock, marked differences in length distributions did occur. In 1980, the mean lengths of young of the year varied as much as 3.3 cm (35% of the overall mean length) among the seven geographical strata. In general, fish were smallest in the southwest and lengths increased toward the northeast (Fig. 42). In 1981, mean lengths varied by 2.0 cm (20% of the overall mean). There was again a general trend, although less noticeable, of increasing lengths from southwest to northeast. In 1982, mean lengths varied by 1.0 cm (12% of the overall mean) among the three strata surveyed.

Similar types of variations were also shown by 1-yr-olds (Fig. 43). In 1980, the mean lengths of 1-yr-olds varied by 6.9 cm (36% of the overall mean length) among the seven strata, and. there was a marked trend of increasing lengths from southwest to the northeast. The mean length ranged from 17.7 cm near Unalaska Island to 24.6 cm on the eastern side of Kodiak Island. In 1981 and 1982, mean lengths varied by 3.6 cm (15% of the overall mean) and 3.2 cm (16% of the overall mean), respectively, among the strata surveyed.

On an annual basis, overall mean lengths for both ages of walleye pollock were highest in 1981. For 1-yr-olds, this change represented a

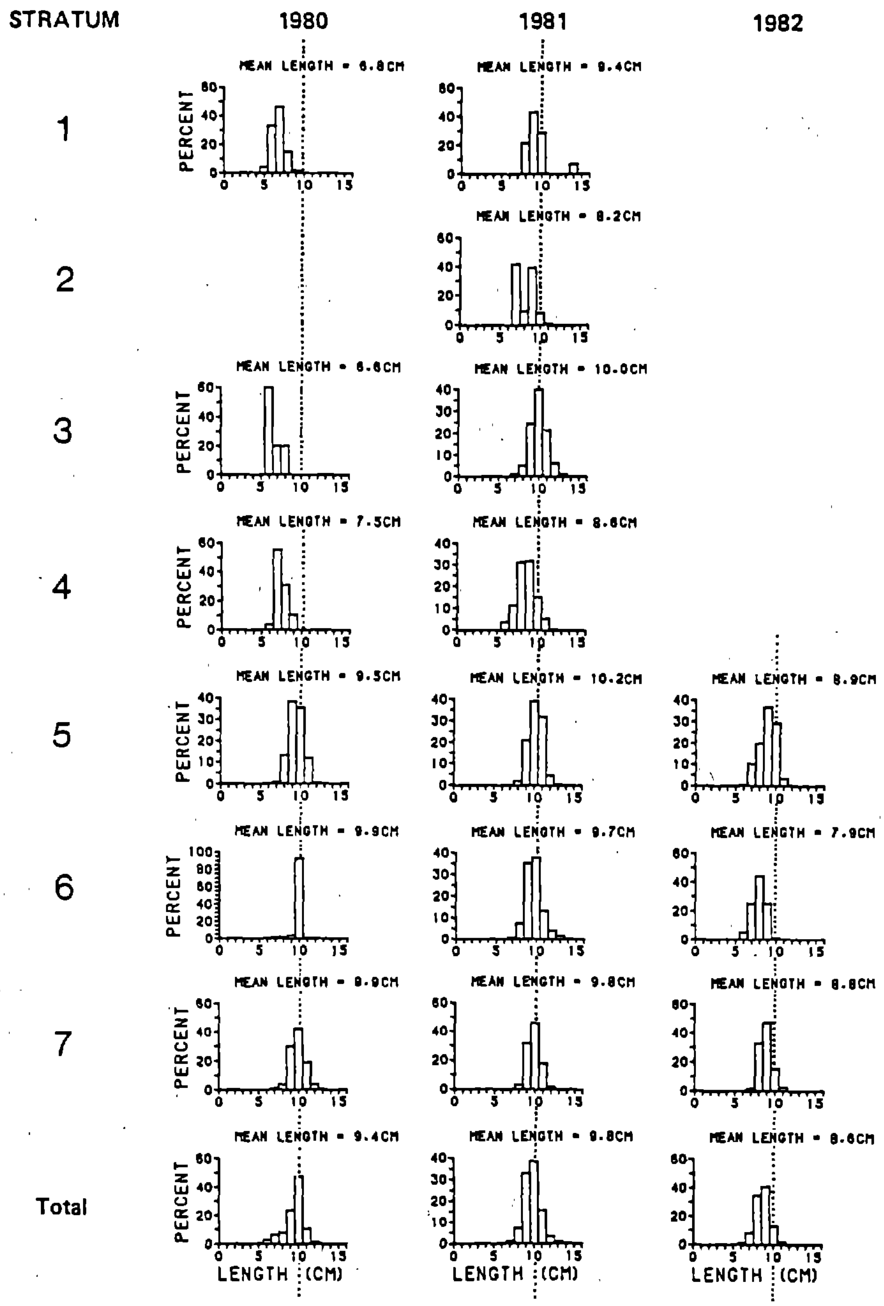

Figure 42.--Comparisons of the length-frequency distributions of O-group walleye pollock among different regions of the northwestern Gulf of Alaska during 1980-82. See Table 2 for an explanation of the geographical strata; in general, stratum numbers correspond to subdivisions of the study area from southwest (stratum 1) to northeast (stratum 7). The data shown are unweighted; the dotted lines at 10 cm length are provided for reference.

