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Demersal Fish Resources of the Eastern Bering Sea: Spring 1976

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Demersal Fish Resources of the Eastern Bering Sea: Spring 1976

GARY B. SMITH and RICHARD G. BAKKALA[1]

ABSTRACT

During the spring of 1976, 683 otter trawl samples were collected within an area of 337,930 km² in the second of two baseline surveys designed to describe characteristics of Bering Sea demersal fish and shellfish populations.

Climatic conditions during the spring 1976 survey were anomalously cold, affecting both the pattern of trawl sampling and the apparent distributions of fish populations. During April and May, winter pack ice still covered 50-75% of the study area. Most demersal fish populations were distributed in deep water along the outer continental shelf where bottom water temperatures were warmest. At least two species populations showed extensive migrations.

A total of 78 fish species distributed among 22 families was recorded during the 1976 survey. The overall apparent mean density of demersal fish was 12.3 t/km² of which pleuronectids accounted for 67.8%, gadids 18.8%, and cottids 8.7%. Specific regions of highest fish densities were the outer continental shelf between St. George and Unimak Islands, directly west of St. Paul Island, and the central shelf area between Cape Newenham and Port Moller.

Comparisons between results of the first (August-October 1975) and second (April-June 1976) surveys were interpreted as representing seasonal extremes. During the survey of August-October 1975, apparently large-scale migratory movements had ended and the demersal fish popuations were in late summer distributional patterns. Geographical ranges were generally broad and many species extended into Bristol Bay. During the survey of April-June 1976, demersal fish populations were apparently sampled during a period of transition from late winter to early summer distributions. Compared to August-October 1975, species ranges were restricted more to deep water, although some populations were initiating migrations across the continental shelf.

INTRODUCTION

Purpose

In the summer of 1975 and spring of 1976, the Northwest and Alaska Fisheries Center (NWAFC), National Marine Fisheries Service (NMFS), conducted multivessel surveys of demersal fish and macroinvertebrates of the continental shelf and upper continental slope regions of the eastern Bering Sea. These resource assessment surveys—a part of the NMFS Marine Monitoring, Assessment and Prediction program—were also in response to needs of the Bureau of Land Management to assess the demersal fish stocks of the Bering Sea and their vulnerability to oil development.

Results of the first phase trawl survey, conducted August-October 1975, were summarized in Pereyra et al. (1976[2]). These included a review of the history of commercial fisheries in the eastern Bering Sea, results from previous research surveys in the region, the 1975 survey results for demersal fish and invertebrates, and summaries of the status of knowledge of commercially important species and their stock conditions.

The present study summarizes results of the second phase of the field studies—the spring 1976 demersal trawl survey. The purpose of this second survey was to describe the distributions of demersal fish and invertebrates at a time when they were expected to be near the winter extreme of their seasonal, geographical movements. Maximum ice cover in the southeastern Bering Sea generally occurs during March and April, with maximum cooling of the water column (Potocsky 1975; McLain and Favorite 1976).

The objectives of this report are

1) To describe the species composition, geographical distributions, and apparent abundance of demersal fish resources of the eastern Bering Sea during the survey period, April-June 1976;
2) To describe characteristics of the important demersal fish populations that could be changed by environmental stress (e.g., abundance, size and age composition, growth rates, and body form); and
3) To compare and explain results of the 1975 and 1976 surveys.

Environmental Setting

The regional setting for the investigations was the eastern Bering Sea between lat. 54°-63°N and from long. 180° eastward to the Alaska coast. The area is a unique subarctic ocean environment because of its recent geological origin (i.e., submergence), partial separation from the Pacific Ocean by the Aleutian Ridge, unusually broad and flat continental shelf, and variable seasonal ice cover (Fig. 1). The area is also distinguished biologically by large marine mammal and seabird populations.

The topography of the eastern Bering Sea continental shelf shows an extremely flat, featureless plain. The width of the continental shelf varies from about 500 km in the southeast to over 800 km in the north, with an average gradient of 0.24 m/km. Along the outer edge the continental slope is a steep, rugged, and deeply canyon-scarred 3,200-3,400 m declivity (Sharma 1979).

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

[2] Pereyra, W. T., J. E. Reeves, and R. G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Unpubl. manuscr., 619 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Boulevard East, Seattle, WA 98112. Bound copies are available on request.

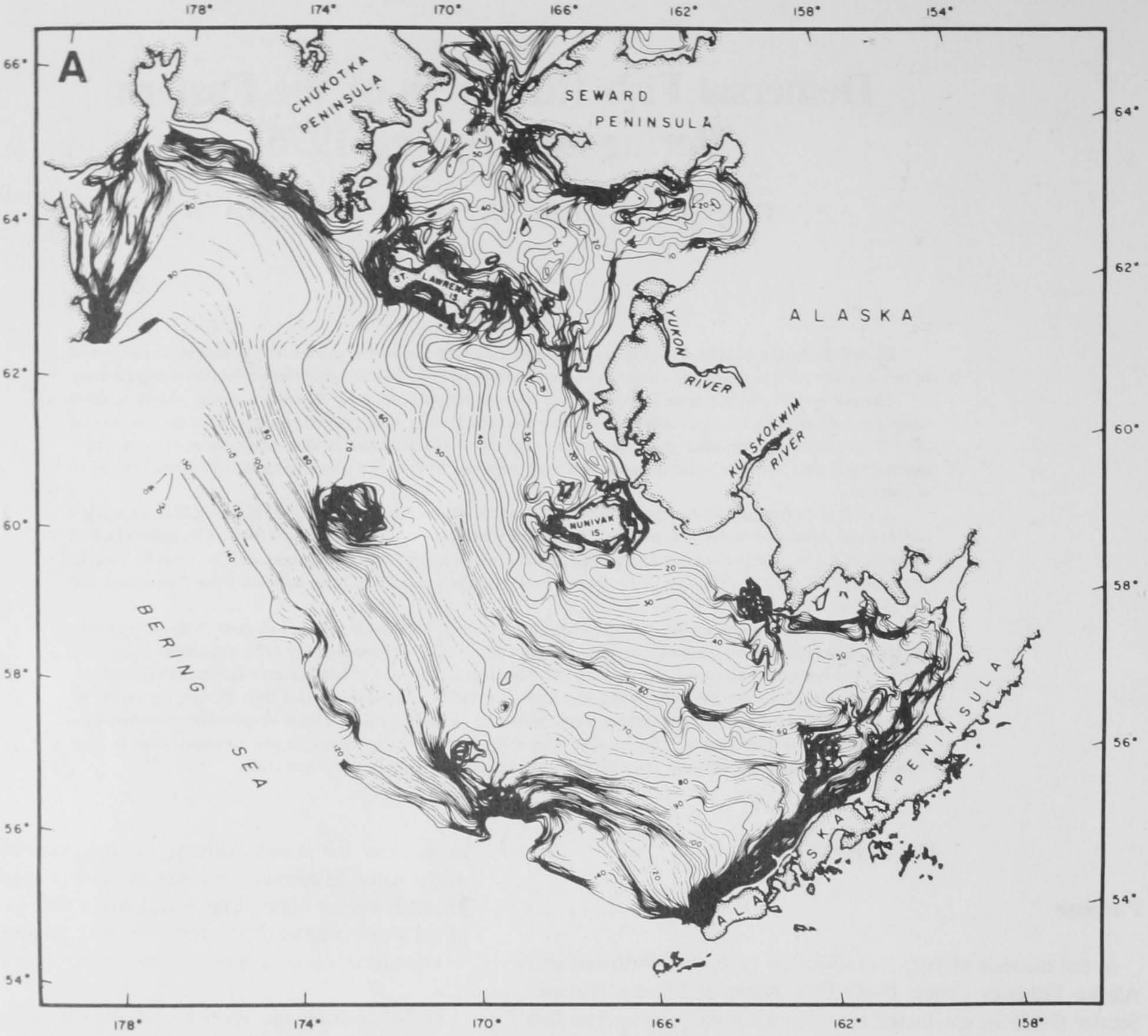

Figure 1.—Characteristics of the eastern Bering Sea: A) bathymetry (from Sharma 1979); B) water masses and circulation (from Takenouti and Ohtani 1974); C) surface sediments (from Sharma 1979).

Water masses in the eastern Bering Sea appear to result from mixing of shelf and oceanic waters within apparently broad zones of interaction along and over the eastern continental shelf. The present concept of dominant long-term mean water circulation is an extremely slow ($\simeq$1 cm/s) drift to the northwest approximately parallel to the bathymetry (Coachman 1979[3]).

Surface sediments of the eastern continental shelf are primarily sand or silt, although gravel and clay components may be present in some local areas (Sharma 1979).

METHODS

Survey Approach and Rationale

For the baseline survey of 1975, the study area was divided into four major statistical subareas, with two subareas (3N,S and 4N,S) further subdivided into southern and northern regions (Fig. 2; Pereyra et al. see footnote 2). Trawling stations were arranged in a systematic grid pattern within each subarea. Subdivisions of the survey area and the density of stations within each subarea were based upon 1) the location of potential oil lease sites, 2) prior knowledge of the distribution patterns of principal demersal fish and shellfish species in the study area, and 3) hypotheses that some species may have separate genetically variant southern and northern spawning populations. Sampling density was greatest (one station per 647 km² (250 mi²)) in subareas 1, 2, and 3N and S where petroleum development activities may take place and where major concentrations of walleye pollock, *Theragra chalcogramma*; yellowfin sole, *Limanda aspera*; king crab, *Paralithodes* spp.; Tanner crab, *Chionoecetes* spp.; and other species are located. These subareas also contain spawning and nursery areas for many of the commercially important species. In subarea 4N and S, where the abundance of adult fish is lower than in subareas 1, 2, and 3N and S, but which is a nursery area for a number of species, sampling density was reduced to one station per 1,036 km² (400 mi²).

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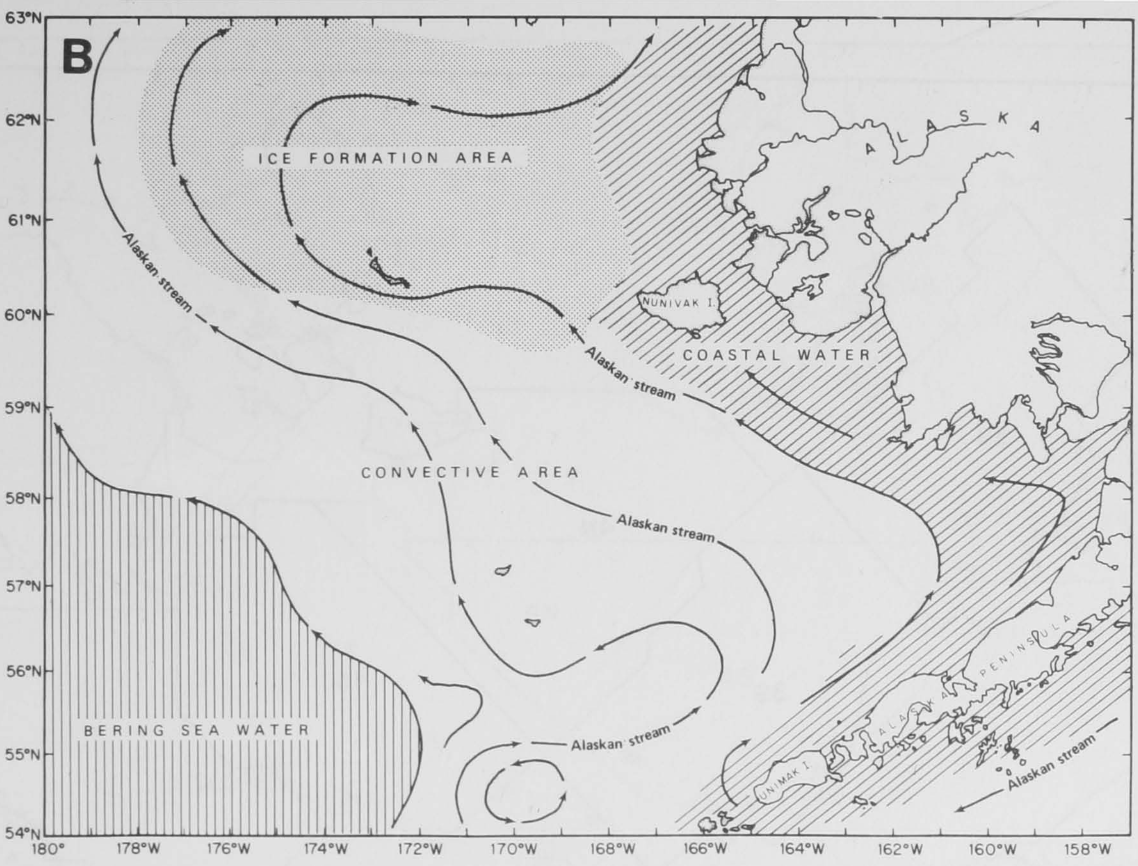
[3] Coachman, L. K. 1979. Water circulation and mixing in the southeast Bering Sea. *In* C. P. McRoy and J. J. Goering (editors), Progress report, PROBES phase I, 1977-78, p. 1-46. Institute of Marine Science, University of Alaska, Fairbanks, AK 99701.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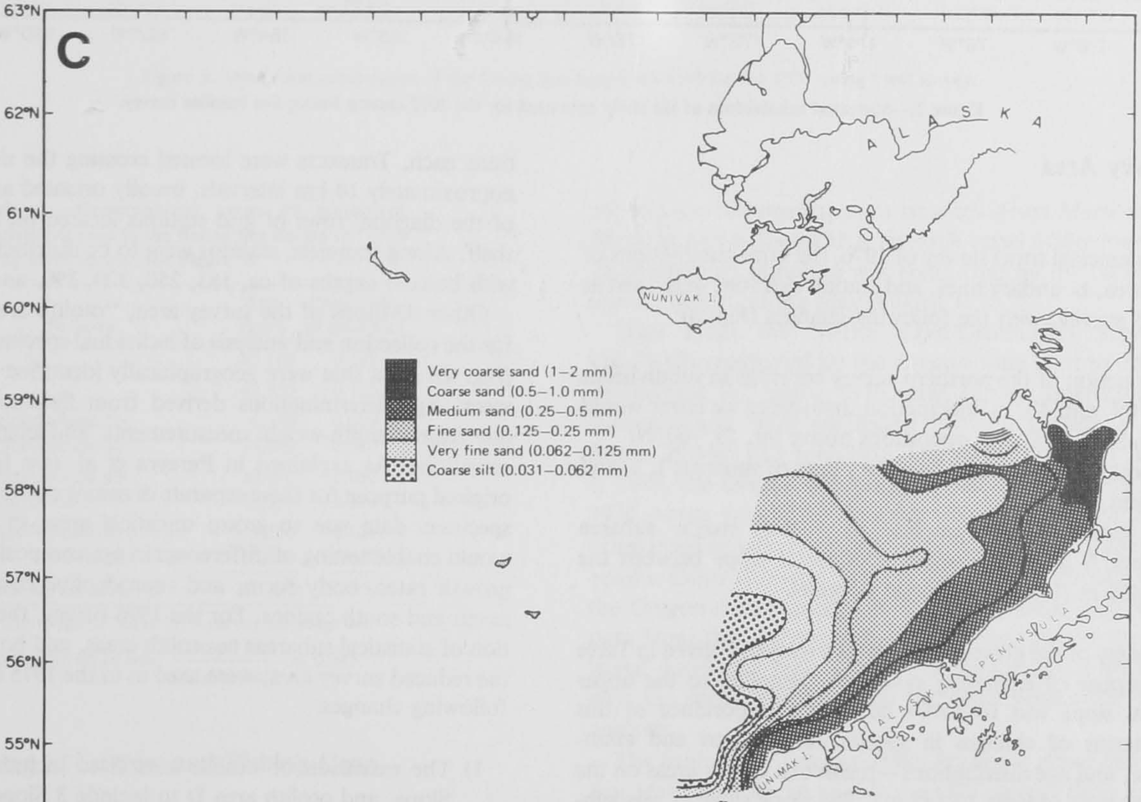
172°W
170°W
168°W
166°W
164°W
162°W
160°W
158°W
ICE FORMATION AREA
ALASKA
Alaskan stream
NUNIVAK I.
COASTAL WATER
Alaskan stream
CONVECTIVE AREA
Alaskan stream
ALASKA PENINSULA
BERING SEA WATER
Alaskan stream
UNIMAK I.
Alaskan stream


C
63°N
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180°
178°W
176°W
174°W
172°W
170°W
168°W
166°W
164°W
162°W
160°W
158°W
ALASKA
NUNIVAK I.
ALASKA PENINSULA
UNIMAK I.
Very coarse sand (1–2 mm)
Coarse sand (0.5–1.0 mm)
Medium sand (0.25–0.5 mm)
Fine sand (0.125–0.25 mm)
Very fine sand (0.062–0.125 mm)
Coarse silt (0.031–0.062 mm)

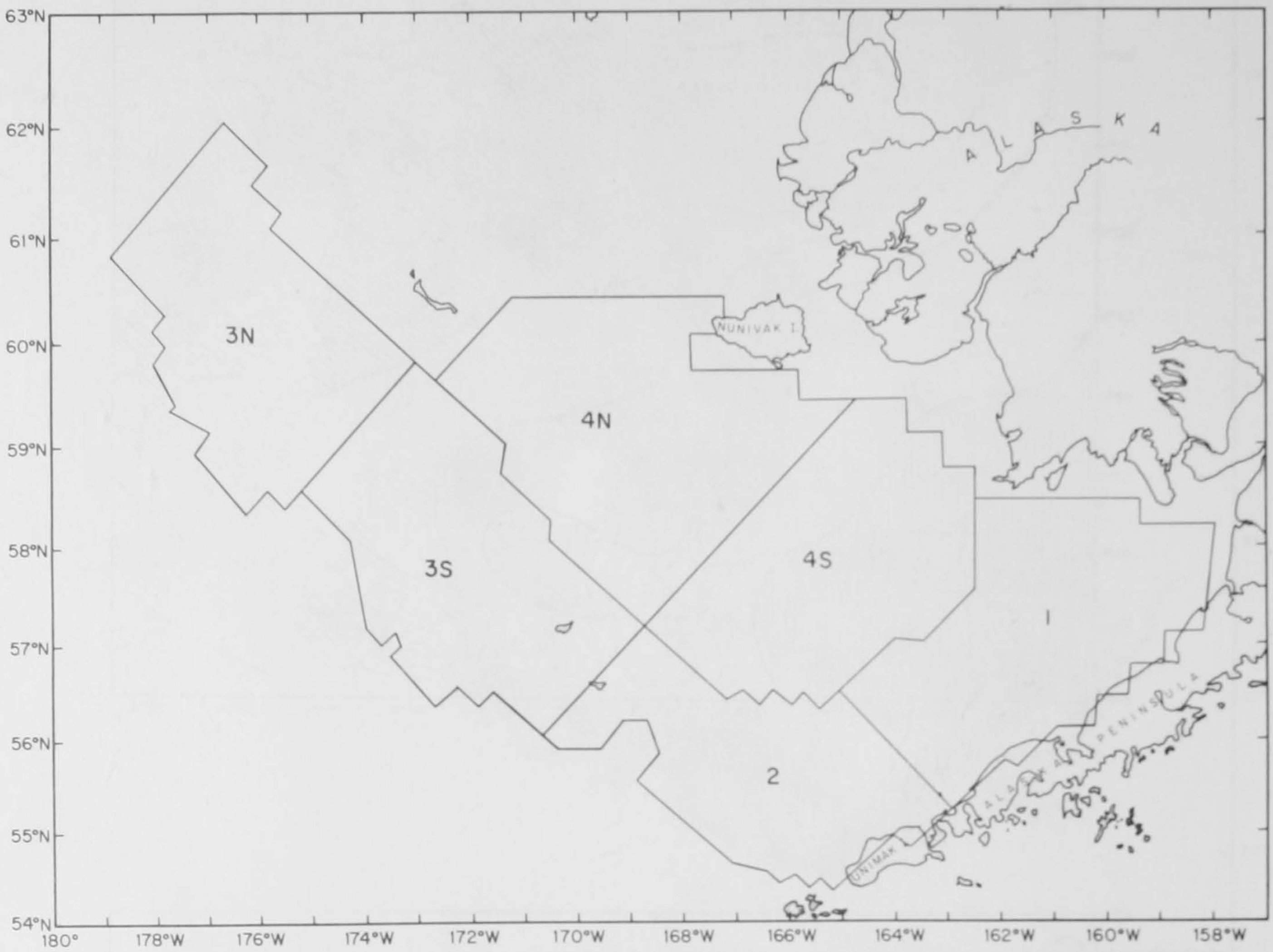

Figure 2.—Statistical subdivisions of the study area used for the 1975 eastern Bering Sea baseline survey.

1976 Survey Area

For the demersal trawl survey of 1976, the same subdivisions of the study area, boundary lines, and station densities were used as in the 1975 survey, with the following changes (Fig. 3):

1) A reduction of the northern survey coverage in subdivisions 3N, 4N, and 4S, in anticipation that spring ice cover would probably block ship operations above lat. 59°-60°N;
2) Smoothing of the outer boundary lines of subareas 1, 2, and 3N and S; and
3) The extension of sampling to a fifth major subarea ("Slope") along the upper continental slope between the 183-457 m (100-250 fathoms) isobaths.

A summary of the geographical areas surveyed is given in Table 1. The purpose of extending systematic sampling to the upper continental slope was to better define the importance of this area—in terms of changes in species composition and abundance, size, and age distributions—relative to survey areas on the continental shelf (depths 10-183 m). The slope subarea was subdivided into northern (3 Slope) and southern (2 Slope) regions (Fig. 3). Samples were to be taken along 29 transects of five stations each. Transects were located crossing the slope subarea at approximately 14 km intervals, usually oriented as continuations of the diagonal rows of grid stations located on the continental shelf. Along transects, stations were to be distributed at positions with bottom depths of ca. 183, 250, 320, 390, and 457 m.

Other divisions of the survey area, "otolith areas," were used for the collection and analysis of individual specimen information (Fig. 4). Data that were geographically identified by otolith area were: Age determinations derived from field-collected otoliths and scales, length-weight measurements, and length-maturity observations. As explained in Pereyra et al. (see footnote 2), the original purpose for these separate divisions of the survey area for specimen data was to group statistical areas in a manner that would enable testing of differences in age composition, individual growth rates, body form, and reproductive condition between north and south regions. For the 1976 survey, the same distribution of statistical subareas to otolith areas, and boundaries within the reduced survey area, were used as in the 1975 survey, with the following changes:

1) The extension of otolith area B to include subdivision 2 Slope, and otolith area D to include 3 Slope; and
2) The inclusion of subdivision 3N within otolith area D, rather than otolith area E.

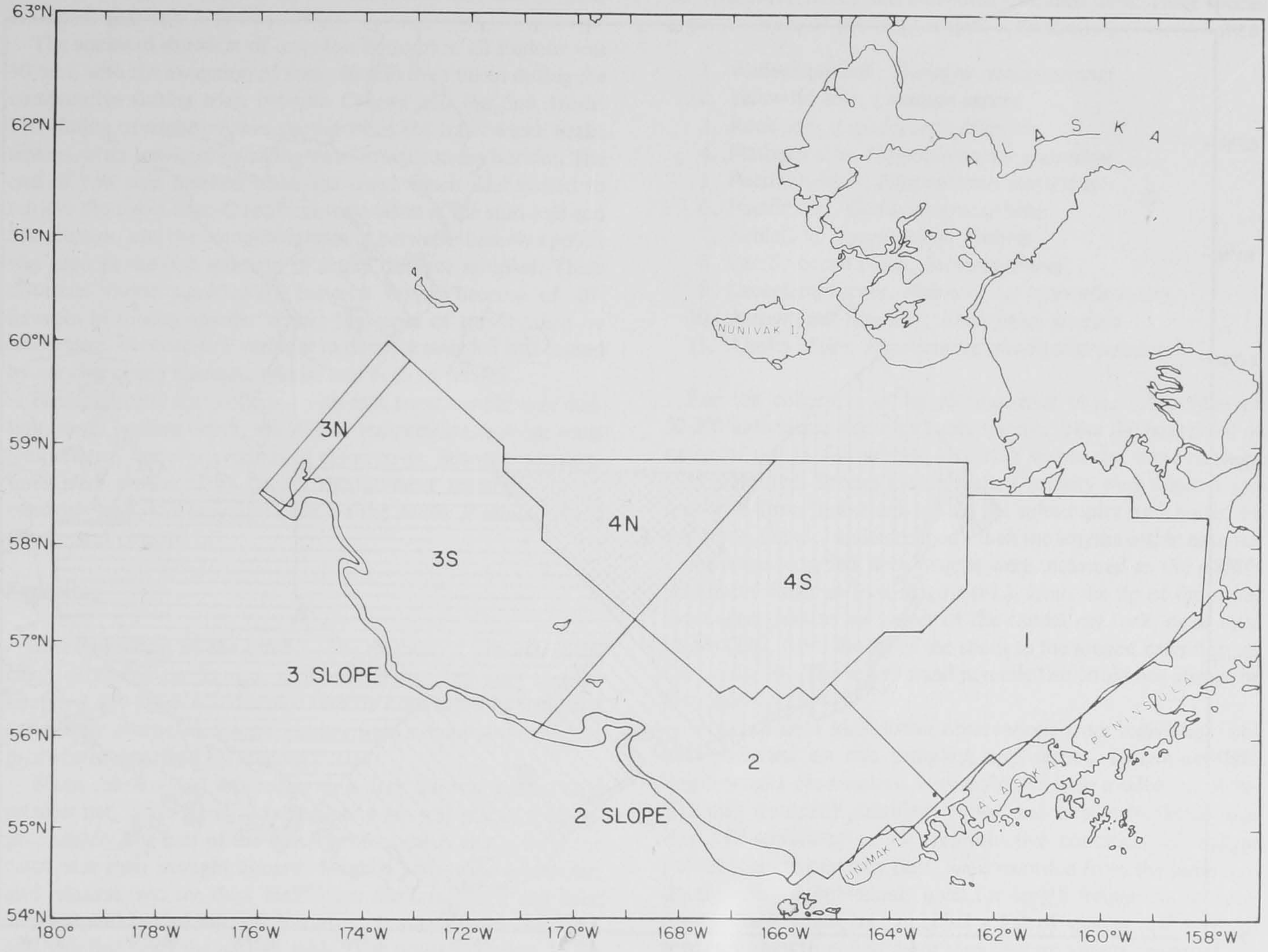

Figure 3.—Statistical subdivisions of the Bering Sea study area used for the 1976 spring trawl survey.

Table 1.—Geographical areas of statistical subdivisions used in the Bering Sea during the 1976 spring trawl survey (See Figure 3).

Subarea	Area (km^2)	Proportion of total area
1	82,100	0.243
2	62,550	0.185
3 Subdivision 3N	6,550	0.019
Subdivision 3S	73,020	0.216
4 Subdivision 4N	30,960	0.092
Subdivision 4S	72,350	0.214
Slope Subdivision 2 Slope	7,160	0.021
Subdivision 3 Slope	3,240	0.010
Total survey area:	[1]337,930	1.000

[1] The ratio of total 1976 survey coverage to 1975 coverage was $\frac{337{,}930\ \text{km}^2}{493{,}014\ \text{km}^2} = 0.685.$

Vessels, Timing of Survey, and Fishing Gear

Vessels participating in the April-June 1976 demersal trawl survey were the same vessels used to conduct the 1975 baseline survey: the commercial stern trawlers *Anna Marie* and *Pat San Marie* as well as the NOAA research vessel *Miller Freeman* (Table 2). Additional sampling was conducted by the NOAA research vessel *Oregon* during May-August 1976.

Data from the NMFS Crab-Groundfish Survey (Cruise OR-76-02) conducted by the *Oregon* were used to complete and supplement the spring 1976 trawl survey. Intercomparisons of fishing power were conducted between *Oregon* and *Pat San Marie,* 29 May to 9 June 1976. During the period 11 June to 4 July 1976, the *Oregon* occupied stations that completed the spring 1976 survey grid; these data were included with those from the other three vessels for all analyses of the spring survey grid station results. Other analyses, by month, used all catch data collected by the *Oregon* during cruise OR-76-02, combined with all the catch data from the other vessels. In addition, all specimen data collected during the entire *Oregon* cruise OR-76-02 were combined with the specimen data from the other vessels for overall 1976 analyses.

The fishing gear used by *Miller Freeman, Anna Marie,* and *Pat San Marie* were the same as in the 1975 survey (Table 3). The trawl used by the *Oregon* had footrope and headrope lengths of approximately 85% those of the gear used by the other vessels.

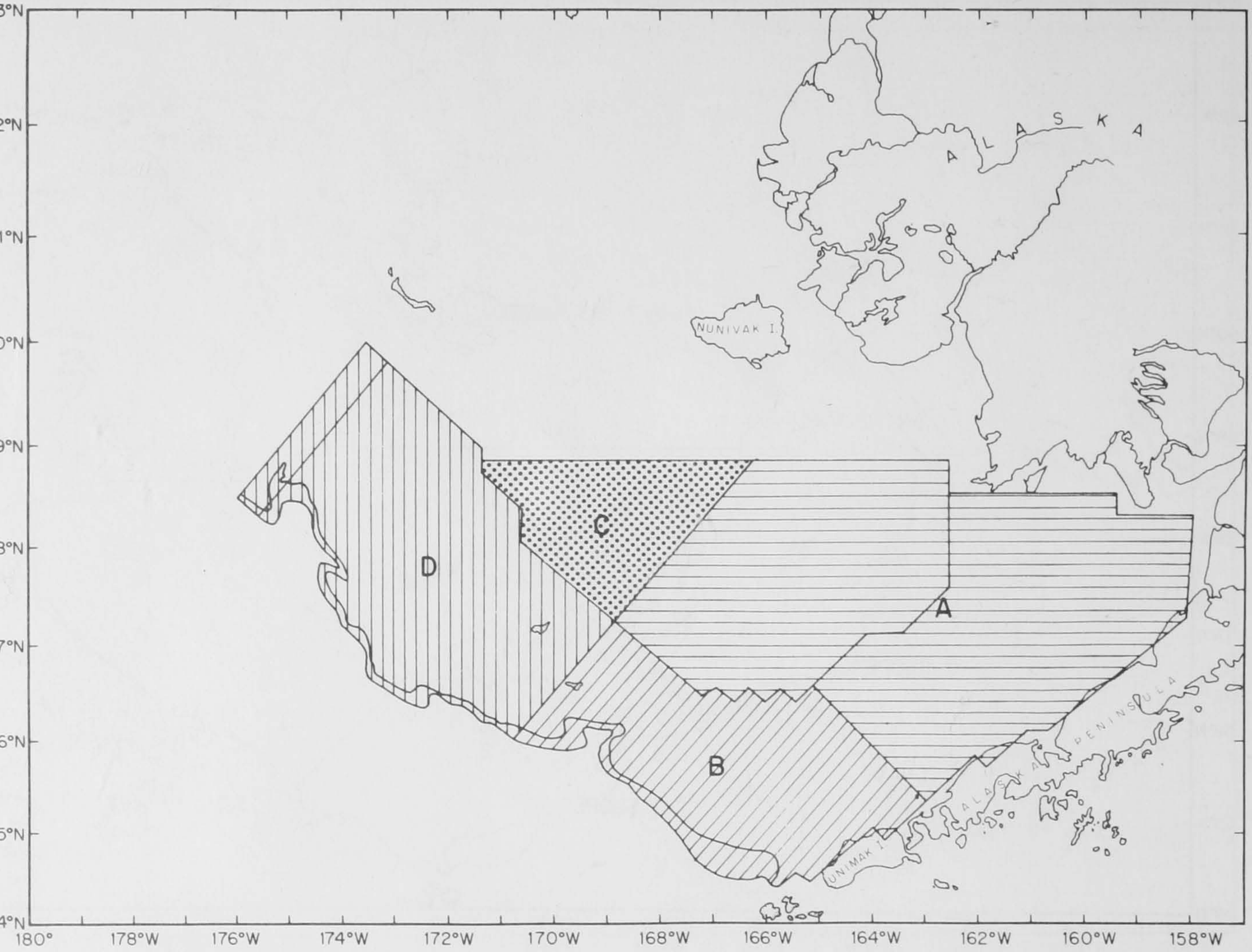

Figure 4.—Bering Sea "otolith" areas used for collection of age data and other individual specimen data during the 1976 spring trawl survey.

Table 2.—Vessels participating in the 1976 Bering Sea demersal fish survey.

Vessel	Overall length (m)	Gross tonnage	Horse-power	Survey period	
				Start	Finish
Miller Freeman	65.5	1,500	2,200	1 Apr. 1976	31 May 1976
Anna Marie	26.2	177	665	21 Apr. 1976	13 June 1976
Pat San Marie	30.0	200	765	21 Apr. 1976	20 June 1976
Oregon	30.4	219	600	29 May 1976	9 Aug. 1976

Standard Procedures at Stations

Station positions were determined by loran-C, with radar also used as a nearshore navigational aid. Some stations where untrawlable bottom might have been encountered were first surveyed by an echosounder transect to establish the bottom condition and to determine a course that would provide the least variation in bottom depth during the tow. For most stations on the continental shelf where the bottom was known to be generally smooth sand and mud, this precaution was not taken. If the echosounder record indicated rough bottom, the vessel proceeded on to the next station.

The trawl was set so that the intended station position was passed midway through the tow. Actual mean towing speeds for the four vessels were *Miller Freeman,* 6.3 km/h (3.4 kn); *Anna Marie,* 5.9

Table 3.—Fishing gear used during the 1976 Bering Sea demersal fish survey.

Vessel	Headrope length (m)	Footrope length (m)	Mesh sizes				Accessory gear	
			Wing and body (mm)	Inter-mediate (mm)	Cod end (mm)	Cod end liner (mm)	Door[1] width & length (m)	Dandy line length (m)
Miller Freeman	25.3	34.1	102	89	89	32	2.1 × 3.0	65.8
Anna Marie	25.3	34.1	102	89	89	32	1.8 × 2.7	49.4
Pat San Marie	25.3	34.1	102	89	89	32	1.8 × 2.7	49.4
Oregon	21.6	28.7	102	89	89	32	1.8 × 2.7	45.7

[1] The weight of an individual door was about 1,000 kg.

km/h (3.2 kn); *Pat San Marie,* 5.9 km/h (3.2 kn); and *Oregon,* 3.7 km/h (2.0 kn).

The standard duration of tows (on bottom) at all stations was 30 min, with the exception of some 60-min tows taken during the comparative fishing trials between *Oregon* and *Pat San Marie.* The timing of each tow was started when the trawl winch brake was set, after having allowed the trawl to settle to the bottom. The end of tow was marked when the trawl winch was started to retrieve the net. Loran-C readings were taken at the start and end of each tow, and the computed distance between these two points was used as the best estimate of actual distance sampled. These distances varied significantly between vessels because of differences in towing speeds. Within the series of trawls taken by each vessel, between-tow variance in distance sampled was caused by varying ocean currents, winds, and bottom friction.

Environmental data collected with each trawl sample were position, mean bottom depth, sea surface temperature, bottom water temperature, and observations of cloud cover. Seawater temperatures were measured by bucket thermometer readings and expendable bathythermograph casts on the *Miller Freeman, Anna Marie,* and *Oregon.*

Sampling

Initial handling of the catch.—The method of processing the catch depended on its size. If the catch was less than approximately 1,150 kg, it was dumped directly onto a sorting table and completely processed. Larger catches were subsampled using the procedures described by Hughes (1976).

When subsampling was required, a deck bin was lined with a retainer net, upon which a subsampling net was placed over approximately one-half of the bin. The total catch or a split of the catch was then brought aboard, weighed with a dynamometer, and released into the deck bin. When the total catch had been weighed and loaded into the bin, the subsampling net was lifted and emptied onto the sorting table. The unused portion of the catch remaining in the deck bin was then quickly returned to the sea by lifting the retainer net.

Sorting and weighing the catch.—After the catch had been transferred to the sorting table, it was sorted by species into wire bushel baskets and tubs. For catches numerically dominated by a single species, sets of two to three baskets were filled at the same time with that species, weighed, and placed on the deck in rows. When a large number of baskets (15-25) were required for a single species, only 1 basket was kept from each set of 2-3 baskets, and the others emptied and reused for sorting the remainder of the catch. While the dominant species was being sorted, other species were sorted into single baskets or other containers. The procedure of filling single or sets of baskets was repeated until the entire catch (or subsample) was sorted and weighed. Baskets were placed on deck in order of sorting, so that they could be identified as if they were from the top, middle, or bottom of the trawl sample.

Most organisms occurring in the trawl samples were identified to species, although those that were difficult to reliably identify were grouped by genus or combined within a higher taxonomic level. Catch weights for all taxa were determined by weighing baskets to the nearest 0.5 kg on a 140 kg capacity platform scale. Numbers of individuals were determined by direct count or by expanding the number determined from a weighed subsample.

Subsampling for biological data.—After weighing and counting, the catches of 11 species of principal interest were further processed for length-frequency and individual specimen data. These species were (in order of priority for data collection)

1. Walleye pollock, *Theragra chalcogramma*
2. Yellowfin sole, *Limanda aspera*
3. Rock sole, *Lepidopsetta bilineata*
4. Flathead sole, *Hippoglossoides elassodon*
5. Pacific halibut, *Hippoglossus stenolepis*
6. Pacific cod, *Gadus macrocephalus*
7. Sablefish, *Anoplopoma fimbria*
8. Pacific ocean perch, *Sebastes alutus*
9. Greenland turbot, *Reinhardtius hippoglossoides*
10. Arrowtooth flounder, *Atheresthes stomias*
11. Alaska plaice, *Pleuronectes quadrituberculatus.*

For the collection of length-frequency data, subsamples of 50-200 individuals were randomly selected from the baskets of as many of the 11 fish species occurring within the trawl catch as time permitted. Species having highest priority were selected and measured first. Individuals within the subsamples were sorted by sex (male, female, undetermined), then the lengths within each sex group were recorded. Fish lengths were measured to the nearest centimeter either as fork lengths (FL), from the tip of the snout (or longest jaw) to the center of the caudal ray fork, or as total length (TL), from the tip of the snout to the longest extension of the caudal fin. The sex of small juvenile fish could not always be determined.

Specimen data (descriptive observations from individual fish) were collected by two sampling approaches. Length-age and length-weight observations were collected with a selection of individuals (samples) stratified by sex and centimeter length-size class. Observations of the reproductive condition of walleye pollock (length-maturity data) were recorded from the same randomly selected individuals used for length-frequency measurements. Each vessel was assigned a list of species and types of specimen data to collect from the different survey areas.

For each species, length-age data were collected by taking 6-10 age (skeletal) structures for each sex-centimeter length-size group, within each assigned otolith area. Saccular otoliths were used for determining the ages of all species except Pacific cod, for which scales were used because they showed clearer annual growth rings. Otoliths were stored in glass vials in 50% isopropanol. Pacific cod scales were stored dry in small paper envelopes.

Length-weight determinations were made for five individuals within each sex-centimeter length-size group. Whole, freshly caught individual fish were weighed at sea to the nearest gram on a triple-beam balance.

Age Determinations

Age determinations made as a part of the present study have assumed that rings in otoliths and scales (zonal discontinuities) indicated annual marks. Previous studies have supported the hypothesis that an annual time scale can be fitted to the patterns of skeletal ring formation of walleye pollock (LaLanne 1975[4]) and yellowfin sole (Hatanaka 1968). Although similar analyses have not yet been conducted for other Bering Sea species, zonal discon-

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[4] LaLanne, J. J. 1975. Age determination of walleye pollock (*Theragra chalcogramma*) from otoliths. Unpubl. manuscr., 19 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Boulevard East, Seattle, WA 98112.

tinuities were assumed to indicate annual marks. In assigning ages, we allocated a birthday of 1 January for all species.

Ages were determined in the laboratory by counting apparent annulae in the structural pattern of whole otoliths and scales. All age readings were performed by trained specialists at the NWAFC Montlake Laboratory. Otolith rings were counted by viewing whole otoliths, immersed in water, with direct lighting through a binocular microscope at 7-10× magnification. Scales were prepared using the methods of Kennedy (1970) and rings were counted with the aid of a projection viewer.

To assess the reliability (precision) of age determinations, 789 skeletal structures, collected during the 1976 survey from seven common Bering Sea fish species, were independently analyzed by two of the age reading specialists (Table 4). Ages of young fish were estimated most precisely. The age determinations of old fish were less reliable due to narrowing and crowding of outer rings.

Table 4.—Summary of comparisons of ages determined by two age reading specialists.

Fish species	Skeletal structure	Age range (yr)	Number of comparisons	Percentage with perfect agreement in age group assignment[1]
Walleye pollock	Otoliths[2]	1-7	87	88
		8-12	84	63
Pacific cod	Scales	2-3	58	85
		4-6	33	79
Yellowfin sole	Otoliths[2]	5-12	180	93
		13-16	9	67
Alaska plaice	Otoliths[2]	6-12	25	76
		13-16	11	60
Rock sole	Otoliths[2]	3-12	127	83
		13-14	7	71
Flathead sole	Otoliths[2]	3-12	53	83
		13-15	13	70
Greenland turbot	Otoliths[2]	2-6	66	85
		7-11	36	75

[1] 90% of all disagreements in age group assignment differed by only 1 yr.

[2] Saccular otoliths.

Analytical Procedures

See Table 5 for definition of symbols.

Standardization of catches.—All trawl catches were standardized to a basic sampling unit, the weight of catch taken per 1.0 km trawling distance, including a scaling of each vessel's fishing performance to that of the *Miller Freeman:*

$$\mathrm{CPUE}_{ijk} = \frac{W_{ijk}}{D_{ij} \cdot F_{vk}}, \tag{1}$$

where CPUE_{ijk} is the catch per unit of effort (kg/km) for species k for the jth station in the ith subarea; W_{ijk} is the weight of catch (kg), D_{ij} is the distance trawled (km) computed from the start and ending loran-C readings at each station, and F_{vk} is the relative fishing power correction factor for vessel v in respect to species k.

Fishing power correction factors had previously been determined during the 1975 survey for the *Anna Marie* and *Pat San Marie* relative to *Miller Freeman* (Pereyra et al. see footnote 2). Because of the participation of the *Oregon* in the 1976 survey, additional comparative fishing trials were conducted in an attempt to intercalibrate the fishing efficiencies of all four vessels. Vessel correction factors used for all subsequent analyses are given in Table 6.

Catch per unit of effort.—Mean CPUE by species and subarea was computed using the mean per unit estimate:

$$\overline{\mathrm{CPUE}}_{ik} = \frac{\sum_{j=1}^{n_i} \mathrm{CPUE}_{ijk}}{n_i}, \tag{2}$$

where n_i is the number of successfully trawled stations in the ith subarea. The variance of this estimate was:

Table 5.—Summary of symbols used in the description of analytical procedures.

Terms	
A	Geographical area (km²)
B	Population weight (kg)
C	Coefficient of vulnerability (scalar)
CPUE	Catch per unit of fishing effort (kg/km)
D	Computed distance trawled (km)
F	Relative fishing power correction factor (scalar)
K	Growth completion rate (per yr)
L	Number of length categories (integer)
L_∞	Mean asymptotic length (cm)
N	Number of individuals within catch (integer)
P	Population number (integer)
S	Number of individuals within a standard sampling unit (no./km)
VAR	Statistical variance
W	Observed catch weight (kg)
a	Coefficient of length-weight relationship (g/cm³)
b	Exponent of length-weight relationship (dimensionless)
n	Number of samples (integer)
n_e	Number of effective degrees of freedom (dimensionless)
Terms	
p	Effective trawl path width (km)
q	Coefficient of catchability (per km)
s	Number of individuals within a subsample (integer)
t	Age (yr)
t_0	Hypothetical age of zero length (yr)
w	Individual weight (kg)
Subscripts	
i	Statistical subarea
j	Station
k	Species
l	Individual length class
m	Sex class
T	Total survey area (= all statistical subareas combined)
v	Vessel
Symbols	
—	(Over a term) A mean value
∧	(Over a term) An estimated value
$\sum$	Summation

Table 6.—Fishing power correction factors for the vessels *Anna Marie*, *Pat San Marie*, and *Oregon* relative to *Miller Freeman*.

Species	*Anna Marie*	*Pat San Marie*	*Oregon*
Walleye pollock (<20 cm)	0.52	0.34	0.21
Walleye pollock (≥20 cm)	0.79	0.61	0.63
All pollock	0.75	0.57	0.35
Rock sole	0.65	0.76	1.21
Snow (Tanner) crab	0.66	0.75	2.53
King Crab	0.70	1.05	1.63

[1] For all other species, the fishing power correction factor for each vessel was assumed equal to 1.00.

$$\text{VAR}\ \overline{\text{CPUE}}_{ik} = \frac{\sum_{j=1}^{n_i} (\text{CPUE}_{ijk} - \overline{\text{CPUE}}_{ik})^2}{n_i(n_i - 1)} . \tag{3}$$

The overall mean CPUE for the entire survey area ($\overline{\text{CPUE}}_{Tk}$) was determined as the sum of the weighted mean CPUE values of the individual subareas:

$$\overline{\text{CPUE}}_{Tk} = \frac{\sum_i (\overline{\text{CPUE}}_{ik} \cdot A_i)}{A_T} , \tag{4}$$

where A_i is the area of the ith subarea and A_T is the total area of all subareas combined.

The variance of this estimate was determined as the weighted sum of the individual variances of each subarea:

$$\text{VAR}\ \overline{\text{CPUE}}_{Tk} = \sum_i \left[\left(\frac{A_i}{A_T} \right)^2 \cdot \text{VAR}\ \overline{\text{CPUE}}_{ik} \right] . \tag{5}$$

Standing stock estimates.—Estimates of population weight (biomass) were made using the methods described by Alverson and Pereyra (1969) that relate CPUE and stock density within an area surveyed as

$$\hat{B}_{ik} = \overline{\text{CPUE}}_{ik} / q_k , \tag{6}$$

where $\hat{B}_{ik}$ is the estimated standing stock weight (kg) of the kth species in the ith subarea, and q_k is a coefficient of catchability. This coefficient, relating the capture efficiency of the sampling gear and sampling unit size, is defined:

$$q_k = C_k (\bar{p}/A_i) , \tag{7}$$

where C_k is a proportionality coefficient describing the vulnerability of individuals of species k to be caught and retained, and $\bar{p}$ is the average effective path width swept. The ratio $\bar{p}/A_i$ relates the size of individual sampling units (1.0 km in length) to the size of each survey subarea.

The coefficient of vulnerability (C) can be considered to consist of two components: 1) C_h, the efficiency of the gear to capture fish within the path of the trawl's cross-sectional mouth area; and 2) C_u, the proportion of the target fish population distributed in the water column within the trawl's vertical sampling path. Although the specific vulnerabilities of Bering Sea demersal fish to the sampling gear and methods used in the present study have not been well evaluated, all analyses of this study have assumed 100% capture efficiency ($C = 1.00$).

The average effective horizontal spread ($\bar{p}$) of the modified eastern trawl used by the reference vessel *Miller Freeman* was estimated by diving observations to be 0.017 km (Pereyra et al. see footnote 2). Other studies of eastern trawl performance have estimated the vertical opening to average approximately 2.3 m, with a range of 1.9-2.7 m (Wathne 1977).

The biomass of species k within subarea i was then estimated by the expansion:

$$\hat{B}_{ik} = \left(\frac{A_i}{\bar{p}} \right) \cdot \overline{\text{CPUE}}_{ik} , \tag{8}$$

having a variance of

$$\text{VAR}\ \hat{B}_{ik} = \left(\frac{A_i}{\bar{p}} \right) \cdot \text{VAR}\ \overline{\text{CPUE}}_{ik} . \tag{9}$$

Confidence intervals for biomass estimates were computed as

$$\hat{B}_{ik} \pm t_{(\alpha, n_e)} \sqrt{\text{VAR}\ \hat{B}_{ik}} , \tag{10}$$

where the number of effective degrees of freedom (n_e) was determined according to Cochran (1977), equation 5.16:

$$n_e = \frac{\left(\sum_{i=1} f_i \cdot \text{VAR CPUE}_{ijk} \right)^2}{\sum_{i=1} \frac{f_i^2 \cdot (\text{VAR CPUE}_{ijk})^2}{n-1}} \tag{11}$$

where

$$f = \frac{N_i(N_i - n_i)}{n_i} , \tag{12}$$

N_i equals the total number of sampling units in the ith subarea [$= A_i/(\bar{p} \bullet 1.0\ \text{km})$], and n_i equals the number of stations in subarea i. The biomass estimate for a given species or taxonomic group and its variance for the total survey area were obtained by summing the subarea biomasses and variances, respectively:

$$\hat{B}_{Tk} = \sum_{i=1} \hat{B}_{ik} , \tag{13}$$

and

$$\mathrm{VAR}\ \hat{B}_{Tk} = \sum_{i=1} \mathrm{VAR}\ \hat{B}_{ik}$$

$$= \sum_{i=1} \left[\left(\frac{A_i}{\bar{p}} \right)^2 \cdot \mathrm{VAR}\ \overline{\mathrm{CPUE}}_{ik} \right] \cdot \qquad (14)$$

Population numbers.—Because the numbers of fish caught during each trawl were not always recorded, estimates of the number of individuals within each subarea were usually obtained by dividing the estimated popuation weight by the mean weight per individual:

$$\hat{P}_{ik} = \frac{\hat{B}_{ik}}{\bar{w}_{ik}}, \qquad (15)$$

where $\hat{P}_{ik}$ is the estimated number of individuals of species k in subarea i available to the sampling gear. Depending on the availability of data for each species and subarea, the mean weight per individual ($\bar{w}_{ik}$) was computed by either of two methods.

Method 1. Where length-frequency data were available from most stations (>50% of total) and the relationship between the length and weight of individuals ($w = a \cdot 1^b$) within each subarea had been determined, then mean weight at each station with length-frequency data was computed:

$$\bar{w}_{ijk} = \frac{\sum_{l=1}^{L_{ijk}} s_{ijkl} \cdot w_{ikl}}{\sum_{l=1}^{L_{ijk}} s_{ijkl}} \qquad (16)$$

where s_{ijkl} is the number of individuals of species k of length l within each length-frequency subsample, w_{ikl} is the calculated weight (from the length-weight relationship) of individuals of length l, and L is the number of size categories recorded. The number of individuals caught per standard sampling unit (1.0 km) at each station with length-frequency data was then estimated as

$$\hat{S}_{ijk} = \frac{\mathrm{CPUE}_{ijk}}{\bar{w}_{ijk}}. \qquad (17)$$

The overall mean weight per individual within each subarea was then calculated:

$$\bar{w}_{ik} = \frac{\sum_{j=1}^{n_i} \mathrm{CPUE}_{ijk}}{\sum_{j=1}^{n_i} \hat{S}_{ijk}}, \qquad (18)$$

where n_i indicates the number of stations in subarea i with length-frequency data available for species k.

Method 2. Where length-frequency data and/or length-weight relationships were not available, the overall mean weight per individual within each subarea was calculated from stations at which the number of individuals had been reliably determined:

$$\bar{w}_{ik} = \frac{\sum_{j=1}^{n_i} W_{ijk}}{\sum_{j=1}^{n_i} N_{ijk}} \qquad (19)$$

where W indicates observed catch weight, N is the number of individuals within each catch, and n_i is the number of stations with determinations of numbers of individuals.

With both methods, estimates of population numbers for the entire survey area were the sum of the population estimates for the individual subareas.

Population size composition.—For species for which length-frequency data had been collected, estimates of the numbers of individuals (available to the trawl) of each sex within 1 cm size classes were made by proportioning the total population estimate for each subarea by the overall fraction of each size class within all length-frequency observations.

At each station with accompanying length-frequency data, the number of individuals (samples) within each sex and centimeter size class was estimated by expanding the length-frequency subsample to the total catch (per standard sampling unit):

$$\hat{S}_{ijklm} = s_{ijklm} \cdot \frac{\hat{S}_{ijk}}{\sum_{m=1}^{3} \sum_{l=1}^{L} s_{ijklm}}, \qquad (20)$$

where s_{ijklm} is the number of individuals within the length-frequency subsample of species k at the jth station of subarea i for length l and sex m, and L is the number of size classes represented.

The number of individuals (population) within sex and centimeter size classes for each statistical subarea was then estimated:

$$\hat{P}_{iklm} = \hat{P}_{ik} \cdot \frac{\sum_{j=1}^{n_i} \hat{S}_{ijklm}}{\sum_{j=1}^{n_i} \sum_{l=1}^{L} \bar{\hat{S}}_{ijklm}}, \qquad (21)$$

where $\hat{P}_{ik}$ was determined from Equation (15), and n_i indicates the number of length-frequency samples.

The overall size composition of populations within the total survey area was determined by summing the estimated numbers for each sex and centimeter size class over all possible statistical subareas.

Length-weight relationships.—Determinations of length-weight relationships were made to enable estimates of population numbers using Method 1 (Equations (15)-(18)), and to compare the body form and condition (weight-at-length) of individuals between sexes and geographical areas.

The basic relationship between the length and weight of individuals of fish species k can be described by the power function (Ricker 1975):

$$\text{weight} = a \cdot (\text{length})^b, \text{ or} \qquad (22)$$

$$\log(\text{weight}) = \log(a) + b\,[\log(\text{length})]. \qquad (23)$$

Length and weight data for each species were pooled in different combinations (cases) of otolith areas (geographical areas of collection) and sex. For each case, the length (cm) and weight (g) data were first transformed by taking logarithms (base 10). The data were then fitted to a straight line (Equation (23)) by a regression of "log(weight)" on "log(length)," and the values of a and b were determined. The least squares method of linear regression was used (Dixon and Massey 1969).

Analysis of covariance was used to evaluate the extent of differences between the length-weight relationships shown by data within the different test cases. The question asked by this analysis was, "For each fish species, did the relationship between length and weight significantly vary between sexes and between different geographical areas of the Bering Sea?"

The purpose of analysis of covariance was to 1) test whether one regression line could be used for each pooling of observations (case), if the slopes (b) of the regression lines within individual data sets were the same, and 2) test if the individual data sets had common adjusted mean values (Dixon and Massey 1969).

Analyses of covariance were performed on the same logarithmic-transformed length and weight data as used in the linear regression analyses.

Age composition and growth.—The age-frequency distributions of populations vulnerable to the trawl were estimated by proportioning the computed population length-frequency distributions to ages using age-length keys (Ricker 1975). For each case, length-age data were selected by species, sex, and area of collection (otolith area, Fig. 4) to construct a rectangular array (age-length key) of the number of observations at each age (column) and length (row). The estimated number of individuals within the population at each length ($\hat{P}_{iklm}$ of Equation (21)) was then proportioned to age groups (years) based upon the percentage of each age, among fish of the same length (i.e., row), within the array of actual length-age observations.

The selection of data for age-length keys was based on two principal considerations: 1) Data were selected for the same, or closely neighboring, geographical area as that of the length-frequency distribution; and 2) data were pooled between areas, when necessary, to provide adequate representation of length classes.

The proportion of females was determined for each age group following the estimations of age-frequency distributions.

Population growth characteristics were described by comparing the mean lengths of age groups within the expanded length-age array consisting of the estimated number of individuals in the population (vulnerable to the trawl) at each length and age. For each pooling of data by species, sex, and geographical area, a decaying exponential growth curve (von Bertalanffy 1938) was fitted to the vector of mean-lengths-at-age:

$$l_t = L_\infty (1 - e^{-K(t - t_0)}), \qquad (24)$$

where l_t is the length (cm) of individuals at time t (year). L_∞ is a mean asymptotic length (cm), K is a constant describing growth completion rate (per year), and t_0 is the hypothetical age (year) of zero length. The method of Fabens (1965) was used for the mathematical fitting of each growth curve, involving an iterative least squares approximation of K and L_∞.

Two von Bertalanffy growth curves were fitted to each set of data. The first curve was fitted using the complete and unaltered vector of mean-lengths-at-age of all age groups represented within the data set. The second curve was fitted to an adjusted vector from which mean-lengths-at-age based upon <10 length-age determinations were excluded, and an artificial data point (0,0) was added. In nearly all cases, the second curve fitting to the adjusted data resulted in a substantial reduction of the mean square deviation of sample points from the regression line in the approximation of K and L_∞, and was considered the "best" description of growth characteristics.

Reproductive condition.—The reproductive condition of the population of walleye pollock within the survey area (and vulnerable to the trawl) was assessed using the same computational procedures as the estimation of age-frequency distributions. Observations of gonad condition were made on individuals collected as subsamples of the length-frequency samples within otolith areas A, B, and D (Fig. 4). The reproductive condition (maturity stage) of each individual was coded on a scale of 1 to 5 (Table 7) based upon the visual appearance of the gonads (Holden and Raitt 1974). For each sex, the length-maturity observations were then organized into a rectangular array (length-maturity key) of the numbers of observations at each length (rows) and stage of gonad condition (column). The estimated number of individuals within the population at each length ($\hat{P}_{iklm}$ of Equation (21)) was then proportioned to stages of reproductive condition based upon the percentage of each stage, among fish of the same length (i.e., row), within the array of actual length-maturity observations.

Table 7.—The five-point scale for stages of gonad condition applied to walleye pollock during the April-June 1976 Bering Sea survey.

Code	Gonad condition	Description
1	Immature	Sexual organs very small, situated close to vertebral column; ovaries pink or translucent; testes translucent with slight leafing.
2	Developing	Ovaries small to about one-half length of ventral cavity; transparent and/or opaque ova visible to naked eye; testes with increased leafing and swelling.
3	Spawning	Roe and milt run under slight pressure.
4	Spent	Ovaries and testes flaccid and empty; ovaries may contain remnants of disintegrating ova; testes bloodshot.
5	Inactive	Adults with gonads firm, shaped, and empty.

RESULTS

Sampling

A total of 683 trawls was taken during the 5 mo of combined surveys (Table 8); 497 trawls were taken by the *Miller Freeman, Anna Marie,* and *Pat San Marie* during April-June; 186 trawls were taken by the *Oregon* for the 1976 Crab-Groundfish Survey during May-August. Of the total 683 trawls, 19 were unsuccessful.

Sampling activities were significantly influenced by the extreme southerly distribution of sea ice in the eastern Bering Sea during the winter of 1975-76. Pack ice limits during April-June 1976 were at an extreme southern latitude compared to positions of the pack edge in the same months, 1954-70 (Potocsky 1975). Late pack ice breakup during spring 1976 also caused some delay in survey coverage.

During April 1976 pack ice extended south to approximately lat. 56°N, enclosing the Pribilof Islands and Port Moller. Trawling during April was restricted to stations north and northwest of Unimak Island in deep water (Fig. 5). During May-June, the areas of sampling progressed north and northeast, following the open water exposed by pack ice recession (Fig. 6, 7). Subsequent sampling during July-August was conducted along the outer continental shelf north of Unimak Island to complete the Crab-Groundfish Survey (Fig. 8, 9).

The 664 successful trawls were assigned to three categories: 1) 435 grid stations that satisfied requirements for even spacing of sampling locations within subareas, to be used for estimates of population abundance; 2) 44 additional stations that were taken at opportunities independent of the station grid, to supplement the grid stations for distributional analyses; and 3) 185 other trawls that included Crab-Groundfish Survey stations and 60 comparative trawls used only for vessel intercalibration and specimen data collections.

Catches during the spring survey were usually <3,300 kg/trawl, but on a few occasions when large concentrations of yellowfin sole were encountered they ranged from 5,300 to 23,000 kg/trawl. Of the 664 successful hauls taken by the four vessels, only 177 (17.6%) were subsampled rather than completely processed (Table 9).

All subdivisions of the study area were sampled in the planned station pattern, with the following exception: Because of rough bottom encountered in the slope subareas, particularly in subdivision 3 Slope, only 14 of the 29 intended station transects were completed. A total of 51 successful trawls were taken in the slope subareas.

Distribution of Temperature

Because sea surface and bottom water temperature distributions changed relatively rapidly during spring warming, it was necessary to summarize the temperature data by individual months. Unfortunately, temperature measurements were not taken at each trawling station, and the percentage of stations with temperature data (compared to the total number of trawls taken during each month) were April, 65%; May, 40%; and June, 55%. Within each month, the geographical areas for which temperature data had been collected were, in some regions, extremely disjunct.

During April, surface temperatures in the area surveyed (Fig. 10) ranged from −1.1° to +3.9°C, with a gradient of progressively decreasing temperature from the outer to inner continental shelf. Subzero surface temperatures prevailed to the east and northeast near the pack ice edge, extending as far south as lat. 55°10′N. Bottom water temperatures ranged from −0.5° to +5.7°C and also showed progressive cooling towards the inner shelf. Relatively warm bottom water (+3.0° to +5.7°C) occurred in the southern region of the study area between water depths of ca. 130-360 m.

In May, as the survey progressed north and northeast following recession of the pack ice, relatively cold (−1.7° to +2.0°C) surface and bottom water occurred throughout all of the eastern Bering Sea continental shelf inside of approximately the 120 m isobath (Fig. 11). Surface temperatures ranged from −1.4° to +4.0°C. Bottom water temperatures ranged from −1.7° to +6.8°C. As in April, warmest water temperatures were found along the outer edge of the continental shelf.

By June, both surface and bottom water had warmed in the inner Bristol Bay shallows east of long. 162°-164°W (Fig. 12). Overall, surface temperatures ranged from 0.0° to +6.6°C, with a broad region of relatively warm water (+3° to +6°C) in central Bristol Bay. Bottom water temperatures were also warmest (+2° to +5°C) along the north shore of Bristol Bay, progressively cooling towards apparently residual cold (−1.2° to −0.3°C) water remaining in the central shelf region.

Table 8.—Summary of sampling activities during the 1976 Bering Sea surveys.

Survey	Months	Trawls included[1] in spring 1976 station pattern		Other trawls[2]	Additional unsuccessful trawls	Total
1976 spring trawl survey	April	112	(106)	6	7	125
(Vessels *Miller Freeman,*						
Anna Marie, and *Pat*	May	231	(195)	17	9	257
San Marie)	June	93	(91)	20	2	115
Subtotal		436	(392)	43	18	497
1976 crab-groundfish						
survey	May	0	(0)	14	0	14
(Vessel *Oregon*)	June	30	(30)	47	0	77
	July	13	(13)	48	1	62
	August	0	(0)	33	0	33
Subtotal		43	(43)	142	1	186
Total		479	(435)	185	19	683

[1] Numbers without parentheses indicate total number of trawls. Numbers in parentheses indicate the subset of grid stations used for biomass and population analyses.

