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Part I, Three-Year Comparisons

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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

Juvenile groundfish were studied in the northwestern Gulf of Alaska to describe 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 emphasizes comparisons of descriptive and analytical results for the study areas that received comparable sampling coverage over all 3 yr. Repetitive coverage was available for 12 major inlets along the central Alaska Peninsula and west and east sides of Kodiak Island. Data were used from a subset of 366 trawling stations.

Juveniles of at least 13 fishes were observed in these coastal nursery areas. Most abundant were: walleye pollock, Theragra chalcogramma; Pacific cod, Gadus macrocephalus; and sablefish, Anoplopoma fimbria. Each of these species was represented by the three youngest age groups.

Walleye pollock young of the year occurred in shallow areas of nearly all the inlets and showed a pattern of decreasing densities from north to south. over the 3 yr studied, year-class strengths measured at the O-group level varied from 272 individuals/lO,OOO m^2 in 1980, to 1,642 individuals/lO,OOO m^2 in 1981, to 197 individuals/10,000 m2 in 1982; the catch data from the 3 yr were found to be significantly different. One-yr-olds were also found in almost all areas and were abundant in the survey samples; their densities showed an opposite gradient, decreasing from south to north. Two-yr-olds were taken, but only in relatively low abundance.

Pacific cod young of the year were found in the shallow areas of inlets, primarily at depths less than 80 m. Year-class strengths measured at the

O-group level varied from 0.04 individuals/lO,OOO m^2 in 1980 (based on only one catch), to 7.16 individuals/lO,OOO m^2 in 1981, to 1.29 individuals/lO,OOO m^2 in 1982; however, variation in the catch data over the 3 yr was not statistically significant. Because of their shallow distributions, 0-qroup populations may not have been surveyed with the same effectiveness from year to year. One and two-yr-olds occurred at only a few stations and showed spotty densities.

Sablefish showed a rather distinct separation of fish at different ages. Young of the year were observed only in 1981, when they were found in the shallows of three inlets. One-yr-olds occurred at relatively high densities in all 3 yr and were the dominant age group. Year-class strenqths measured at the 1-yr-old level varied from 9.65 individuals/lO,OOO m^2 in 1980, to 1.02 individuals/lO,OOO m^2 in 1981, to 3.30 individuals/lO,OOO m^2 in 1982; the catch data, however, did not differ significantly between years. Two-yr-olds were only incidentally taken.

Problems that were encountered and indicated a need for further research included the following areas: the evaluation and improvement of the methods used for population estimation; the development of procedures for associating statistical confidence intervals with point estimates of age group abundance; exploratory sampling, both on-bottom and in midwater, to improve our understanding of distribution patterns and seasonal movements; the reevaluation of sample size requirements and the appropriate survey scope needed to detect changes. Some of these subjects will be addressed in two additional reports.

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INTRODUCTION

This study reports the results from our participation in three shrimp and juvenile fish surveys conducted in the northwestern Gulf of Alaska during the late summer periods, of 1980-82. The surveys were made by the Alaska Department of Fish and Game (ADF&G), as part of an on-going-census series, for the purpose of assessing the abundance of shrimp populations in the bays and nearshore waters of the central Alaska Peninsula and Kodiak Island. Because juvenile and adult groundfish were reported to occur commonly in the ADF&G samples, it seemed likely that these surveys could provide useful information on the distribution, relative abundance, and other ecological characteristics of these groups.

We participated as guests on the ADF&G surveys for the 3 yr to increase the-sampling coverage of fishes within trawl catches and to build standard sets of observations that would enable interannual comparisons. Objectives for our studies 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.

Background

Groundfish populations in the Gulf of Alaska are sources of supply for large and important commercial fisheries. Foreign trawl and longline fisheries have operated in the region since the early 1960's, and in 1982 these fisheries harvested 152,853 metric tons (t) of groundfish from the U.S. fishery conservation zone (Thompson 1983). Approximately 20-30 fish species accounted for most of the catch. Particularly important were: walleye pollock, *Theragra chalcogramma*; Pacific cod, *Gadus macrocephalus*; Atka mackerel, *Pleurogrammus monopterygius*; rockfish, including Pacific ocean perch, *Sebastes alutus*, and about l0-13 other *Sebastes* spp.; sablefish, *Anoplopoma fimbria*; and several pleuronectid flatfish. Domestic trawl and longline fisheries have also become important in the region, primarily directed toward Pacific cod (6,434 t landed in 1982), sablefish (3,008 t, 1982) and Pacific halibut, *Hippoglossus stenolepis* (15,137 t, 1982). In addition, a large joint-venture fishery has recently developed that targets on prespawning and spawning, walleye pollock in the Shelikof Strait region (Alton 1983).[1/] As catches by this fishery have grown from 1,136 t in 1980 to 131,391 t in 1983, it has become one of the important new fisheries off Alaska.

One of the needs for efficient management of these and other fisheries is a better understanding of the variability in fish abundance (Beddington and May 1977; Martin l979; Doubleday 1980). Important questions are: What are the characteristic temporal variations in resource availability, what are the sources of uncertainty, and to what extent can resource fluctuations be predicted? Much of the variation in stock size and production is due to varying levels of recruitment (Cushing 1977). The size of the spawning population, amount of egg production, and abiotic and biotic factors affecting survival in the prerecruit life history period--i.e., egg, larval, and juvenile stages--may all be important in determining subsequent year-class abundance and the number of recruits.

In general, studies of the reproductive biology and early life history periods of most Gulf of Alaska groundfish are in an early, descriptive phase of investigation. Most of the literature that applies to the region is

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[1/] A joint-venture is an arrangement between U.S. and foreign interests in which U.S. vessels catch and sell fish to foreign processing vessels operating in the U.S. fishery conservation zone.

summarized by Garrison and Miller (1982), though their study was directed toward the Puget Sound. Hirschberger and Smith (1983) described spawning locations, seasonal timing, and depths for several important species throughout Alaskan and pacific coast waters. Ichthyoplankton studies in the Kodiak Island region have provided useful information on the seasonal timing, geographic distribution, and abundance of egg and larval stages for a large number of continental shelf species (Borets 1979; Dunn et al. 1979; Kendall et al. 1980a, b; Bates and Clark 1983; Kendall and Dunn 1984). Surveys of the nearshore zone, bays, estuaries, and fjords have provided evidence that these areas are important nurseries for larval and juvenile stages of many fish species (Carlson and Haight 1976; Harris and Hartt 1977; Blackburn and Jackson 1978). At these locations, the larvae and juveniles are often important prey for other fishes (Feder and Jewett 1977; Gosho 1977; Jewett 1978; Feder et al. 1979; Hunter 1979; Rogers et al. 1980), seabirds (Sanger et al. 1978; Krasnow et al. 1979; Sanger 1983), and marine mammals (pitcher 1980, 1981). Juvenile fishes may themselves be important predators of some life history stages of the pandalid shrimp species that co-occur in these habitats (Hunter 1979).

Specific Research Issues

Three of the most important groundfish resources in the region are walleye pollock, pacific cod, and sablefish. Walleye pollock has been an important component of the foreign groundfish catch in the Gulf of Alaska since 1972, and in 1982 accounted for 60.5% of the total catch (Thompson 1983). Assessments of the availability of the resource have been based on catch per unit of effort (CPUE) indicators from the commercial fisheries, or made from analyses of catch-at-age and acoustic surveys (Alton and Deriso 1983a, b). The age of first recruitment to offshore trawl fisheries, however, is approximately 2-3 yr; little is known of the biology of walleye pollock during the prerecruit period, nor are there many sources of information. Shelikof Strait has been found to be a major spawninq site (Nunnallee et al. 1982; Alton 1983). Eggs and larvae are planktonic and, therefore, subject to variable transport by ocean currents and other environmental uncertainties affecting dispersal and survival. Although the fisheries data are subject to imprecision from sources such as varying catchability, the 7-yr time series of age data available indicates that strong year-classes (compared to the 1973 and 1974 groups) were spawned in 1975, 1976, 1977, 1978, and 1979. Because of the large annual catch quotas for walleye pollock and rapid build-up of a large harvesting capacity by the joint-venture fisheries, it would be desirable to improve our abilities to forecast resource conditions so as to enable the use of a more adaptive manaqement approach.

The importance of Pacific cod in the Gulf of Alaska groundfish catch has grown since 1977 as a result of increased targeting by foreiqn lonqline fisheries and the development of new U.S. fisheries (Zenger 1983). Unfortunately, age determination methods for cod are unreliable, and assessments of the resource rely primarily on CPUE indicators from the commercial fisheries and survey statistics for CPUE and length composition. Consequently, there is limited ability to estimate stock production or model population dynamics. The age of recruitment to trawl and longline fisheries is about 3 yr; like walleye pollock, the bioloqy of cod durinq the prerecruit phase is poorly understood. Pacific cod apparently spawn offshore at depths of 150-250 m and have demersal eqqs (Ketchen 1961; Thomson 1963; Hirschberger and Smith 1983), but larvae can be found in the plankton (Bates and Clark 1983). The recruitment pattern of Pacific cod in the eastern Bering Sea, where there is a 9-yr data series, indicates large variations in year-class abundance (Wespestad et al. 1982; Bakkala and Wespestad 1984). This pattern is also typical of

Atlantic cod, Gadus morhua, although the variation in recruitment appears to be less extreme than that of other exploited stocks (Hennemuth et al.1980). In the Gulf of Alaska, based on qualitative analyses of length-frequencies, the year-classes spawned in 1977 and 1980 have been described as being relatively strong (Zenger 1983).

Sablefish is an important resource for foreign and domestic longline fisheries, and stocks in the Gulf of Alaska are presently being monitored for signs of recovery from past overfishing (Stauffer 1983): Assessments of resource condition are based on a mix of different CPUE indicators from the commercial fisheries and surveys. Similar to the situation with Pacific cod; though, age determination methods have been unreliable and there is only limited ability to analyze population dynamics. The length of first recruitment to fisheries is about 42 cm fork length (at an age of about 3 yr), with 50% recruitment at 55 cm and full recruitment at 62-65 cm (Balsiger 1983). In waters off western Canada, spawning occurs mainly along the continental slope at depths >300 m, eggs hatch in deep water, and then young stages move into the surface layers (Mason et al. 1983). A general onshore movement occurs, followed by a period when juveniles are found in inshore waters and major inlets (McFarlane and Beamish 1983a). It appears that over extensive parts of the species range--e.g., off western Canada, in the Gulf of Alaska, and in the eastern Bering Sea--the recruitment of sablefish is characterized by infrequent, strong year-classes that become important components of the regional stocks (McFarlane and Beamish 1983b; Sasaki 1983; Stauffer 1983; Umeda et al. 1983). The 1977 year-class has received attention for having been identified as a year-class showing this type of exceptional abundance.

Organization of Study

The results of our studies will be reported in three parts, of which this paper is the first. The three parts are as follows:

1. Three-year comparisons;
2. Biological characteristics in the extended region; and
3. Estimation of sample size requirements.

The present report emphasizes 3-yr comparisons of descriptive and analytical results for the three major species: walleye pollock, Pacific cod, and sable-fish. This work was based on, and limited to, the subregions of the total study area that received relatively consistent sampling coverage over all 3 yr. The second report will describe results from the complete sampling coverage in each of the 3 yr, for additional species, and from other types of studies. The third report will contain an intensive analysis of quantitative aspects of the study--including evaluations of data characteristics, appropriate statistical distribution models, and estimation of sample size requirements.

MATERIALS AND METHODS

Experimental Design

The data used in this study for interannual comparisons were from a subset of the 749 total stations occupied during the 1980-82 ADF&G shrimp surveys, and included 366 trawling stations in 12 major inlets (strata) between long. 152-159°W (Fig. 1, Table 1). Strata were designated by the name of the bay or associated nearshore waters, and generally consisted of waters within individual inlets whose depth exceeded 40-90 m. Many of the inlets surveyed are parts of glacially-cut valleys and fjords, and are deeper than much of the surrounding continental shelf (Sharma 1979).

Strata (inlets) and stations were selected on the basis of providing the best repetition of systematic sampling coverage as possible over all 3 yr. Unfortunately, because many areas were surveyed by ADF&G in only one or two years, about 51% of the available data could not be used. These results will be described in the second report of the three-part series.

The 12 strata were grouped into three regions: the central Alaska peninsula, east Kodiak Island, and west Kodiak Island. Bays of Kodiak Island were classified as belonging to eastern or western regions on the basis of their likely hydrographic relationships. Water circulation along the southeast side of Kodiak Island is dominated by strong, southwestward flow of the Alaskan Stream (net drift 10-30 cm/s) seaward of the shelf break (Favorite 1967; Thomson 1972; Reed et al. 1980); inshore over the continental shelf, surface flow is weak (net drift 2-3 cm/s southwest), dominated by tidal currents, and made complex by the effects of troughs and banks (Ingraham 1981). Circulation on the northwest side of Kodiak Island consists of a strong, seasonally-varying, southwesterly flow through Shelikof Strait (net drift 20-30 cm/s); this flow results from southwestward continuation of the coastal Kenai Current and the

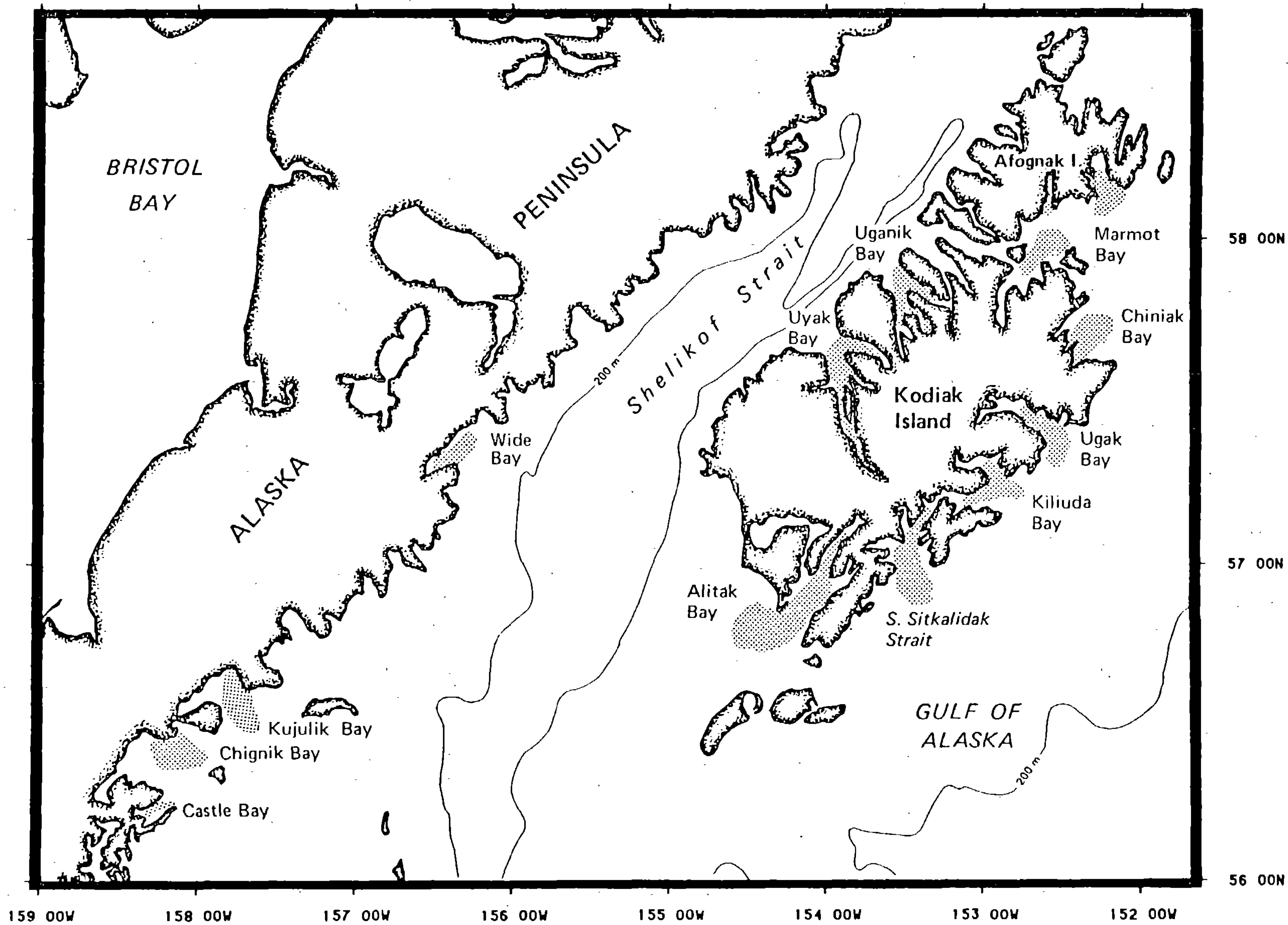

Figure 1.--Map of the study area in the northwestern Gulf of Alaska showing the 12 strata used for estimating juvenile fish abundance, 1980-82.

Table 1.-- Survey areas used in the northwestern Gulf of Alaska for estimating juvenile fish abundance, geographic areas, and sampling effort, 1980-82.

Stratum[a]	Geographic area (Km^2)	Number of tows			
		1980	1981	1982	Total
Alaska Peninsula					
Wide Bay	25.8	6	6	6	18
Kujulik Bay	74.0	10	11	10	31
Chignik Bay	114.0	9	8	7	24
Castle Bay	28.5	4	4	4	12
Subtotal	242.3	29	29	27	85
East Kodiak Island					
Marmot Bay	195.9	11	12	16	39
Chiniak Bay	58.2	6	10	8	24
Ugak Bay	91.9	11	11	10	32
Kiliuda Bay	154.2	10	10	9	29
S. Sitkalidak Strait	235.8	12	12	16	40
Subtotal	736.0	50	55	59	164
West Kodiak Island					
Uganik Bay	69.6	8	8	7	23
Uyak Bay	88.2	9	9	8	26
Alitak Bay	426.6	18	29	21	68
Subtotal	584.4	35	46	36	117
Total	1562.7	114	130	122	366

[a] See Figure 1.

alongshore pressure gradient induced by the Alaskan Stream (Schumacher and Reed 1980; Mysak et al. 1981).

Strata in the central Alaska Peninsula region were: Wide Bay, Kujulik Bay, Chignik Bay, and Castle Bay. Major inlets that were surveyed in the east Kodiak Island region were: Marmot Bay, Chiniak Ray, Ugak Bay, Kiliuda Bay, and south Sitkalidak Strait. Bays surveyed in the west Kodiak Island region were: Uganik Bay, Uyak Bay, and Alitak Bay (including Deadman Bay). Table 1 summarizes the geographic area of these survey areas and the yearly sampling effort.

Survey Approach

Many aspects of each year's survey--e.g., samplinq design, timing, and field methods--were beyond our control due to the nature of our involvement as quest observers. The four stern trawling vessels that ADF&G used to conduct the 1980-82 shrimp surveys were similar in size and power, approximately 25-30 m in length and 500-600 hp. All the surveys were conducted in late summer and most sampling was done in September (Table 2).

The sampling technique followed a form of stratified random sampling. The boundaries of strata were defined by charted contour lines for specific bottom depths. In the shallowest strata, Alitak and Wide Bays, the survey areas included all waters deeper than 20 fathoms (37 m). In Kujulik, Chignik, Castle, Marmot, and Chiniak Bays the survey areas included all waters deeper than 40 fathoms (73 m). The survey areas in Ugak, Kiliuda, Uganik, and Uyak Bays and south Sitkalidak Strait included all waters deeper than 50 fathoms (91 m). Each year, depending on the amount of time available for surveying, the sampling effort was distributed among strata on a proportional basis. The allocation of samples within strata, and station pattern, was based on a subdivision of strata into 1 mi^2 statistical blocks. The statistical blocks to be sampled

Table 2.--Summary of survey dates, starting and ending locations, and direction of travel for each fishing vessel used during the 1980-82 shrimp surveys conducted in the northwestern Gulf of Alaska by the Alaska Department of Fish and Game.

			Survey period		Stratum[a]		
Year	Vessel	Region	Start	End	Start	End	Progression
1980	Royal Baron	Kodiak Island	23 Aug.	5 Sept.	Ugak	Marmot	Southwest
	Resolution	Kodiak Island	9 Sept.	15 Sept.	Marmot	Chiniak	Southwest
	Commander	Peninsula	12 Sept.	18 Sept.	Castle	Wide	Northeast
1981	Resolution	Kodiak Island	3 Sept.	27 Sept.	Chiniak	Marmot	Southwest
	Alaska	Peninsula	12 Sept.	18 Sept.	Castle	Wide	Northeast
1982	Royal Baron	Kodiak Island	24 Aug.	10 Sept.	Uganik	Marmot	Southwest
	Royal Baron	Peninsula	11 Sept.	21 Sept.	Castle	Wide	Northeast

[a] See Figure 1.

were picked by random selection, then a trawling station was assigned to each one.

Sampling Gear

The ADF&G shrimp surveys used identical sampling gear each year: a high-opening, small mesh 61-foot shrimp trawl (Wathne 1977:fig. 11). The trawl was constructed primarily of 32 mm mesh netting and had 18.6 m (61 ft) head-rope and footrope lengths. Based on the studies of gear performance reported by Wathne (1977), the ADF&G shrimp trawls were assumed to have an effective path width (i.e., net spread) of 9.8 m and a 3.5 to 4.1 m vertical opening. The trawl was used with a 16.8 m (55 ft) tickler chain, and was rigged to make the net fish approximately 30 cm off the bottom. In this study, it was not possible to evaluate selective or biasing characteristics of the sampling gear other than from interpretations of the survey results.

Field procedures

One biologist from the National Marine Fisheries Service (NMFS) accompanied each ADF&G vessel during each survey. Standard methods of fish resource surveys as described by Smith and Bakkala (1982) were used, scaled to be employed by the available personnel. A single 15 or 30 min bottom tow was taken at each trawling station.

Station position and distance towed were determined by Loran-C or radar fixes. The area of bottom "swept" by the trawl was estimated from the distance towed multiplied by the path width measured by Wathne (1977) and was generally between 10,000 and 20,000 m^2. Station data collected at each site included: position, mean bottom depth, time of day, distance towed,. and sea surface temperature. Water column temperatures were obtained from expendable bathythermograph (XBT) profiles taken at 175 stations.

Trawl catches were sampled using the shipboard procedures of Hughes (1976). Fish and invertebrates were sorted by taxa, identified to the lowest reliable taxonomic level, weighed, and counted. Fish length-frequency measurements, recorded to the nearest centimeter, were obtained from species of particular interest using randomly selected subsamples. Walleye pollock, Pacific cod, and sablefish were measured by fork length. Saccular otoliths were collected from walleye pollock and sablefish, and scale scrape samples were collected from Pacific cod, for age determinations.

Analytical Procedures

The analyses used in this study followed two principal approaches. The simplest form of analysis was the summarization and presentation of basic catch data. More complex statistics were used for estimation of year-class population abundance. Both approaches had certain advantages and limitations.

Population estimates were based on the "area swept" methods of Alverson and Pereyra (1969), using the equations elaborated by Smith and Bakkala (1982: equations l-19), except that number of individuals instead of weight was estimated. Population size composition was calculated by proportioning the population estimates by the overall fraction of each 1 cm size class within all length-frequency observations (Smith and Bakkala 1982:equations 20-21).

The principal method used to assign ages was to classify size categories into age groups using the normal curve separation (NCS) techniques of MacDonald and Pitcher (1979). This method is particularly useful for distinguishing young age groups with clearly defined modes in the length-frequency distributions.

For the lengths and ages of walleye pollock and Pacific cod of interest to us in this study, we considered the NCS method preferable to using age-length tables. The NCS method was used to estimate length intervals corresponding to the three youngest age groups and to proportion estimates of population size composition into age-frequency distributions. Ages determined from walleye pollock otolith samples collected during the surveys were used to validate our assignments of ages to length modes.

Because of the problems and uncertainties in determining the ages of sablefish, we relied upon interpretations of ages from the length-frequency distributions and an age-length table built from otolith samples collected on the 1981 survey. Applications of both methods were aided by the studies of Beamish and Chilton (1982). The NCS method Was used to estimate length intervals for the three youngest age groups of sablefish. However, the single age-length table was used to estimate population age-frequency distributions for all three survey years.

Estimates were made, for each species, of the population number of the three youngest age groups (young of the year, l-yr, and 2-yr) in each of the 12 strata; these indicators were used for evaluating geographical distribution and the relative importance of different regions. Standardized densities were then computed by dividing the population estimates by the corresponding geographic areas; these indicators were used to measure relative concentration and year-class strengths.

The basic catch data were used to examine statistical characteristics of the density distributions of the different species and age groups, to display geographic and depth distributions, and for testing interannual variations in abundance. The relative density of fish at each station was calculated, by species, as the ratio of the number caught and-the estimate of bottom area sampled (number/10,000 m^2). To examine the distribution of particular size and age groups, the apparent densities were proportioned according to the fraction that a specific size group was represented in the length-frequency measurements taken at each station. The size groups used were nonoverlapping length intervals based on the results from the NCS analyses.

Although we believed the best measures of year-class abundance should be the estimates of population number and standardized densities, because of their rigorous calculation, these indicators were limited by the inability of our procedures to carry information on statistical variance through all analytical steps. As a result, since the precision of the population estimates was unknown, it was not possible to directly test if year-to-year variations in abundance were significantly different. Instead, we accomplished testing in an indirect manner by using the simple, unweighted catch data (i.e., individual sample values of fish densities) in a Kruskal-Wallis sum of ranks or H test (Tate and Clelland 1959).

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RESULTS

General Characteristics

Most of the shrimp trawl tows were taken at bottom depths between 40 and 140 m, in all 3 yr (Fig. 2). specific sampling limits were: 1980, 38-205 m; 1981, 35-199 m; and 1982, 33-203 m.

Sea surface temperatures (SST) were warmest in 1981 and coldest in 1982 (Fig. 3). During August-September 1980, mean SST was 10.8°C (range 9.4 to 12.5°C); in September 1981, mean SST was 11.4°C (8.8 to 13.2°C); and during August-September 1982, mean SST was 10.5°C (8.8 to 12.6°C). Bottom water temperatures (BWT) were relatively warm in 1980-81 and coldest in 1982 (Fig. 4). In 1980, mean BWT was 8.5°C (range 5.7 to 10.5°C); in 1981, mean BWT was 8.6°C (3.6 to 11.6°C); and in 1982, mean BWT was 7.1°C (2.1 to 10.3°C).

A total of 80 fish taxa, representing 21 families, and 64 invertebrate taxa were identified from the 366 trawl samples. Particularly prominent groups were cottids (sculpins, 20 species), pleuronectids (righteye flounders, 11 species), cyclopterids (snailfishes, 7 species), and scorpaenids (scorpionfishes, 7 species) which together represented 56% of the total fish taxa. Caridean shrimp species accounted for almost 22% of the total invertebrate taxa. Only minor differences were noted in the fauna1 lists from year to year.