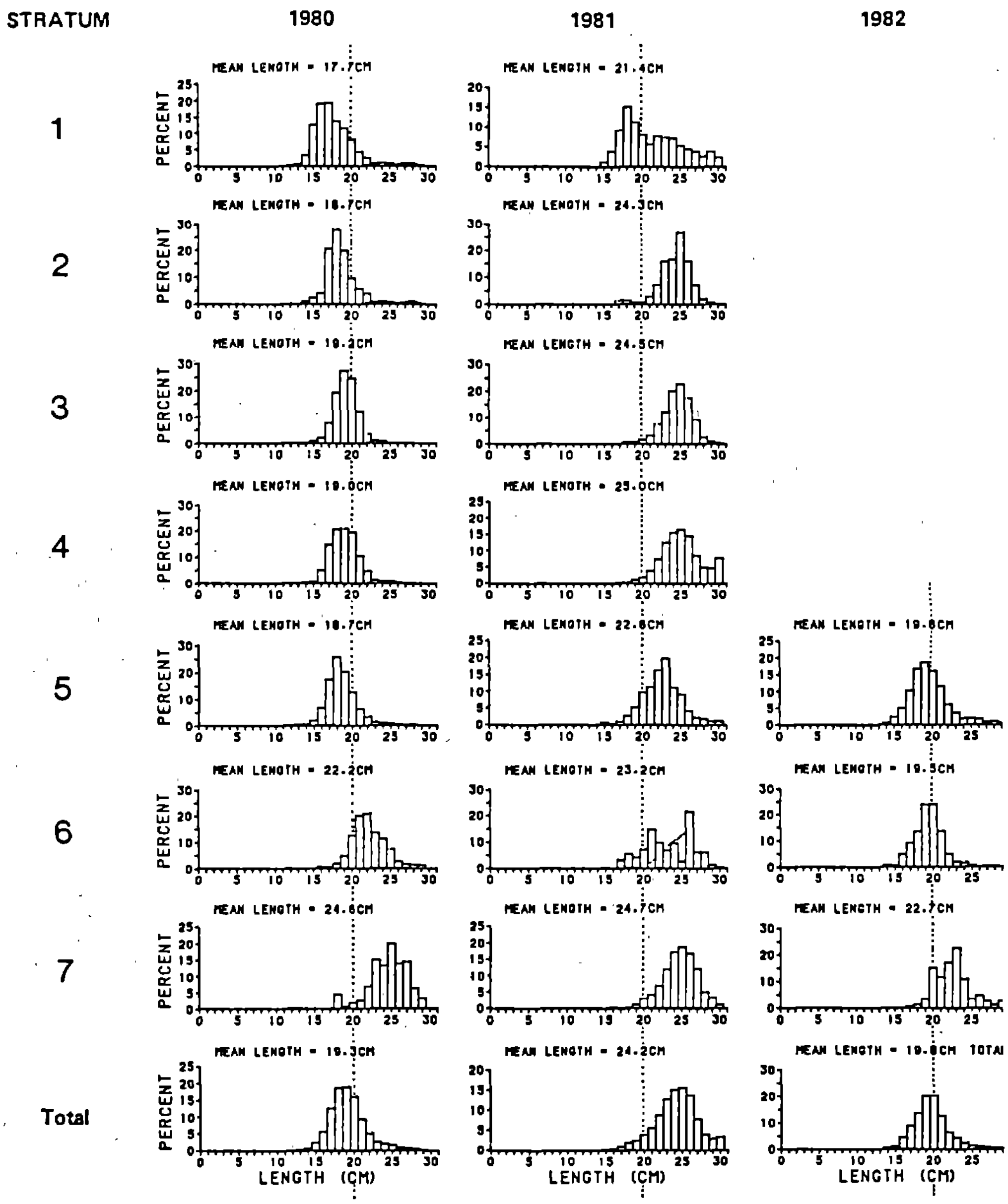

Figure 43. --Comparisons of the length-frequency distributions of 1-yr-old walleye pollock among different regions of the northwestern Gulf of Alaska during 1980-82. See Table 2 for an explanation of the geographical strata; in general, stratum numbers correspond to subdivisions of the study area from southwest (stratum 1) to northeast (stratum 7). The data shown are unweighted; the dotted lines at 20 cm length are provided for reference.

25% increase in mean length between 1980 and 1981. These annual differences in mean length also varied by geographical area (Figs. 42,43). Young of the year from Unalaska Island and along the Alaska Peninsula (strata 1-5) were larger in 1981 than in 1980. However, around Kodiak Island (strata 6-7) they were slightly smaller. One-yr-olds showed a similar trend. Large differences in mean length occurred between 1980 and 1981 for strata 1-5, but there was little difference for strata 6-7.

Faunal Associations

The use of cluster analysis techniques provided an objective way to measure and describe the associations of species, and age groups of the major species, based on their distributions among the survey stations. The results for each year are presented as dendrograms (Figs. 44-46) showing the similarity between entities (i.e., taxa or age groups) and groups of entities. In general, entities that were common in most areas appear together with high similarity values (near the bottom of each dendrogram) and entities that were rare had low similarity values (near the top of each dendrogram). The association between entities is indicated by their similarity values and proximity in the dendrogram.

Two of the entities that showed the strongest associations in all 3 yr were flathead sole and pandalid shrimp (grouped as "all shrimp" in 1982). Both entities were common in nearly all regions of the study area including Unalaska Island, bays and nearshore waters along the Alaska Peninsula, and all areas surveyed off Kodiak Island.

Associations of the three entities representing walleye pollock (O-group, 1-yr-olds, and >2 yr) varied from year to year. In 1980, O-group fish were distributed mainly along the Alaska Peninsula, and eastern and southeastern sides of Kodiak Island (Fig. 8). Associated