[2] Includes 60 comparative trawls between *Oregon* and *Pat San Marie.*

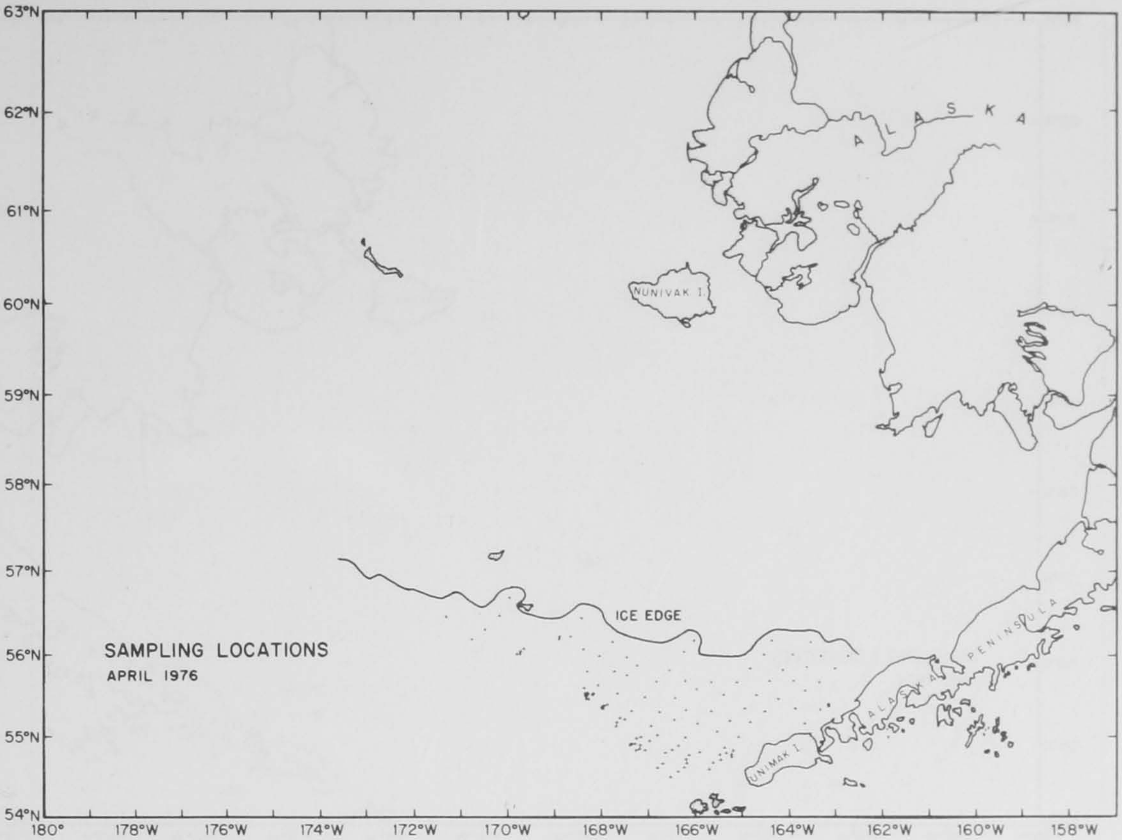

Figure 5.—Location of successful trawling stations in the Bering Sea during April 1976.

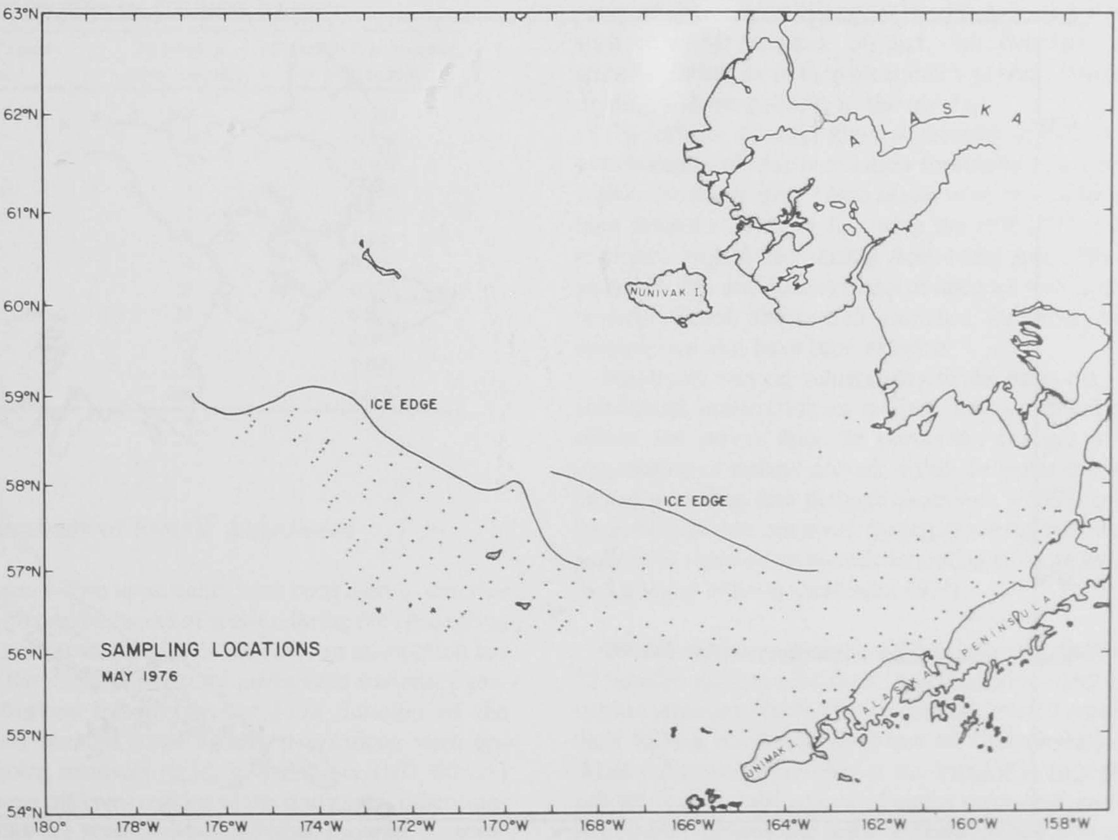

Figure 6.—Location of successful trawling stations in the Bering Sea during May 1976.

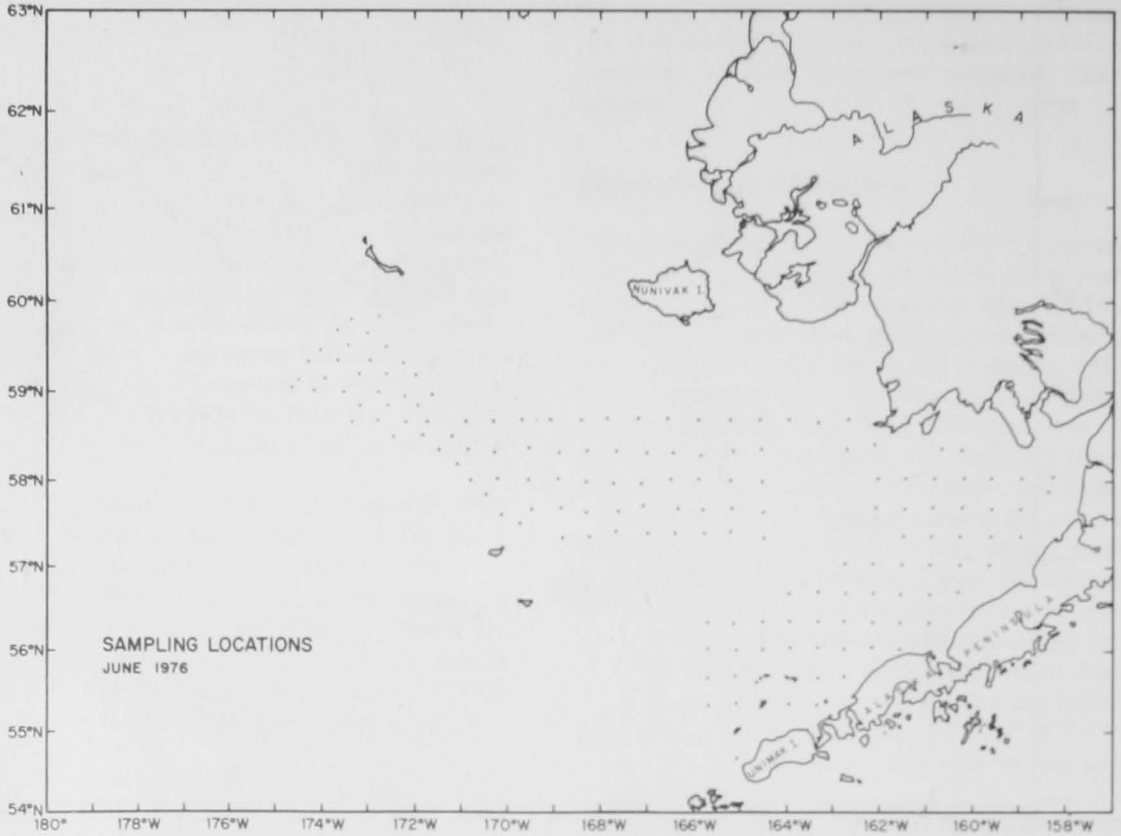

Figure 7.—Location of successful trawling stations in the Bering Sea during June 1976.

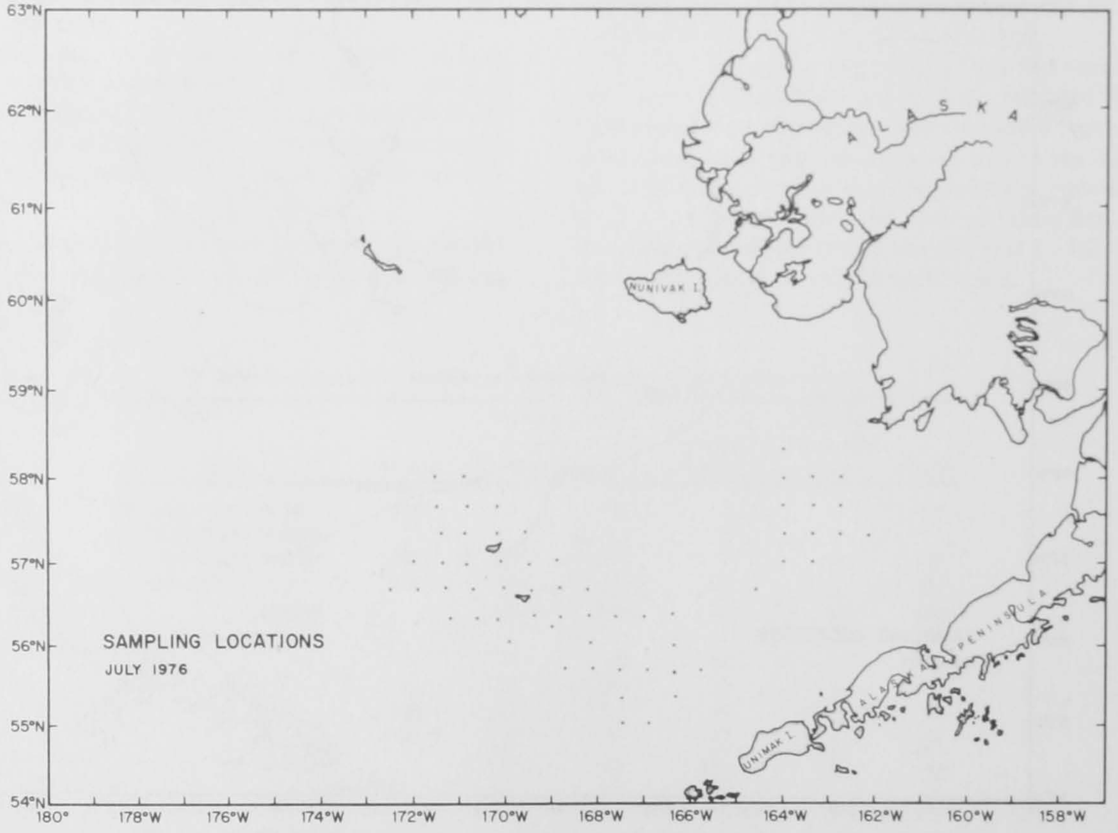

Figure 8.—Location of successful trawling stations in the Bering Sea during July 1976.

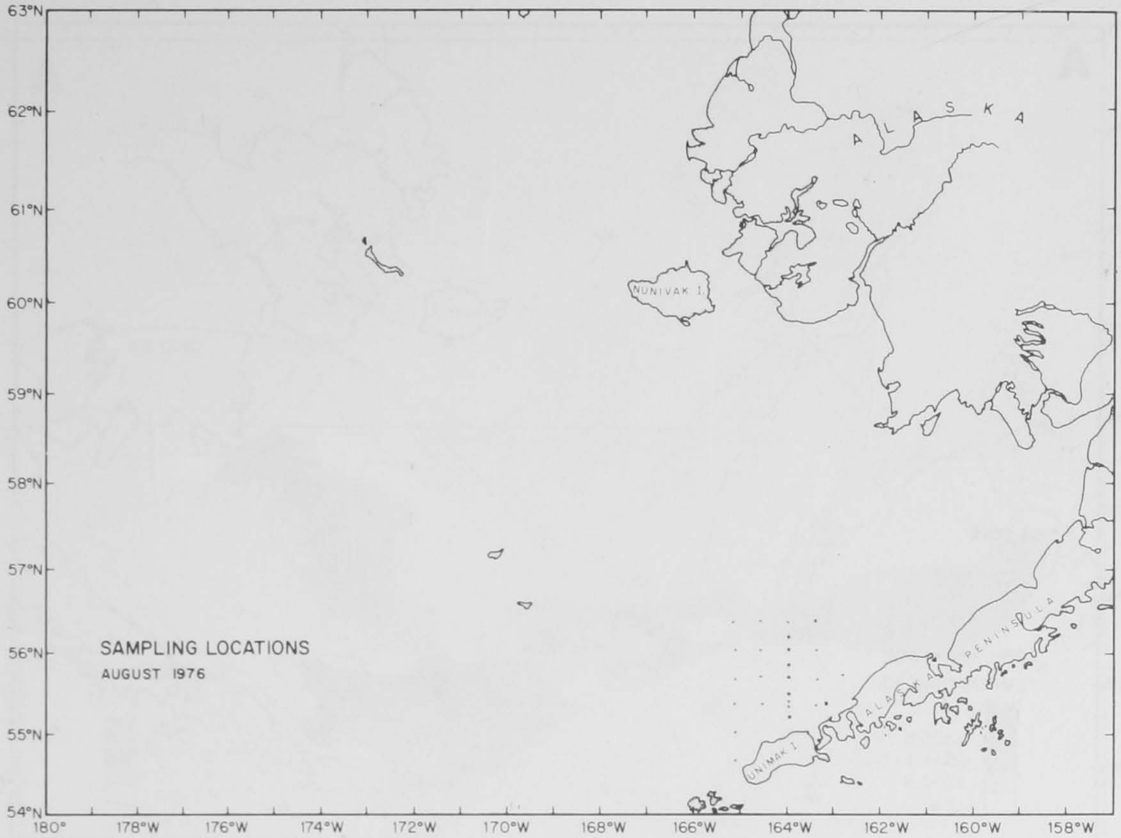

Figure 9.—Location of successful trawling stations in the Bering Sea during August 1976.

Table 9.—Summary of subsampling for processing successful trawl catches during the 1976 Bering Sea surveys.

Percentage of catch processed	Number of trawl samples	Cumulative proportion of total number
100	547	0.824
90-99	0	0.824
80-89	0	0.824
70-79	0	0.824
60-69	5	0.831
50-59	8	0.843
40-49	19	0.872
30-39	25	0.910
20-29	28	0.952
10-19	24	0.988
<10	8	1.000
Total	664	1.000

General Distributions of Faunal Abundance

Sampling biases.—Two approaches have been used to describe the distributions and abundances of species during the 1976 spring trawl survey. For most summaries of the data, an assumption has been made that the target populations maintained stationary geographical distributions throughout the 3-mo duration of the survey. However, because some species populations were apparently undergoing relatively rapid, long-distance (100-300 km) migrations between different regions of the study area, other summaries of the data are presented by individual months.

Measures of abundance during the survey were apparently affected by two major sources of error: The progression of the survey following the dispersal of some populations from deep to shallow waters (particularly yellowfin sole and Alaska plaice), with repeated sampling of high fish densities; and possible seasonal variations in the vulnerability of some populations (most notably walleye pollock) to the trawl.

The effects of migration apparently influenced substantial overestimates of true population (primarily flounder) abundance within the study area. These biases were caused by exceptionally high flounder densities following the recession of the pack ice edge into Bristol Bay during April-May. Although estimates of yellowfin sole and Alaska plaice abundance were apparently most severely biased, the overall estimates for other migrating fish species may also have been affected.

Seasonally varying vulnerability to the trawl may have caused substantial underestimates of true walleye pollock abundance within the survey area. In particular, changes in the vertical distribution of walleye pollock within the water column may have caused a varying (but perhaps sometimes large) proportion to be missed by the bottom trawl. Spring spawning behavior of walleye pollock is reported to include schooling of large individuals high in the water column (Serobaba 1974).

Overall catches.—A total of 78 fish species distributed among 22 families was recorded from the 435 trawl samples used for population analyses (Table 10). In general, overall trawl catch rates were highest north and northeast of Unimak Island, along the Alaska Peninsula, and east of the Pribilof Islands (Fig. 13). The overall observed abundance of major taxonomic groups are summarized in Table 11 and expanded to apparent biomasses in Table 12. Fish accounted for approximately 73% of the mean total catch, and invertebrates 27%.

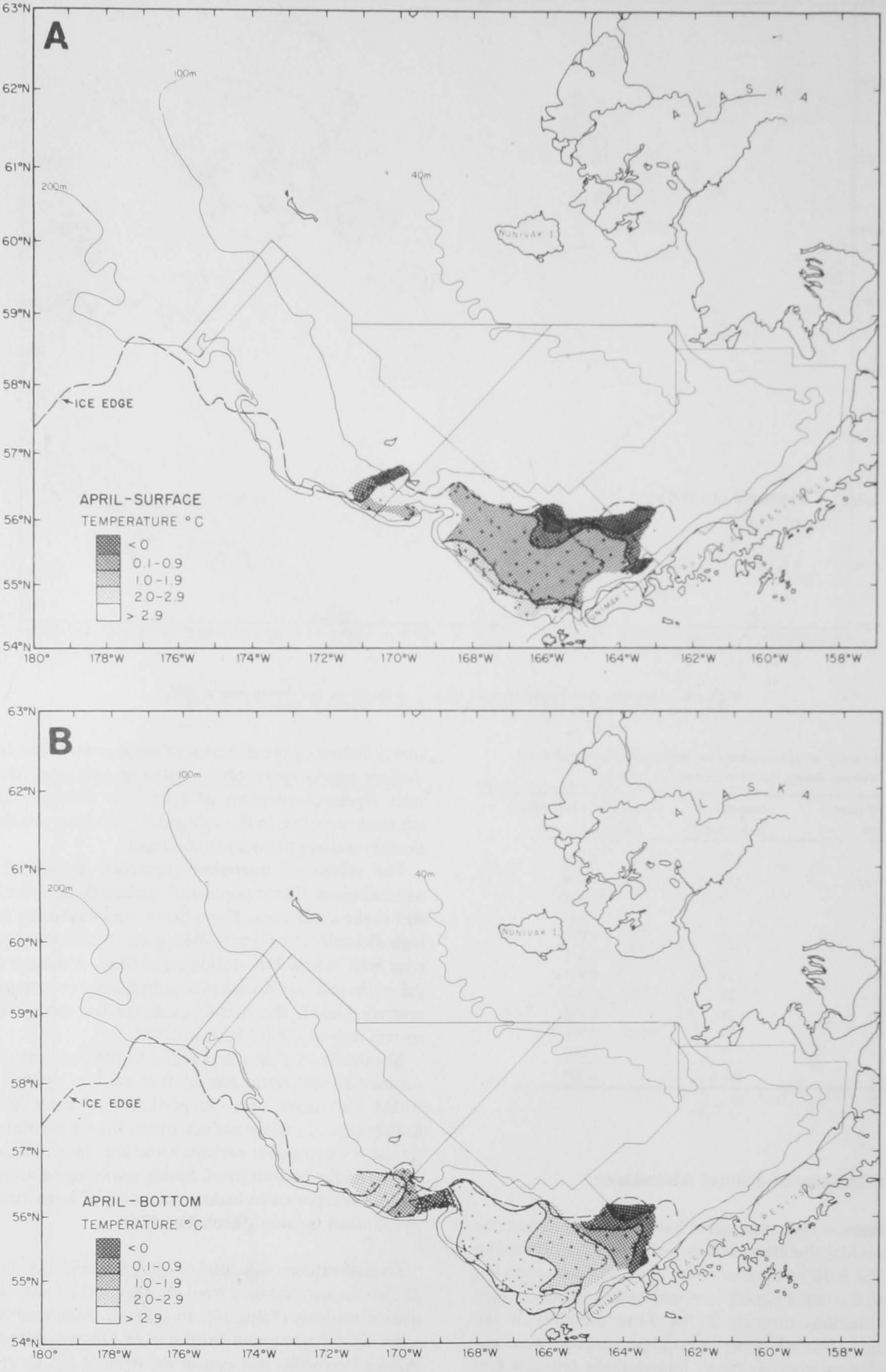

Figure 10.—Distribution of water temperatures observed in the Bering Sea during April 1976: A) sea surface; B) bottom.

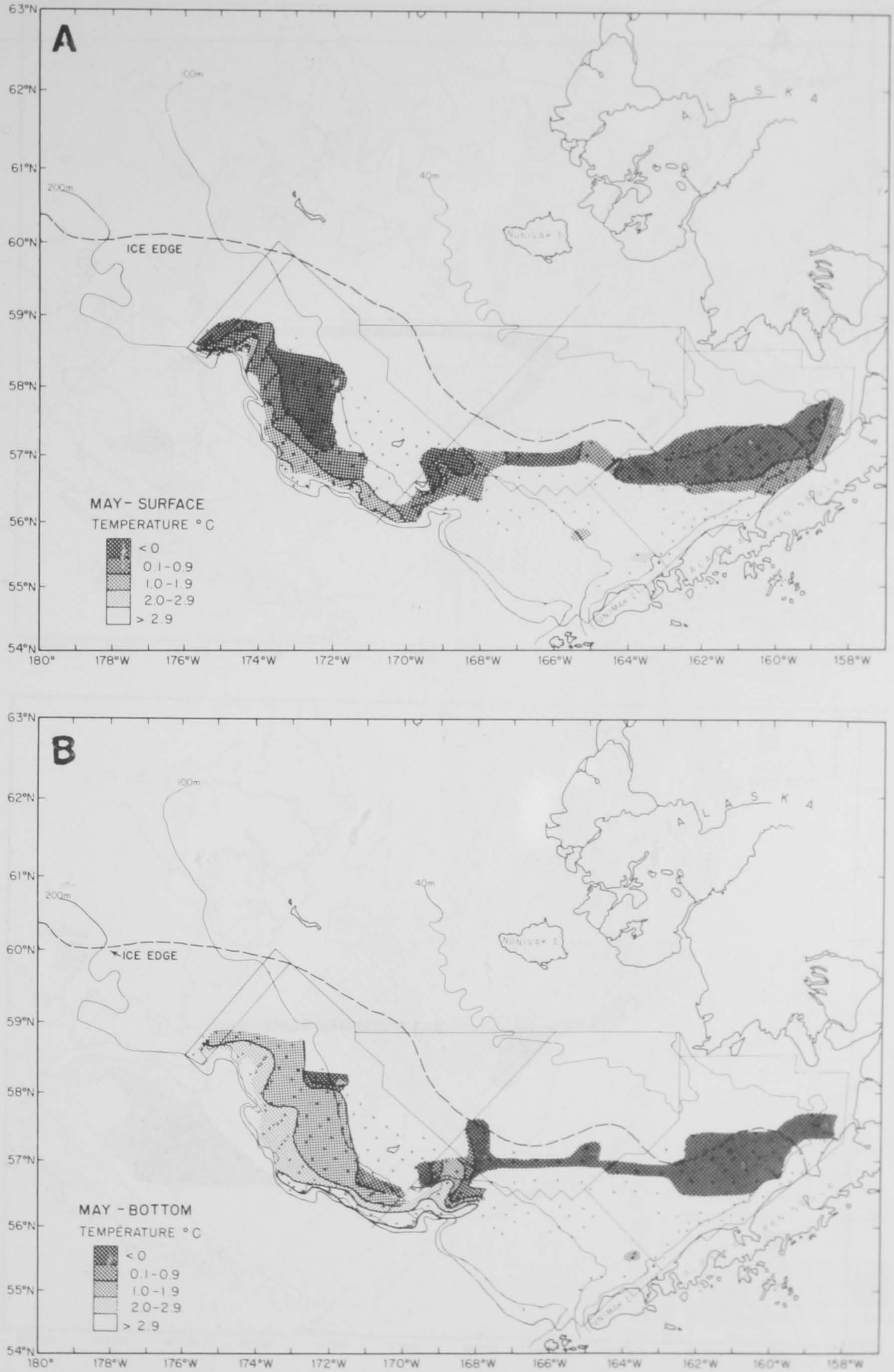

Figure 11.—Distribution of water temperatures observed in the Bering Sea during May 1976: A) sea surface; B) bottom.

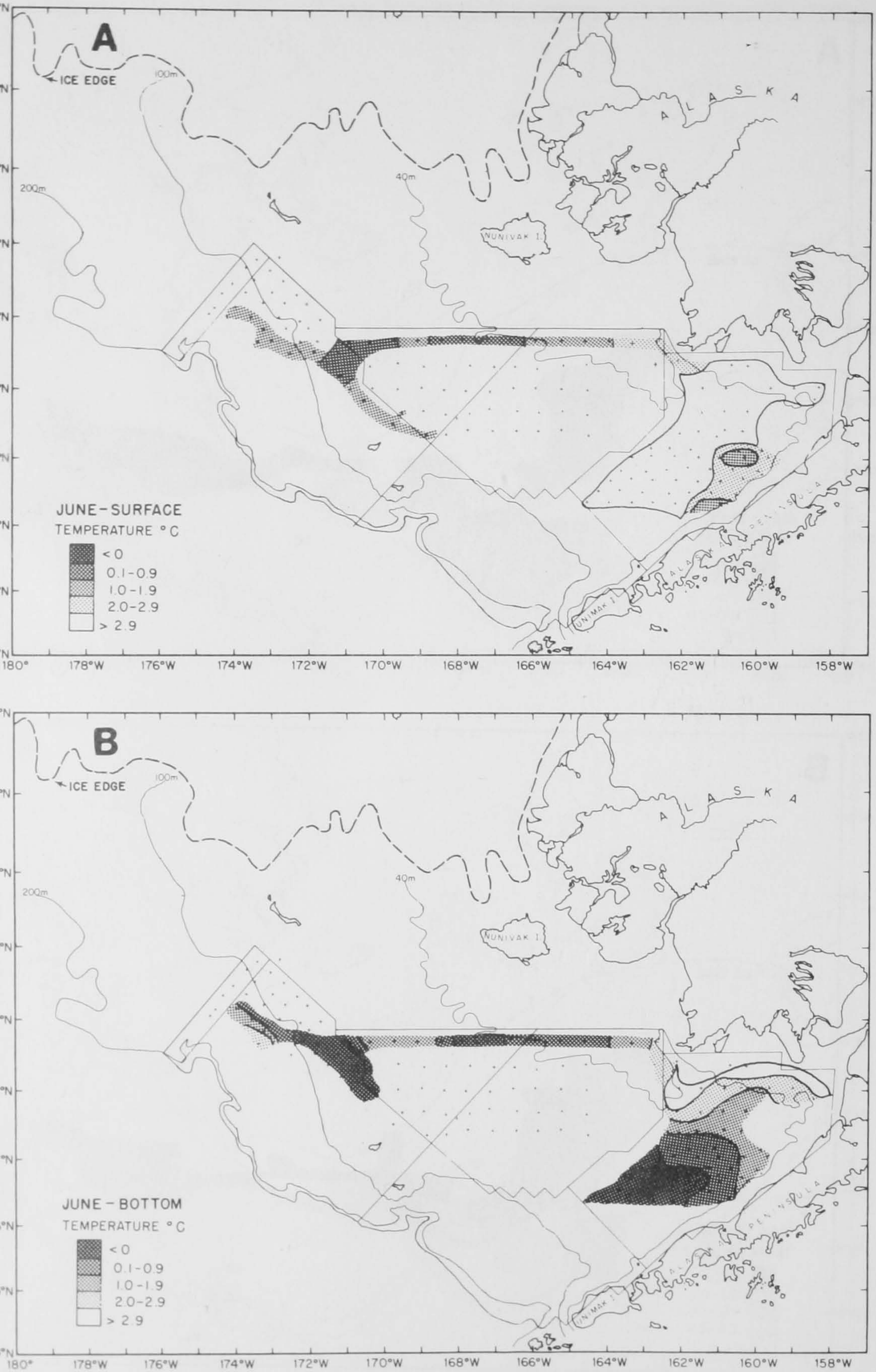

Figure 12.—Distribution of water temperatures observed in the Bering Sea during June 1976: A) sea surface; B) bottom.

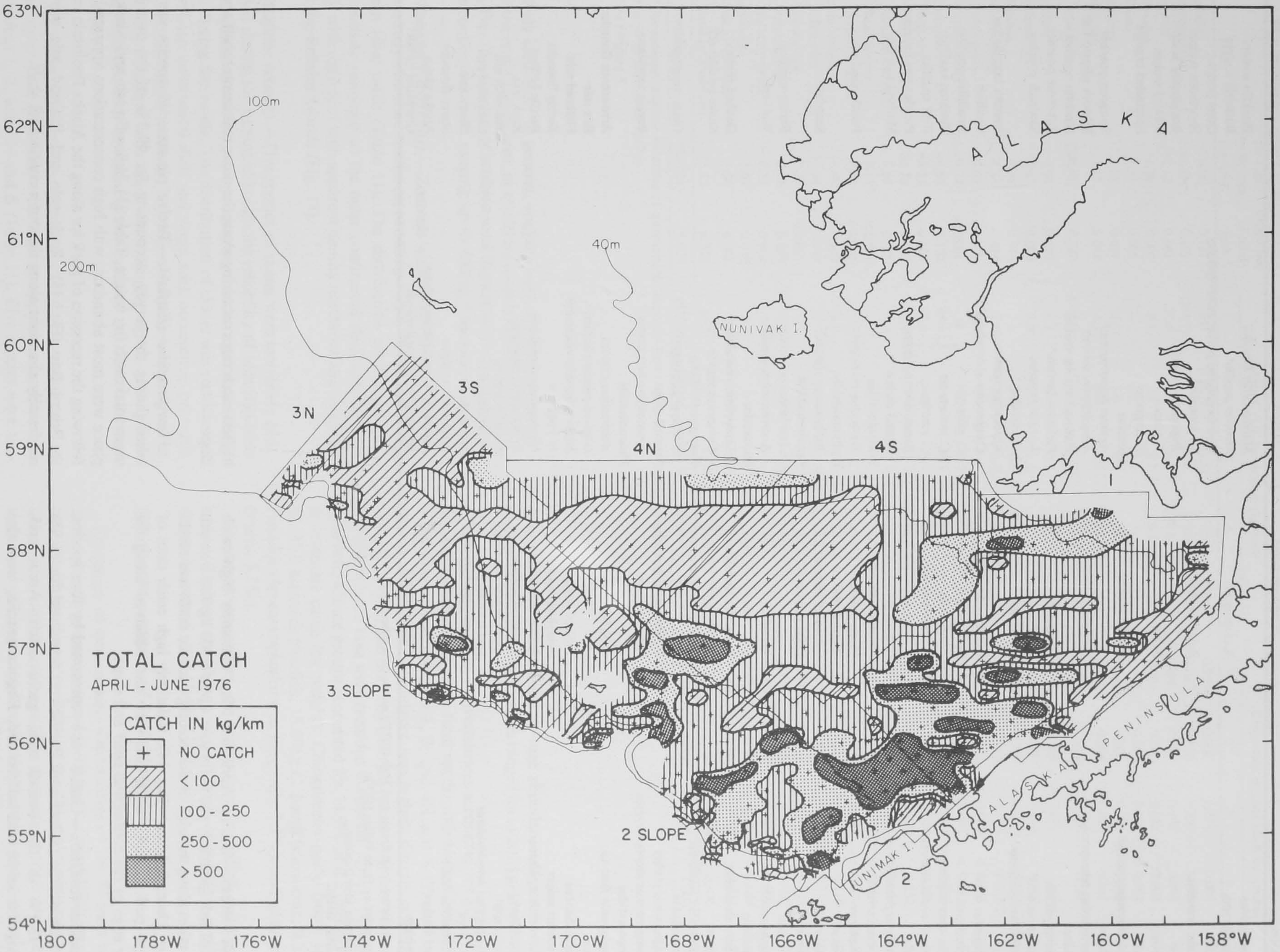

Figure 13.—Distribution and relative abundance of total fish and invertebrates during the 1976 Bering Sea spring trawl survey (by weight).

Table 10.—List of fish collected in the Bering Sea during the 1976 spring trawl survey[1].

Taxon	Common name	Taxon	Common name
Petromyzontidae		*Malacocottus kincaidi*	Blackfin sculpin
Lampetra spp.	[1]Lamprey	*Melletes papilio*[2]	Butterfly sculpin
Squalidae		*Myoxocephalus polyacanthocephalus*	Great sculpin
Squalus acanthias	Spiny dogfish	*M. scorpius*[3]	Shorthorn sculpin
Rajidae		*Triglops macellus*[3]	Roughspine sculpin
Raja spp.	Skate	*T. pingeli*	Ribbed sculpin
Clupeidae		*T. scepticus*	Spectacled triglops
Clupea harengus pallasi	Pacific herring	Agonidae	
Salmonidae		*Agonus acipenserinus*[2]	Sturgeon poacher
Oncorhynchus tshawytscha	Chinook salmon	*Anoplagonus inermis*	Smooth alligatorfish
Osmeridae		*Bathyagonus nigripinnis*	Blackfin poacher
Mallotus villosus	Capelin	*Pallasina barbata*[3]	Tubenose poacher
Osmerus mordax[2]	Rainbow smelt	*Sarritor frenatus*	Sawback poacher
Thaleichthys pacificus	Eulachon	Cyclopteridae	
Gadidae		*Aptocyclus ventricosus*	Smooth lumpsucker
Boreogadus saida	Arctic cod	*Careproctus abbreviatus*[3]	Snailfish
Eleginus gracilis	Saffron cod	*C. gilberti*[3]	Smalldisk snailfish
Gadus macrocephalus[2]	Pacific cod	*C. melanurus*	Blacktail snailfish
Theragra chalcogramma	Walleye pollock	*C. rastrinus*	Pink snailfish
Zoarcidae		*Eumicrotremus orbis*	Pacific spiny lumpsucker
Lycodapus parviceps[3]	Eelpout	*Liparis dennyi*[3]	Marbled snailfish
Lycodes brevipes	Shortfin eelpout	Trichodontidae	
L. diapterus	Black eelpout	*Trichodon trichodon*	Pacific sandfish
L. palearis	Wattled eelpout	Bathymasteridae	
L. polaris[3]	Canadian eelpout	*Bathymaster signatus*	Searcher
L. turneri[3]	Polar eelpout	Anarhichadidae	
Macrouridae		*Anarhichas orientalis*[3]	Bering wolffish
Coryphaenoides spp.	Rattail	*Anarrhichthys ocellatus*	Wolf-eel
Scorpaenidae		Stichaeidae	
Sebastes aleutianus	Rougheye rockfish	*Leptoclinus maculatus*[3]	Daubed shanny
S. alutus	Pacific ocean perch	*Lumpenus sagitta*	Snake prickleback
Sebastolobus alascanus	Shortspine thornyhead	Cryptacanthodidae	
Hexagrammidae		*Delolepis gigantea*[2, 3]	Giant wrymouth
Hexagrammos stelleri	Whitespotted greenling	Ammodytidae	
Pleurogrammus monopterygius	Atka mackerel	*Ammodytes hexapterus*	Pacific sand lance
Anoplopomatidae		Pleuronectidae	
Anoplopoma fimbria	Sablefish	*Atheresthes stomias*	Arrowtooth flounder
Cottidae		*Glyptocephalus zachirus*	Rex sole
Blepsias bilobus	Crested sculpin	*Hippoglossoides elassodon*	Flathead sole
Dasycottus setiger	Spinyhead sculpin	*H. robustus*	Bering flounder
Gymnocanthus galeatus	Armorhead sculpin	*Hippoglossus stenolepis*	Pacific halibut
G. pistilliger	Threaded sculpin	*Lepidopsetta bilineata*	Rock sole
G. triscuspis[3]	Arctic staghorn sculpin	*Limanda aspera*	Yellowfin sole
Hemilepidotus hemilepidotus	Red Irish lord	*L. proboscidea*	Longhead dab
H. jordani	Yellow Irish lord	*Microstomus pacificus*	Dover sole
Hemitripterus bolini[2]	Bigmouth sculpin	*Platichthys stellatus*	Starry flounder
Icelus scutiger[3]	Sculpin	*Pleuronectes quadrituberculatus*	Alaska plaice
I. spiniger	Thorny sculpin	*Reinhardtius hippoglossoides*	Greenland turbot[4]

[1] Nomenclature from Quast and Hall (1972), unless otherwise noted.

[2] Nomenclature from Bailey (1970).

[3] Uncertain identification.

[4] Market name.

Fish catches.—During April and May, extremely high catch rates of fish (primarily yellowfin sole, up to 6,803 kg/km trawled) were taken along the edge of the receding pack ice north and northeast of Unimak Island (Fig. 14). Relatively high catch rates of walleye pollock and Pacific cod were also observed along the outer edge of the continental shelf and slope.

Gadidae (codfish).—Gadids were represented by four species, of which walleye pollock and Pacific cod accounted for 86.8% and 13.1% of the overall total gadid catch. Arctic cod, *Boreogadus saida,* and saffron cod, *Eleginus gracilis,* were also taken in northern regions of the study area. Both walleye pollock and Pacific cod showed broad distributional patterns, with highest catch rates occurring along the outer continental shelf and slope.

Pleuronectidae (flatfish).—Twelve pleuronectid species were taken during the survey, accounting for 49.3% of the overall mean total catch (by weight, Table 11). Yellowfin sole and Alaska plaice were most abundant, with high concentrations apparently following the recession of pack ice along the Alaska Peninsula into Bristol Bay (Fig. 15). Rock sole and flathead sole were moderately abundant along the outer continental shelf.

Cottidae (sculpins).—Cottids were observed to be diverse and relatively abundant during the survey, with 17 species being ten-

Table 11.—Summary of average catch per unit fishing effort of major taxonomic groups in the Bering Sea, 1976 spring trawl survey.[1]

Taxa	Mean CPUE for total survey area (kg/km)	Proportion of total catch	Mean CPUE by subarea (kg/km)[2]					Proportion of total catch by subarea[3]				
			1	2	3	4	Slope	1	2	3	4	Slope
Gadidae	(39.16)	0.137	3.0	(136.7)	(41.1)	1.3	(99.4)	0.007	0.305	0.277	0.006	0.445
Pleuronectidae	(141.41)	0.493	(283.7)	(205.2)	34.2	(79.6)	68.0	0.687	0.458	0.230	0.396	0.304
Cottidae	18.12	0.063	27.4	22.3	6.2	18.8	4.0	0.066	0.050	0.042	0.094	0.018
Zoarcidae	1.90	0.007	0.1	3.3	4.7	0.4	1.2	<0.001	0.007	0.032	0.002	0.005
Rajidae	1.31	0.005	—	2.5	1.8	tr	13.6	—	0.006	0.012	< 0.001	0.061
Agonidae	3.01	0.011	5.5	2.6	0.4	3.6	0.1	0.013	0.006	0.003	0.018	< 0.001
Other fish	3.57	0.012	4.3	2.0	4.6	2.7	8.4	0.010	0.004	0.031	0.013	0.038
Total fish	(208.48)	0.727	(324.0)	(374.6)	(93.0)	(106.4)	(194.7)	0.784	0.836	0.626	0.530	0.871
Porifera	1.94	0.007	6.1	1.4	0.1	0.6	0.1	0.015	0.003	< 0.001	0.003	< 0.001
Coelenterata	2.45	0.009	3.8	2.7	2.1	1.5	1.6	0.009	0.006	0.014	0.007	0.007
Mollusca	4.48	0.016	2.6	2.8	5.9	5.9	4.8	0.006	0.006	0.040	0.029	0.021
Gastropoda	4.14	0.014	2.4	2.2	5.7	5.7	1.5	0.006	0.005	0.038	0.028	0.007
Pelecypoda	0.07	<0.001	0.1	tr	tr	0.1	tr	<0.001	<0.001	< 0.001	< 0.001	< 0.001
Cephalopoda	0.27	<0.001	tr	0.6	0.2	tr	3.3	<0.001	0.001	0.001	< 0.001	0.015
Crustacea	48.66	0.170	45.4	61.3	38.8	54.8	13.2	0.110	0.137	0.261	0.273	0.059
Total crabs	48.51	0.169	45.3	61.1	38.5	54.7	12.5	0.110	0.136	0.259	0.272	0.056
Chionoecetes spp.	38.78	0.135	24.4	50.7	32.4	50.6	11.8	0.059	0.113	0.218	0.252	0.053
Paralithodes spp.	6.62	0.023	17.4	9.0	2.4	0.5	0.1	0.042	0.020	0.016	0.002	< 0.001
Total shrimp	0.11	<0.001	tr	0.1	0.3	tr	0.7	<0.001	<0.001	0.002	< 0.001	0.003
Other crustacea	0.04	<0.001	0.1	0.1	tr	0.1	tr	<0.001	<0.001	< 0.001	< 0.001	< 0.001
Echinodermata	16.60	0.058	25.7	4.9	8.2	23.6	9.1	0.062	0.011	0.055	0.117	0.041
Asteroidea	13.14	0.046	23.0	0.9	2.4	22.1	2.3	0.056	0.002	0.016	0.110	0.010
Echinoidea	0.28	<0.001	0.9	0.2	tr	tr	0.2	0.002	<0.001	< 0.001	< 0.001	0.001
Ophiuroidea	2.68	0.009	0.6	3.8	5.8	1.5	0.6	0.001	0.008	0.039	0.007	0.003
Holothuroidea	0.51	0.002	1.3	tr	tr	0.1	5.9	0.003	<0.001	< 0.001	< 0.001	0.026
Ascidiacea	3.00	0.010	5.2	tr	tr	5.7	tr	0.013	<0.001	< 0.001	0.028	< 0.001
Other invertebrates	1.00	0.003	0.4	0.2	0.5	2.4	tr	0.001	<0.001	0.003	0.012	< 0.001
Total invertebrates	78.13	0.273	89.2	73.3	55.6	94.5	28.8	0.216	0.164	0.374	0.470	0.129
Total catch	(286.61)	1.000	(413.2)	(447.9)	(148.6)	(200.9)	(223.5)	1.000	1.000	1.000	1.000	1.000

[1] Parentheses indicate estimates of questionable accuracy due to potential sampling problems.

[2] tr = CPUE <0.05 kg/km.

[3] See Figure 3.

tatively identified. In general, sculpins were ubiquitous throughout the entire survey area, at moderate levels of abundance (Table 11, Fig. 16). Catches of sculpins were highest in central regions of the continental shelf, ranging up to 450 kg/km trawled.

Zoarcidae (eelpouts).—Zoarcids were relatively rare, with six tentatively identified species representing only 0.7% of the overall mean total catch (Table 11). The distribution of eelpouts was essentially restricted to the outer continental shelf (depths >75 m), with regions of high apparent density northwest and southeast of the Pribilof Islands (Fig. 17).

Rajidae (skates).—Five species of skates were tentatively identified during the survey, although the reliability of identifications was questionable due to the poor taxonomic descriptions available for Bering Sea rajids. The distribution of skates was restricted to the outer continental shelf and slope, with occurrences primarily at bottom depths >100 m (Fig. 18). Abundances were highest in the slope subarea with catch rates ranging up to 156 kg/km, although relatively low throughout most of the observed range (Table 11).

Agonidae (poachers).—Agonids occurred throughout most of the study area (Fig. 19), with highest apparent abundance in subareas 1, 2, and 4N and S (Table 11). Five species were tentatively identified, with the sturgeon poacher, *Agonus acipenserinus,* accounting for 77% of the overall total agonid catch. Although the overall average abundance of poachers was relatively low, individual catches ranged up to 201 kg/km trawled.

Invertebrate catches.—Invertebrates accounted for 27% of the weight of the overall mean total catch, with highest abundance being observed in subareas 1, 2, and 4N and S (Table 11). In general, invertebrate abundance was highest directly east of the Pribilof Islands, and north of Unimak Island (Fig. 20). A total of 169 invertebrate taxa were recorded during the survey. Five principal invertebrate groups accounted for 74.9% of the overall total invertebrate catch (by weight): *Chionoecetes opilio* (snow crab, 36.5%); asteroids (starfish, 16.8%); *C. bairdi* (snow crab, 9.3%); *Paralithodes camtschatica* (red king crab, 7.2%); and gastropods (snails, 5.1%).

Twenty-seven species of snails were identified during the survey. Highest abundance was observed in subareas 3 and 4 along the central shelf (Table 11, Fig. 21).

Relative Importance of Individual Species

Frequency of occurrence.—Occurrences of the 20 most common fish taxa are summarized in Table 13. Only 14 fish taxa occurred in more than 130 (30%) of the 435 grid station trawls; 19 fish taxa occurred only once. The percentage of occurrences of individual species varied considerably between geographical subdivisions of the study area, reflecting differences in distributional range and density distribution.

Table 12.—Summary of apparent biomasses of major taxonomic groups in the Bering Sea, 1976 spring trawl survey.[1]

Taxa	Estimated biomass for total survey area (t)	Proportion of total biomass	Estimated biomass by subarea (t)[2,3]					Proportion of total estimated biomass by taxa				
			1	2	3	4	Slope	1	2	3	4	Slope
Gadidae	(778,386)	0.137	14,488	(502,974)	(192,348)	7,899	(60,813)	0.019	0.646	0.247	0.010	0.078
Pleuronectidae	(2,810,815)	0.493	(1,370,101)	(755,013)	169,056	(483,689)	41,602	0.488	0.269	0.057	0.172	0.015
Cottidae	360,172	0.063	132,326	82,051	29,016	114,238	2,447	0.367	0.228	0.081	0.317	0.007
Zoarcidae	37,766	0.007	483	12,142	21,996	2,431	734	0.013	0.321	0.582	0.064	0.019
Rajidae	26,039	0.005	—	9,198	8,424	122	8,320	—	0.353	0.323	0.005	0.319
Agonidae	59,830	0.011	26,562	9,566	1,872	21,875	61	0.443	0.160	0.031	0.365	0.001
Other fish	70,961	0.012	20,766	7,359	21,528	16,407	5,139	0.292	0.103	0.302	0.230	0.072
Total fish	(4,143,969)	0.727	(1,564,726)	(1,378,303)	(435,240)	(646,540)	(119,117)	0.378	0.333	0.105	0.156	0.029
Porifera	38,561	0.007	29,459	5,151	468	3,646	61	0.760	0.133	0.012	0.094	0.002
Coelenterata	48,699	0.009	18,352	9,934	9,828	9,115	979	0.381	0.206	0.204	0.189	0.020
Mollusca	89,049	0.016	12,556	10,302	27,612	35,851	2,937	0.141	0.115	0.309	0.402	0.033
Gastropoda	82,291	0.014	11,591	8,095	26,676	34,636	918	0.141	0.099	0.326	0.423	0.011
Pelecypoda	1,391	<0.001	483	37	47	608	1	0.411	0.031	0.040	0.517	<0.001
Cephalopoda	5,367	<0.001	2	2,208	936	18	2,019	<0.001	0.426	0.181	0.003	0.390
Crustacea	967,218	0.170	219,255	225,547	181,584	332,992	8,076	0.227	0.233	0.188	0.344	0.008
Total crabs	964,236	0.169	218,772	224,811	180,180	332,385	7,648	0.227	0.233	0.187	0.345	0.008
Chionoecetes spp.	770,832	0.135	117,837	186,546	151,632	307,471	7,219	0.153	0.242	0.197	0.399	0.009
Paralithodes spp.	131,586	0.023	84,032	33,115	11,232	3,038	61	0.639	0.252	0.085	0.023	<0.001
Total shrimp	2,186	<0.001	89	368	1,404	36	428	0.038	0.158	0.604	0.015	0.184
Other crustacea	795	<0.001	483	368	—	608	—	0.331	0.252	—	0.417	—
Echinodermata	329,959	0.058	124,116	18,029	38,376	143,405	5,567	0.377	0.055	0.116	0.435	0.017
Asteroidea	261,185	0.046	111,076	3,311	11,232	134,291	1,407	0.425	0.013	0.043	0.514	0.005
Echinoidea	5,566	<0.001	4,346	736	187	—	122	0.806	0.137	0.035	—	0.023
Ophiuroidea	53,271	0.009	2,898	13,982	27,144	9,115	367	0.054	0.261	0.507	0.170	0.007
Holothuroidea	10,137	0.002	6,278	11	9	608	3,610	0.597	0.001	<0.001	0.058	0.343
Ascidiacea	59,631	0.010	25,113	11	140	34,636	1	0.419	<0.001	0.002	0.578	<0.001
Other invertebrates	19,877	0.003	1,932	736	2,340	14,584	—	0.099	0.038	0.119	0.744	—
Total invertebrates	1,552,995	0.273	430,782	269,700	260,208	574,229	17,620	0.277	0.174	0.168	0.370	0.011
Total catch	(5,696,964)	1.000	(1,995,508)	(1,648,003)	(695,448)	(1,220,769)	(136,737)	0.350	0.289	0.122	0.214	0.024
Geographical area (km^2)	337,930	—	82,100	62,550	79,570	103,310	10,400	—	—	—	—	—

[1] Parentheses indicate estimates of questionable accuracy due to potential sampling biases.

[2] Biomass = (CPUE/trawl width) × (geographical area) × (10^{-3} t/kg), where trawl width = 0.017 km. Metric tons = t.

[3] See Figure 3.

The most frequently occurring fish taxa among all areas were walleye pollock (77%), yellowfin sole (71%), Pacific cod (63%), Alaska plaice (60%), and Greenland turbot (59%).

Most frequently occurring invertebrate taxa overall were snow crab, *C. opilio* (77%) and *C. bairdi* (72%), unidentified snails (68%), unidentified hermit crabs (55%), and unidentified starfish (48%).

Relative abundance.—Apparent abundance observed during the spring 1976 survey is summarized in Tables 14-19. With the exception of the estimates of questionable accuracy obtained for walleye pollock, yellowfin sole, and Alaska plaice, Tables 14-19 provide comparisons of relative apparent densities and relative species composition (on a weight basis) between geographical regions of the study area.

Table 14 summarizes the observed overall mean abundance. Yellowfin sole and walleye pollock showed the highest apparent mean abundance, accounting for 48.2% of the overall mean total catch. The 20 most abundant fish taxa (7.6% of 264 total fish and invertebrate taxa recorded during the survey) accounted for 71.9% of the overall total catch.

In general, faunal similarity (as measured by the number of common taxa and the relative proportion of the total CPUE's) between subareas followed similarity in physical environment. Faunal composition was most similar between inner shelf subareas 1 (Table 15), and 4N and 4S (Table 18), with 19 common taxa among the 20 most abundant in each subarea. Yellowfin sole ranked highest in abundance in both subareas, followed by Alaska plaice, sculpins, and rock sole. Of the 19 common taxa between subareas, most were more abundant in subarea 1.

Based on the above criteria, outer shelf subareas 2, 3N, and 3S were also similar in faunal composition, with 13 taxa in common among their most abundant 20 (Tables 16, 18). In subarea 2, yellowfin sole was most abundant, followed by walleye pollock. In subareas 3N and 3S, walleye pollock ranked first, followed by yellowfin sole. Rock sole, flathead sole, Alaska plaice, and Pacific halibut were relatively abundant in subarea 2, but not in subareas 3N and 3S. Relatively abundant taxa in subareas 3N and 3S, but not in subarea 2, were Greenland turbot, eelpouts, and Pacific herring, *Clupea harengus pallasi.*

The slope subareas showed a relatively different faunal composition from all shelf subareas (Table 19). Dissimilarities were most marked between the slope subarea and inner shelf subareas 1, 4N, and 4S, with only 8 or 9 common taxa among the 20 most abundant in each area. There were 11 or 12 common taxa between the slope subarea and outer shelf subareas 2, 3N, and 3S. Walleye pollock was the most abundant species on the slope, with large flounders (arrowtooth flounder, Greenland turbot, and Pacific halibut), Pacific cod, and skates also showing relatively high densities. Deepwater taxa that were taken in abundance only in the

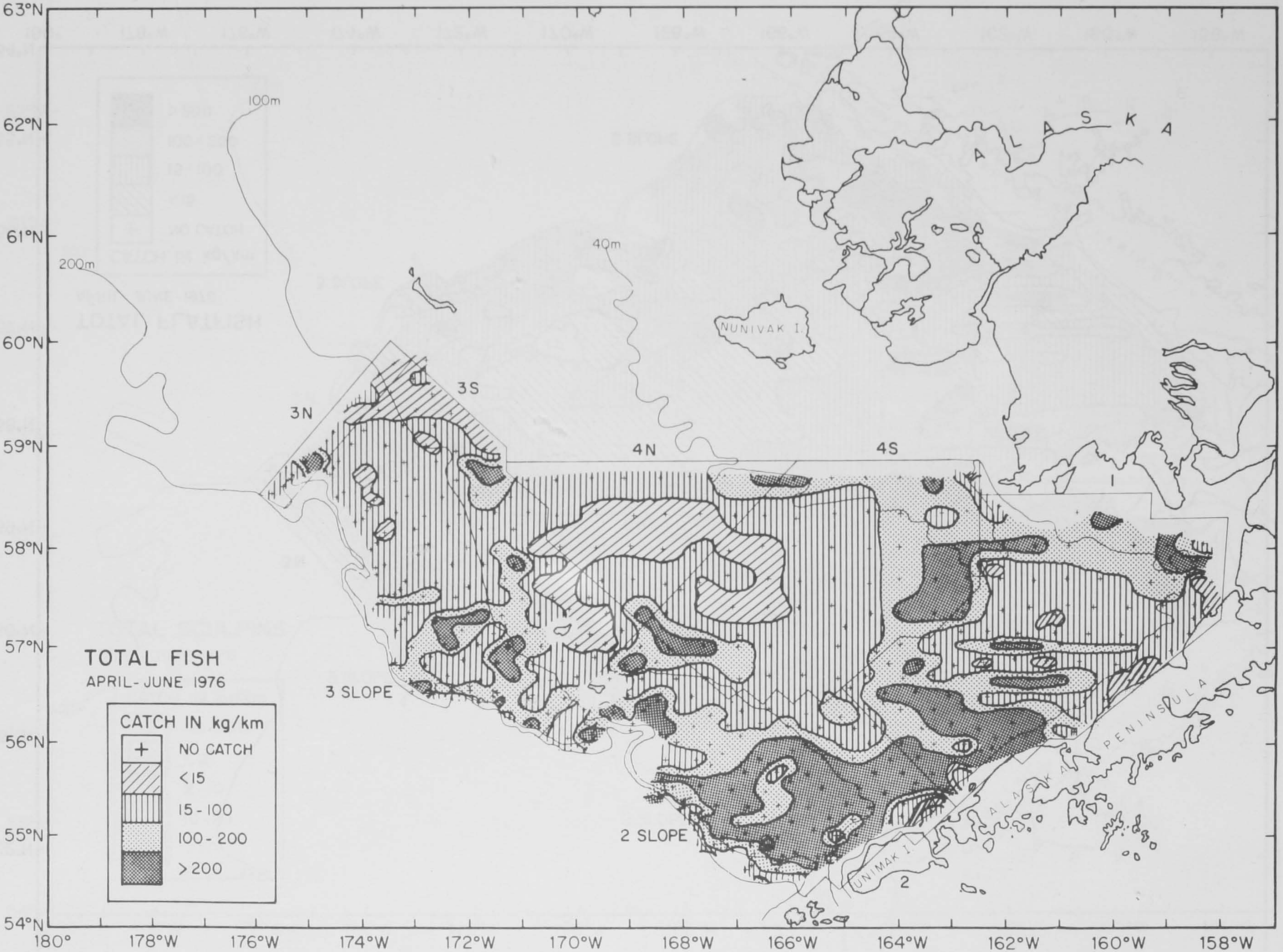

Figure 14.—Distribution and relative abundance of total fish during the 1976 Bering Sea spring trawl survey (by weight).

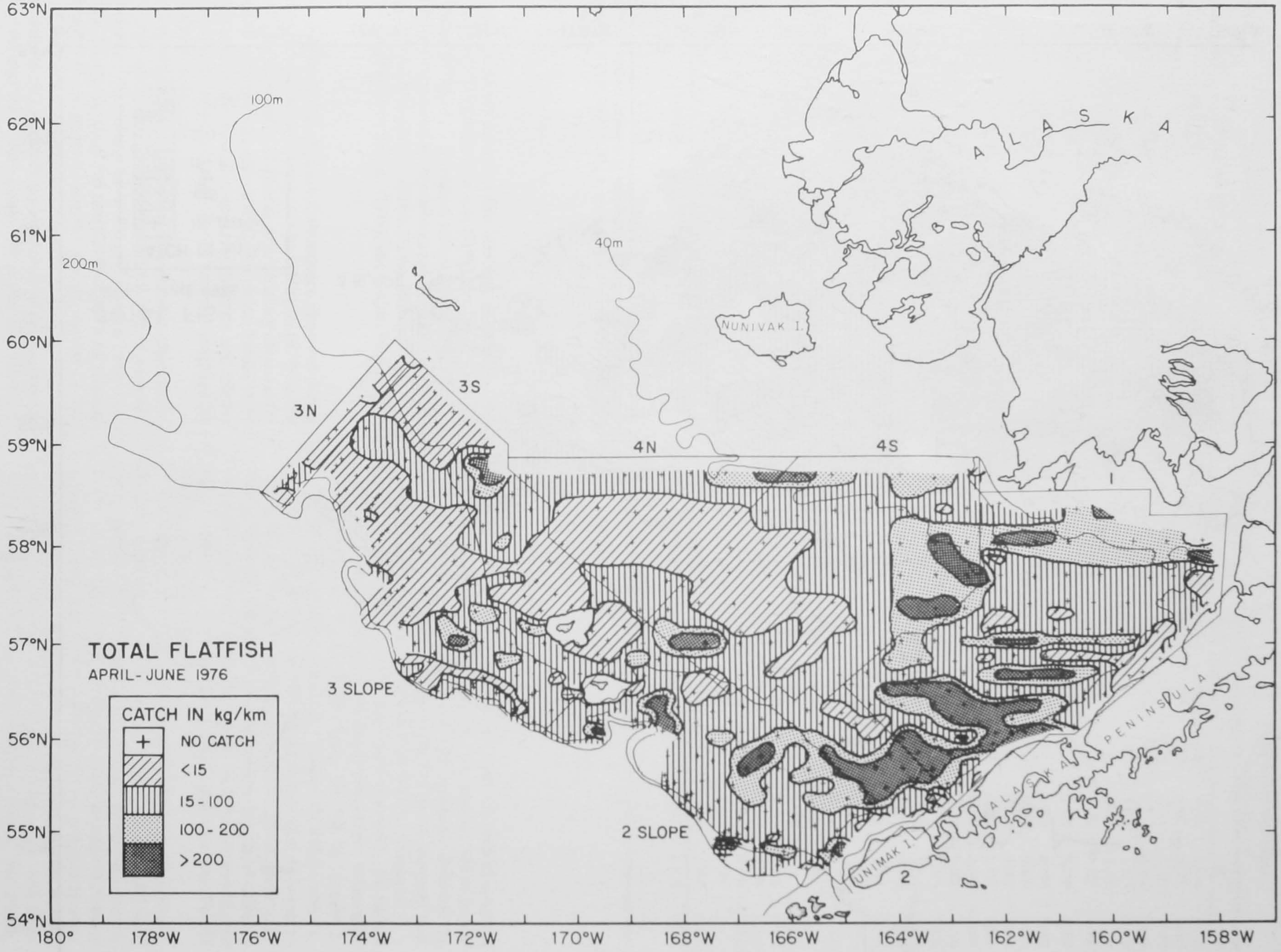

Figure 15.—Distribution and relative abundance of flatfish during the 1976 Bering Sea spring trawl survey (by weight).