Regional variations in the species composition of the trawl catches consisted mainly of changes in the relative abundance of the dominant taxa, and changes in the presence or absence of relatively rare species. Important factors appeared to be region, depth, and bottom conditions. Catches in the central Alaska Peninsula region were dominated on a weight basis by: walleye pollock; flathead sole, Hippoglossoides elassodon; pink shrimp, Pandalus borealis; Pacific cod; and humpy shrimp, P. goniurus. In the east Kodiak

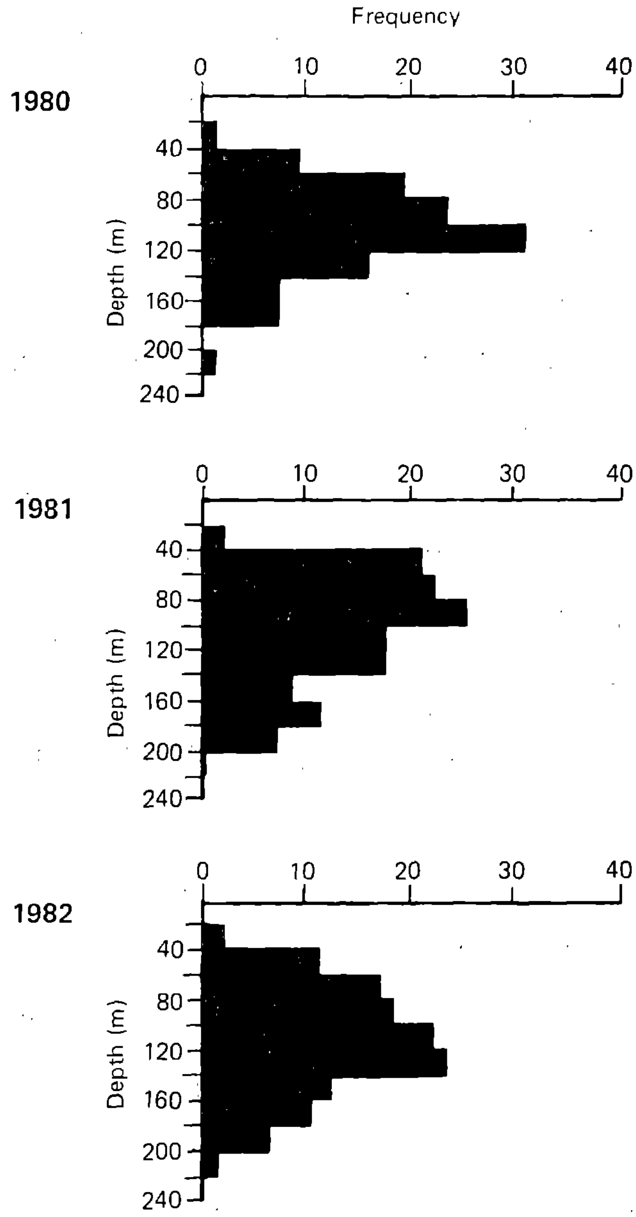

Figure 2.--Sampling depths of shrimp trawl tows taken during the three years of investigations in the northwestern Gulf of Alaska, 1980-82.

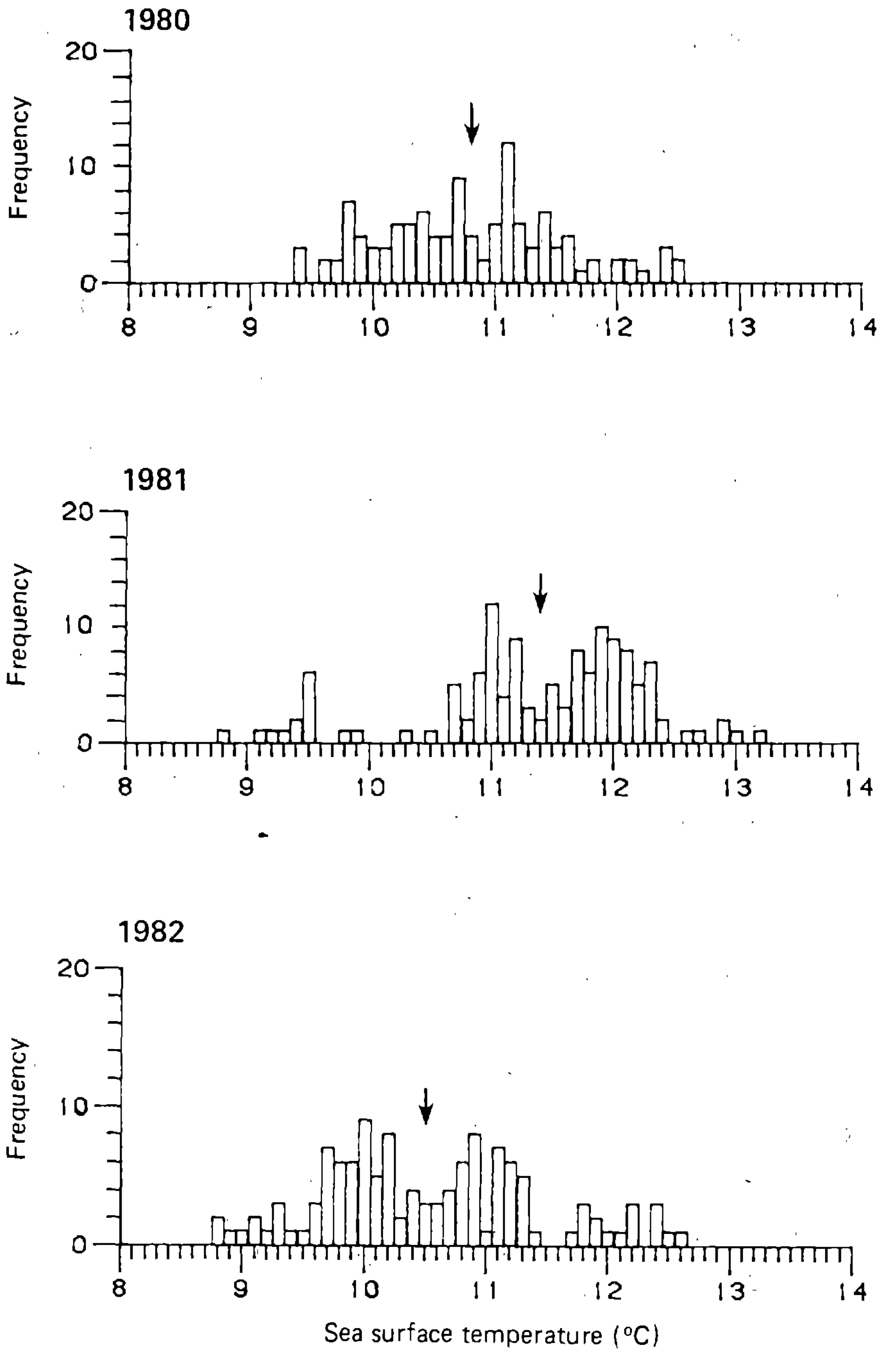

Figure 3.--Sea surface temperatures observed during the three years of investigations in the northwestern Gulf of Alaska, 1980-82. Arrows show mean values.

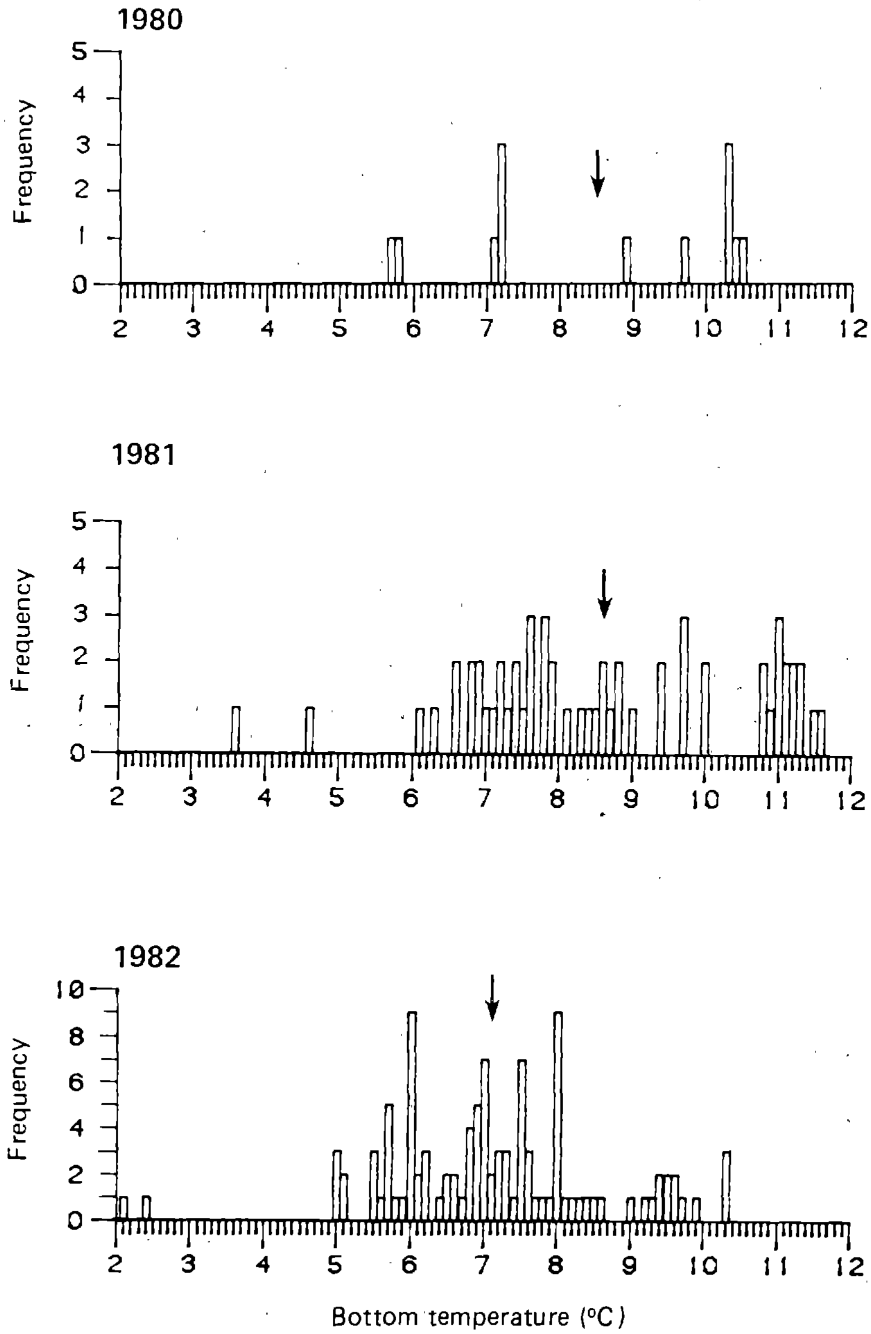

Figure 4.--Bottom water temperatures observed during the three years of investigations in the northwestern Gulf of Alaska, 1980-82. Arrows show mean values.

region catches were dominated by pink shrimp, jellyfish, walleye pollock, flathead sole, and arrowtooth flounder. Catches in the west Kodiak Island region were dominated by pink shrimp, walleye pollock, flathead sole, humpy shrimp, and yellowfin sole, Limanda aspera.

Juveniles of 13 species of fishes were noted over the 3 yr of surveys. Juveniles <15 cm length observed, and the number of years in which they occurred, were: walleye pollock, 3; Pacific cod, 3; flathead sole, 3; yellowfin sole, 3; rex sole, Glyptocephalus zachirus, 3; Pacific herring, Clupea harengus pallasi, 3; arrowtooth flounder, Atheresthes stomias, 2; rock sole, Lepidopsetta bilineata, 2; Pacific halibut, 1; northern rockfish, Sebastes polyspinis, 1; Pacific tomcod, Microgadus proximus, 1; and Pacific sandfish, Trichodon trichodon, 1. In addition, juvenile sablefish <50 cm length occurred all 3 yr. Juveniles of eight species occurred at lengths <10 cm. These included, with the number of years observed: walleye pollock, 3; Pacific cod, 3; flathead' sole, 3; yellowfin sole, 2; arrowtooth flounder, 1; rock sole, 1; Pacific tomcod, 1; and Pacific sandfish, 1.

Walleye Pollock

Walleye pollock occurred in 351 (95.9%) of the 366 trawl samples, and was the most abundant fish species taken during each of the three survey years. Although the total size range of fish in the samples was 6 to 72 cm, the majority were juveniles smaller than 30 cm (Fig. 5). In all 3 yr, the length-frequency distributions of walleye pollock showed distinct modes that could be attributed to the two youngest age groups--i.e., young of the year (O-group) and 1-yr-olds. These, and the length distributions of 2-yr-olds, were analyzed using the NCS method to determine length intervals corresponding to each age. Based on these results, subsequent analyses of the geographic and bathymetric distribution patterns of O-group walleye pollock were done

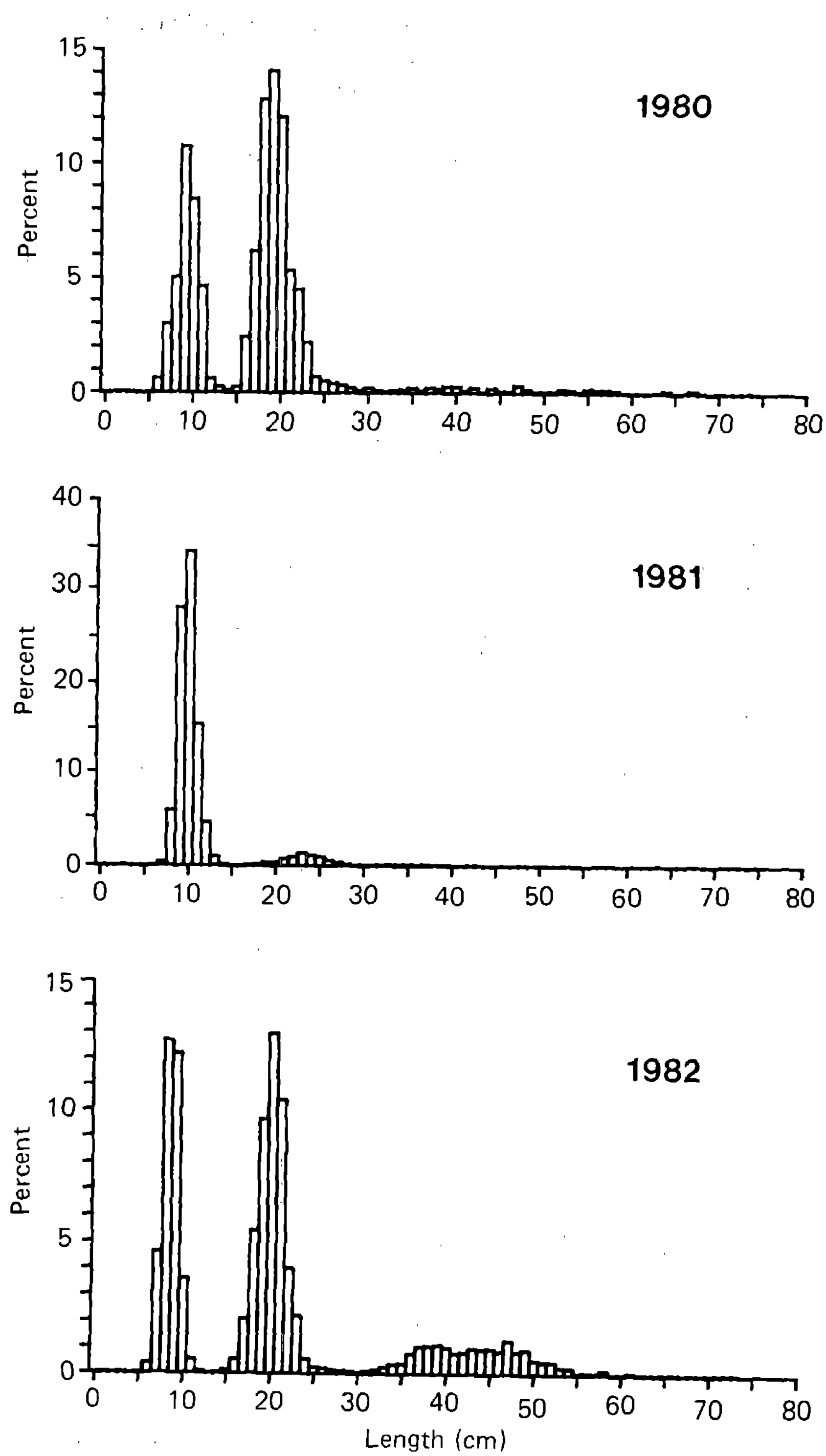

Figure 5.--Length-frequency distributions of walleye pollock taken in the northwestern Gulf of Alaska, 1980-82.

using the interval 5-15 cm for all 3 yr. One-yr-olds were estimated using the interval 16-23 cm for 1980 and 1982; the interval 16-25 cm was used for 1981 data because of generally larger sizes at age. Although the length modes of 2-yr-olds were not as clearly distinguished, 2-yr-olds were estimated using the interval 24-31 cm for 1980 and 1982 and 26-31 cm for 1981.

O-Group

Young-of-the-year walleye pollock, approximately 6 mo old, were found in 10 of the 12 inlets in 1980, and in all strata in 1981 and 1982 (Fiqs. 6-8). Number of occurrences in samples were: 1980, 65; 1981, 115; and 1982, 77. Mean lengths were: 1980, 9.2 cm; 1981, 9.9 cm; and 1982, 8.5 cm.

The catch data for O-group walleye pollock, and for the other age groups and species studied, resulted in frequency distributions that were skewed to the left (Fig. 9). At a large number of stations, a particular species and age group was either absent or present in only low densities. High densities were observed at only a few locations. These characteristics of the data--i.e., that the fish showed contagious distributions and that the catch data were not normally distributed--also placed limitations on the statistical analyses used in the study and had important implications for evaluations of the appropriate experimental design for further work. Some aspects of this problem are discussed in the present study, and others will he elaborated in the third report of the three-part series.

Population estimates for the 12 strata, 3 regions, and study area as a whole are shown in Table 3. Over the 3 yr studied, the total number of 0-group walleye pollock varied from 42.4 million in 1980, to 256.6 million in 1981, to 30.7 million in 1982. Bays that supported large populations were : Chiniak and Alitak Hays in 1980; Alitak, Ugak, and Kiliuda Bays in

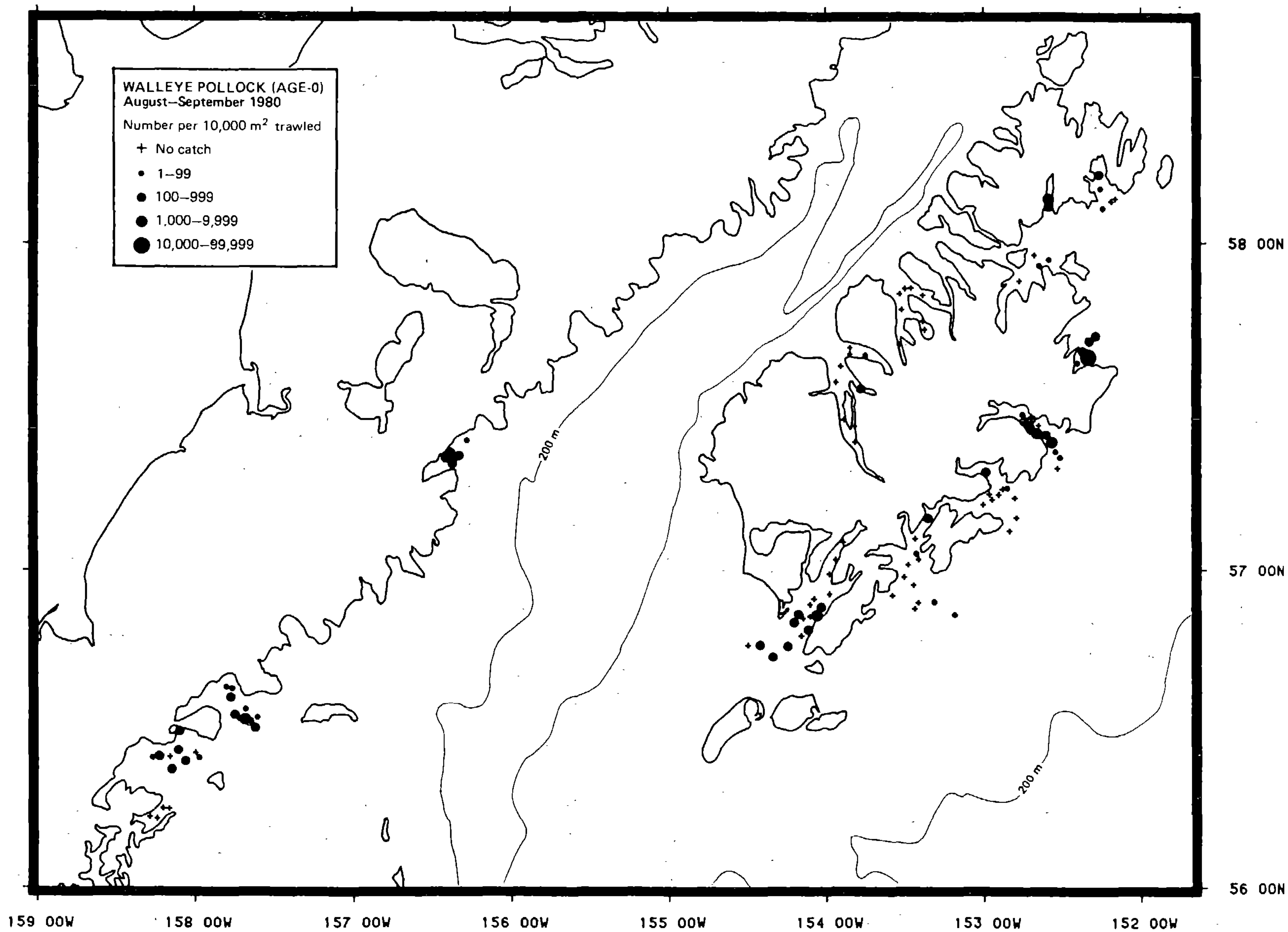

Figure 6.--Distribution and relative abundance of O-group walleye pollock in the northwestern Gulf of Alaska in 1980.

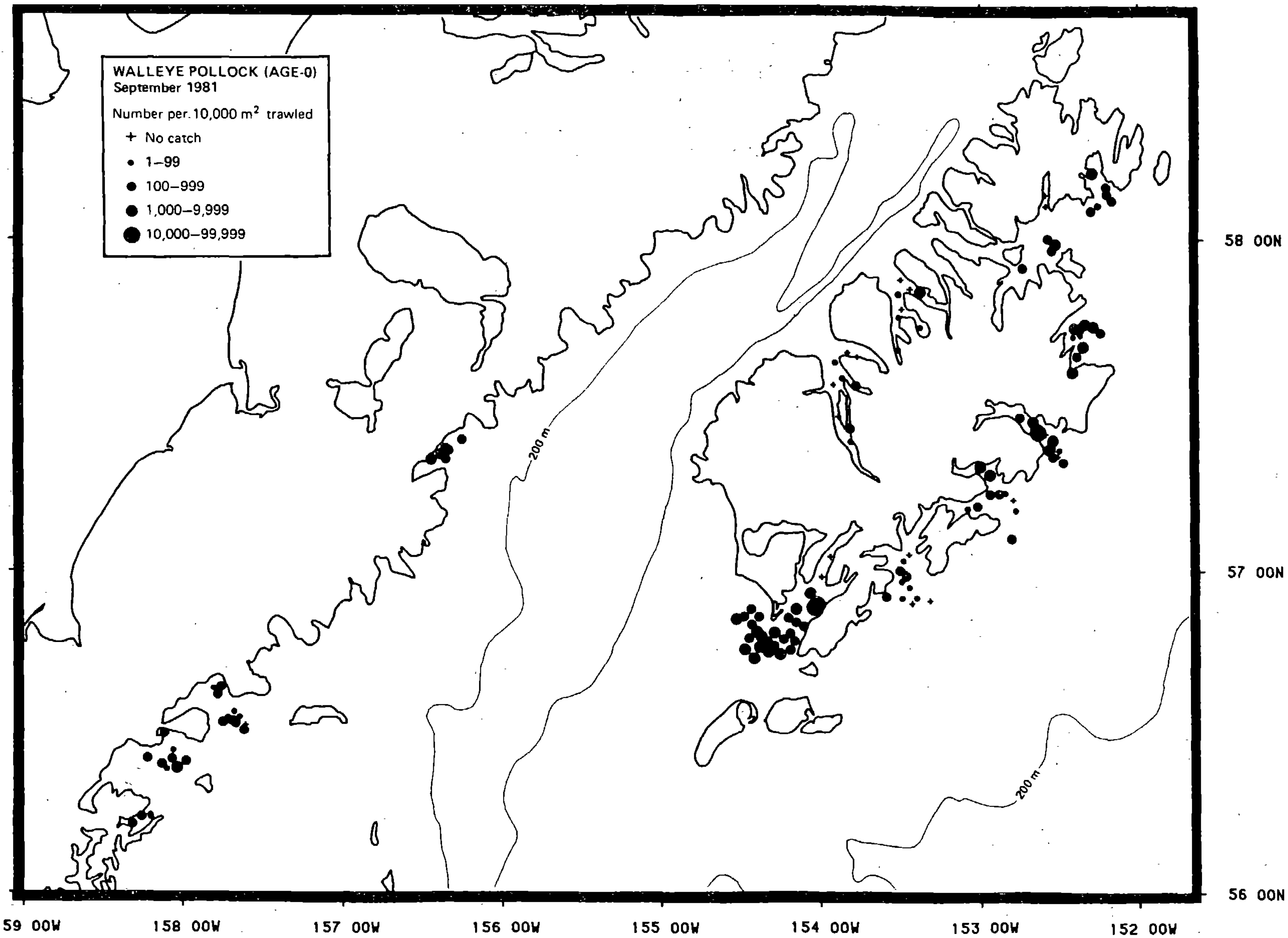

Figure 7.--Distribution and relative abundance of 0-group walleye pollock in the northwestern Gulf of Alaska in 1981.

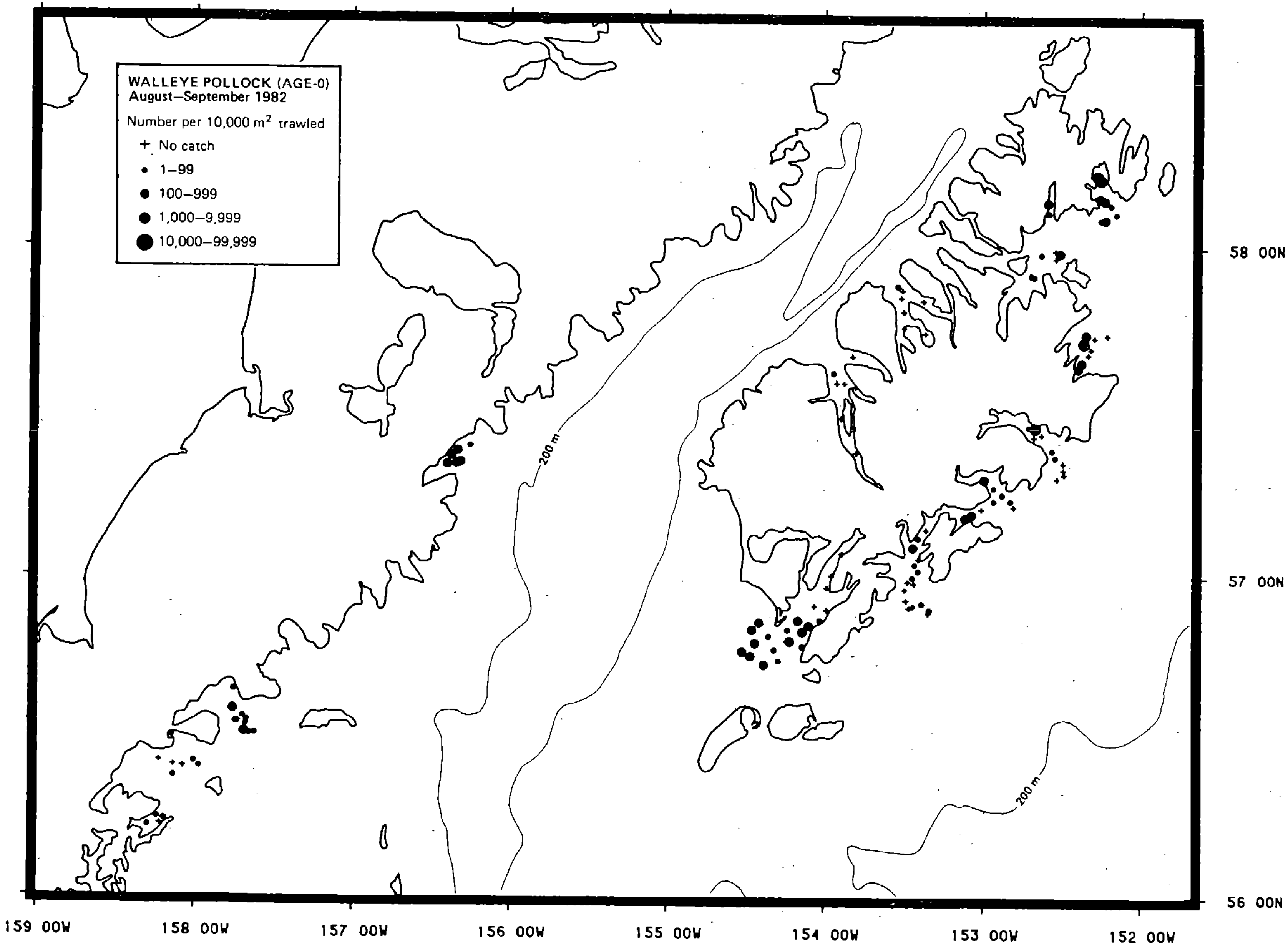

Figure 8.--Distribution and relative abundance of O-group walleye pollock in the northwestern Gulf of Alaska in 1982.