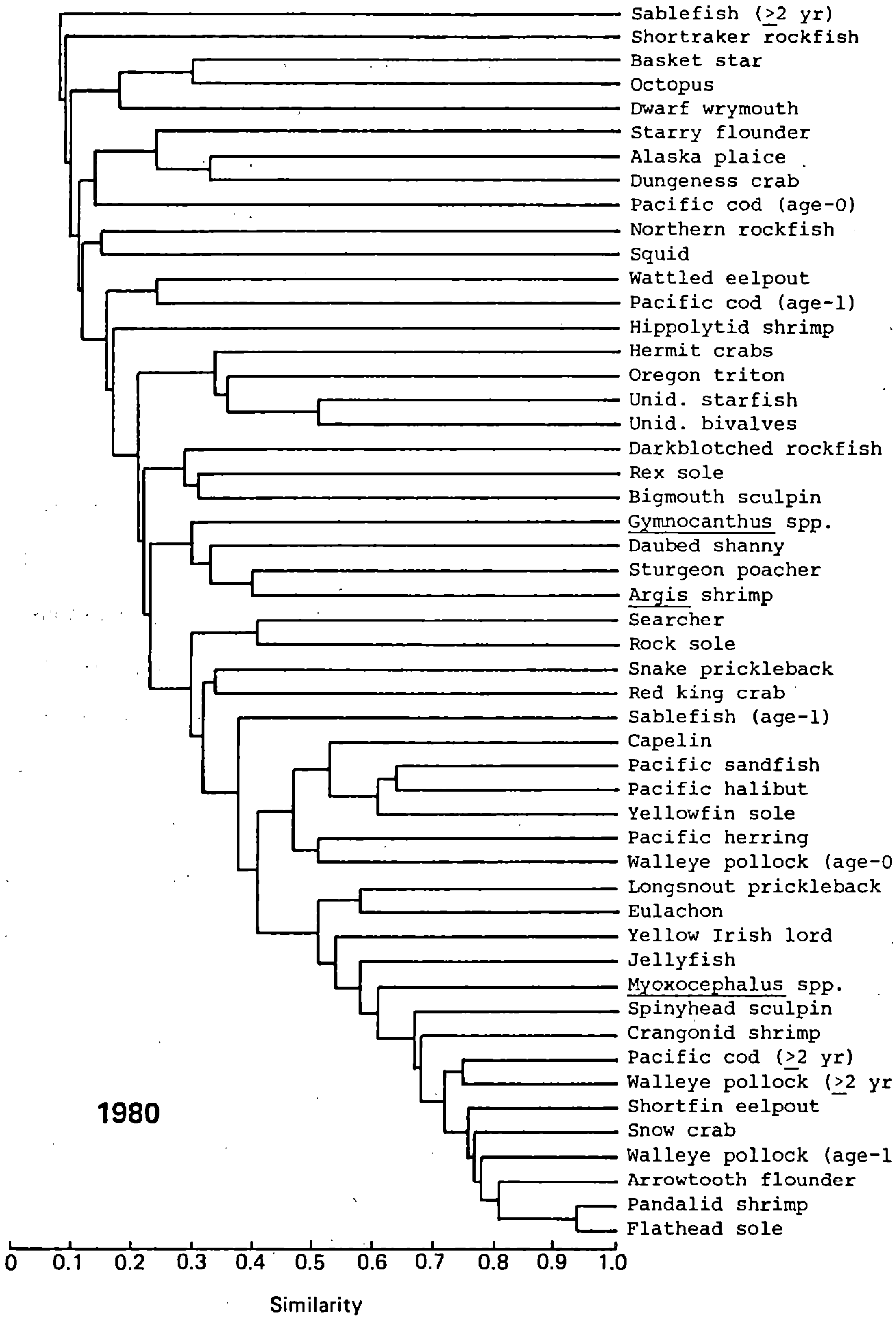

Figure 44.--Dendrogram showing relationships between fish and invertebrate species, and specific age groups of the major fish species, based on similiarity of distribution patterns measured from the 1980, survey coverage in the northwestern Gulf of Alaska.

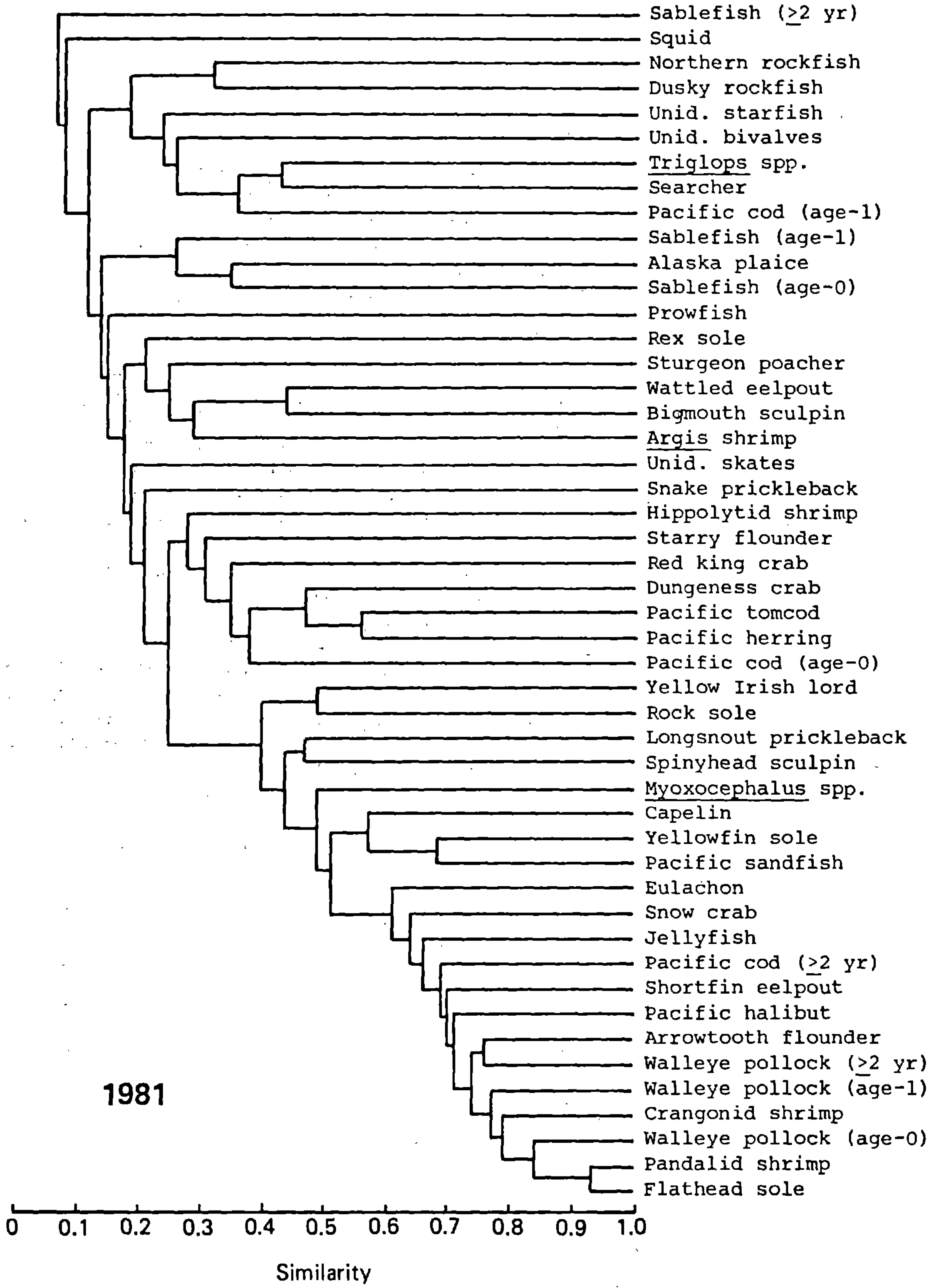

Figure 45.--Dendrogram showing relationships between fish and invertebrate species, and specific age groups of the major fish species, based on similarity of distribution patterns measured from the 1981 survey coverage in the northwestern Gulf of Alaska.