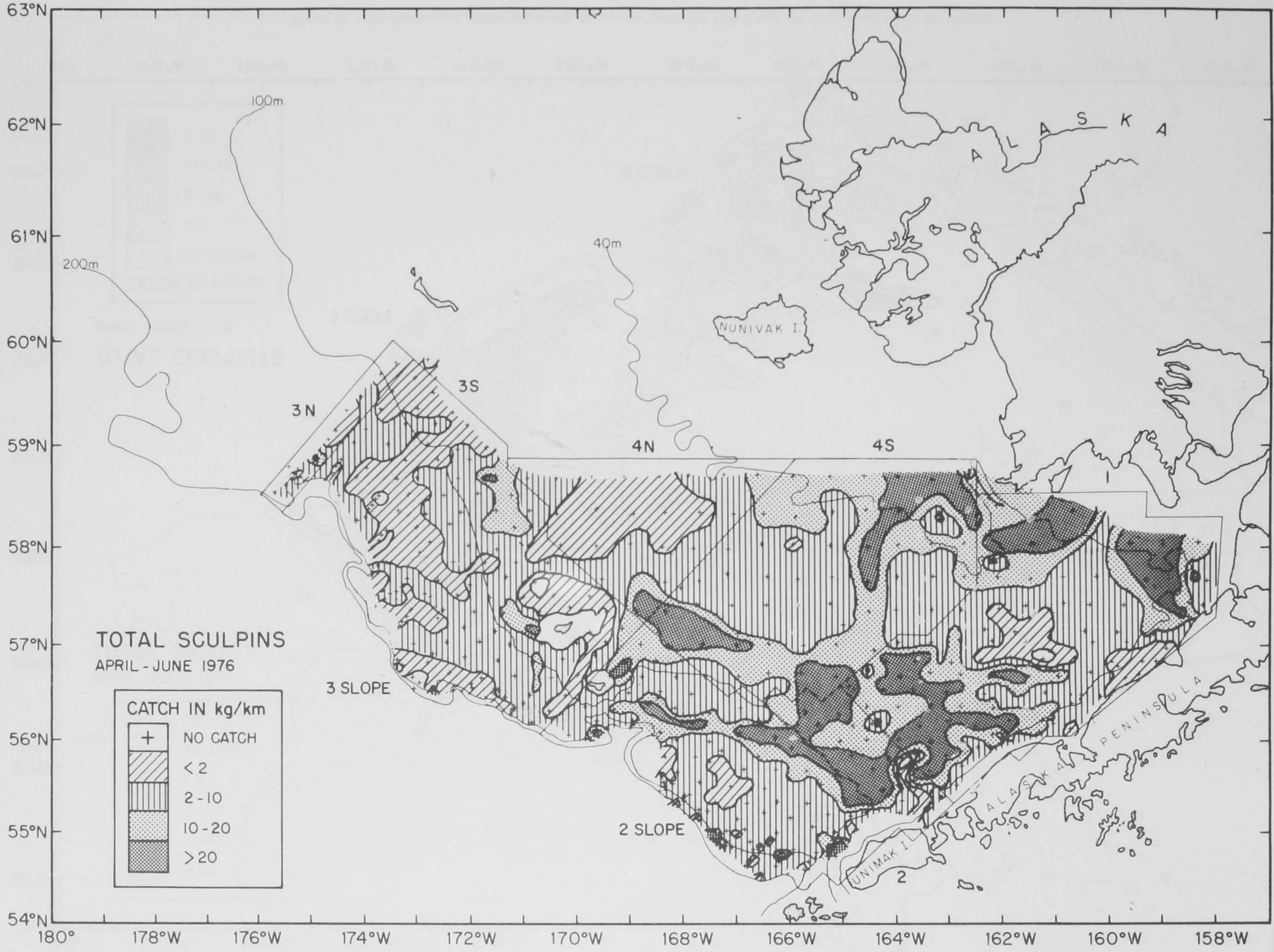

Figure 16.—Distribution and relative abundance of sculpins during the 1976 Bering Sea spring trawl survey (by weight).

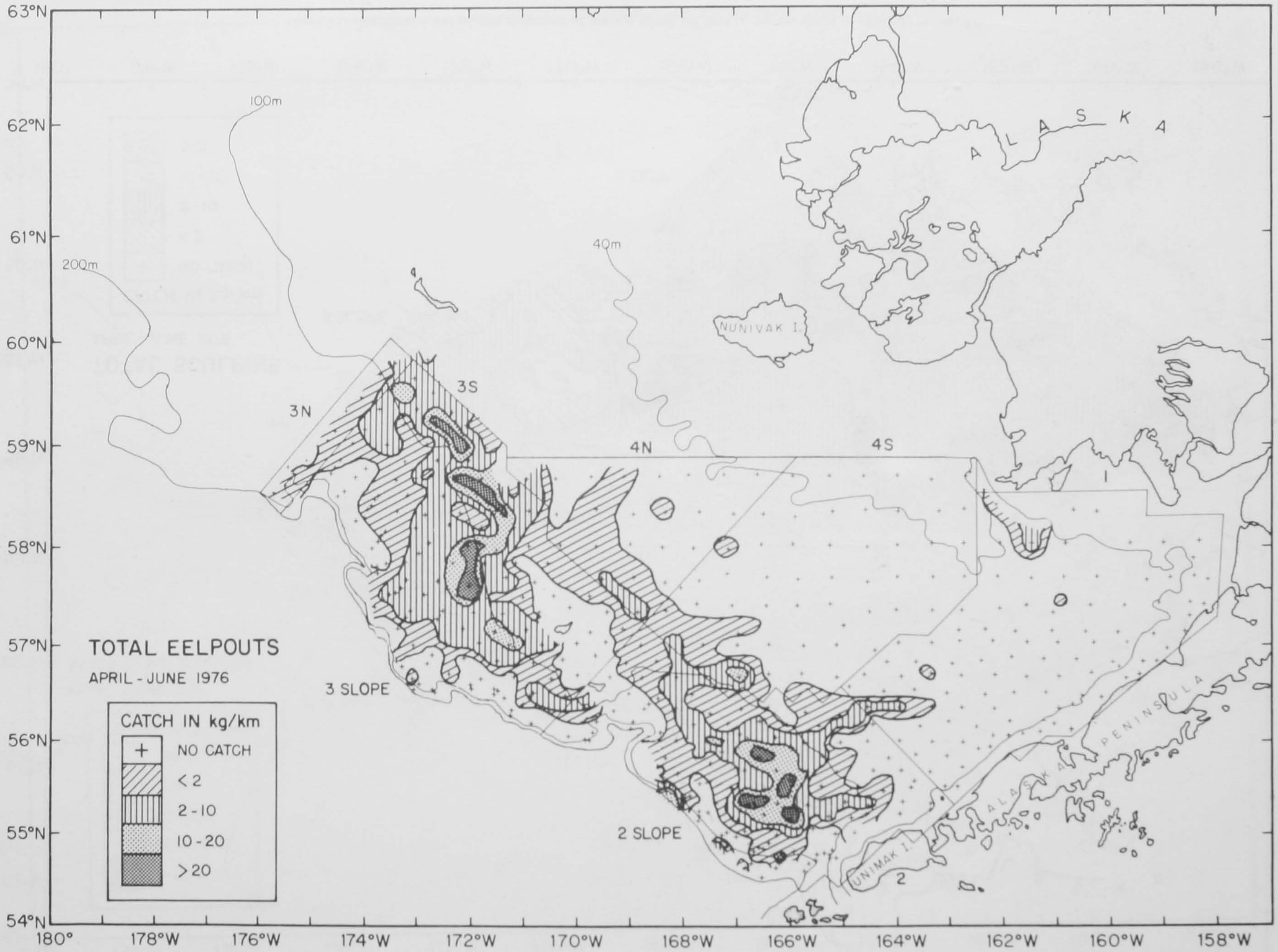

Figure 17.—Distribution and relative abundance of eelpouts during the 1976 Bering Sea spring trawl survey (by weight).

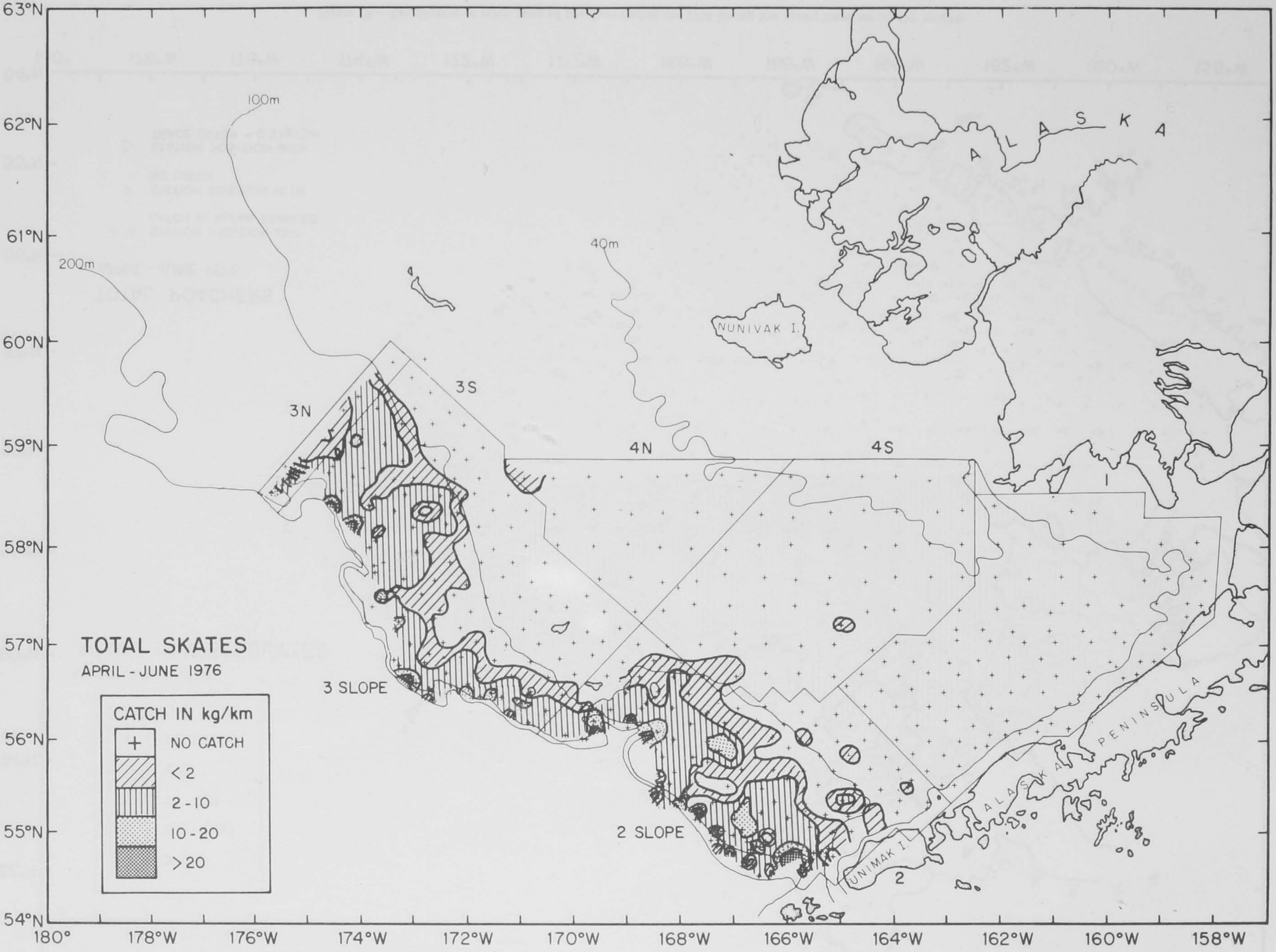

Figure 18.—Distribution and relative abundance of skates during the 1976 Bering Sea spring trawl survey (by weight).

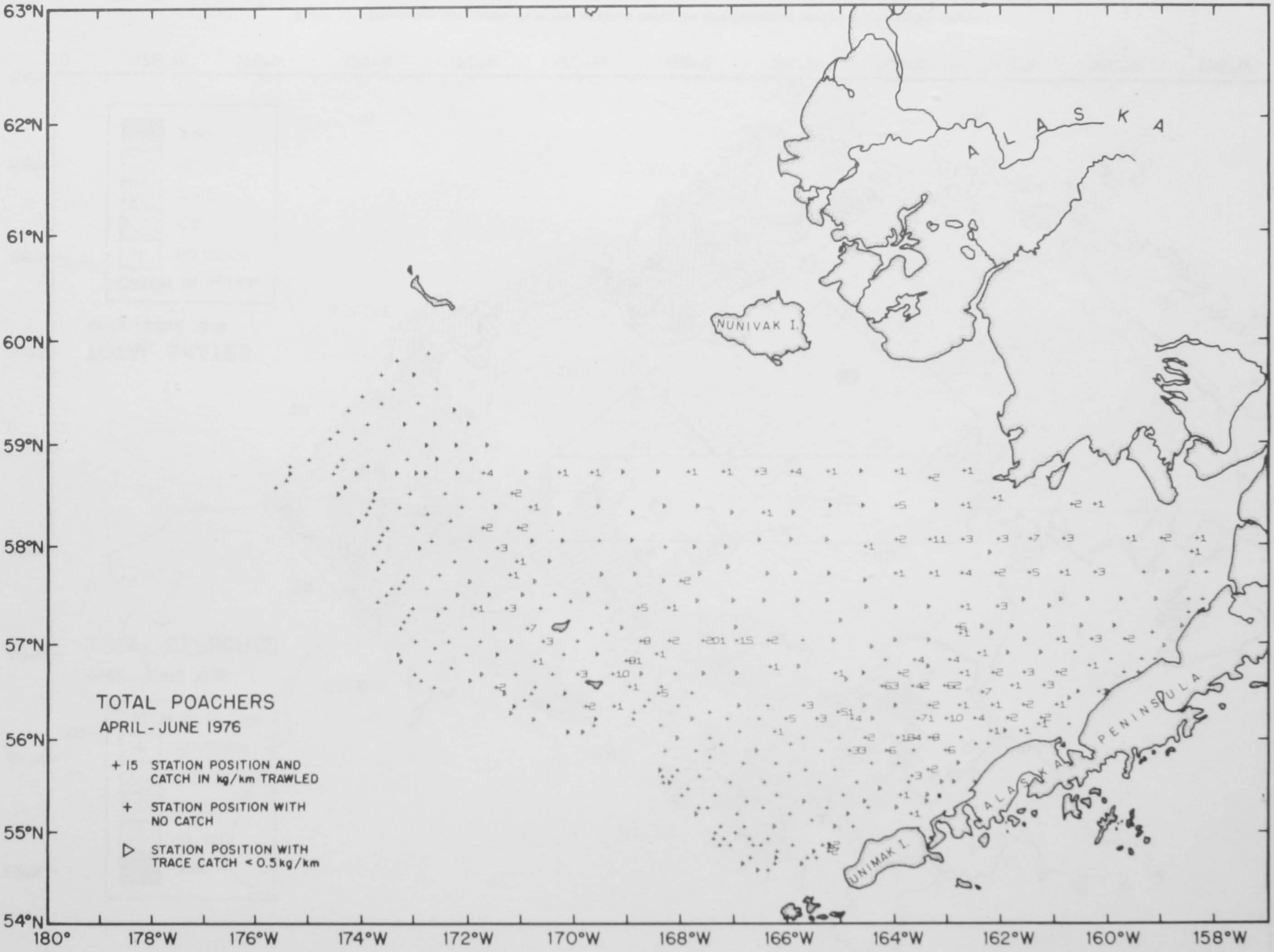

Figure 19.—Distribution of catch rates of poachers during the 1976 Bering Sea spring trawl survey (by weight).

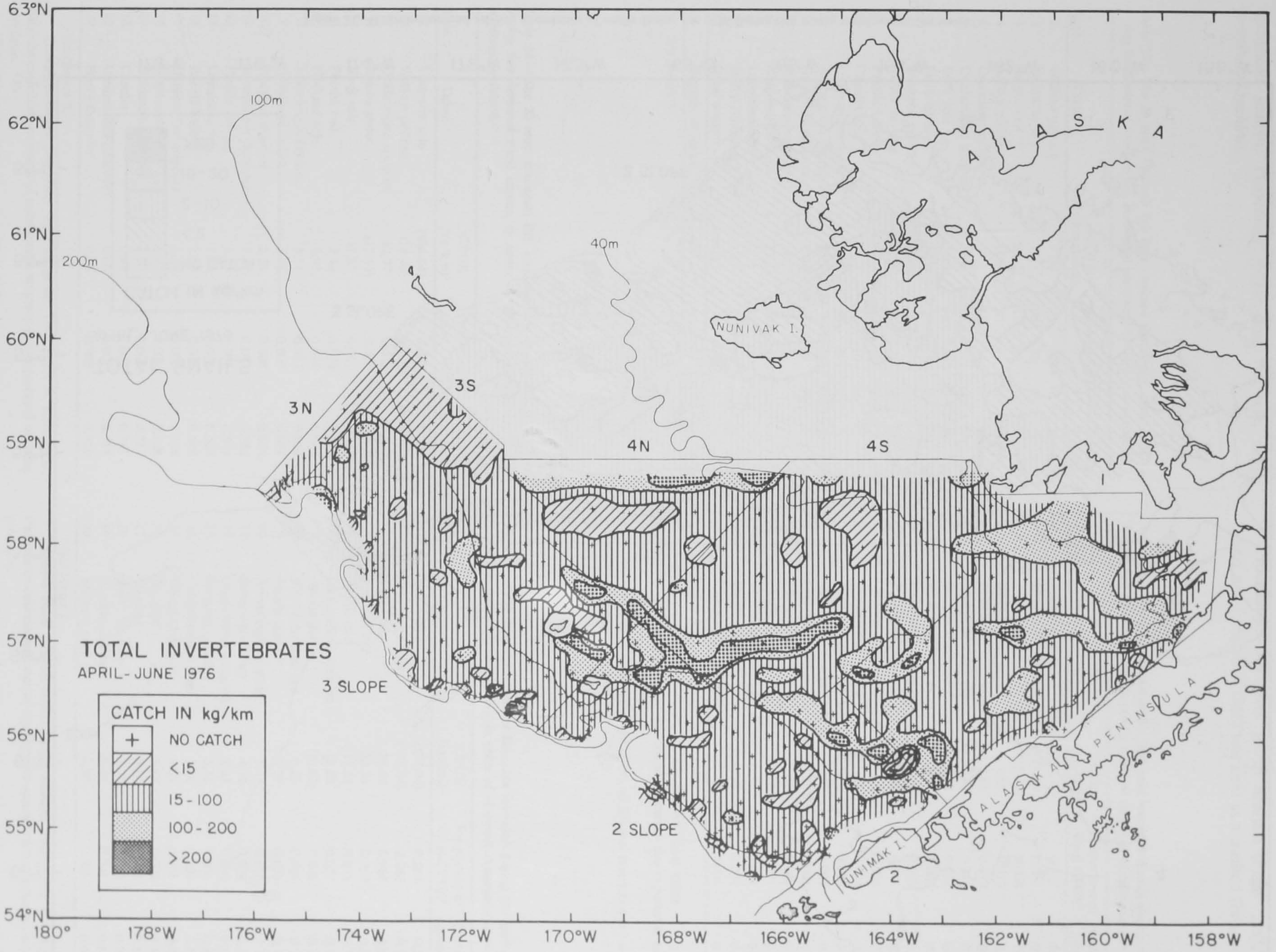

Figure 20.—Distribution and relative abundance of total invertebrates during the 1976 Bering Sea spring trawl survey (by weight).

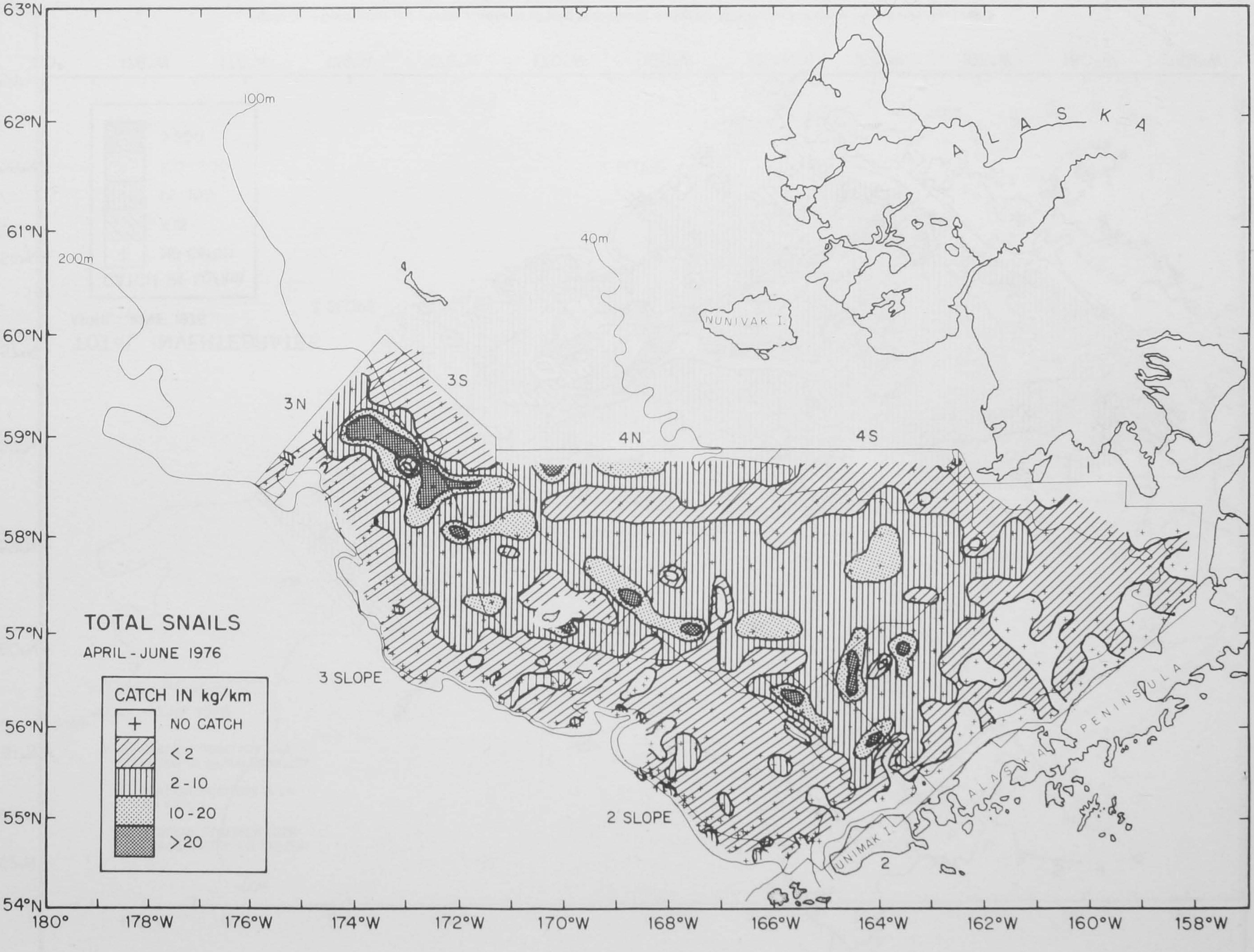

Figure 21.—Distribution and relative abundance of snails during the 1976 Bering Sea spring trawl survey (by weight).

slope subarea included rattails (Macrouridae); Pacific ocean perch; sablefish; bigmouth sculpin, *Hemitripterus bolini*; spinyhead sculpin, *Dasycottus setiger*; and rex sole, *Glyptocephalus zachirus*.

Table 13.—The 20 most common fish taxa recorded during the spring 1976 Bering Sea demersal trawl survey, in order of percentage frequency of occurence.

Rank	Taxon	All areas combined	Subarea[1] 1	2	3	4	Slope
1	Walleye pollock	77.0	49	92	90	73	82
2	Yellowfin sole	71.3	100	53	73	99	2
3	Pacific cod	63.2	41	84	61	64	75
4	Alaska plaice	60.0	80	49	50	100	0
5	Greenland turbot	58.6	18	74	86	32	88
6	Unidentified sculpins	54.5	59	54	62	37	55
7	Rock sole	54.0	49	88	68	19	27
8	Flathead sole	50.6	25	75	68	19	65
9	Sturgeon poacher	44.8	60	39	30	78	8
10	Pacific herring	41.4	39	29	50	73	0
11	Pacific halibut	37.0	23	75	16	9	88
12	Capelin	35.4	54	10	21	85	0
13	Unidentified snailfish	30.8	10	25	55	21	43
14	Arrowtooth flounder	30.1	0	72	15	0	98
15	Unidentified eelpouts	28.5	3	40	55	12	24
16	*Myoxocephalus* spp.	28.0	32	36	15	46	10
17	Unidentified skates	27.8	0	42	38	4	71
18	Longhead dab	27.1	72	4	0	54	0
19	Starry flounder	22.3	55	24	3	23	0
20	Great sculpin	13.3	8	0	13	45	0
	Number of trawls	435	100	89	117	78	51

[1] See Figure 3.

Table 14.—The 20 most abundant fish taxa recorded during the spring 1976 Bering Sea demersal trawl survey, in order of observed abundance, for all subareas combined.[1]

Rank	Taxon	CPUE (kg/km)[2]	Proportion of total CPUE[3]	Cumulative proportion
1	Yellowfin sole	(104.04)	0.363	0.363
2	Walleye pollock	(34.00)	0.119	0.482
3	Unidentified sculpins	12.77	0.045	0.527
4	Alaska plaice	(12.19)	0.043	0.570
5	Rock sole	11.81	0.041	0.611
6	Pacific cod	5.12	0.018	0.629
7	Flathead sole	4.95	0.017	0.646
8	*Myoxocephalus* spp.	3.51	0.012	0.658
9	Greenland turbot	2.56	0.009	0.667
10	Sturgeon poacher	2.33	0.008	0.675
11	Arrowtooth flounder	2.12	0.007	0.682
12	Pacific herring	1.75	0.006	0.688
13	Longhead dab	1.62	0.006	0.694
14	Pacific halibut	1.57	0.005	0.699
15	Unidentified eelpouts	1.31	0.005	0.704
16	Great sculpin	1.27	0.004	0.708
17	Unidentified skates	1.00	0.004	0.712
18	Capelin	0.85	0.003	0.715
19	Unidentified poachers	0.66	0.002	0.717
20	Starry flounder	0.46	0.002	0.719

[1] See Figure 3.

[2] Overall catch per unit effort, kg/km trawled. Total effort = 1,279.8 km. Parentheses indicate estimates of questionable accuracy due to potential sampling problems.

[3] Proportion of total catch per unit effort, all fish and invertebrates combined. Total CPUE = 286.6 kg/km.

Species Associations

Procedures.—Recurrent group analysis (Fager 1957, 1963; Fager and Longhurst 1968) was used as a method for summariz-

Table 15.—The 20 most abundant fish taxa recorded during the spring 1976 Bering Sea demersal trawl survey, in order of observed abundance, subarea 1.[1]

Rank	Taxon	CPUE (kg/km)[2]	Proportion of total CPUE[3]	Cumulative proportion
1	Yellowfin sole	(258.98)	0.627	0.627
2	Unidentified sculpins	21.08	0.051	0.678
3	Alaska plaice	(10.71)	0.026	0.704
4	Rock sole	6.86	0.017	0.721
5	Longhead dab	4.93	0.012	0.733
6	*Myoxocephalus* spp.	4.40	0.011	0.744
7	Sturgeon poacher	3.34	0.008	0.752
8	Walleye pollock	2.77	0.007	0.759
9	Unidentified poachers	2.14	0.005	0.764
10	Pacific herring	2.01	0.005	0.769
11	Capelin	1.65	0.004	0.773
12	Great sculpin	1.51	0.004	0.777
13	Starry flounder	1.20	0.003	0.780
14	*Gymnocanthus* spp.	0.40	0.001	0.781
15	Greenland turbot	0.37	0.001	0.782
16	Flathead sole	0.36	0.001	0.783
17	Pacific halibut	0.28	0.001	0.784
18	Unidentified Osmeridae	0.25	0.001	0.785
19	Pacific cod	0.20	0.001	0.786
20	Unidentified snailfish	0.10	0.001	0.787

[1] See Figure 3.

[2] Overall catch per unit effort, kg/km trawled. Total effort = 271.8 km. Parentheses indicate estimates of questionable accuracy due to potential sampling problems.

[3] Proportion of total catch per unit effort, all fish and invertebrates combined. Total CPUE = 413.21 kg/km.

Table 16.—The 20 most abundant fish taxa recorded during the spring 1976 Bering Sea demersal trawl survey, in order of observed abundance, subarea 2.[1]

Rank	Taxon	CPUE (kg/km)[2]	Proportion of total CPUE[3]	Cumulative proportion
1	Yellowfin sole	(127.04)	0.284	0.284
2	Walleye pollock	(119.24)	0.266	0.550
3	Rock sole	29.67	0.066	0.616
4	Flathead sole	22.34	0.050	0.666
5	Pacific cod	17.21	0.038	0.704
6	Unidentified sculpins	12.02	0.027	0.731
7	Alaska plaice	(10.02)	0.022	0.753
8	*Myoxocephalus* spp.	8.62	0.019	0.772
9	Pacific halibut	5.79	0.013	0.785
10	Arrowtooth flounder	5.29	0.012	0.797
11	Greenland turbot	4.10	0.009	0.806
12	Unidentified eelpouts	2.65	0.006	0.812
13	Sturgeon poacher	2.48	0.006	0.818
14	Unidentified skates	1.54	0.003	0.821
15	Yellow Irish lord	1.25	0.003	0.824
16	Big skate	0.84	0.002	0.826
17	Searcher	0.74	0.002	0.828
18	Starry flounder	0.72	0.002	0.830
19	Shortfin eelpout	0.43	0.001	0.831
20	Saffron cod	0.25	0.001	0.832

[1] See Figure 3.

[2] Overall catch per unit effort, kg/km trawled. Total effort = 283.5 km. Parentheses indicate estimates of questionable accuracy due to potential sampling problems.

[3] Proportion of total catch per unit effort, all fish and invertebrates combined. Total CPUE = 447.94 kg/km.

Table 17.—The 20 most abundant fish taxa recorded during the spring 1976 Bering Sea demersal trawl survey, in order of observed abundance, subarea 3.[1]

Rank	Taxon	CPUE (kg/km)[2]	Proportion of total CPUE[3]	Cumulative proportion
1	Walleye pollock	(36.54)	0.246	0.246
2	Yellowfin sole	21.67	0.146	0.392
3	Unidentified sculpins	5.21	0.035	0.427
4	Greenland turbot	4.82	0.032	0.459
5	Pacific cod	4.59	0.031	0.490
6	Pacific herring	3.60	0.024	0.514
7	Unidentified eelpouts	2.88	0.019	0.533
8	Rock sole	2.67	0.018	0.551
9	Flathead sole	2.18	0.015	0.566
10	Alaska plaice	1.92	0.013	0.579
11	Unidentified skates	1.43	0.010	0.589
12	Polar eelpout	1.43	0.010	0.599
13	Arrowtooth flounder	0.65	0.004	0.603
14	Unidentified snailfish	0.48	0.003	0.606
15	Great sculpin	0.46	0.003	0.609
16	Sturgeon poacher	0.25	0.002	0.611
17	Black skate	0.24	0.002	0.613
18	Canadian eelpout	0.23	0.002	0.615
19	Capelin	0.21	0.001	0.616
20	*Myoxocephalus* spp.	0.21	0.001	0.617

[1] See Figure 3.

[2] Overall catch per unit effort, kg/km trawled. Total effort = 359.4 km. Parentheses indicate estimates of questionable accuracy due to potential sampling problems.

[3] Proportion of total catch per unit effort, all fish and invertebrates combined. Total CPUE = 148.61 kg/km.

Table 18.—The 20 most abundant fish taxa recorded during the spring 1976 Bering Sea demersal trawl survey, in order of observed abundance, subarea 4.[1]

Rank	Taxon	CPUE (kg/km)[2]	Proportion of total CPUE[3]	Cumulative proportion
1	Yellowfin sole	40.86	0.203	0.203
2	Alaska plaice	(23.80)	0.118	0.321
3	Unidentified sculpins	13.43	0.067	0.388
4	Rock sole	13.03	0.065	0.453
5	Sturgeon poacher	3.27	0.016	0.469
6	Great sculpin	2.60	0.013	0.482
7	*Myoxocephalus* spp.	2.59	0.013	0.495
8	Longhead dab	1.37	0.007	0.502
9	Pacific herring	1.28	0.006	0.508
10	Walleye pollock	1.17	0.006	0.514
11	Capelin	1.16	0.006	0.520
12	Unidentified eelpouts	0.37	0.002	0.522
13	Unidentified poachers	0.35	0.002	0.524
14	Greenland turbot	0.22	0.001	0.525
15	Unidentified snailfish	0.19	0.001	0.526
16	*Gymnocanthus* spp.	0.15	0.001	0.527
17	Starry flounder	0.10	0.001	0.528
18	Pacific cod	0.09	0.001	0.529
19	Pacific halibut	0.09	0.001	0.530
20	Flathead sole	0.08	0.001	0.531

[1] See Figure 3.

[2] Overall catch per unit effort, kg/km trawled. Total effort = 222.2 km. Parentheses indicate estimates of questionable accuracy due to potential sampling problems.

[3] Proportion of total catch per unit effort, all fish and invertebrates combined. Total CPUE = 200.93 kg/km.

Table 19.—The 20 most abundant fish taxa recorded during the spring 1976 Bering Sea demersal trawl survey, in order of observed abundance, slope subarea.[1]

Rank	Taxon	CPUE (kg/km)[2]	Proportion of total CPUE[3]	Cumulative proportion
1	Walleye pollock	(74.34)	0.333	0.333
2	Arrowtooth flounder	32.09	0.144	0.477
3	Pacific cod	25.09	0.112	0.589
4	Greenland turbot	16.55	0.074	0.663
5	Unidentified skates	12.23	0.055	0.718
6	Pacific halibut	11.74	0.053	0.771
7	Flathead sole	6.06	0.027	0.798
8	Unidentified rattails	3.69	0.017	0.815
9	Unidentified sculpins	2.93	0.013	0.828
10	Pacific ocean perch	2.05	0.009	0.837
11	Rock sole	1.25	0.006	0.843
12	Big skate	1.02	0.005	0.848
13	Unidentified eelpouts	0.85	0.004	0.852
14	Searcher	0.72	0.003	0.855
15	Unidentified snailfish	0.72	0.003	0.858
16	Sablefish	0.65	0.003	0.861
17	Bigmouth sculpin	0.36	0.002	0.863
18	Canadian eelpout	0.29	0.001	0.865
19	Spinyhead sculpin	0.25	0.001	0.865
20	Rex sole	0.25	0.001	0.866

[1] See Figure 3.

[2] Overall catch per unit effort, kg/km trawled. Total effort = 142.9 km. Parentheses indicate estimates of questionable accuracy due to potential sampling problems.

[3] Proportion of total catch per unit effort, all fish and invertebrates combined. Total CPUE = 223.53 kg/km.

ing general patterns of species associations during the 1976 spring trawl survey. The procedure identifies species relationships on the basis of cooccurrence within samples and a dichotomy of grouping rules. The geometric mean of the proportion of joint occurrences, corrected for sample size, is used as an index of affinity:

$$\frac{c}{\sqrt{ab}} - \frac{1}{2\sqrt{b}}, \tag{25}$$

where c is the number of joint occurrences, a is the number of occurrences of species A, and b is the number of occurrences of species $B (b \geq a)$. If the affinity indices of species pairs are greater than or equal to a specific breakpoint value (usually 0.50), then the species are considered to show affinity. Grouping is based on rules that include: All species within a group must show affinity with all other group members, the largest possible groups are formed, and no species may occur in more than one group.

After recurrent groups were defined, intergroup relationships were determined as the ratio of the number of observed species-pair affinities between groups to the maximum number of possible connections. The occurrences of groups among stations were also listed and plotted.

Catch data from the 435 grid station trawls of the 1976 survey were examined. Although a total of 264 fish and invertebrate taxa was recorded at these stations, the analysis was restricted to 63 taxa considered to have been consistently and reliably identified by all field parties during all legs of the investigations (Table 20). These taxa included 45 fish taxa (18 families) representing the most abundant members of the demersal fish community, and 18 abundant invertebrate taxa.

Results.—The recurrent grouping procedure organized 25 taxa, with one or more affinity values > 0.50, into five groups. Other taxa included in the analysis did not occur frequently enough to show affinity at the assigned level. Group composition and intergroup relationships are shown in Figure 22.

The 25 taxa with significant relationships accounted for 78.9% (by weight) of the total catch of fish and invertebrates taken dur-

Table 20.—List of taxa included in the analysis of species associations, 1976 Bering Sea spring trawl survey.[1]

Taxon	Common name
Raja spp.	Unidentified skates
Clupea harengus pallasi	Pacific herring
Mallotus villosus	Capelin
Osmerus mordax	Rainbow smelt
Thaleichthys pacificus	Eulachon
Boreogadus saida	Arctic cod
Eleginus gracilis	Saffron cod
Gadus macrocephalus	Pacific cod
Theragra chalcogramma	Walleye pollock
Lycodes palearis	Wattled eelpout
Coryphaenoides spp.	Unidentified rattails
Trichodon trichodon	Pacific sandfish
Bathymaster signatus	Searcher
Lumpenus sagitta	Snake prickleback
Anarrhichthys ocellatus	Wolf-eel
Anarhichas orientalis	Bering wolffish
Ammodytes hexapterus	Pacific sand lance
Sebastes aleutianus	Rougheye rockfish
S. alutus	Pacific ocean perch
Sebastolobus alascanus	Shortspine thornyhead
Anoplopoma fimbria	Sablefish
Hexagrammos stelleri	Whitespotted greenling
Dasycottus setiger	Spinyhead sculpin
Hemilepidotus hemilepidotus	Red Irish lord
H. jordani	Yellow Irish lord
Icelus spiniger	Thorny sculpin
Melletes papilio	Butterfly sculpin
Myoxocephalus polyacanthocephalus	Great sculpin
Triglops pingeli	Ribbed sculpin
Hemitripterus bolini	Bigmouth sculpin
Agonus acipenserinus	Sturgeon poacher
Careproctus rastrinus	Pink snailfish
Eumicrotremus orbis	Pacific spiny lumpsucker
Atheresthes stomias	Arrowtooth flounder
Glyptocephalus zachirus	Rex sole
Hippoglossoides elassodon	Flathead sole
H. robustus	Bering flounder
Hippoglossus stenolepis	Pacific halibut
Lepidopsetta bilineata	Rock sole
Limanda aspera	Yellowfin sole
L. proboscidea	Longhead dab
Microstomus pacificus	Dover sole
Platichthys stellatus	Starry flounder
Pleuronectes quadrituberculatus	Alaska plaice
Reinhardtius hippoglossoides	Greenland turbot
Octopus spp.	Unidentified octopus
Crangon communis	
C. dalli	
Pandalopsis dispar	Sidestripe shrimp
Pandalus borealis	Pink shrimp
P. goniurus	Humpy shrimp
P. montagui tridens	
Chionoecetes angulatus	Snow (Tanner) crab (angulatus)
C. bairdi	Snow crab (bairdi)
C. opilio	Snow crab (opilio)
Chionoecetes sp.	Snow crab (hybrid)
Hyas coarctatus alutaceus	
Hyas lyratus	Elbow crab
Oregonia gracilis	Decorator crab
Erimacrus isenbeckii	Korean horsehair crab
Lithodes aequispina	Golden king crab
Paralithodes camtschatica	Red king crab
P. platypus	Blue king crab

[1] See Figure 22.

ing the 1976 survey. The distribution patterns of group occurrences were regional with limited geographical overlap and were similar to results from the 1975 Bering Sea survey (Pereyra et al. see footnote 2). The associations and distributions defined by the groups follow.

Group 1 (outer shelf group): The 10 species of group 1 (Fig. 22) individually showed broad distribution patterns, ranging from north to south limits of the survey area and from inner Bristol Bay to the outer continental slope. In contrast to the extended ranges of the individual species, the occurrences of group 1 members together were restricted to 92 stations (depths 100-185 m) along the outer continental shelf (Fig. 23).

Group 2 (central shelf group): Group 2 consisted of five fish species, plus one associated crab species, that were broadly distributed over the central Bering Sea continental shelf. The two most abundant species, yellowfin sole and Alaska plaice, were apparently migrating from deep to shallow water during the survey. Group 2 members occurred together at 62 stations in a large midshelf region between bottom depths of approximately 30-80 m (Fig. 24).

Group 3 (northern outer shelf group): The three fish species of group 3 occurred as an isolated northern group, showing no affinities to members from any other recurrent group. Group 3 members occurred together at 13 stations (depths 84-110 m) between lat. 58°45′ and 60°00′N, directly south of St. Matthew Island (Fig. 25).

Group 4 (southern deepwater group): Group 4 was composed of three flatfish species that occurred together at 50 stations in deep water (depths 115-450 m) along the outer continental shelf and slope (Fig. 26).

Group 5 (Alaska Peninsula group): The two flatfish and one crab species of group 5 occurred together at 49 stations primarily in a broad area along the Alaska Peninsula between bottom depths of approximately 18-65 m (Fig. 27).

Similarities between the recurrent species groupings observed during the 1976 spring trawl survey, and those of Pereyra et al. (see footnote 2), support the hypothesis that the Bering Sea demersal fish and shellfish community can be characterized by a few major, large-scale organizational features. A relatively small number of principal species accounts for most of the trawlable biomass. These species apparently show recurrent, although seasonally influenced, patterns of association within relatively well defined geographical regions of the Bering Sea continental shelf and slope.

Distribution, Abundance, and Biological Characteristics of Principal Fish Populations

Walleye pollock.

Distribution and abundance.—Walleye pollock were widely distributed throughout the survey area, occurring at 335 (77.0%) of the 435 grid trawling stations, at an overall mean abundance of 34.00 kg/km trawled. Regions of highest abundance by weight were along the outer continental shelf (subareas 2, 3N, and 3S) west and southeast of the Pribilof Islands (Table 21, Fig. 28). Large numbers of juvenile walleye pollock (age 1 yr) were observed in regions of the inner continental shelf (subareas 1, 4S, and 4N), although their estimated total biomass was relatively low.

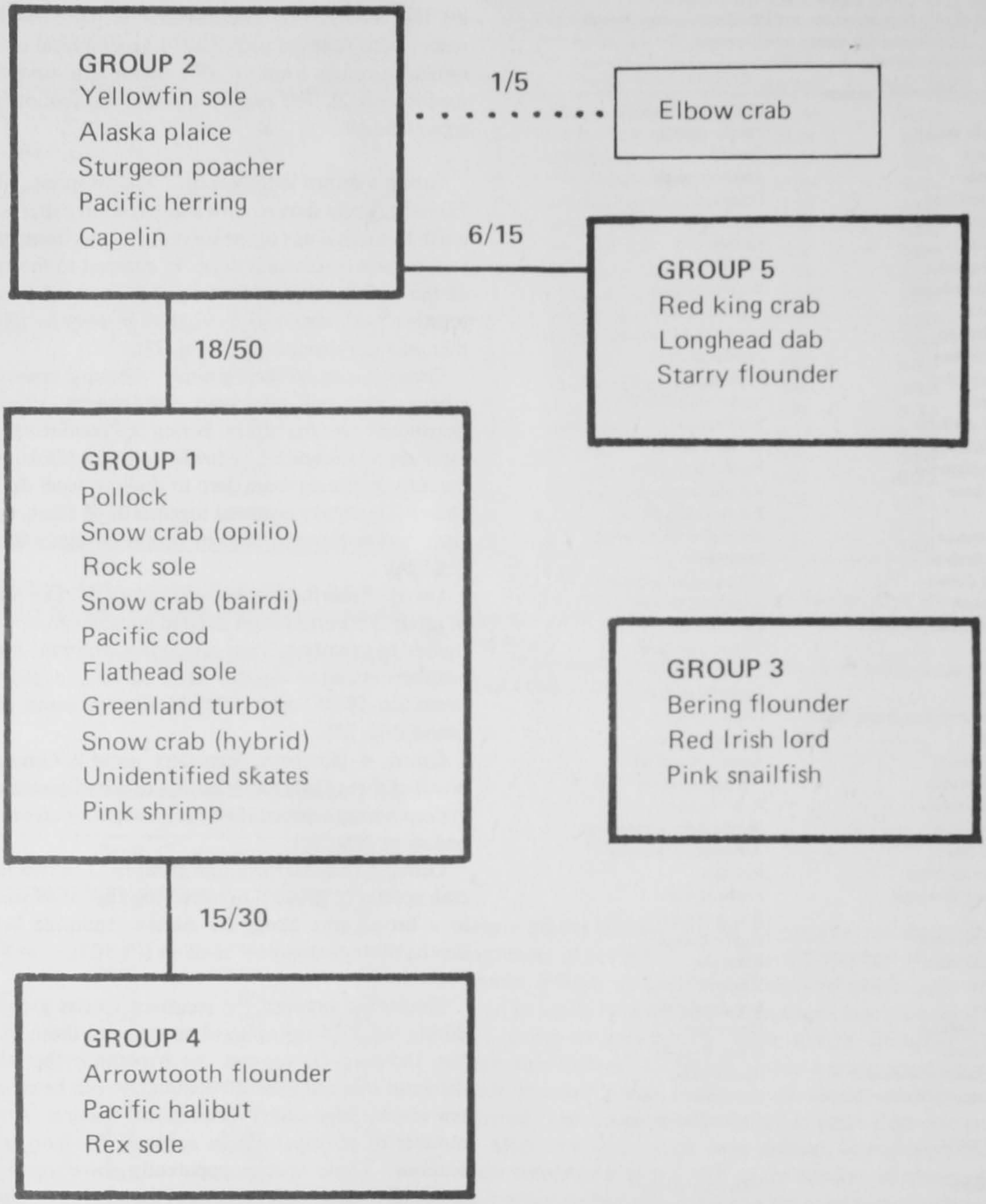

Figure 22.—Recurrent species groups observed in the Bering Sea during the 1976 spring trawl survey and their relationships. Species are listed in order of relative abundance within each group. Fractions indicate the ratio of the number of observed species-pair affinities between groups to the maximum number of possible connections (maximum possible connections for any two groups = product of number of species within both groups). Dotted lines indicate associated taxa showing affinity with some group members, but not all.

The total apparent population biomass of walleye pollock within the study area was 0.679 million t (95% confidence limits 0.480-0.879 million t), which appeared to be a relatively low estimate. During 1970-75, commercial catches of walleye pollock from the study area by Japan alone ranged from 0.6 to 1.2 million t/yr. The total Japanese walleye pollock catch during the period November 1975 to October 1976 was 0.8 million t. Another comparison indicating that the 1976 survey estimate for walleye pollock biomass was low was the 1975 survey estimate of 2.43 million t (95% confidence limits 2.00-2.85 million t) from the same region (Pereyra et al. see footnote 2).

Possible causes of the low estimate of walleye pollock biomass for 1976 include 1) decreased catchability—the availability of walleye pollock to demersal survey trawling may have been low because some of the population was off bottom for spring spawning (Serobaba 1974); 2) emigration—seasonal and environmentally related shifts in geographical distribution may have decreased the proportion of the eastern Bering Sea population of walleye pollock within the survey area, as a result of cold temperatures and heavy ice cover over the continental shelf during spring 1976; and 3) true decline—an actual decrease in population biomass may have occurred between 1975 and 1976 as a result of natural and fishing mortalities.

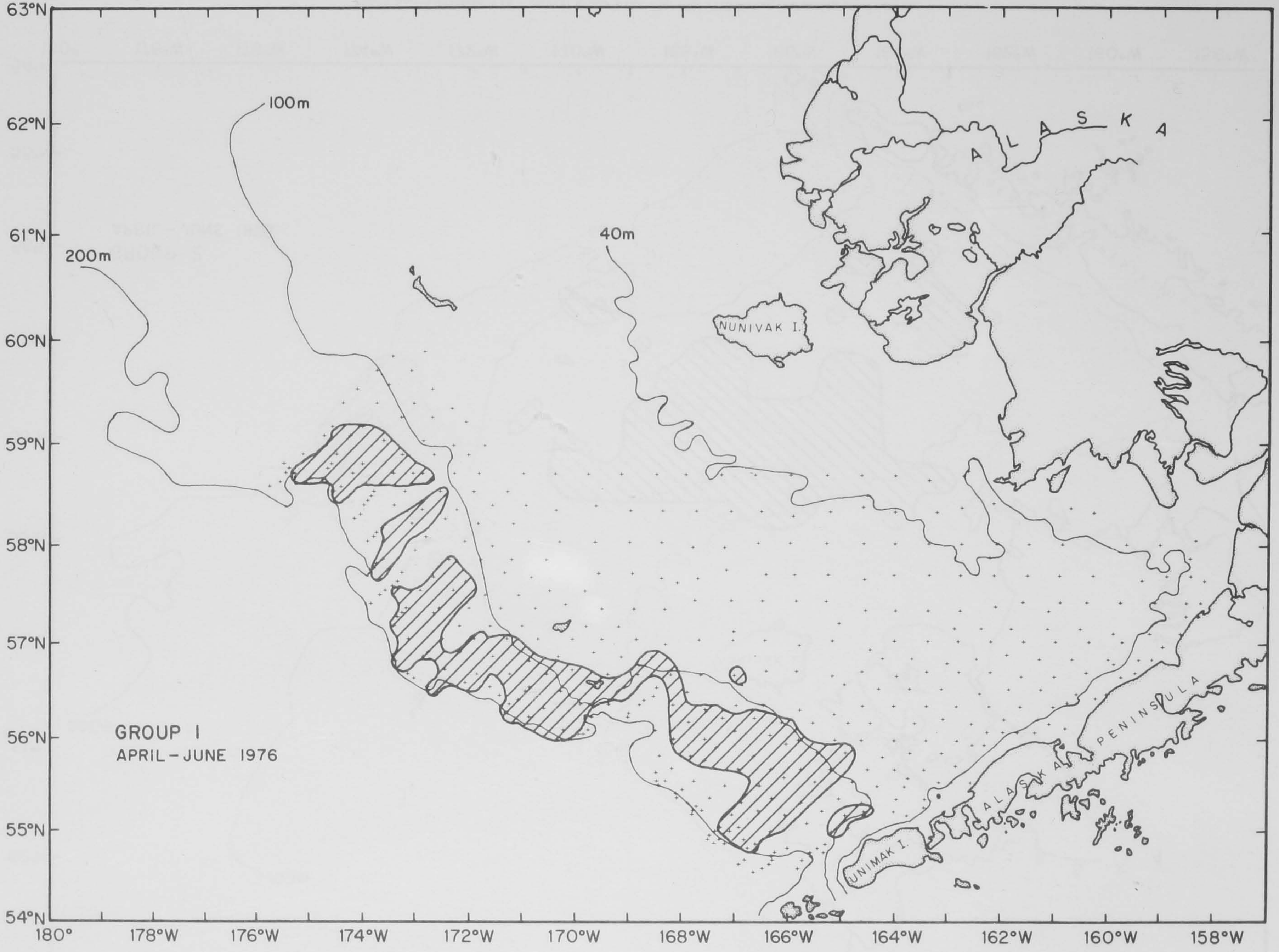

Figure 23.—Occurrences of recurrent group 1 (see Fig. 22), 1976 Bering Sea spring trawl survey.

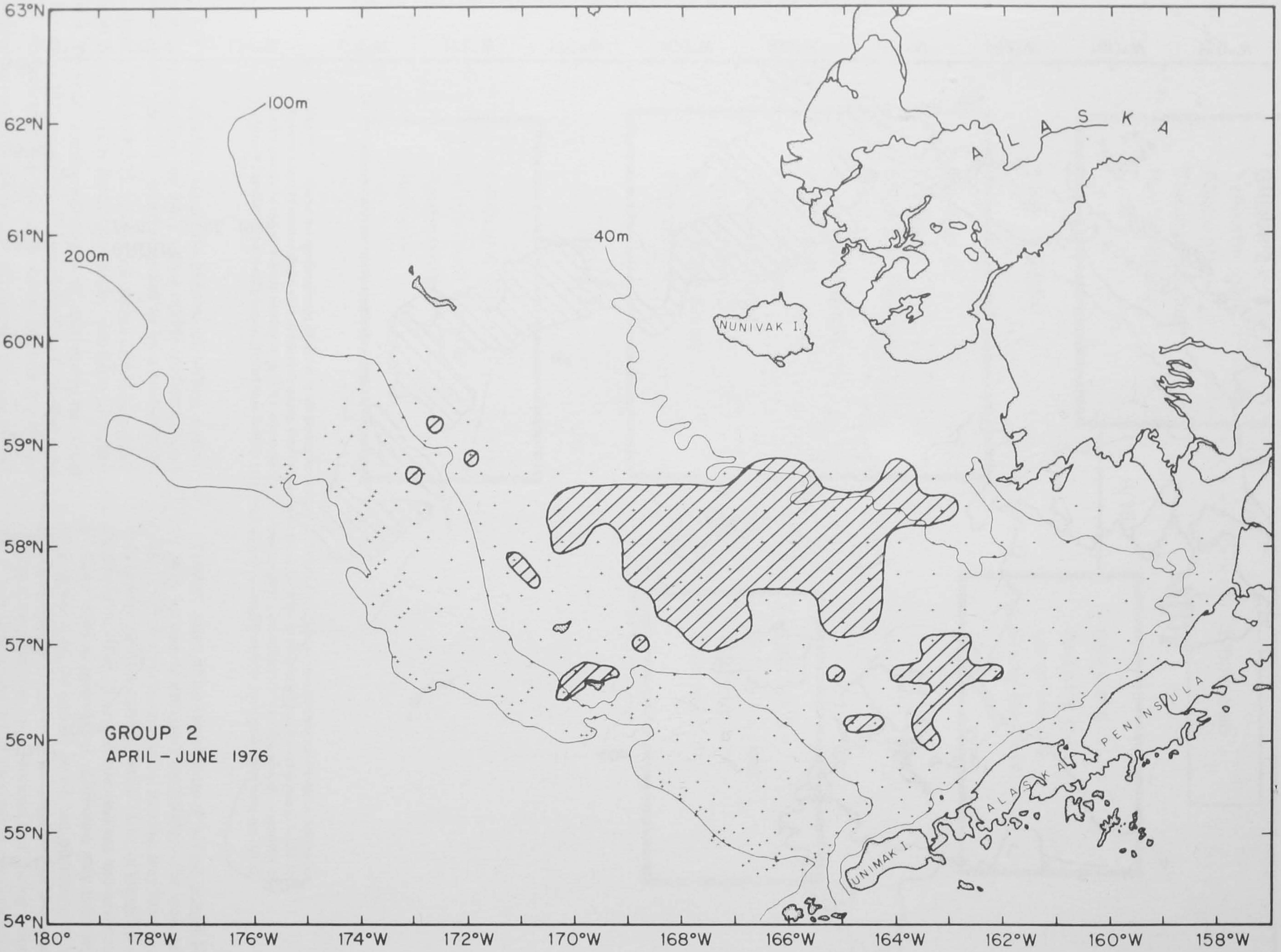

Figure 24.—Occurrences of recurrent group 2 (see Fig. 22). 1976 Bering Sea spring trawl survey.

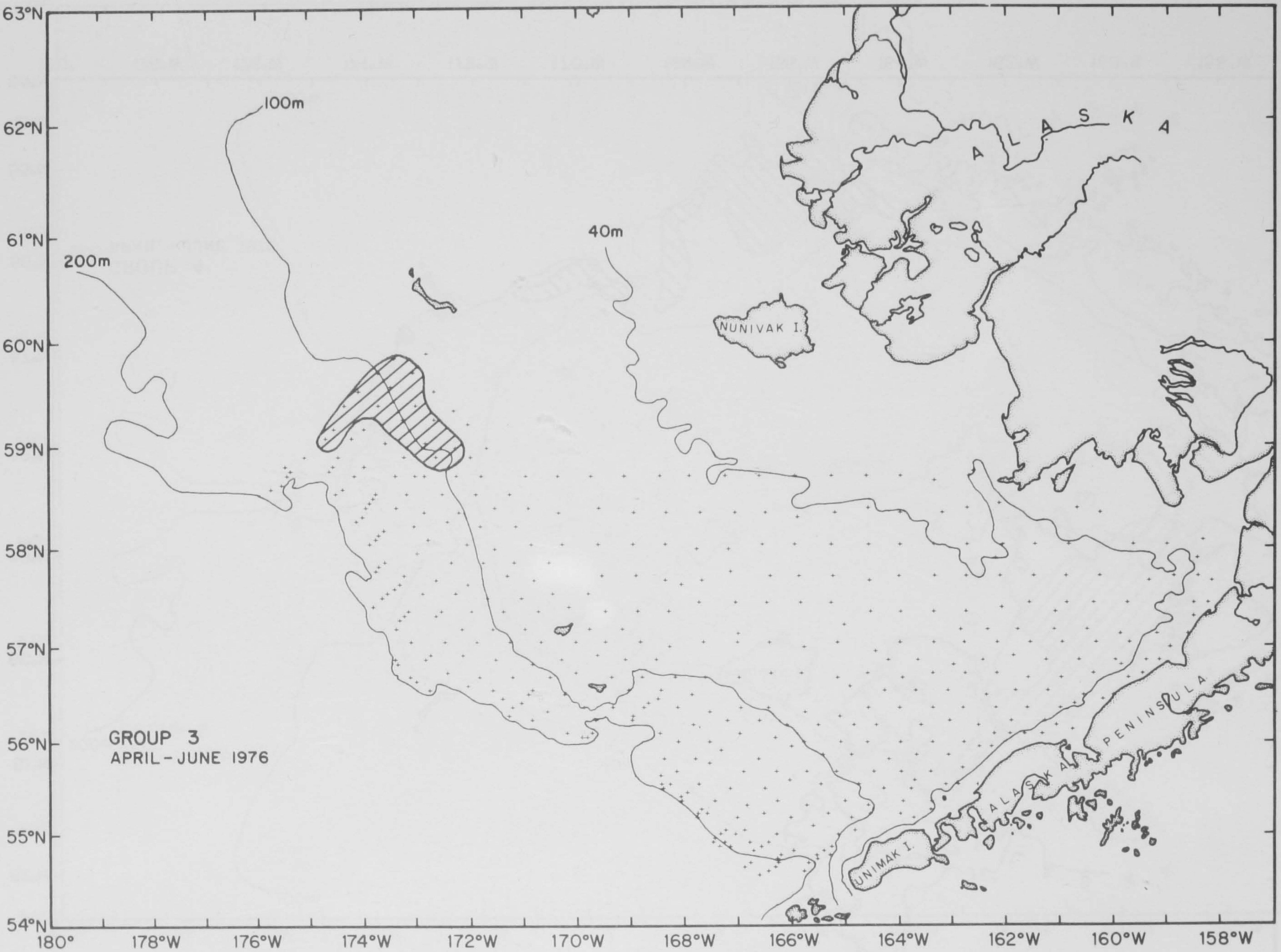

Figure 25.—Occurrences of recurrent group 3 (see Fig. 22), 1976 Bering Sea spring trawl survey.

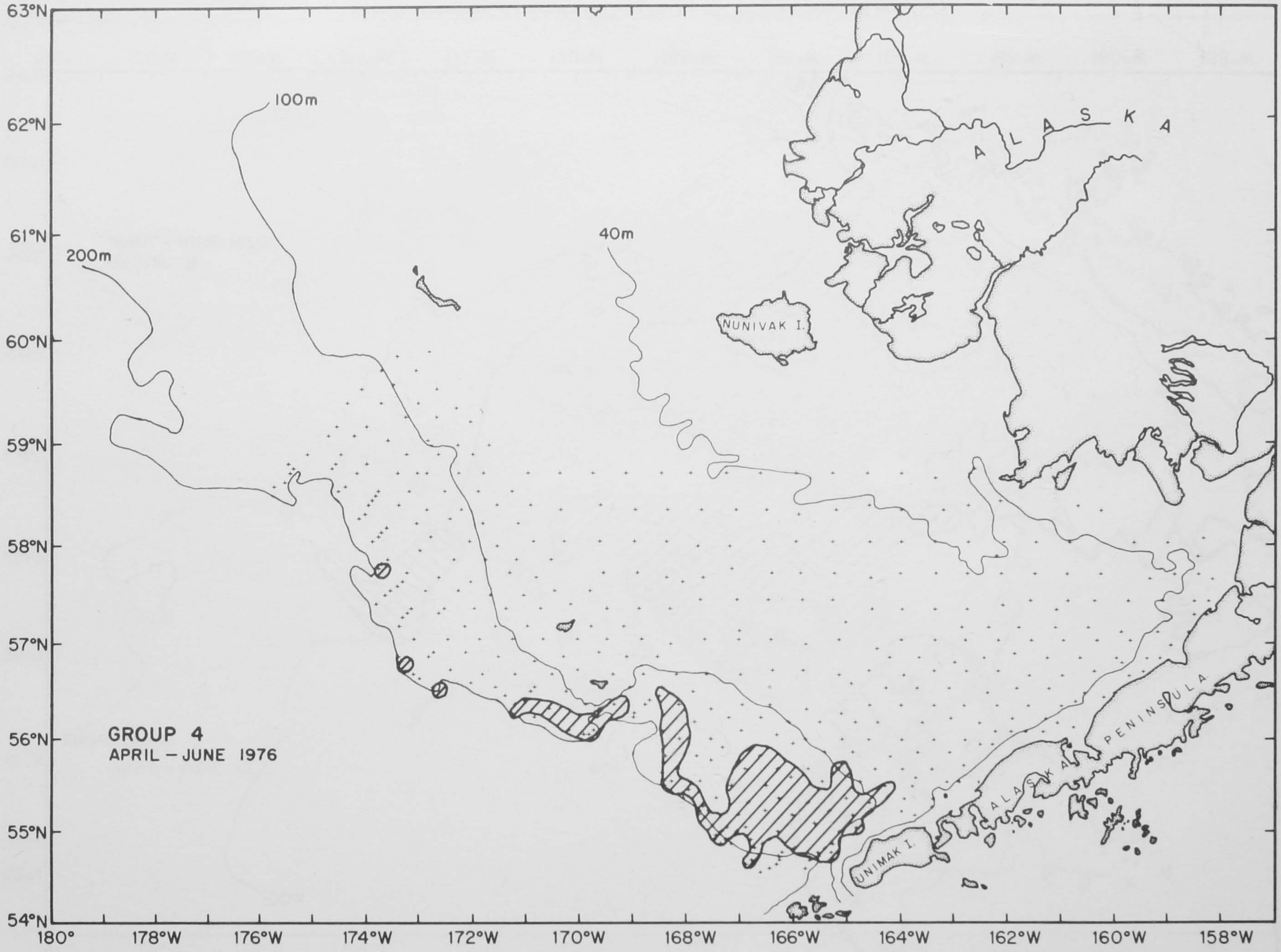

Figure 26.—Occurrences of recurrent group 4 (see Fig. 22), 1976 Bering Sea spring trawl survey.