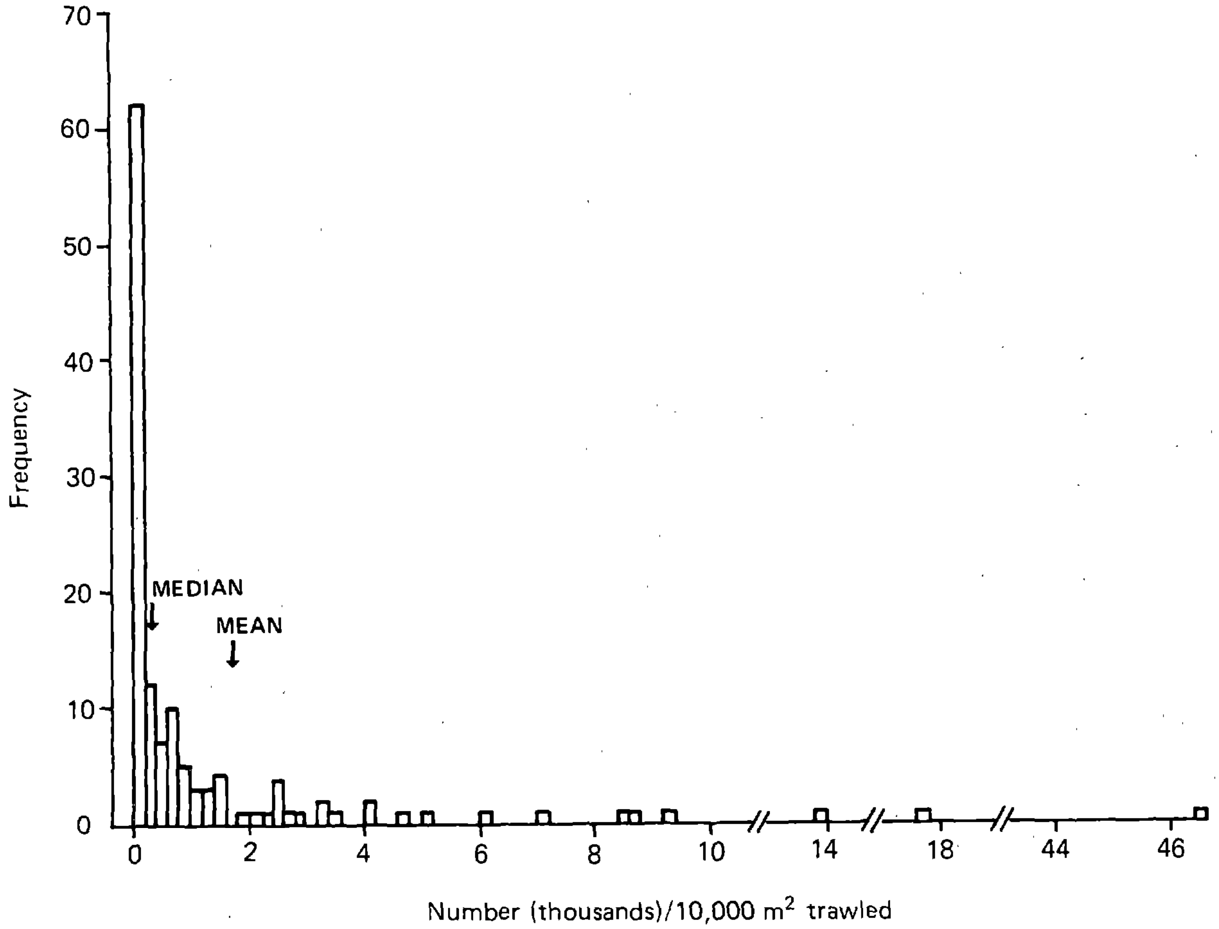

Figure 9. --Example of the type of skewed frequency distribution that was characteristic of the catch data for juvenile groundfish, showing the 1981 catch data for O-group walleye pollock.

Table 3.--Estimated population size of juvenile age groups (0-2 yr) of walleye pollock in bays and nearshore areas of the northwestern Gulf of Alaska during late summer periods, 1980-82.

Stratum[a]	Estimated population (millions)								
	1980			1981			1982		
	0	1	2	0	1	2	0	1	2
Alaska Peninsula									
Wide Bay	1.75	0.36	--	2.57	1.04	--	0.93	0.24	0.04
Kujulik Bay	1.85	6.26	0.09	4.11	0.43	0.01	0.85	1.10	0.03
Chignik Bay	1.03	29.02	0.26	4.04	6.61	0.87	0.09	0.81	0.02
Castle Bay	--	20.47	0.46	0.70	0.23	0.01	0.03	1.22	0.01
Subtotal	4.63	56.11	0.81	11.42	8.31	0.89	1.90	3.37	0.10
East Kodiak Island									
Marmot Bay	3.60	0.35	0.48	11.90	1.01	5.93	9.38	0.25	0.23
Chiniak Bay	18.55	0.02	--	9.95	0.15	0.24	6.52	0.01	--
Ugak Bay	3.99	0.03	--	29.79	0.02	--	1.15	0.88	0.17
Kiliuda Bay	0.80	--	0.37	15.00	0.46	0.01	1.25	0.05	<0.01
S. Sitkalidak Strait	2.05	0.04	0.01	2.66	0.70	0.21	0.47	0.91	0.21
Subtotal	28.99	0.44	0.86	69.30	2.34	6.39	18.77	2.10	0.61
West Kodiak Island									
Uganik Bay	--	1.03	0.29	1.25	0.17	0.99	0.07	1.57	0.08
Uyak Bay	0.20	2.45	0.41	0.49	1.75	0.08	0.09	4.74	0.07
Alitak Bay	8.61	16.89	0.09	174.17	0.16	0.24	9.91	31.68	0.06
Subtotal	8.81	20.37	0.79	175.91	2.08	1.31	10.07	37.99	0.21
Total	42.43	76.92	2.46	256.63	12.73	8.59	30.74	43.46	0.92

[a] See Figure 1.

1981; and Alitak, Marmot, and Chiniak Bays in 1982. Although O-group fish occurred in samples from nearly the entire depth range surveyed, highest densities were observed in samples from 40 to 120 m (Fiq. 10).

Among the 12 strata, relative concentrations of O-group fish were highest on east and west sides of Kodiak Island, with gradients in the densities (from bay to bay) from north to south (Table 4). Concentrations in the individual bays varied from year to year, although interpretations of the extent of real differences are limited by the small sample sizes.

Along the Alaska Peninsula highest densities were observed in Wide Bay in all 3 yr, then densities progressively declined in the bays to the southwest. Along east Kodiak Island the highest densities were found in Chiniak and Ugak Rays, and there was a general decline in concentrations to the south; relatively high densities were observed in Marmot Bay in all 3 yr. Along west Kodiak Island an exceptionally high concentration was observed in Alitak Bay in 1981, but otherwise, densities were only moderate.

Estimates of year-class strength, measured as standardized densities within the study area overall, varied as follows: 1980 year-class, 272 individuals/1O,000 m^2; 1981 year-class, 1,642 individuals/1O,OOO m^2; and 1982 year-class, 197 individuals/lO,OOO m^2 (Table 4). To examine if these measures of population levels were significantly different, the three sets (years) of catch data were tested using the nonparametric H test. The 366 samples were combined into an ordered series and ranked from lowest density of O-group walleye pollock to highest. The sum of ranks for each year's data was then compared with the expected values, including a correction for tied ranks. For O-group walleye pollock, the null hypothesis that the catch data did not vary between years was discredited at the 0.001 level.

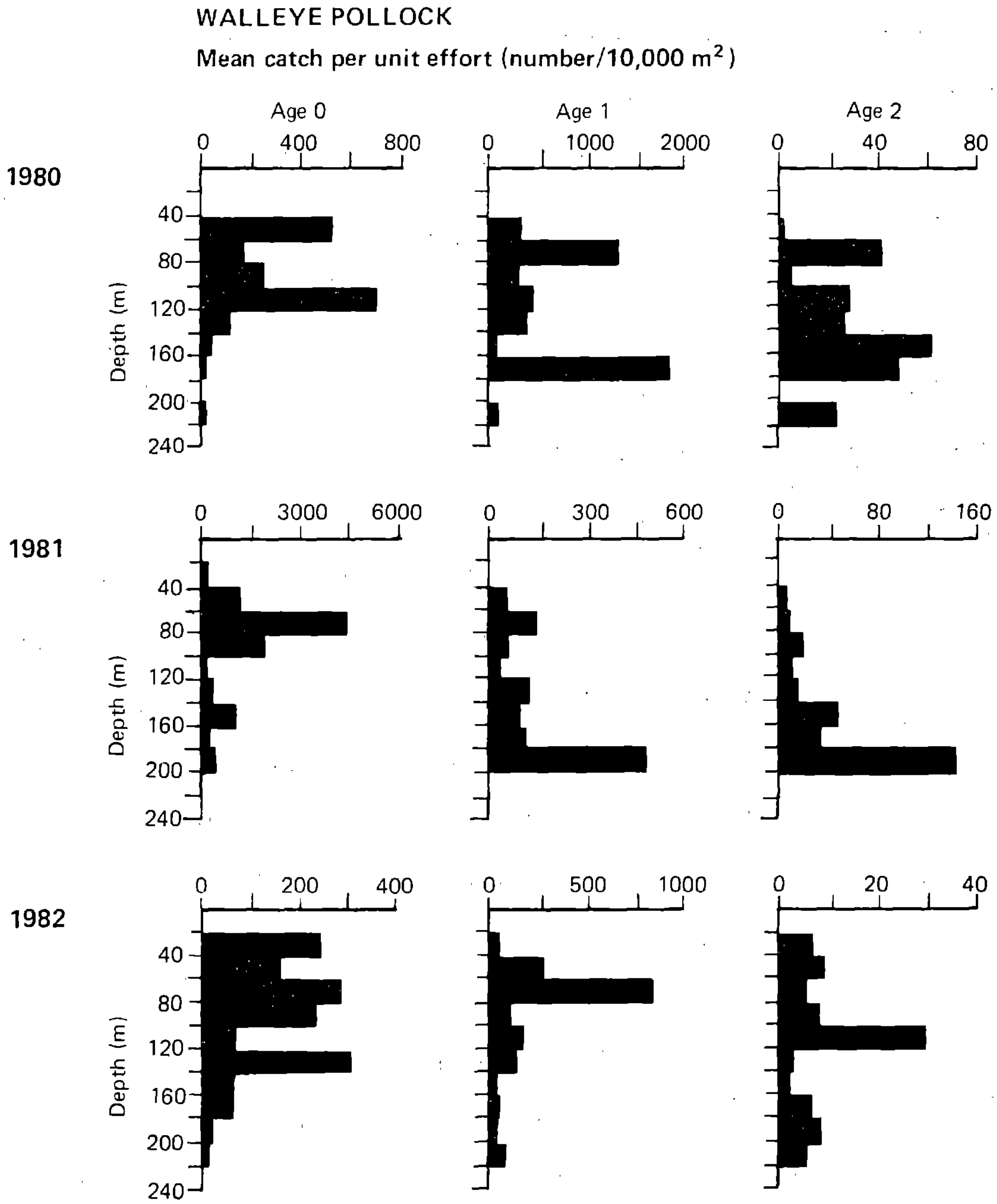

Figure 10.--Variations of walleye pollock densities with sampling depth, ages 0-2 yr, in the northwestern Gulf of Alaska.

Table 4.--Standardized densities[a] of juvenile age groups (0-2 yr) of walleye pollock in bays and nearshore areas of the northwestern Gulf of Alaska, 1980-82.

	Apparent density (number/10,000 m²)								
	1980			1981			1982		
Stratum[b]	0	1	2	0	1	2	0	1	2
Alaska Peninsula									
Wide Bay	678	140	--	996	403	--	360	93	16
Kujulik Bay	250	846	12	555	58	1	115	149	4
Chignik Bay	90	2546	23	354	580	76	8	71	2
Castle Bay	--	7182	161	246	81	4	11	428	4
Region	191	2316	33	471	343	37	78	139	4
East Kodiak Island									
Marmot Bay	184	18	25	607	52	303	479	13	12
Chiniak Bay	3187	3	--	1710	26	41	1120	2	--
Ugak Bay	434	3	--	3242	2	--	125	96	18
Kiliuda Bay	52	--	24	973	30	1	81	3	<1
S. Sitkalidak Strait	87	2	<1	113	30	9	20	39	9
Region	394	6	12	942	32	87	255	29	8
West Kodiak Island									
Uganik Bay	--	148	42	180	24	142	10	226	11
Uyak Bay	23	278	46	56	198	9	10	537	8
Alitak Bay	202	396	2	4083	4	6	232	743	1
Region	151	349	14	3010	36	22	172	650	4
Overall	272	492	16	1642	81	55	197	278	6

[a] Computed by dividing population estimates in Table 3 by the corresponding geographic areas in Table 1. Regional densities were' calculated from the previous subtotals.'

[b] See Figure 1.

Age- 1

One-yr-old walleye pollock were found in 11 of the 12 inlets in 1980, and in all strata during 1981 and 1982 (Figs. 11-13). Number of occurrences in samples were: 1980, 57; 1981, 70; and 1982, 68. 'Mean lengths were: 1980, 19.2 cm; 1981, 23.9 cm; and 1982, 20.0 cm.

Population estimates for 1-yr-olds are also shown in Table 3. Over the 3 yr, the total number varied from 76.9 million in 1980, to 12.7 million in 1981, to 43.5 million in 1982. Bays with large populations were Chignik, Castle, and Alitak Bays in 1980; Chignik Bay in 1981; and Alitak Bay in 1982. Similar to O-group fish, 1-yr-olds occurred in samples from practically the entire range of depths surveyed (Fig. 10). During 1980 and 1981, the highest densities were observed in samples from between 60 and 80 m; the apparent distribution in 1982 was somewhat shallower.

The standardized population densities showed that, in contrast to the O-group population, l-yr-old walleye pollock had highest concentrations along the Alaska Peninsula and west side of Kodiak Island (Table 4). In these two regions there were general gradients in concentrations (from bay to bay) from south to north. Along the Alaska Peninsula highest densities were observed in Castle Bay in 1980 and 1982, and Chignik Bay in 1981; concentrations generally declined in the bays to the northwest. In the west Kodiak Island region highest densities were found in Alitak Bay in 1980 and 1982, and Uyak Bay in 1981; densities declined to the north in 1980 and 1982. One-yr-olds were not abundant in inlets along the east side of Kodiak Island.'

Estimates of year-class strength, measured as standardized densities within the study area overall, varied as follows: 1979 year-class, 492 individuals/lO,OOO m^2; 1980 year-class,, 81 individuals/lO,OOO m^2; and 1981 year-class, 278 individuals/lO,OOO m^2 (Table 4). Despite these apparent

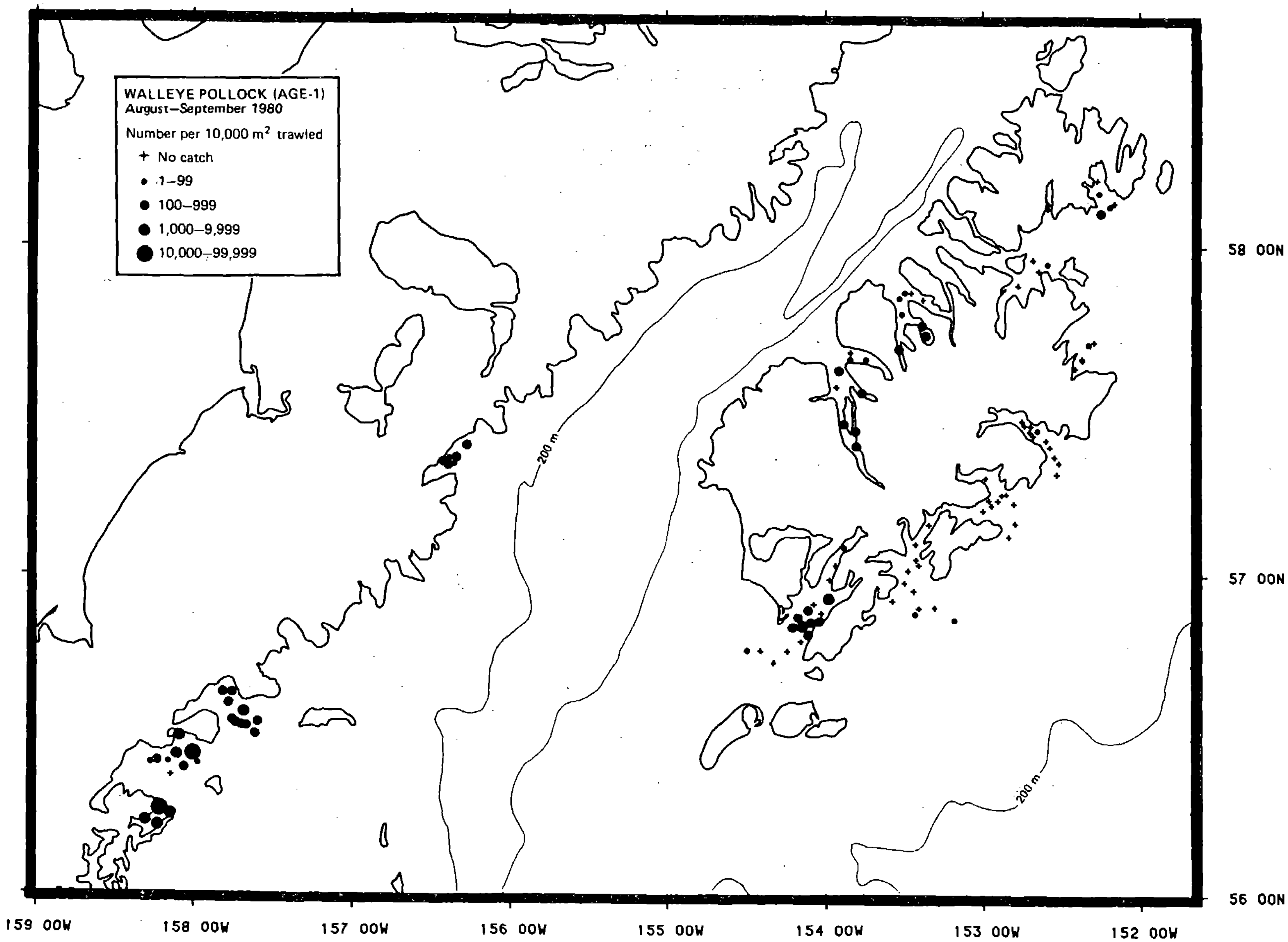

Figure 11.--Distribution and relative abundance of 1-yr-old walleye pollock in the -northwestern Gulf of Alaska in 1980.

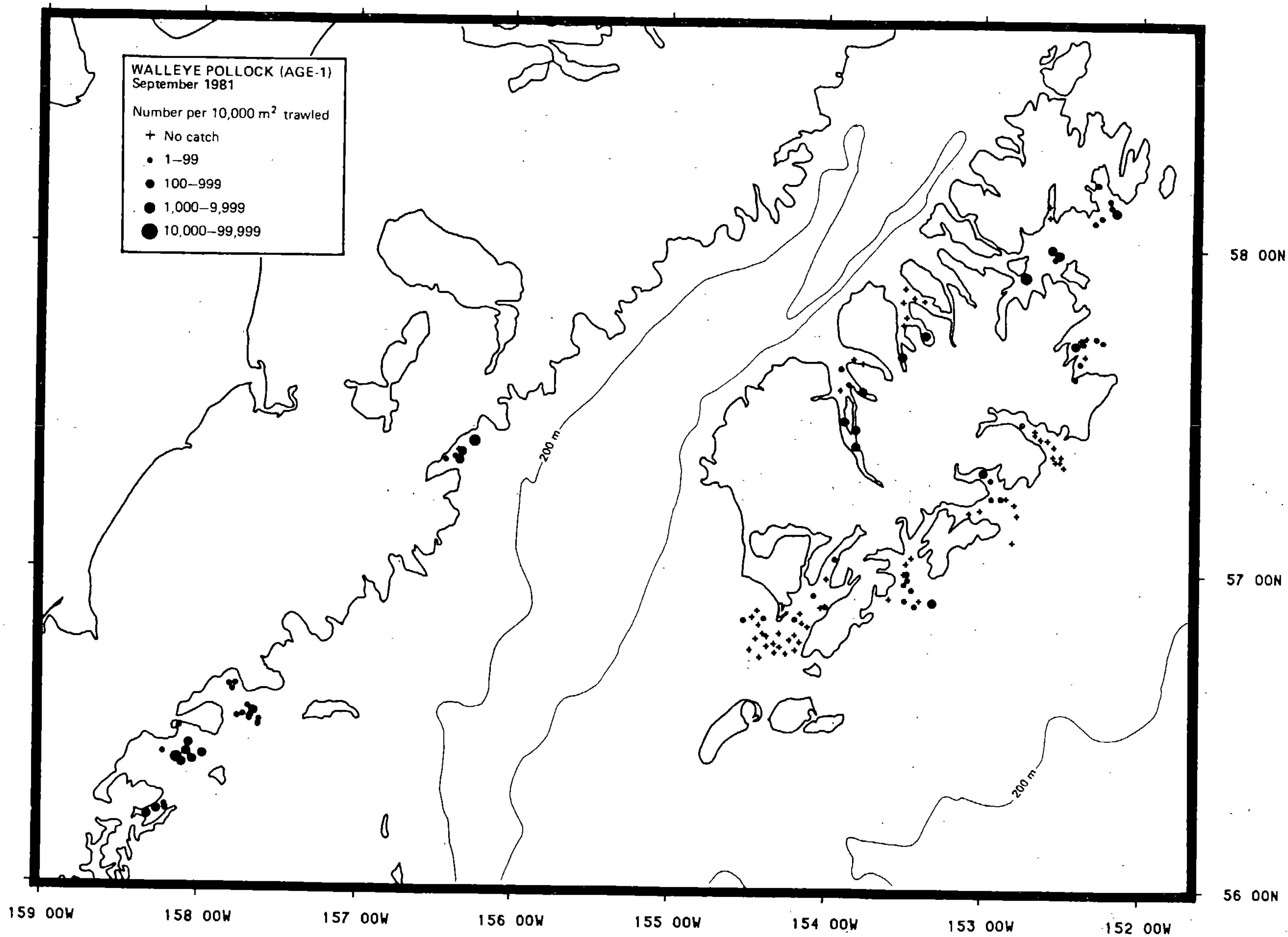

Figure 12.--Distribution and relative abundance of 1-yr-old walleye pollock in the northwestern Gulf of Alaska in 1981.

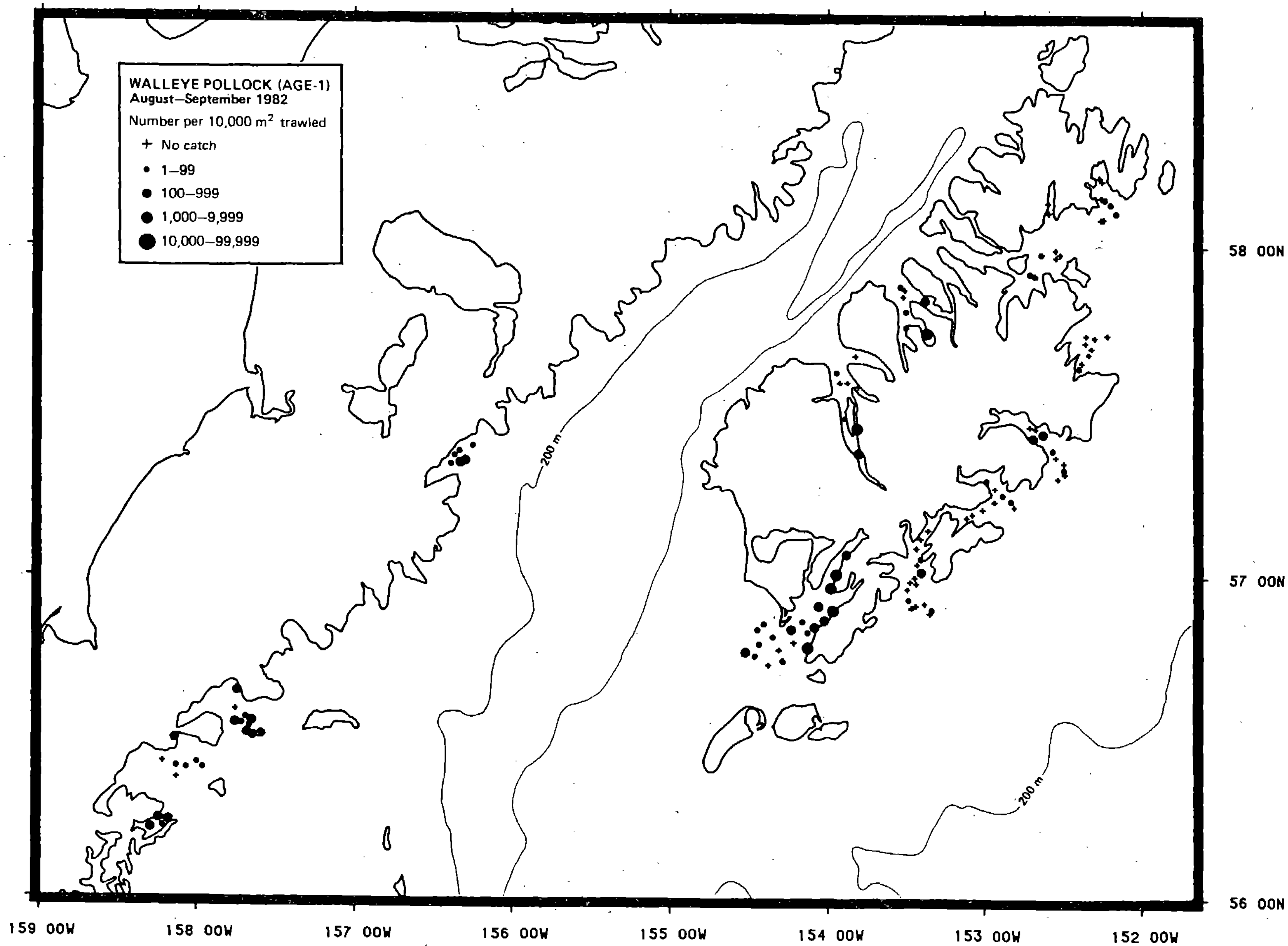

Figure 13.--Distribution and relative abundance of 1-yr-old walleye pollock in the northwestern Gulf of Alaska in 1982.

changes in abundance, when the three sets of catch data were compared with the H test, the data were found to be not, significantly different. One would have to conclude either that the population levels of 1-yr-olds did not actually vary much between years, or that (perhaps because of the limited sample sizes) the survey coverage did not provide adequate sensitivity to detect significant changes.