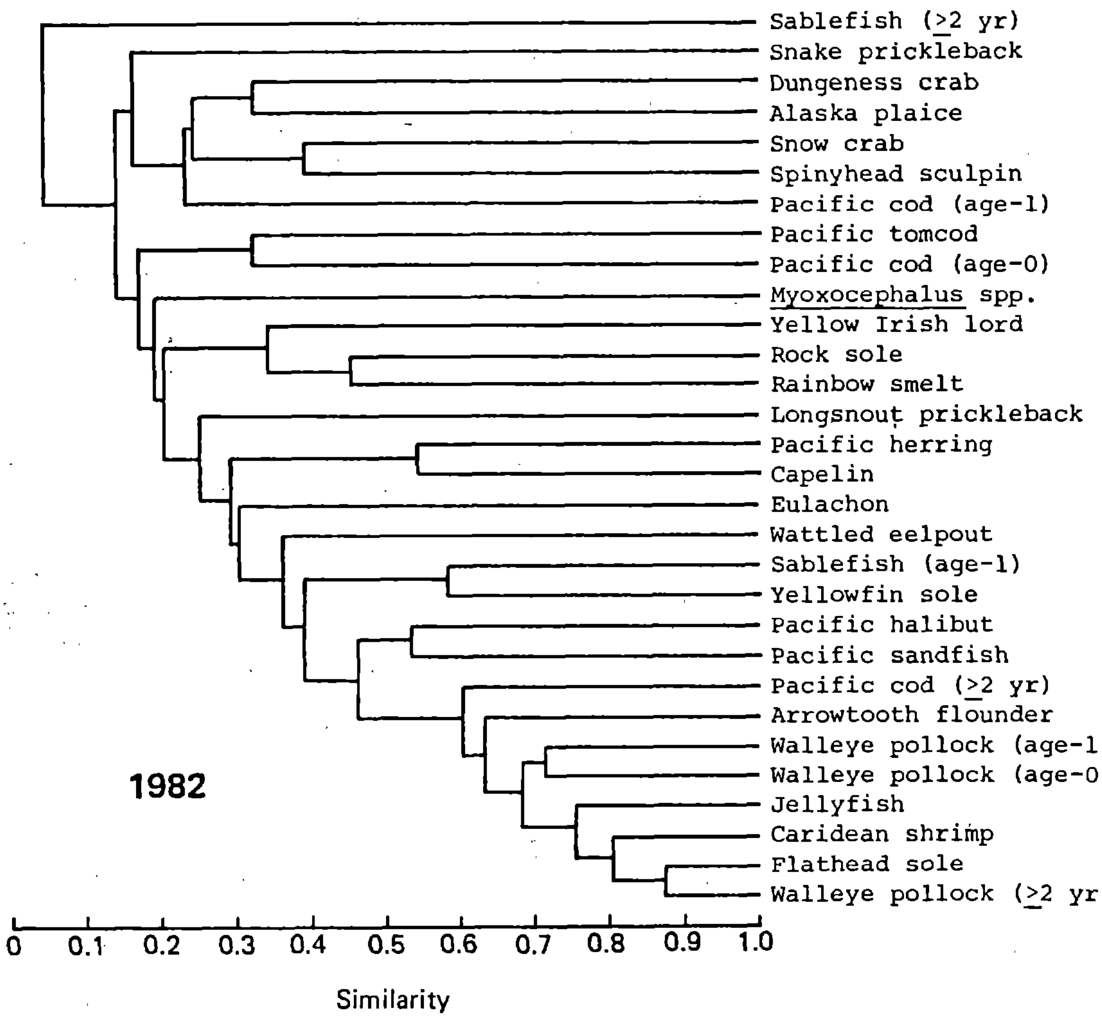

Figure 46.--Dendrogram showing relationships between fish and invertebrate species, and specific age groups of the major fish species, based on similarity of distribution patterns measured from the 1982 survey coverage in the northwestern Gulf of Alaska.

species included: Pacific herring, Clupea harengus pallasi; yellowfin sole; Pacific halibut, Hippoglossus stenolepis; Pacific sandfish, Trichodon trichodon; and capelin. In 1981, O-group fish were more widely distributed throughout the study area (Fig. 9); associated entities were pandalid shrimp, flathead sole, crangonid shrimp, and 1-yr-old walleye pollock. In 1982, 0-group fish also showed a relatively widespread distribution along eastern and southeastern Kodiak Island, and the north-central Alaska Peninsula (Fig. 10); principal associates were 1-yr-old walleye pollock, jellyfish, shrimp, flathead sole, and older walleye pollock. Principal associates of 1-yr-old walleye. pollock over the three years were arrowtooth flounder, pandalid shrimp, flathead sole, O-group walleye' pollock, and age-2 and older walleye pollock. In general, the three age groups of walleye pollock often occurred in survey samples together, particularly in 1981 and 1982;

In contrast, the analyses indicated that there was little association among the three age groups (O-group, 1-yr-olds, and >2 yr) of Pacific cod. The two youngest age groups were relatively rare in the survey catches (e.g., Figs. 16, 18-22 1, but where they did occur, young of the year were usually found in shallow water (Fig. 17). Principal associates of O-group fish over the 3 yr were shallow water species: Dungeness crab, Cancer magister; starry flounder, Platichthys stellatus; and Pacific tomcod, Microgadus proximus. One-yr-old Pacific cod had few consistent associates over the 3 yr; most were benthic species that varied from year to year.

As mentioned above, older sablefish (>2 yr) were seldom taken on the surveys, and young of the year were taken only in 1981. However, where sablefish did occur, only one age group was usually present. This infrequent association among the age groups is shown in the dendrograms. In 1981, the depth distribution of catches of young sablefish suggested that O-group fish were primarily found in shallower water than 1-yr-olds (Fig. 25). Even though 1-yr-old sablefish were most common in the surveys, they had few consistent associates over the 3 yr. Principal co-occurrences were with Pacific sandfish, Pacific halibut, and yellowfin sole.

Other faunal associations could also be noted. Older (>2 yr) walleye pollock and Pacific cod showed some association in every year, particularly closely in 1980. In that year, older walleye pollock and Pacific cod were taken in 175 and 199 samples, respectively. They occurred together in 140 of those samples, primarily along the southcentral and lower Alaska Peninsula., In 1980, four species (yellowfin sole, Pacific sandfish, . . . Pacific halibut, and capelin) had similar distributions along the lower. Alaska Peninsula and east side of Kodiak Island. Their relationships. and areas of co-occurrence were similar in 1981, although Pacific halibut was not as strongly associated. Some of those relationships were also evident in the results from 1982.