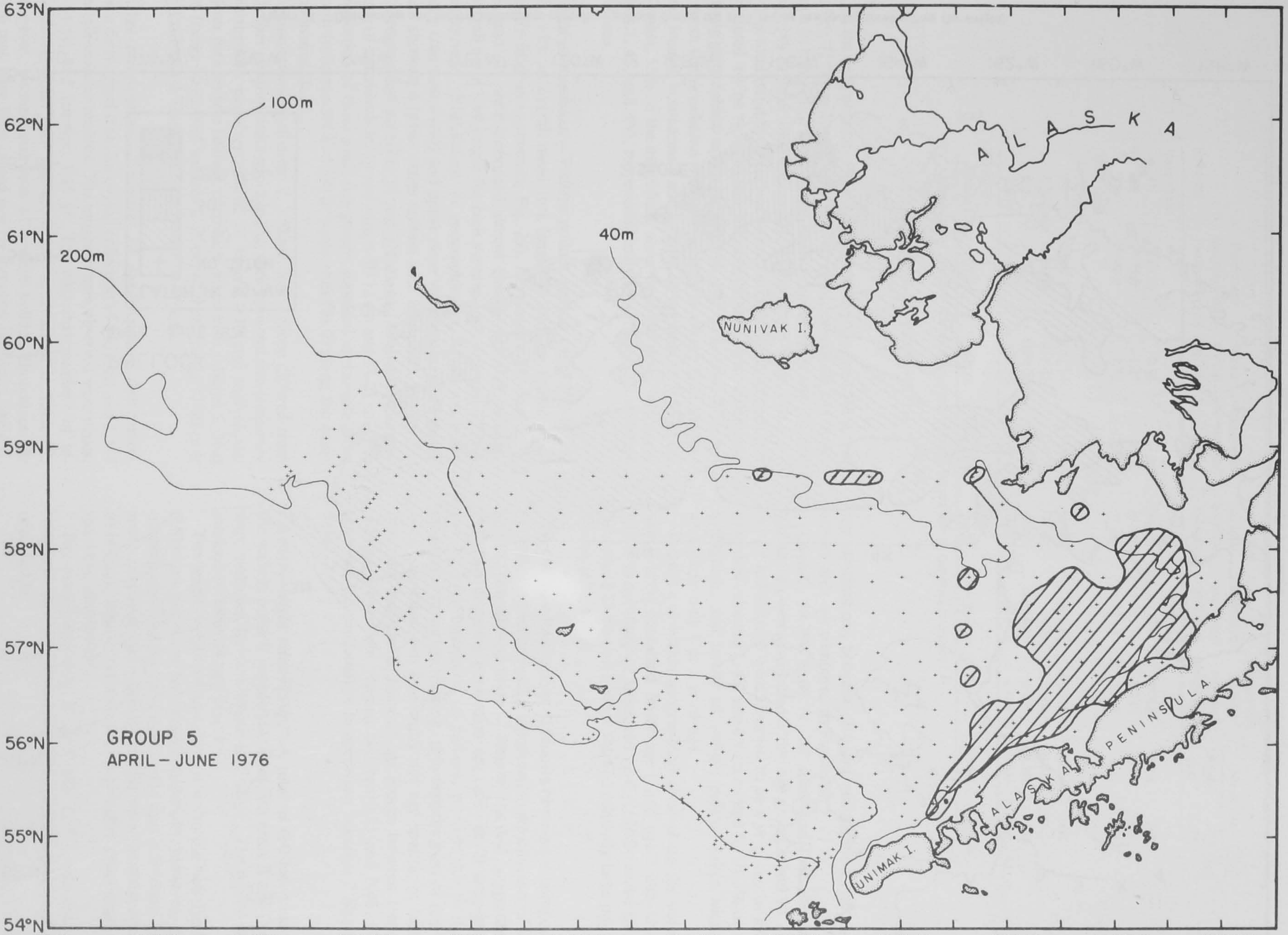

Figure 27.—Occurrences of recurrent group 5 (see Fig. 22), 1976 Bering Sea spring trawl survey.

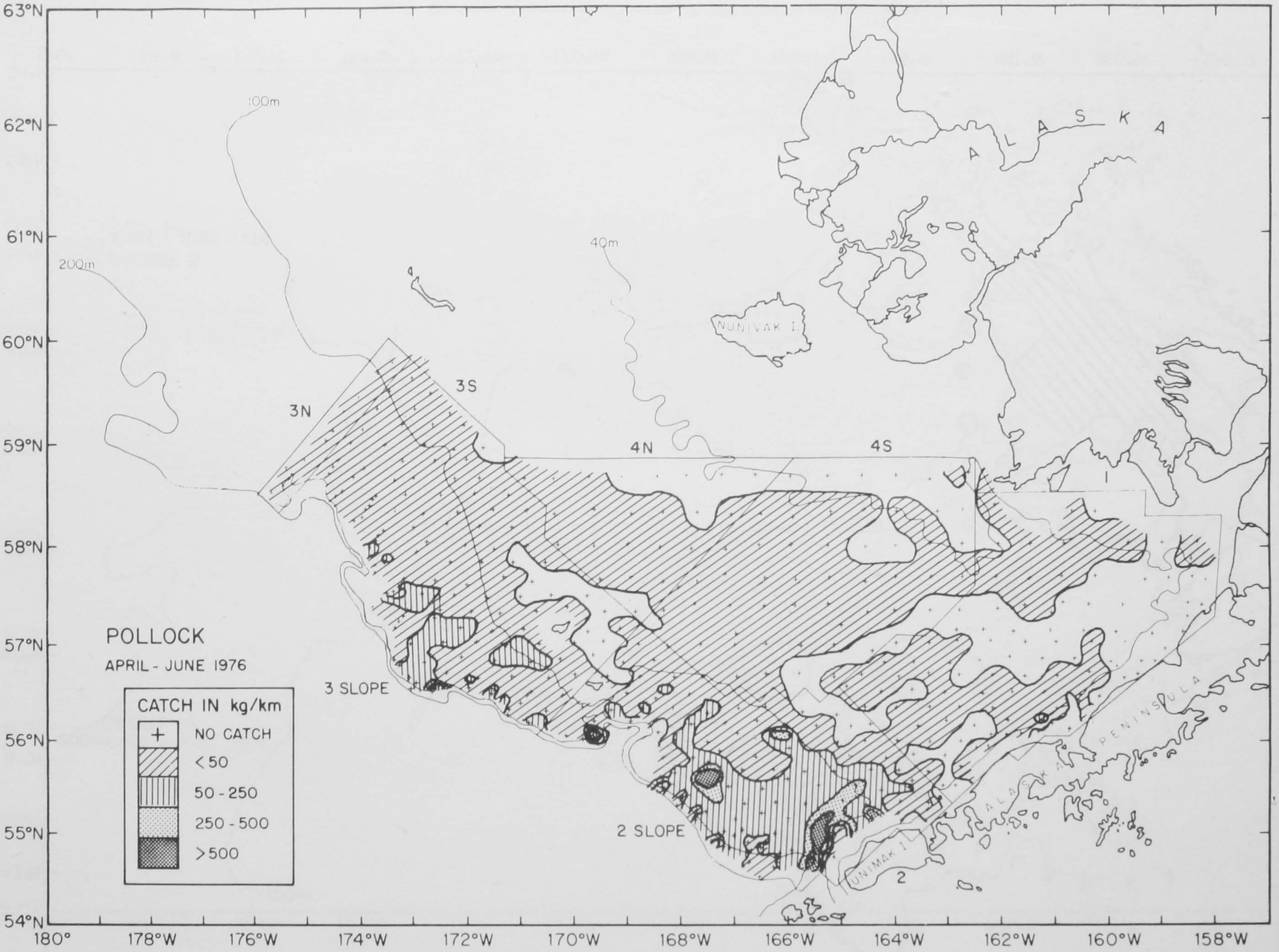

Figure 28.—Distribution and relative abundance of walleye pollock during the 1976 Bering Sea spring trawl survey (by weight).

Table 21.—Estimated biomass and population numbers of walleye pollock by subarea and for all subareas combined, 1976 Bering Sea spring trawl survey.[1]

Subarea[2]	Percentage frequency of occurrence	Mean CPUE (kg/km)	Estimated biomass (t)	Proportion of total estimated biomass	Estimated population (millions)	Proportion of total estimated population	Mean size Weight (kg)	Mean size FL (cm)
Inner shelf								
4N	68.2	0.92	1,706	0.003	298.1	0.066	0.096	9.9
4S	75.0	1.27	5,502	0.008	1,052.1	0.234	0.005	9.9
1	49.0	2.77	13,595	0.020	1,123.4	0.249	0.012	11.7
Outer shelf and slope								
3	89.7	(36.54)	(171,750)	0.253	(801.1)	0.178	0.214	26.6
3 Slope	90.9	(15.41)	(2,986)	0.004	(4.4)	0.001	0.672	45.1
2	92.1	(119.24)	(445,281)	0.655	(1,164.7)	0.259	0.382	36.0
2 Slope	80.0	(90.54)	(38,673)	0.057	(61.1)	0.014	0.633	42.9
All subareas combined	77.0	(34.00)	(679,492)[3]		(4,504.9)		0.151	20.5

[1] Parentheses indicate estimates that may be badly biased due to sampling problems.

[2] See Figure 3.

[3] 95% confidence limits: 480,060-878,925 t.

Of the total population biomass estimated from the 1976 spring survey, 71% was located on the outer continental shelf and upper slope in subareas 2 and 2 Slope, 26% in subarea 3N and 3S, and only 3% in inner shelf subareas 1, 4N, and 4S (Table 21).

The total number of walleye pollock within the study area was estimated to be 4.50 billion individuals that were distributed among geographical subdivisions of the study area quite differently from the population biomass. Only 27% of the total number were located in subareas 2 and 2 Slope, as opposed to 71% of the biomass; 55% of the individuals occurred in the inner shelf (subareas 1, 4S, and 4N), representing only 3% of the total apparent biomass.

Size composition.—Walleye pollock ranged from 7 to 90 cm FL, with an overall mean fork length of 20.5 cm (based upon 38,231 field measurements; Fig. 29). Populations in subareas 1, 4S, and 4N were composed almost entirely of small juveniles (overall mean fork length for each subarea 11.7, 9.9, and 9.9 cm, respectively). Populations in geographical subareas along the outer continental shelf and upper slope were composed of mixed sizes showing a broad range around each mean fork length.

Geographical subareas 3S and 3N showed substantial proportions of individuals in the size ranges 10-12 cm and 17-21 cm. The proportion of these small size groups appeared to decrease from north (subareas 3N and 3S) to south (subarea 2) along the outer continental shelf.

Populations in subareas 2, 2 Slope, and 3 Slope differed from all other geographical regions in that their apparent size-frequency distributions mainly consisted of large (>30 cm) individuals. Mean fork lengths in these deepwater areas were subarea 2, 36.0 cm (range 10-82 cm); subarea 2 Slope, 42.9 cm (range 17-90 cm); and subarea 3 Slope, 45.1 cm (range 34-66 cm).

Age composition.—Estimates of age-frequency distribution were determined from an overall collection of 846 male and 1,144 female saccular otoliths. The ranges in ages observed were males, 1-14 yr, and females, 1-15 yr. The estimated numbers of individuals within each age group are summarized in Table 22. However, because estimates of walleye pollock abundance for 1976 may have been biased low by sampling problems, the estimated numbers at each age (particularly in deepwater subareas 2, 2 Slope, 3N, 3S, and 3 Slope) are of uncertain accuracy. Relative age distributions between different geographical regions of the survey area are compared in Figure 30.

Overall, 59.7% (2.69×10^9 individuals) of the estimated population were distributed within age group 1, and 90. 1% (4.06×10^9 individuals) were observed to be 4 yr of age or less. Geographical subareas 1, 4S, and 4N accounted for 91.3% of all age-1 individuals, and nearly all walleye pollock taken within those areas were only 1 or 2 yr of age.

Populations within geographical areas along the outer continental shelf contained fewer age-1 and age-2 individuals and higher proportions of large, old (≥ 4 yr) individuals. Deepwater subareas 2 Slope and 3 Slope showed relatively large proportions of age groups 7-10.

Sex ratio.—Proportions of females observed in components of the estimated walleye pollock population are summarized in Table 23. The overall proportion of females was 0.43, suggesting either 1) a true disparate population sex ratio, or 2) sampling biases causing underestimation of females, perhaps due to decreased availability to survey trawling. If underestimation of females did occur, its cause was apparently not age specific or isolated to spawning individuals, since all age groups between 1 and 10 yr showed proportions ranging between 0.33 and 0.46. Females, however, did predominate in deepwater subareas 2 Slope and 3 Slope.

Length-weight relationship.—A total of 690 individuals from the walleye pollock populations in otolith areas B and D (Fig. 4) were measured for fork length and weight. The results are summarized in Table 24 and Figure 31.

The length-weight relationships of males did not significantly differ between north and south populations. However, the relationship observed for females indicated that individuals from the southern population (otolith area B) were significantly heavier (6-14%) at length, perhaps due to a higher proportion of ripe spawning individuals.

The overall equation, $\widehat{W} = 0.0034\ L^{3.1775}$, was used for all computations of population numbers requiring a length-weight relationship.

Age-length relationship and growth.—Age-length keys were calculated from age data of 1,990 fish, and the mean fork length

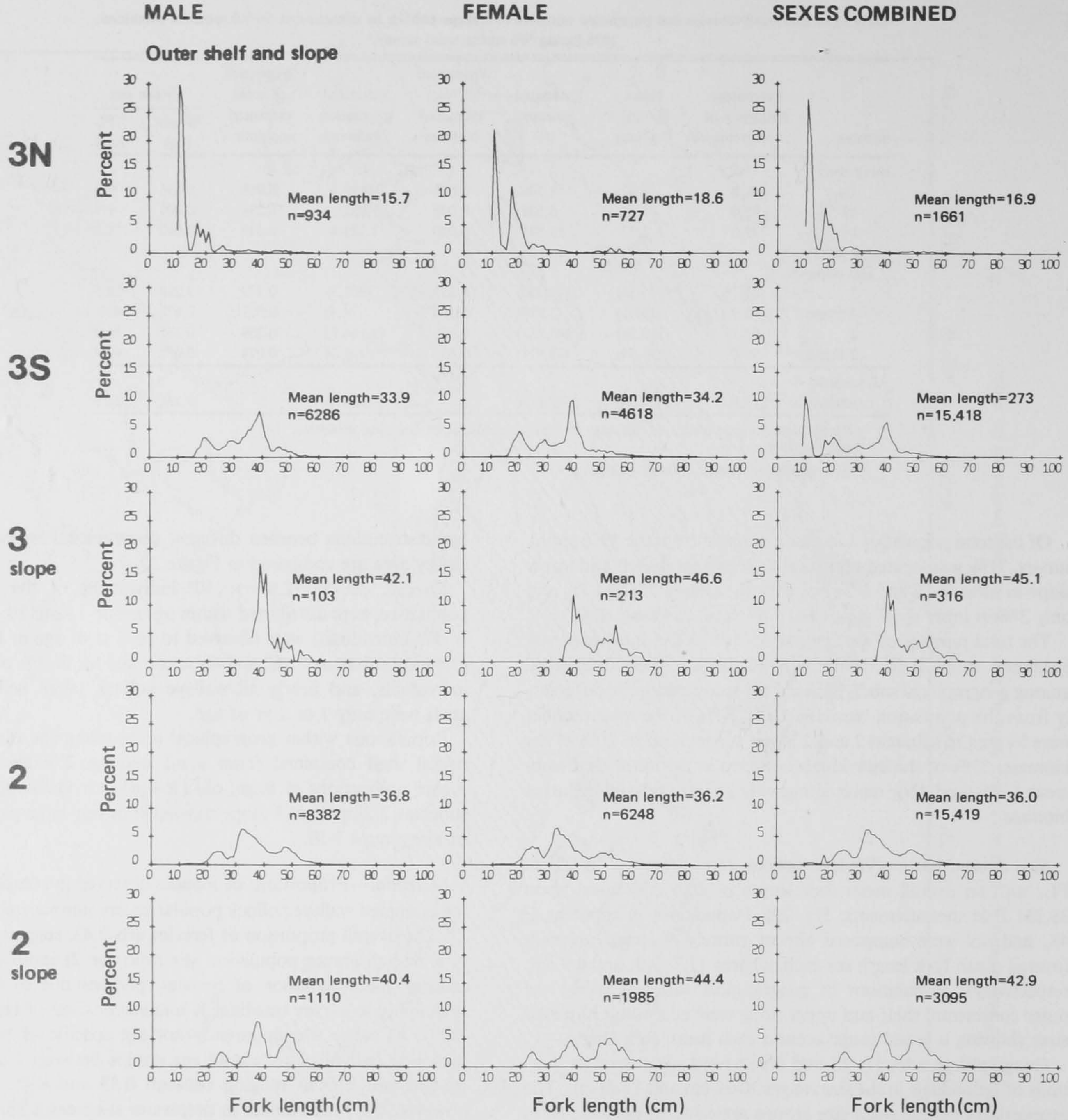

Figure 29.—Size composition of walleye pollock taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

of age groups within the different sets of data was determined. Because only a limited number of age determinations was obtained from otolith area A, observations from otolith areas A and B were combined for analysis.

Results of the growth curve fittings are summarized in Table 25. Overall, females showed a slightly higher growth completion rate (see Equation (24)) than males and approximately 8% larger asymptotic length (Fig. 32).

Comparisons of growth characteristics between geographical regions are shown in Figure 33. For walleye pollock, comparisons between otolith areas A and B (combined) and otolith area D correspond to comparisons between populations northwest and southeast of the Pribilof Islands. Both males and females had higher growth completion rates and larger asymptotic lengths in the southeastern geographical region.

Reproductive condition.—Previous studies of the reproductive biology of eastern Bering Sea walleye pollock have reported spawning to occur seasonally (March to mid-July), with peak gonad development and spawning behavior occurring in May (Serobaba 1968, 1971, 1974). Because the spring 1976 survey provided good coverage of this seasonal time period, one of the survey objectives was to assess the reproductive condition of the walleye pollock population within the study area.

A total of 2,379 males and 3,585 females were examined for gonad condition during the 1976 spring survey. The frequency

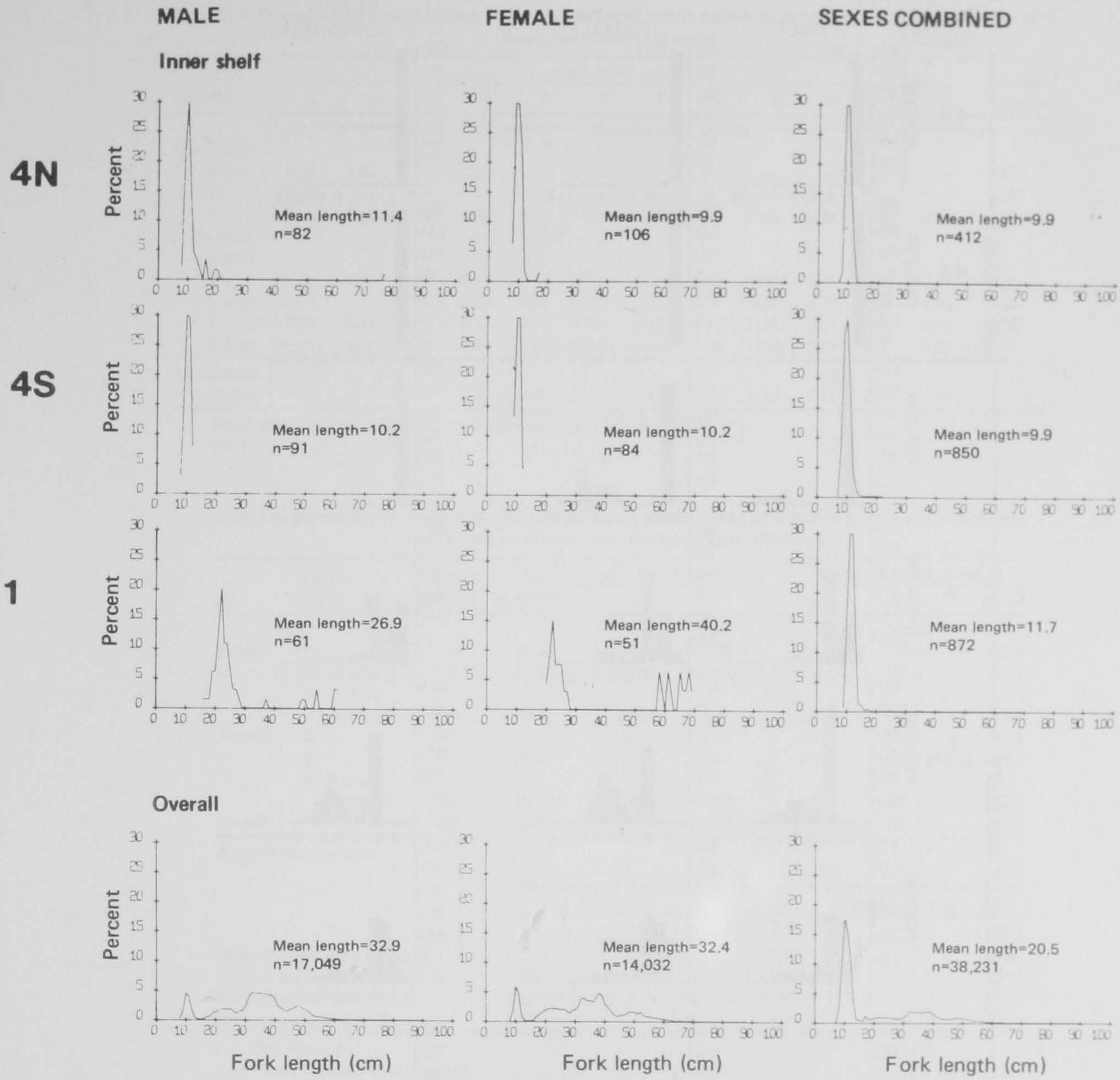

Figure 29.—*Continued.*

Table 22.—Estimated population size of walleye pollock age groups and year classes within survey subareas, 1976 Bering Sea spring trawl survey.[1]

	1	2	3	4	5	6	7	8	9	10	11	≥12	Ages unknown	All ages combined
Subarea[2]	1975	1974	1973	1972	1971	1970	1969	1968	1967	1966	1965	—		
	millions of fish													
Inner shelf														
4N	296.91	1.13	—	—	—	—	—	—	—	—	—	—	0.05	298.09
4S	1,049.61	2.47	0.02	—	—	—	—	—	—	—	—	—	—	1,052.10
1	1,109.19	9.09	1.84	1.41	0.02	0.02	0.12	0.26	0.40	0.27	0.40	0.15	0.22	1,123.39
Outer shelf and slope														
3	(218.05)	(153.68)	(81.52)	(240.27)	(29.84)	(8.51)	(13.64)	(19.50)	(20.70)	(12.06)	(2.25)	(0.74)	(0.33)	(801.09)
3 Slope	—	—	(0.04)	(1.76)	(0.46)	(0.16)	(0.27)	(0.53)	(0.67)	(0.40)	(0.10)	(0.05)	—	(4.44)
2	(14.94)	(208.45)	(306.59)	(328.74)	(77.12)	(34.79)	(48.13)	(55.66)	(41.90)	(27.33)	(15.95)	(4.68)	(0.38)	(1,164.66)
2 Slope	—	(6.58)	(5.40)	(17.37)	(4.73)	(2.58)	(5.20)	(6.51)	(5.29)	(3.88)	(2.63)	(0.81)	(0.15)	(61.13)
All subareas combined	(2,688.70)	(381.40)	(395.41)	(589.55)	(112.17)	(46.06)	(67.36)	(82.46)	(68.96)	(43.94)	(21.33)	(6.43)	(1.13)	(4,504.90)
Proportion of total	0.597	0.085	0.088	0.131	0.025	0.010	0.015	0.018	0.015	0.010	0.005	0.001	0.001	

[1] Parentheses indicate estimates that may be badly biased due to sampling problems.

[2] See Figure 3.

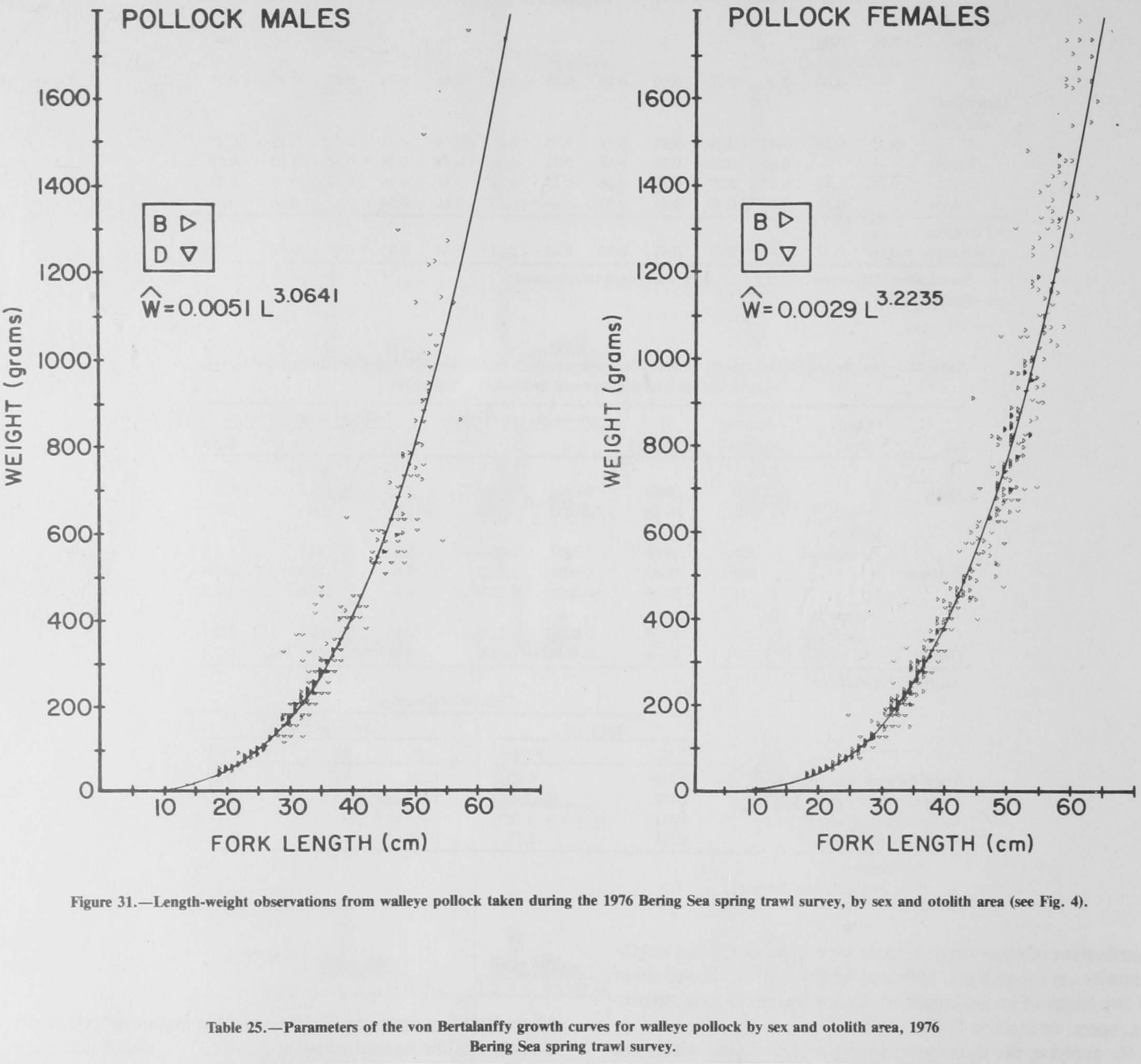

Figure 31.—Length-weight observations from walleye pollock taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4).

Table 25.—Parameters of the von Bertalanffy growth curves for walleye pollock by sex and otolith area, 1976 Bering Sea spring trawl survey.

Sex	Otolith areas[1]	Data set	Number of age readings	Age range (yr)	FL range (cm)	Standard error of curve fit	Parameters		
							L_∞	K	t_0
Male	A B	All ages	525	1-14	12-67	3.25	62.61	0.23	0.01
		Selected ages		0, 2-11	17-67	1.46	55.77	0.27	−0.01
	D	All ages	321	1-12	9-63	1.15	54.34	0.26	0.11
		Selected ages		0, 2-10	15-58	1.67	55.34	0.23	−0.01
	A B D	All ages	846	1-14	9-67	3.49	61.93	0.23	0.22
		Selected ages		0, 2-11	15-67	1.87	56.58	0.24	−0.02
Female	A B	All ages	810	1-15	12-72	3.94	75.74	0.15	−0.32
		Selected ages		0, 2-12	18-72	0.79	60.29	0.24	0.00
	D	All ages	334	2-13	18-74	4.57	65.44	0.21	0.42
		Selected ages		0, 3-11	25-74	2.25	58.62	0.23	0.02
	A B D	All ages	1,144	1-15	12-74	3.89	77.55	0.14	−0.29
		Selected ages		0, 2-12	18-74	1.07	60.95	0.22	0.00

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[1] See Figure 4.

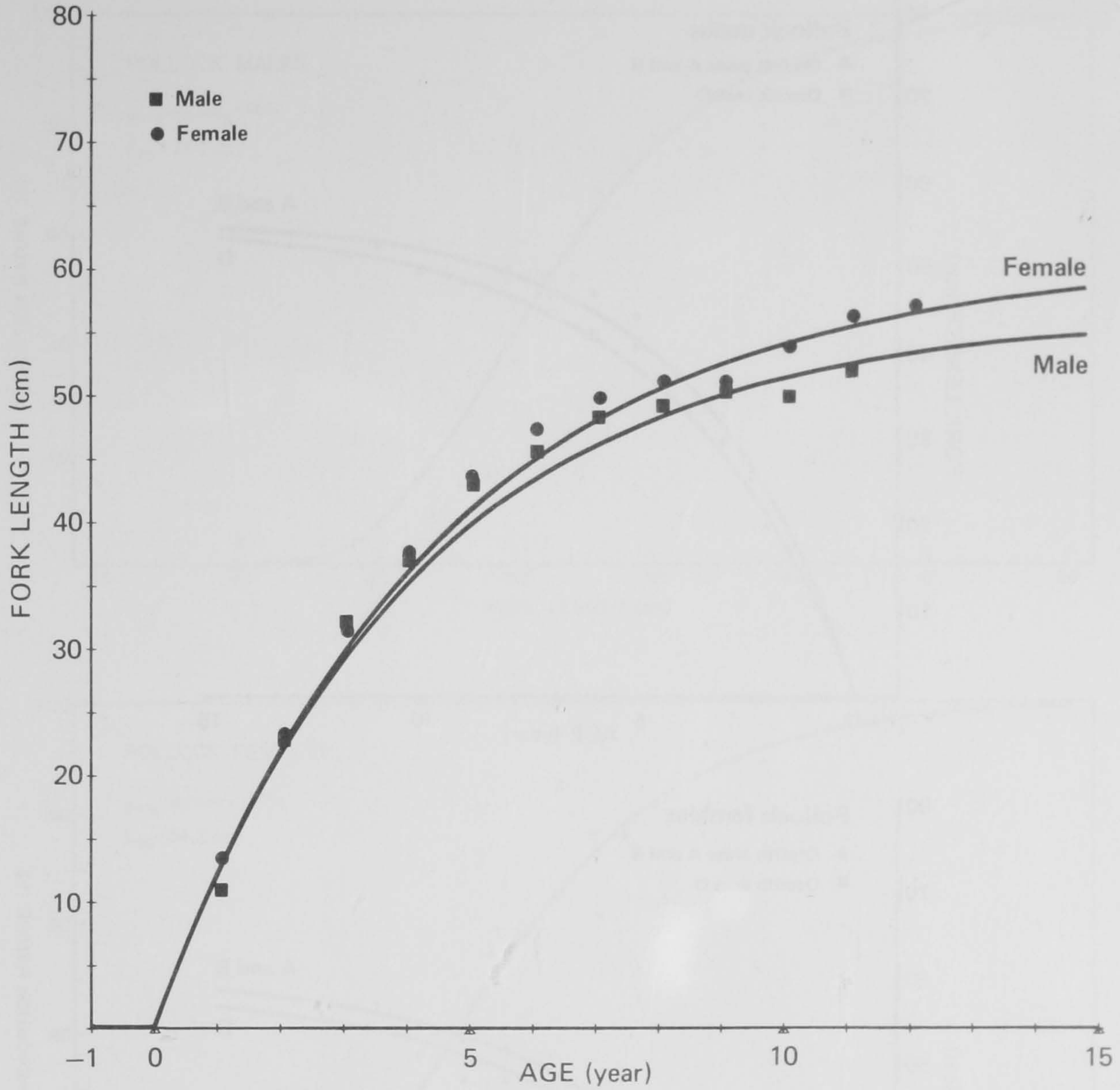

Figure 32.—Von Bertalanffy growth curves for male and female walleye pollock, 1976 Bering Sea spring trawl survey (selected ages). Symbols indicate the mean length at each age.

$$P = e^{-867.088e^{-0.209L}}, \qquad (29)$$

with the fork length, at 50% maturity, equal to 34.2 cm.

By applying Equations (28) and (29) to the respective expanded age-length table (consisting of the estimated number of individuals in the population at each length and age), it was possible to approximate the percentage of sexually mature individuals within each age class (Table 26). However, because individuals within older age classes at a given length can be expected to be represented by a higher proportion of mature individuals, the estimates presented in Table 26 include the following potential biases: The percentage mature within young age classes (2 and 3 yr) may be somewhat overestimated; and the percentage mature within older age classes (≥4 yr) may be slightly underestimated.

By summing the estimated number of individuals within each gonad condition code (Table 7), over all lengths, an estimate was obtained of the distribution of reproductive conditions among the sampled populations (Fig. 35). As noted in the summaries of length and age distributions, the relative distribution of gonad conditions within the combined sex population (males, females, and undetermined) was markedly different from the distributions of male and female populations, due to the large influence of the population of small, immature fish of undetermined sex. Individuals of undetermined sex accounted for 55.8% of the overall estimated walleye pollock population. Nonetheless, the combined sex estimates provide the best description of the relative reproductive condition of the sampled population.

The overall percent frequency distribution (combined sexes) of gonad conditions observed was immature, 77.3%; developing, 11.7%; spawning, 6.8%; spent, 2.3%; and inactive, 1.8%.

Because the walleye pollock population within the study area may have been poorly sampled by the spring 1976 survey (as indicated by low estimates of overall population size and low proportion of females), the preceding analyses should be considered initially as only summaries of the sampled population. The relation

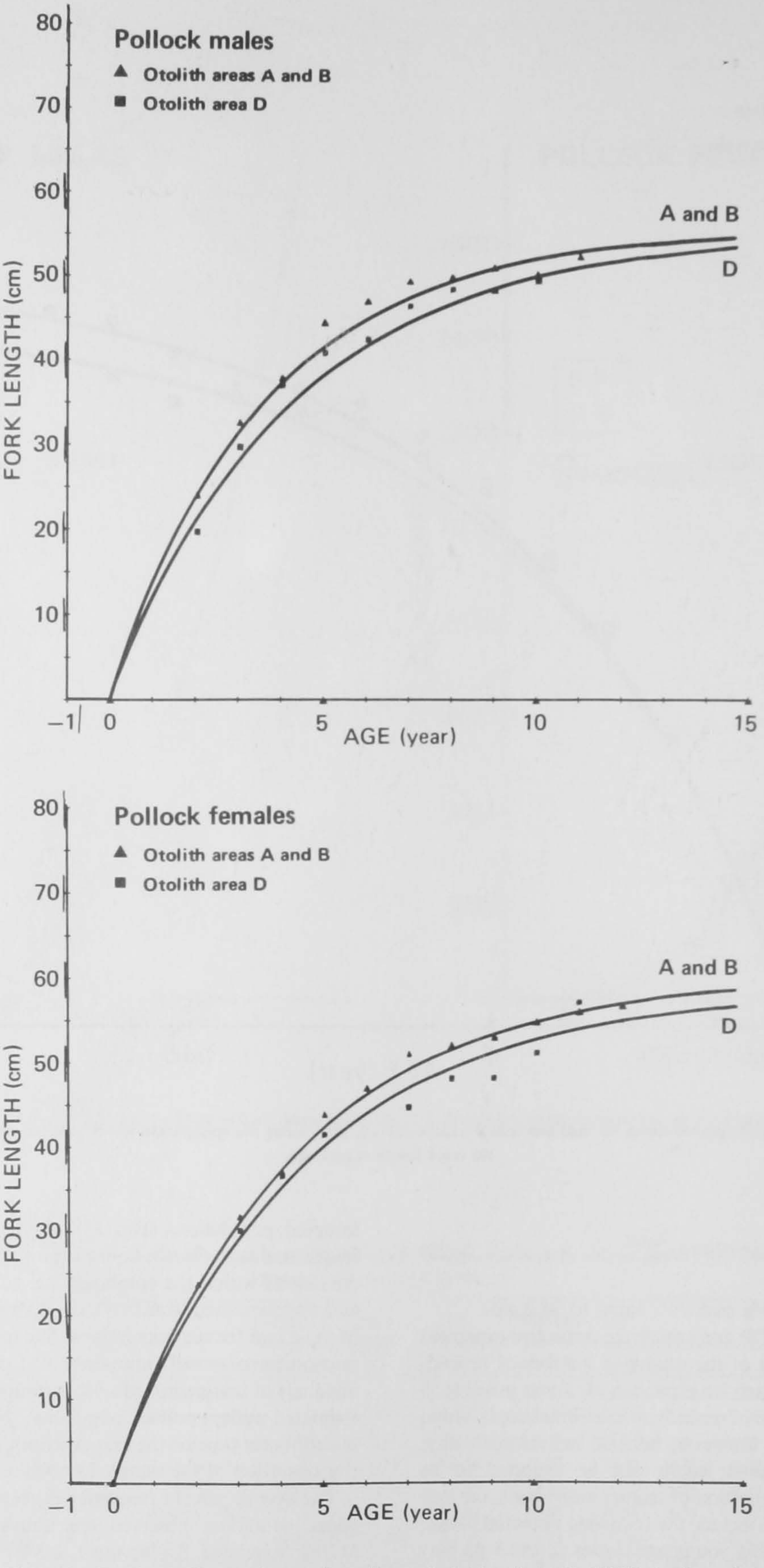

Figure 33.—Von Bertalanffy growth curves for walleye pollock taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4). Symbols indicate the mean length at each age.

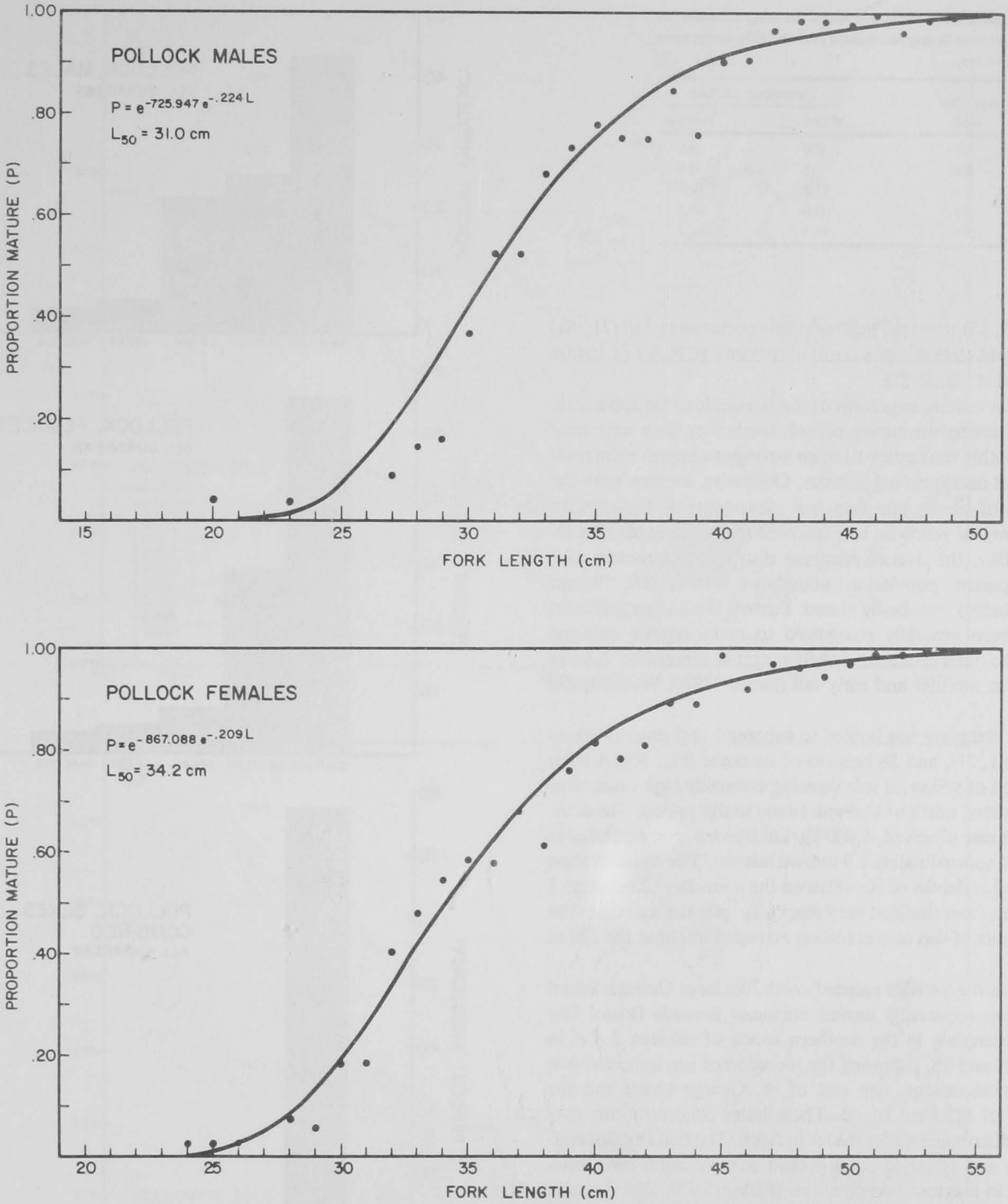

Figure 34.—Length-maturity relationships observed from walleye pollock taken during the 1976 Bering Sea spring trawl survey.

of these results to the actual population is dependent upon the degree of influence of the following potential sources of bias: If large, spawning individuals were less vulnerable to the trawl than nonspawners, as a result of an off-bottom distribution and/or avoidance, then the estimated numbers and overall relative population proportions of mature and spawning individuals may have been substantially underestimated; and differential vulnerability to the trawl of immature and mature individuals within each centimeter length class may have affected the estimate of proportion mature at each length.

Yellowfin sole.

Distribution and abundance.—During the entire survey period, April-June 1976, yellowfin sole were taken over a broad region of the survey area along the central continental shelf and in Bristol

Table 26.—Estimated sexual maturity schedule for eastern Bering Sea walleye pollock, 1976 spring trawl survey.

Age class (yr)	Percentage mature	
	Males	Females
1+	0.0	0.0
2+	5.6	0.8
3+	37.2	28.9
4+	80.0	64.1
5+	94.1	84.2

Bay (Fig. 36, 37). Overall, yellowfin sole occurred at 310 (71.3%) of the 435 grid stations, at a mean abundance (CPUE) of 104.04 kg/km trawled (Table 27).

Because an inshore migration of the population was apparently in progress during the survey period, the survey data were analyzed in monthly time intervals in an attempt to improve the resolution of real distributional features. Otherwise, because both the progression of survey sampling and movements of high-density concentrations of yellowfin sole followed the receding pack ice into Bristol Bay, the overall apparent distributional pattern and overall apparent population abundance (Table 27: "Mean CPUE" column) were badly biased. Eastern Bering Sea yellowfin sole have been generally recognized to make regular seasonal migrations to outer continental shelf waters in winter and to inner shelf areas in summer and early fall (Fadeev 1970; Wakabayashi 1974[5]).

In April, sampling was limited to subarea 2 and small portions of subareas 1, 3N, and 3S because of ice cover (Fig. 36). A large concentraton of yellowfin sole showing extremely high catch rates was encountered north of Unimak Island in this period. The maximum catch rate observed, 6,800 kg/km trawled, corresponded to a density of approximately 2.9 individuals/m^2. The concentration was centered at depths of 90-100 m on the boundary of subareas 1 and 2. Catch rates declined very markedly near the ice edge. The offshore limits of this concentration extended to about the 120 m isobath.

In May, as the ice edge receded north, the large Unimak Island concentration apparently moved northeast towards Bristol Bay (Fig. 36). Sampling in the northern sector of subarea 2 and in subareas 3N and 3S, following the recession of ice, indicated two smaller concentrations, one east of St. George Island and the other west of St. Paul Island. These latter concentrations may have been distributed under the ice in April. The two Pribilof concentrations and larger Unimak Island concentration have been recognized in previous investigations (Fadeev 1970; Wakabayashi et al. 1977[6]).

As ice cover continued to recede from the survey area in June, the Unimak Island concentration appeared to disperse over the inner Bristol Bay shelf (Fig. 37). The large concentration of yellowfin sole observed in Bristol Bay during June may have been composed of migrants from the Unimak Island group and individuals that overwintered under ice cover on the inner shelf. Fadeev (1970) reported a population of small yellowfin sole that apparently remained in Bristol Bay through winter.

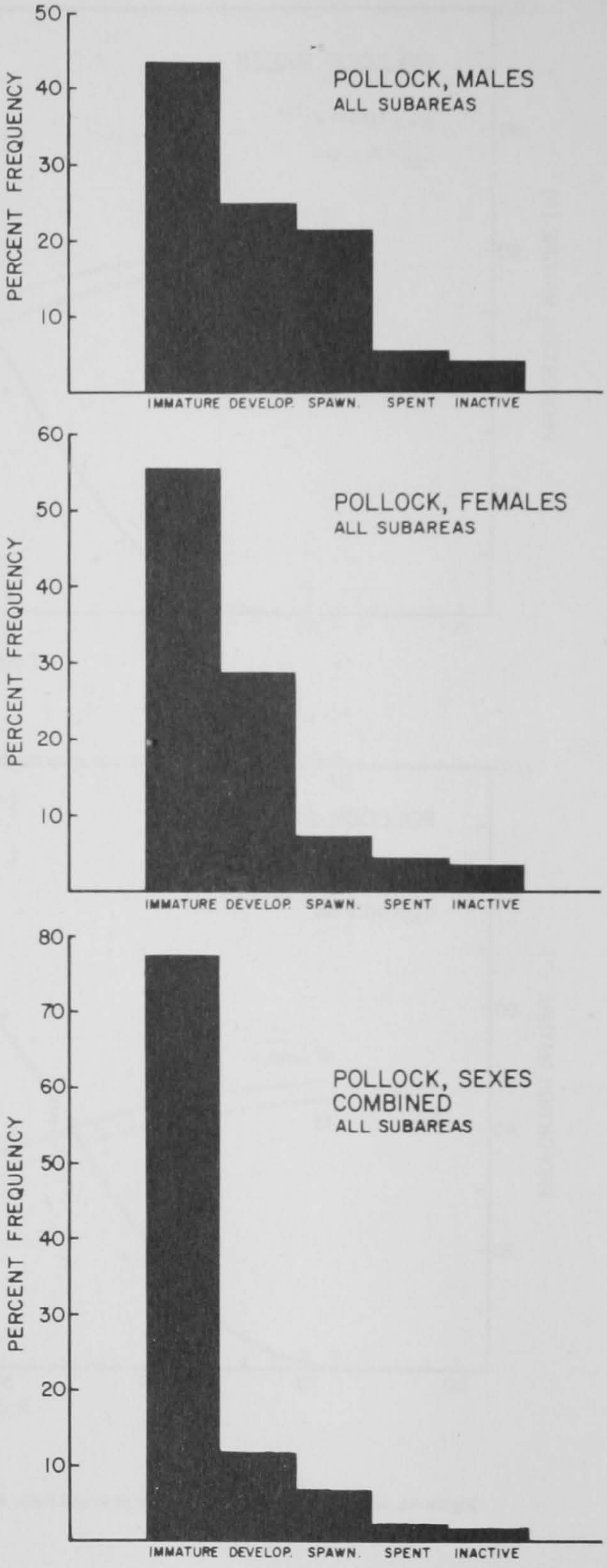

Figure 35.—Reproductive condition of walleye pollock taken during the 1976 Bering Sea spring trawl survey.

Previous tagging studies have indicated a migration of yellowfin sole from a wintering area west of St. Paul Island towards Nunivak Island in spring (Wakabayashi see footnote 5). The concentration encountered between the Pribilof Islands and

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[5] Wakabayashi, K. 1974. Studies on resources of the yellowfin sole in the eastern Bering Sea. I. Biological characters. Fishery Agency of Japan, Far Seas Fisheries Research Laboratory, 1000 Orido, Shimizu 424, Japan, 77 p.

[6] Wakabayashi, K., R. Bakkala, and L. Low. 1977. Status of the yellowfin sole resource in the eastern Bering Sea through 1976. Fishery Agency of Japan, Far Seas Fisheries Research Laboratory, 1000 Orido, Shimizu 424, Japan, 45 p.

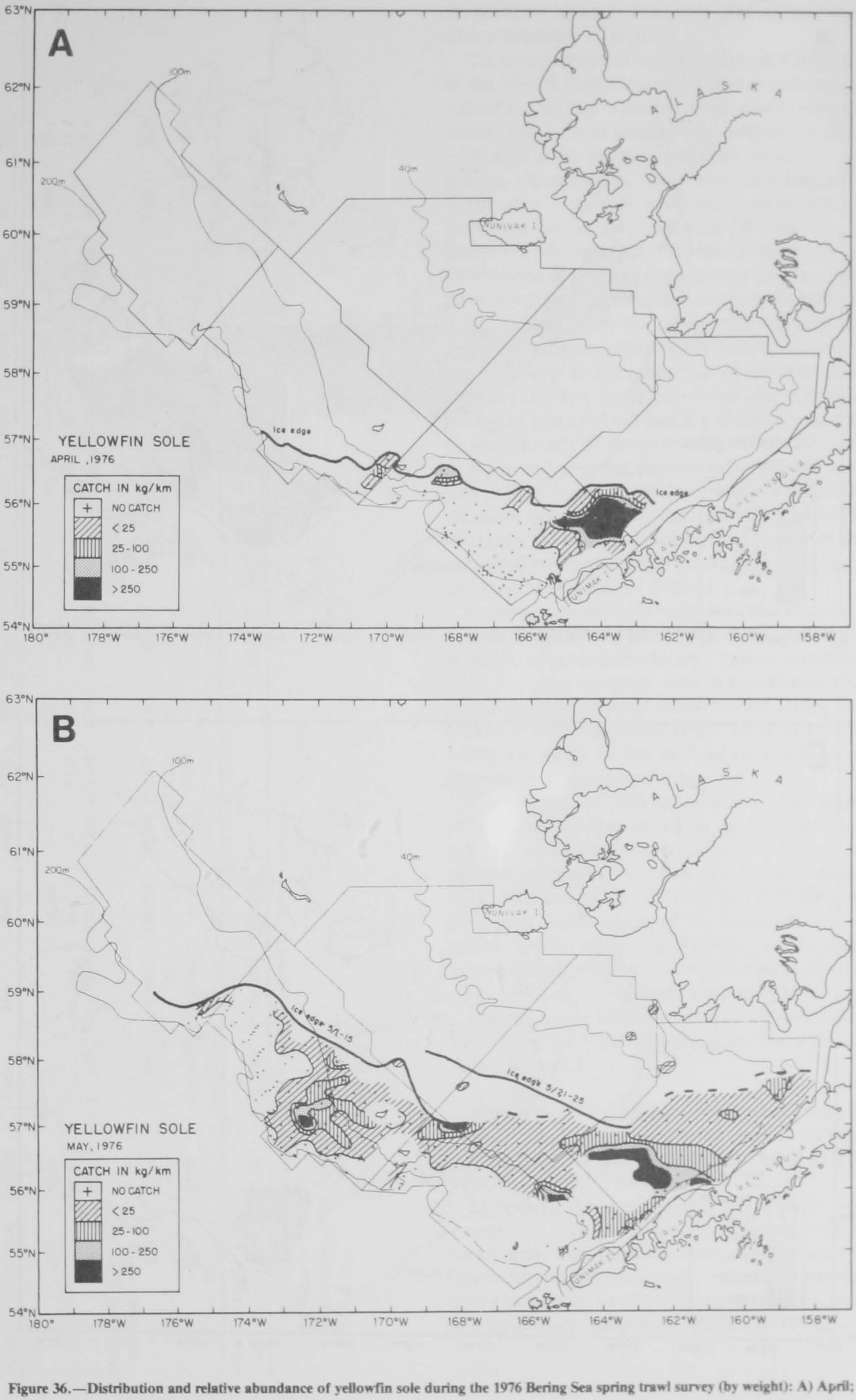

Figure 36.—Distribution and relative abundance of yellowfin sole during the 1976 Bering Sea spring trawl survey (by weight): A) April; B) May.

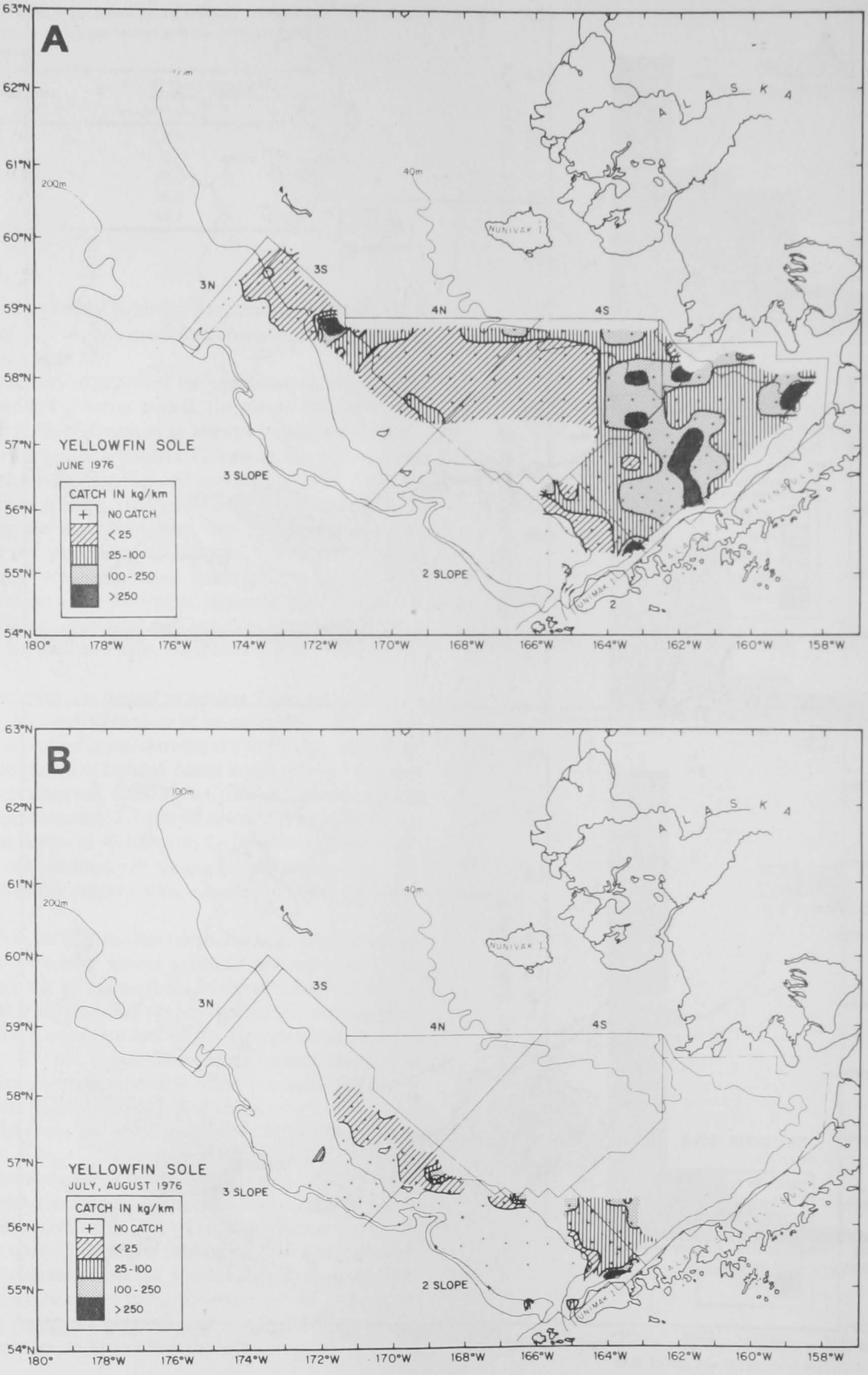

Figure 37.—Distribution and relative abundance of yellowfin sole during the 1976 Bering Sea spring trawl survey (by weight): A) June; B) July- August.

Table 27.—Estimated biomass and population numbers of yellowfin sole in the Bering Sea by subarea and for all subareas combined during April, May, and June 1976.[1]

Subarea[2]	Percentage frequency of occurrence April-June	Mean CPUE April-June (kg/km)	Estimated biomass (t) April	Estimated biomass (t) May	Estimated biomass (t) June	Proportion of total estimated biomass April	Proportion of total estimated biomass May	Proportion of total estimated biomass June	Estimated population (millions) April	Estimated population (millions) May	Estimated population (millions) June	Proportion of total estimated population April	Proportion of total estimated population May	Proportion of total estimated population June	Mean size April-June Weight (kg)	Mean size April-June TL (cm)
Inner shelf																
4N	100.0	23.94	—	—	44,249	—	—	0.037	—	—	489.9	—	—	0.054	0.090	19.1
4S	98.2	47.50	—	148,883	88,151	—	0.114	0.074	—	1,273.4	854.2	—	0.129	0.093	0.121	21.3
1	100.0	258.98	(5,115,342)	976,007	939,471	0.865	0.746	0.788	(34,092.9)	7,458.8	7,001.1	0.863	0.753	0.766	0.137	22.8
Outer shelf and slope																
3	72.6	21.67	(105,788)	92,932	120,753	0.018	0.071	0.101	(568.9)	559.9	799.3	0.014	0.057	0.087	0.161	24.3
3 Slope	9.1	0.14	—	27	—	—	<0.001	—	—	0.1	—	—	<0.001	—	—	—
2	52.8	127.04	(690,005)	90,359	—	0.117	0.069	—	(4,849.8)	609.3	—	0.123	0.062	—	0.139	22.9
2 Slope	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
All subareas combined	71.3	104.04	(5,911,135)[3]	[3]1,308,207	[2]1,192,624				(39,511.6)	9,901.4	9,144.5				0.135	22.6

[1] Parentheses indicate estimates that may be badly biased due to sampling problems.

[2] See Figure 3.

[3] 95% confidence limits: April: 0-15,520,670 t
May: 405,108-2,211,307 t
June: 661,690-1,723,558 t.

St. Matthew Island in June 1976 (Fig. 37) may have represented such a migration in progress.

Catch rates observed during the July and August 1976 sampling of the NMFS Crab-Groundfish Survey indicated that almost all yellowfin sole had migrated from waters west of the Pribilof Islands and most of subarea 2 by midsummer (Fig. 37).

Because of the sampling problems caused by rapid inshore migration, abundance estimates were imprecise and questionable. Large concentrations of individuals were probably sampled more than once during the April-June 1976 survey period, or even within individual months. Particularly severe biasing due to multiple sampling of high fish densities may have occurred during April when sampling was concentrated along the pack ice edge.

However, because the survey and migrating population appeared to progress together, the pattern of sampling may have provided fairly complete coverage of the entire population within each month. As a result, population and biomass estimates were computed overall (April-June), and for comparisons, also for individual months of survey coverage (Table 27).

The overall apparent population biomass for yellowfin sole was 2.09 million t (95% confidence limits 1.17-3.02 million t); the estimated population size was 15.4 billion individuals. Estimates of population biomass obtained from the survey coverage during individual months were April, 5.91 million t; May, 1.31 million t; and June, 1.19 million t (Table 27).

In relation to previous estimates (Wakabayashi 1975[7]; Wakabayashi et al. see footnote 6), the overall and April estimates for yellowfin sole population biomass appear unrealistically high. The May and June estimates were approximately the same as the overall estimate obtained from the 1975 Bering Sea survey (1.04 million t; 95% confidence limits 0.87-1.21 million t) and were within the range of the 1975 survey's 95% confidence limits (Pereyra et al. see footnote 2).

The precision of 1976 survey biomass estimates was relatively poor because of high variability in catch rates between stations and months, and the smaller number of samples upon which each estimate was based. As a measure of relative variance, the width of the 95% confidence limits for each 1976 biomass estimate (expressed as a percentage of the estimated total biomass) was overall, ±44%; April, ±163%; May, ±69%; and June, ±44%. In comparison, the overall relative variance observed in the 1975 survey estimate for yellowfin sole was ±16%.

During April, May, and June, approximately 79% (range 75-86%) of the apparent population biomass was distributed in survey subarea 1.

Size composition.—Yellowfin sole taken during the 1976 spring trawl survey ranged from 5 to 44 cm TL, with an overall mean total length of 22.5 cm (based upon 39,352 field measurements, Fig. 38).

In general, the size-frequency distributions were remarkably symmetrical and similar among all geographical regions of the survey area. Populations in inner shelf subareas 1, 4S, and 4N showed the broadest size range, with higher proportions of small, young individuals (<10 cm). Mean total length and the size range in each area were subarea 4N, 19.1 cm (8-41 cm); subarea 4S, 21.3

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[7] Wakabayashi, K. 1975. Studies on resources of the yellowfin sole in the eastern Bering Sea. II. Stock size estimated by the method of virtual population analysis and its annual changes. Fishery Agency of Japan, Far Seas Fisheries Research Laboratory, 1000 Orido, Shimizu 424, Japan, 22 p.