Age-2

Two-yr-old walleye pollock were not a prominent component in the bays and nearshore areas covered by these surveys. Although found in most strata, they were only present in about 30% of the hauls during each year (Figs. 14-16, Table 3). Number of occurrences in samples were: 1980, 41; 1981, 45; and 1982, 34. The length distributions of 2-yr-olds did not form prominent modes, like those of the younger age groups, but ranged from about 24 to 32 cm (Fig. 5).

There were no clear patterns in the geographical distributions of 2-yr-olds from year to year. In 1980, the highest densities were observed in Castle Bay on the Alaska Peninsula and in Uyak and Uganik Bays on the northwest side of Kodiak Island. In 1981, Marmot and Uganik Rays had the highest densities. In 1982, none of the areas were found to have many 2-yr-olds. Similar to the younger age groups, 2-yr-old walleye pollock occurred in samples from nearly all depths surveyed (Fiq. 10). Highest densities were observed in samples from trawls made deeper than 100 m.

Pacific Cod

Pacific cod were captured in 202 (55.2%) of the 366 trawl samples. The total size range was 7 to 88 cm (Fig. 17). Juvenile Pacific cod <41 cm occurred in 69 samples, but were not as common or abundant as young walleye

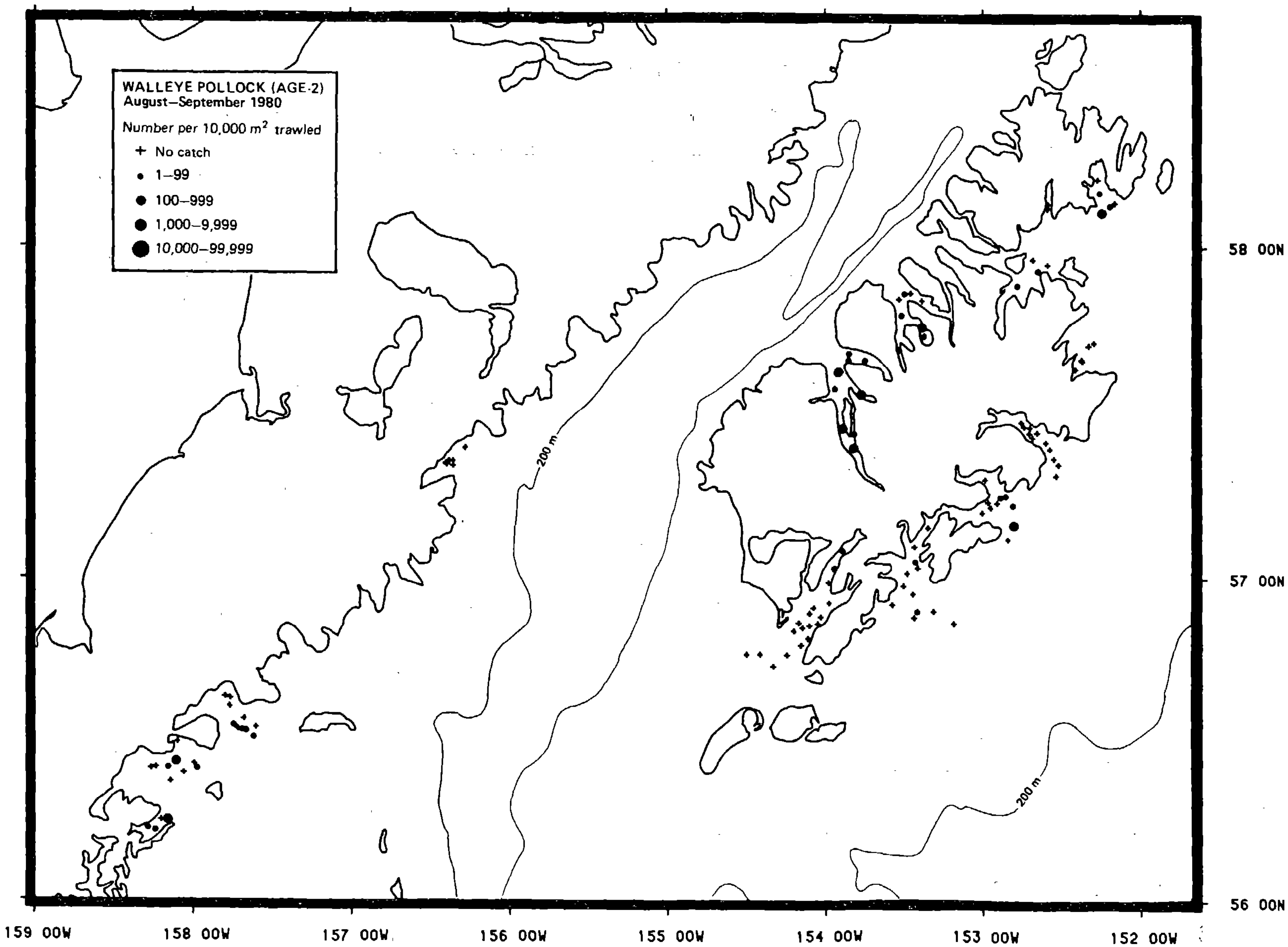

Figure 14.--Distribution and relative abundance of 2-yr-old walleye pollock in the northwestern Gulf of Alaska in 1980.

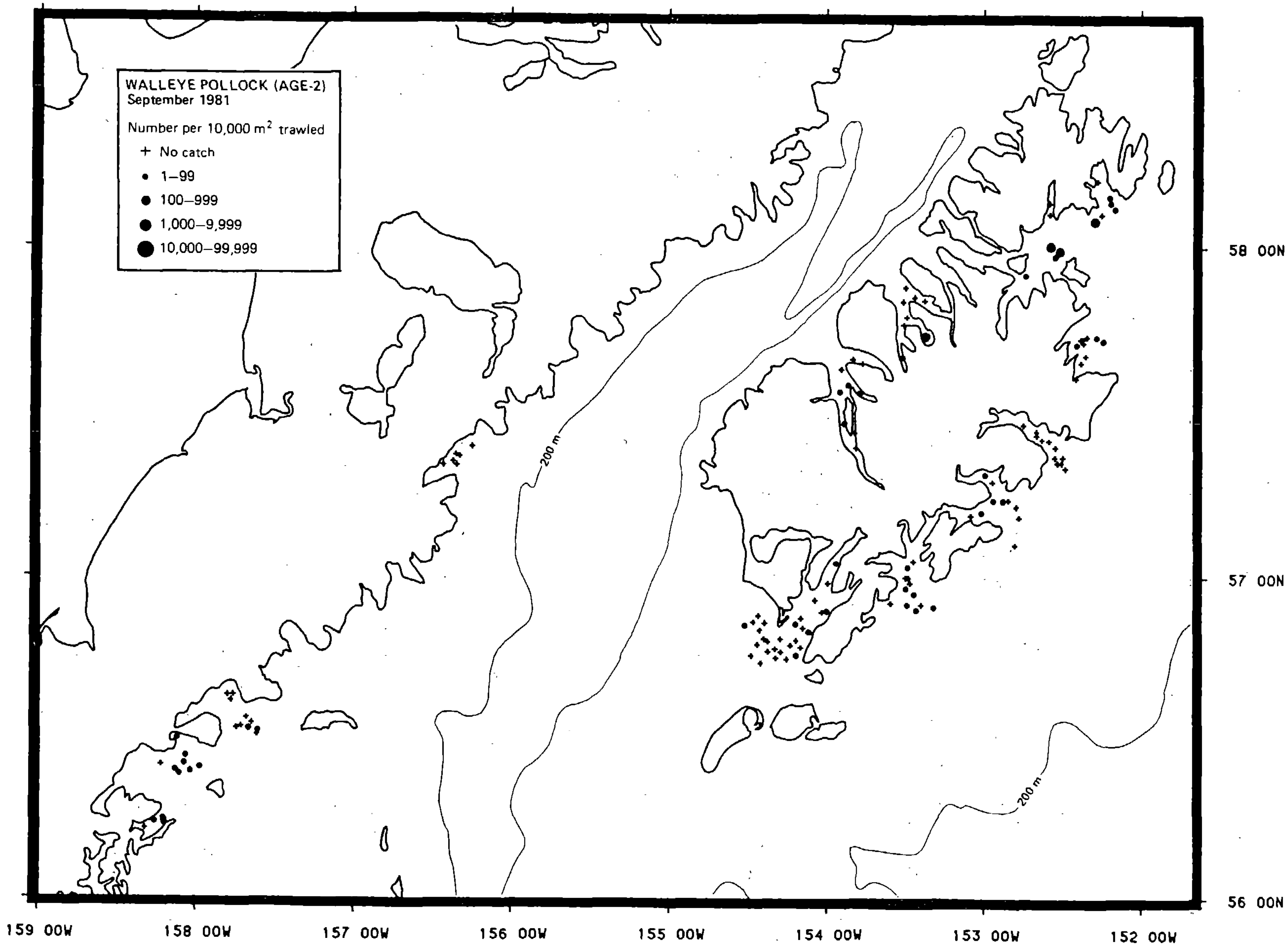

Figure 15.--Distribution and relative abundance of 2-yr-old walleye pollock in the northwestern Gulf of Alaska in 1981.

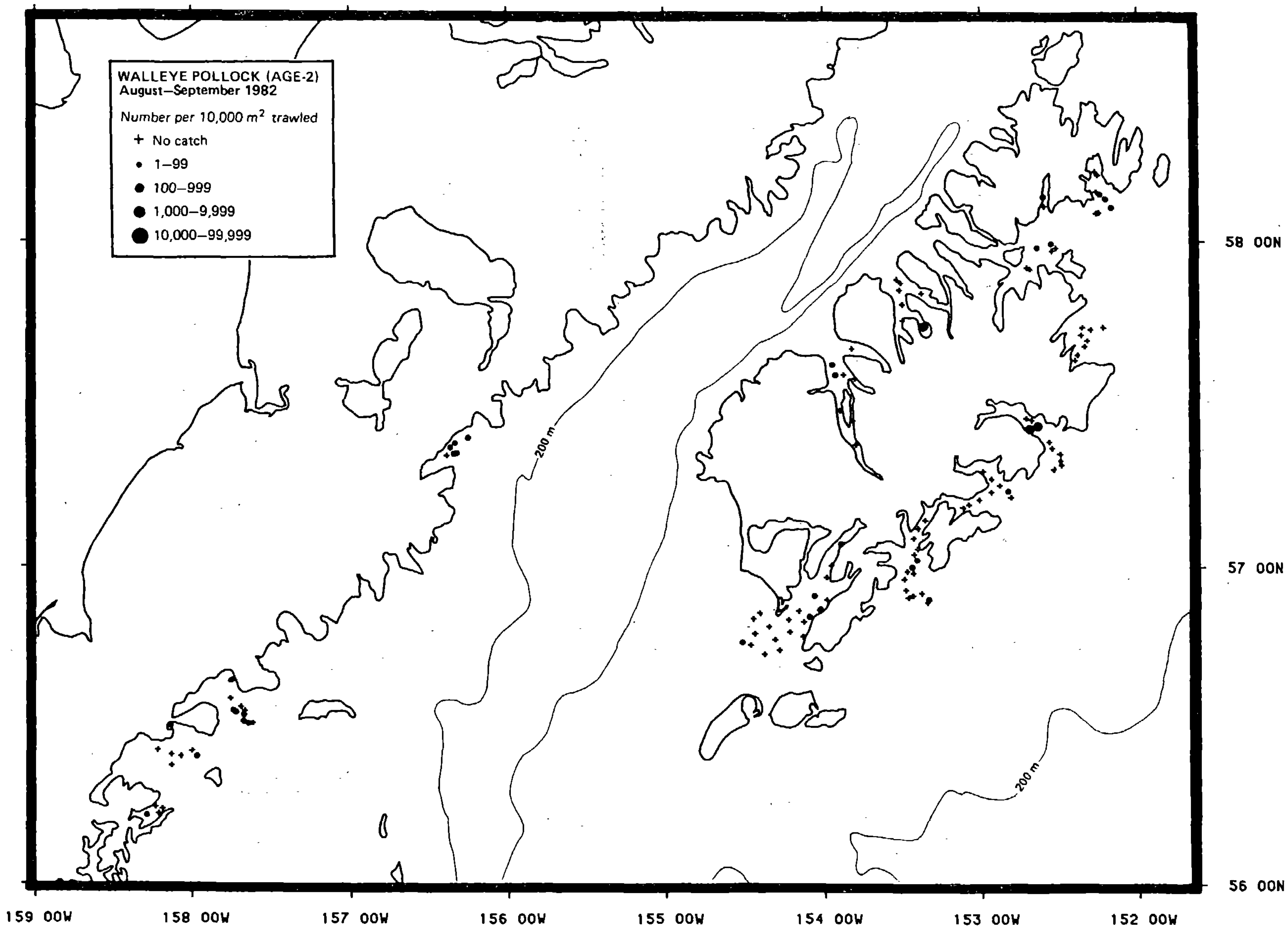

Figure 16.--Distribution and relative abundance of 2-yr-old walleye pollock in the northwestern Gulf of Alaska in 1982.

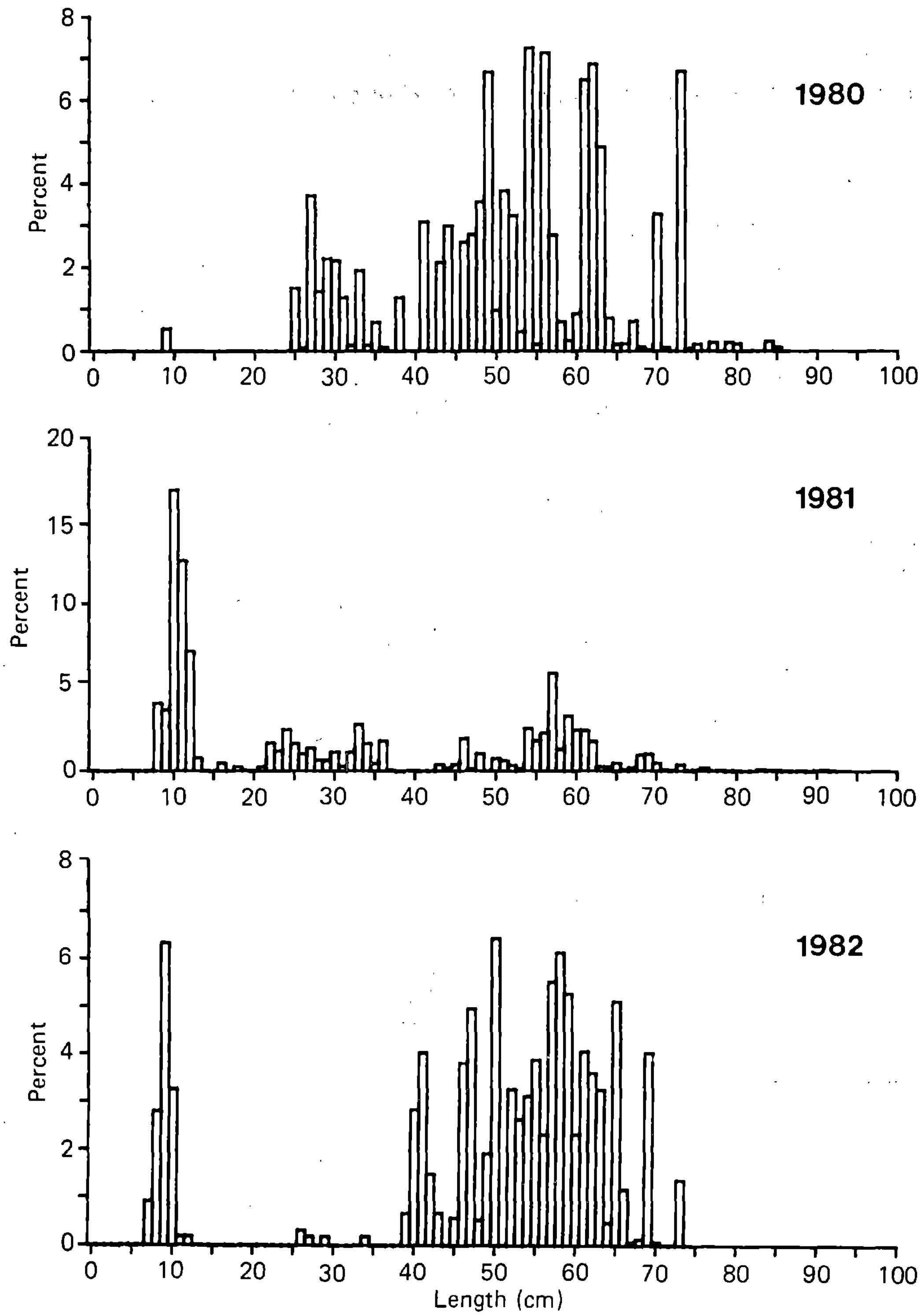

Figure 17.--Length-frequency distributions of Pacific cod taken in the northwestern Gulf of Alaska, 1980-82.

pollock. Of the 12 inlets surveyed, juvenile Pacific cod (ages O-2 yr) were found in all 3 yr only in Kujulik and Wide Rays on the Alaska. Peninsula.

As with walleye pollock, the NCS method was used to distinguish modes in the length distributions and assign ages. The length intervals found to approximately delimit the three youngest age groups, and used in subsequent analyses of all three survey years, were: O-group, 7-15 cm; age 1, 16-30 cm; and age 2,31-41 cm.

O-Group

Young of the year Pacific cod, approximately 5-7 months old, were found in 5 of the 12 inlets studied and their occurrences varied considerably from year to year (Figs. 18-20, Table 5). Number of occurrences in samples were: 1980, 1; 1981, 24; and 1982, 13. Mean lengths were: 1980, 9.0 cm; 1981, 10.4 cm; and 1982, 9.0 cm.

In 1980, O-group Pacific cod were found only in one sample in Wide Bay on the Alaska Peninsula. In 1981, exceptionally large numbers were observed in Alitak and Wide Bays. Important bays in 1982 were Alitak, Wide and Uyak Bays.

In general, O-group Pacific cod were found almost exclusively in samples from depths shallower than 80 m (Fig. 21). The five bays in which they were observed also contained most of the shallow sampling stations in the study. In 1981, 56% of the 45 samples collected at depths shallower than 80 m contained O-group Pacific cod; they were found in only 1 of the 85 samples from deeper water.

Standardized population densities for Pacific cod are given in Table 6. The locations of high concentrations of O-group fish varied from year to year and there were no clear patterns. The estimates of year-class strength, measured as standardized densities within the study area overall, were: 1980 year-class, 0.04 individuals/10,000 m^2; 1981 year-class, 7.16 individuals/

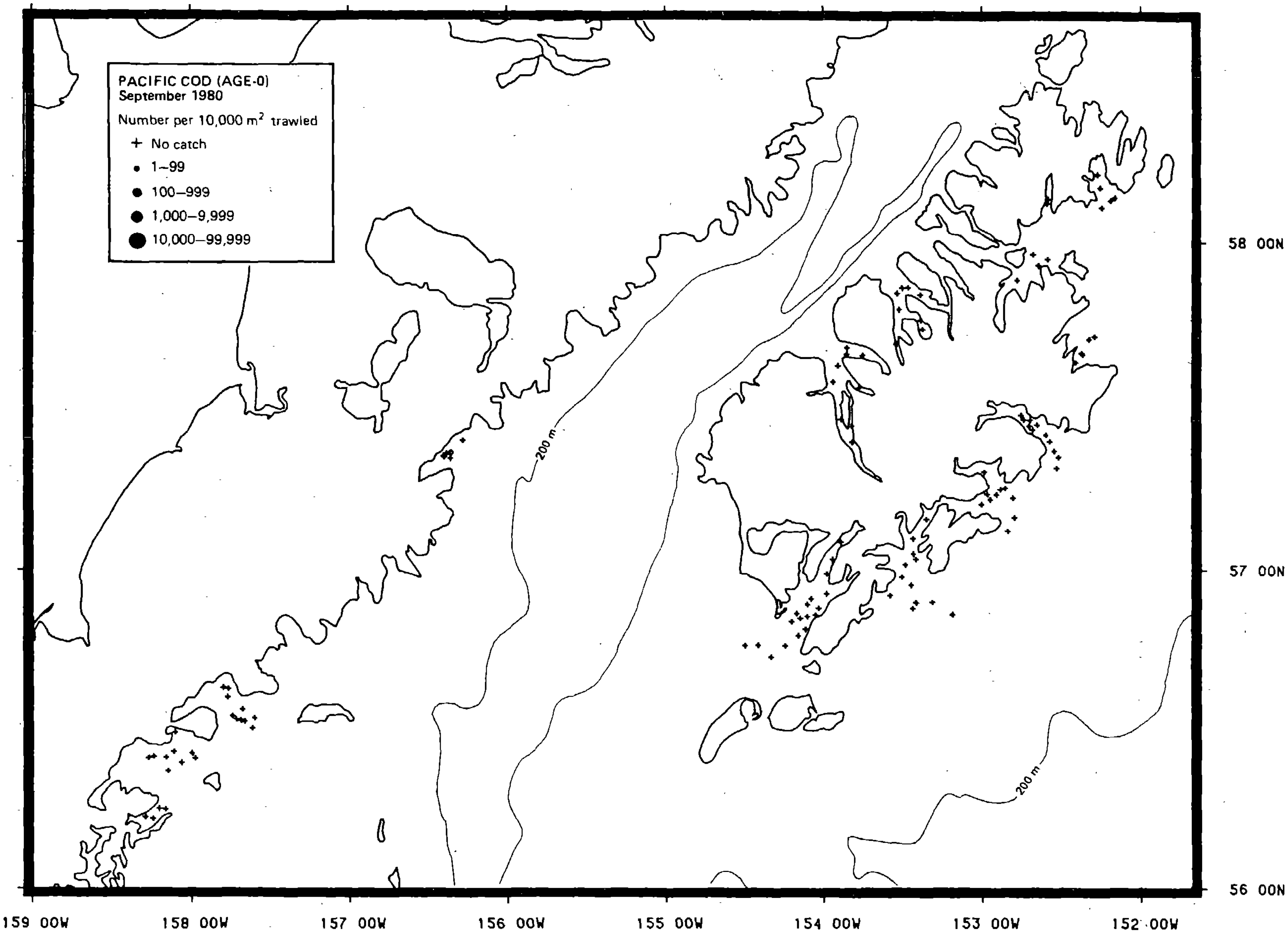

Figure 18. --Distribution and relative abundance of O-group Pacific cod in the northwestern Gulf of Alaska in 1980.

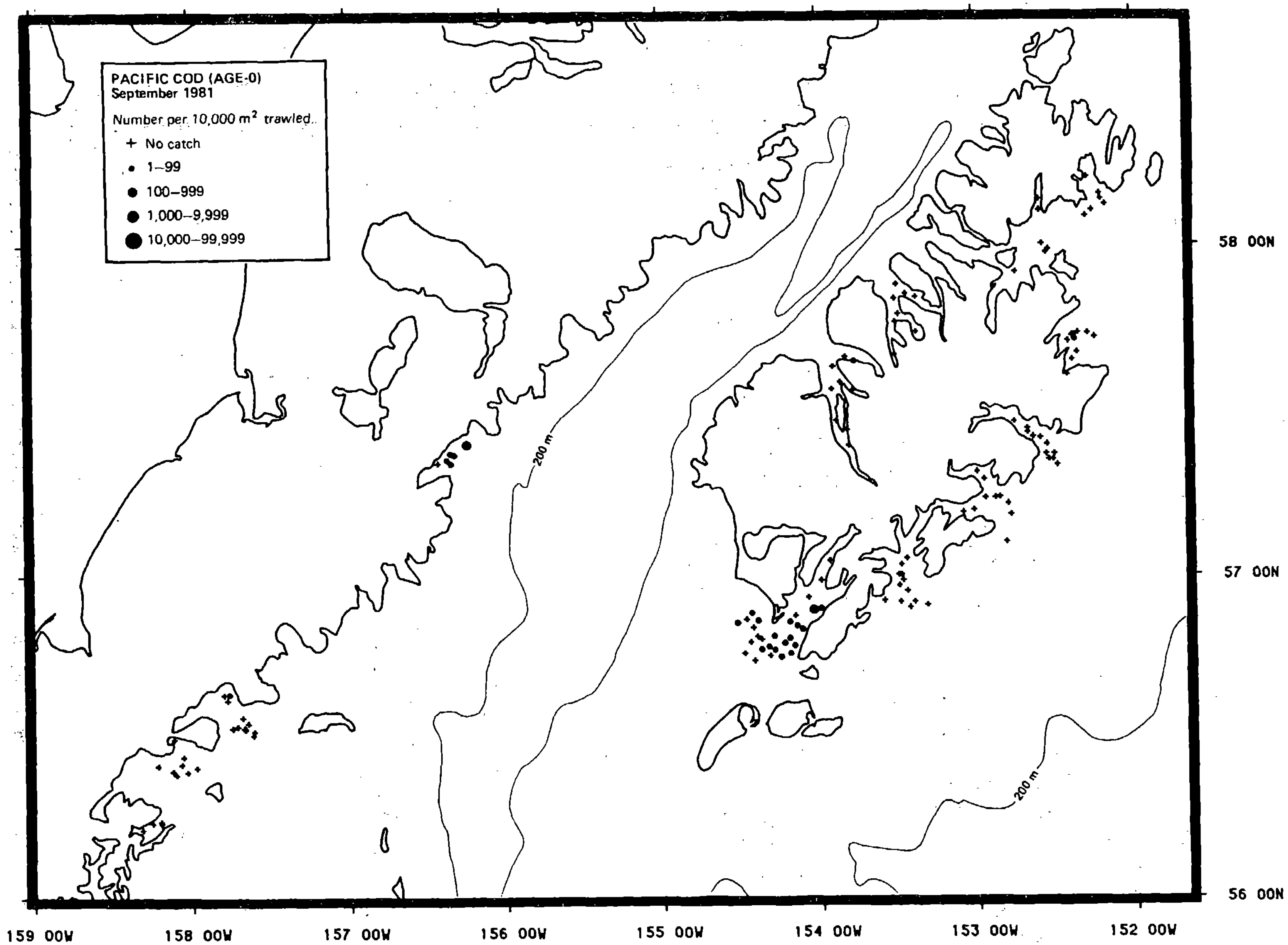

Figure 19.--Distribution and relative abundance of 0-group Pacific cod in the northwestern Gulf of Alaska in 1981.