Walleye Pollock Feeding Studies

The 44 subsamples of 1-yr-old walleye pollock that were collected for stomach content analyses were from a wide range of stations in bays and nearshore waters of the northwestern Gulf of Alaska (Fig. 47). Of the 439 individuals examined, 414 (94.3%) stomachs contained food items and 25 (5.7%) were empty (Table 5). Major prey categories, in terms of percentage dry weight contribution, were: euphausiids, 46.6%; juvenile caridean shrimp, 17.8%; fish, 14.8%; and mysids, 12.8%. Other prey that were common, but did not contribute significantly on a weight basis, were copepods, amphipods, crab larvae, and small gastropods.

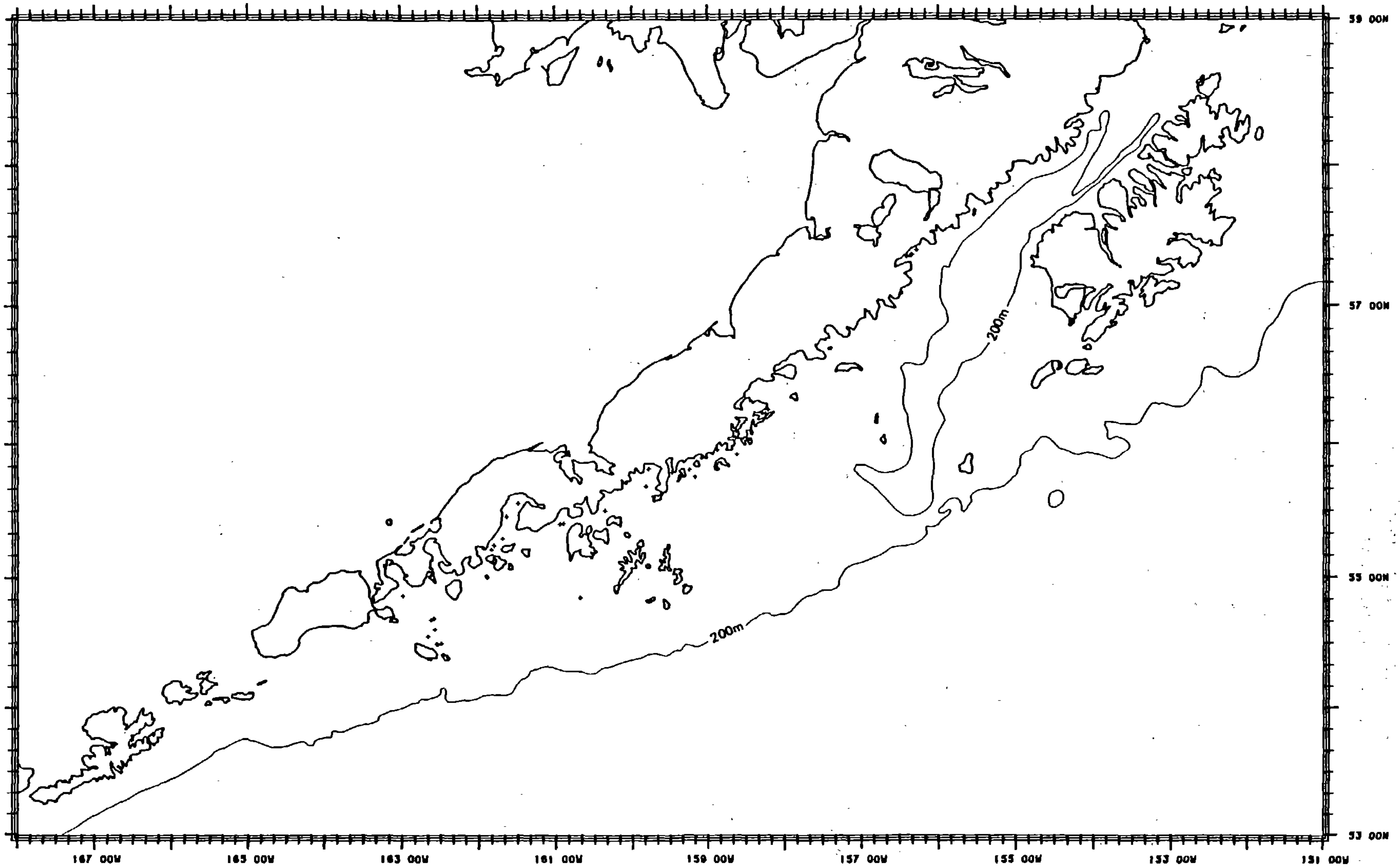

Figure 47.--Sampling stations where 1-yr-old walleye pollock were collected for stomach contents analyses during 1980 in the northwestern Gulf of Alaska.

Table 5.--Summary of the stomach contents of one-yr-old walleye pollock in the northwestern Gulf of Alaska, June-September 1980.[a]

Stomach contents	Frequency (%)	Mean number	Mean wet weight (mg)	Dry/wet ratio[b]	Mean dry weight (mg)	Dry weight (%)
With food items	94.3	--	--	--	--	--
Euphausiids	63.8	11.0	251.4	0.101	25.4	46.8
Caridean shrimp	12.8	0.3	65.8	0.147	9.7	17.8
Fishes	9.6	0.2	51.0	0.158	8.1	14.8
Mysids	25.5	3.0	61.9	0.112	6.9	12.8
Copepods	32.8	8.2	9.2	0.089	0.8	1.5
Amphipods	8.7	0.4	4.4	0.111	0.5	0.9
Polychaetes	1.6	<0.1	3.4	0.123	0.4	0.8
Crabs	7.1	0.8	3.2	0.102	0.3	0.6
Gastropods	4.3	0.8	2.5	0.108	0.3	0.5
Cumaceans	3.2	0.1	0.7	0.110	0.1	0.1
Chaetognaths	2.1	0.1	0.7	0.104	0.1	0.1
Unidentified	18.0	--	trace	--	trace	trace
Digested	40.1	--	25.3	0.076	1.9	3.5
Empty	5.7	--	--	--	--	--
	Total	24.8	479.5		54.3	100.0

[a] Based on 439 individuals examined from 44 collection sites.

[b] Determined by drying subsamples at 60°C for 24 hr.