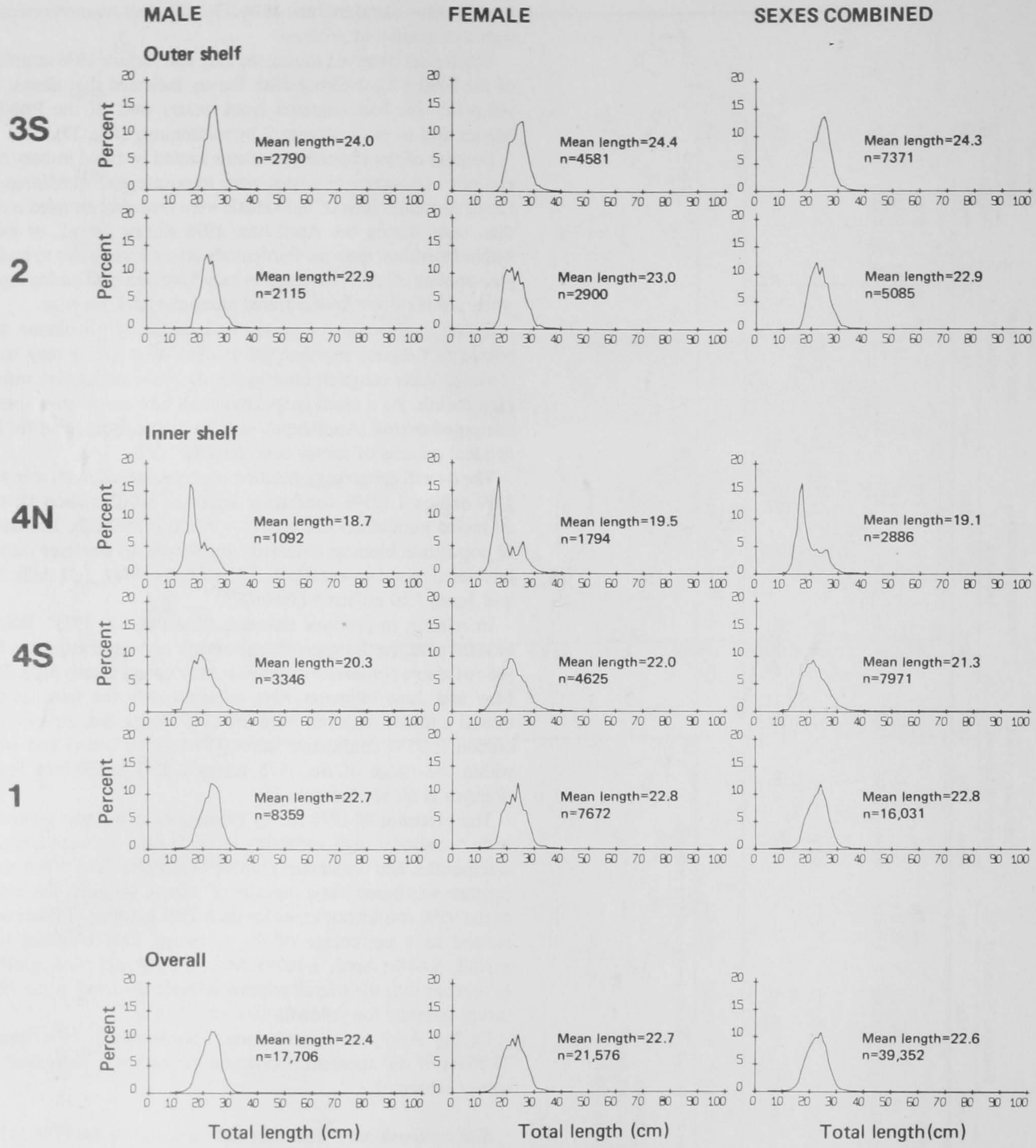


Figure 38.—Size composition of yellowfin sole taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

cm (9-44 cm); subarea 1, 22.8 cm (5-39 cm); subarea 3N, 25.9 cm (23-35 cm); subarea 3S, 24.3 cm (15-41 cm); and subarea 2, 22.9 cm (10-39 cm).

Sampling stations with particularly high proportions (>50% of all yellowfin sole taken) of small-sized (<20 cm) individuals were located in inner Bristol Bay during May and along the northern boundaries of subareas 4S and 4N during June. These latter stations showed relatively high proportions of individuals sized 16-18 cm.

Age composition.—Totals of 507 male and 600 female saccular otoliths were collected from yellowfin sole in the size range 13-36 cm. The observed ranges in ages were males, 3-16 yr, and females, 3-21 yr.

Although the overall estimates of yellowfin sole total population abundance were apparently badly biased by the effects of migration, the overall estimated numbers of individuals at each length were used as the best estimators of relative age-frequency distribution. This analytical approach assumed that even if sampling problems caused overestimation of total population abundance, the effects may have been fairly uniformly distributed among all size and age groups. The validity of this assumption can

Table 28.—Estimated population size of yellowfin sole age groups and year classes within survey subareas of the eastern Bering Sea, 1976 spring trawl survey.[1]

	≤3	4	5	6	7	8	9	10	11	12	13	14	15	16	≥17	Age	All ages
Subarea[2]	—	1972	1971	1970	1969	1968	1967	1966	1965	1964	1963	1962	1961	1960	—	unknown	combined
	millions of fish																
Inner shelf																	
4N	11.0	58.4	103.5	128.3	77.3	38.2	35.9	17.5	5.4	5.8	3.6	1.8	2.0	0.1	0.2	0.9	489.9
4S	36.9	89.1	204.6	377.9	381.4	219.2	203.2	96.2	32.8	33.2	21.6	13.0	11.2	1.4	1.3	6.6	1,729.6
1	(69.2)	(119.0)	(546.5)	(1,607.2)	(2,139.2)	(1,658.4)	(1,637.2)	(765.8)	(239.7)	(205.4)	(121.5)	(68.5)	(57.8)	(5.8)	(2.7)	(4.5)	(9,248.4)
Outer shelf																	
3	—	0.4	11.4	72.2	131.7	130.6	138.8	71.5	23.1	21.1	13.1	7.2	6.1	0.7	0.4	0.9	629.2
2	(0.1)	(13.0)	(147.5)	(564.8)	(819.0)	(616.2)	(593.9)	(284.4)	(92.9)	(82.6)	(49.5)	(27.3)	(23.3)	(3.1)	(1.2)	(2.3)	(3,321.1)
All subareas combined	(117.2)	(279.9)	(1,013.5)	(2,750.4)	(3,548.6)	(2,662.6)	(2,609.0)	(1,235.4)	(393.9)	(348.1)	(209.3)	(117.8)	(100.4)	(11.1)	(5.8)	(15.2)	(15,418.2)
Proportion of total	0.008	0.018	0.066	0.178	0.230	0.173	0.169	0.080	0.026	0.023	0.014	0.008	0.007	0.001	<0.001	0.001	

[1] Parentheses indicate estimates that may be badly biased due to sampling problems.

[2] See Figure 3.

only be evaluated by comparisons with independent estimates of age composition from other stock assessment programs.

The numbers of individuals within each age group of the sampled population (available to capture by trawling) are summarized in Table 28. The estimates from geographical subareas 1 and 2, and also all subareas combined, are considered to be biased due to sampling errors caused by the effects of migration. But if biases were not age specific, the proportion of each age group within the available population may still be estimated with relative accuracy. The relative age-frequency distributions observed in different geographical regions of the study area are compared in Figure 39.

In general, major features of the age composition observed in all geographical subareas were quite similar, although some differences were evident. Overall, 75.0% of the apparent population was distributed within age groups 6, 7, 8, and 9 yr. In subareas 4N and 4S, the proportions of the apparent populations that were 5 yr or younger were approximately a factor of 4-7 times higher than observed in the other geographical regions. In subareas 3N and 3S, the apparent population was composed of relatively higher proportions of age groups 8 and older than in all other areas.

Sex ratio.—Proportions of females in the apparent yellowfin sole population are summarized in Table 29. The overall proportion of females was 0.52, and females predominated in all geographical regions except subarea 1. There were no evident age-related trends in sex ratio.

Length-weight relationship.—A total of 506 individuals from the yellowfin sole populations in otolith areas A and C (Fig. 4) were measured for total length and weight (Table 30, Fig. 40). The length-weight relationships of male and female populations in otolith area A significantly differed, with females approximately 1-9% heavier at each length than males.

Geographical differences were also observed between populations in otolith areas A and C. Up to approximately 20 cm TL, both males and females showed significantly higher weights-at-length (up to 48% heavier at 10 cm length) in otolith area A. At sizes > 20 cm, males and females had higher weights-at-length in otolith area C.

Age-length relationship and growth.—A total of 1,007 yellowfin sole otoliths were collected in otolith area A and 100 in otolith area C. Results of the growth curve fittings are summarized in Table 31. Male and female populations had very similar growth characteristics, although females showed a slightly higher growth completion rate and approximately 1% larger asymptotic total length (Fig. 41).

Rock sole.

Distribution and abundance.—Rock sole were widely distributed along the outer continental shelf and the Alaska Peninsula into Bristol Bay (Fig. 42). Overall, rock sole were taken at 235 (54.0%) of the 435 grid stations, at a mean abundance of 11.81 kg/km trawled (Table 32). Centers of high density were located in subarea 2 (north of Unimak Island and southeast of St. George Island), subarea 4S (directly east of the Pribilof Islands), and subarea 1 (directly off Port Moller). In general, catch rates were low throughout other regions of the observed range.

The total apparent population biomass was 236,000 t (95% confidence limits 80,000-392,000 t), approximately 39% larger than the estimate of 170,000 t from the 1975 survey (Pereyra et al. see footnote 2). While it is difficult to assess the true accuracy of

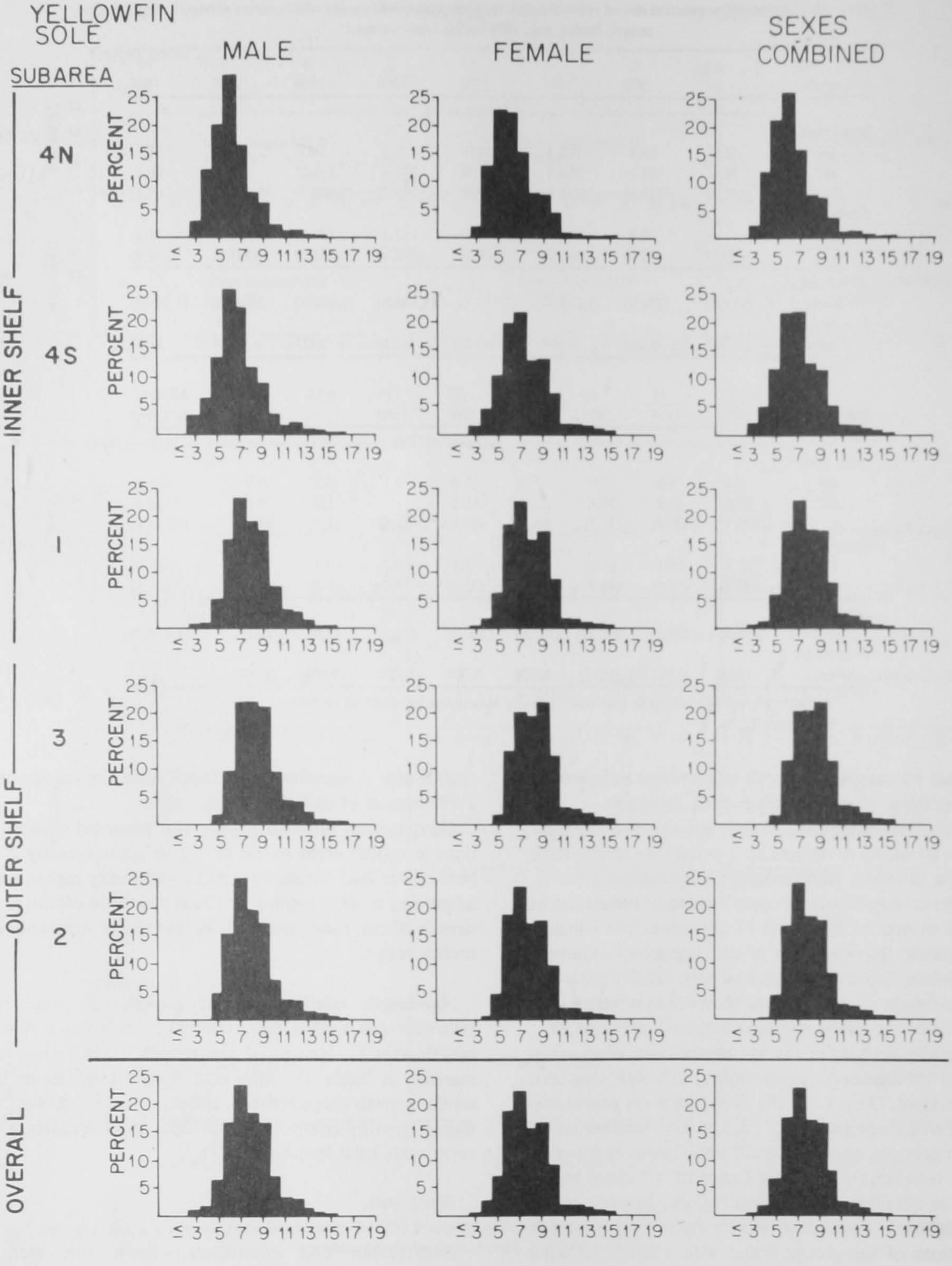


Figure 39.—Relative age composition of yellowfin sole taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

Table 29.—Proportions of females in the apparent yellowfin sole population by age group and geographical area, 1976 Bering Sea spring trawl survey.[1]

Subarea[2]	Age group (yr)														All ages combined
	≤3	4	5	6	7	8	9	10	11	12	13	14	15	16	
	Proportion of females														
Inner shelf															
4N	0.51	0.61	0.62	0.52	0.57	0.59	0.65	0.75	0.58	0.58	0.62	0.66	0.81	0.43	0.59
4S	0.43	0.52	0.53	0.52	0.58	0.61	0.68	0.76	0.60	0.58	0.72	0.69	0.81	0.27	0.58
1	0.42	0.61	0.51	0.51	0.46	0.42	0.47	0.53	0.33	0.36	0.42	0.56	0.58	0.57	0.47
Outer shelf															
3	—	0.88	0.59	0.68	0.60	0.59	0.62	0.68	0.51	0.53	0.59	0.71	0.71	0.20	0.62
2	0.50	0.97	0.58	0.62	0.56	0.54	0.57	0.64	0.43	0.44	0.56	0.53	0.61	0.28	0.57
All subareas combined	0.44	0.60	0.54	0.54	0.51	0.48	0.52	0.58	0.39	0.41	0.49	0.58	0.63	0.37	0.52

[1] Based upon sampled individuals for which sexes could be determined.

[2] See Figure 3.

Table 30.—Length-weight relationships observed for yellowfin sole during the 1976 Bering Sea spring trawl survey, with testing for between-area and between-sex differences.

Sex	Otolith area[1]	Number sampled	TL range (cm)	Length-weight coefficients		Predicted weight-at-length		
				a	*b*	10 cm	20 cm	30 cm
						grams		
Males	A	180	9-33	0.0226	2.7504	12.7	85.5	260.9
	C	33	16-27	0.0044	3.2909	8.6	84.7	—
	Both areas combined	213	9-33	0.0208	2.7790	12.4	85.6	264.2
Females	A	193	10-37	0.0195	2.8197	12.8	90.8	284.9
	C	100	17-34	0.0058	3.2162	9.5	88.9	327.6
	Both areas combined	293	10-37	0.0168	2.8698	12.4	91.1	291.9
Overall		506	9-37	0.0172	2.8532	12.2	88.7	282.2

Analysis of covariance

	Slope (*b*)		Common means	
	df	F ratio	df	F ratio
Males between areas A and C	1:209	10.3**	—	—
Females between areas A and C	1:289	10.1**	—	—
Between sexes in area A	1:369	1.1	1:370	16.9
Between sexes in area C	1:129	0.2	1:130	3.3

[1] See Figure 4.

[2] ** = $P \le 0.01$.

the two estimates, the 1976 spring survey estimate may have been biased high—similar to yellowfin sole—by effects of inshore migration (Shubnikov and Lisovenko 1964). The distribution of apparent population biomass during the 1976 survey was subarea 2, 46.9%; subarea 4S, 32.9% (resulting from high catch rates along the subarea's western boundary); and subarea 1, 14.3% (Table 32).

The total number of rock sole within the study area (available to the trawl) was estimated to be 928.9 million individuals, distributed among geographical regions similar to the apparent biomass.

Size composition.—Rock sole ranged from 6 to 48 cm TL, with an overall mean total length of 27.8 cm (based upon 10,561 field measurements; Fig. 43). In general, the observed size-frequency distributions were similar among all geographical areas. In all areas, the frequency distributions for male populations were shifted toward small sizes, with mean total lengths approximately 86% (range 85-90%) those of the female populations.

Populations in subareas 4S and 2 Slope had the largest mean total lengths (31.3 and 30.4 cm). Populations in subareas 1, 2, and 3S showed smaller size distributions (mean total lengths 26.0, 27.0, and 27.0 cm) due to relatively higher proportions of small, young individuals (< 24 cm). Particularly broad size ranges were observed in subarea 2 (6-48 cm) and subarea 1 (12-47 cm). Trawling stations with high proportions (> 50% of all rock sole taken) of small (< 24 cm) individuals were primarily located directly north of the Alaska Peninsula, between Unimak Island and Port Moller.

Age composition.—Estimates of age-frequency distribution were based upon an overall collection of 252 male and 451 female saccular otoliths. The ranges in ages were males, 3-14 yr, and females, 3-16 yr. The estimated number of individuals in each age group (available to the trawl) are summarized in Table 33. Overall, 79.4% of the apparent population was represented within age groups 6-10 yr.

Relative age distributions between geographical areas and sexes are compared in Figure 44. In all areas, female populations were relatively older than males; overall, 25.7% of females were older than 10 yr, compared to only 2.0% of males.

The proportional representation of each age group was quite variable between different geographical areas. In subareas 4S and

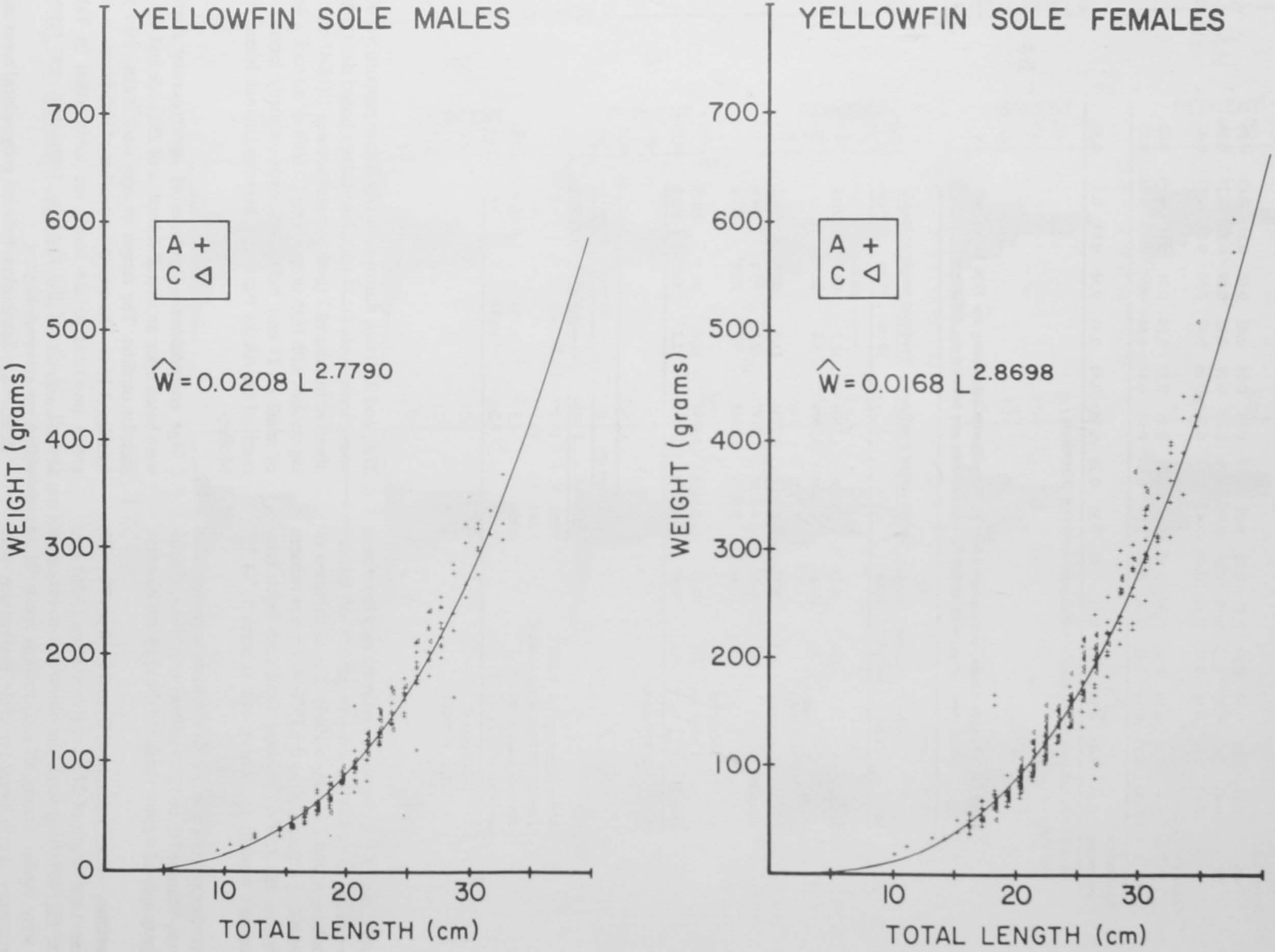


Figure 40.—Length-weight observations from yellowfin sole taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4).

Table 31.—Parameters of the von Bertalanffy growth curves for yellowfin sole by sex, 1976 Bering Sea spring trawl survey.

Sex	Otolith areas[1]	Data set	Number of age readings	Age range (yr)	TL range (cm)	Standard error of curve fit	Parameters L_∞	K	t_0
Male	A C	All ages	507	3-16	13-36	1.19	37.37	0.11	−1.13
		Selected ages		0, 4-12	0, 13-33	0.31	31.88	0.17	−0.02
Female	A C	All ages	600	3-21	13-36	0.68	32.81	0.16	−0.06
		Selected ages		0, 4-14	0, 13-36	0.66	32.23	0.18	0.10

[1] See Figure 4.

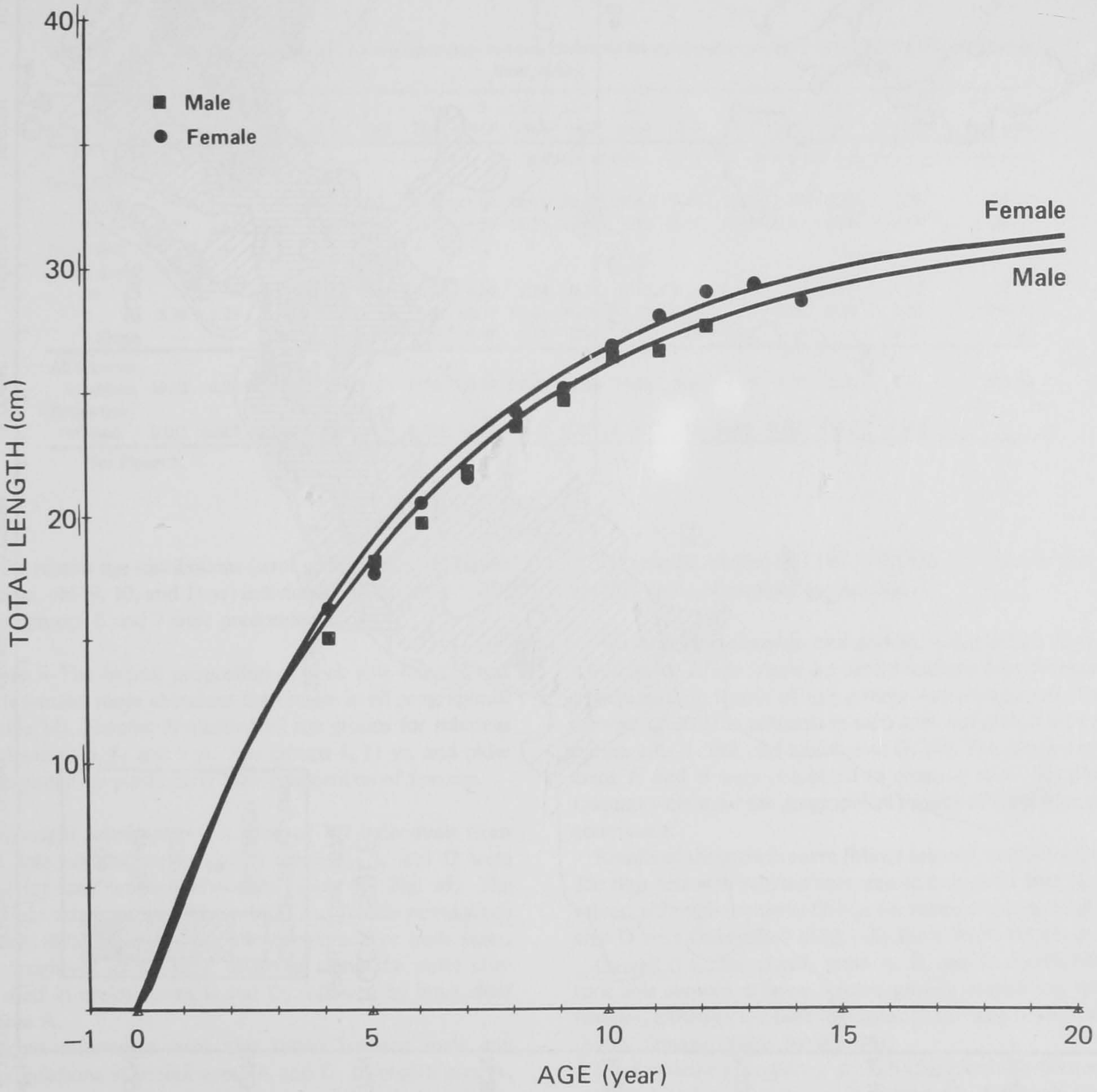


Figure 41.—Von Bertalanffy growth curves for yellowfin sole taken during the 1976 Bering Sea spring trawl survey (selected ages). Symbols indicate the mean length at each age.

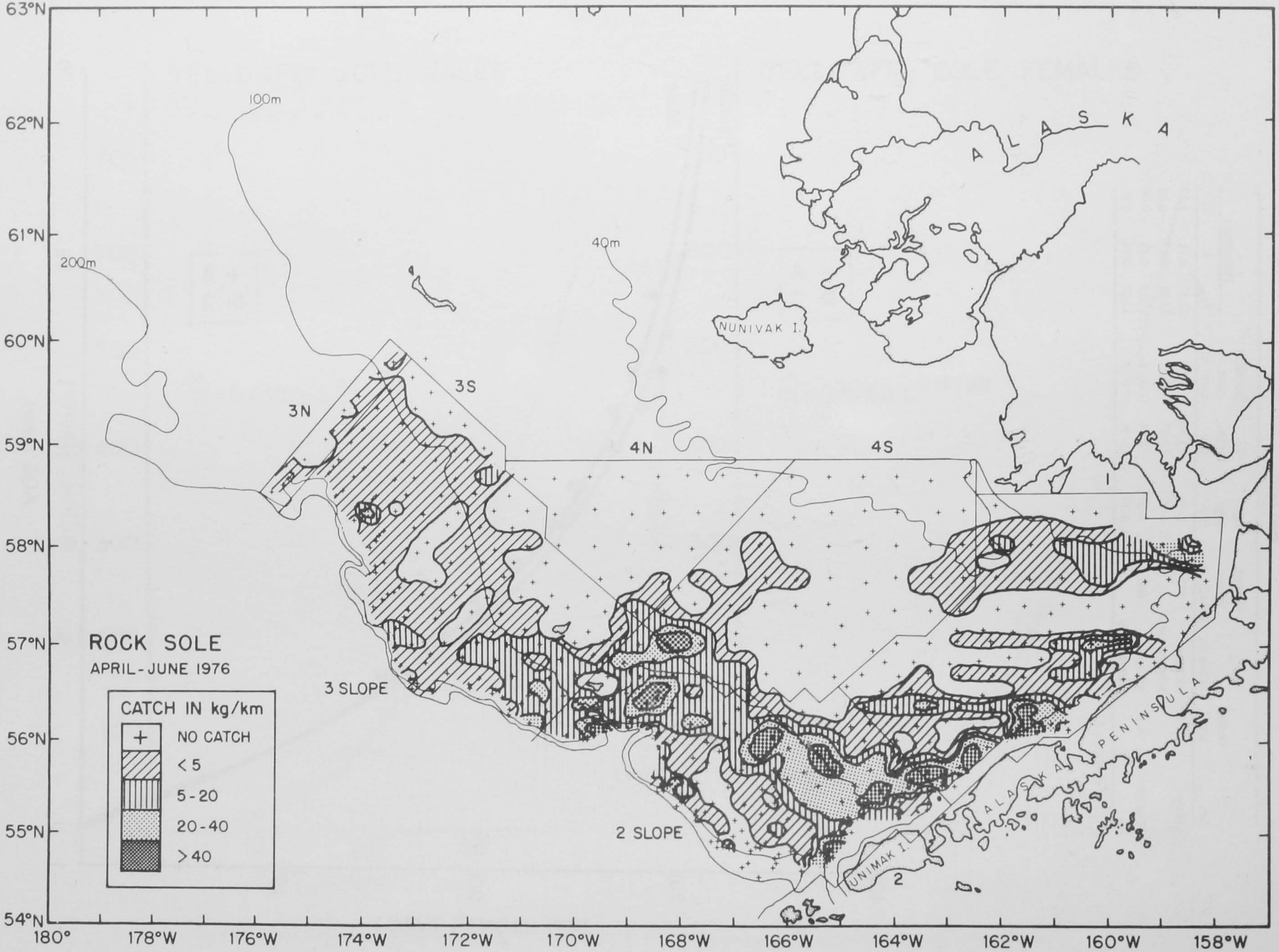


Figure 42.—Distribution and relative abundance of rock sole during the 1976 Bering Sea spring trawl survey (by weight).

Table 32.—Estimated biomass and population numbers of rock sole by subarea and for all subareas combined, 1976 Bering Sea spring trawl survey.

Subarea[1]	Percentage frequency of occurrence	Mean CPUE (kg/km)	Estimated biomass (t)	Proportion of total estimated biomass	Estimated population (millions)	Proportion of total estimated population	Mean size	
							Weight (kg)	TL (cm)
Inner shelf								
4N	9.1	0.39	721	0.003	1.6	0.002	0.454	—
4S	23.2	17.99	77,708	0.329	218.2	0.235	0.356	31.3
1	49.0	6.86	33,643	0.143	158.1	0.170	0.213	26.0
Outer shelf and slope								
3	67.5	2.67	12,514	0.053	58.4	0.063	0.214	27.0
3 Slope	45.5	0.26	51	< 0.001	0.1	<0.001	0.415	—
2	87.6	29.67	110,781	0.469	490.5	0.528	0.226	27.0
2 Slope	22.5	1.52	649	0.003	2.1	0.002	0.314	30.4
All subareas combined	54.0	11.81	[2]236,067		928.9		0.254	27.8

[1]See Figure 3.

[2]95% confidence limits: 79,984-392,151 t.

Table 33.—Estimated population size of rock sole age groups and year classes within survey subareas of the eastern Bering Sea, 1976 spring trawl survey.

Subarea[1]	≤3	4	5	6	7	8	9	10	11	12	13	14	15	≥16	Age	All ages
	—	1972	1971	1970	1969	1968	1967	1966	1965	1964	1963	1962	1961	—	unknown	combined
	millions of fish															
Inner shelf																
4S	—	—	1.17	14.95	23.75	21.00	41.00	48.11	36.67	19.22	2.94	2.04	1.67	1.33	1.32	218.17
1	4.28	3.67	6.64	43.11	27.87	13.03	19.93	18.33	13.40	5.43	0.92	0.76	0.35	0.21	0.14	158.07
Outer shelf and slope																
3S	—	—	0.37	26.09	13.36	7.73	6.85	1.74	0.14	0.37	—	—	—	—	1.19	58.39
2	5.74	1.23	9.78	109.01	96.14	53.52	80.79	67.83	45.29	14.79	1.97	1.57	0.55	0.46	1.85	490.52
2 Slope	—	—	0.01	0.16	0.23	0.22	0.41	0.48	0.40	0.12	0.02	0.02	—	—	0.01	2.07
All subareas combined	10.02	4.90	17.97	193.32	161.35	95.50	148.98	136.49	98.90	39.93	5.85	4.39	2.57	2.00	4.51	928.93
Proportion of total	0.011	0.005	0.019	0.209	0.174	0.103	0.161	0.147	0.107	0.043	0.006	0.005	0.003	0.002	0.005	

[1]See Figure 3.

2 Slope, the relative age distributions (sexes combined) were skewed toward large, old (9, 10, and 11 yr) individuals. In subareas 1, 3S, and 2, age groups 6 and 7 were predominant.

Sex ratio.—The overall proportion of rock sole females was 0.55, with females more abundant than males in all geographical areas (Table 34). Females dominated all age groups for subareas combined except 6, 8, and 9 yr. Age groups 4, 11 yr, and older were represented by particularly high proportions of females.

Length-weight relationship.—A total of 707 individuals from the rock sole populations in otolith areas A, B, and D were measured for total length and weight (Table 35, Fig. 45). The length-weight relationships of both male and female populations significantly differed among the three regions. For both sexes, heaviest weights-at-length were observed along the outer continental shelf in otolith areas B and D, followed by inner shelf otolith area A.

Significant differences were also found between male and female populations in otolith areas A and D. In otolith area A, females were approximately 24-36% heavier at length than males. In otolith area D, females were approximately 13-69% heavier at length.

The overall relationship ($\widehat{W} = 0.0026\ L^{3.4113}$) was used for all computations of population numbers.

Age-length relationship and growth.—Age-length keys resulting from the 703 rock sole age determinations were developed and the mean total length of age groups was determined. The total number of otoliths collected in each area was otolith area A, 277; otolith area B, 280; and otolith area D, 146. The data from otolith areas A and B were combined to create a more complete age-frequency table for the geographical regions of highest population abundance.

Results of the growth curve fittings are summarized in Table 36. The data sets with selected ages seemed to give the best parameter values, although the curve fittings for males and females in otolith area D were determined using only three mean lengths-at-age.

Overall (i.e., for otolith areas A, B, and D combined), male rock sole showed a faster relative growth completion rate than females, although the male asymptotic total length was only 85% that of females (Table 36; Fig. 46).

Comparisons of apparent growth characteristics between geographical regions are shown in Figure 47. Although the small number of data points representing otolith area D certainly limits conclusions, at the ages for which data were available from both

Table 34.—Proportions of females in the estimated population of rock sole by age group and geographical area, 1976 Bering Sea spring trawl survey.[1]

Subarea[2]	Age group (yr) ≤3	4	5	6	7	8	9	10	11	12	13	14	15	≥16	All ages combined
	Proportion of females														
Inner shelf															
4S	—	—	0.41	0.50	0.51	0.44	0.43	0.61	0.93	0.99	1.00	0.77	1.00	1.00	0.63
1	0.75	1.00	0.65	0.55	0.50	0.38	0.34	0.57	0.96	0.98	—	0.93	1.00	1.00	0.53
Outer shelf and slope															
3S	—	—	0.21	0.53	0.53	0.11	0.82	0.97	1.00	1.00	—	—	—	—	0.53
2	0.49	1.00	0.62	0.48	0.55	0.41	0.34	0.51	0.91	0.94	1.00	0.58	1.00	1.00	0.51
2 Slope	—	—	1.00	0.86	0.90	0.87	0.85	0.93	0.98	0.99	1.00	0.88	—	—	0.92
All subareas combined	0.63	1.00	0.63	0.50	0.56	0.30	0.43	0.61	0.93	0.98	1.00	0.75	1.00	1.00	0.55

[1] Based upon sampled individuals for which sexes could be determined.

[2] See Figure 3.

Table 35.—Length-weight relationships observed for rock sole during the 1976 Bering Sea spring trawl survey, with testing for between-area and between-sex differences.

Sex	Otolith area[1]	Number sampled	TL range (cm)	Length-weight coefficients a	b	Predicted weight-at-length 10 cm	20 cm	30 cm
						grams		
Males	A	80	12-32	0.0040	3.1908	6.1	56.5	206.3
	B	129	23-39	0.0082	3.1038	10.4	89.7	315.8
	D	80	21-33	0.0032	3.3302	6.7	68.1	262.9
	All areas combined	289	12-39	0.0013	3.6144	5.3	65.2	282.3
Females	A	136	13-45	0.0063	3.1217	8.3	72.2	256.1
	B	187	24-43	0.0057	3.2170	9.3	86.7	319.5
	D	95	19-38	0.0122	2.9693	11.3	89.0	296.8
	All areas combined	418	13-45	0.0049	3.2333	8.4	79.2	294.1
Overall		707	12-45	0.0026	3.4113	6.7	71.9	286.9

Analysis of covariance

	Tests for differences[2] Slope (b) df	F ratio	Common means df	F ratio
Males between areas A, B, and D	2:283	0.22	2:285	80.9**
Females between areas A, B, and D	2:412	1.67	2:414	74.6**
Between sexes in area A	1:212	0.20	1:213	36.6**
Between sexes in area B	1:312	0.71	1:313	0.07
Between sexes in area D	1:171	2.70	1:172	38.5**

[1] See Figure 4.

[2] ** = $P \leq 0.01$.

geographical regions both male and female populations showed larger mean total lengths in this area.

Flathead sole.

Distribution and abundance.—Flathead sole were widely distributed along the outer continental shelf at bottom depths >75-90 m, with only scattered low-density occurrences in shallower inner-shelf areas (Fig. 48). Overall, flathead sole were taken at 220 (50.6%) of the 435 grid sampling stations, at a mean abundance of 4.95 kg/km trawled (Table 37). A single large concentration centered in subarea 2, between St. George and Unimak Islands, accounted for most of the estimated population biomass. Although commonly taken in other areas of the outer continental shelf and slope (subareas 3N, 3S, 2 Slope, and 3 Slope), densities in those areas were relatively low.

The total apparent population biomass of flathead sole within the study area was 99,400 t (95% confidence limits 63,800-135,000 t, approximately 88% of the 1975 survey estimate of 113,000 t (Pereyra et al. see footnote 2). The distribution of biomass among geographical regions was subarea 2, 83.9%; subareas 3N and 3S, 10.3%; subareas 2 Slope and 3 Slope (combined), 3.5%; and all inner shelf subareas (combined), 2.3%.

The total number within the 1976 study area (available to the trawl) was estimated to be 440.1 million individuals. The distribution of population numbers among geographical areas was essentially the same as apparent population biomass.

Size composition.—Flathead sole taken during the 1976 spring survey ranged from 8 to 50 cm TL, with an overall mean total length of 27.5 cm (based upon 6,479 field measurements; Fig. 49). In all subareas, male populations were composed of smaller sized

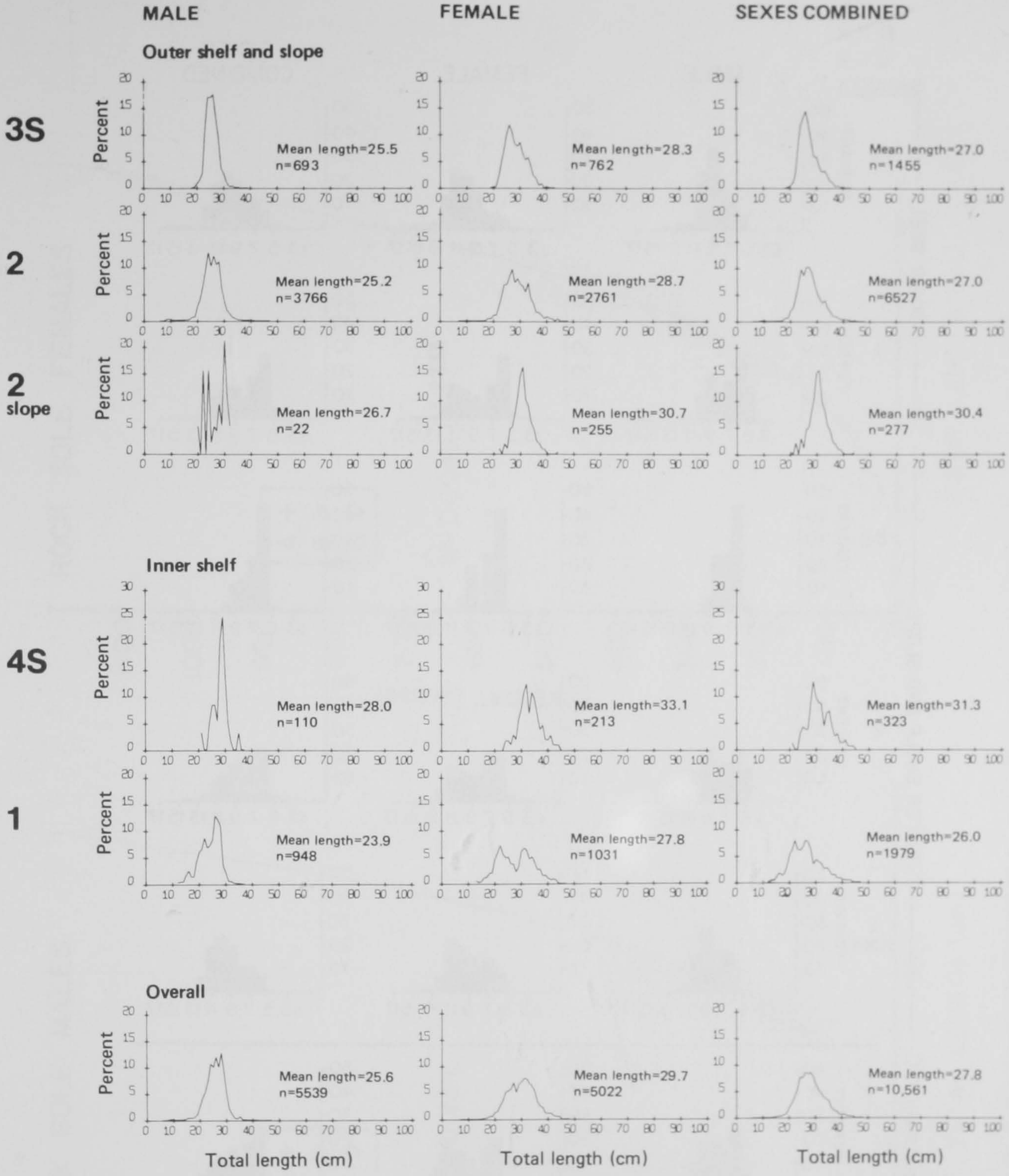


Figure 43.—Size composition of rock sole taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

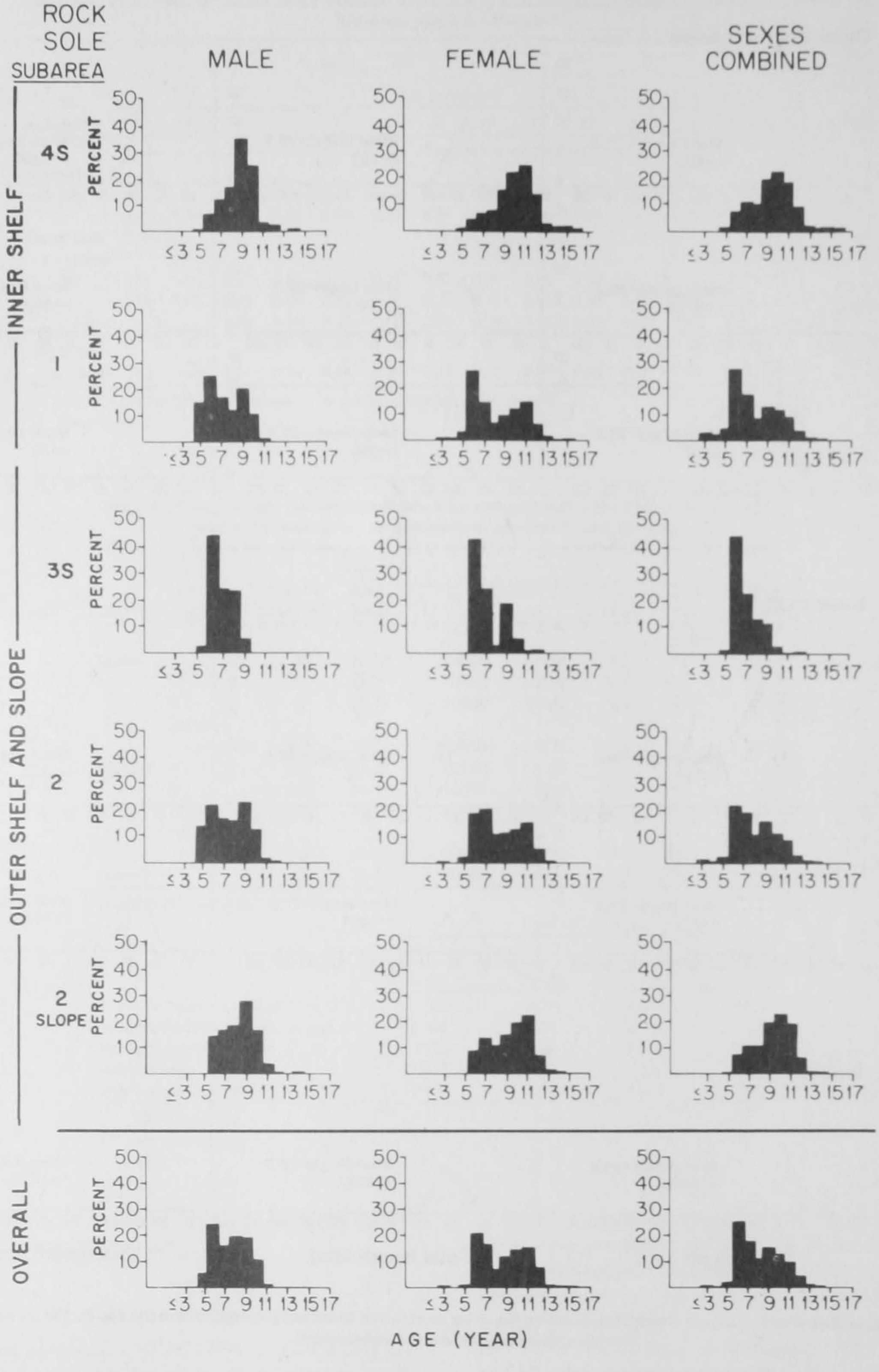


Figure 44.—Relative age composition of rock sole taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

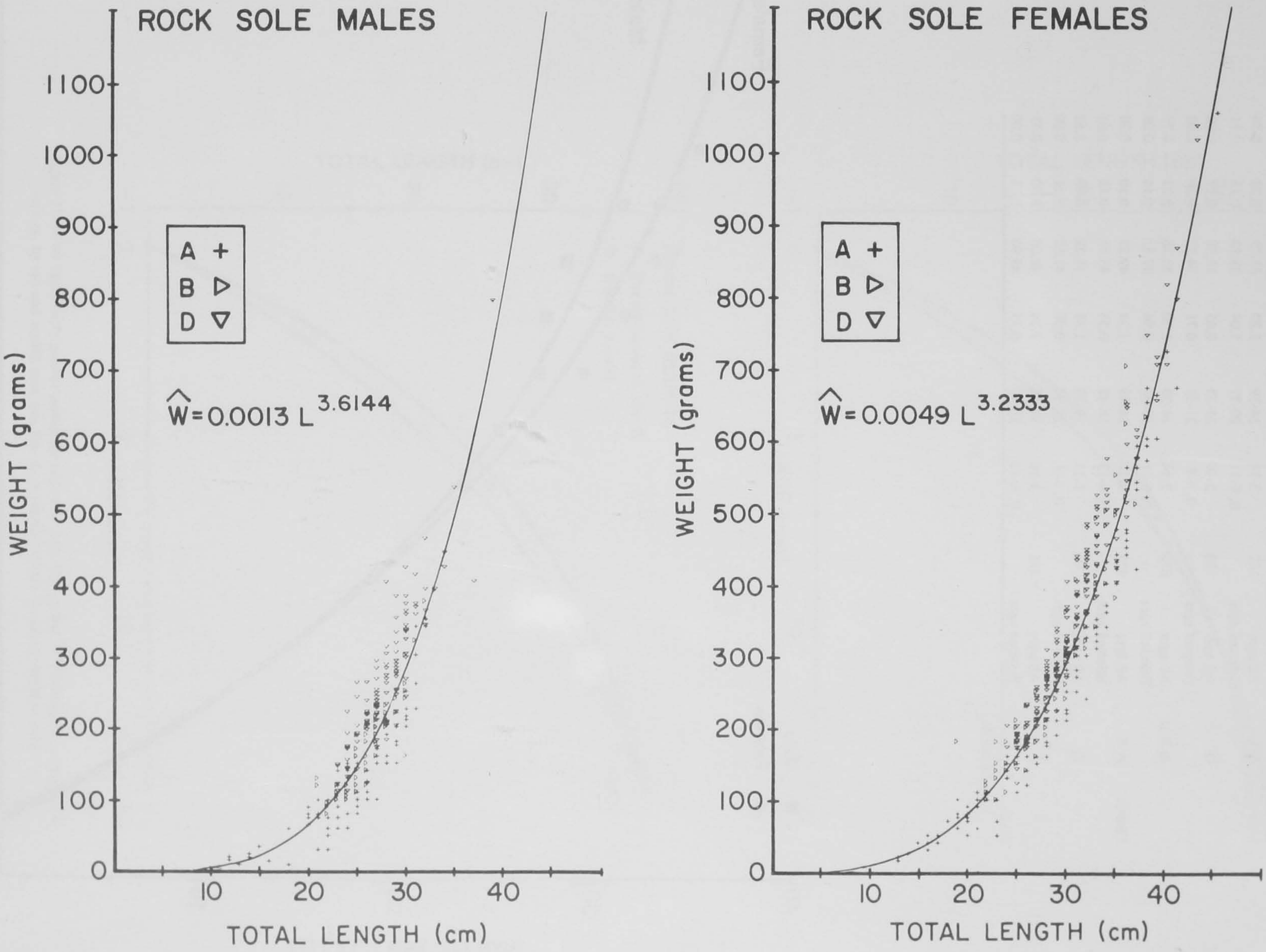


Figure 45.—Length-weight observations from rock sole taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4).

Table 36.—Parameters of the von Bertalanffy growth curves for rock sole by sex and otolith area, 1976 Bering Sea spring trawl survey.[1]

Sex	Otolith areas[1]	Data set	Number of age readings	Age range (yr)	TL range (cm)	Standard error of curve fit	Parameters		
							L_∞	K	t_0
Male	A B	All ages	182	3-14	14-39	1.20	33.29	0.22	0.76
		Selected ages		0, 6-11	20-37	1.04	38.13	0.15	0.11
	D	All ages	70	5-10	21-33	0.65	13.58	0.17	0.00
		Selected ages		0, 6-8	21-33	0.71	34.32	0.20	0.02
	A B D	All ages	252	3-14	14-39	1.20	33.36	0.23	0.73
		Selected ages		0, 6-11	20-37	0.94	37.51	0.16	0.08
Female	A B	All ages	375	3-16	14-45	1.34	49.27	0.10	−0.20
		Selected ages		0, 6-12	18-45	0.56	45.43	0.12	−0.02
	D	All ages	76	5-12	19-38	1.88	35.28	0.49	3.62
		Selected ages		0, 6-9	22-34	0.08	41.62	0.16	0.00
	A B D	All ages	451	3-16	14-45	1.34	49.06	0.10	−0.43
		Selected ages		0, 6-12	18-45	0.47	43.90	0.13	0.00

[1] See Figure 4.

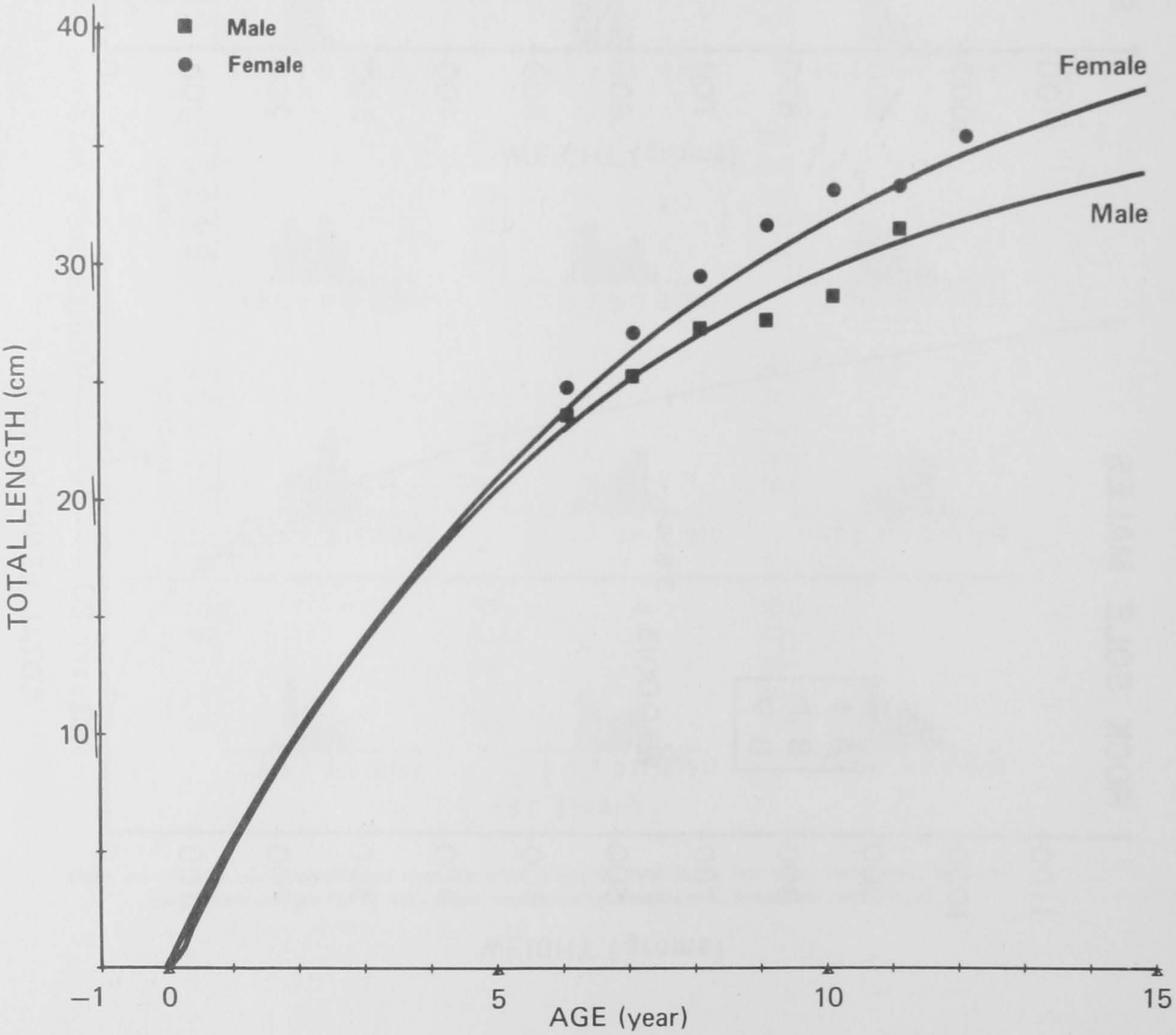
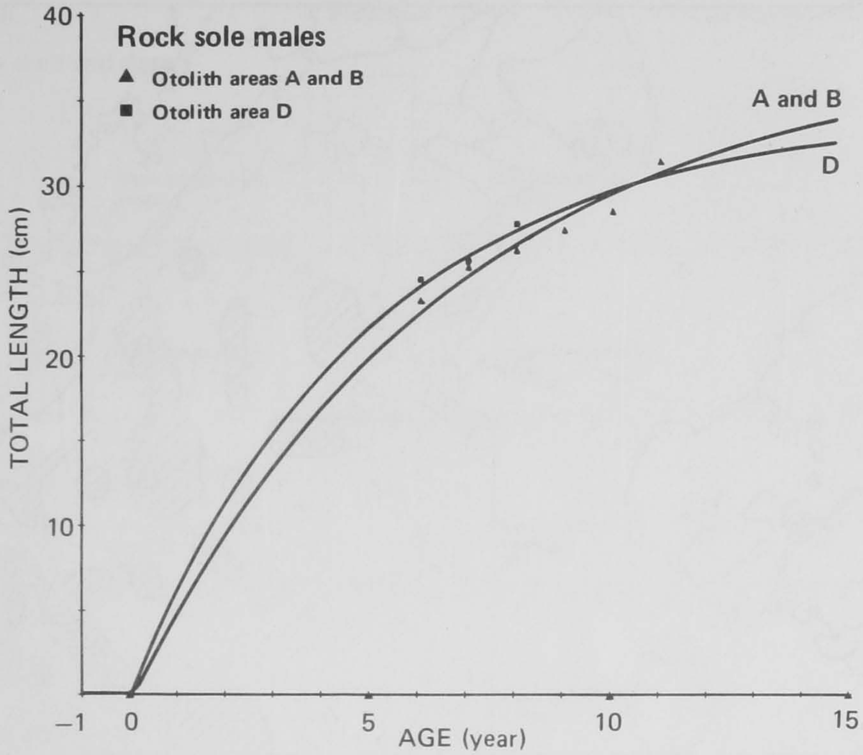


Figure 46.—Von Bertalanffy growth curves for male and female rock sole, 1976 Bering Sea spring trawl survey (selected ages). Symbols indicate the mean length at each age.



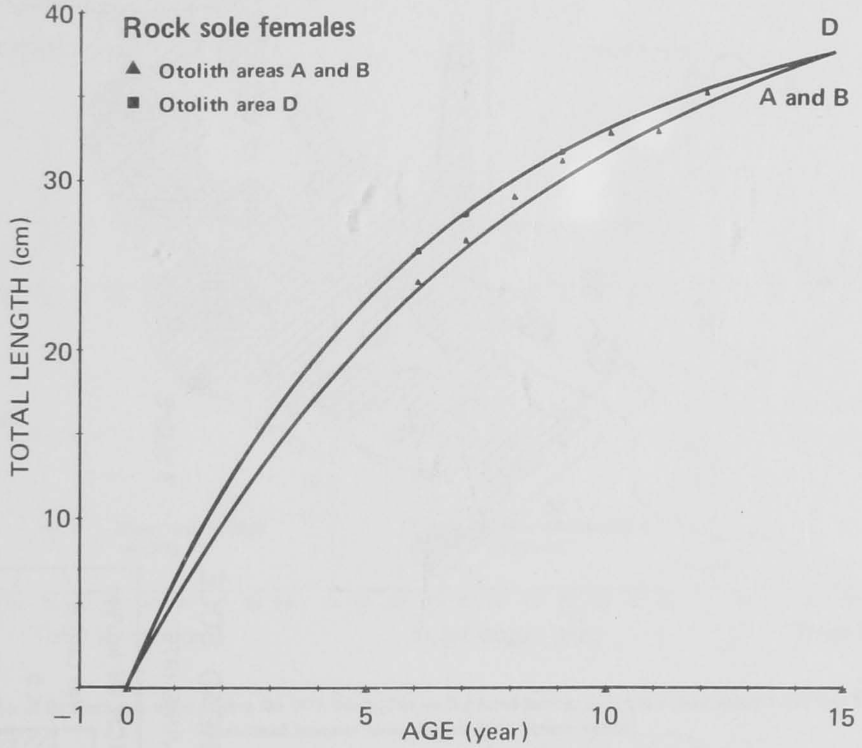


Figure 47.—Von Bertalanffy growth curves for rock sole taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4). Symbols indicate the mean length at each age.

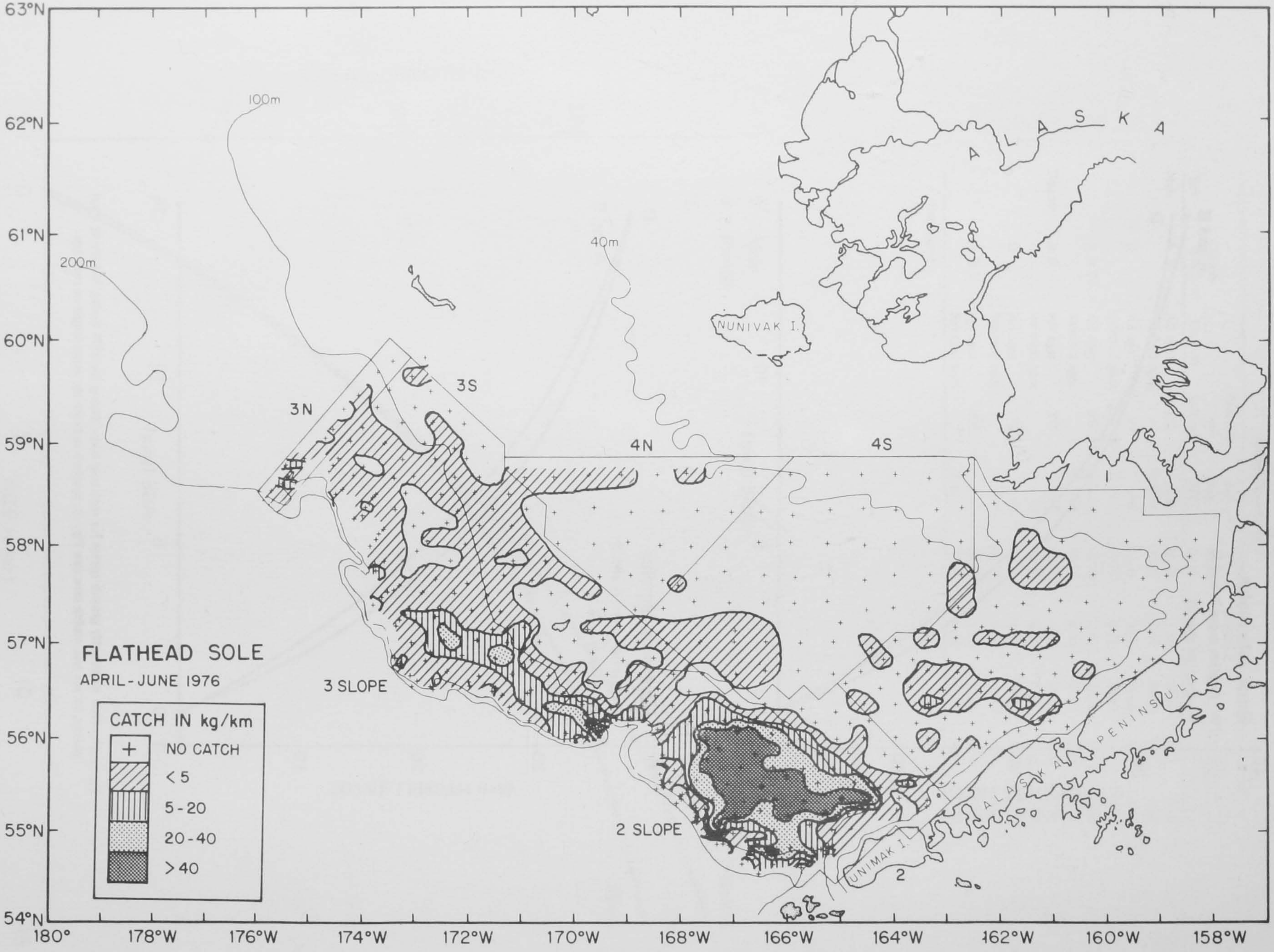


Figure 48.—Distribution and relative abundance of flathead sole during the 1976 Bering Sea spring trawl survey (by weight).