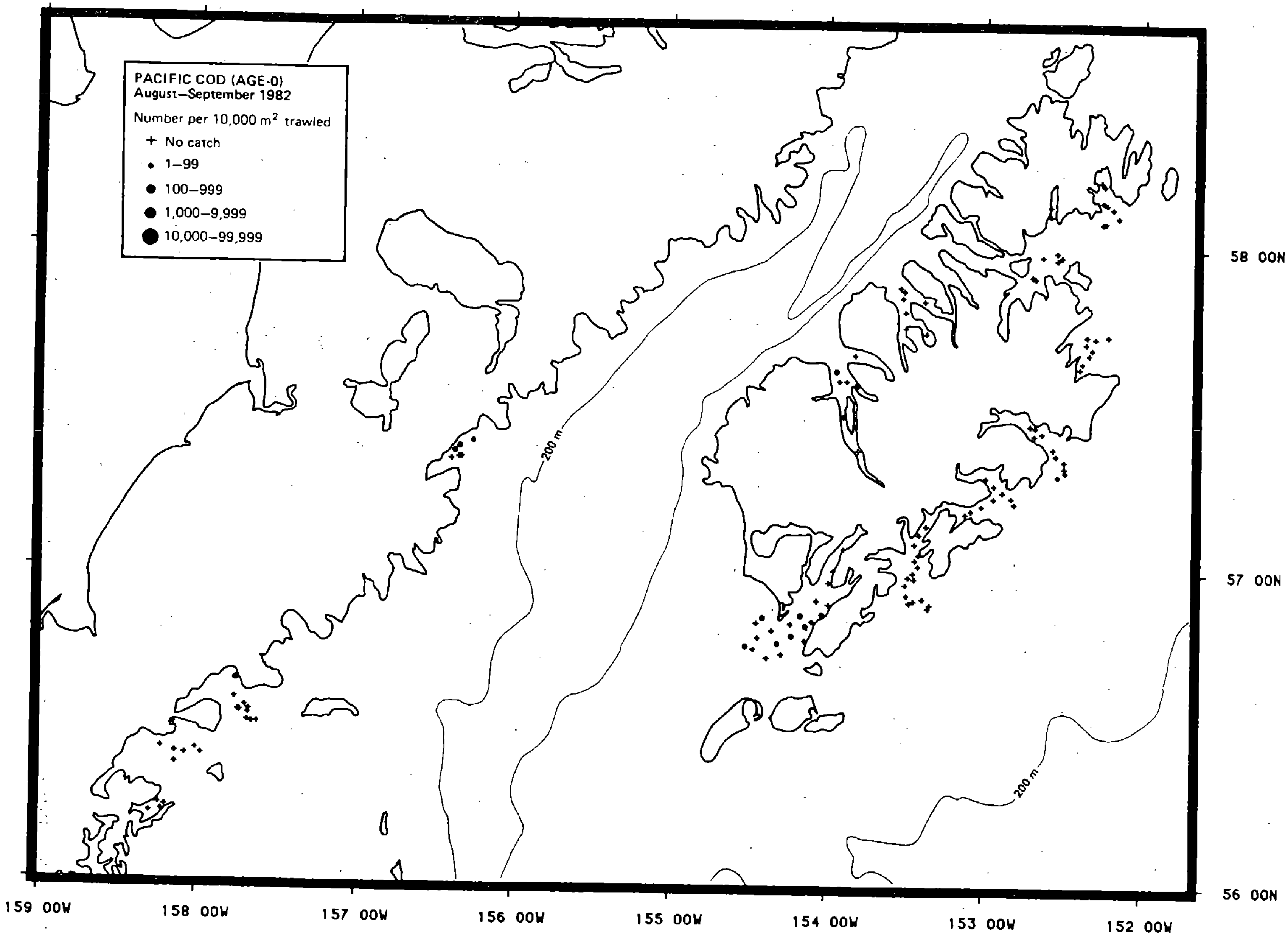

Figure 20.--Distribution and relative abundance of 0-group Pacific cod in the northwestern Gulf of Alaska in 1982.

Table 5.--Estimated population size of juvenile age groups (0-2 yr) of Pacific cod in bays and nearshore areas of the northwestern Gulf of Alaska during late summer periods, 1980-82.

	Estimated population (thousands)								
	1980			1981			1982		
Stratum[a]	0	1	2	0	1	2	0	1	2
Alaska Peninsula									
Wide Bay	5.71	1.66	--	258.94	235.31	--	60.09	9.87	5.38
Kujulik Bay	--	5.33	13.26	1.48	--	--	5.33	--	--
Chignik Bay	--	108.68	41.56	--	--	--	--	--	--
Castle Bay	--	--	26.65	--	--	1.34	--	--	--
Subtotal	5.71	115.67	81.47	260.42	235.31	1.34	65.42	9.87	5.38
East Kodiak Island									
Marmot Bay	--	--	6.90	--	--	61.49	--	--	--
Chiniak Bay	--	--	--	19.33	--	35.12	no measurements		
Ugak Bay	--	--	--	--	7.79	--	--	--	9.70
Kiliuda Bay	--	--	--	--	--	--	--	--	--
S. Sitkalidak Strait	--	--	--	--	75.46	95.09	--	--	88.69
Subtotal	--	--	6.90	19.33	83.25	191.70	--	--	98.39
West Kodiak Island									
Uganik Bay	--	0.48	1.93	--	--	--	--	--	9.35
Uyak Bay	--	--	--	0.08	1.46	0.61	51.26	--	--
Alitak Bay	--	--	--	838.76	2.42	--	85.08	--	--
Subtotal	--	0.48	1.93	838.84	3.88	0.61	136.34	--	9.35
Total	5.71	116.15	90.30	1118.59	322.44	193.65	201.76	9.87	113.12

[a] See Figure 1.

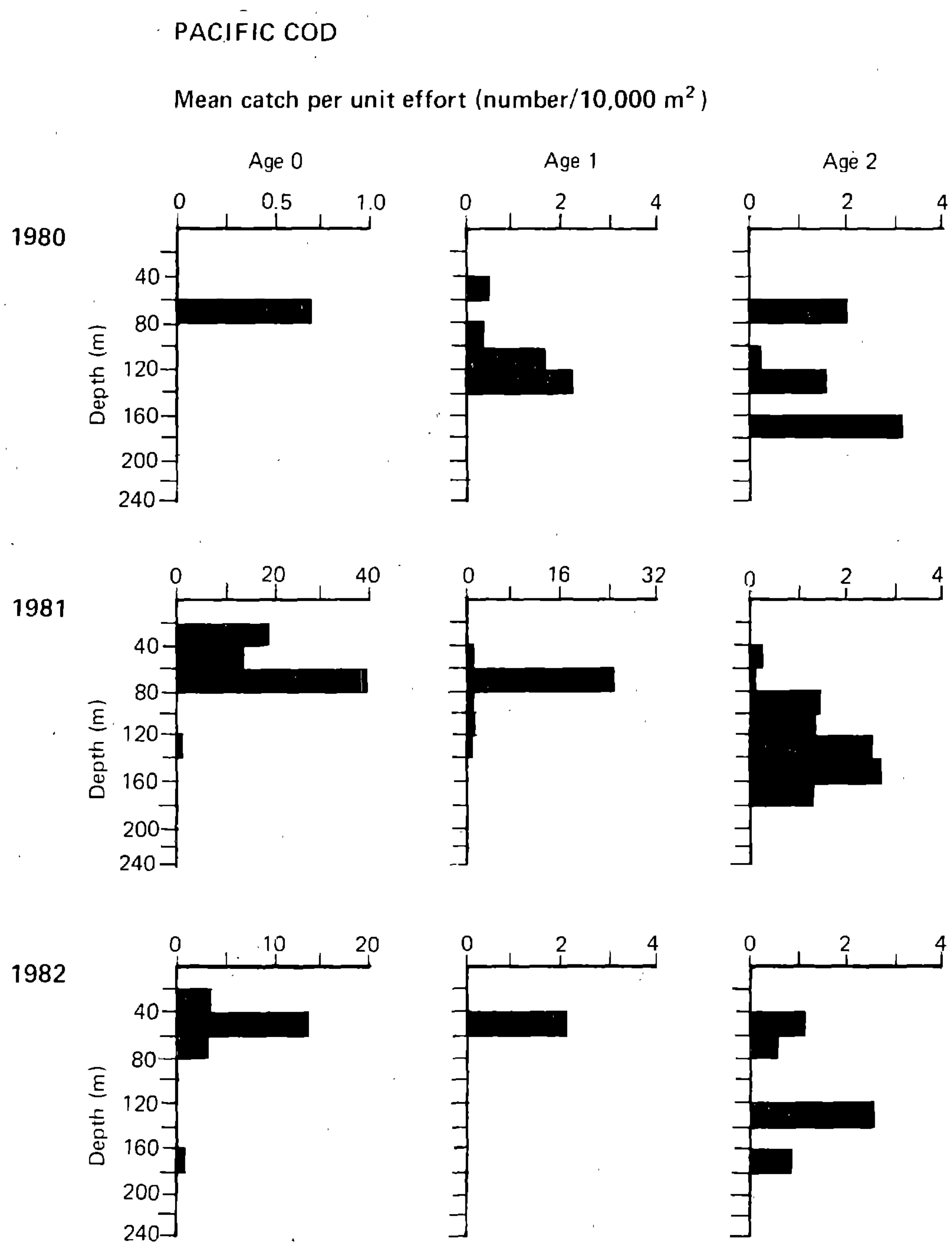

Figure 21.--Variations of Pacific cod densities with sampling depth, ages 0-2 yr, in the northwestern Gulf of Alaska.

10,000 m^2; and 1982 year-class, 1.29 individuals/l0,OOO m^2. When the three sets of catch data were compared with the. H test, the null hypothesis that the data were not different was discredited at the 0.001 level. However, because O-group Pacific cod appeared to predominantly occur in shallow areas that were not well-sampled by the surveys, the reliability and value of these indicators of year-class strength are questionable.

Age-l

One-yr-old Pacific cod were found in 8 of the 12 inlets, and like the O-group populations, their distributions among bays were inconsistent from year to year (Figs. 22-24, Table 5). Number of occurrences in samples were: 1980, 6; 1981, 7; and 1982, 2. Mean lengths were: 1980, 29.2 cm; 1981, 25.0 cm; and 1982, 28.6 cm.

In 1980, the highest densities of 1-yr-olds were observed in Chignik and Kujulik Bays. In 1981, relatively high densities were observed at one station in Wide Bay and several locations in south Sitkalidak Strait. In 1982, 1-yr-olds were found only at two locations in Wide Bay. Over the 3 yr, 1-yr-old Pacific-cod occurred in samples from depths of 42 to 134 m (Fig. 21).

Estimates of year-class strength, measured as standardized densities within the study area overall, were as follows: 1979 year-class, 0.74 individuals/l0,000 m^2; 1980 year-class, 2.06 individuals/l0,000 m^2; and 1981 year-class, 0.06 individuals/l0,000 m^2 (Table 6). Despite these apparent changes in population levels, when compared using the H test the three sets of catch data were found to be not significantly different. This was probably a result of the limited sample sizes in the surveys and few occurrences of this age group.

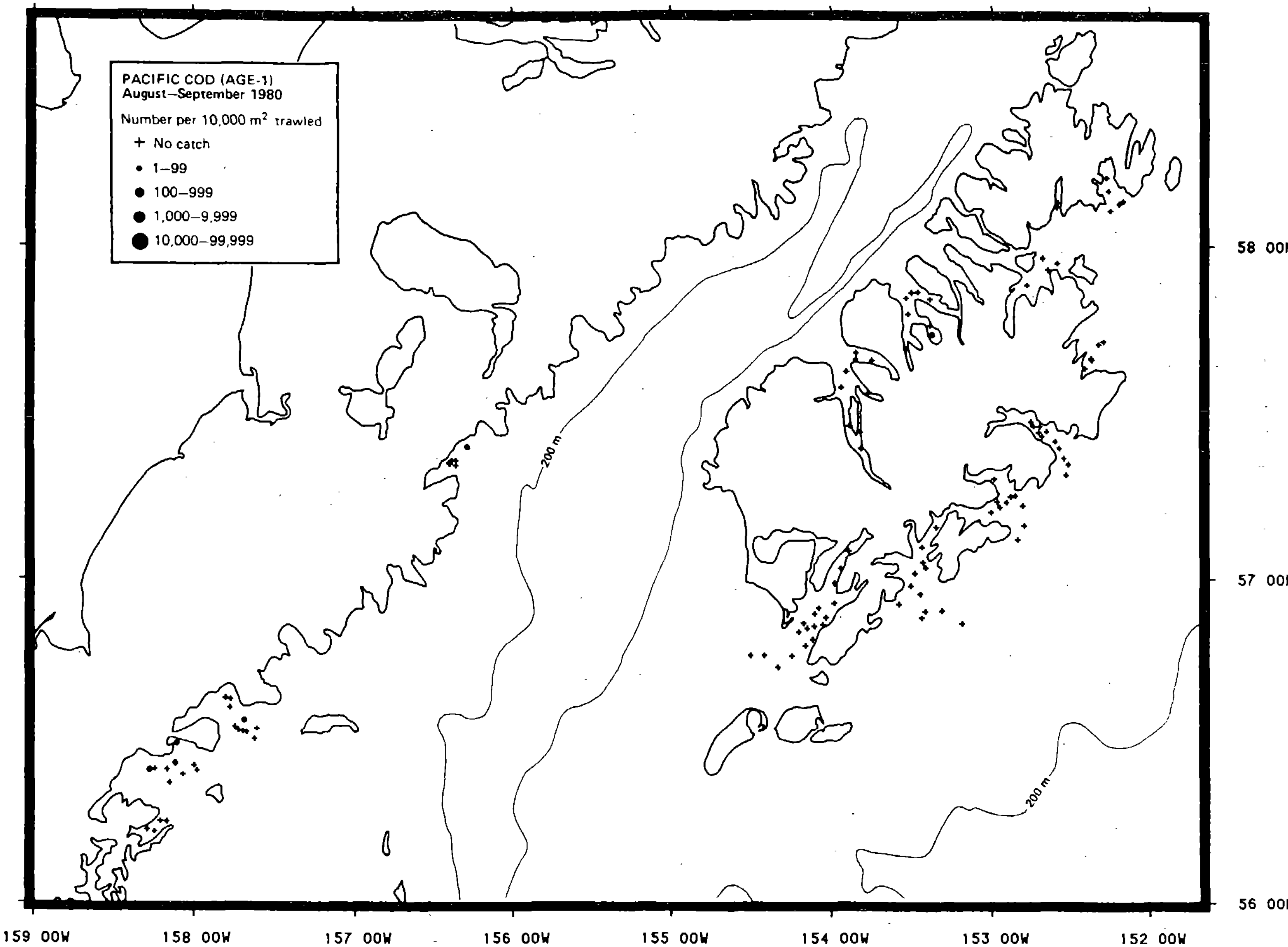

Figure 22.--Distribution and relative abundance of 1-yr-old Pacific cod in the northwestern Gulf of Alaska in 1980.

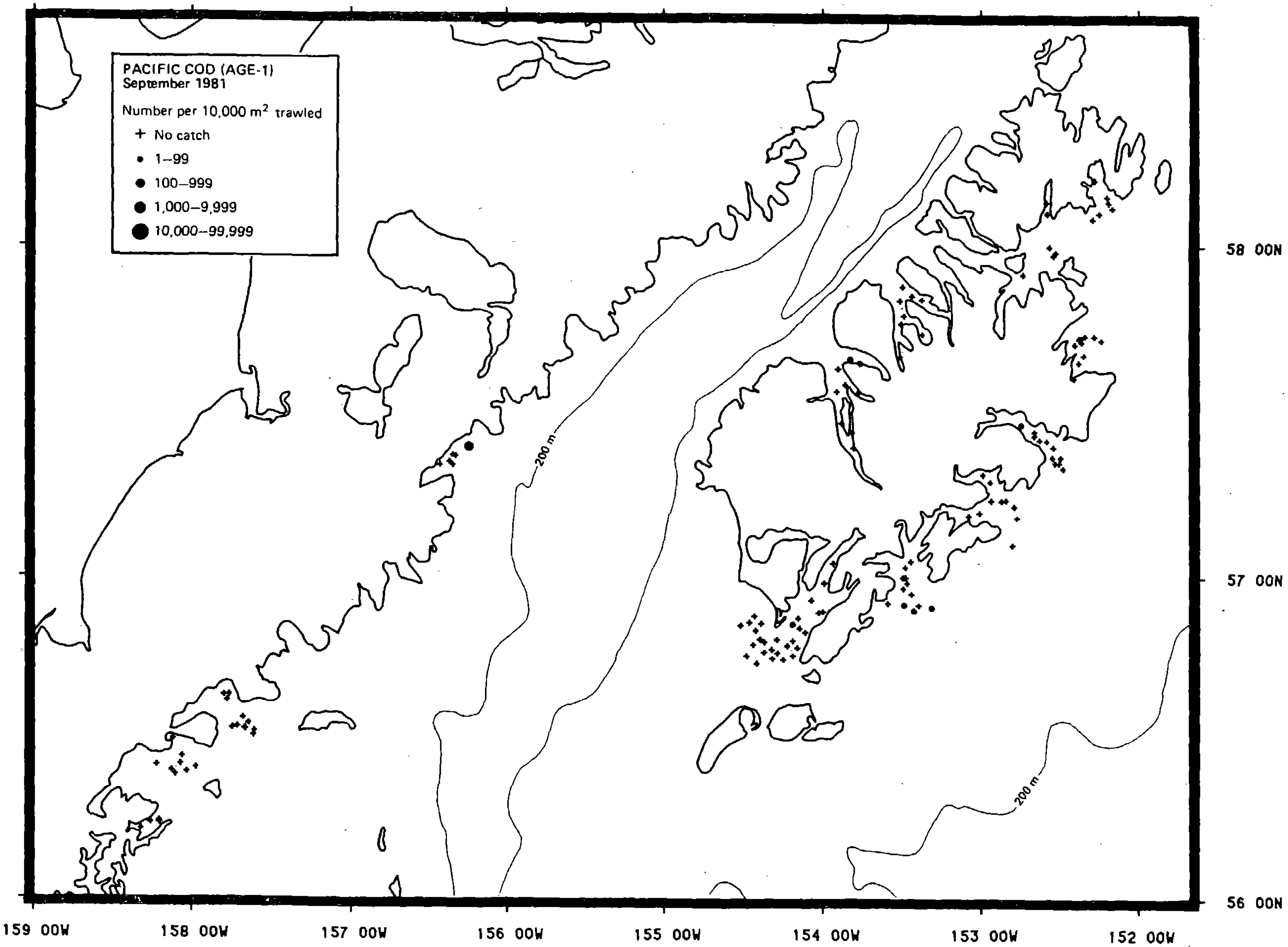

Figure 23.--Distribution and relative abundance of 1-yr-old Pacific cod in the northwestern Gulf of Alaska in 1981.

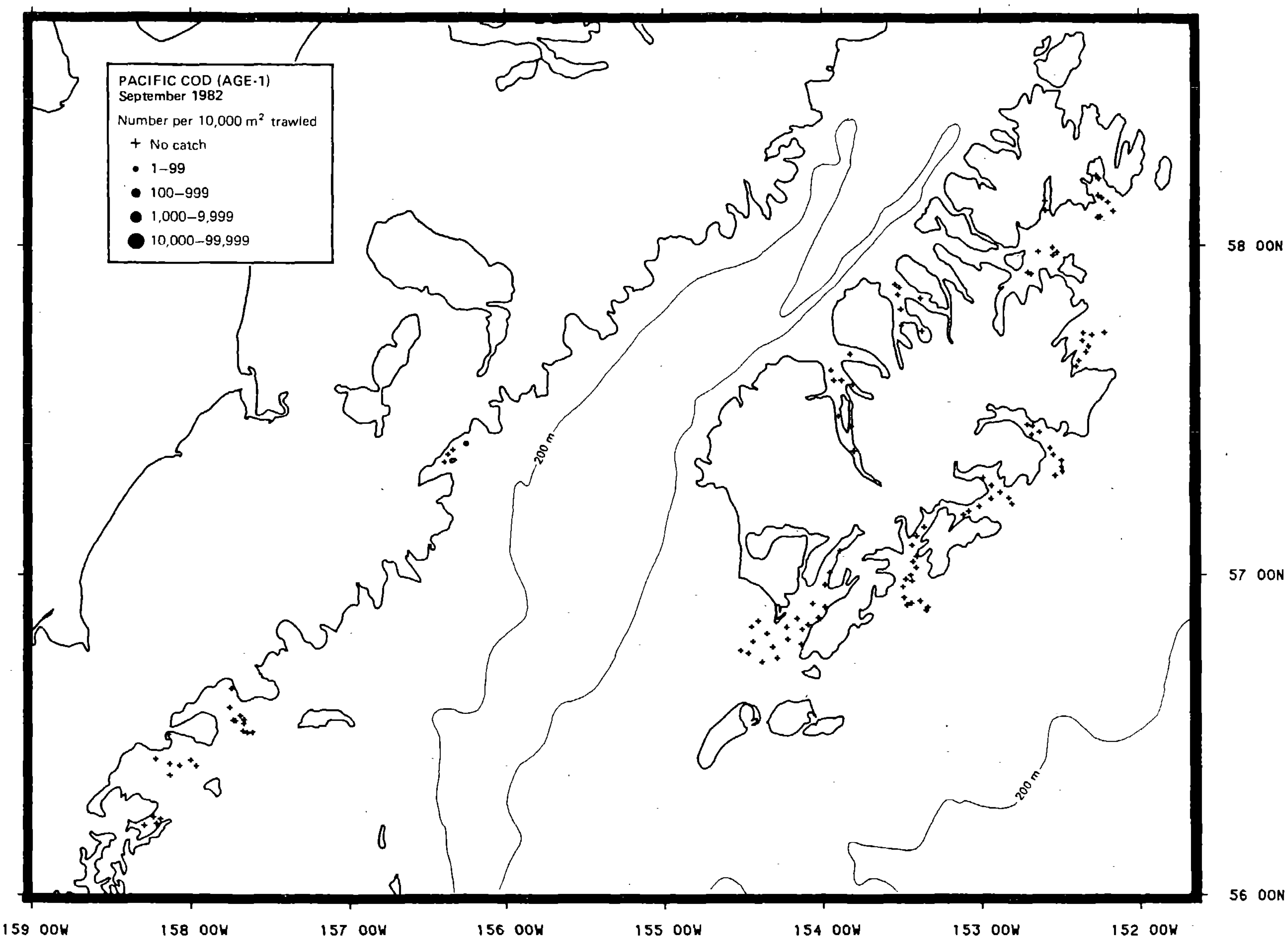

Figure 24.--Distribution and relative abundance of 1-yr-old Pacific cod in the northwestern Gulf of Alaska in 1982.

Table 6.--Standardized densities[a] of juvenile age groups (0-2 yr) of Pacific cod in bays and nearshore areas of the northwestern Gulf of Alaska, 1980-82.

	Apparent density (number/10,000 m²)								
	1980			1981			1982		
Stratum[b]	0	1	2	0	1	2	0	1	2
Alaska Peninsula									
Wide Bay	2.21	0.64	--	100.36	91.21	--	23.29	3.83	2.09
Kujulik Bay	--	0.72	1.79	0.20	--	--	0.72	--	--
Chignik Bay	--	9.53	3.65	--	--	--	--	--	--
Castle Bay	--	--	9.35	--	--	0.47	--	--	--
Region	0.24	4.77	3.36	10.75	9.71	0.06	2.70	0.41	0.22
East Kodiak Island									
Marmot Bay	--	--	0.35	--	--	3.14	--	--	--
Chiniak Bay	--	--	--	3.32	--	6.03		no measurements	
Ugak Bay	--	--	--	--	0.85	--	--	--	1.06
Kiliuda Bay	--	--	--	--	--	--	--	--	--
S. Sitkalidak Strait	--	--	--	--	3.20	4.03	--	--	3.76
Region	--	--	0.09	0.26	1.13	2.60	--	--	1.34
West Kodiak Island									
Uganik Bay	--	0.07	0.28	--	--	--	--	--	1.34
Uyak Bay	--	--	--	0.01	0.17	0.07	5.81	--	--
Alitak Bay	--	--	--	19.66	0.06	--	1.99	--	--
Region	--	0.01	0.03	14.35	0.07	0.01	2.33	--	0.16
Overall	0.04	0.74	0.58	7.16	2.06	1.24	1.29	0.06	0.72

[a] Computed by dividing population estimates in Table 5 by the corresponding geographic areas in Table 1. Regional densities were calculated from the previous subtotals.
[b] See Figure 1.

Age-2

Two-yr-old Pacific cod also occurred at scattered locations in low densities (Figs. 25-27, Table 5). Number of occurrences were: 1980, 9; 1981, 10; and 1982, 6. No clear modes were evident in the length distributions of the relatively few 2-yr-old fish caught in 1980 and 1982; in 1981, the mean length was 33.8 cm.

In 1980, 2-yr-olds were most abundant in Chignik, Castle, and Kujulik Bays along the Alaska Peninsula. In 1981, relatively large populations of 2-yr-olds were estimated to occur in inlets on the east side of Kodiak Island--e.q., south Sitkalidak Strait, Marmot Bay, and Chiniak Bay. In 1982, a large population of 2-yr-olds was again found in south Sitkalidak Strait. However, all of these observations and estimates were based on relatively small sample sizes. Over the 3 yr, 2-yr-old Pacific cod occurred in samples from depths of 46 to 172 m, and highest densities were in samples from waters deeper than 100 m (Fig. 21).

Sablefish

Adult sablefish were not found in the bays and nearshore areas covered by these surveys. However, juvenile sablefish <50 cm length were consistently observed in 25-30% of the trawl samples each year, and were found in every inlet during at least one sampling period.

In 1980 and 1982, the length distributions of sablefish taken in the surveys were unimodal with modes centered around 32-34 cm (Fig. 28); we considered 'nearly all of these fish to be l-yr-olds, on the basis of the 1981 age-length table (Table 7). In 1981, the length distribution was bimodal with modes centered near 20 cm and 36-37 cm; we interpreted-these size groups to be young of the year and 1-yr-olds, predominantly. The NCS method was used to analyze these length distributions, and the best nonoverlapping length intervals for

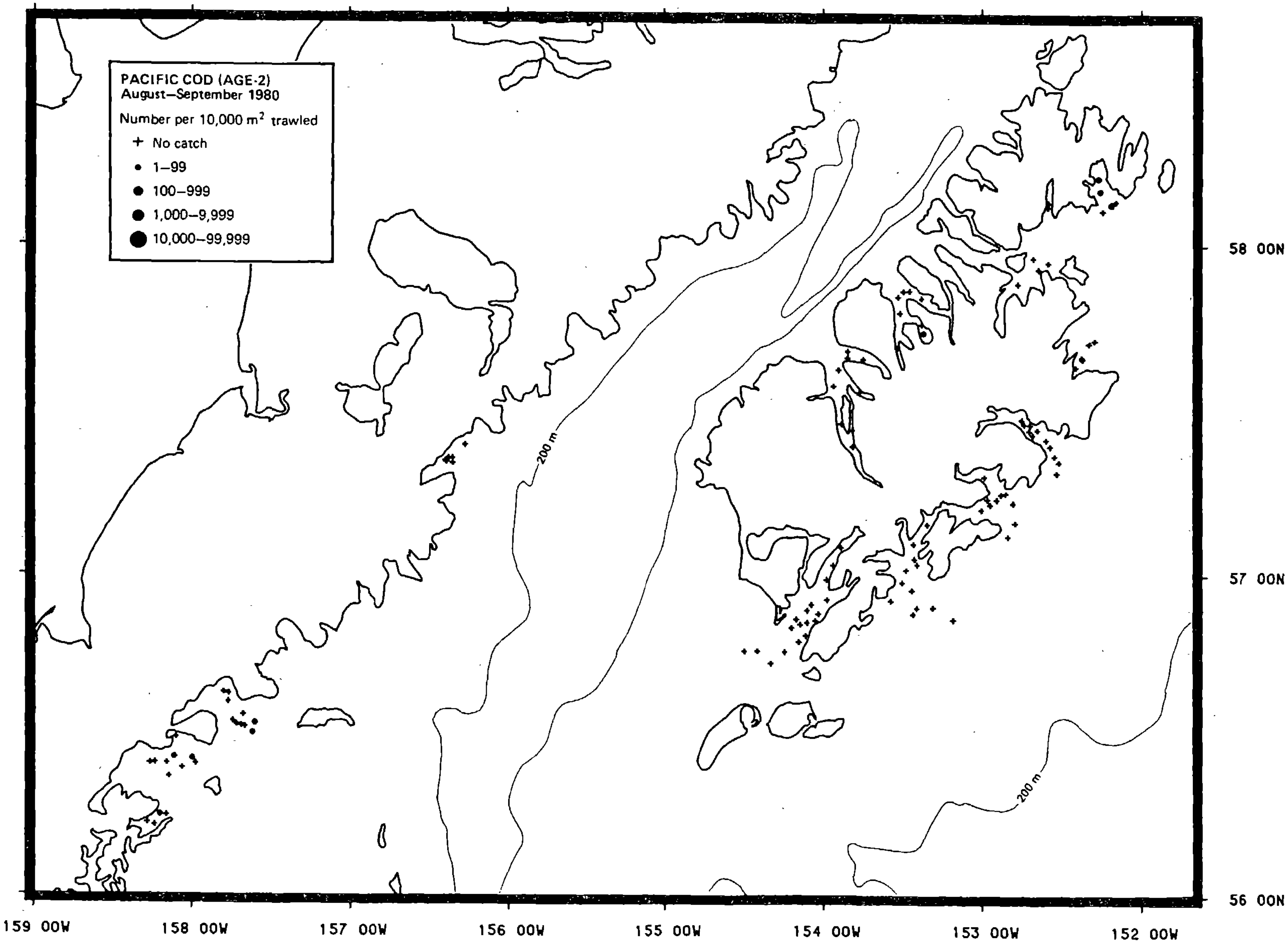

Figure 25.--Distribution and relative abundance of 2-yr-old Pacific cod in the northwestern Gulf of Alaska in 1980.