Specific euphausiid prey included, in order of decreasing number: *Thysanoessa spinifera,* T. *inermis,* T. *raschii*, and *Euphausia pacifica*. Caridean shrimp prey, and their mean carapace lengths (measured from the posterior orbit to the posterior middorsal margin), were: *Eualus biunguis,* 11.4 mm; sidestripe shrimp, *Pandalopsis dispar,* 6.7 mm; humpy shrimp, *Pandalus goniurus,* 6.4 mm; coonstripe shrimp, P. *danae,* 6.5 mm; and pink shrimp, 5.6 mm. Pink shrimp showed the highest relative abundance of any of the caridean shrimp within trawl catches, yet it was one of the rarest prey in 1-yr-old walleye pollock stomachs. Although fish prey were generally in poor condition due to partial or near-complete digestion, specific prey identified were small stichaeids, osmerids (probably capelin), and O-group pleuronectids (flathead sole and perhaps others). Gastropod prey appeared to include only planktonic thecosomes, probably *Limacina helicina*.

In summary, in 1980, 1-yr-old walleye pollock fed mostly on planktonic (e.g., euphausiids and copepods) and epibenthic (e.g., caridean shrimp, juvenile fish, and mysids) prey items, although some benthic organisms (e.g., polychaetes and cumaceans) were also included in the diet. Since most items in the stomachs were generally intact, the feeding behavior appeared to involve picking individual prey.

DISCUSSION

The results described in this second report extend the analyses of the initial study (Smith et al. 1984) to a, larger area and to additional species. They also include new analyses of size distributions, food habits, and species associations.

Important characteristics of the physical environment of the study area were its large size, the narrowness of the continental shelf, and the complexity of the coastline and associated shallows. The study area, in its entirety, was a large geographic region. The narrowness of the continental shelf apparently causes the nursery areas for many fish to be compressed against the coast-and into the nearshore zone. In these areas, the complexity of the coastline and numerous island archipelagos provides a variety of shallow, protected environments, such as estuaries and bays, that are used by many groundfish as nursery areas.

One aspect of the physical environment that varied from year to year and showed regional patterns was the late-summer water temperature (Figs. 3, 5). While it was not unexpected to observe 1-2°C differences in mean values from year to year (also shown by the long-term record of sea surface temperature anomalies (Smith et al. 1984:fig. 34)), it was interesting to find evidence for shifts in the southwest-northeast temperature gradients of SST and BWT (Figs. 4, 6). It is likely that these gradients were affected by, and represented, changes in water circulation over and along the continental shelf. All temperature variations, like these, can be expected to have associated biological effects.

The biological environments in bays and nearshore waters of the study area were rich in fish and shrimp, and a large number of fish species were present in the juvenile life history stage. The lists of fish and invertebrates recorded during the surveys were quite long (Tables 3, 4). Many of these taxa, particularly those that were relatively abundant, occurred in characteristic patterns that could be recognized as community associations (Figs. 44-46). Juvenile fishes were important components in some of these communities.

Walleye pollock was the most abundant species taken during each of the three survey years, and both juveniles and adults were widely distributed throughout the study area. Results from the complete survey coverage were reported for O-group fish and 1-yr-olds; in addition, the comparative study (Smith et al. 1984) described results for 2-yr-olds and attempted to interpret the general recruitment process.

Young-of-the-year walleye pollock were widely distributed among the nearshore areas studied and showed large variations in distribution and abundance from year to year. In the initial comparative study (Smith et al. 1984), limited to 12 major inlets in the Kodiak Island and central Alaska Peninsula regions, it was found that O-group fish showed contagious spatial distributions, population levels varied widely from year to year, and there 'was a general decrease in fish concentrations (based on bay-to-bay averages) from north to south. Results from the complete survey coverage (Figs. 8-10) emphasized the extent of year-to-year differences:. in 1980, O-group fish were principally found in the northeast in only moderate densities; in 1981, O-group fish were found in high abundance both in the Kodiak Island.

region and along the Alaska Peninsula south to Pavlof Bay. Although in this second study it was not possible to estimate concentration gradients in the same manner as before, highest densities occurred in northeast parts of the study area. In all 3 yr, particularly in 1981, high densities of O-group fish on the northeast side of Kodiak Island indicated , that a major spawning site might be located to the northeast. Despite the extensive coverage obtained from the surveys, however, questions remain regarding the distribution of O-group fish farther offshore, beyond the limits of our sampling.

The results for 1-yr-old walleye pollock were similar in pattern, but more extreme. Previous interpretations were that 1-yr-olds were widely distributed, their population levels may have varied widely from year to year, and highest concentrations occurred along the Alaska Peninsula and west side of Kodiak Island, with a gradient of decreasing concentrations from south to north (i.e., showing an opposite trend compared to the O-group populations). The results from the complete survey coverage showed how extensive the distribution of 1-yr-olds in the lower Alaska Peninsula region had really been in 1980-81, particularly in the region between Pavlof and Kujulik Bays (Figs. 12,13).

Pacific cod was an important species in our studies, although juveniles were taken at relatively few locations in the surveys. Young of the year were taken at scattered locations in all three years, mainly at shallow depths (Figs. 16-19). Because of this shallow distribution, we concluded in our first study that many O-group fish probably were missed by the surveys (Smith et al. 1984). One-yr-olds were also taken at only a few locations and were relatively rare (Figs. 20-22).

Sablefish was another species that was important in our studies, but showed wide variations in distribution and abundance. Young of the year were observed only in 1981, mainly in shallow water at scattered locations in the northeastern part of the study area (Figs. 24, 25). Previous interpretations concluded that 1-yr-olds were the dominant age group found in the study area; in 1980-81, most occurred in the Alaska Peninsula region and in 1982, highest population levels were found on the east side of Kodiak Island (Smith et al. -1984). The results from the complete survey coverage showed that 1-yr-olds were mainly taken in the central Alaska Peninsula region, although at different times scattered occurrences were found throughout nearly the entire study area (Figs. 26-28).

Juvenile arrowtooth flounder, one of the additional fish species described in this second study, were widely distributed throughout the study area. The reproductive biology and early life history of arrowtooth flounder in the Gulf of Alaska are not well understood. Based on gonad maturity data, Hirschberger and Smith (1983) reported spawning fish occurring at scattered points along the outer continental shelf in the northeastern Gulf of Alaska, mainly within the depth interval 108-200 m. In the Bering Sea, spawning is reported to occur from December to March at depths greater than 150 m (Garrison and Miller 1982). In this present study, 1- and 2-yr-old arrowtooth flounder could be distinguished fairly easily on the basis of length groups (see Fig. 29). One-yr-olds were found in samples from a broad depth range (Fig. 33), and were relatively abundant along the entire Alaska Peninsula and west and northeast sides of Kodiak Island (Figs. 30-32). Two-yr-olds showed a similar distribution, but were generally farther offshore (Figs. 34-36). In 1981-82, they were particularly abundant in outer Marmot Bay, off the southeastern side of Afognak Island.