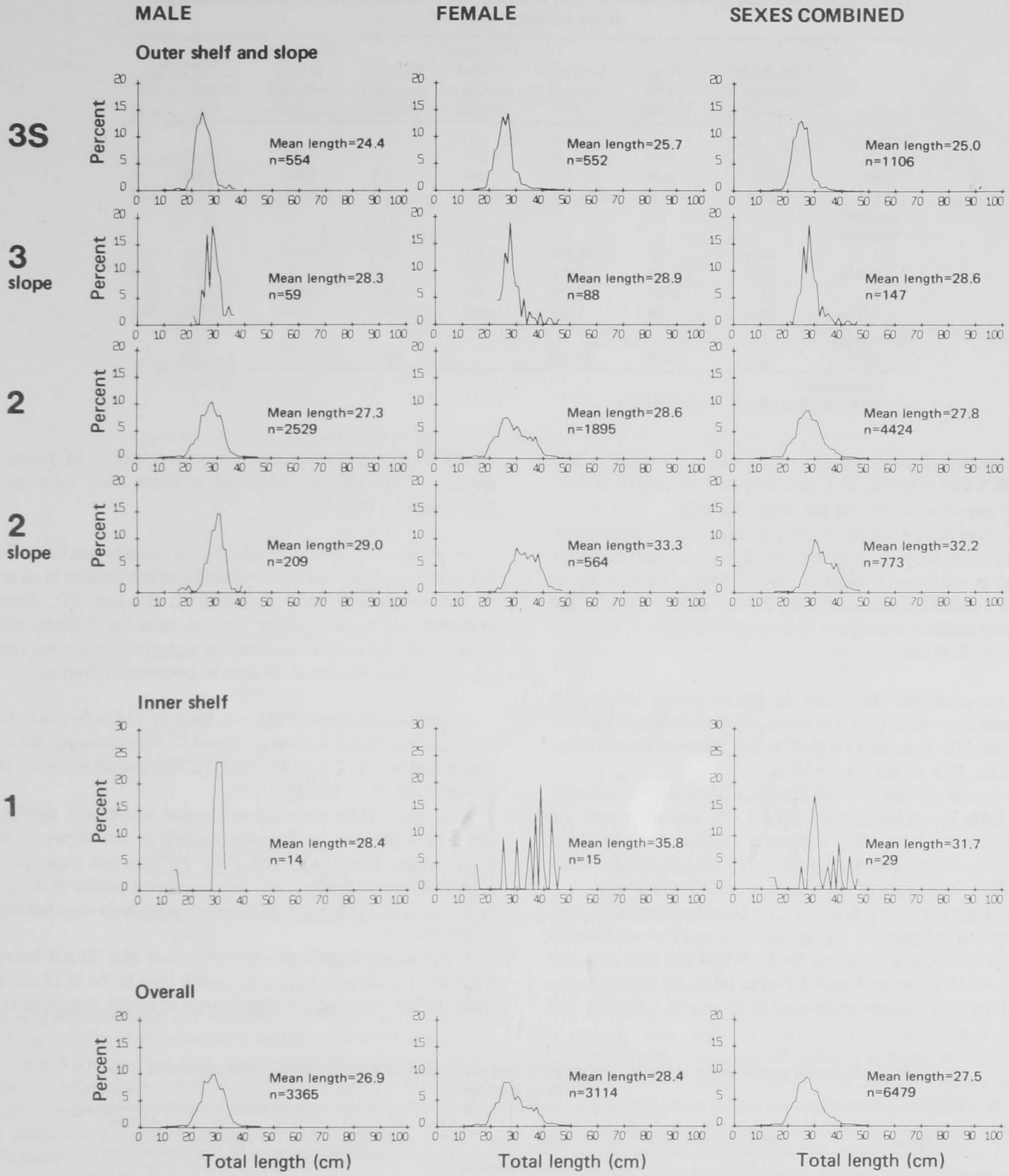


Figure 49.—Size composition of flathead sole taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

Table 37.—Estimated biomass and population numbers of flathead sole by subarea and for all subareas combined, 1976 Bering Sea spring trawl survey.

Subarea[1]	Percentage frequency of occurrence	Mean CPUE (kg/km)	Estimated biomass (t)	Proportion of total estimated biomass	Estimated population (millions)	Proportion of total estimated population	Mean size Weight (kg)	Mean size TL (cm)
Inner shelf								
4N	22.7	0.07	128	0.001	0.7	0.002	0.183	—
4S	17.9	0.08	356	0.004	2.5	0.006	0.145	—
1	25.0	0.36	1,769	0.018	4.8	0.011	0.369	31.7
Outer shelf and slope								
3	68.4	2.18	10,255	0.103	63.6	0.145	0.161	25.0
3 Slope	90.9	2.43	471	0.005	1.9	0.004	0.244	28.6
2	75.3	22.34	83,437	0.839	358.2	0.814	0.233	27.8
2 Slope	57.5	7.06	3,014	0.030	8.4	0.019	0.361	32.2
All subareas combined	50.6	4.95	[2]99,430		440.1		0.226	27.5

[1] See Figure 3.

[2] 95% confidence limits: 63,848-135,012 t.

individuals than female populations (overall mean total length: Males, 26.9 cm; females, 28.4 cm). Female populations showed higher proportions of individuals >30-35 cm TL.

Differences in size composition were also evident between geographical areas. Largest mean total lengths (sexes combined) were observed in subareas 2 Slope, 1, and 3 Slope. Populations in subareas 2 and 3S (sexes combined) showed both the largest size ranges and smallest individuals (size ranges: Subarea 2, 8-50 cm; subarea 3S, 9-48 cm).

Age composition.—Estimates of age-frequency distribution were based upon an overall collection of 183 male and 209 female saccular otoliths from areas B and D. The observed ranges in age were males, 3-15 yr; females, 3-19 yr.

The age composition of each apparent population is summarized in Table 38, excluding subareas 3N, 4S, and 4N because no length-frequency data were collected. Despite these excluded areas, Table 38 includes 435.8 million (99.0%) of the estimated 440.1 million individuals of the overall population (Table 37).

Relative age distributions between sexes and geographical areas are compared in Figure 50. Age groups 7, 8, and 9 yr were important in all subareas, accounting for 63.8% of the total apparent population. In subareas 1 and 2 Slope, relatively large proportions of the populations were aged 9 yr or older (40.1% and 45.9%, respectively). Relatively large proportions of young individuals (≤6 yr) were observed in outer shelf subareas 3S (30.9%) and 2 (17.2%).

Sex ratio.—The overall proportion of females was 0.41 (Table 39). Although males were more abundant than females in all areas of the continental shelf (subareas 1, 2, and 3S), females predominated in deep water (i.e., in subareas 2 Slope and 3 Slope). With the exception of the 6-yr age group, males were more abundant than females at all ages in combined subareas.

Length-weight relationship.—A total of 316 individuals from the populations in otolith areas B and D were measured for total length and weight (Table 40, Fig. 51). The overall observed relationship was $\hat{W} = 0.0053\ L^{3.1784}$.

Male and female populations showed statistically significant differences between geographical regions in the slopes of their length-weight linear regression lines. At sizes less than approximately 20 cm, individuals of both sexes were heavier at length in otolith area D. At larger total lengths, individuals were heavier in otolith area B.

A statistically significant difference was also found between male and female populations in otolith area B. At >13 cm TL, male flathead sole were 1-25% heavier at length than females.

Table 38.—Estimated population size of flathead sole age groups and year classes within survey subareas of the eastern Bering Sea, 1976 spring trawl survey.[1]

Subarea[2]	≤2 —	3 1973	4 1972	5 1971	6 1970	7 1969	8 1968	9 1967	10 1966	11 1965	≥12 —	Age unknown	All ages combined
	millions of fish												
Inner shelf													
1	0.10	0.21	—	—	0.01	0.71	0.91	0.93	0.28	0.35	1.30	—	4.80
Outer shelf and slope													
3S	0.06	0.64	0.29	10.48	7.85	26.69	10.65	3.20	0.92	0.78	0.90	0.06	62.52
3 Slope	—	—	—	0.03	0.07	0.71	0.53	0.28	0.09	0.08	0.13	—	1.92
2	2.57	4.53	1.41	31.74	21.47	112.89	74.07	41.55	17.11	21.68	28.02	1.18	358.22
2 Slope	—	0.05	0.01	0.07	0.09	1.39	1.60	1.30	0.69	1.16	1.82	0.16	8.34
All subareas combined	2.73	5.43	1.71	42.32	29.49	142.39	87.76	47.26	19.09	24.05	32.17	1.40	435.80
Proportion of total	0.006	0.012	0.004	0.097	0.068	0.327	0.201	0.108	0.044	0.055	0.074	0.003	

[1] Populations in subareas 3N, 4S, and 4N are not included because no length-frequency data were collected.

[2] See Figure 3.

Table 39.—Proportions of females in the estimated population of flathead sole by age group and geographical area, 1976 Bering Sea spring trawl survey.[1]

Subarea[2]	Age group (yr) ≤2	3	4	5	6	7	8	9	10	11	≥12	All ages combined
	Proportion of females											
Inner shelf												
1	—	0.50	—	—	1.00	0.40	0.18	0.23	0.50	0.25	0.87	0.45
Outer shelf and slope												
3S	—	0.41	0.51	0.42	0.51	0.53	0.44	0.52	0.43	0.32	0.45	0.49
3 slope	—	—	—	0.76	0.83	0.70	0.53	0.47	0.54	0.30	0.56	0.60
2	—	0.36	0.47	0.43	0.53	0.40	0.33	0.33	0.45	0.25	0.44	0.38
2 slope	—	0.24	0.00	0.52	0.81	0.72	0.74	0.69	0.83	0.70	0.85	0.75
All subareas combined	—	0.37	0.48	0.43	0.52	0.43	0.36	0.35	0.47	0.26	0.48	0.41

[1] Based upon sampled individuals for which sexes could be determined. Populations in subareas 3N, 4S, and 4N are not included because no length-frequency data were collected.

[2] See Figure 3.

Table 40.—Length-weight relationships observed for flathead sole during the 1976 Bering Sea spring trawl survey, with testing for between-area and between-sex differences.

Sex	Otolith area[1]	Number sampled	TL range (cm)	Length-weight coefficients *a*	*b*	Predicted weight-at-length 10 cm	20 cm	30 cm
						grams		
Males	B	112	14-35	0.0038	3.2946	7.4	72.6	276.4
	D	70	13-34	0.0085	3.0319	9.1	74.7	255.4
	Both areas combined	182	13-35	0.0043	3.2544	7.6	72.8	272.7
Females	B	65	10-39	0.0054	3.1593	7.8	69.7	251.1
	D	69	10-38	0.0101	2.9680	9.3	73.1	243.6
	Both areas combined	134	10-39	0.0073	3.0696	8.5	71.6	248.9
Overall		316	10-39	0.0053	3.1784	8.0	72.6	263.6

Analysis of covariance

	Tests for differences[2] Slope (*b*) df	F ratio	Common means df	F ratio
Males between areas B and D	1:178	7.15**	—	—
Females between areas B and D	1:130	6.70*	—	—
Between sexes in area B	1:173	3.49	1:174	36.6**
Between sexes in area D	1:135	0.39	1:136	3.39

[1] See Figure 4.

[2] * = $P \le 0.05$, ** = $P \ge 0.01$.

Age-length relationship and growth.—Because only a limited number of otoliths were collected in otolith areas B (262) and D (130), data from the two areas were combined to create more complete age-frequency tables. Results of the growth curve fittings are summarized in Table 41 and Figure 52. Male flathead sole showed a faster growth completion rate (see Equation (24)) than females, although the male asymptotic total length (selected ages) was only 70.1% that of females.

Pacific cod.

Distribution and abundance.—Pacific cod were widely distributed over the study area, being taken at 275 (63.2%) of the 435 grid stations, at an overall mean abundance of 5.12 kg/km trawled (Table 42). High densities, on a weight basis (i.e., CPUE), were observed only along the outer continental shelf and slope (in subareas 2 Slope, 2, and 3 Slope) at bottom depths > 100-150 m (Fig. 53). In shallower areas (subareas 1 and 4S), juvenile cod (age 1 yr) were abundant, but their weight density and total estimated biomass were low.

The total apparent population biomass of Pacific cod within the survey area was 102,300 t (95% confidence limits 70,600-134,000 t). Although this value is a factor of 1.59 times larger than the 1975 survey estimate of 64,500 t (Pereyra et al. see footnote 2), both estimates may considerably underestimate true Pacific cod abundance within the study area. A primary cause of underestimation may have been low catchability. Since Pacific cod exhibit semidemersal behavior, only a portion of the population may have been vertically distributed so as to be available to bottom trawling (i.e., within 1.9-2.7 m of the bottom). During the period 1973-75, foreign fishing activities removed approximately 60,000 t of Pacific cod from eastern Bering Sea and Aleutian Island waters per year, although not all of these catches were taken within the 1975 and 1976 study area boundaries.

The distribution of apparent population biomass observed during the 1976 spring survey was 74.3% in subareas 2 and 2 Slope (combined), 24.2% in subareas 3N, 3S, and 3 Slope (combined), and only 1.5% in inner shelf subareas 1, 4S, and 4N (combined).

The total number of Pacific cod within the study area (available to the trawl) was estimated to be 128.2 million individuals. In

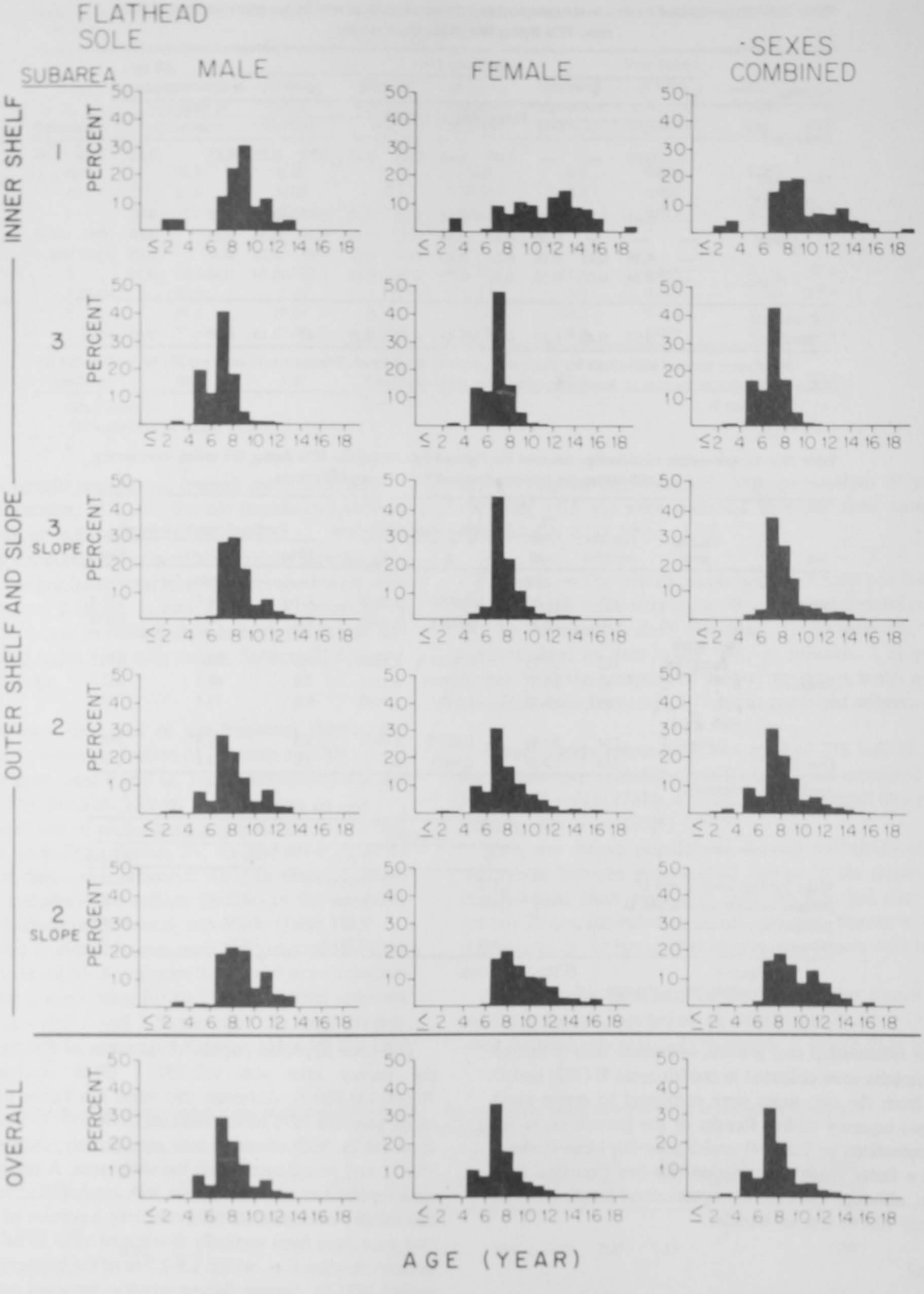


Figure 50.—Relative age composition of flathead sole taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

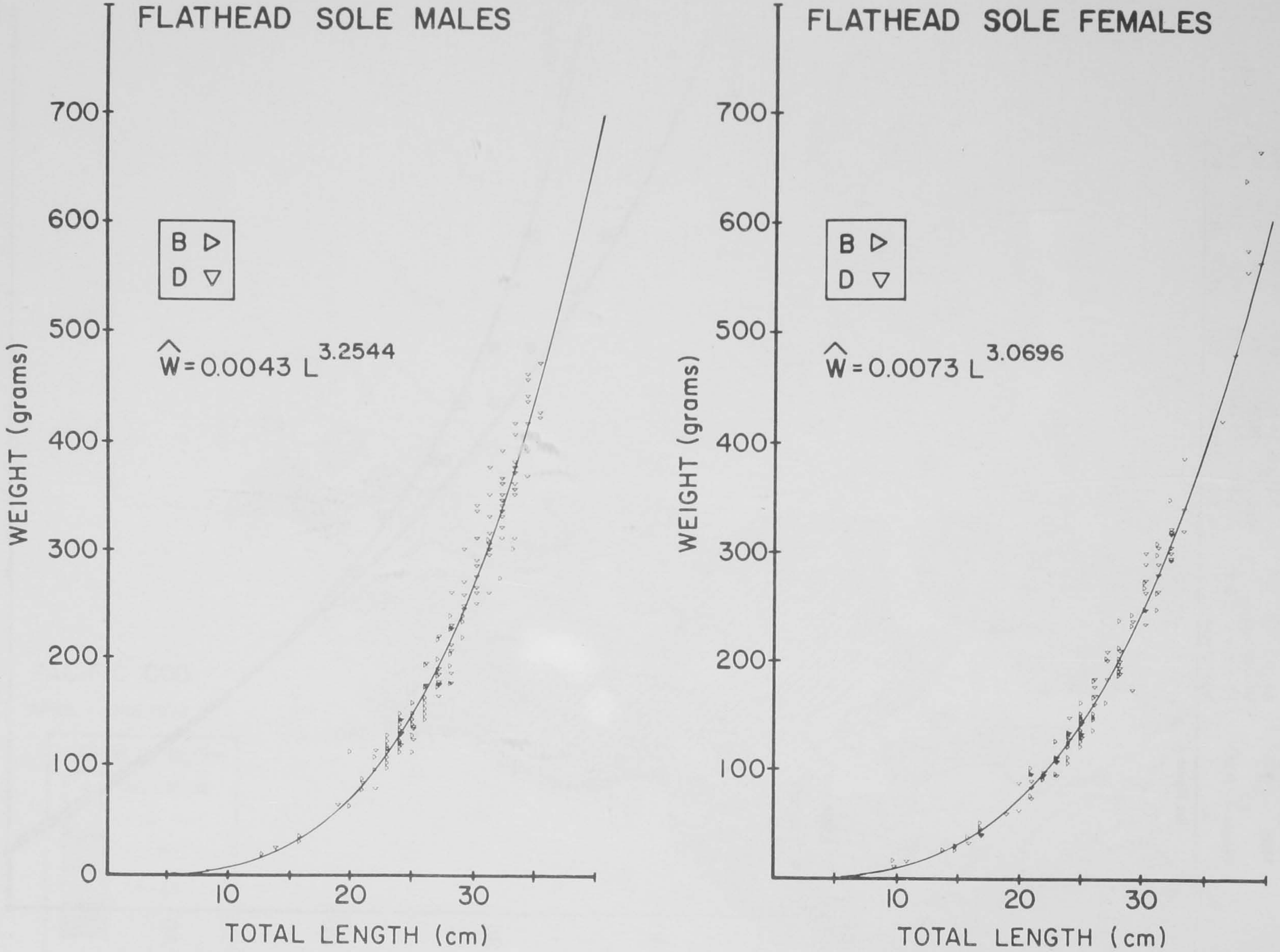


Figure 51.—Length-weight observations from flathead sole taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4).

Table 41.—Parameters of the von Bertalanffy growth curves for flathead sole, 1976 Bering Sea spring trawl survey.

Sex	Otolith area[1]	Data set	Number of age readings	Age range (yr)	TL range (cm)	Standard error of curve fit	Parameters		
							L_∞	K	t_0
Male	B D	All ages	183	3-15	14-36	0.63	40.39	0.13	−0.50
		Selected ages		0, 5-11	18-36	0.41	39.14	0.15	0.03
Female	B D	All ages	209	3-19	15-48	1.82	66.81	0.06	−0.97
		Selected ages		0, 5-11	18-40	0.67	55.87	0.10	0.11

[1] See Figure 4.

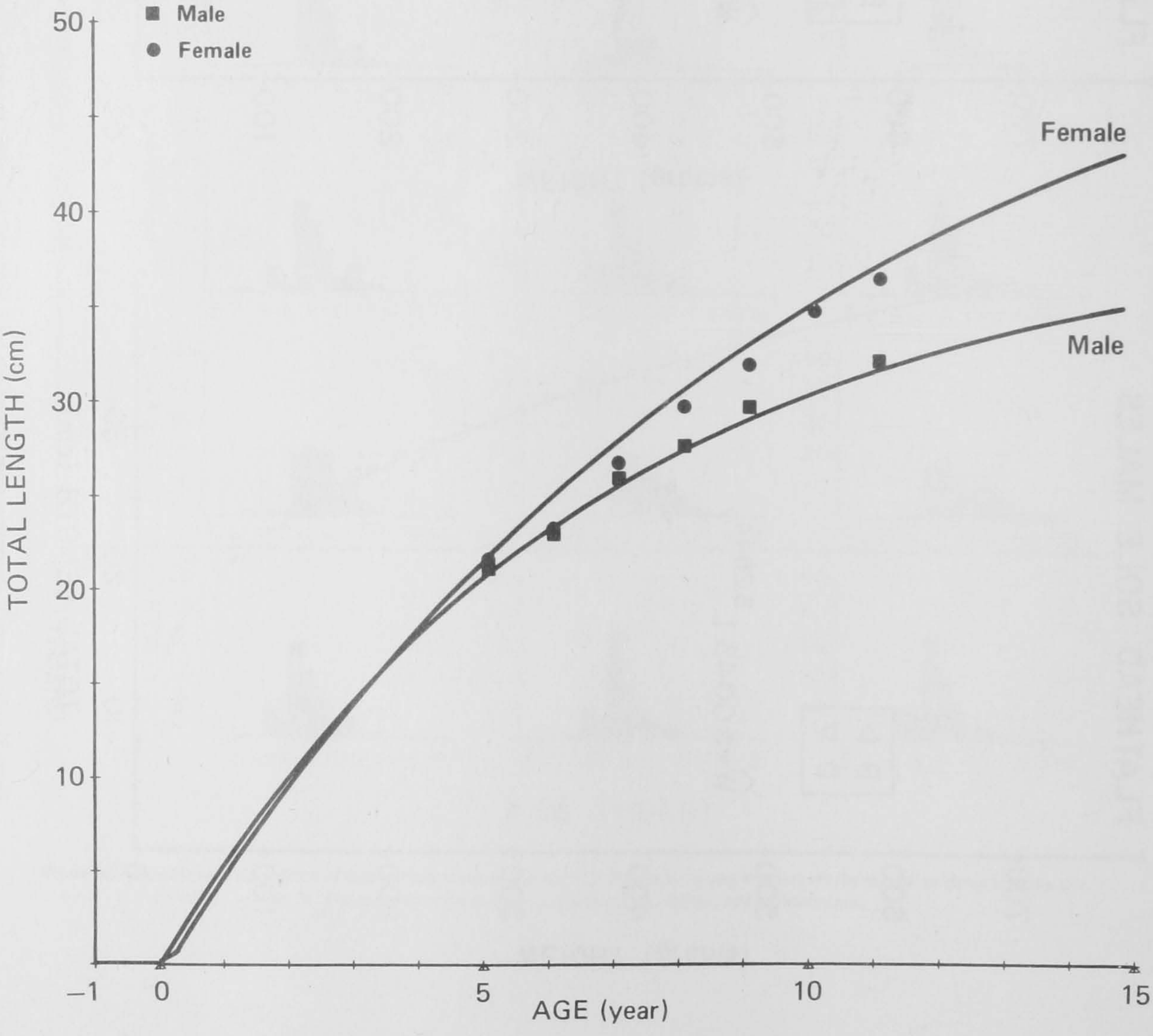


Figure 52.—Von Bertalanffy growth curves for male and female flathead sole, 1976 Bering Sea spring trawl survey (selected ages). Symbols indicate the mean length at each age.

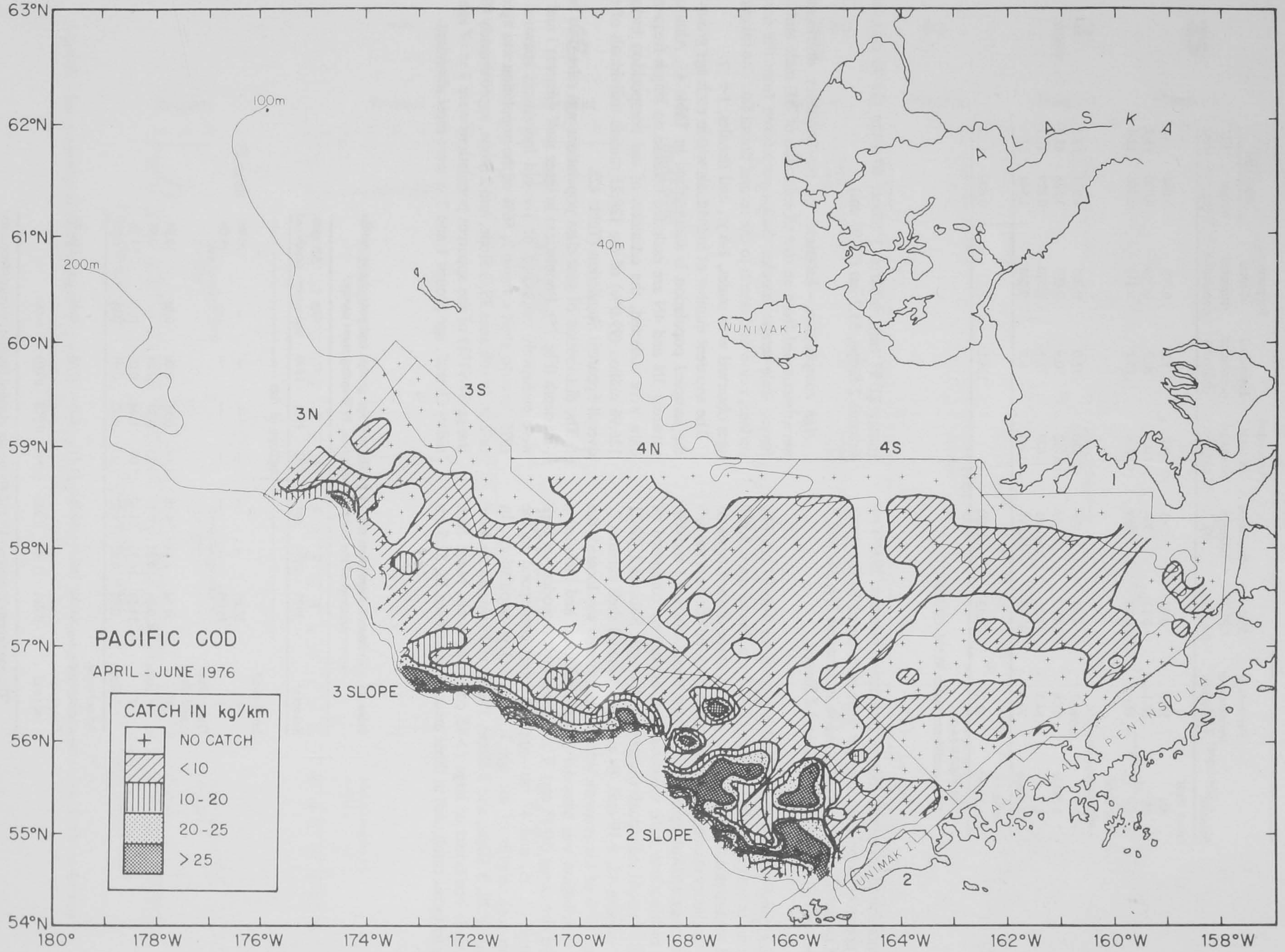


Figure 53.—Distribution and relative abundance of Pacific cod during the 1976 Bering Sea spring trawl survey (by weight).

Table 42.—Estimated biomass and population numbers of Pacific cod by subarea and for all subareas combined, 1976 Bering Sea spring trawl survey.

Subarea[1]	Percentage frequency of occurrence	Mean CPUE (kg/km)	Estimated biomass (t)	Proportion of total estimated biomass	Estimated population (millions)	Proportion of total estimated population	Mean size Weight (kg)	Mean size FL (cm)
Inner shelf								
4N	59.1	0.02	41	< 0.001	1.2	0.009	0.034	—
4S	66.1	0.12	534	0.005	20.9	0.163	0.026	13.2
1	41.0	0.20	989	0.010	15.1	0.118	0.066	18.4
Outer shelf and slope								
3	60.7	4.59	21,496	0.210	11.0	0.086	1.953	52.5
3 Slope	63.6	16.72	3,239	0.032	0.9	0.007	3.536	65.4
2	84.3	17.21	64,285	0.629	73.1	0.570	0.879	37.1
2 Slope	77.5	27.39	11,698	0.114	6.0	0.046	1.944	53.7
All subareas combined	63.2	5.12	[2]102,282		128.2		0.809	33.2

[1] See Figure 3.

[2] 95% confidence limits: 70,581-133,983 t.

comparison to the distribution of population biomass, 29.0% of the apparent population number were distributed in the inner shelf (subareas 1, 4S, and 4N); 9.3% in subareas 3N, 3S, and 3 Slope; and 61.6% in subareas 2 and 2 Slope.

Size composition.—Pacific cod ranged from 9 to 97 cm FL, with an overall mean fork length of 33.2 cm (based upon 3,938 field measurements; Fig. 54). In general, three distinct types of size-frequency distributions were shown by populations in the different geographical regions. In the inner shelf (subareas 1 and 4S), size distributions were unimodal and exclusively composed of small, 1-yr-old individuals (range in fork length: Subarea 1, 12-21 cm; subarea 4S, 9-19 cm). In outer continental shelf subarea 2, where 63% of the apparent population biomass was located, the size distribution was trimodal (sexes combined) and included a broad size range (10-85 cm). The three principal modes—at fork lengths 17, 35, and 47 cm—approximately correspond to the mean fork lengths of the age 1, 2, and 3 yr populations. In subareas 3S, 3 Slope, and 2 Slope, Pacific cod populations were primarily composed of large (>45 cm) individuals. Mean fork lengths (sexes combined) in those areas were subarea 3S, 52.5 cm (range 21-97 cm); subarea 3 Slope, 65.4 cm (31-90 cm); and subarea 2 Slope, 53.7 cm (31-97 cm).

Age composition.—Estimates of age-frequency distribution were determined from an overall collection of 200 male and 185 female scale scrape samples. Scales were taken from the dorsal surface, below and lateral to the second dorsal fin. The ranges in ages observed were males, 1-6 yr, and females, 1-6 yr.

The apparent number of individuals within each age group of the sampled population is summarized in Table 43. Although subareas 3N and 4N are excluded because no length-frequency data were collected, the estimates of age composition include 126.96 million (99.0%) of the 128.21 million individuals of the overall apparent population (Table 42).

The distribution of year-class populations was related to bottom depth (Fig. 55). Populations in inner shelf subareas 1 and 4S were exclusively composed of 1-yr-old individuals spawned in 1975. In outer shelf subarea 2, 56% of the population was aged 1 or 2 yr. In subareas 3S, 3 Slope, and 2 Slope, approximately 89% (range 84-97%) of the apparent populations were 3 yr of age or older. Overall, age groups 1 and 3 yr were most abundant.

Table 43.—Estimated population size of Pacific cod age groups and year classes within survey subareas of the eastern Bering Sea, 1976 spring trawl survey.[1]

Subarea[2]	1 1975	2 1974	3 1973	4 1972	5 1971	6 1970	Age unknown	All ages combined
	millions of fish							
Inner shelf								
4S	20.86	—	—	—	—	—	—	20.86
1	15.09	—	—	—	—	—	—	15.09
Outer shelf and slope								
3S	0.54	1.52	4.59	3.18	0.95	0.08	0.08	10.94
3 Slope	< 0.01	0.02	0.15	0.43	0.27	0.04	—	0.91
2	24.51	16.55	23.10	7.00	1.64	0.05	0.29	73.14
2 Slope	0.03	0.65	3.02	1.80	0.42	0.01	0.09	6.02
All subareas combined	61.03	18.74	30.86	12.41	3.28	0.18	0.46	126.96
Proportion of total	0.481	0.148	0.243	0.098	0.026	0.001	0.004	

[1] The populations in subareas 3N and 4N are not included because no length-frequency data were collected.

[2] See Figure 3.

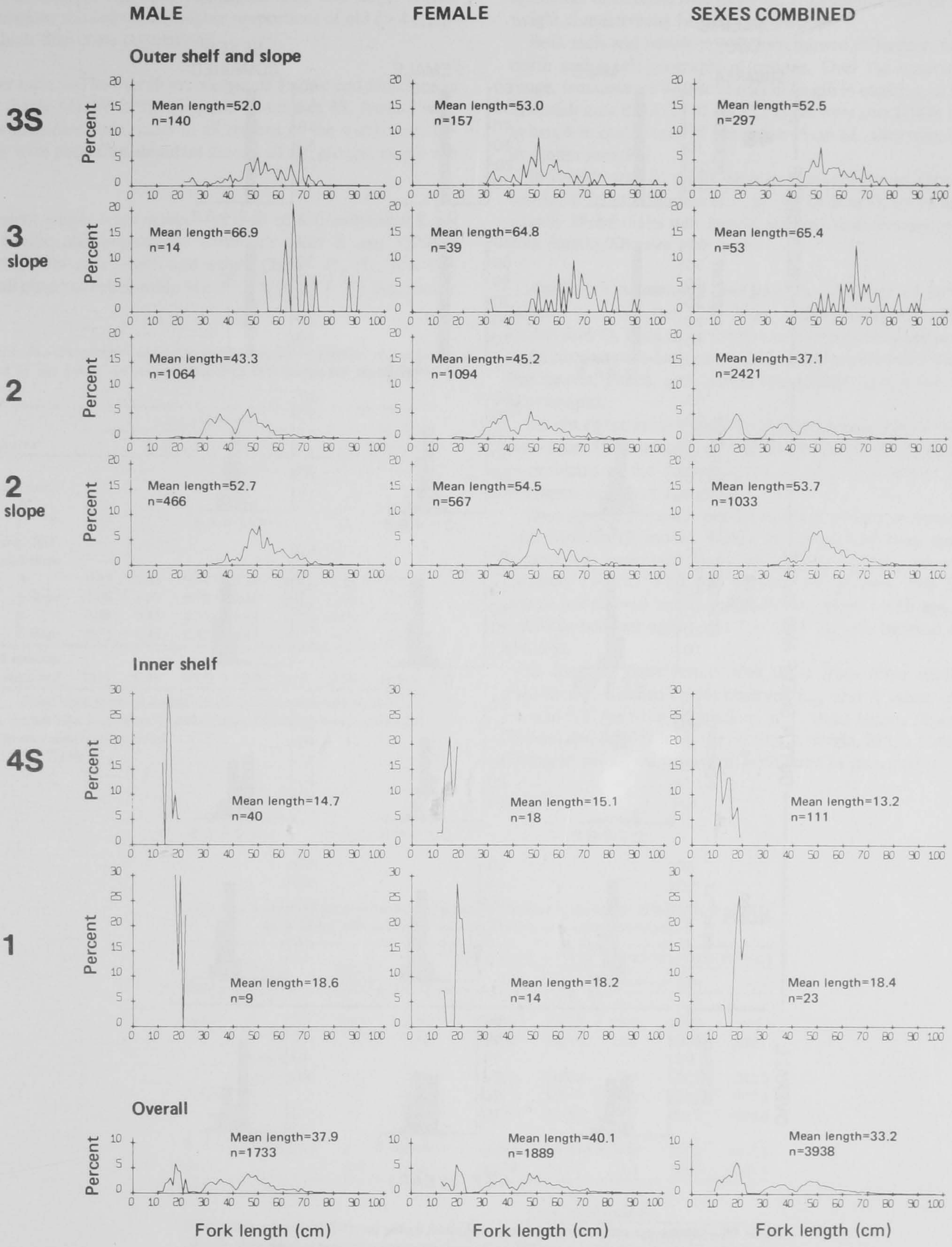


Figure 54.—Size composition of Pacific cod taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

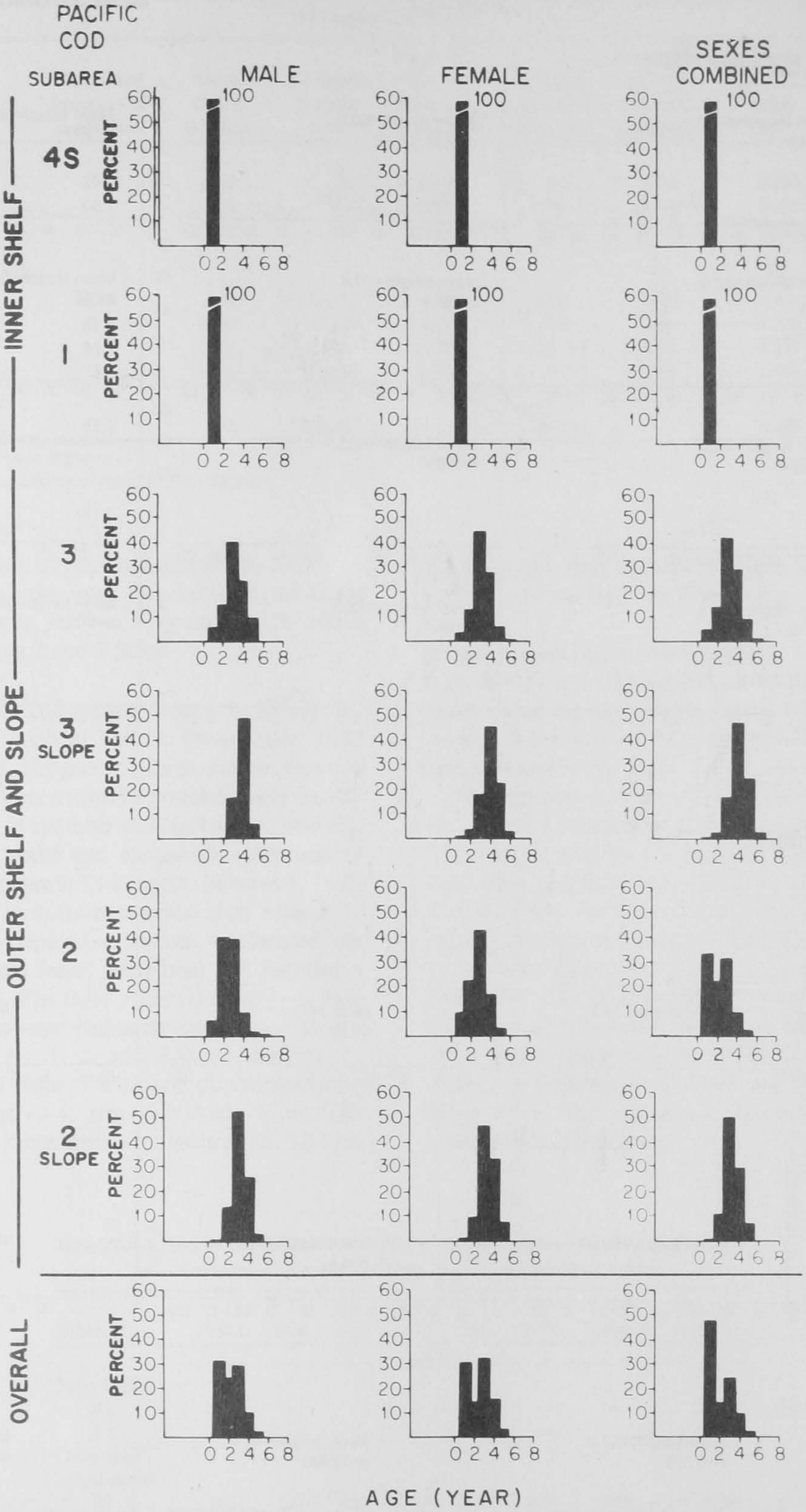


Figure 55.—Relative age composition of Pacific cod taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

In all areas of the outer continental shelf and slope, female populations showed slightly higher proportions of old (> 4 yr) individuals than male populations.

Sex ratio.—The overall proportion of Pacific cod females was 0.51 (Table 44). With the exception of subarea 4S, females were more abundant than males in all regions of the study area. Females were also more abundant among all age groups, except age 2 yr.

Length-weight relationship.—A total of 650 individuals from the Pacific cod populations in otolith areas B and D were measured for fork length and weight (Table 45, Fig. 56). The overall observed relationship was $\widehat{W} = 0.0072\,L^{3.1125}$. Statistically significant differences were observed in all comparisons of length-weight characteristics between populations.

Table 44.—Proportions of females in the estimated population of Pacific cod by age group and geographical area, 1976 Bering Sea spring trawl survey.[1]

Subarea[2]	Age group (yr) 1	2	3	4	5	6	All ages combined
	Proportion of females						
Inner shelf							
4S	0.32	—	—	—	—	—	0.32
1	0.61	—	—	—	—	—	0.61
Outer shelf and slope							
3S	0.37	0.49	0.54	0.56	0.39	0.96	0.52
3 Slope	1.00	1.00	0.75	0.72	0.91	1.00	0.74
2	0.58	0.37	0.53	0.65	0.65	0.00	0.51
2 Slope	0.75	0.46	0.52	0.62	0.73	1.00	0.55
All subareas combined	0.51	0.38	0.53	0.62	0.59	0.54	0.51

[1] Based upon sampled individuals for which sexes could be determined. Populations in subareas 3N and 4N are not included because no length-frequency data were collected.

[2] See Figure 3.

Both male and female populations showed differences between north and south geographical regions. Over the observed size range, females were 9-10% heavier at length in otolith area D than in otolith area B. Up to 65 cm FL, males were also 1-58% heavier at length in otolith area D, but above 65 cm FL, they were heavier in otolith area B.

In otolith area B, males were increasingly (up to about 4%) heavier at length than females. In otolith area D, up to approximately 50 cm, males were heavier at length than females; at larger fork lengths, females were heavier.

Age-length relationship and growth.—A total of 385 scale samples were collected, 215 from otolith area B and 170 from otolith area D. Data from the two areas were combined to create more complete age-frequency tables. Compared to other demersal fish species, Pacific cod showed remarkably rapid growth at all ages sampled.

Results of the growth curve fittings are summarized in Table 46 and Figure 57. In general, the results were poor and indicated likely problems in the determination of ages, particularly for the youngest and oldest age groups.

Data sets including all ages did not fit the decaying exponential (von Bertalanffy) model. Within the male population, apparent growth was essentially linear with nearly constant growth increments (+8 to +10 cm) between age groups. The female population showed increasing growth increments with age, from +8.3 cm between ages 1 and 2 yr to +16.8 cm between ages 5 and 6 yr.

To compare these results with those from other studies of Pacific cod, Ketchen (1964) observed L_∞ and K values of 94.0 cm and 0.27/yr from populations in northern Hecate Strait, and 75.0 cm and 0.56/yr from the Strait of Georgia, British Columbia (fitting to combined data from both sexes in each study).

Table 45.—Length-weight relationships observed for Pacific cod during the 1976 Bering Sea spring trawl survey, with testing for between-area and between-sex differences.

Sex	Otolith area[1]	Number sampled	FL range (cm)	Length-weight coefficents *a*	*b*	Predicted weight-at-length 10 cm	40 cm	70 cm
						grams		
Males	B	213	31-74	0.0070	3.1213	9.2	697.0	3998.1
	D	60	32-90	0.0198	2.8693	14.6	780.8	3889.4
	Both areas combined	273	31-90	0.0079	3.0893	9.7	706.9	3982.7
Females	B	253	32-81	0.0074	3.0984	9.2	681.2	3857.8
	D	124	28-107	0.0078	3.1081	10.0	743.9	4235.8
	Both areas combined	377	28-107	0.0065	3.1412	8.9	695.2	4032.2
Overall		650	28-107	0.0072	3.1125	9.3	701.4	4003.9

Analysis of covariance

	Tests for differences[2] Slope (*b*) df	F ratio	Common means df	F ratio
Males between areas B and D	1:269	6.32*	—	—
Females between areas B and D	1:373	0.19	1:374	33.3**
Between sexes in area B	1:462	0.17	1:463	4.77*
Between sexes in area D	1:180	4.97*	—	—

[1] See Figure 4.

[2] * = $P \leq 0.05$, ** = $P \leq 0.01$.

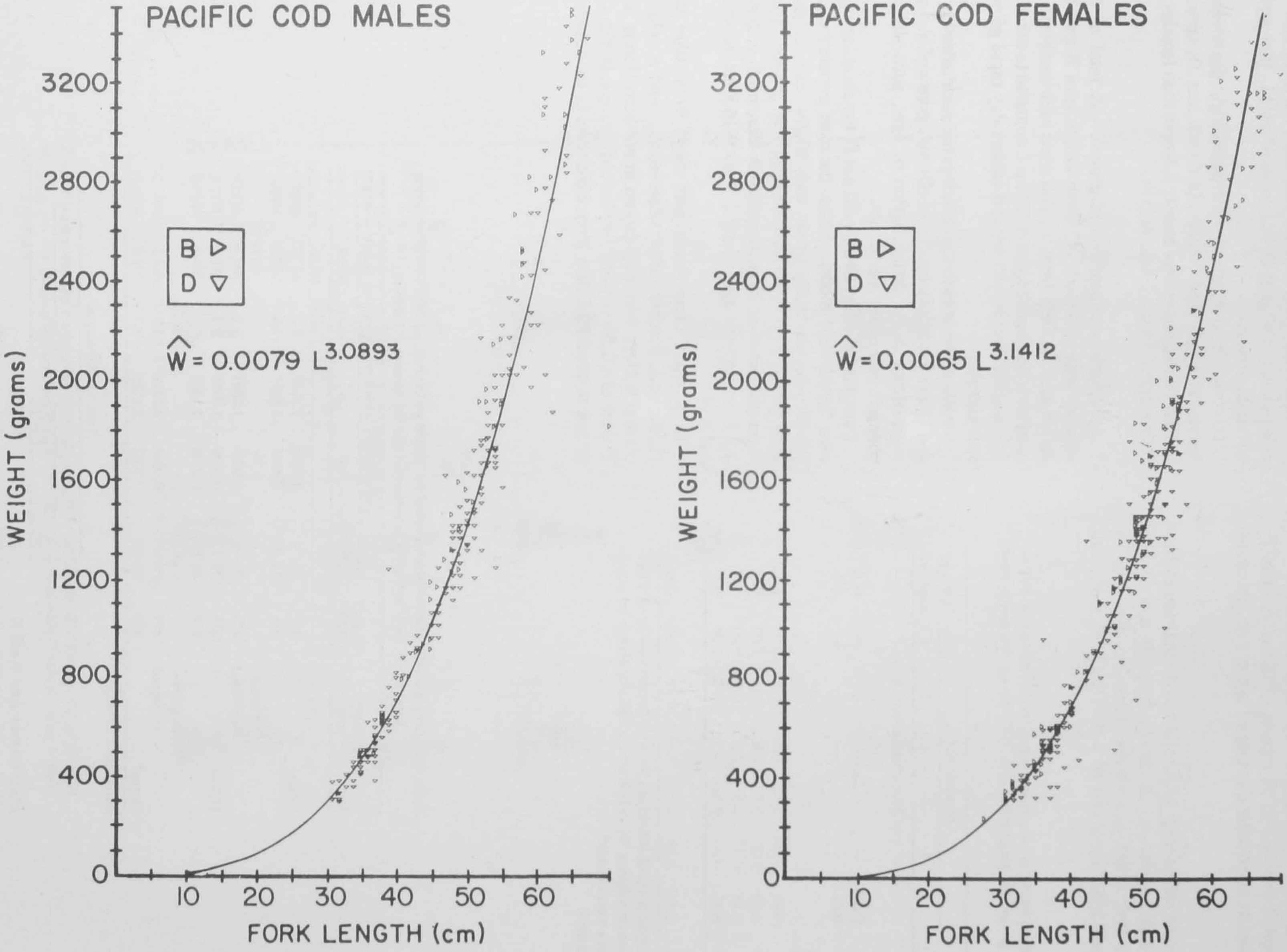


Figure 56.—Length-weight observations from Pacific cod taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4).

Table 46.—Parameters of the von Bertalanffy growth curves for Pacific cod, 1976 Bering Sea spring trawl survey.[1]

Sex	Otolith area[2]	Data set	Number of age readings	Age range (yr)	FL range (cm)	Standard error of curve fit	Parameters		
							L_∞	K	t_0
Male	B D	All ages	200	1-6	28-76	1.24	(– 124.95)	(– 0.05)	(– 3.58)
		Selected ages		0, 2-4	30-75	0.72	86.94	0.25	0.01
Female	B D	All ages	185	1-6	28-90	0.66	(3.61)	(–0.22)	(0.00)
		Selected ages		0, 2-5	31-90	2.55	140.25	0.13	0.07

[1] Parentheses indicate results where the von Bertalanffy model was inappropriate.

[2] See Figure 4.

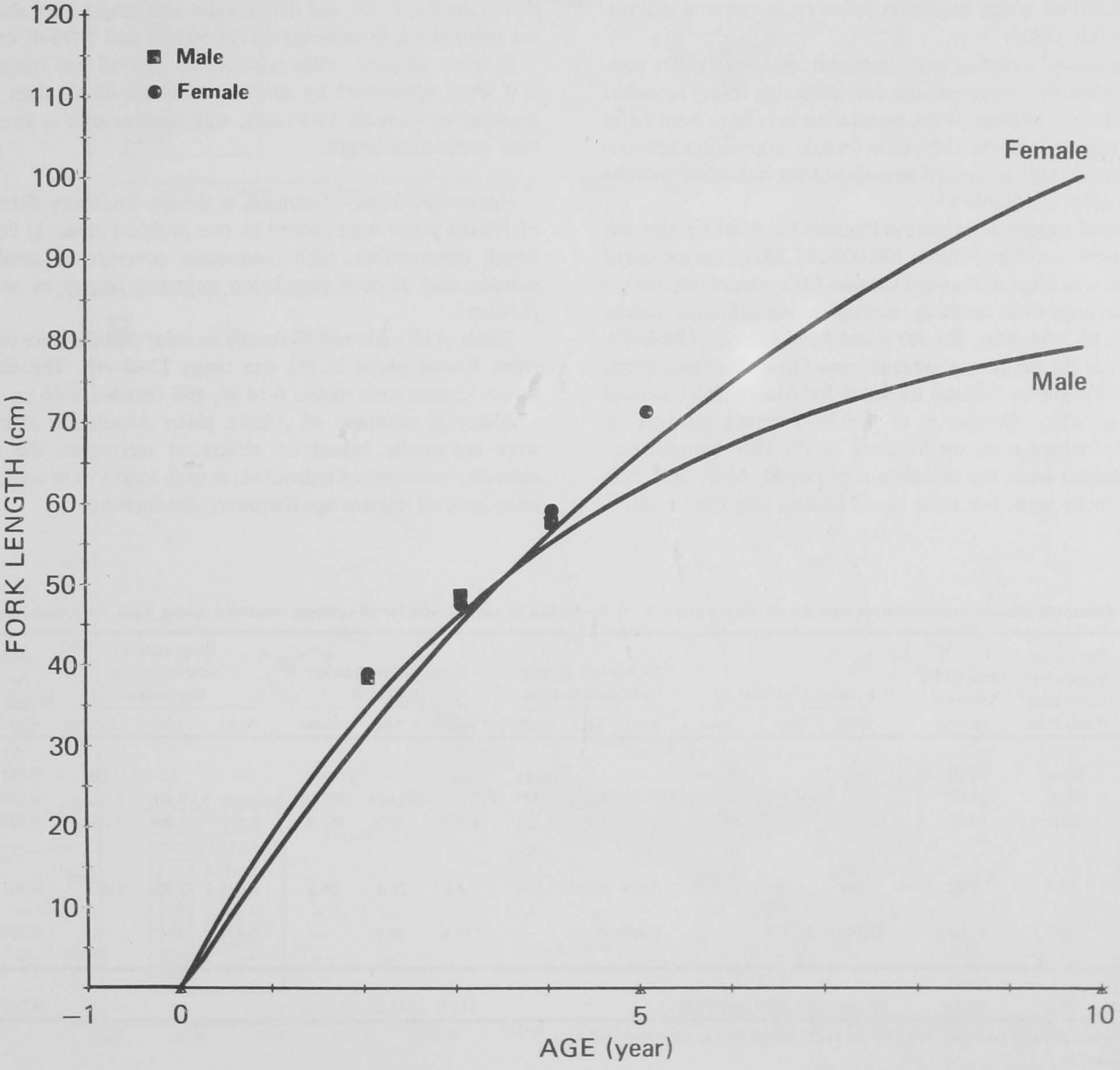


Figure 57.—Von Bertalanffy growth curves for male and female Pacific cod, 1976 Bering Sea spring trawl survey (selected ages). Symbols indicate the mean length at each age.

Alaska plaice.

Distribution and abundance.—During the entire survey period, April-June 1976, Alaska plaice were taken over a broad, central region of the study area, from inner Bristol Bay to the outer continental shelf (Fig. 58, 59). Although Alaska plaice were moderately abundant over their geographical range compared to most fish taxa, very high densities (>200 kg/km trawled) were never observed. Overall, Alaska plaice occurred at 261 (60.0%) of the 435 grid stations at a mean abundance of 12.19 kg/km (Table 47).

However, like yellowfin sole, the Alaska plaice population was apparently migrating inshore during the survey period. In April, a large high-density concentration was encountered between Unimak Island and the pack ice edge. In May, after the ice edge had receded north and allowed fishing on the inner shelf, two major concentrations were encountered east of the Pribilof Islands. Two large high-density regions were also evident in June, west and southwest of Cape Newenham, in addition to smaller concentrations directly north of the Alaska Peninsula and in midshelf. By July and August, Alaska plaice showed only restricted low-density distributions in outer shelf subareas 2 and 3S. The overall observed pattern of spring migration followed the general description of Fadeev (1965).

Because survey sampling and the migrating Alaska plaice population apparently progressed together, following spring recession of the pack ice, coverage of the population may have been fairly complete each month. As with yellowfin sole, population and biomass estimates were computed overall and for individual months of survey coverage (Table 47).

The overall apparent population biomass for Alaska plaice was 243,700 t (95% confidence limits 190,000-297,200 t); the estimated population was 856.4 million individuals. Estimates of population biomass obtained from sampling coverage during individual months were April, 83,700 t; May, 221,300 t; and June, 169,900 t (Table 47).

Because of the sampling problems caused by inshore migration, all of the 1976 survey biomass estimates for Alaska plaice were of dubious accuracy. Compared to the 1975 survey estimate of 127,000 t (Pereyra et al. see footnote 2), the 1976 biomass estimates obtained from the overall survey period, May, and June appeared to be high. For these cases, biasing may have resulted from oversampling of high-density concentrations, particularly in subarea 4S.

Although the precision obtained in the 1975 and 1976 survey overall biomass estimates was approximately the same, the 1976 monthly estimates were relatively imprecise. As a measure of relative variance, the width of the 95% confidence limits for each 1976 biomass estimate (expressed as a percentage of the estimated total biomass) was overall, ±22%; April, ±73%; May, ±43%; and June, ±36%. The relative variation observed in the 1975 survey estimate for Alaska plaice was ±20%.

During May and June 1976, approximately 82% of the apparent population biomass was distributed in survey subareas 4S and 1.

Size composition.—Alaska plaice taken during the 1976 spring survey ranged from 11 to 50 cm TL, with an overall mean total length of 28.3 cm (based upon 9,788 field measurements; Fig. 60). Similar size-frequency distributions were observed from all geographical areas. Overall (sexes combined), individuals in the size range 25-31 cm TL accounted for 50.2% of the total apparent population. Small individuals (< 20 cm) occurred only in inner shelf subareas 1, 4S, and 4N. Largest size ranges were shown by the populations in subareas 4S (11-50 cm) and 1 (13-47 cm).

In most subareas, male populations (overall size range 11-41 cm) were represented by smaller sized individuals than female populations (overall, 17-50 cm), with less variance in size about their mean total length.

Age composition.—Estimates of the age-frequency distribution of Alaska plaice were limited by two problem areas: 1) Few age-length observations, with inadequate coverage of small individuals, and 2) poor population estimates caused by sampling problems.

Totals of 69 male and 88 female saccular otoliths were collected from Alaska plaice in the size range 22-48 cm. The observed ranges in ages were males, 6-14 yr, and females, 6-16 yr.

Although estimates of Alaska plaice population abundance were apparently biased by effects of migration, the overall estimated numbers of individuals at each length were used as best estimators of relative age-frequency distribution.

Table 47.—Estimated biomass and population numbers of Alaska plaice in the Bering Sea by subarea and for all subareas combined during April, May, and June 1976.[1]

Subarea[2]	Percentage frequency of occurrence April-June	Mean CPUE April-June (kg/km)	Estimated biomass (t)			Proportion of total estimated biomass			Estimated population (millions)			Proportion of total estimated population			Mean size April-June	
			April	May	June	April	May	June	April	May	June	April	May	June	Weight (kg)	TL (cm)
Inner shelf																
4N	100.0	10.40	—	—	19,214	—	—	0.113	—	—	73.4	—	—	0.129	0.262	27.5
4S	100.0	29.07	—	(134,055)	(90,947)	—	0.606	0.535	—	(434.0)	(297.7)	—	0.600	0.522	0.270	27.7
1	80.0	10.71	40,453	47,211	49,440	0.483	0.213	0.291	173.2	149.9	162.9	0.551	0.207	0.286	0.323	29.6
Outer shelf and slope																
3	50.4	1.92	2,306	8,888	10,318	0.028	0.040	0.061	4.8	28.6	36.1	0.015	0.040	0.063	0.302	29.0
3 Slope	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	49.4	10.02	40,940	31,154	—	0.489	0.141	—	136.6	110.7	—	0.434	0.153	—	0.298	29.0
2 Slope	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
All subareas combined	60.0	12.19	[3]83,698	(221,307)[3]	(169,919)[3]				314.6	(723.2)	(570.0)				0.285	28.3

[1] Parentheses indicate estimates that may be badly biased due to sampling problems.

[2] See Figure 3.

[3] 95% confidence limits: April: 22,632-144,764 t.
May: 126,070-316,545 t
June: 108,464-231,375 t.