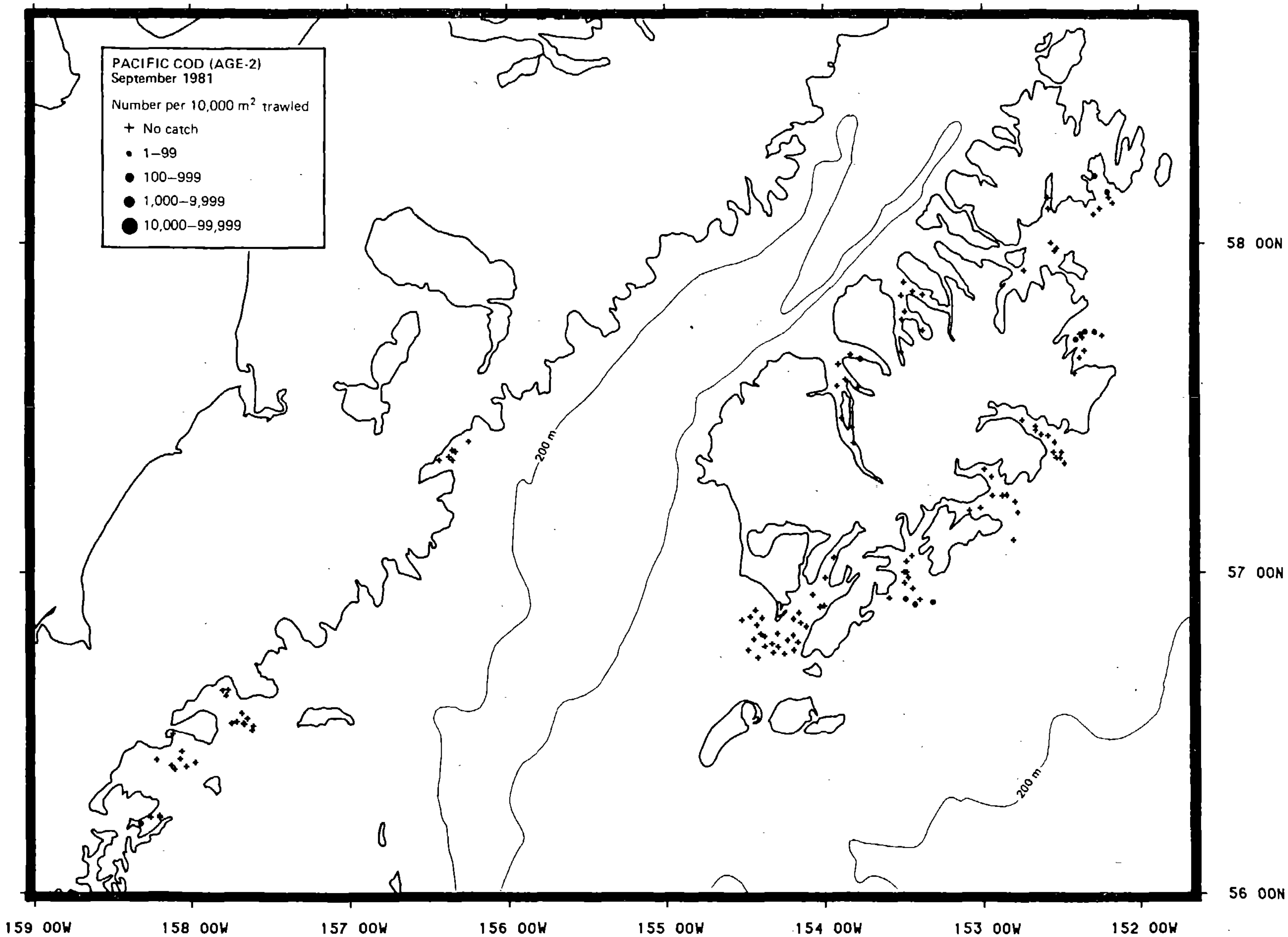

Figure 26.--Distribution and relative abundance of 2-yr-old Pacific cod in the northwestern Gulf of Alaska in 1981.

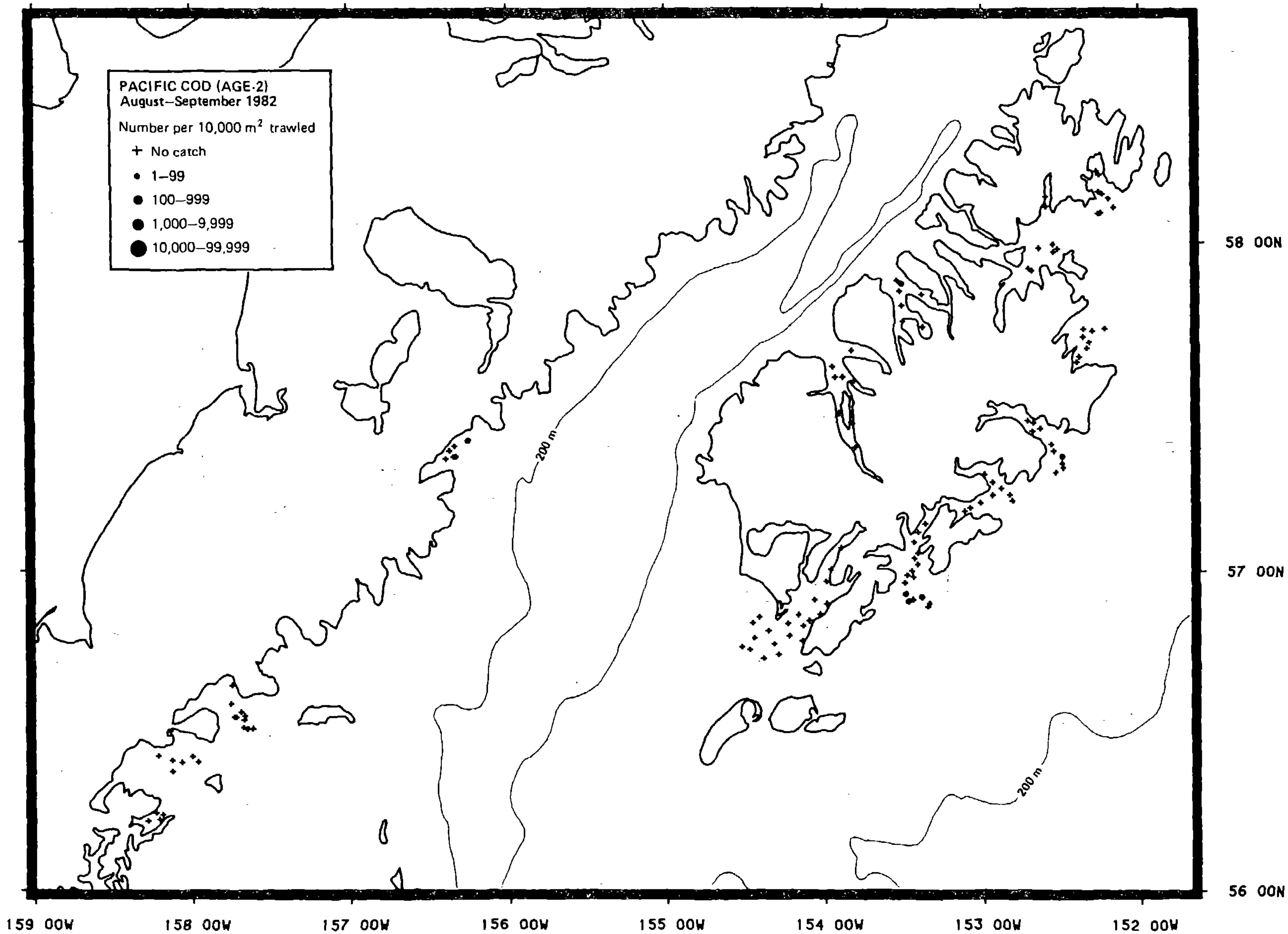

Figure 27.--Distribution and relative abundance of 2-yr-old Pacific cod in the northwestern Gulf of Alaska in 1982.

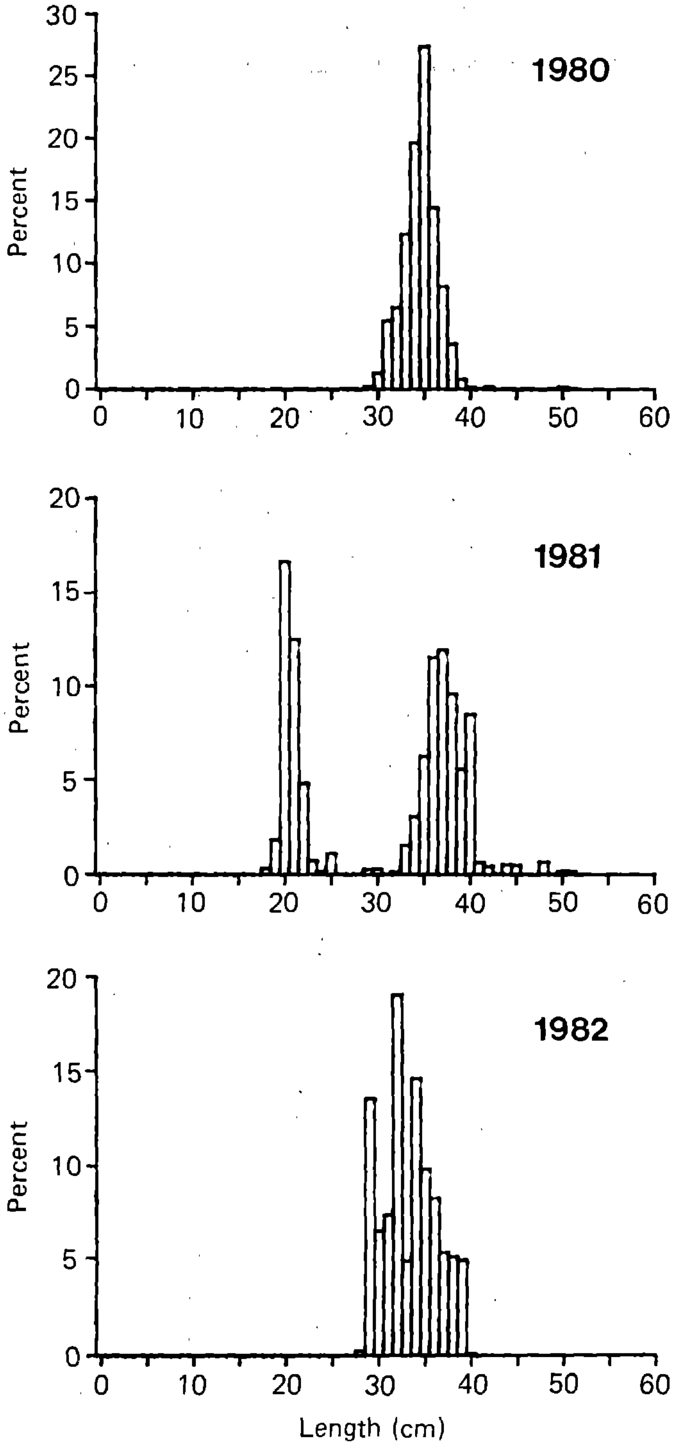

Figure 28.--Length-frequency distributions of sablefish taken in the northwestern Gulf of Alaska, 1980-82.

Table 7.--Sablefish age-length table developed from otolith samples collected on the 1981 survey of bays and nearshore areas of the northwestern Gulf of Alaska, showing the number of observations at each length and age.

Length (cm)	Age (yr)[a] 0	1	2	3	Total
19	2	0	0	0	2
20	2	0	0	0	2
21	2	0	0	0	2
22	2	0	0	0	2
23	6	0	0	0	6
24	2	0	0	0	2
25	2	0	0	0	2
26	2	0	0	0	2
27	1	0	0	0	1
28	2	0	0	0	2
29	1	0	0	0	1
30	0	2	0	0	2
31	0	1	0	0	1
32	0	4	0	0	4
33	0	5	0	0	5
34	0	6	0	0	6
35	0	6	0	0	6
36	0	6	0	0	6
37	0	6	0	0	6
38	0	6	0	0	6
39	0	6	0	0	6
40	0	6	0	0	6
41	0	4	0	0	4
42	0	1	0	0	1
43	0	0	2	0	2
44	0	0	1	0	1
45	0	0	1	0	1
48	0	0	1	0	1
50	0	0	1	0	1
51	0	0	1	0	1
Total	24	59	7	0	90

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

delimiting the three youngest age groups were found to be the followinq: O-group, 18-26 cm; age 1, 27-42 cm; and age 2, 43-50 cm.

O-Group

Young of the year sablefish were observed only in 1981 in three hays--, Alitak Bay, Kujulik Bay, and Marmot Bay--in seven samples (Fig. 29, Tables 8 and 9). Alitak Bay had the highest density and largest population. Highest densities were observed in samples from <40 m (Fig. 30). The mean length of this age group was 20.7 cm.

Age-l

One-yr-olds were the dominant age group. of sablefish found in the study area; the group occurred in 9 inlets in 1980 and 1981, and in 10 of the 12 inlets in 1982 (Figs. 31-33). Number of occurrences in samples were: 1980, 30; 1981, 27; and 1982, 26. Mean lengths were: 1980, 34.5 cm; 1981, 37.1 cm; and 1982, 33.3 cm.

Total population estimates for 1-yr-olds (for the area covered by the 12 inlets) varied from 1,508.7 thousand in 1980, to 159.7 thousand in 1981, to 514.9 thousand in 1982 (Table 8). In 1980 and 1981, most 1-yr-old sablefish occurred in the Alaska Peninsula region. Bays with large populations were Kujulik Bay, Chignik Bay, and Castle Bay. In 1982, most 1-vr-olds were found on the east side of Kodiak Island in Marmot Bay, Chiniak Bay, and south Sitkalidak Strait; they were also abundant in Kujulik Bay on the Alaska Peninsula as in previous years. Over the 3 yr, 1-yr-old sablefish occurred in samples from nearly all depths surveyed, and highest densities were generally in samples from 80-120 m (Fig. 30).

In general, the distribution of standardized densities for 1-yr-old sablefish was similar to that of the estimated populations. In 1980 and 1981,

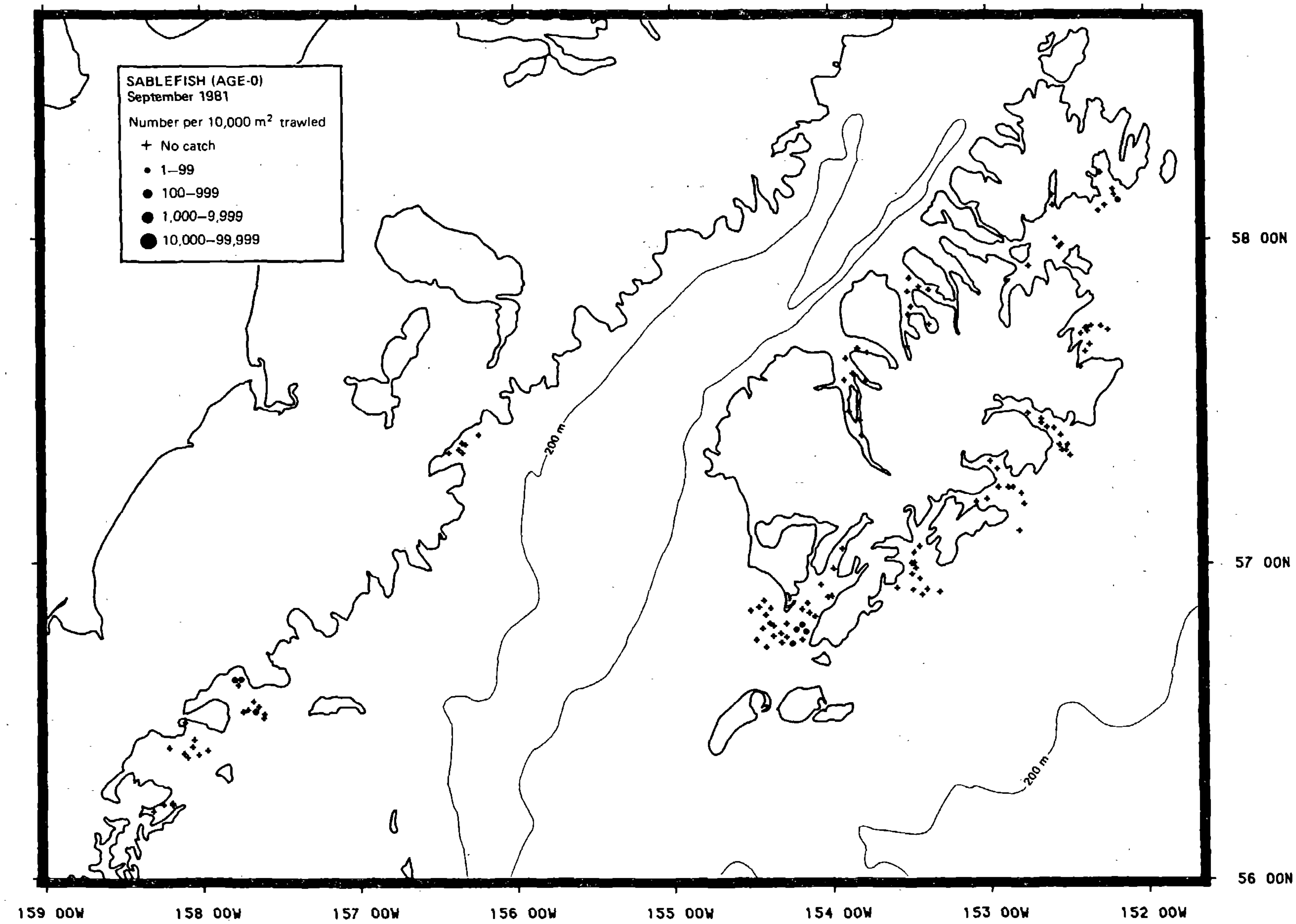

Figure 29.--Distribution and relative abundance of O-group sablefish in the northwestern Gulf of Alaska in 1981.

Table 8.--Estimated population size of juvenile age groups (0-2 yr) of sablefish in bays and nearshore areas of the northwestern Gulf of Alaska during late summer periods, 1980-82.

	Estimated population (thousands)								
	1980			1981			1982		
Stratum[a]	0	1	2	0	1	2	0	1	2
Alaska Peninsula									
Wide Bay	--	0.48	--	--	--	--	--	4.50	--
Kujulik Bay	--	559.92	--	4.37	87.16	--	--	98.12	--
Chignik Bay	--	651.42	--	--	32.62	1.59	--	3.54	--
Castle Bay	--	190.42	--	--	15.78	--	--	1.87	--
Subtotal		1402.24		4.37	135.56	1.59	--	108.03	--
East Kodiak Island									
Marmot Bay	--	5.67	--	0.80	0.80	--	--	274.48	--
Chiniak Bay	--	2.38	--	--	0.35	--	--	63.78	--
Ugak Bay	--	--	--	--	--	--	--	2.79	--
Kiliuda Bay	--	--	--	--	9.39	--	--	4.53	--
S. Sitkalidak Strait	--	59.69	2.18	--	4.49	--	--	60.40	--
Subtotal		67.74	2.18	0.80	15.03	--	--	405.98	--
West Kodiak Island									
Uganik Bay	--	27.46	--	--	8.33	2.25	--	--	--
Uyak Bay	--	--	--	--	0.75	--	--	--	--
Alitak Bay	--	11.22	--	96.50	--	1.42	--	0.91	--
Subtotal	--	38.68	--	96.50	9.08	3.67	--	0.91	--
Total	--	1508.66	2.18	101.67	159.67	5.26	--	514.92	--

[a] See Figure 1.

Table 9.--Standardized densities[a] of juvenile age groups (0-2 yr) of sablefish in bays and nearshore areas of the northwestern Gulf of Alaska, 1980-82.

	Apparent density (number/10,000 m²)								
	1980			1981			1982		
Stratum[b]	0	1	2	0	1	2	0	1	2
Alaska Peninsula									
Wide Bay	--	0.19	--	--	--	--	--	1.74	--
Kujulik Bay	--	75.66	--	0.59	11.78	--	--	13.26	--
Chignik Bay	--	57.14	--	--	2.86	0.14	--	0.31	--
Castle Bay	--	66.81	--	--	5.54	--	--	0.66	--
Region	--	57.87	--	0.18	5.59	0.07	--	4.46	--
East Kodiak Island									
Marmot Bay	--	0.29	--	0.04	0.04	--	--	14.01	--
Chiniak Bay	--	0.41	--	--	0.06	--	--	10.96	--
Ugak Bay	--	--	--	--	--	--	--	0.30	--
Kiliuda Bay	--	--	--	--	0.61	--	--	0.29	--
S. Sitkalidak Strait	--	2.53	0.09	--	0.19	--	--	2.56	--
Region	--	0.92	0.03	0.01	0.20	--	--	5.52	--
West Kodiak Island									
Uganik Bay	--	3.95	--	--	1.20	0.32	--	--	--
Uyak Bay	--	--	--	--	0.09	--	--	--	--
Alitak Bay	--	0.26	--	2.26	--	0.03	--	0.02	--
Region	--	0.66	--	1.65	0.16	0.06	--	0.02	--
Overall	--	9.65	0.01	0.65	1.02	0.03	--	3.30	--

[a] Computed by dividing population estimates in Table 8 by the corresponding geographic areas in Table 1. Regional densities were calculated-from the previous subtotals.
[b] See Figure 1.

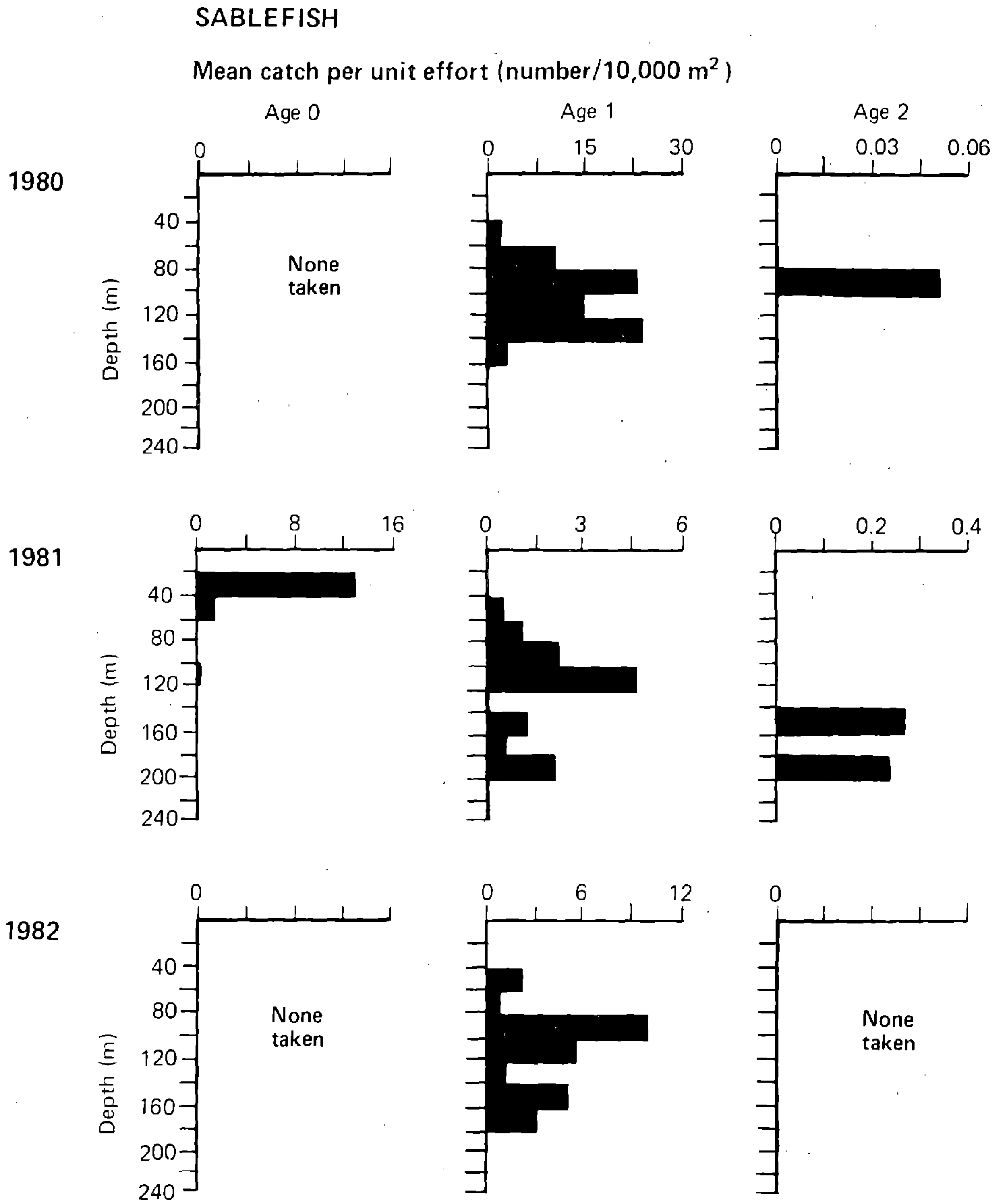

Figure 30.--Variations of sablefish densities with sampling depth, ages 0-2 yr, in the northwestern Gulf of Alaska.

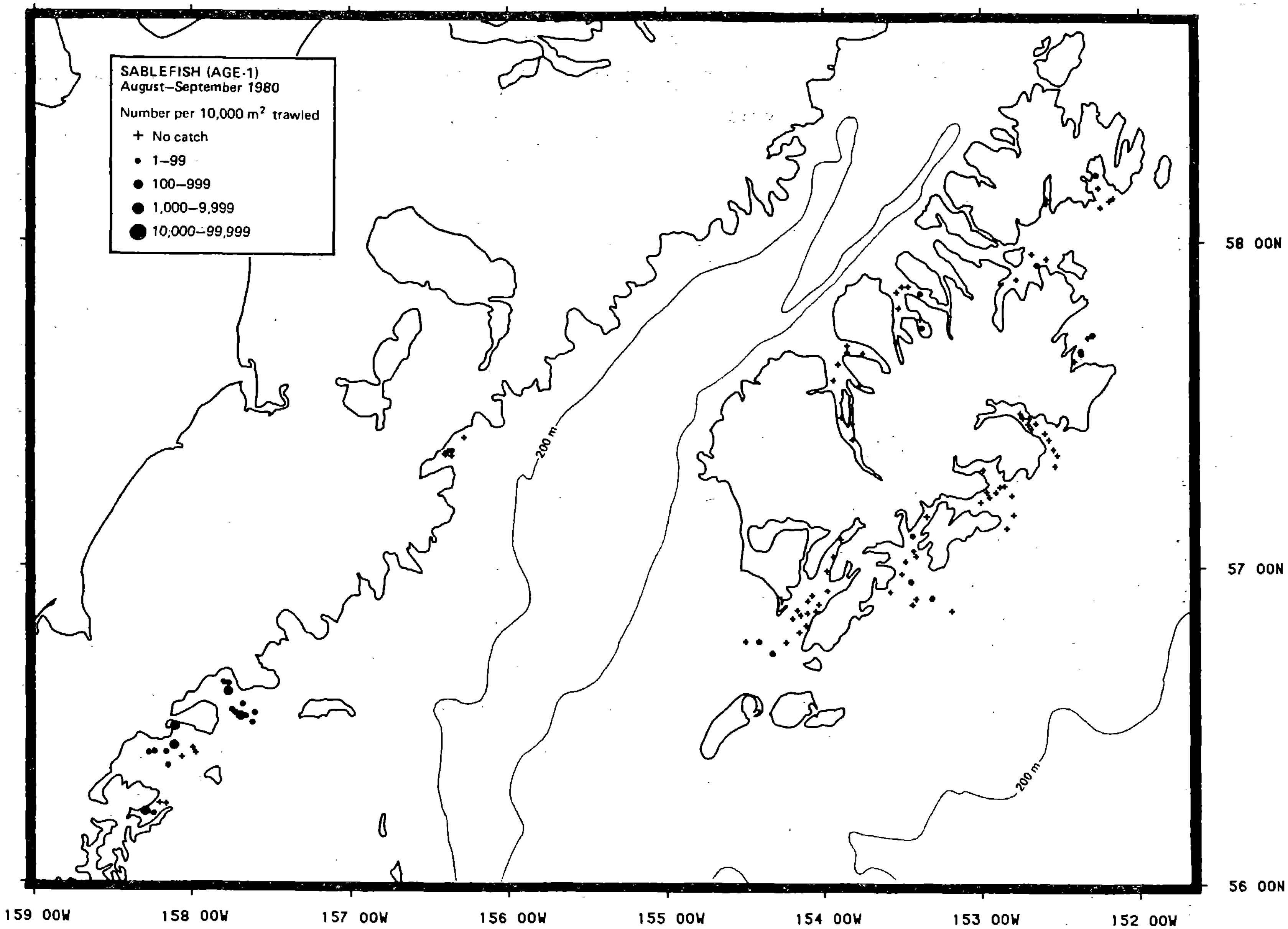

Figure 31.--Distribution and relative abundance of 1-yr-old sablefish in the northwestern Gulf of Alaska in 1980.