Flathead sole, another of the additional fish species described in this report, was very common in the, study area as both juveniles and adults. Unfortunately, our methods were not very effective for distinguishing juvenile age groups on the basis of length intervals, because most ages had overlapping size distributions (Fig. 37). Like so many of the other groundfish species, the spawning biology and early life history of flathead sole in the Gulf of Alaska are poorly understood. Based on observations of gonad conditions, Hirschberger, and Smith (1983) reported that spawning occurred mainly from March to May at depths of 108-200 m. Fish in spawning condition were observed in Shelikof Strait, the Chirikof Island area, and at scattered locations along the edge of the outer continental shelf from Albatross Bank to Yakutat Valley. In the present study, 1-yr-old flathead sole were found to have widespread distributions that varied from year to year (Figs. 38-40). In 1980, 1-yr-olds were found at moderate densities throughout nearly the entire study area. They were very abundant in the major inlets of Kodiak Island in 1981, but not during 1982.

The variations in length characteristics of walleye pollock that were observed (Figs. 42, 43) were of interest because of their possible relationships to environmental factors. Both annual and geographic variations in mean length may have been influenced by direct effects of seawater temperatures on growth rates. Young of the year and 1-yr-olds had their largest mean lengths in 1981, the year when SST and BWT conditions were wannest (Figs. 3, 5). Similarly, trends in the mean lengths of O-group fish and 1-yr-olds, observed- from southwest to northeast regions of the study area, were strongest in 1980. This was the year when the southwest-northeast temperature gradients of SST and BWT also showed the steepest slopes (Figs. 4, 6).

However, exceptions and other possible contributing factors should be noted. Regional trends in length characteristics were observed in 1981, even though there were no clear gradients in temperature conditions across the study area. Of course, other environmental factors that could have important influences on length characteristics include the timing and location of spawning (i.e., characteristics of the sources of larval and juvenile supply), food availability, and selective removal by predation.

Geographic variations of the length characteristics of walleye pollock may change with age. Hughes and Hirschhorn (1979), in their study of the biology of walleye pollock in the western Gulf of Alaska noted that "size and age of adult pollock consistently increased when moving from the southeast Kodiak and Shelikof Strait regions westward through the Chirikof region and into the Sanak-Unalaska region." This trend is in the opposite direction to what we observed in 1980-81 for O-group fish and 1-yr-olds. However, in Hughes and Hirschhorn's table of mean lengths at age (Hughes and Hirschhorn 1979: Table 21, the mean lengths of 1-yr-olds in the various regions were described as follows:. Sanak, 20.00 cm (male); Chirikof, 19.49 cm (male), 20.02 cm (female); Kodiak, 23.07 cm (male), 23.09 cm (female); Shelikof, 20.71 cm (male), 20.74 (female); and Kenai, 21.92 cm (male), 21.23 cm (female). Thus, Hughes and Hirschhorn's results for 1-yr-olds are consistent with our own.

The geographic differences that we observed in length characteristics also provided further evidence that walleye pollock off the eastern side of Kodiak Island may originate from a separate spawning stock. Over the 3 yr, the length-frequency distributions of young of the year and 1-yr-olds showed least variation in the eastern Kodiak Island stratum (i.e., stratum 7).

Our studies of the feeding relationships of walleye pollock, the most abundant fish species in our surveys of bays and nearshore waters, indicated the potential importance of linkages between juvenile fish and their invertebrate prey, primarily in these inshore nursery areas. For example, one of the principal prey of 1-yr-old walleye pollock was juvenile caridean shrimp, a food category that included at least four shrimp species important in the region's commercial fisheries. It is conceivable that fluctuations in the year-class strength of walleye pollock might result in varying grazing pressures on juvenile shrimp, where they both occur in nursery habitats, which could subsequently affect shrimp recruitment. It would be useful to model the material exchanges and population dynamics that could result from feeding interactions of this type, and include grazing pressures from other sources.

ACKNOWLEDGMENTS

This paper is dedicated to the memory of the fishing vessel Commander and her crew. Skipper Phil Edwards, Jon Edwards, Sam Bisset, and Phil Edwards Jr. were lost at sea in the Gulf of Alaska shortly after completion of the 1980 ADF&G shrimp survey.

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APPENDIX

Table A-l .--Walleye pollock age-length table developed from otolith samples collected during the 1980 survey of bays and nearshore areas of the northwestern Gulf of Alaska, showing the number of observations at each length (up to 40 cm) and age.

Length (cm)	Age (yr)[a] 0	1	2	3	>4	Total
6	4	0	0	0	0	4
7	10	0	0	0	0	10
8	6	0	0	0	0	6
9	12	0	0	0	0	12
10	9	0	0	0	0	9
11	9	0	0	0	0	9
12	2	2	0	0	0	4
13	0	3	0	0	0	3
14	1	8	0	0	0	9
15	2	13	0	0	0	15
16	0	21	0	0	0	21
17	0	18	0	0	0	18
18	0	24	0	0	0	24
19	0	19	1	0	0	20
20	0	18	3	0	0	21
21	0	19	3	0	0	22
22	0	12	2	0	0	14
23	0	9	7	0	0	16
24	0	7	3	0	0	10
25	0	2	7	1	0	10
26	0	0	9	0	0	9
27	0	0	8	0	0	8
28	0	0	10	1	0	11
29	0	0	11	1	0	12
30	0	0	11	0	0	11
31	0	0	12	0	0	12
32	0	0	13	0	0	13
33	0	0	13	1	0	14
34	0	0	11	0	1	12
35	0	0	10	2	0	12
36	0	0	4	3	0	7
37	0	0	0	1	3	4
38	0	0	0	3	2	5
39	0	0	0	1	2	3
40	0	0	0	1	0	1
Total	55	175	138	15	8	391

[a] Determined by readings of the external surface of the otoliths.

Table A-2.--Walleye pollock age-length table developed from otolith samples collected during the 1981 survey of bays and nearshore areas of the northwestern Gulf of Alaska; showing the number of observations at each length (up to 40 cm) and age.