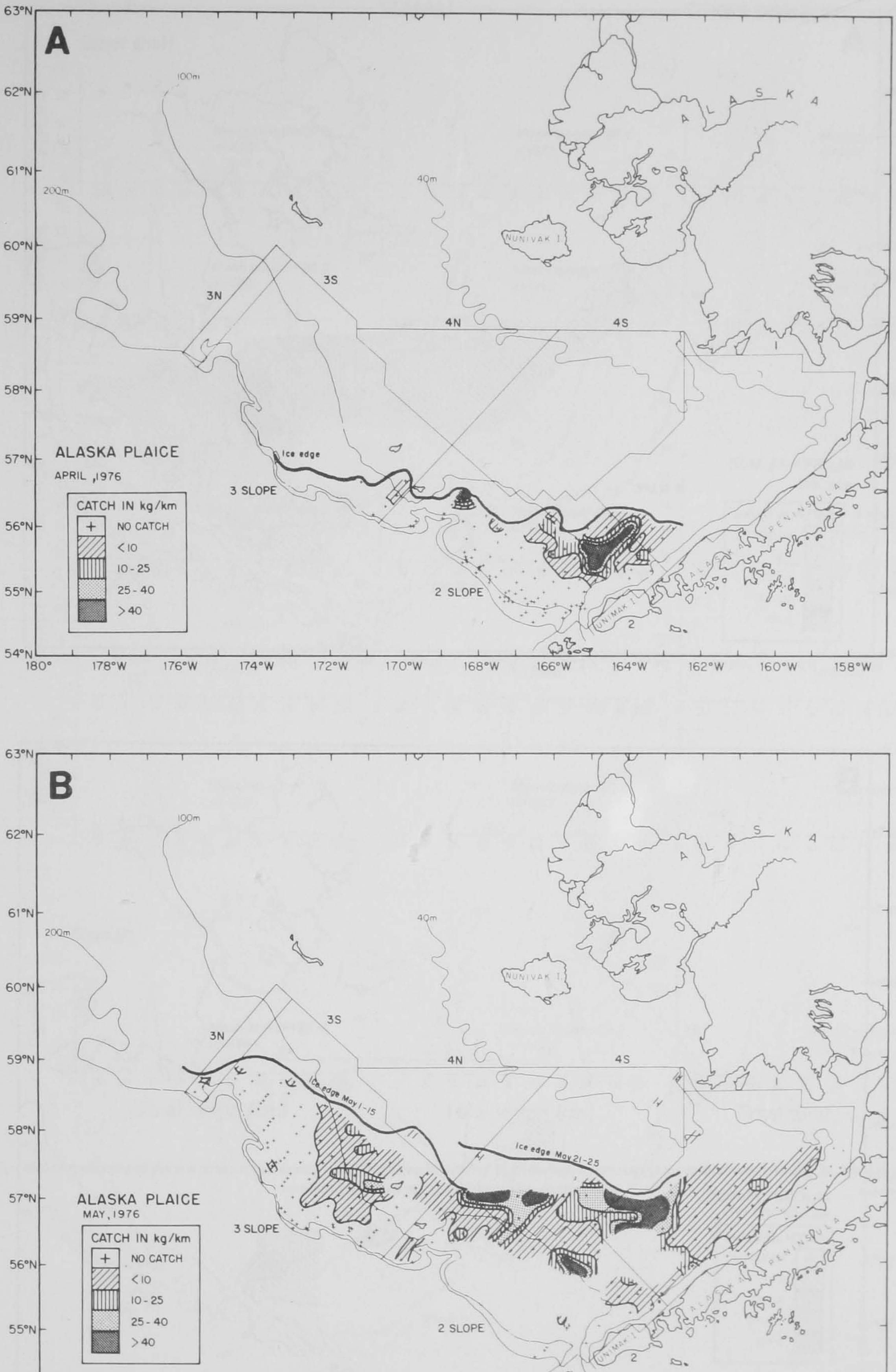


Figure 58.—Distribution and relative abundance of Alaska plaice during the 1976 Bering Sea spring trawl survey (by weight): A) April; B) May.

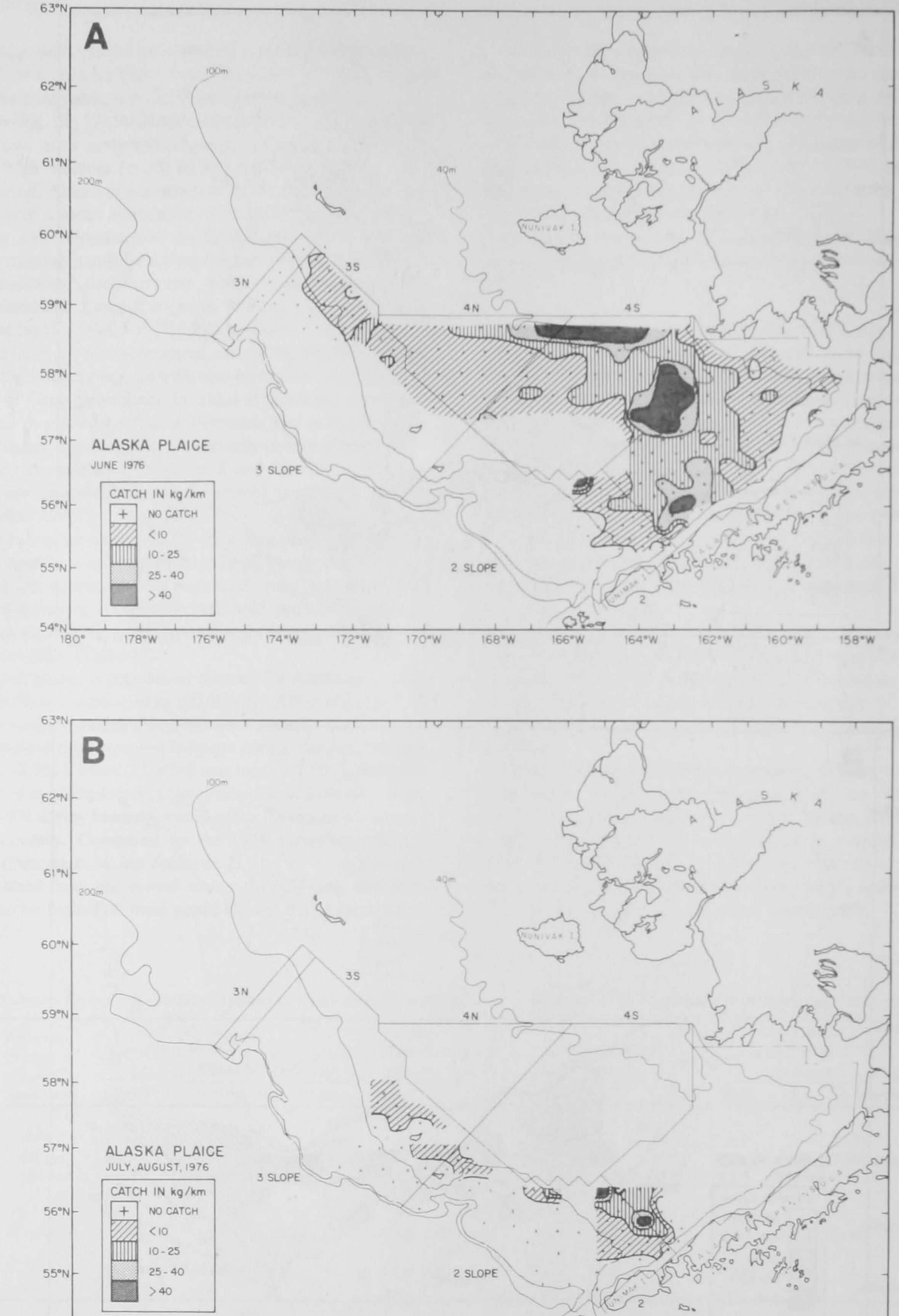


Figure 59.—Distribution and relative abundance of Alaska plaice during the 1976 Bering Sea spring trawl survey (by weight): A) June; B) July-August.

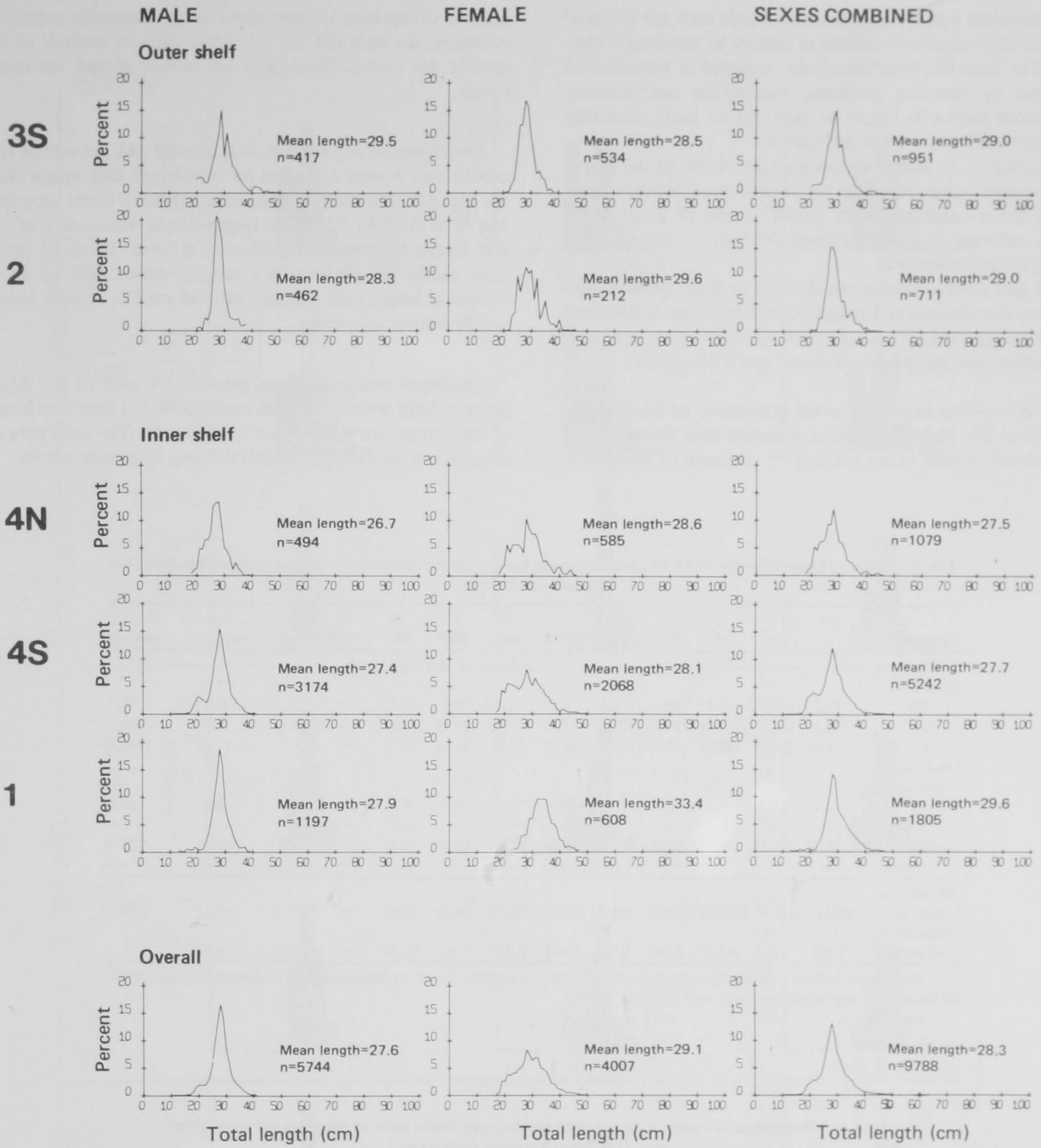


Figure 60.—Size composition of Alaska plaice taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

The apparent number of individuals within each age group of the sampled population (available to capture by trawling) is summarized in Table 48. While the results presented in Table 48 may be biased by sampling problems, the relative age-frequency distributions shown in Figure 61 may still be fairly accurately estimated, if biases were not age specific.

Age groups 7, 8, and 9 yr accounted for 70.2% of the overall apparent population. Although the relative age-frequency distributions (sexes combined) were similar among all geographical regions, subareas 4S and 4N showed the highest proportions of young (≤6 yr) individuals.

Male and female populations differed in their apparent age-frequency distributions in that females showed higher proportions of both young (≤6 yr) and old (≥10 yr) individuals, and their predominant age groups were 8 (male) and 9 (female) yr.

Sex ratio.—The overall observed proportion of females was 0.42 (Table 49). Males were more abundant than females in all geographical regions except subarea 3S. Because of the limited number of age-length observations and questionable population estimates, the data did not support a rigorous analysis of age-specific sex ratios. There were no evident overall age-related trends.

Length-weight relationship.—A total of 148 individuals from otolith area A were measured for total length and weight (Table 50, Fig. 62). The overall observed relationship (sexes combined) was $\widehat{W} = 0.0073\ L^{3.1342}$. The length-weight relationships of male and female populations significantly differed. Below 26 cm TL (and within the observed size ranges), males were up to 4% heavier at length than females. At ≥26 cm TL, females were up to 7% heavier at length.

Age-length relationship and growth.—A total of 157 Alaska plaice otoliths were collected in otolith area A. Mean total lengths of age groups are summarized in Figure 63. The data were not adequate to support mathematical fitting of growth curves.

Table 48.—Estimated population size of Alaska plaice age groups and year classes within survey subareas of the eastern Bering Sea, 1976 spring trawl survey.[1]

Subarea[2]	≤6 —	7 1969	8 1968	9 1967	10 1966	11 1965	12 1964	13 1963	14 1962	15 1961	16 1960	Age unknown	All ages combined
	millions of fish												
Inner shelf													
4N	17.2	12.7	19.1	16.4	4.4	1.1	1.1	0.6	0.1	—	—	0.6	73.3
4S	(103.3)	(71.8)	(120.0)	(114.2)	(32.0)	(7.7)	(7.7)	(5.3)	(1.3)	—	(<0.1)	(1.9)	(465.2)
1	(11.8)	(26.1)	(48.7)	(48.9)	(13.8)	(4.0)	(4.3)	(2.9)	(0.7)	—	—	(1.2)	(162.4)
Outer shelf and slope													
3S	2.7	4.9	9.4	8.7	2.3	0.5	0.6	0.4	0.1	—	—	0.2	29.8
3 Slope	—	—	—	—	—	—	—	—	—	—	—	—	—
2	(8.0)	(23.4)	(40.7)	(35.9)	(11.0)	(2.0)	(2.8)	(1.2)	(0.4)	—	—	(0.3)	(125.7)
2 Slope	—	—	—	—	—	—	—	—	—	—	—	—	—
All subareas combined	(143.0)	(138.9)	(237.9)	(224.1)	(63.5)	(15.3)	(16.5)	(10.4)	(2.6)	—	(<0.1)	(4.2)	(856.4)
Proportion of total	0.167	0.162	0.278	0.262	0.074	0.018	0.019	0.012	0.003	—	<0.001	0.005	

[1] Parentheses indicate estimates that may be badly biased due to sampling problems. The population in subarea 3N is not included because no length-frequency data were collected.

[2] See Figure 3.

Table 49.—Proportions of females in the estimated population of Alaska plaice by age group and geographical area, 1976 Bering Sea spring trawl survey.[1]

Subarea[2]	Age group (yr) ≤6	7	8	9	10	11	12	13	14	15	16	All ages combined
	Proportion of females											
Inner shelf												
4N	0.50	0.34	0.35	0.57	0.49	1.00	0.52	0.05	1.00	—	—	0.45
4S	0.60	0.32	0.31	0.52	0.41	1.00	0.47	0.14	0.81	—	1.00	0.45
1	0.08	0.09	0.17	0.47	0.45	1.00	0.60	0.10	0.54	—	—	0.30
Outer shelf												
3S	0.78	0.39	0.44	0.63	0.48	1.00	0.48	0.30	0.81	—	—	0.54
3 Slope	—	—	—	—	—	—	—	—	—	—	—	—
2	0.57	0.36	0.34	0.53	0.48	1.00	0.47	0.03	0.38	—	—	0.43
2 Slope	—	—	—	—	—	—	—	—	—	—	—	—
All subareas combined	0.54	0.29	0.29	0.52	0.44	1.00	0.50	0.11	0.68	—	1.00	0.42

[1] Based upon sampled individuals for which sexes could be determined. The population in subarea 3N is not included because no length-frequency data were collected.

[2] See Figure 3.

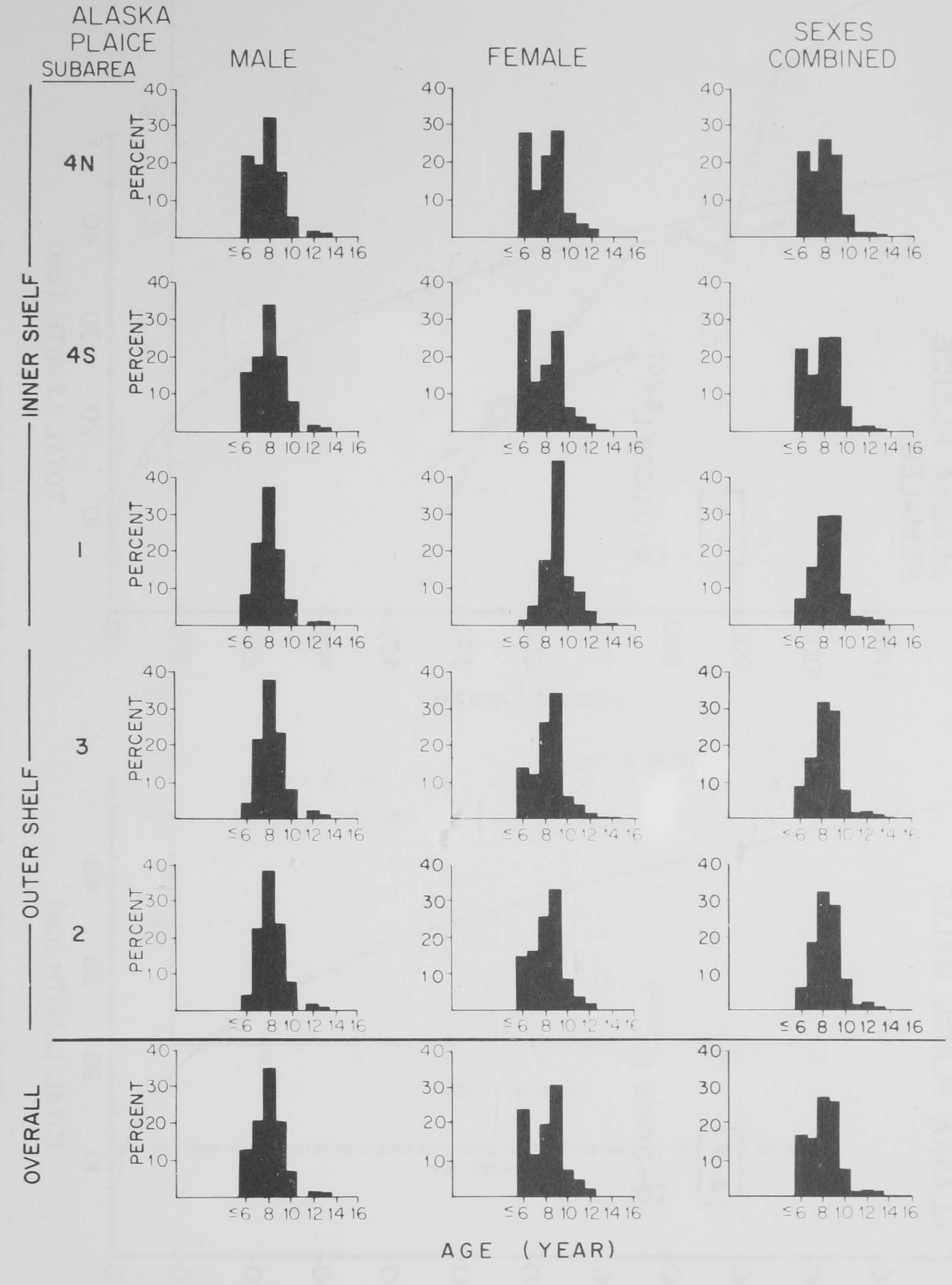


Figure 61.—Relative age composition of Alaska plaice taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

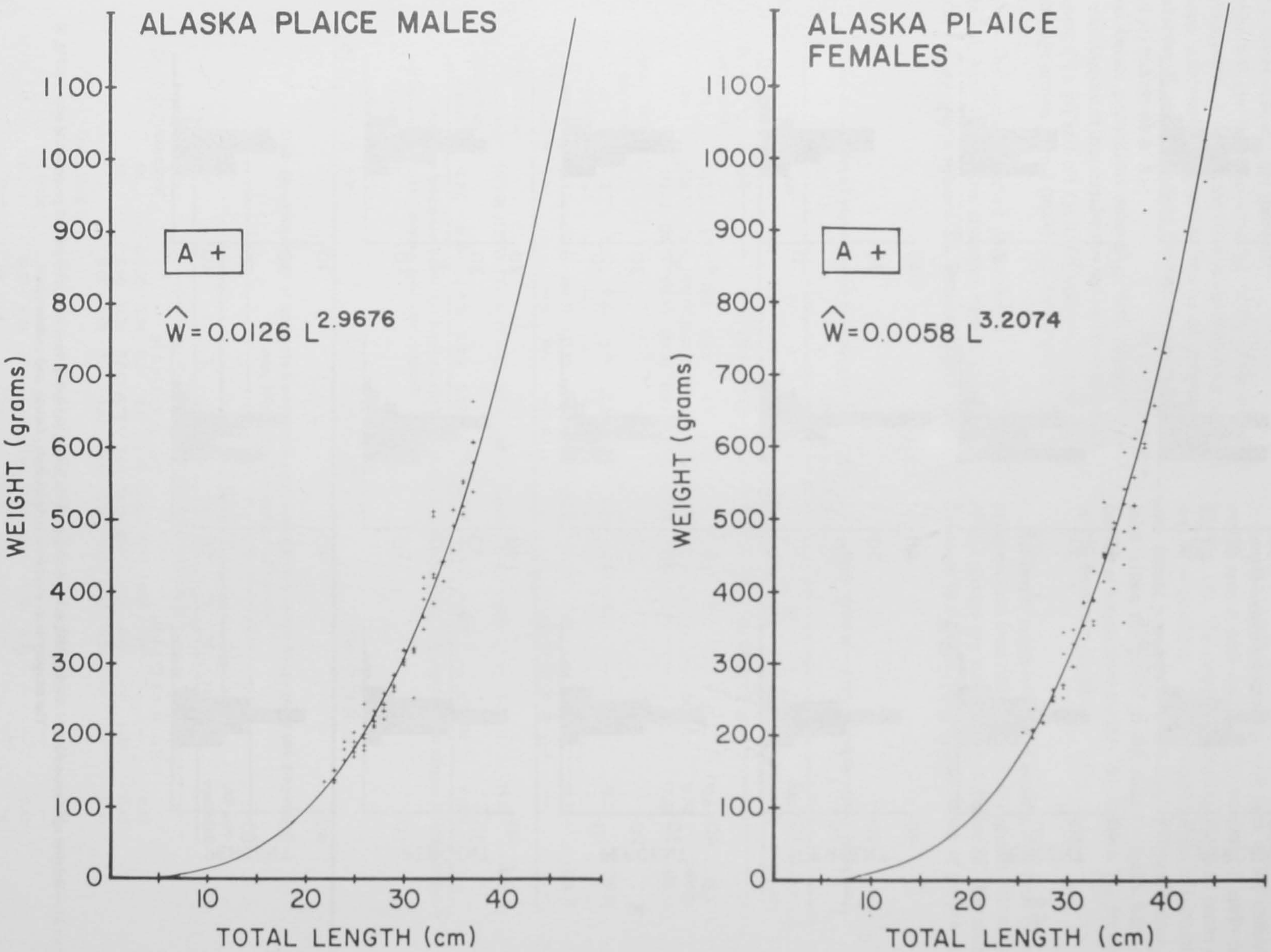


Figure 62.—Length-weight observations from Alaska plaice taken during the 1976 Bering Sea spring trawl survey.

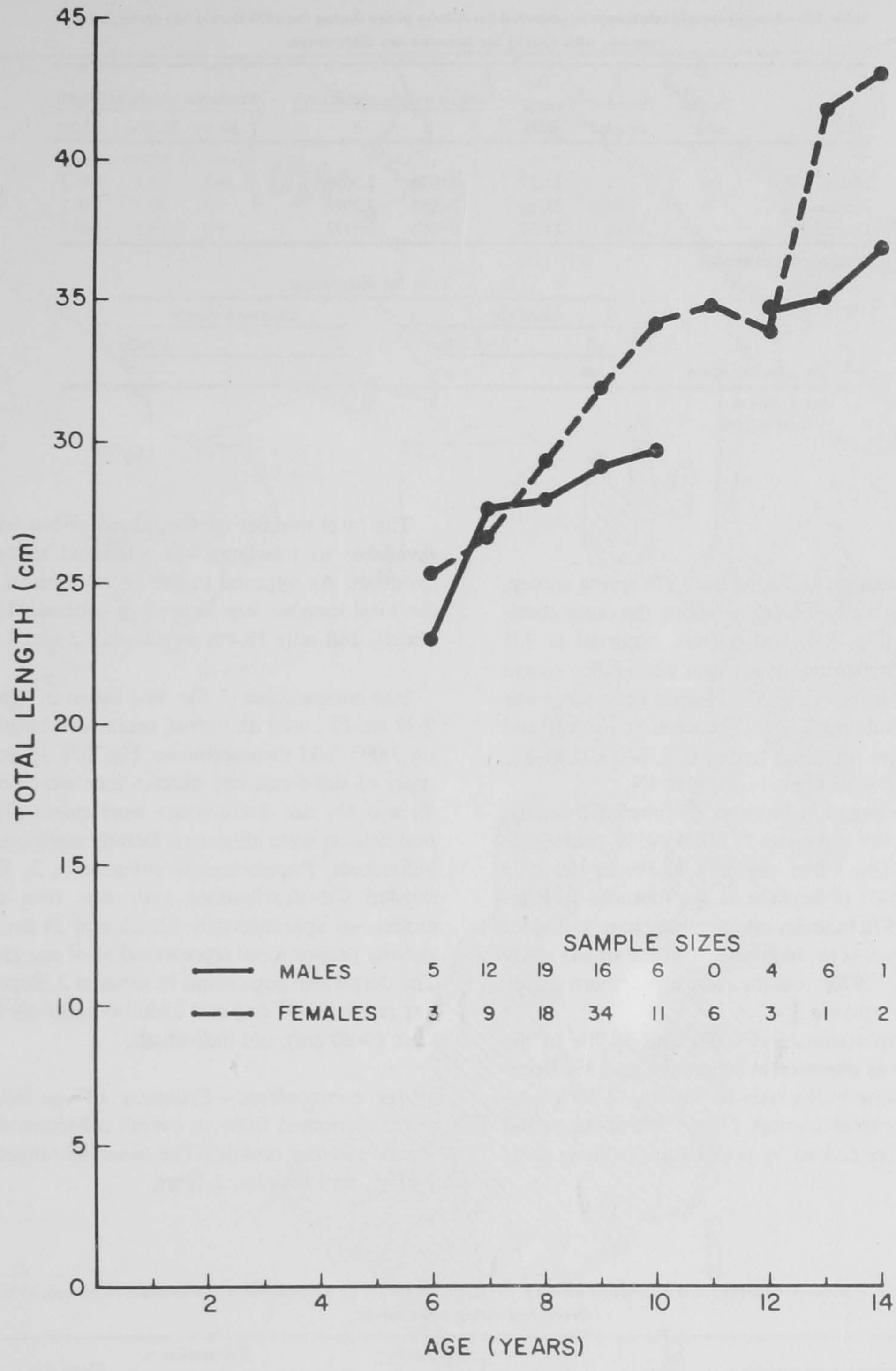


Figure 63.—Mean lengths-at-age of Alaska plaice taken during the 1976 Bering Sea spring trawl survey, otolith area A (see Fig. 4).

Table 50.—Length-weight relationships observed for Alaska plaice during the 1976 Bering Sea spring trawl survey, with testing for between-sex differences.

Sex	Otolith area[1]	Number sampled	TL range (cm)	Length-weight coefficients		Predicted weight-at-length		
				a	*b*	10 cm	20 cm	35 cm
						grams		
Males	A	75	22-37	0.0126	2.9676	11.7	91.8	483.3
Females	A	73	25-50	0.0058	3.2074	9.3	86.1	518.5
Overall		148	22-50	0.0073	3.1342	9.9	87.7	506.7

Analysis of covariance	Tests for differences[2]			
	Slope (*b*)		Common means	
	df	F ratio	df	F ratio
Between sexes in area A	1:146	5.44*	—	—

[1] See Figure 4.

[2] * = $P \leq 0.05$.

Greenland turbot.

Distribution and abundance.—During the 1976 spring survey, Greenland turbot were broadly distributed along the outer continental shelf and slope (Fig. 64), and overall, occurred at 255 (58.6%) of the 435 grid stations, at a mean abundance (mean CPUE) of 2.56 kg/km trawled (Table 51). Highest abundance was observed in deep water (subarea 2 Slope) between St. George and Unimak Islands. Only low densities (mean CPUE's <0.40 kg/km) were found in inner shelf areas 1, 4S, and 4N.

The total apparent population biomass (Estimated Biomass, Table 51) within the survey area was 51,000 t (95% confidence limits 43,200-58,800 t). This value was only 40.3% of the 1975 survey estimate of 126,700 t (Pereyra et al. see footnote 2). Principal causes of the low 1976 biomass estimate may have included: Seasonally related emigration to deep water outside of the study area boundaries (Shuntov 1970); and the reduced northern survey coverage, particularly in subarea 3N.

During spring 1976, approximately 30.0% and 38.9% of the total apparent biomass was observed in subareas 2 and 3S. Deepwater populations of large individuals in subarea 2 Slope accounted for 16.6% of the total biomass. Only 6.3% of the overall apparent biomass was represented by populations in inner shelf areas 1, 4S, and 4N.

The total number of Greenland turbot within the study area (available to trawling) was estimated to be 350.9 million individuals. As opposed to the distribution of biomass, 30.2% of the total number was located in subareas 1, 4S, and 4N (combined), and only 19.4% in subareas 2 and 2 Slope (combined).

Size composition.—The size range of Greenland turbot was 9-99 cm FL, with an overall mean fork length of 21.6 cm (based on 7,097 field measurements; Fig. 65). In general, three distinct types of size-frequency distributions were observed. In subareas 4S and 4N size distributions were essentially unimodal and the populations were almost exclusively composed of small, 1-yr-old individuals. Populations in subareas 1, 2, 3N, 3S, and 3 Slope showed size distributions with one, two, or three prominent modes—at approximately 12, 22, and 34 cm FL—resulting from varying proportional representation of age groups 1, 2, and 3 yr. The deepwater population in subarea 2 Slope showed the largest size range (24-99 cm) and included relatively high proportions of large (>60 cm), old individuals.

Age composition.—Estimates of age-frequency distribution were determined from an overall collection of 193 male and 182 female saccular otoliths. The observed ranges in age were males, 2-11 yr, and females, 2-16 yr.

Table 51.—Estimated biomass and population numbers of Greenland turbot by subarea and for all subareas combined, 1976 Bering Sea spring trawl survey.

Subarea[1]	Percentage frequency of occurrence	Mean CPUE (kg/km)	Estimated biomass (t)	Proportion of total estimated biomass	Estimated population (millions)	Proportion of total estimated population	Mean size Weight (kg)	Mean size FL (cm)
Inner shelf								
4N	45.5	0.25	460	0.009	36.6	0.104	0.013	11.7
4S	26.8	0.21	895	0.018	61.7	0.176	0.014	11.6
1	18.0	0.37	1,811	0.036	7.8	0.022	0.234	29.1
Outer shelf and slope								
3	86.3	4.82	23,178	0.454	174.9	0.498	0.132	23.2
3 Slope	90.0	4.76	923	0.018	1.9	0.005	0.481	36.7
2	74.2	4.10	15,294	0.300	64.4	0.184	0.238	28.9
2 Slope	87.5	19.78	8,451	0.166	3.6	0.010	2.356	59.7
All subareas combined	58.6	2.56	[2]51,013		350.9		0.145	21.6

[1] See Figure 3.

[2] 95% confidence limits: 43,247-58,778 t.

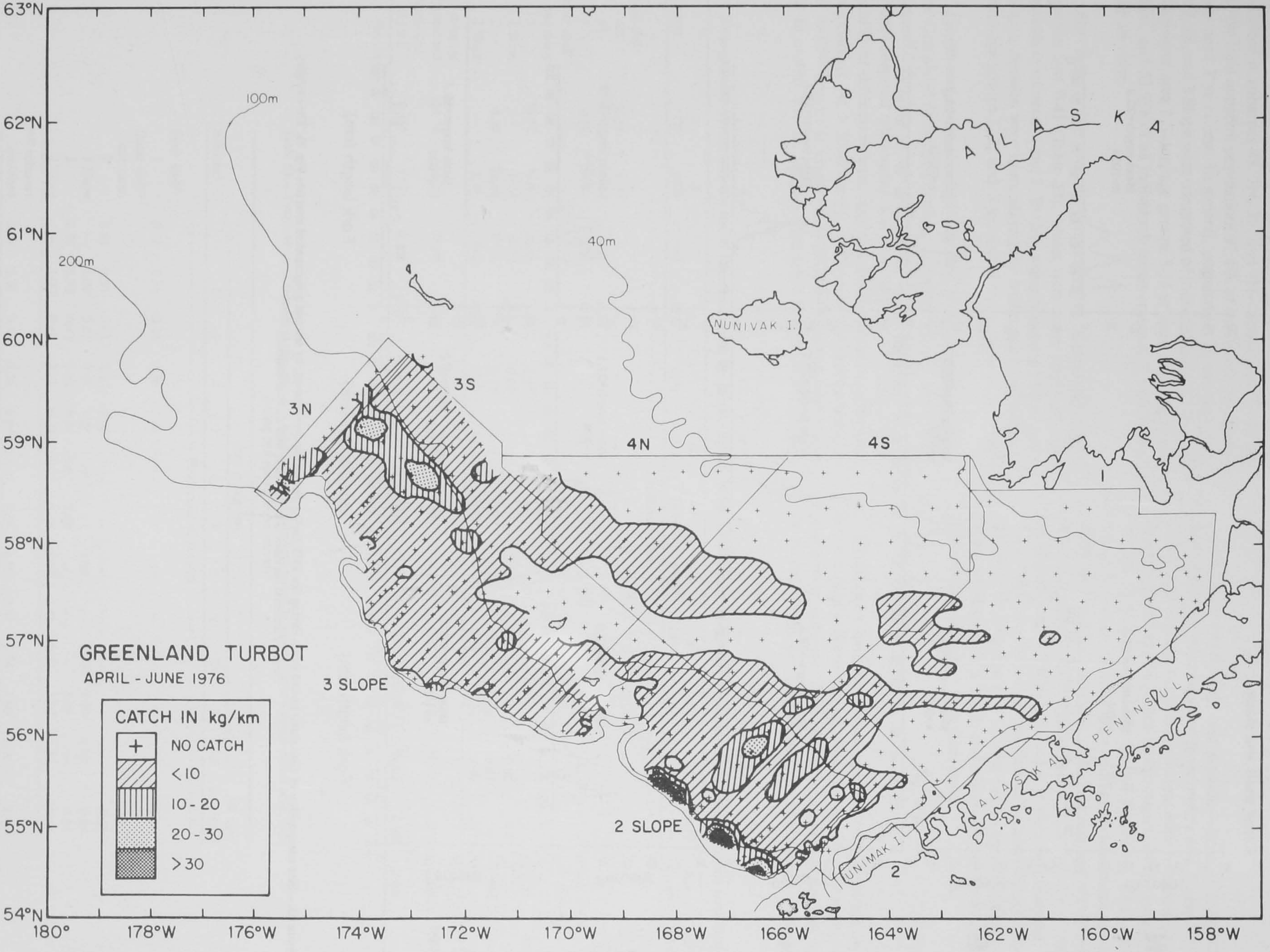


Figure 64.—Distribution and relative abundance of Greenland turbot during the 1976 Bering Sea spring trawl survey (by weight).

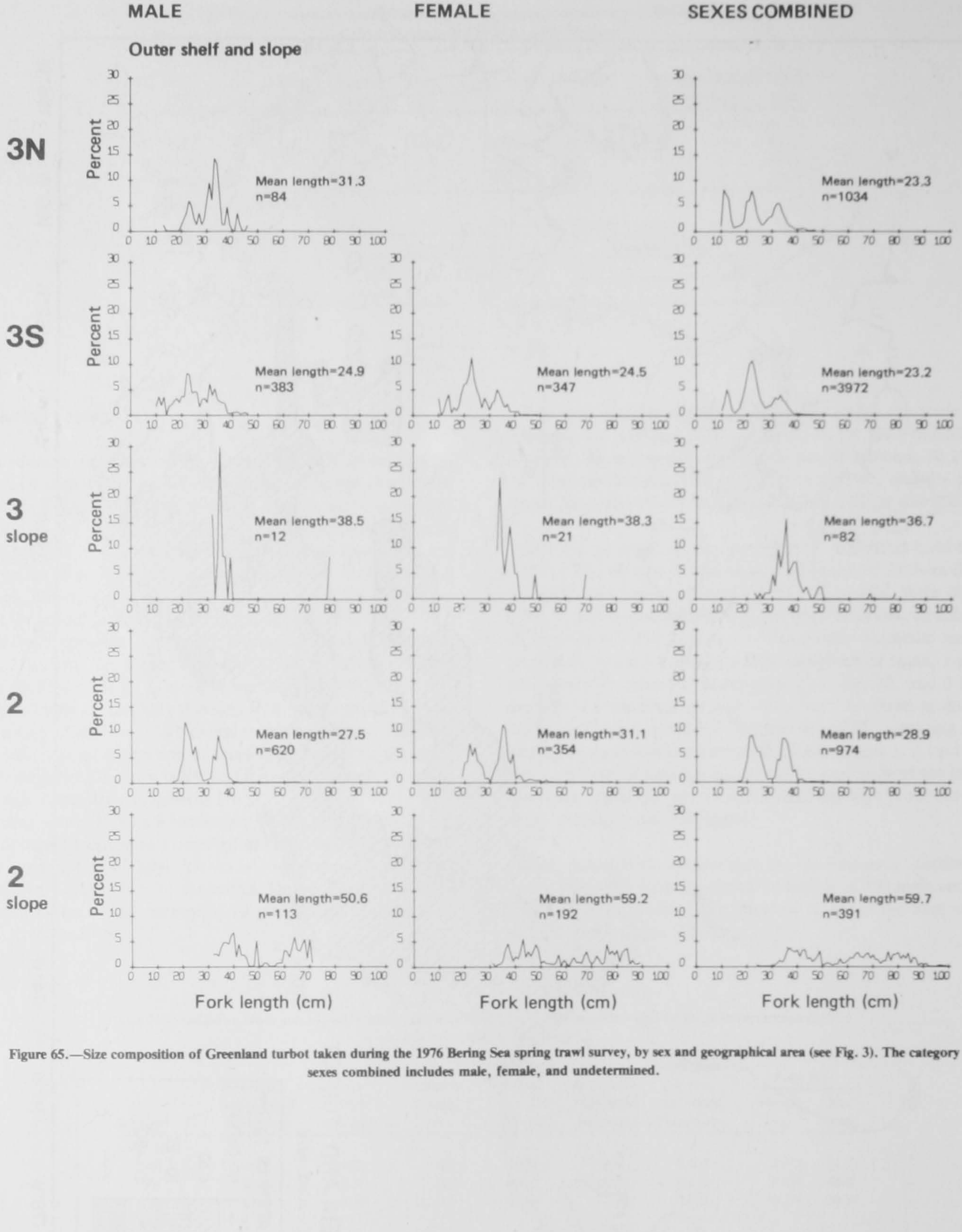


Figure 65.—Size composition of Greenland turbot taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

The estimated size of each age group population is summarized in Figure 66 and Table 52. Overall, 1 yr olds—primarily distributed in subareas 4S, 3N, 3S, and 4N—accounted for 45.5% of the total apparent population; 97.4% of the overall population was aged 3 yr or less. In general, populations in subareas 1, 2, 3N, 3S, and 3 Slope were composed of individuals aged 1-4 yr. In deepwater area 2 Slope, age groups 3-16 yr were relatively abundant, and 53.9% of all individuals (sexes combined) were 6 yr of age or older.

Sex ratio.—The overall proportion of Greenland turbot females was 0.41 (Table 53). Males were more abundant than females in subareas 1 and 2. In deep water (subareas 2 Slope and 3 Slope), females were more abundant. Males appeared to dominate age groups 1, 2, and 3 yr, and females, ages 4 and 5 yr.

Length-weight relationship.—A total of 358 individuals from the Greenland turbot populations in otolith areas B and D were measured for fork length and weight (Table 54, Fig. 67). The overall observed relationship was $\hat{W} = 0.0064\,L^{3.0721}$. Statistically significant differences were observed in all comparisons between populations. At > 30-40 cm FL, both males and females were up to 10-12% heavier at length in otolith area B than in otolith area D. In otolith area D, females were 6-8% heavier at length than males, at all sizes. In otolith area B, females were heavier at length than males, but only at > 40 cm FL.

Age-length relationship and growth.—Because only 206 age determinations were obtained from otolith area B and 169 from otolith area D, data from the two areas were combined to create more complete age-frequency tables. Results of the growth curve fittings, summarized in Table 55 and Figure 68, were uncertain due to limitations of both male and female age-frequency tables. In the age-frequency table for males, the only age groups with 10 or more age-length observations were 2, 3, 4, 7, and 8 yr. Among females only age groups 2, 3, and 4 yr were well sampled.

Although the choice of best fit was unclear, results from the two data sets indicated that females had an approximately 5-15% larger asymptotic fork length and slightly slower growth completion rate (see Equation (24)) than males.

Arrowtooth flounder.

Distribution and abundance.—Arrowtooth flounder showed an exclusively deepwater distribution pattern, occurring from southern to northern limits of the survey area at bottom depths >75-110 m (Fig. 69). Overall, arrowtooth flounder were taken at

Table 52.—Estimated population size of Greenland turbot age groups and year classes within survey subareas of the eastern Bering Sea, 1976 spring trawl survey.

Subarea[1]	1 1975	2 1974	3 1973	4 1972	5 1971	6 1970	7 1969	8 1968	9 1967	10 1966	11 1965	≥ 12 —	Age unknown	All ages combined
	millions of fish													
Inner shelf														
4N	36.55	0.02	—	—	—	—	—	—	—	—	—	—	—	36.57
4S	61.06	0.40	0.19	0.05	—	—	—	—	—	—	—	—	—	61.70
1	0.63	3.14	3.78	0.20	—	—	—	—	—	—	—	—	—	7.75
Outer shelf and slope														
3	56.74	76.49	39.49	1.98	0.15	—	—	—	—	—	—	—	0.10	174.95
3 Slope	—	0.14	1.37	0.33	0.04	—	—	0.01	0.01	—	0.02	0.01	—	1.93
2	4.76	29.06	27.41	2.76	0.22	0.02	0.03	0.03	—	0.02	0.03	—	0.04	64.38
2 Slope	—	0.01	0.63	0.73	0.17	0.13	0.23	0.19	0.24	0.12	0.30	0.72	0.11	3.58
All subareas combined	159.74	109.26	72.87	6.05	0.58	0.15	0.26	0.23	0.25	0.14	0.35	0.73	0.25	350.86
Proportion of total	0.455	0.311	0.208	0.017	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	

[1] See Figure 3.

Table 53.—Proportions of females in the estimated population of Greenland turbot by age group and geographical area, 1976 Bering Sea spring trawl survey.[1]

Subarea[2]	Age group (yr) 1	2	3	4	5	6	7	8	9	10	11	12	All ages combined
	Proportion of females												
Inner shelf													
1	0.51	0.24	0.29	0.80	—	—	—	—	—	—	—	—	0.30
Outer shelf and slope													
3	0.51	0.55	0.43	0.40	0.38	—	—	—	—	—	—	—	0.50
3 Slope	—	1.00	0.61	0.83	1.00	—	—	0.00	—	—	1.00	1.00	0.64
2	0.26	0.30	0.42	0.88	0.95	0.00	0.00	—	—	—	1.00	—	0.38
2 Slope	—	1.00	0.49	0.62	0.76	0.19	0.12	0.00	0.42	0.54	1.00	1.00	0.64
All subareas combined	0.41	0.36	0.42	0.76	0.86	0.15	0.08	0.00	0.42	0.54	1.00	1.00	0.41

[1] Based upon sampled individuals for which sexes could be determined.

[2] See Figure 3.

Table 54.—Length-weight relationships observed for Greenland turbot during the 1976 Bering Sea spring trawl survey, with testing for between-area and between-sex differences.

Sex	Otolith area[1]	Number sampled	FL range (cm)	Length-weight coefficients		Predicted weight-at-length		
				a	*b*	10 cm	30 cm	50 cm
						grams		
Males	B	161	20-76	0.0050	3.1351	6.8	213.1	1057.1
	D	42	14-43	0.0120	2.8757	9.0	212.5	—
	Both areas combined	203	14-76	0.0063	3.0749	7.4	217.9	1048.3
Females	B	93	19-85	0.0031	3.2635	5.7	207.1	1097.0
	D	62	14-52	0.0125	2.8844	9.5	227.3	992.1
	Both areas combined	155	14-85	0.0066	3.0717	7.7	225.9	1085.0
Overall		358	14-85	0.0064	3.0721	7.5	221.4	1063.6

Analysis of covariance

	Tests for differences[2]			
	Slope (*b*)		Common means	
	df	F ratio	df	F ratic
Males between areas B and D	1:199	34.8**	—	—
Females between areas B and D	1:151	35.1**	—	—
Between sexes in area B	1:250	8.79**	—	—
Between sexes in area D	1:100	0.03	1:101	11.5**

[1]See Figure 4.

[2]** = $P \leq 0.01$.

Table 55.—Parameters of the von Bertalanffy growth curves for Greenland turbot, 1976 Bering Sea spring trawl survey.[1]

Sex	Otolith area[2]	Data set	Number of age readings	Age range (yr)	FL range (cm)	Standard error of curve fit	Parameters		
							L_∞	K	t_0
Male	B	All ages	193	2-11	21-78	4.67	75.13	0.27	0.73
		Selected ages		0, 2-9	21-78	5.11	92.47	0.14	−0.07
Female	B D	All ages	182	2-16	21-85	2.48	86.53	0.19	0.39
		Selected ages		0, 2-13	21-84	3.13	96.82	0.13	0.03

[1]For Greenland turbot, each mean length-at-age in the selected ages data sets was based upon only six or more length-age determinations.

[2]See Figure 4.

131 (30.1%) of the 435 grid sampling stations, at a mean abundance (mean CPUE) of 2.12 kg/km trawled (Table 56). Regions of highest abundance (by weight) were subareas 2 Slope and 3 Slope (bottom depths 183-457 m), where mean densities were 38.98 and 7.03 kg/km, respectively. The maximum observed catch rate was 425.0 kg/km. No arrowtooth flounder was taken in inner shelf subareas 1, 4S, and 4N.

The total apparent population biomass within the study area was 40,800 t (95% confidence limits 30,000-51,700 t), a factor of 1.45 times larger than the 1975 survey estimate of 28,000 t

Table 56.—Estimated biomass and population numbers of arrowtooth flounder by subarea and for all subareas combined, 1976 Bering Sea spring trawl survey.

Subarea[1]	Percentage frequency of occurrence	Mean CPUE (kg/km)	Estimated biomass (t)	Proportion of total estimated biomass	Estimated population (millions)	Proportion of total estimated population	Mean size	
							Weight (kg)	FL (cm)
Inner shelf								
4N	—	—	—	—	—	—	—	—
4S	—	—	—	—	—	—	—	—
1	—	—	—	—	—	—	—	—
Outer shelf and slope								
3	14.5	0.65	3,063	0.075	10.5	0.070	0.291	—
3 Slope	100.0	7.03	1,361	0.033	15.6	0.038	0.243	27.2
2	71.9	5.29	19,747	0.484	105.3	0.706	0.188	25.8
2 Slope	97.5	38.98	16,651	0.408	27.8	0.186	0.599	36.0
All subareas combined	30.1	2.12	[2]40,822		149.2		0.274	27.9

[1]See Figure 3.

[2]95% confidence limits: 29,990-51,654 t.

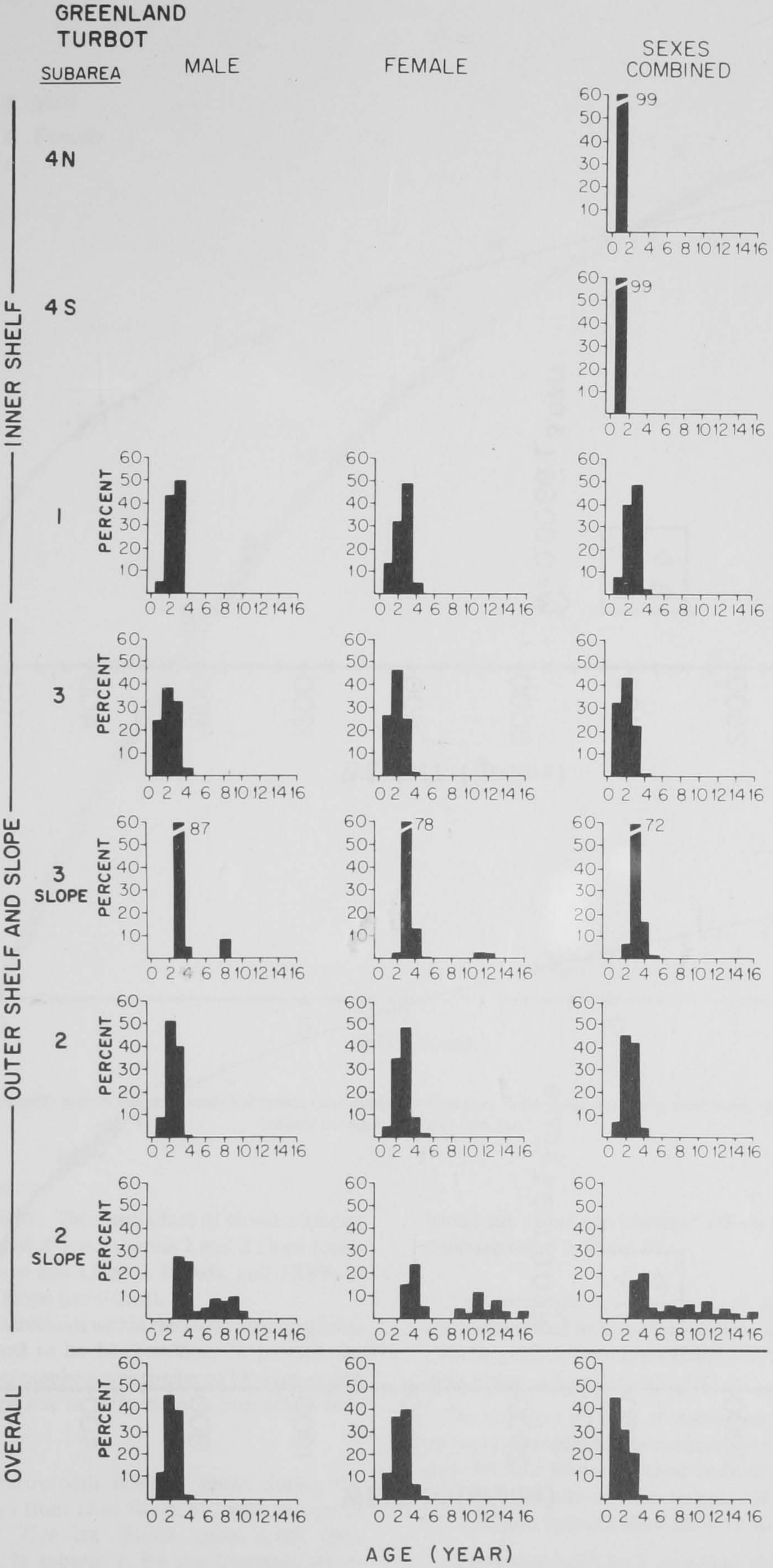


Figure 66.—Relative age composition of Greenland turbot taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

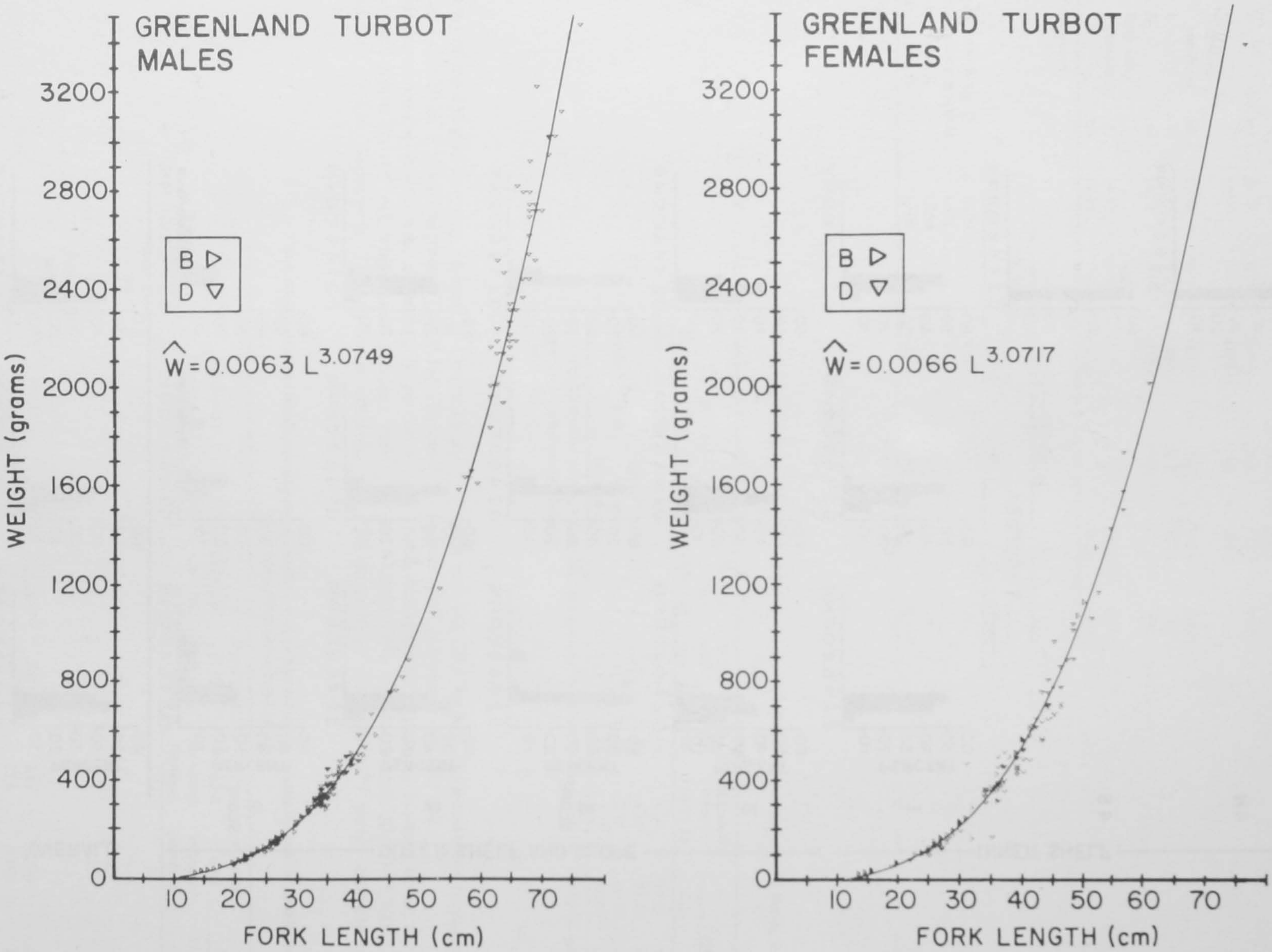


Figure 67.—Length-weight observations from Greenland turbot taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4).

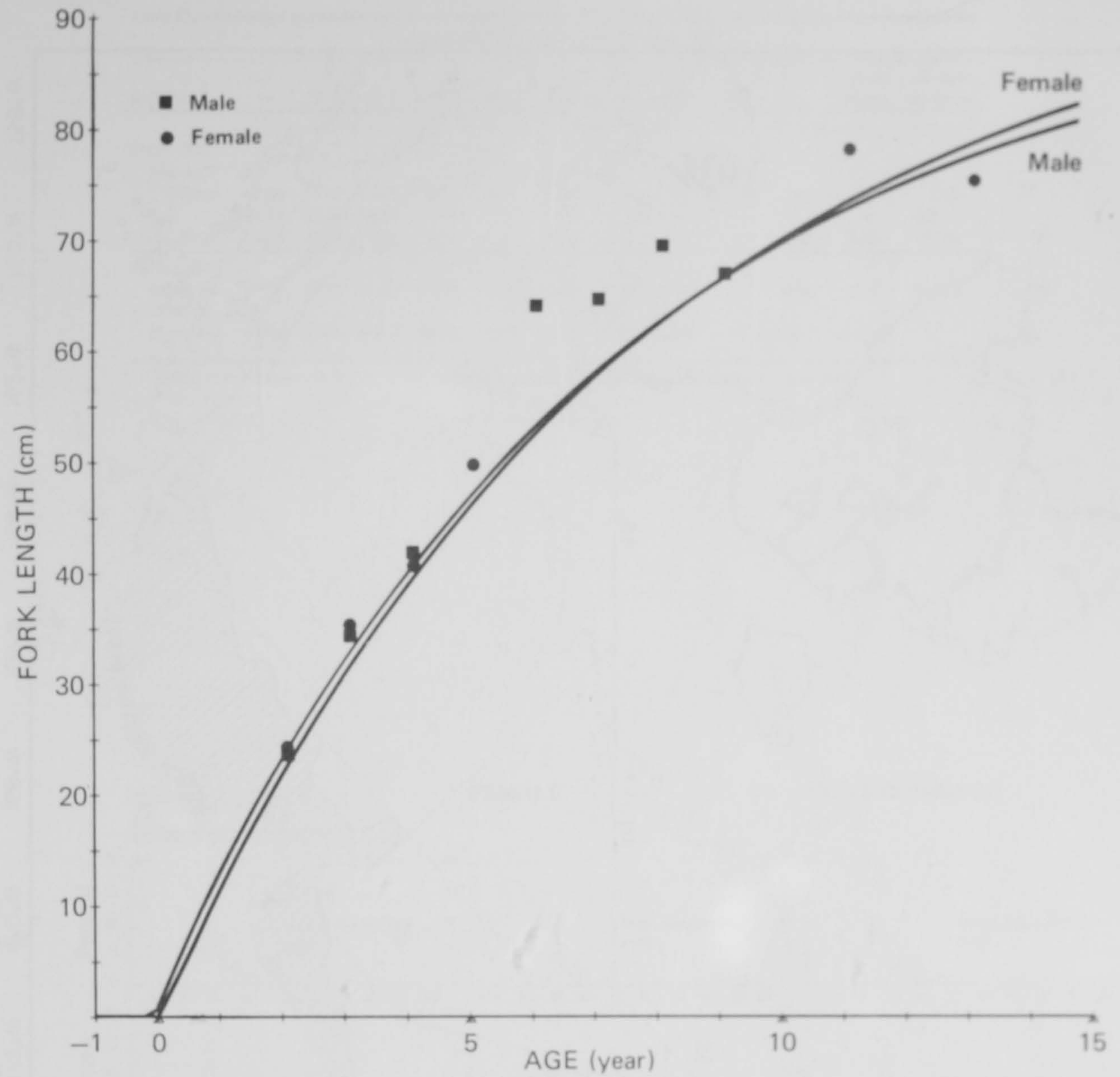


Figure 68.—Von Bertalanffy growth curves for male and female Greenland turbot, all areas, 1976 Bering Sea spring trawl survey (selected ages). Symbols indicate the mean length at each age.

(Pereyra et al. see footnote 2). The distribution of biomass among geographical regions was 89.2% in subareas 2 and 2 Slope (combined) between St. George and Unimak Islands, and 10.8% in subareas 3N, 3S, and 3 Slope (combined).

The total number of individuals within the study area (available to trawling) was estimated to be 149.2 million. In general, the distribution of population numbers was similar to biomass except in subareas 2 and 2 Slope due to differences in population size-frequency distributions.

Size composition.—Arrowtooth flounder taken during the 1976 spring survey ranged from 12 to 68 cm FL, with an overall mean fork length of 27.9 cm (based upon 4,103 field measurements; Fig. 70). In subarea 2, the size-frequency distributions of male and female populations were sharply unimodal and nearly symmetrical, with an overall mean fork length (sexes combined) of 25.8 cm (range 12-50 cm). In subareas 2 Slope, a broad size range was observed (18-68 cm), and 62.1% of all individuals were > 30 cm FL.

Age composition.—Estimates of age-frequency distribution were made from an overall collection of 126 male and 257 female saccular otoliths from areas B and D. The ranges in ages observed were males, 3-8 yr; females, 3-12 yr.

The apparent number of individuals within each age group of the sampled population is summarized in Table 57. Although subareas 3N and 3S are excluded because no length-frequency data were collected, the estimates include 138.66 million (92.9%) of the 149.2 million individuals of the overall apparent population.