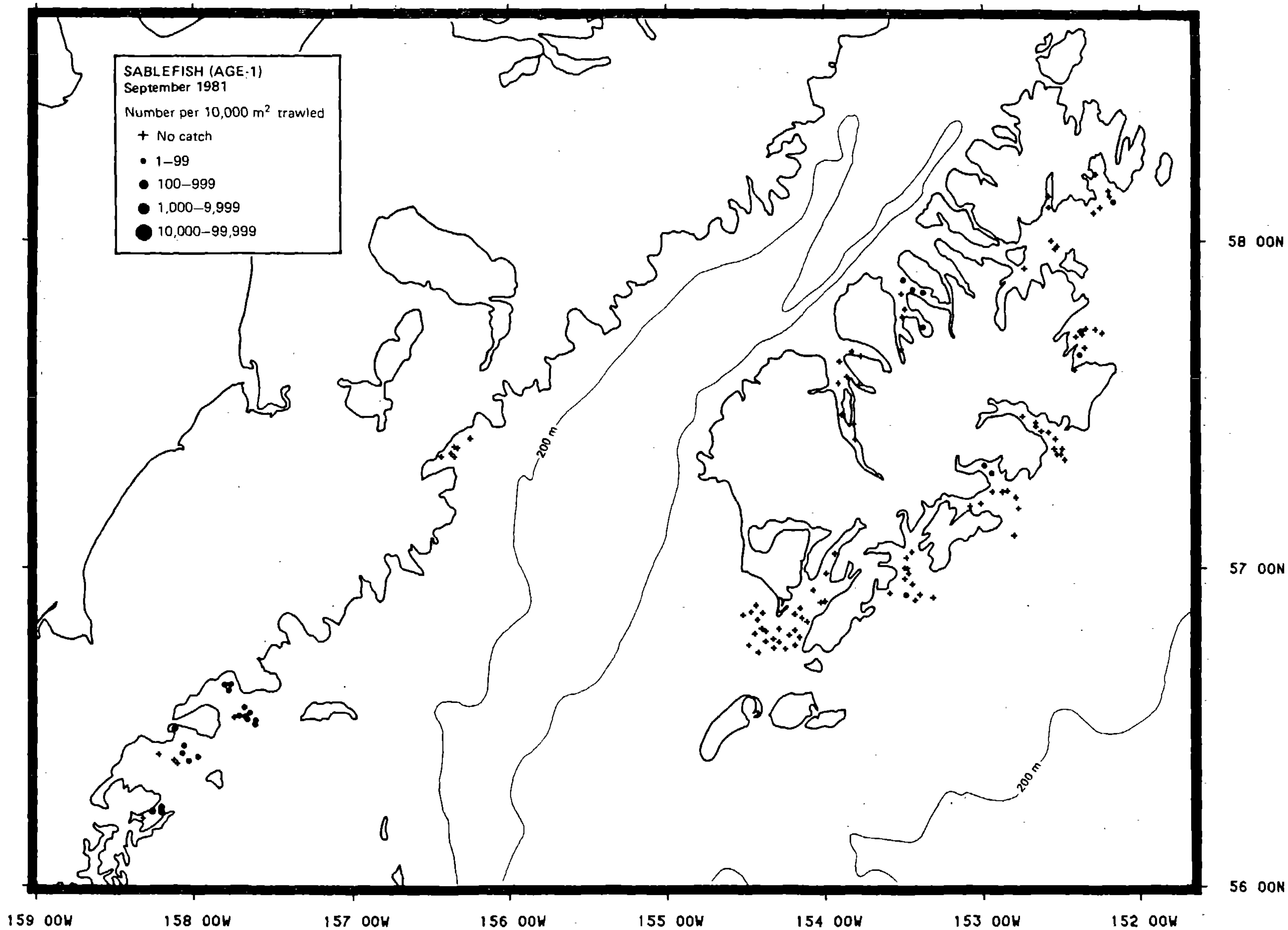

Figure 32.--Distribution and relative abundance of 1-yr-old sablefish in the northwestern Gulf of Alaska in 1981.

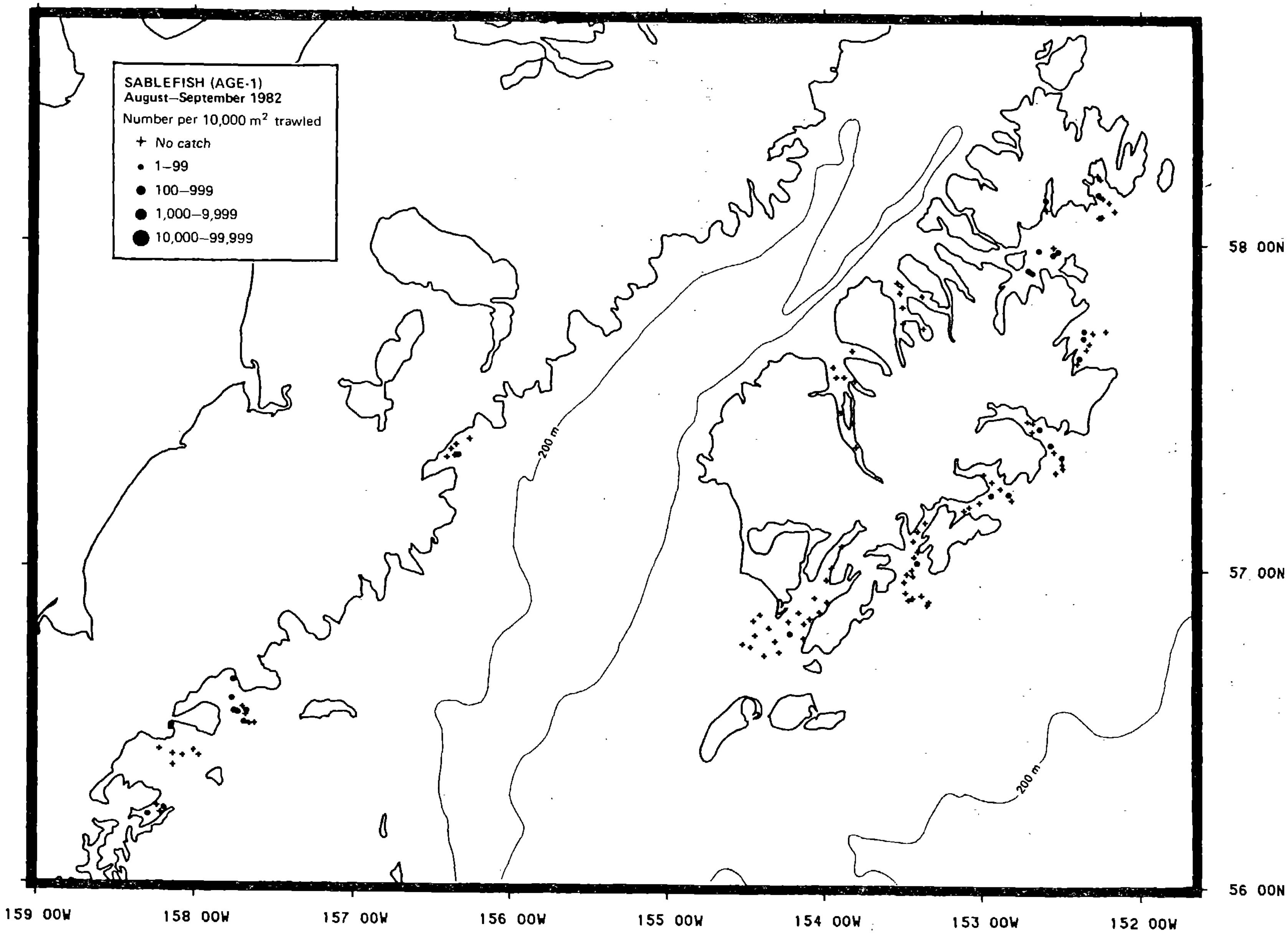

Figure 33.--Distribution and relative abundance of 1-yr-old sablefish in the northwestern Gulf of Alaska in 1982.

densities were high along the Alaska Peninsula in Kujulik, Castle, and Chignik Bays. In 1982, the highest densities occurred in Marmot, Kujulik, and Chiniak Bays. In all 3 yr, densities of 1-yr-olds were relatively low in the west Kodiak Island region.

Estimates of year-class strength, measured as standardized densities within the study area overall, varied as follows: 1979 year-class, 9.65 individuals/lO,OOO m^2; 1980 year-class, 1.02 individuals/lO,OOO m^2; and 1981 year-class, 3.30 individuals/lO,OOO m^2 (Table 9). Despite these apparent changes, when compared using the H test, the catch data from the 3 yr were found to be not significantly different.

Aqe-2

Two-yr-old sablefish were seldom taken in these nearshore areas. They were found in one sample from south Sitkalidak Strait in 1980, and four samples from three of the bays (Chignik Bay, Uganik Bay, and Alitak Ray) in 1981; none of the density estimates for these areas exceeded 0.4 individuals/ 10,000 m^2. In general, 2-yr-olds occurred in samples from the same depths or slightly deeper than 1-yr-olds.

DISCUSSION

Evaluation of Approach

The juvenile life history stage of fishes is often poorly understood because the young occur in different areas than the adults and larvae, and because they can be difficult to sample (Bakun et al. 1982). However, there is a need to improve our knowledge of the ecology, distributions, migratory movements, and interactions of juveniles to understand factors that influence population dynamics. In addition, there is the possibility that monitoring juveniles will, in some cases, enable useful predictions of future resource availability and recruitment.

Juvenile studies, such as ours, involve a number of different aspects of research. First, there is the need to study and describe the basic population biology and characteristics of the recruitment process--e.g., the relative abundance, distribution pattern, ontogenetic movements, and size and growth of juveniles--over at least several years. Then, in order to obtain useful measurements of year-class strength, there is a need to establish a process for ongoing evaluation and development of the specific methods used for population sampling and estimation.

Our studies found that over the 3 yr, 1980-82, juveniles of a number of groundfish species occurred commonly in shrimp trawl samples collected from bay and nearshore waters of the central Alaska Peninsula and Kodiak Island. These observations--and the studies of Carlson and Haight (1976), Harris and Hartt (1977), Blackburn and Jackson (1978), and Rosenthal (1980)--support the conclusion that these types of coastal habitats are important nursery areas for many fish species. The present study and the second report of our three-part series provide a considerable amount of new information describing these aspects of juvenile bioloqy.

Only limited evaluations of the specific methods of sampling were possible, though, because of our involvement in the ADF&G surveys as quest observers. Under ideal conditions, and over a longer time, sampling methods should be evaluated by experimentation in the field (e.g., comparing sampling gear performance and conducting exploratory sampling in other areas and time periods), varying the experimental design, and comparing the results with those of other studies. Our evaluations of sampling methods were limited to interpretations of the survey results and comparisons with other literature.

Methods of estimation have been evaluated, in a sense, by our selection of analytical procedures and in developing our recommendations for further work. Some of the problems encountered included: the skewed, nonnormal distributions of the juvenile catch data; the inability of the procedures used to estimate population size to also calculate the statistical variance, or confidence limits, for estimates of age group abundance: and the need to use the simple, unweighted catch data for testing year-to-year differences, rather than the best estimates (i.e., population estimates) of year-class abundance. Most of these problems are recommended as subjects for further research.

Evaluation of Results

Walleye Pollock

Although the recruitment process of walleye pollock in the Gulf of Alaska is incompletely understood, many of the important events, sites, and exchanges can be inferred from the literature and the results of this study. A large fraction of the adult population of walleye pollock in the western and central 'Gulf of Alaska is thought to migrate to a relatively fixed reproductive area in inner Shelikof Strait, where peak spawning occurs in March (Nunnallee et al. 1982; Alton 1983; Bates and Clark 1983). There is evidence from other sources, however, of additional spawning along the outer continental shelf. For example, based on gonad maturity observations recorded during fisheries research surveys in the period 1975-81, Hirschberger and Smith (1983) reported fish in spawning condition occurring along the edge of the outer continental shelf from Chirikof Island to Cape St. Elias. Ichthyoplankton surveys have also occasionally found high concentrations of eggs offshore of the east and southeast sides of Kodiak Island (Kendall et al. 1980b; Bates and Clark 1983; Jean Dunn, Northwest and Alaska Fisheries Center, Seattle, WA 98112, pers. commun. 1984).

In the northwestern Gulf of Alaska, where currents such as the Kenai Current and Alaskan Stream may have velocities of 20-70 cm/s or more (Schumacher and Reed 1980, 1983; Mysak et al. 1981), the horizontal advection of walleye pollock eggs and larvae may be a particularly important part of the recruitment process. Incze et al. (1984) reviewed and estimated the approximate development times for these planktonic stages in the eastern Bering Sea. The egg stage requires about 22 days from spawning to hatching at temperatures of 3.0-3.5°C; the yolk-sac larval stage, about 15 days; and the postlarval stage, about 36 days until the full development of dorsal fin rays at approximately 22 mm standard length. Since water temperatures in the Gulf of Alaska are warmer, about 4.0 to 6.0°C (Hirschberger and Smith 1983:fig. 7), development is probably more rapid.

Considering the prevailing currents, eggs and larvae resulting from releases at spawning sites in Shelikof Strait or off the east side of Kodiak Island should drift predominantly to the southwest along the Alaska Peninsula. At average current velocities of 20-30 cm/s, it would theoretically be possible for eggs and larvae to be transported 1,200 to 1,800 km during a 70-day planktonic period.

In our investigations, young-of-the-year walleye pollock (approximately 6 mo old) were found in highest concentrations in inlets along the east side of Kodiak Island, in Alitak Bay at the southwest end of Kodiak Island, and in bays along the Alaska Peninsula (Figs. 6-8, Table 4). In all of these regions, there was a general trend of decreasing densities to the southwest.

Along the Alaska Peninsula, the observed density gradient was generally consistent with the concept that inner Shelikof Strait is a major spawning site. If the spawning event and location can be considered an instantaneous point source of young, then advection and turbulent diffusion would be.expected to result in a concentration distribution similar to the one observed (assuming constant loss rates).

For similar reasons, the high abundance of O-group walleye pollock along the east side of Kodiak Island and their concentration gradient suggest that a major spawning site may be located to the northeast. In view of the predominant current flows, it is difficult to imagine how significant numbers of eggs or larvae could be transported to these bays from Shelikof Strait; current flow over the continental shelf on the east side of Kodiak Island is slow and erratic. Migrations of large numbers of early juveniles to this region from Shelikof Strait also seem unlikely. If walleye pollock on the east side of Kodiak Island do originate from a northeastern spawning stock, then some of their population characteristics--e.g., seasonal timing, growth and development, and migratory movements--may be different from populations associated with Shelikof Strait.

One-yr-old walleye pollock were observed in highest concentrations along the Alaska Peninsula and west side of Kodiak Island, and in these areas densities generally declined to the northeast; this trend was opposite to the concentration distribution shown by the O-group populations. In addition, few 1-yr-olds were observed in inlets along the east side of Kodiak Island. Migratory movements and the distribution of sources of mortality (e.g., predation) may have been important in determining these patterns, although interpretations are limited by the sampling methods and lack of other supporting data.

The low densities of 2-yr-olds observed in these studies indicated that, by this age, most older juveniles had probably migrated from the coastal habitats into deeper water. However, since deep water areas were not surveyed, this observation is speculative.

The table of standardized densities for the three age groups over the three successive years enabled estimates of age-specific population mortality rates, despite the limitations of the survey design. These calculations were also useful for examining the behavior and reliability of the data series. The instantaneous rates of total mortality observed, based on the data in Table 4, were: at the O-group level, 1.21 yr^{-1} (1980 year-class, comparing 1980 to 1981) and 1.78 yr^{-1} (1981 year-class, 1981 to 1982); and at the 1-yr-old level, 2.19 yr^{-1} (1979 year-class, 1980 to 1981) and 2.60 yr^{-1} (1980 year-class, 1981 to 1982). These values were generally higher than the mortality rates reported for walleye pollock in the eastern Bering Sea (Smith 1981), but do not seem unreasonable.

It was also possible to compare these mortality rates, and the O-group and 1-yr-old population estimates (i.e., Tables 3 and 4), with the estimates of Alton and Deriso (1983b) for 3-yr-old population levels; these comparisons were another way to check the reliability of our survey data. Based on catch-at-age analyses of data from the commercial trawl fisheries, Alton and Deriso (1983b:fig. l-2) estimated the abundance of 3-yr-old walleye pollock populations in western and central regulatory areas of the Gulf of Alaska for each year, from 1973 to 1979. Their estimates of population size at age 3 ranged from about 0.4 to 3.2 billion fish.

To compare these values with our estimates, we expanded the fish densities given in Table 4 up to the regional scale used by Alton and Deriso. We assumed that all coastal waters inside of the charted 50 fathom (91 m) isobath were potential nursery grounds, and that the average densities we observed (i.e., the values given in Table 4, overall) were representative of all nursery ground area. The potential nursery ground area was estimated to be approximately 90,000 km^2. The expanded survey estimates for O-group walleye pollock in' the region, calculated by multiplying the densities in Table 4 by this area, were: 1980, 2.4 billion; 1981, 14.8 billion; and 1982, 1.8 billion. Expanded estimates for 1-yr-olds were: 1980, 4.4 billion; 1981, 0.7 billion; and 1982, 2.5 billion. Despite the uncertainties of our assumptions and our limited understanding of the importance of midwater distributions, these estimates--with their statistical range and the mortality rates implied--are consistent with the catch-at-age results.

A number of environmental factors are likely to have important effects on the recruitment of walleye pollock. Some of these factors may be inferred from excellent reviews of the Gulf of Alaska and analogous ecosystems (Ingraham et al. 1976; Bakun and Parrish 1980; Bakun et al. 1982; Schumacher and Reed 1983) and from our own work. Temperature conditions can be expected to influence growth rates, population distributions, and the general activity levels of fishes and their migratory movements. Horizontal advection may be important in the region because of the vigorous and narrow coastal flows, and the possible movement of eggs and larvae from the continental shelf to the oceanic North Pacific.

Only limited data were available for examining possible relationships between environmental conditions, and the variations we observed in the distribution and abundance of juvenile walleye pollock. Figure 34 shows the long-term record of sea surface temperature conditions in the general region of the study area (estimated for a gridpoint at lat. 58°N, long. 150°W) from April 1962 to March 1983. During this time, there were periods when conditions were anomalously warm (e.g., 1967-70, 1977-82) or cold (1962-64, 1971-73, 1975). Favorite and McLain (1973) observed temperature fluctuations with a 5-6 yr period to be a characteristic of the northern transpacific region. Our juvenile fish surveys were conducted during a period of relatively warm conditions.

In the eastern Bering Sea, walleye pollock spawn along extensive areas of the shelf edge, and in their first year and as 1-yr-olds they are broadly distributed over the entire central and outer continental shelf (Smith 1981). Such widespread distributions of juveniles have not been reported in reviews of the biology of walleye pollock in the Gulf of Alaska (Ronholt et al. 1978; Hughes and Hirschhorn 1979). This may be due to incomplete sampling coverage and the few midwater investigations to date. One exception, however, is an observation from September 1983 of O-group walleye pollock (approximately 10 cm FL) occurring up to 60 km east of Marmot Bay (Craig Rose, Northwest and Alaska Fisheries Center, Seattle, WA 98112, pers. commun. 1984). These young fish were found at depths of 80-200 m. This suggests that the gullies and troughs extending from coastal inlets may be important routes for seasonal and ontogenetic movements of juveniles.

If eggs and larvae are transported from spawning sites on the continental shelf to offshore waters, then could the North Pacific oceanic region (e.g., the Alaska gyre) be a nursery area for young? Probably not; there are at

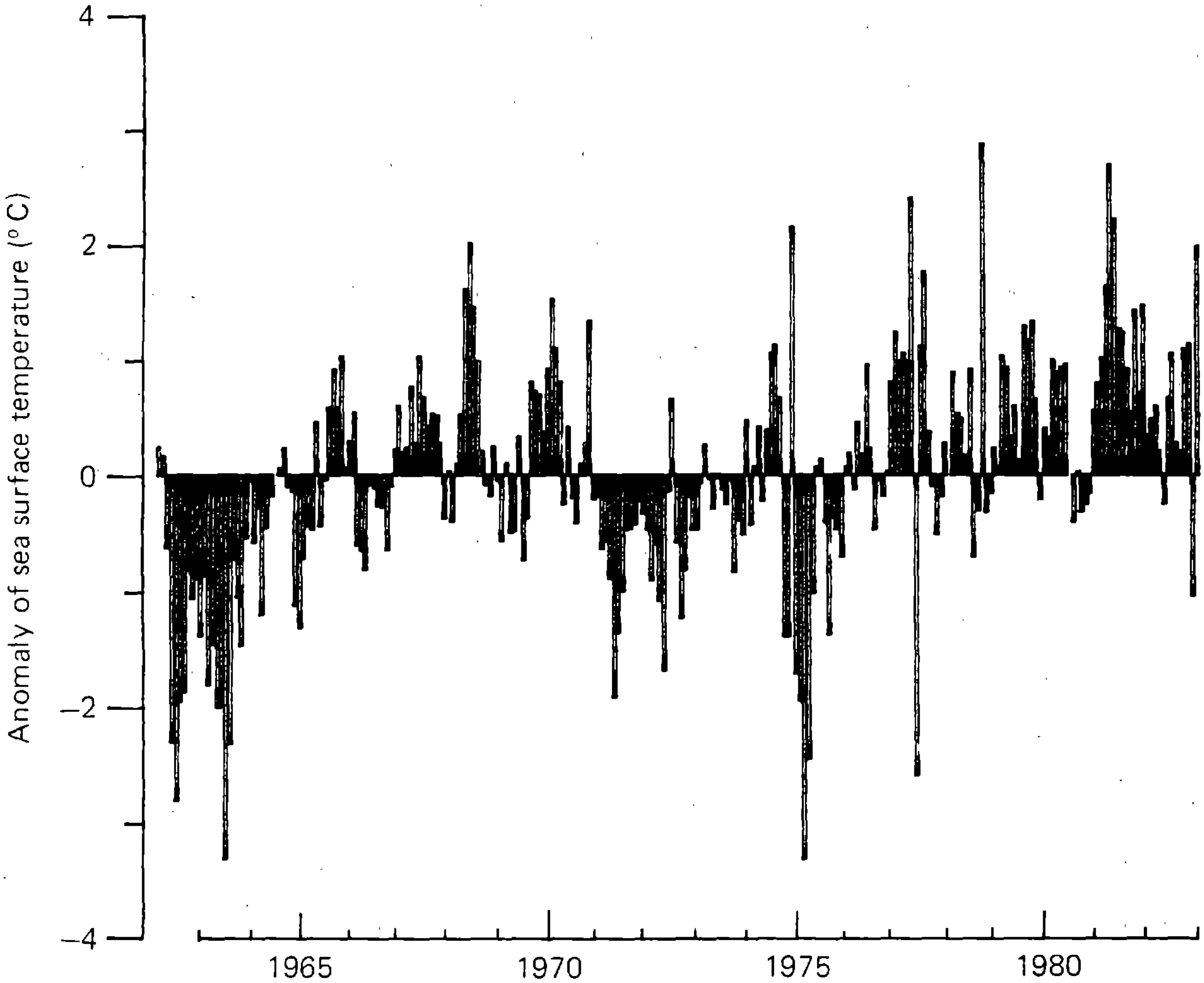

Figure 34. --Anomaly of mean sea surface temperature in the northwestern Gulf of Alaska from April 1962 to March 1983. Values were interpolated at lat. 58°00' N, long. 150°00'W, from gridpoint analysis fields developed by the Fleet Numerical Oceanography Center. Data were provided courtesy of Douglas McLain, Pacific Environmental Group, Monterey, CA 93940.

least three sources of evidence against it: 1) in an extensive study of midwater fishes and other nektonic organisms in the northeastern Pacific Ocean, the principal fishes taken were myctophids and there was no mention of walleye pollock (Aron 1962); similarly, 2) surveys of the food of salmonid fishes in the North Pacific have reported the principal prey to be myctophids, squid, and juvenile rockfishes (Allen and Aron 1957; Manzer 1968); and 3) studies of the diet of Dall's porpoise, Phocoenoides dalli, in the North Pacific have reported the principal food organism to be squid (Mizue et al. 1966).

Apparently older walleye pollock are not very common in the Gulf of Alaska oceanic region, either. In the extensive high seas gill-netting surveys reported by Larkins (1964)--which included net sets in the North Pacific, Bering Sea, and Gulf of Alaska--walleye pollock were caught only in the southern Bering Sea.

Pacific Cod

In comparison to walleye pollock, tie are limited to a relatively fragmentary understanding of the recruitment process of Pacific cod in the Gulf of Alaska; however, it is possible to infer some of the important activity areas and their relationships to the seasonal migratory cycle. In the Gulf of Alaska, adult Pacific cod are thought to migrate to deep water in winter, spawn primarily along the outer continental shelf at depths 150-250 m during February and March (Hirschberger and Smith 1983), and migrate to shallower areas in spring and summer. It also seems likely that some fish spawn in inshore regions of the continental shelf; ichthyoplankton surveys have sometimes found moderate concentrations of larvae in inner Shelikof Strait (e.g.., Bates and Clark 1983). This pattern of population activity and movement is similar to the seasonal cycle that Ketchen (1961) described for Pacific cod in Canadian waters.

Off British Columbia, Pacific cod spawn primarily off the open coast at depths 90-l50 m, but also in bays and straits (Yusa et al. 1977). In Japanese waters, spawning is reported to occur primarily in bays and straits (Yusa et al. 1977). Port Townsend Bay is a major spawning site in the Puget Sound (Karp 1982).

Since the eggs of Pacific cod are demersal and 'adherent (Thomson 1963), they may largely remain near their deposition sites until hatching. Development times and other aspects of the early life history have been reviewed by Yusa et al. (1977). At the environmental temperatures observed in the Gulf of Alaska, approximately 4.5 to 5.9^{o}C (Hirschberger and Smith 1983:24), the time required from spawning to hatching is expected to be about 14-18 days. Off Japan, the postlarval stage is completed about 1 month after hatching at about 10 mm length; dorsal and anal fin rays are developed at about 14-17 mm total length (Yusa et al. 1977).