Length (cm)	Age (yr)[a] 0	1	2	3	≥4	Total
6	4	0	0	0	0	4
7	6	0	0	0	0	6
8	6	0	0	0	0	6
9	5	0	0	0	0	5
10	6	0	0	0	0	6
11	7	0	0	0	0	7
12	5	0	0	0	0	5
13	4	0	0	0	0	4
14	3	0	0	0	0	3
15	1	3	0	0	0	4
16	0	2	0	0	0	2
17	0	4	0	0	0	4
18	0	8	0	0	0	8
19	0	8	0	0	0	8
20	0	7	0	0	0	7
21	0	9	0	0	0	9
22	0	8	0	0	0	8
23	0	10	0	0	0	10
24	0	10	0	0	0	10
25	0	6	2	0	0	8
26	0	6	3	0	0	9
27	0	4	4	0	0	8
28	0	3	5	1	0	9
29	0	3	3	2	0	8
30	0	1	5	1	0	7
31	0	0	4	3	0	7
32	0	0	4	2	0	6
33	0	0	3	4	0	7
34	0	0	4	4	0	8
35	0	0	8	0	0	8
36	0	0	1	3	3	7
37	0	0	0	4	0	4
38	0	0	0	5	2	7
39	0	0	0	2	6	8
40	0	0	0	4	5	9
Total	47	92	46	35	16	236

a Determined by readings of the external surface of the otoliths and with "break and burn" techniques.

Table A-3.--Walleye pollock age-length table developed from otolith samples collected during the 1982 survey of bays and nearshore areas of the northwestern Gulf of Alaska, showing the number of observations at each length (up to 40 cm) and age.

Length (cm)	Age (yr)[a] 0	1	2	3	≥4	Total
14	0	1	0	0	0	1
15	0	2	0	0	0	2
16	0	3	0	0	0	3
17	0	5	0	0	0	5
18	0	5	0	0	0	5
19	0	4	0	0	0	4
20	0	5	0	0	0	5
21	0	4	0	0	0	4
22	0	4	0	0	0	4
23	0	4	0	0	0	4
24	0	4	0	0	0	4
25	0	1	1	0	0	2
26	0	0	1	0	0	1
27	0	1	1	0	0	2
28	0	0	0	0	0	0
29	0	0	2	0	0	2
30	0	0	2	0	0	2
31	0	0	3	0	0	3
32	0	0	2	2	0	4
33	0	0	1	2	0	3
34	0	0	2	2	0	4
35	0	0	0	3	1	4
36	0	0	0	4	0	4
37	0	0	0	3	1	4
38	0	0	0	4	0	4
39	0	0	0	1	3	4
40	0	0	0	1	3	4
Total	0	43	15	22	8	88

[a] Determined by readings of the external surface of the otoliths and with "break and burn" techniques.

Table A-4.--Arrowtooth flounder age-length table developed from otolith samples collected during the 1981 survey of bays and nearshore areas of the northwestern Gulf of Alaska, showing the number of observations at each length (up to 40 cm) and age.

Length (cm)	Age (yr)[a] 0	1	2	3	>4	Total
11	0	1	0	0	0	1
12	0	0	0	0	0	0
13	0	1	0	0	0	1
14	0	3	0	0	0	3
15	0	6	0	0	0	6
16	0	9	0	0	0	9
17	0	8	0	0	0	8
18	0	7	0	0	0	7
19	0	5	0	0	0	5
20	0	1	3	0	0	4
21	0	2	1	0	0	3
22	0	1	2	0	0	3
23	0	0	6	0	0	6
24	0	0	4	2	0	6
25	0	0	4	0	0	4
26	0	0	5	1	0	6
27	0	0	4	0	0	4
28	0	0	3	0	0	3
29	0	0	4	0	0	4
30	0	0	0	5	0	5
31	0	0	0	1	0	1
32	0	0	0	2	0	2
33	0	0	0	1	0	1
34	0	0	0	1	0	1
35	0	0	0	3	1	4
36	0	0	0	2	1	3
37	0	0	0	0	3	3
38	0	0	0	1	0	1
39	0	0	0	0	4	4
40	0	0	0	0	4	4
Total	0	44	36	19	13	112

[a] Determined by readings of the external surface of the otoliths.

Table A-5.--Flathead sole age-length table developed from otolith samples collected during the 1980 survey of bays and nearshore areas of the northwestern Gulf of Alaska, showing the number of observations at each length (up to 20 cm) and age.

Length (cm)	Age (yr)[a] 0	1	2	≥3	Total
3	1	0	0	0	1
4	0	0	0	0	0
5	0	0	0	0	0
6	0	6	0	0	6
7	0	6	0	0	6
8	0	6	0	0	6
9	0	6	0	0	6
10	0	4	2	0	6
11	0	1	7	0	8
12	0	0	12	0	12
13	0	0	10	0	10
14	0	0	7	4	11
15	0	0	5	4	9
16	0	0	1	7	8
17	0	0	0	10	10
18	0	0	2	8	10
19	0	0	0	9	9
20	0	0	0	11	11
Total	1	29	46	53	129

[a] Determined by readings of the external surface of the otoliths.

Table A-6.--Flathead sole age-length table developed from otolith samples collected during the 1981 survey of bays and nearshore areas of the northwestern Gulf of Alaska, showing the number of observations at each length (up to 20 cm) and age.

Length (cm)	Age (yr)[a] 0	1	2	≥3	Total
8	0	2	0	0	2
9	0	2	0	0	2
10	0	2	0	0	2
11	0	2	0	0	2
12	0	2	0	0	2
13	0	2	1	0	3
14	0	0	2	0	2
15	0	0	3	0	3
16	0	0	4	0	4
17	0	0	0	6	6
18	0	0	1	3	4
19	0	0	0	4	4
20	0	0	0	3	3
Total	0	12	11	16	39

[a] Determined by readings of the external surface of the otoliths.

Table A-7.--Flathead sole age-length table developed from otolith samples collected during the 1982 survey of bays and nearshore areas of the northwestern Gulf of Alaska, showing the number of observations at each length (up to 20 cm) and age.

Length (cm)	Age (yr)[a] 0	1	2	≥3	Total
9	0	2	0	0	2
10	0	2	0	0	2
11	0	1	1	0	2
12	0	0	0	0	0
13	0	0	2	0	2
14	0	0	0	4	4
15	0	0	0	4	4
16	0	0	0	3	3
17	0	0	0	3	3
18	0	0	0	3	3
19	0	0	0	4	4
20	0	0	0	3	3
Total	0	5	3	24	32

[a] Determined by readings of the external surface of the otoliths.