All the early life history stages appear to be closely associated with bottom waters. In plankton surveys, larvae are usually caught only in deep oblique net tows and are seldom, if ever, taken in neuston samples (Bates and Clark 1983). Early juveniles are thought to be epibenthic, (Karp 1982). Because of this orientation toward the bottom environment, the early stages of Pacific cod may be influenced by markedly different transport, dispersal, and mixing processes than fish that have pelagic eggs and larvae such as walleye pollock.

In this study, young-of-the-year Pacific cod (9-10 cm FL) were found in 5 of the 12 bays and primarily at depths shallower than 80 m. Major information gaps in our understanding of the recruitment process, then, are the sources and transport mechanisms for these -juveniles. Important questions include: Are the spawning areas along the outer continental shelf the principal sources of young? If so, how do larvae and early juveniles move across the shelf to shallows, and what are the important factors influencing their survival and migratory success? What spawning occurs in or near bays?

If deepwater spawning sites are the principal sources of larvae, and if coastal embayments and other shallow areas of the continental shelf are the nursery areas, then it seems reasonable to hypothesize that the shoreward migration of young along the bottom might be a particularly critical phase of the recruitment process. Effects of near-bottom oceanographic conditions, such as coastal current flows, may be important. For example, the conditions of divergence and upwelling at the coast that are typical from June to August (Ingraham et al. 1976:table 2) should result in shoreward movements of deep shelf water. Similarly, the related deepwater current flows into Shelikof Strait and up the troughs along the east coast of Kodiak Island (Schumacher et al. 1978;,Lagerloef 1983). may be important avenues for shoreward larval transport. Further research is needed in these areas.

In our studies, O-group Pacific cod were taken in relatively few samples in 1980 and 1982, and densities in the 12 inlets were relatively spotty (Figs. 18-20, Table 6). As a result, year-class strengths estimated from the surveys showed high variation from year to year. Only Wide Bay was observed to have O-group juveniles in all 3 yr (only at one location in 1980)'; elsewhere, the locations where high densities occurred were inconsistent from year to year. There were-no evident trends in abundance. For these reasons, and because our results appeared to be sensitive to small differences in the survey approach, one would have to conclude that the specific sampling methods were not very effective and need improvement.

For example, the vertical distribution of O-group Pacific cod in their nursery areas, both on-bottom and in midwater, needs to be more clearly' determined. If the target populations for our surveys were almost entirely located at depths shallower than 80 m (e.g., see Fig. 21), then they nay not have been sampled with the same effectiveness from year to year; 25.4% of the trawl tows taken in 1980 were at depths < 80 m; in 1981, 34.6%; and in 1982, only 24.6% (Fig. 2).

The abundance estimates for 1 and 2-yr-old Pacific cod were also characterized by a low number of occurrences, high variability, and inconsistent mortality rates from year to year. There was little evidence for residence of large or small populations in individual inlets. This suggests that migration between inlets and seasonal exchange between inlets and shelf are probably important at these ages, and a part of progressive movements onto the outer continental shelf.

The surveys probably occurred at the end of the optimum tine period for sampling juvenile Pacific cod effectively. Yusa et al. (1977) reported that young Pacific cod move out of the bays of Japan in late summer. This sane behavior is likely to occur in the Gulf of Alaska.

Sablefish

Specific characteristics of the spawning biology and early life history of sablefish in the Gulf of Alaska are poorly understood. Off the west coast of Canada, peak spawning activity occurs in February, although females have been found in spawning condition from January through March (Mason et al. 1983). Observations from other studies provide evidence suggesting that the reproductive timing may be similar in other areas of the species range (Mason et al. 1983).

Spawning areas for sablefish in the Gulf of Alaska are not well known. Off western Canada, studies of the distribution and abundance of eggs have indicated that spawning activities occur coastwide, primarily over the continental slope (Mason et al. 1983). But on the basis of size and tagging data, Bracken (1982) hypothesized that offshore areas in the eastern Gulf of Alaska--including deepwater areas off British Columbia,. southeastern Alaska, and Yakutat--may be major spawning grounds.

In the 12 inlets that we studied, we found three juvenile age groups of sablefish. One-yr-olds were the dominant age group in all 3 yr of our surveys; they occurred in almost all 12 strata in high densities (see Table 9). In 1980 and 1981, they were particularly abundant in bays along the Alaska Peninsula. In 1982, they were abundant in Kujulik Bay and in inlets along the east side of Kodiak Island. Young-of-the-year sablefish (approximately 20 cm length). were observed only in 1981, when they were taken in the shallows of Alitak, Kujulik, and Marmot Bays; warn temperature conditions in that year (e.g., see Figs. 3 and 34) may have contributed to this occurrence.

A notable feature of the results for sablefish was the distinct separation of the different age groups. Young of the year were rarely found in our surveys, and then only in samples from the shallows of inlets. These fish may have been more abundant in the shallows than our predominantly deep-water surveys showed; some may have still been offshore. In contrast, 1-yr-olds were fairly common in the areas and depth zones covered by the surveys.' Two-yr-olds were seldom taken, but occasionally occurred at scattered locations in low densities.

In the studies of sablefish reported by McFarlane and Beamish (1983a), which followed juveniles from an exceptionally abundant 1977 year-class, the movements of juveniles within the inside waters off the west coast of Canada were found to be complex. Fish remained in inside waters--including Hecate Strait, Queen Charlotte Sound, the Strait of Georgia, and mainland inlets--until age 3+, then began to move offshore. A large percentage remained in inside waters at least until age 5+. Corresponding aspects of the biology of juvenile sablefish in the Gulf of Alaska could be clarified by similar assessment and tagging studies.

Because the recruitment of sablefish appears to be characterized by infrequent, strong year-classes, Sasaki (1983) and others have pointed out the need to obtain early estimates of the abundance of year-classes through field investigations. Our results indicated that it might be possible to do this by surveying l-yr-olds in inshore nursery areas. However, some aspects of the methods we used for sampling and estimation need improvement. For example, despite the apparent variations shown by the best estimates of abundance, our surveys did not detect significant changes in the catch data of l-yr-olds over the 3 yr studied. This suggests that larger sample sizes nay be needed to detect changes in population levels between years; the optimal sample size should be evaluated before further fieldwork is conducted. In addition, the optimum timing for prerecruit surveys (which, in our studies, was impossible to explore) needs to be examined.

Forecasting Resource Abundance

One of the goals of forecasting is to define the future in terns of probabilities, so that the possible futures can be incorporated as ingredients in the long-range planning process (Helmer 1983). This type of planning is an important, although relatively undeveloped, aspect of the management of groundfish fisheries in the Alaska region. Here, the major trawl and longline fisheries are managed using the technique of "active" regulations applied to the harvesting sector. Annual catch quotas are established for the important target species, based on the most current information on population size and condition. At present, however, much of the population assessment is retrospective and there is little information available that allows looking ahead.

Our studies provided evidence that, with additional improvements, it may be feasible to use bottom trawl surveys of coastal nursery areas in the northwestern Gulf of Alaska to obtain useful, early measures of year-class abundance. Species and age groups that were relatively common in our samples, and that we believe offer the best opportunities for surveying, were O-group and l-yr-old walleye pollock; O-group Pacific cod; and 1-yr-old sablefish. In most cases, measures of these species and ages provide indicators that are 3-5 yr in advance of the other information used for stock assessment.

Further research needs to be done, however, to evaluate and develop specific aspects of this approach. Do the measures of prerecruit abundance really provide useful information? How reliable and valid, in a statistical sense, are projections made from them? How do the statistical properties of the data affect the sensitivity to detect changes? What is the appropriate timing and area coverage for surveys, sampling design, and sample size?

It is too early to answer some of these questions, because none of the year-classes studied have yet been reported in any analyses of commercial fisheries data. In any event, a longer time series will be required for meaningful validation. Some of these questions will require new field studies and exploratory sampling. Some of the questions relating to characteristics of juvenile populations in the larger geographic region, and the quantitative aspects of the assessment problem, will be explored in the second and third reports.

Recommendations

1. The methods developed by this study, based on annual surveys of juvenile fish and shrimp in important bays and nearshore waters of the northwestern Gulf of Alaska, appear to offer reasonable opportunities for obtaining early measures of the year-class strengths of walleye pollock, Pacific cod,' sablefish, and some other groundfish. We recommend that this type of survey approach--i.e., establishing a standard survey series--be continued and improved.

2. The approaches described in this study--i.e., the September timing, 12 strata, sampling gear, and field methods--should be held constant as a "core" sampling program, so as to maximize the return on the sampling effort already invested. Beyond this basic program, however, it is important to evaluate and improve the specific methods of sampling; this should involve both experimentation and standardization. More exploratory survey work is-needed for better evaluation of distribution patterns and seasonal movements. For example, we believe that additional sampling in shallow water would improve the population estimates for O-group Pacific cod, and sampling in additional bays might improve the assessments of O-group and 1-yr-old walleye pollock. At the same time, the distribution of sampling depths should be standardized.

3. There is a need to evaluate and improve the methods used for estimating prerecruit population levels. This should include exploring statistical properties of the catch data, evaluating the experimental design, and estimating sample size requirements. Procedures need to be developed for associating confidence intervals with the point estimates of age group abundance. This is important for evaluating the reliability of the estimates and for comparing values (e.g., measures of year-class strength) between different populations, years, or regions.

4. It should be recognized that a long-term commitment will be required before the predictive validity of population indicators from the surveys can be adequately tested. This is because there is a tine lag between the acquisition of the data and the criteria against which its performance as an indicator will likely be measured, i.e., recruitment to the first one or two age groups represented in the commercial fisheries catch data. For example, the 1980 year-class of walleye pollock described in this study will not be included in catch-at-age analyses of commercial fisheries data until later in 1984. If the survey coverage is resumed and conducted annually from 1984 onwards, only six data points (i.e., estimates of the O-group abundance of the year-classes from 1980-82 and 1984-86) will be available by the year 2000.

5. It will be important to clarify, early in the forecasting program, the predictions we expect from these types of studies. We should define specific populations and ages, regulatory area, tine, and any other important objectives.

6. Further investigations should be made of the important environmental factors affecting juvenile abundance, survival, and recruitment to fisheries. Important biological research to be done includes further clarification of the recruitment process for each species--i.e., describing the major sources of eggs and larvae, transport mechanisms, migratory movements of juveniles, and the patterns and sources of mortality during the prerecruit life history stage. Predation is undoubtedly important, but feeding relationships are poorly understood in the Gulf of Alaska. Other research to be done includes evaluation and development of the physical oceanographic and meteorological data bases available for the region. Tine series will be important for

estimating both environmental temperatures experienced by continental shelf organisms and horizontal advection, particularly cross-shelf and off-shelf transport.

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REFERENCES

ALLEN, G. H., and W. ARON.

1957. Food of salmonid fishes of the western North Pacific Ocean. Univ. Wash., Seattle, Dep. Oceanogr. Rep. 57-21, 23 p.

ALTON, M.

1983. Gulf of Alaska pollock fisheries. In G.Stauffer (editor), Condition of groundfish resources of the Gulf of Alaska region as assessed in 1983, p. 2-l to 2-19. NWAFC Processed Rep. 84-02. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

ALTON, M. S., and R. B. DERISO.

1983a. Walleye pollock. In D. H. Ito and J. W. Balsiger (editors), Condition of groundfish resources of the Gulf of Alaska in 1982, p. l-62. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-52.

1983b. Condition of Gulf of Alaska pollock resource. In G. Stauffer (editor), Condition of groundfish resources of the Gulf of Alaska region as assessed in 1983, p. l-l to 1-19. NWAFC Processed Rep. 84-02. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

ALVERSON, D. L., and W. T. PEREYRA.

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

ARON, W.

1962. The distribution of animals in the eastern North Pacific and its relationship to physical and chemical conditions. J. Fish. Res. Board Can. 19:271-314.

BAKKALA, R. G., and V. G. WESPESTAD.

1984. Pacific cod. In R. G. Bakkala and L-L. Low ('editors), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1983, p. 21-36. U.S. Dep. Commer., NOAA Tech. Memo NMFS F/NWC-53.

BAKUN, A., J. BEYER, D. PAULY, J. G. POPE, and G. D. SHARP.

1982. Ocean sciences in relation to living resources. Can. J. Fish. Aquat. Sci. 39:1059-1070.

BAKUN, A., and R. H. PARRISH.

1980. Environmental inputs to fishery population models for eastern boundary current regions. In G. D. Sharp (editor), Workshop on the effects of environmental variation on the survival of larval marine fishes, p. 67-104. UNESCO, Intergov. Oceanogr. Comm., Paris; Workshop Rep. 28.

BALSIGER, J. W.

1983. Sablefish. In D. H. Ito and J. W. Balsiger (editors), Condition of groundfish resources of the Gulf of Alaska in 1982, p. 63-86. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-52.

BATES, R. D., and J. CLARK.

1983. Ichthyoplankton off Kodiak Island and the Alaskan Peninsula during spring 1981. NWAFC Processed Rep. 83-09, 105 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle-, WA 98112.

BEAMISH,, R. J., and D. E. CHILTON.

1982. Preliminary evaluation of a method to determine the age of sablefish (<u>Anoplopoma fimbria</u>). Can. J. Fish. Aquat. Sci. 39:277-287.

BEDDINGTON, J. R., and R. M. MAY.

1977. Harvesting natural populations in a randomly fluctuating environment. Science (Wash., D.C.) 197:463-465.

BLACKBURN, J. E., and P. B. JACKSON.

1978. Seasonal composition, abundance and food web relationships of principal juvenile and adult marine finfish species inhabiting the nearshore zone of Kodiak Island's eastside. In Environmental Assessment of the Alaskan continental shelf, Quarterly Reports, October-December, 1:273-282. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Lab., Boulder, Colo.

BORETS, T. M.

1979. The qualitative and quantitative composition of spring ichthyoplankton of the Gulf of Alaska. Unpubl. manuscr., 20 p. Pac. Res. Inst. Fish. Oceanogr. (TINRO), Vladivostok, U.S.S.R.

BRACKEN, B. E.

1982. Sablefish (<u>Anoplopoma fimbria</u>) migration in the Gulf of Alaska based on gulf-wide tag recoveries, 1973-1981. Alaska Dep. Fish Game, Juneau, Inf. Leafl. 199, 24 p.

CARLSON, H. R., and R. E. HAIGHT.
1976. Juvenile life of Pacific ocean perch, Sebastes alutus, in coastal fiords of southeastern Alaska: their environment, growth, food habits, and schooling behavior. Trans. Am. Fish. Soc. 105:191-201.

CUSHING, D. H.
1977. The problems of stock and recruitment. In J. A. Gulland (editor), Fish population dynamics, p. 116-133. John Wiley & Sons, New York.

DOUBLEDAY, W. G.
1980. Coping with variability in fisheries. In Report of the ACMRR working party on the scientific basis of determining management measures, p. 131-139. Food Agric. Organ. U.N., Rome, FAO Fish. Rep. 236:149 p.

DUNN, J. R., A. W. KENDALL, Jr., R. J. WOLOTIRA, J. H. BOWERMAN, and L. B. QUETIN.
1979. Seasonal plankton composition of the nearshore zone off Kodiak Island, Alaska: summary of field operations fall 1977-spring 1979 and preliminary results of fall 1977 and spring 1978 cruises. NWAFC Processed Rep. 79-5, 75 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

FAVORITE, F.
1967. The Alaskan Stream. Int. North Pac. Fish. Comm., Bull. 21:1-20.

FAVORITE, F., and D. R. MCLAIN.
1973. Coherence in transpacific movements of positive and negative anomalies of sea surface temperature, 1953-60. Nature 244: 139-143.

FEDER, H. M., and S. C. JEWETT.

1977. The distribution, abundance, and diversity of the epifauna1 benthic organisms in two bays (Alitak and Ugak) of Kodiak Island, Alaska. In Environmental assessment of the Alaskan continental shelf,, Quarterly Reports, July-September, 2:655-739. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Lab., Boulder, Colo.

FEDER, H. M., M. HOBERG, and S. C. JEWETT.

1979. Distribution, abundance, community structure and trophic relationships of the nearshore benthos of Kodiak Shelf. In Environmental assessment of the Alaskan continental shelf, Annual Reports 3:84-207. U.S; Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Lab., Boulder, Colo.

GARRISON, K. J., and B. S. MILLER.

1982. Review of the early life history of Puget Sound fishes. Univ. Wash., Seattle, Fish. Res. Inst. Rep. 8216, 729 p.

GOSHO, M. E.

1977. The food and feeding habits of juvenile pink salmon in the estuaries of Kodiak Island, Alaska. M.S. Thesis, Univ. Wash., Seattle, 87 p.

HARRIS, C. K., and A. C. HARTT.

1977. Assessment of pelagic and nearshore fish in three bays on the east and south coasts of Kodiak Island, Alaska, final report. In Environmental assessment of the Alaskan continental shelf, Quarterly Reports, April-June, 1:483-688. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Lab., Boulder, Colo.

HELMER, O.

1983. Looking forward. Sage Publications, Beverly Hills, 376 p.

HENNEMUTH, R. C., J. E. PALMER, and B. E. BROWN.

1980. A statistical description of recruitment in eighteen selected fish stocks. J. Northwest Atl. Fish. Sci. l:lOl-111.

HIRSCHBERGER, W. A., and G. B. SMITH.

1983. Spawning of twelve groundfish species in the Alaska and Pacific Coast regions, 1975-81. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-44, 50 p.

HUGHES, S. E.

1976. System for sampling large trawl catches of research vessels. J. Fish. Res. Board Can. 33:833-839.

HUGHES, S. E., and G. HIRSCHHORN.

1979. Biology of walleye pollock, Theragra chalcogramma, in the western Gulf of Alaska, 1973-75. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 77:263-274.

HUNTER, M. A.

1979. Food resource partitioning among demersal fishes in the vicinity of Kodiak Island, Alaska. M.S. Thesis, Univ. Wash., Seattle, 131 p.

INCZE, L. S., M. E. CLARKE, J. J. GOERING, A. W. KENDALL, T. NISHIYAMA, A. J. PAUL, and P. D. WALLINE.

1984. Pollock eggs, pollock larvae and the planktonic environment. In D. H. Ito (editor), Proceedings of the workshop on walleye pollock and its ecosystem in the eastern Bering Sea. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-series. In press.

INGRAHAM, W. J.

1981. Environment of pink shrimp in the western Gulf of Alaska. In T. Frady (editor), Proceedings' of the international pandalid shrimp symposium, p. 361-375. Univ. Alaska, Fairbanks, Sea Grant Rep. 81-3.

INGRAHAM, W. J., A. BAKUN, and F. FAVORITE.

1976. Physical oceanography of the Gulf of Alaska. Processed Rep., 132 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

JEWETT, S. C.

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

KARP, W. A.

1982. Biology and management of Pacific cod (Gadus macrocephalus Tilesius) in Port Townsend, Washington. Ph.D. Thesis, Univ. Wash., Seattle, 119 p.

KENDALL, A. W., Jr., and J. R. DUNN.

1984. Ichthyoplankton of the continental shelf near Kodiak Island, Alaska. Unpubl. manuscr. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

KENDALL, A. W., Jr., J. R. DUNN, D. E. ROGERS, A. C. MATARESE, and K. J. GARRISON.

1980a. Taxonomic composition, seasonal distribution, and abundance of ichthyoplankton in the nearshore zone of the Kodiak Archipelago, Alaska. NWAFC Processed Rep. 80-14, 62 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

KENDALL, A. W., Jr., J. R. DUNN, R. J. WOLOTIRA, Jr., J. H. BOWERMAN, Jr., D. B. DAY, A. C. MATARESE, and J. E. MUNK.

1980b. Zooplankton, including ichthyoplankton and decapod larvae, of the Kodiak shelf. NWAFC Processed Rep. 80-8, 393 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

KETCHEN, K. S.

1961. Observations on the ecology of the Pacific-cod (Gadus macrocephalus) in Canadian waters. J. Fish. Res. Board Can. 18:513-558.

KRASNOW, L. D., G. A. SANGER, and D. W. WISWAR.

1979. Nearshore feeding ecology of marine birds in the Kodiak area, 1978. In Environmental assessment of the Alaskan continental shelf, Annual Reports 2:348-394. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Lab., Boulder, Colo.

LAGERLOEF, G.

1983. Topographically controlled flow around a deep trough transecting the shelf off Kodiak Island, Alaska. J. Phys. Oceanogr. 13:139-146.

LARKINS, H. A.

1964. Some epipelagic fishes of the North Pacific Ocean, Bering Sea, and Gulf of Alaska. Trans. Am. Fish. Soc. 93:286-290.

MACDONALD, P. D. M., and T. J. PITCHER.

1979. Age-groups from size-frequency data: a versatile and efficient method of. analyzing distribution mixtures. J. Fish. Res. Board Can. 36:987-1001.

MANZER, J. I.

1968. Food of Pacific salmon and steelhead trout in the Northeast Pacific Ocean. J. Fish. Res. Board Can. 25: 1085-1089.

MARTIN, J. B.

1979. An evaluation of the economic feasibility of pollock processing in southeast Alaska. Univ. Alaska, Fairbanks, Sea Grant Rep. 78-16, 123 p.

'MASON, J. C., R. J. BEAMISH, and G. A. MCFARLANE.

1983. Sexual maturity, fecundity, spawning, and early life history of sablefish (Anoplopoma fimbria). off the Pacific coast of Canada. Can. J. Fish. Aquat. Sci. 40:2126-2134.

MCFARLANE, G. A., and R. J. BEAMISH.

1983a. Preliminary observations on the juvenile biology of sablefish (Anoplopoma fimbria) in waters off the west coast of Canada. In Proceedings of the International Sablefish Symposium, p. 119-135. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Fairbanks, Sea Grant Rep. 83-8.

1983b. Biology of adult sablefish (Anoplopoma fimbria) in waters off western Canada. In Proceedings of the International Sablefish Symposium, p. 59-80. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Fairbanks, Sea Grant Rep. 83-8.

MIZUE, K., K. YOSHIDA, and H. TAKAMURA.

1966. On the ecology of Dall's porpoise in Bering Sea and the North Pacific Ocean. (In Japanese, English summary.) Bull. Fac. Fish. Nagasaki Univ. 21:1-21.

MYSAK, L. A., R. D. MUENCH, and J. D. SCHUMACHER.

1981. Baroclinic instability in a downstream varying channel: Shelikof Strait, Alaska. J. Phys: Oceanogr. 11:950-969:

NUNNALLEE, E. P., N. J. WILLIAMSON, and M. 0. NELSON.

1982. Acoustic-trawl surveys of spawning walleye pollock (Theragra chalcogramma) in the Shelikof Strait-Chirikof Island region of Alaska. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 78:797-798.

PITCHER, K. W.

1980. Stomach contents and feces as indicators of harbor seal, Phoca vitulina, foods in the Gulf of Alaska. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 78:797-798.

1981. Prey of the Steller sea lion, Eumetopias jubatus, in the Gulf of Alaska. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 79:467-472.

REED, R. K., R. D. MUENCH, and J. D. SCHUMACHER.

1980. On baroclinic transport of the Alaskan Stream near Kodiak Island. Deep-Sea Res. 27A:509-523.

ROGERS, B. J., M. E. WANGERIN, and D. E. ROGERS.

1980. Seasonal composition and food web relationships of marine organisms in the nearshore zone of Kodiak Island--including ichthyoplankton, zooplankton, and fish. A report on the fish component of the study. Univ. wash., Seattle, Fish. Res. Inst. Rep. 8017, 109 p.

RONHOLT, L. L.,H. H. SHIPPEN, and E. S. BROWN.
1978. Demersal fish and shellfish resources of the Gulf of Alaska from Cape Spencer to Unimak Pass, 1948-1976 (a historical review). Processed Rep., 4 volumes, various pagination. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

ROSENTHAL, R. J.
1980. Shallow water fish assemblages in the northeastern Gulf of Alaska: habitat evaluation, species composition, abundance, spatial distribution, and trophic interaction. Unpubl. manuscr., 84 p. Alaska Coastal Research, P. 0. Box 937, Homer, AK 99603.

SANGER, G. A.
1983., Diets and food web relationships of seabirds in the Gulf of Alaska and adjacent marine regions. Unpubl. manuscr., 130 p. U.S. Fish. Wildl. Serv., 1011 E. Tudor Rd., Anchorage, AK 99503.

SANGER, G. A., V. F. HIRONAKA, and A. K. FUKUYAMA.
1978. The feeding ecology and trophic relationships of key species of marine birds in the Kodiak Island area, May-September 1977. In Environmental assessment of the Alaskan continental shelf, Annual Reports 3:773-848. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Dab., Boulder, Colo.

SASAKI, T.
1983. Relative abundance and size structure of sablefish in the eastern Bering Sea, Aleutian region and Gulf of Alaska based on the results of Japan-U.S. joint longline surveys from 1979 to 1982. In Proceedings of the International-Sablefish Symposium, p. 239-253. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Fairbanks, Sea Grant Rep. 83-8.

SCHUMACHER, J., R. CHARNELL, S. HAYES, H. MOFJELD, and R. MUENCH.

1978. Gulf of Alaska shelf circulation. In Environmental assessment of the Alaskan continental shelf, Annual Reports 9:61-213. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Lab., Boulder, Colo.

SCHUMACHER, J. D., and R. K. REED.

1980. Coastal flow in the northwest Gulf of Alaska: the Kenai Current. J. Geophys. Res. 85:6680-6688.

1983. Interannual variability in the abiotic environment of the Bering Sea and the Gulf of Alaska. In W. S. Wooster (editor), From year to year, p. 111-133. Univ. Wash., Seattle, Sea Grant Publ. WSG-W083-3.

SHARMA, G. D.

1979. The Alaskan shelf. Springer-Verlag, N.Y., 498 p.

SMITH, G. B.

1981. The biology of walleye pollock. In D. W. Hood and J. A. Calder (editors), The eastern Bering Sea shelf: oceanography and resources, volume 1, p. 527-551. U.S. Gov. Print. Off., Washington, D.C.

SMITH, G. B., and R. G. BAKKALA.

1982. Demersal fish resources of the eastern Bering Sea: spring 1976. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-754, 129 p.

STAUFFER, G. D.

1983. Sablefish. In G. Stauffer (editor), Condition of groundfish resources of the Gulf of Alaska region as assessed in 1983, p. 3-l to 3-36. NWAFC Processed Rep. 84-02. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd E., Seattle, WA 98112.

TATE, M. W., and R. C. CLELLAND.

1959. Nonparametric and shortcut statistics. Interstate Printers, Danville, Ill., 171 p.

THOMPSON, B. G.

1983. Fisheries of the United States, 1982. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv.; Current Fish. Statistics No. 8300, 117 p.

THOMSON, J. A.

1963. On the demersal quality of the fertilized eggs of Pacific cod, Gadus macrocephalus Tilesius. J. Fish. Res. Board Can. 20:1087-1088.

THOMSON, R. E.

1972. On the Alaskan Stream. J. Phys. Oceanogr. 2:363-371.

UMEDA, Y., T. M. SAMPLE, and R. G. BAKKALA.

1983. Recruitment processes of sablefish in the eastern Bering Sea. In Proceedings of the International Sablefish Symposium, p. 291-303. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Fairbanks, Sea Grant Rep. 83-8.

WATHNE, F.

1977. Performance of trawls used in resource assessment. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 39(6):16-23.

WESPESTAD, V., R. BAKKALA, and J. JUNE.

1982. Current abundance of Pacific cod (Gadus macrocephalus) in the eastern Bering Sea and expected abundance in 1982-86. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-25, 26 p.

YUSA, T., K. KYUSHIN, and C. R. FORRESTER.
1977. Outline of life history information on some marine fish. Res. Inst. North Pac. Fish., Hokkaido Univ., Spec. Vol., p. 123-173.

ZENGER, H. H., Jr.
1983. Pacific cod. In G. Stauffer (editor), Condition of groundfish resources of the Gulf of Alaska region as assessed in 1983, p. 4-1 to 4-19. NWAFC Processed Rep. 84-02. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd E., Seattle, WA 98112.