Four-yr-old individuals were most abundant in all geographical areas, accounting for 44-50% of the populations in each subarea (Fig. 71). Overall (sexes combined), 83.0% of the total population was aged 4 yr or less. Old individuals were most abundant in

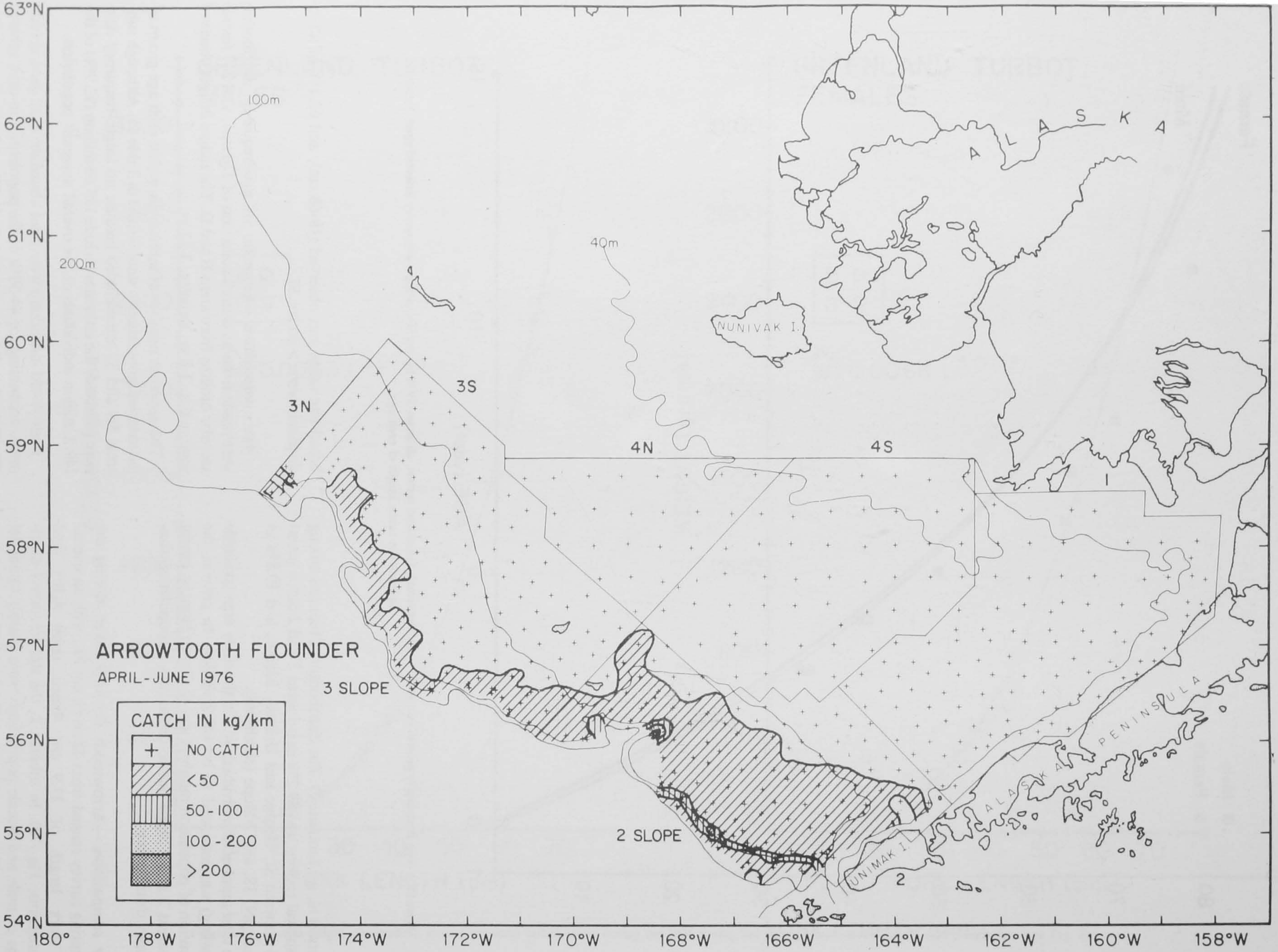


Figure 69.—Distribution and relative abundance of arrowtooth flounder during the 1976 Bering Sea spring trawl survey (by weight).

Table 57.—Estimated population size of arrowtooth flounder age groups and year classes within survey subareas of the eastern Bering Sea, 1976 spring trawl survey.[1]

Subarea[2]	≤3 —	4 1972	5 1971	6 1970	7 1969	8 1968	9 1967	10 1966	11 1965	≥12 —	Age unknown	All ages combined
	millions of fish											
Outer shelf and slope												
3 Slope	2.06	2.69	0.48	0.27	0.09	0.01	—	—	—	—	—	5.60
2	43.23	52.17	6.87	2.94	0.04	0.01	—	—	—	—	—	105.26
2 Slope	2.70	12.32	4.34	4.27	2.54	1.07	0.43	0.07	—	0.04	0.02	27.80
All subareas combined	47.99	67.18	11.69	7.48	2.67	1.09	0.43	0.07	—	0.04	0.02	138.66
Proportion of total	0.346	0.484	0.084	0.054	0.019	0.008	0.003	0.001	—	<0.001	<0.001	

[1] The population in subarea 3 is not included because no length-frequency data were collected.

[2] See Figure 3.

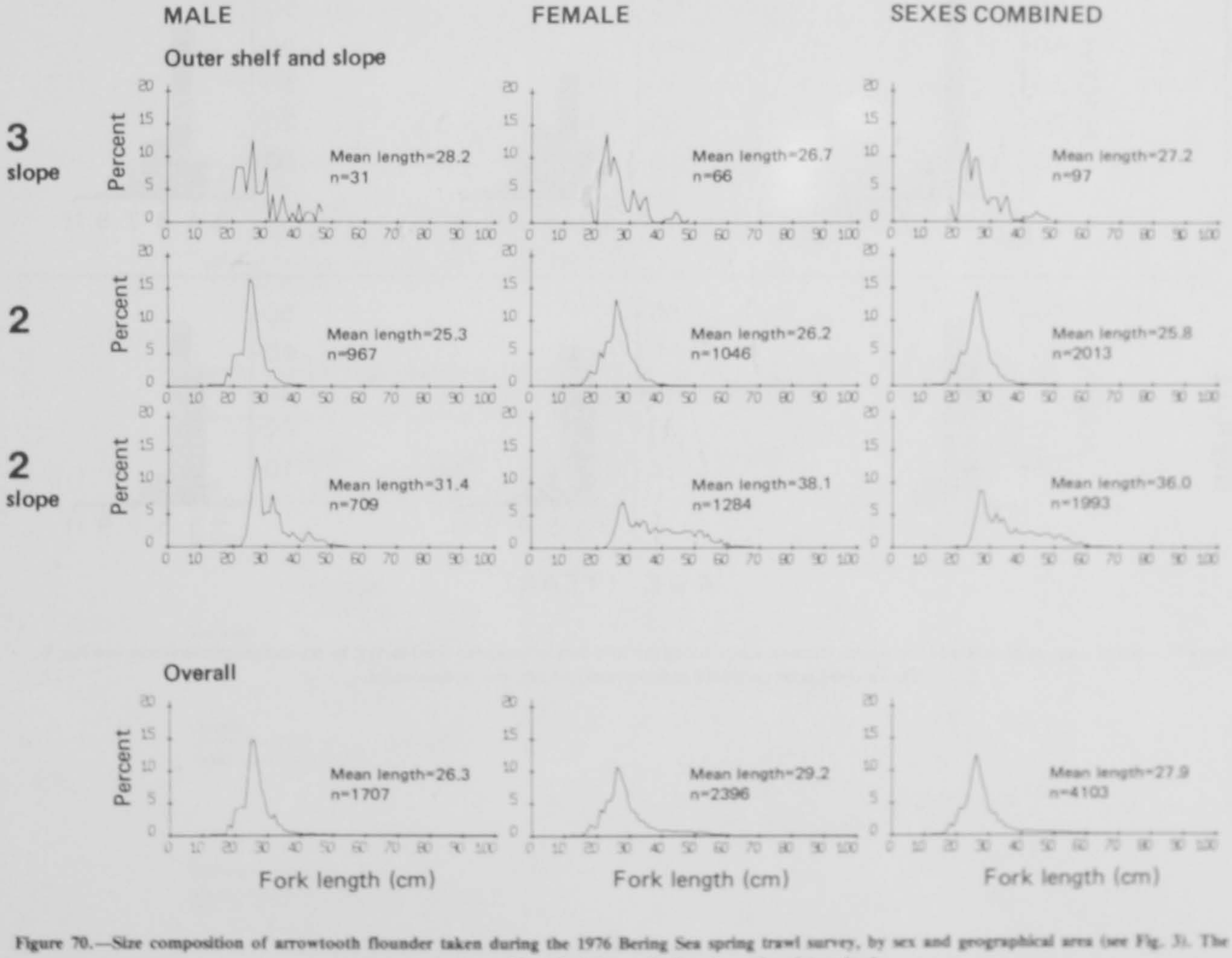


Figure 70.—Size composition of arrowtooth flounder taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

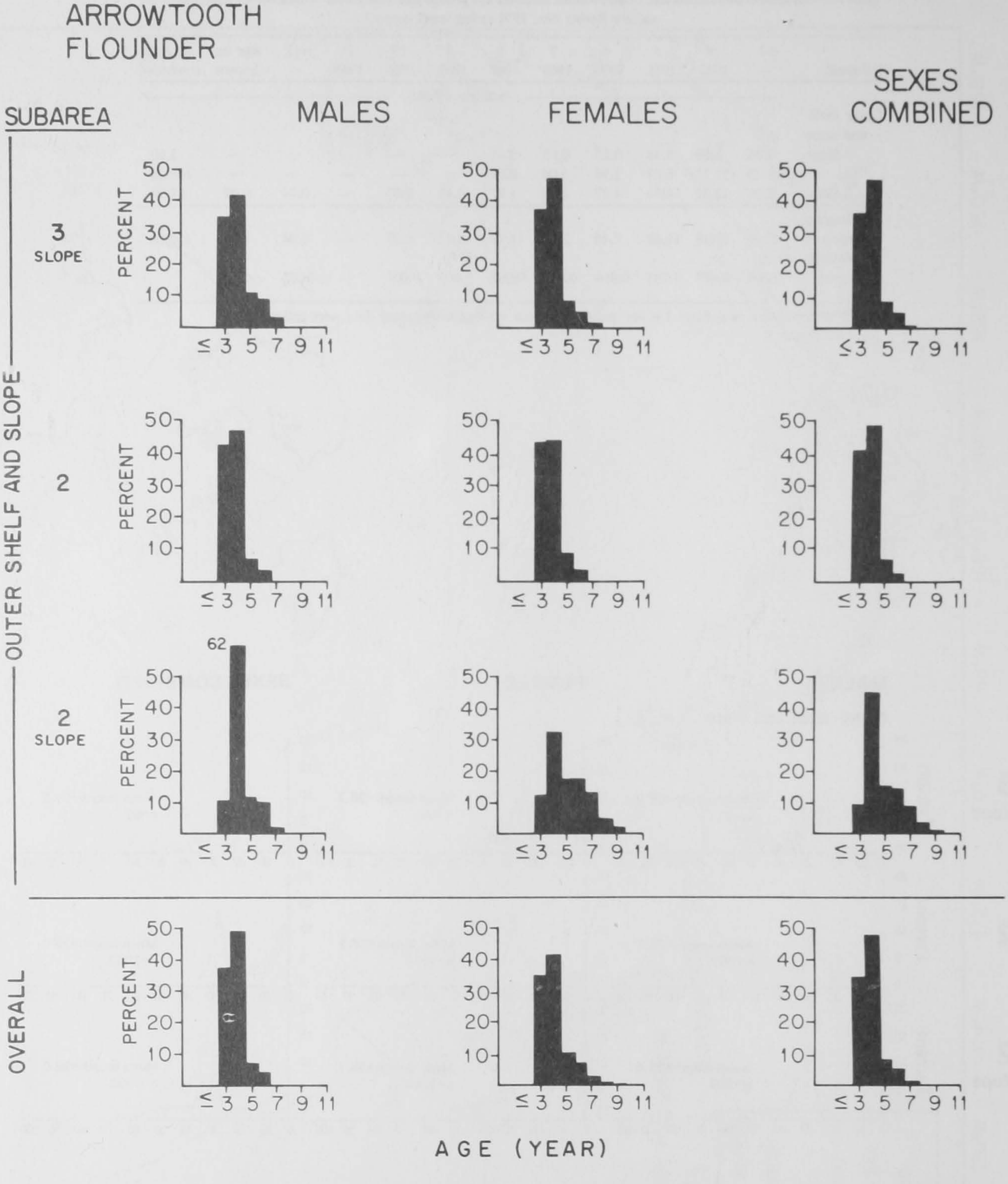


Figure 71.—Relative age composition of arrowtooth flounder taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

subarea 2 Slope, where 30.3% of the apparent population was 6 yr or older.

Sex ratio.—The overall proportion of arrowtooth flounder females was 0.56, and females were more abundant than males in all geographical regions (Table 58). With the exception of the 4-yr group, females were more abundant at all ages, particularly dominating at 7 yr and older.

Length-weight relationship.—A total of 282 individuals from the arrowtooth flounder populations in otolith areas B and D were measured for fork length and weight (Fig. 72, Table 59). The overall relationship obtained was $\hat{W} = 0.0072\ L^{3.1028}$. No statistically significant difference was found between the length-weight characteristics of male and female populations.

Age-length relationship and growth.—The age-length observations from otolith areas B (358 samples) and D (25 samples) were combined to create more complete age-frequency tables. Results of the growth curve fittings are summarized in Table 60 and Figure 73. Both data sets (all ages and selected ages) gave approximately the same results for males, although the mean fork lengths of the 7- and 8-yr age groups were outlying values due to small sample sizes. For females, the inclusion or exclusion of the mean fork lengths of the 10- and 12-yr age groups gave markedly different results. The L_∞ and t_0 values obtained from the all-ages data set seemed most realistic.

The results from both data sets indicated a growth pattern of female arrowtooth flounder having approximately a 70-80% (or greater) larger asymptotic fork length than males and slower relative growth completion rate.

Pacific halibut.

Distribution and abundance.—Pacific halibut showed a primarily deepwater distribution pattern, occurring from southern to northern limits of the survey area at bottom depths > 79-90 m (Fig. 74). Overall, Pacific halibut were taken at 161 (37.0%) of the 435 grid sampling stations, at a mean abundance of 1.57 kg/km trawled (Table 61). Approximately 90% of the apparent population biomass was located in subareas 2 and 2 Slope (combined) along the outer edge of the continental shelf between Unimak and St. George Islands. Only low densities were observed in Bristol Bay, along the inner and central shelf regions, and north of the Pribilof Islands.

Table 58.—Proportions of females in the estimated population of arrowtooth flounder by age group and geographical area, 1976 Bering Sea spring trawl survey.[1]

Subarea[2]	Age group (yr) ≤3	4	5	6	7	8	9	10	11	≥12	All ages combined
	Proportion of females										
Outer shelf and slope											
3 Slope	0.73	0.74	0.65	0.53	0.42	0.20	—	—	—	—	0.71
2	0.51	0.47	0.53	0.50	0.88	0.41	—	—	—	—	0.52
2 Slope	0.67	0.51	0.75	0.78	0.93	0.96	1.00	1.00	—	1.00	0.68
All subareas combined	0.53	0.49	0.61	0.66	0.91	0.94	1.00	1.00	—	1.00	0.56

[1] Based upon sampled individuals for which sexes could be determined. The population in subarea 3 is not included because no length-frequency data were collected.

[2] See Figure 3.

Table 59.—Length-weight relationships observed for arrowtooth flounder during the 1976 Bering Sea spring trawl survey, with testing for between-sex differences.

Sex	Otolith area[1]	Number sampled	FL range (cm)	Length-weight coefficients a	b	Predicted weight-at-length 10 cm	25 cm	45 cm
						grams		
Males	B	57	20-55	0.0106	2.9840	10.1	156.6	905.1
	D	11	34-47	n.d.[2]	n.d.	n.d.	n.d.	n.d.
	Both areas combined	68	20-55	0.0098	3.0061	9.9	156.3	915.0
Females	B	200	18-64	0.0074	3.0970	9.2	157.9	974.9
	D	14	35-66	n.d.	n.d.	n.d.	n.d.	n.d.
	Both areas combined	214	18-66	0.0071	3.1054	9.1	156.8	973.1
Overall		282	18-66	0.0072	3.1038	9.0	155.9	966.1

Analysis of covariance

	Tests for differences Slope (b) df	F ratio	Common means df	F ratio
Between sexes in area B	1:253	1.20	1:254	1.49
Between sexes in both areas combined	1:278	1.20	1:279	1.59

[1] See Figure 4.

[2] n.d. = not determined due to limited sample size.

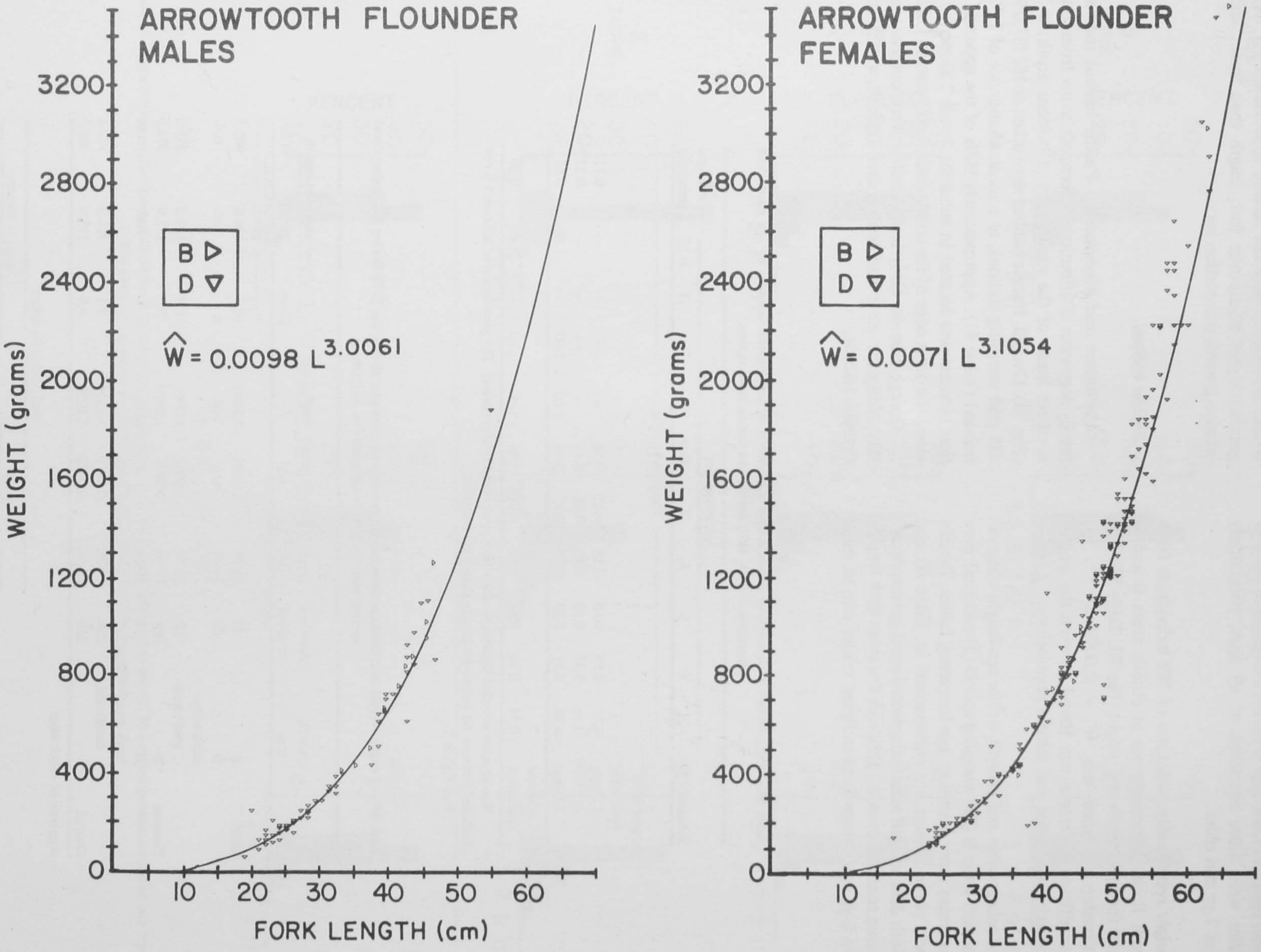


Figure 72.—Length-weight observations from arrowtooth flounder taken during the 1976 Bering Sea spring trawl survey, by sex and otolith area (see Fig. 4).

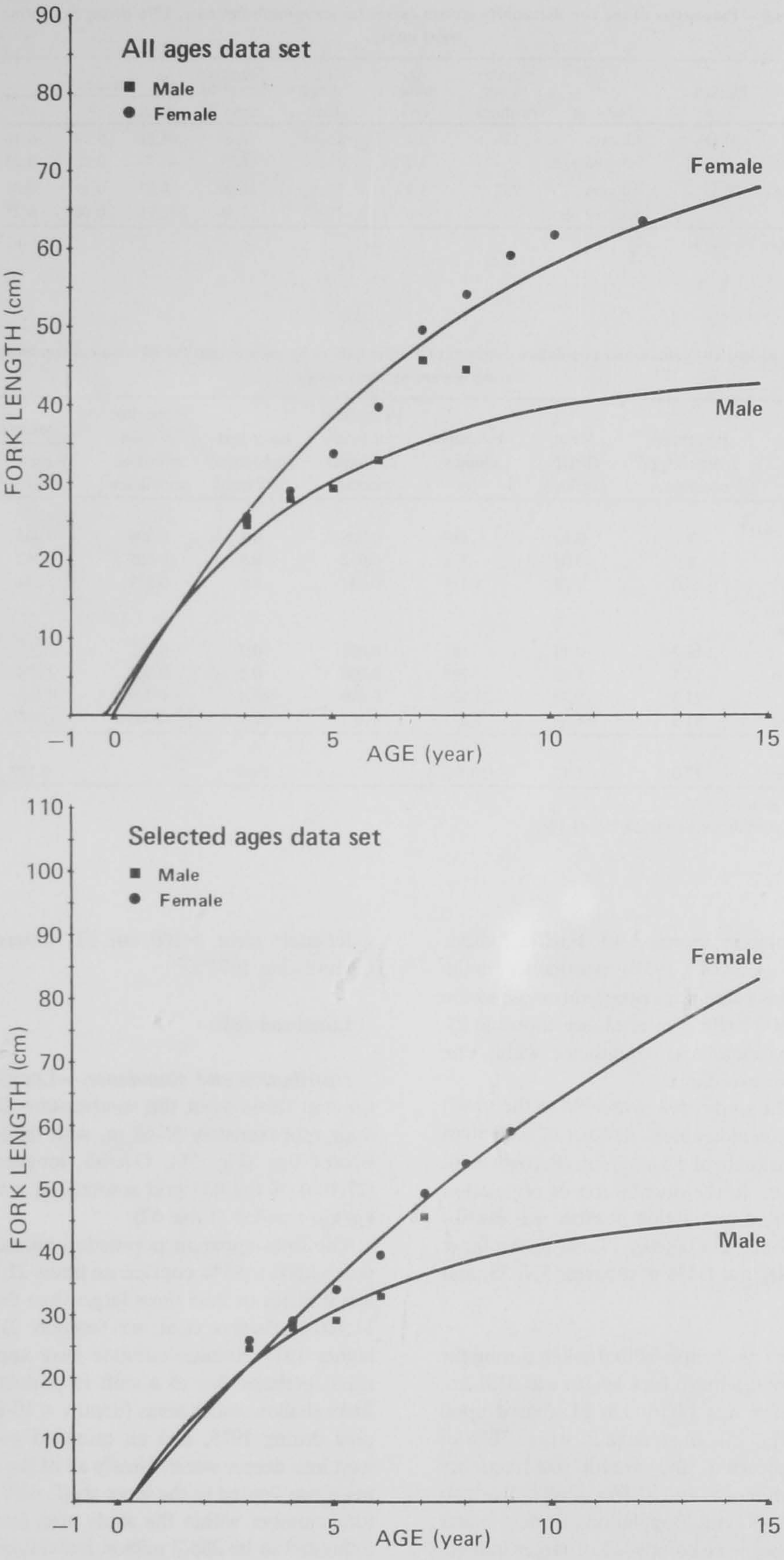


Figure 73.—Von Bertalanffy growth curves for arrowtooth flounder taken during the 1976 Bering Sea spring trawl survey, comparing results of the all ages and selected ages data sets. Symbols indicate the mean length at each age.

Table 60.—Parameters of the von Bertalanffy growth curves for arrowtooth flounder, 1976 Bering Sea spring trawl survey.

Sex	Otolith area[1]	Data set	Number of age readings	Age range (yr)	FL range (cm)	Standard error of curve fit	Parameters L_∞	K	t_0
Male	B D	All ages	126	3-8	21-54	4.19	44.21	0.22	-0.16
		Selected ages		3-7	21-54	4.61	46.78	0.22	0.22
Female	B D	All ages	257	3-12	21-66	3.99	79.27	0.13	-0.01
		Selected ages		3-9	21-61	2.46	142.91	0.06	0.25

[1] See Figure 4.

Table 61.—Estimated biomass and population numbers of Pacific halibut by subarea and for all subareas combined, 1976 Bering Sea spring trawl survey.

Subarea[1]	Percentage frequency of occurrence	Mean CPUE (kg/km)	Estimated biomass (t)	Proportion of total estimated biomass	Estimated population (millions)	Proportion of total estimated population	Mean size Weight (kg)	FL (cm)
Inner shelf								
4N	9.1	0.10	187	0.006	0.5	0.008	0.403	—
4S	8.9	0.08	371	0.012	0.3	0.005	1.342	—
1	23.0	0.28	1,371	0.044	9.5	0.159	0.144	24.4
Outer shelf and slope								
3	16.2	0.19	881	0.028	0.7	0.012	1.267	47.5
3 Slope	54.5	1.48	286	0.009	0.1	0.002	2.974	62.3
2	75.3	5.79	21,629	0.699	46.4	0.779	0.466	33.1
2 Slope	97.5	14.56	6,221	0.201	2.1	0.035	2.910	60.2
All subareas combined	37.0	1.57	[2]30,947		59.6		0.519	33.0

[1] See Figure 3.

[2] 95% confidence limits: 20,755-41,138 t.

The total apparent population biomass of Pacific halibut ithin the study area was 30,900 t (95% confidence limits 0,800-41,100 t). Although this value was remarkably close to the 975 survey estimate of 30,600 t (Pereyra et al. see footnote 2), oth estimates may underestimate true abundance within the tudy area as a result of trawl avoidance.

The total number within the study area (available to the trawl) vas estimated to be 59.6 million individuals, a factor of 4.66 times arger than the 1975 survey estimate of 12.8 million (Pereyra et al. ee footnote 2). In comparison to the distribution of population iomass, 81.4% of the apparent population number was distrib-ted in subareas 2 and 2 Slope (combined), 17.2% in the inner helf (subareas 1, 4S, and 4N), and 1.4% in subareas 3N, 3S, and Slope (combined).

Size composition.—Almost all Pacific halibut taken during the urvey were juveniles. The overall mean fork length was 33.0 cm, nd the observed range in size was 14-101 cm FL (based upon ,163 field measurements; Fig. 75). In subarea 2, where 78% of he apparent population occurred, the overall size-frequency listribution was essentially unimodal and 91.6% of all individuals vas within the size range 25-40 cm. Populations in deep water subareas 2 Slope and 3 Slope) were composed of larger individ-ıals, with a considerably broader distribution of sizes about each nean fork length.

In contrast with the relatively small overall size distribution aken during the 1976 spring trawl survey, the size range of Pacific halibut caught by the North American setline fishery in the eastern Bering Sea during 1976 was 67-215 cm FL, and 75% of all individuals were >100 cm FL (International Pacific Halibut Commission 1977[8]).

Longhead dab.

Distribution and abundance.—Longhead dab was widely distributed throughout the southeastern Bering Sea at depths less than approximately 55-65 m, with highest abundance in central Bristol Bay (Fig. 76). Overall, longhead dab occurred at 118 (27.1%) of the 435 grid stations, at a mean abundance of 1.62 kg/km trawled (Table 62).

The total apparent population biomass within the study area was 32,800 t (95% confidence limits 21,800-43,700 t). This value was a factor of 2.95 times larger than the 1975 survey estimate of 11,100 t (Pereyra et al. see footnote 2). Principal causes of the higher 1976 biomass estimate were apparently higher fish densities, perhaps due to a shift in population distribution pattern from shallow-water areas (depths < 10-20 m) that were not sampled during 1975, and an extended geographical range farther west into deeper water. Nearly all of the apparent population biomass was limited to the inner shelf, with 73.7% in subarea 1. The total number within the study area (available to the trawl) was estimated to be 286.2 million individuals.

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[8] International Pacific Halibut Commission. 1976. Items of information on the halibut fishery in the Bering Sea and the northeastern Pacific Ocean. Unpubl. manuscr., 39 p. International Pacific Halibut Commision, P.O. Box 5009, University Station, Seattle, WA 98105.

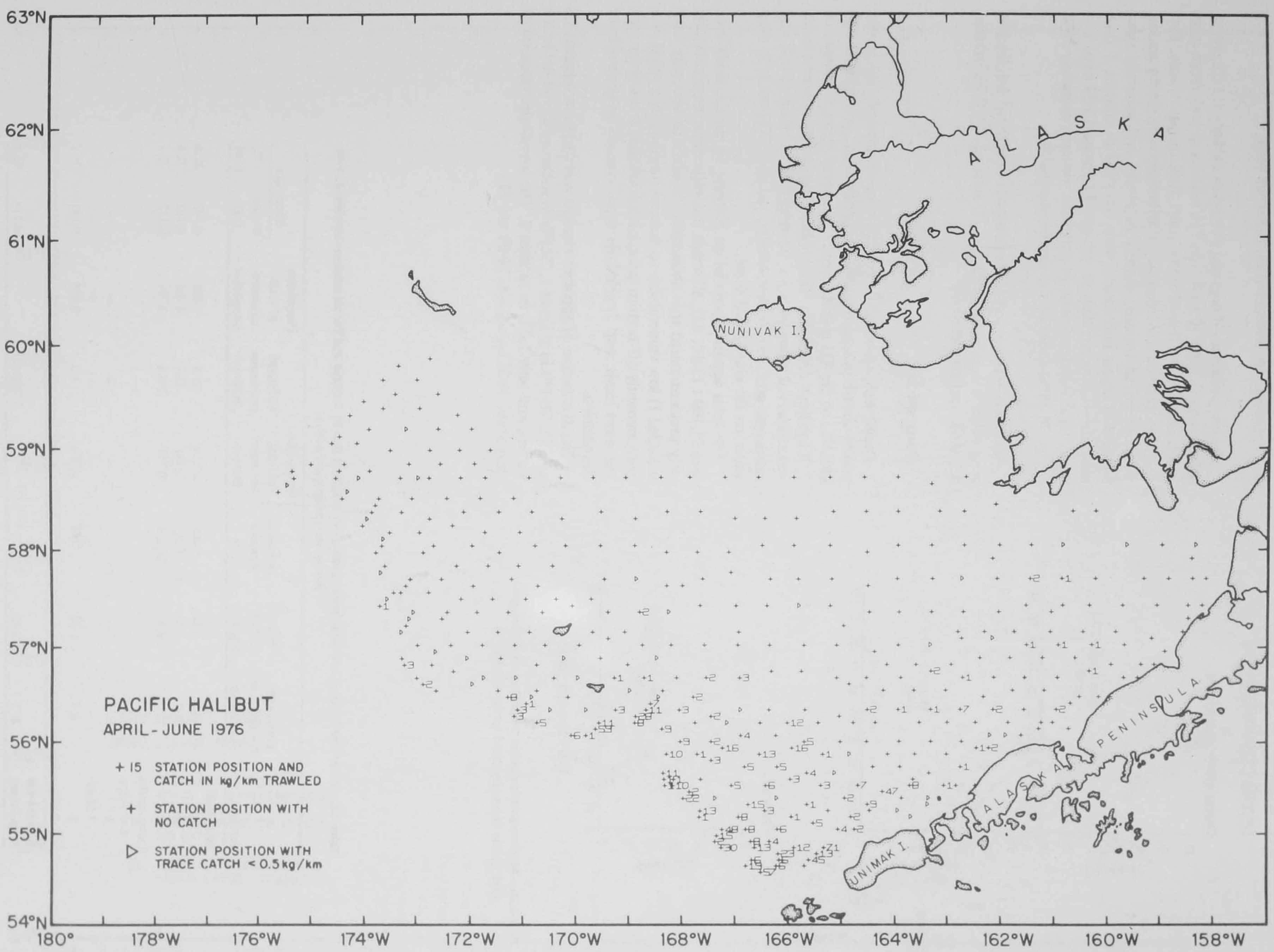

Figure 74.—Distribution of catch rates of Pacific halibut during the 1976 Bering Sea spring trawl survey (by weight).

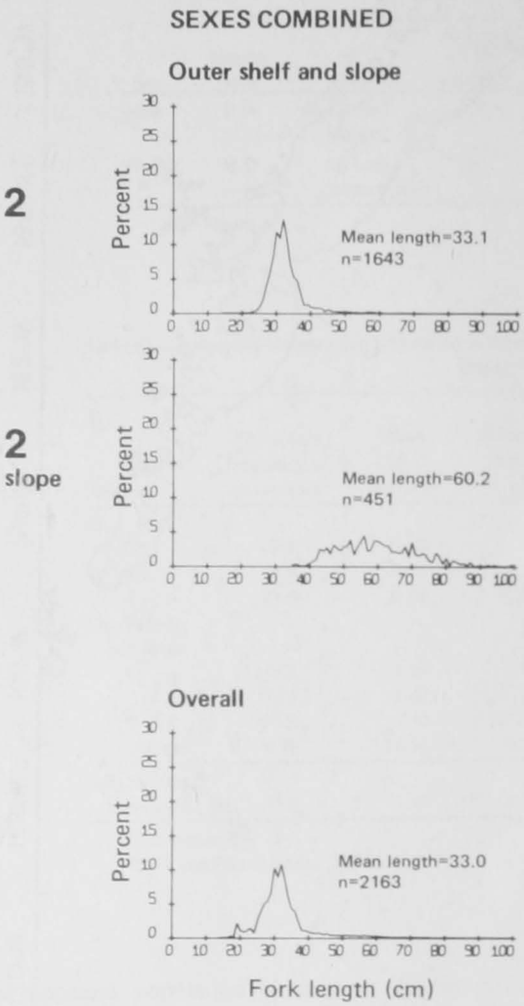

Figure 75.—Size composition of Pacific halibut taken during the 1976 Bering Sea spring trawl survey (see Fig. 3).

Because longhead dab was not observed to be abundant on the outer shelf at any time during the 1976 spring survey, the population apparently overwintered on the inner shelf.

Size composition.—Longhead dab taken during the 1976 spring survey ranged from 10 to 41 cm TL, with an overall mean total length of 23.1 cm (based upon 3,409 field measurements; Fig. 77). The observed size-frequency distributions were similar among all geographical regions, sharply unimodal and generally symmetrical. Largest individuals were observed in subarea 1 (size range 14-41 cm), smallest in subarea 4S (range 10-34 cm). The mean total length of male populations was approximately 78% (range 76-85%) those of the female populations.

Sex ratio.—The observed proportions of longhead dab females were subarea 1, 0.64; subarea 2, 0.33; subarea 4N, 0.70; subarea 4S, 0.63; and overall, 0.64.

Other species.

Pacific herring.—Pacific herring, *Clupea harengus pallasi*, was widely distributed throughout the study area, occurring at 180 (41.4%) of the 435 grid stations at an overall mean abundance of 2.01 kg/km trawled (Fig. 78). Highest densities (on a weight basis) were observed along pack ice northwest of St. Paul Island, and northwest and west of Port Moller, but none was taken in deep water on the continental slope.

The total apparent population biomass within the study area was 35,100 t (Table 63), although this value must have considerably underestimated true abundance. Sources of bias may have included 1) low vulnerability to bottom trawling, as a result of a predominantly off-bottom (pelagic) distribution; 2) losses through the trawl mesh; and 3) relatively rapid changes in geographical distribution.

The distribution of apparent biomass was 48.1% in subareas 3N and 3S, 28.1% in subarea 1, 22.9% in subareas 4S and 4N (combined), and only 1.0% in subarea 2. The overall size range taken during the 1976 survey was 20-31 cm FL.

Table 62.—Estimated biomass and population numbers of longhead dab by subarea and for all subareas combined, 1976 Bering Sea spring trawl survey.

Subarea[1]	Percentage frequency of occurrence	Mean CPUE (kg/km)	Estimated biomass (t)	Proportion of total estimated biomass	Estimated population (millions)	Proportion of total estimated population	Mean size Weight (kg)	Mean size TL (cm)
Inner shelf								
4N	40.9	1.34	2,481	0.076	17.5	0.061	0.142	22.6
4S	58.9	1.38	5,945	0.181	58.1	0.203	0.102	22.6
1	72.0	4.93	24,158	0.737	209.4	0.731	0.115	23.3
Outer shelf and slope								
3	—	—	—	—	—	—	—	—
3 Slope	—	—	—	—	—	—	—	—
2	4.5	0.05	184	0.006	1.3	0.005	0.145	21.1
2 Slope	—	—	—	—	—	—	—	—
All subareas combined	27.1	1.62	[2]32,767		286.2		0.114	23.1

[1] See Figure 3.

[2] 95% confidence limits: 21,793-43,714 t.

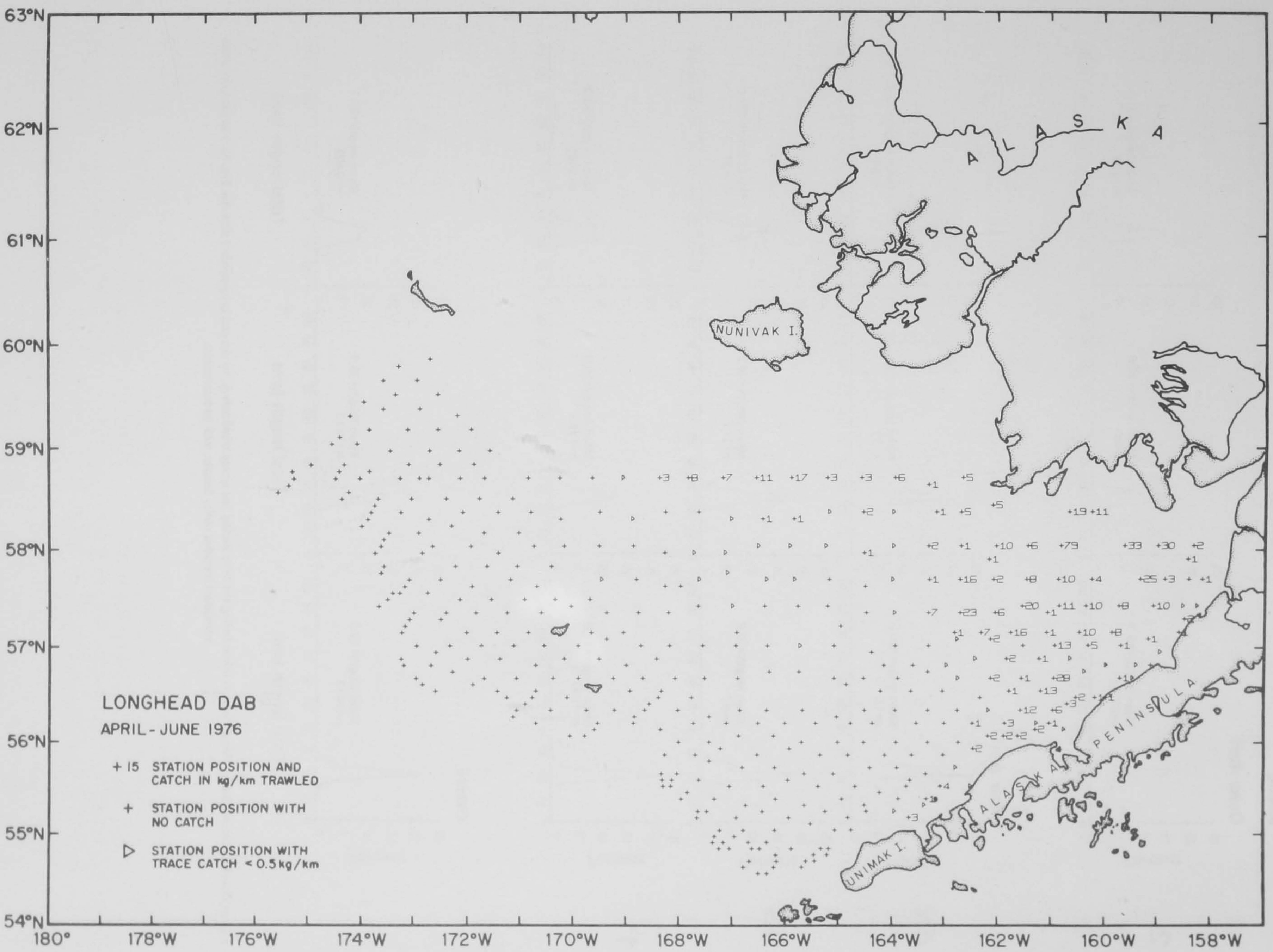

Figure 76.—Distribution of catch rates of longhead dab during the 1976 Bering Sea spring trawl survey (by weight).

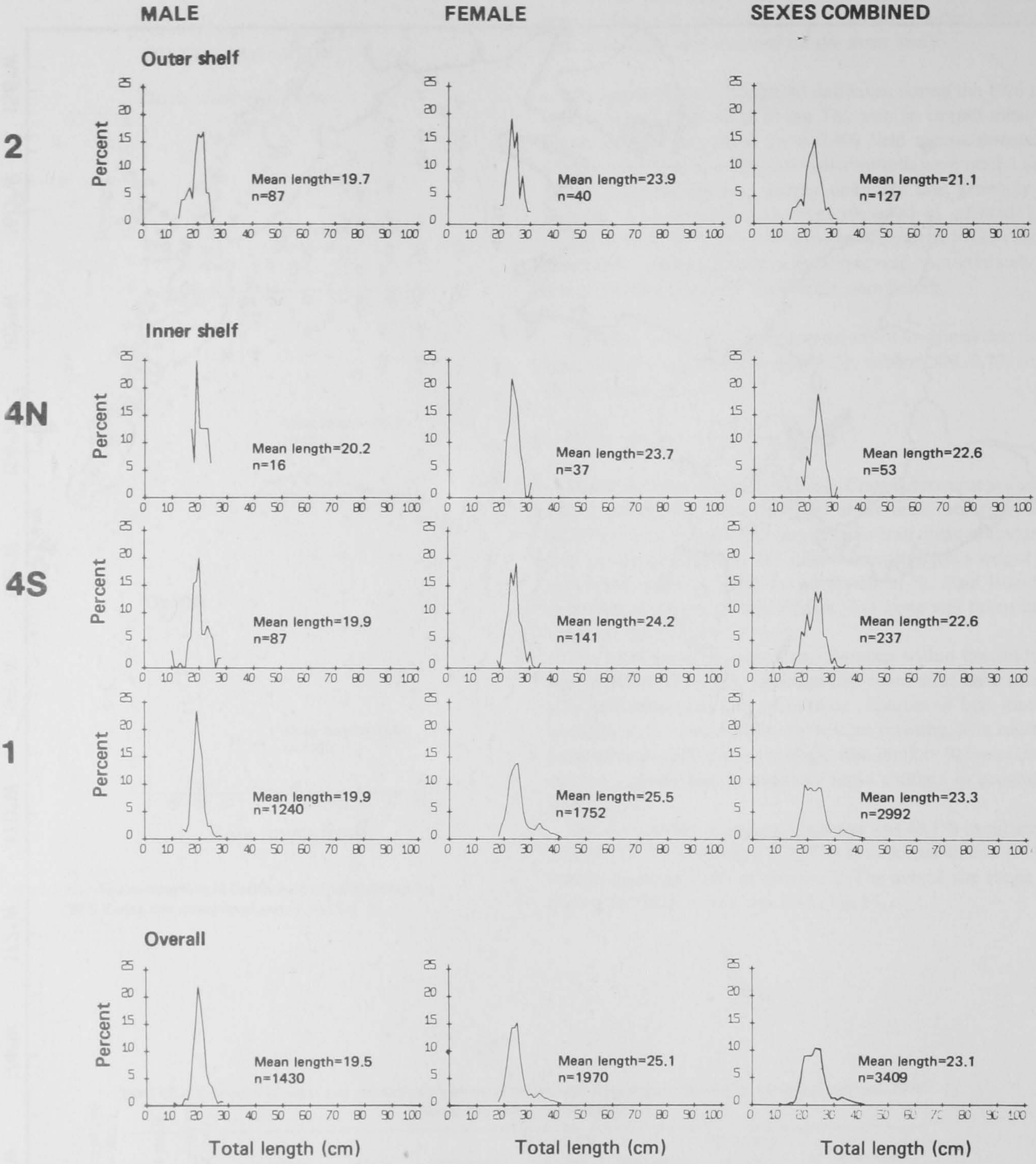

Figure 77.—Size composition of longhead dab taken during the 1976 Bering Sea spring trawl survey, by sex and geographical area (see Fig. 3). The category sexes combined includes male, female, and undetermined.

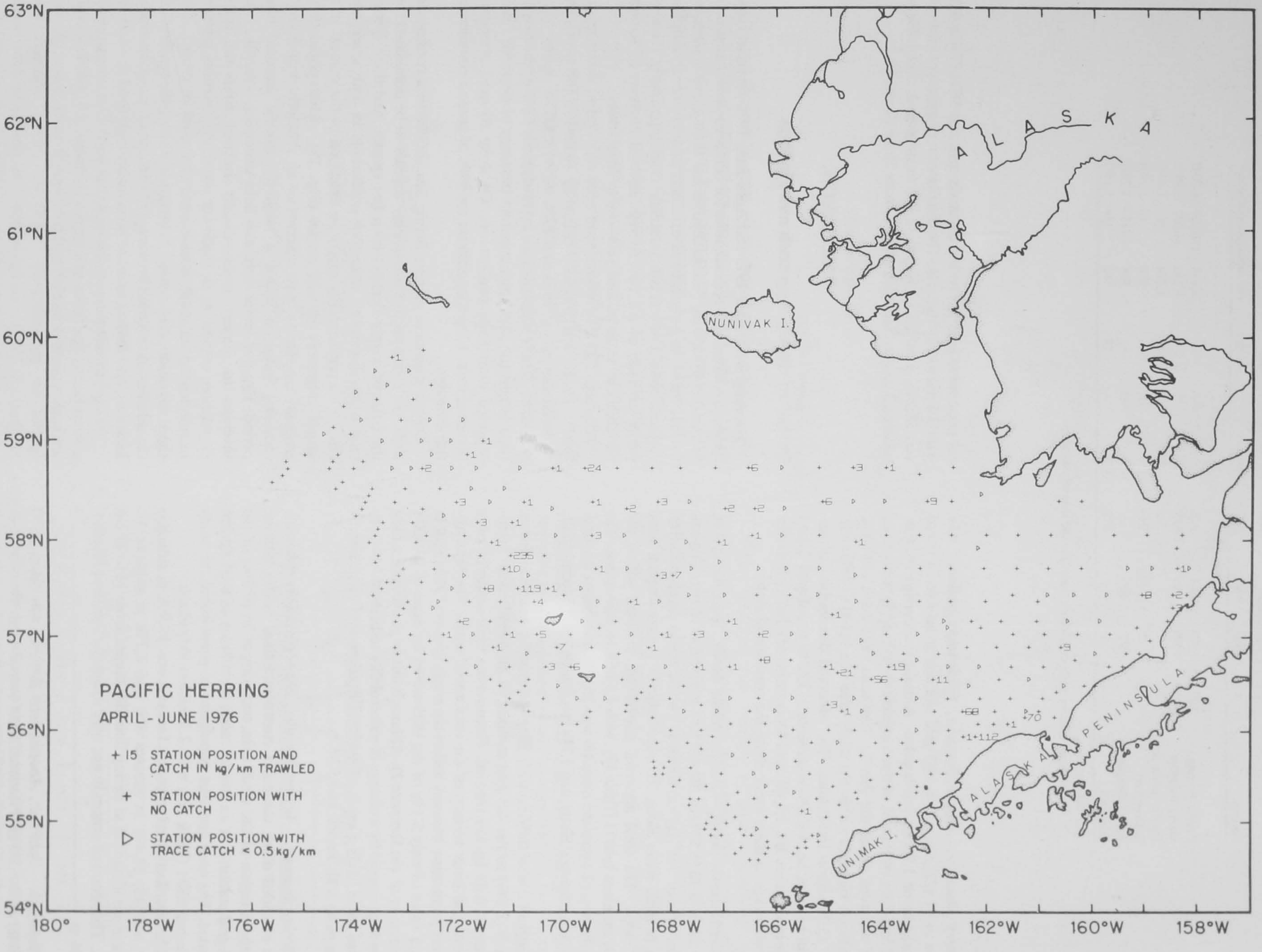

Figure 78.—Distribution of catch rates of Pacific herring during the 1976 Bering Sea spring trawl survey (by weight).

Table 63.—Estimates of the biomass of other fish populations, 1976 Bering Sea spring trawl survey.

	Inner shelf subareas[1]			Outer shelf and slope subareas[1]					
Species	1	4S	4N	2	2 Slope	3	3 Slope	All subareas combined[2]	
	Metric tons								
Pacific herring	9,872	3,975	4,064	338	—	16,882	—	35,131	(12,058-58,204)
Starry flounder	5,891	529	95	2,698	—	55	—	9,268	(4,607-13,933)
Pacific ocean perch	—	—	—	33	784	48	549	1,414	(185- 2,643)
Saffron cod	10	5	—	949	—	6	—	970	(0- 2,389)
Bering flounder	—	25	356	—	—	547	—	928	(157- 1,701)
Sablefish	—	—	—	215	338	—	28	581	(14- 1,148)

[1] See Figure 3.

[2] Parentheses enclose 95% confidence limits for the overall estimates.

Starry flounder.—Starry flounder, *Platichthys stellatus,* was taken at 97 (22.3%) of the 435 grid stations at an overall mean abundance of 1.20 kg/km trawled. Although occurring at scattered locations over most of the continental shelf, highest densities were observed along the Alaska Peninsula. The total apparent population biomass within the study area was 9,300 t (Table 63), with 15.3 million individuals. The observed distribution of apparent biomass was 63.6% in subarea 1, 29.1% in subarea 2, and 7.3% in subareas 3N, 3S, 4S, and 4N (combined). Starry flounder was not taken in deep water along the continental slope.

Pacific ocean perch.—Pacific ocean perch, *Sebastes alutus,* was taken at 30 (6.9%) of the 435 grid stations, at an overall mean abundance of 0.07 kg/km trawled. Pacific ocean perch occurred only in deep water along the outer edge of the continental shelf and slope. The total apparent population biomass within the study area was 1,400 t (Table 63), with 1.5 million individuals. The distribution of apparent biomass was 55.4% in subarea 2 Slope, 38.8% in subarea 3 Slope, and 5.7% in subareas 2 and 3 (combined).

Saffron cod.—Saffron cod, *Eleginus gracilis,* was recorded at only 9 (2.1%) of the 435 grid stations, at an overall mean abundance of 0.05 kg/km trawled. Occurrences were scattered over central and inner regions of the continental shelf. The total apparent population biomass within the study area was 970 t (Table 63), a value of only 5.1% of the 1975 survey estimate of 19,100 t (Pereyra et al. see footnote 2). Although this large difference may have been caused by a change in vulnerability to bottom trawling, it was more likely a result of misidentifications and confusion of specimens with Pacific cod.

Bering flounder.—Bering flounder, *Hippoglossoides robustus,* was recorded along the outer continental shelf in the extreme northern region of the study area, occurring at 26 (6.0%) of the 435 grid stations, at an overall mean abundance of 0.04 kg/km trawled. The total apparent population biomass within the study area was 930 t (Table 63), with 2.9 million individuals.

The distribution of apparent biomass was 58.9% in subareas 3N and 3S, 38.4% in subarea 4N, and 2.7% in subarea 4S. Specimens identified as Bering flounder ranged from 14 to 41 cm TL. The observed ranges in age were males, 5-15 yr, and females, 5-24 yr.

Sablefish.—Sablefish, *Anoplopoma fimbria,* was taken at 30 (6.9%) of the 435 grid stations, at an overall mean abundance of 0.03 kg/km trawled. Occurrences were observed only in deep water along the outer continental shelf and slope. The total apparent population biomass within the study area was 580 t (Table 63), with 0.4 million individuals. The distribution of apparent biomass was 58.2% in subarea 2 Slope, 37.0% in subarea 2, and 4.8% in subarea 3 Slope. Sablefish ranged from 38 to 62 cm FL.

DISCUSSION

Review of Survey Approach and Findings

The August-October 1975 and April-June 1976 demersal trawl surveys provided new opportunities for comprehensive assessment of the eastern Bering Sea ichthyofauna. Both surveys were extremely broad in geographical coverage, and consistent sampling methods enabled direct comparability. And importantly, the temporal coverage of the two surveys enabled analyses of natural variability at seasonal and year-to-year time scales.

Although 235 fish species have been reported to occur in the eastern Bering Sea (Shmidt 1950), only 76 and 78 fish taxa were recorded during the 1975 and 1976 surveys. Of these, the most abundant 20 taxa accounted for approximately 98% of the overall total weight (or also, total apparent biomass) of demersal fishes recorded during the two surveys. Of these 20 most abundant demersal taxa, 10 species account for 99% of present commercial fish landings.

On the expansive eastern Bering Sea soft-bottom continental shelf, the demersal fish community appears to be dominated (on the basis of weight density) by a few species, and these species tend to be distributed somewhat predictably in both space and time. This predictability might be described in the context of a simple migratory circuits model (Fig. 79). Adult populations generally migrate to, and concentrate at, relatively well-defined spawning locations within a relatively specific seasonal time period. Egg and larval drift, and later swimming behavior, take juveniles to nursery areas—usually isolated from the adult population, inshore or in shallower water. As juveniles mature, recruitment to the adult stock occurs as a result of growth, offshore migration, and changes in behavior. During the seasonal cycle, adult stocks migrate between overwintering regions, spawning locations, and feeding areas of presumably high food abundance.

Freezing avoidance mechanisms are an important adaptation of eastern Bering Sea fishes to their environment. All marine teleosts are hypotonic to seawater, and the blood freezing points of most species are approximately −0.5° to −0.8°C (Somero and Hochachka 1976). Under winter ice cover, bottom water temperatures over most of the eastern Bering Sea continental shelf are near the freezing point of seawater (−1.6° to −1.7°C). Even

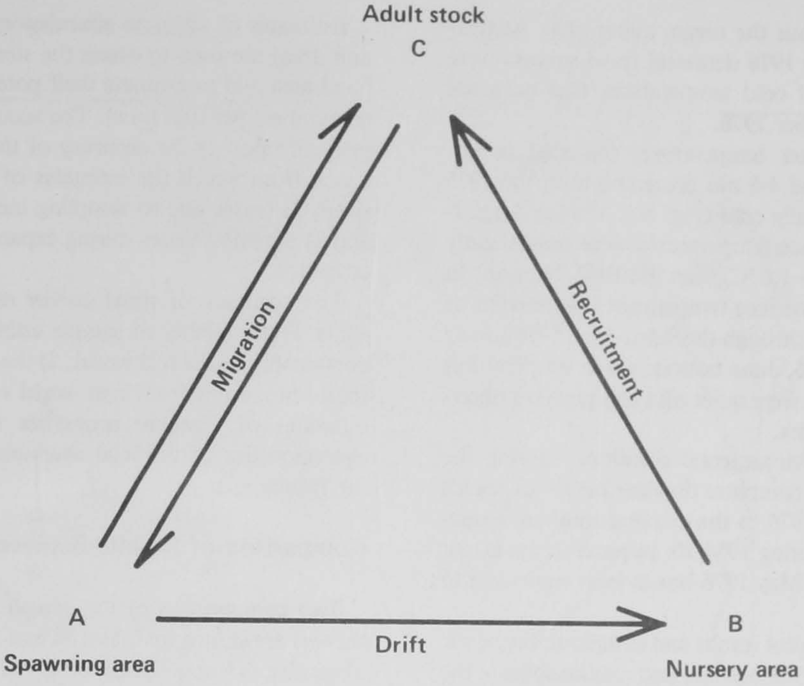

Figure 79.—The annual circuit of migration (Harden Jones 1968).

during summer, large areas of residual subzero winter bottom water remain on the northern central shelf. Faced with potentially lethal conditions, Bering Sea fishes use two principal mechanisms to avoid freezing: Behavioral avoidance (i.e., seasonal migration) and production of biochemical antifreezes. Whereas some of the major fish populations must apparently undergo regular seasonal migrations from shallow to deep water (e.g., yellowfin sole, Pacific halibut, Alaska plaice), other taxa develop glycoprotein and protein antifreezes (e.g., saffron cod and sculpins such as *Myoxocephalus* spp.) (Raymond et al. 1975) that apparently enable survival in all regions of the continental shelf throughout the year.

Figure 80 shows two measures of climatic conditions in the southeastern Bering Sea during the period 1966-77 (McLain and Favorite 1976: figure 1 updated to 1977 with data from the authors; International Pacific Halibut Commission 1976 see footnote 8, 1977[9]). Like most climatic data, both time series indicate extended multiyear periods of warm or cold conditions, rather

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[9] International Pacific Halibut Commission. 1977. Items of information on the halibut fishery in the Bering Sea and the northeastern Pacific Ocean. Unpubl. manuscr., 39 p. International Pacific Halibut Commission, P.O. Box 5009, University Station, Seattle, WA 98105.

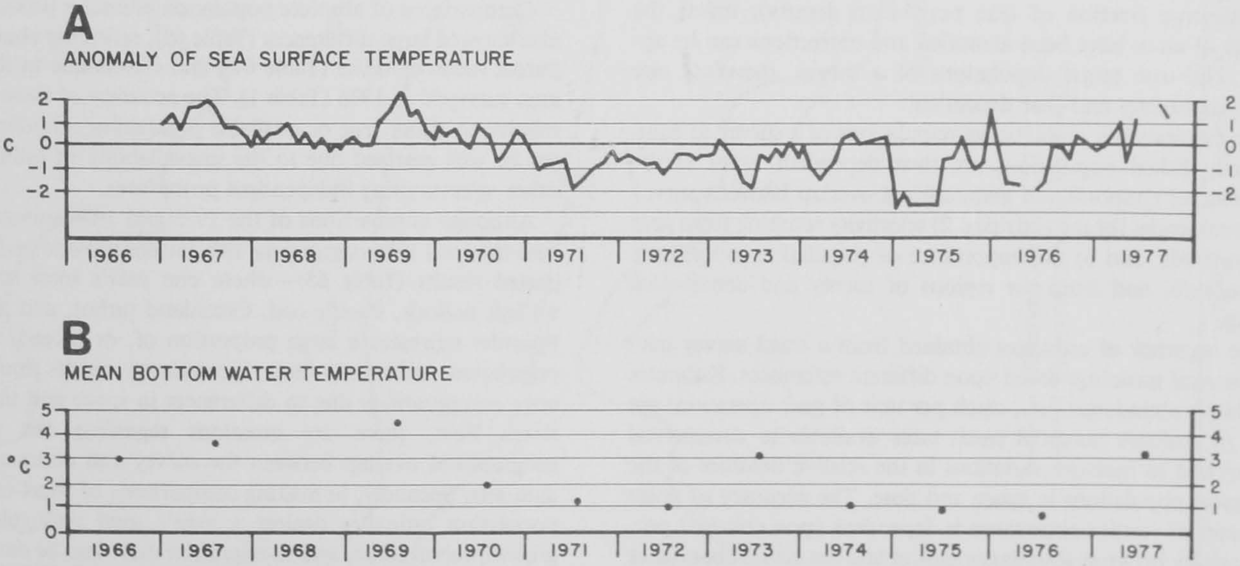

Figure 80.—Climatic conditions in the southeastern Bering Sea 1966-77: A) anomaly of sea surface temperature at lat. 57°N, long. 170°W (near St. Paul Island) from the April 1962-May 1975 mean; B) mean bottom water temperature during June at 34 standard International Pacific Halibut Commission survey stations in the southeastern Bering Sea.

than random fluctuations about the mean values. The August-October 1975 and April-June 1976 demersal trawl surveys were conducted during a period of cold temperatures that occurred from January 1971 to December 1976.

In general, surface seawater temperatures recorded at lat. 57°N, long. 170°W during the 4-6 mo preceding both the 1975 and 1976 surveys were unusually cold (Fig. 80). During August-October 1975, however, surface temperatures were only slightly cooler (anomalies of 0.0° to −1.0°C) than the 1962-75 mean. In comparison, cold winter sea surface temperatures (anomalies of −1.8° to −2.0°C) continued through the April-June 1976 survey period. In both 1975 and 1976, June bottom water temperatures in the southeastern Bering Sea were quite cold compared to observations during most other years.

As a third measure of environmental conditions during the 1976 survey period, Figure 81 compares the distribution of sea ice observed during April-June 1976 to the extreme southern extensions of ice cover observed during 1954-70. In general, the extent of ice cover during April and May 1976 was at least equivalent to the 17-yr (1954-70) extremes.

Before discussing the biological results and comparability of the 1975 and 1976 eastern Bering Sea surveys, and relationships to the above model, it is appropriate to reevaluate basic objectives, assumptions, and limitations of the overall program. The fundamental objective of the surveys was to obtain two short-term descriptions of characteristics (including density distribution, total size, age structure, etc.) of the mixed species populations caught by the sampling gear and to compare these characteristics between time periods. Target populations were implicitly defined by the location of the sampling area and its boundaries, and selective characteristics of the sampling gear and field methods.

The real identity of the target populations of a trawl survey is frequently confused with the desire to measure total population size, true population density, and the commercially fished populations. Clearly, the validity of intentions to measure total population abundance is dependent upon relationships between the area surveyed and species range. Because of biasing characteristics of sampling gear and methods (i.e., imperfect efficiencies), estimates of true population density are usually expressed as measures of available population density (where available population density is usually some fraction of true population density), unless the sources of error have been identified and corrections can be applied. The true target populations of a survey, therefore, are usually boundary and gear dependent.

The relationships of the target populations of a survey to commercially fished populations are then dependent upon 1) the character of temporal and geographical overlap between survey and commercial fishing activities, 2) selectivity resulting from gear and methods, and 3) the importance of population movements within, into, and from the regions of survey and commercial fishing.

The accuracy of estimates obtained from a trawl survey may have several meanings based upon different references. Estimates of relative abundance (i.e., catch per unit of gear operation) are used to evaluate potential catch rates available to commercial fishing and to measure variations in the relative densities of the biological populations in space and time. The accuracy of point estimates of relative abundance is dependent upon constant proportionality between abundance indices and the actual abundance of the populations. Overall estimates of relative abundance are also affected by the relation of survey design to the distributions of target populations, and the validity of stationary distributions and closed populations assumptions.

Estimates of absolute abundance (i.e., population density per unit area) are used to assess the size of populations within a defined area and to estimate their potential absolute yields (weight, or numbers per unit time). The accuracy of these estimates is dependent upon 1) the accuracy of the estimates of relative abundance from which the estimates of absolute abundance are derived, 2) biases due to sampling inefficiencies of the trawl gear, and 3) potential biases during expansion from per unit to overall estimates.

The accuracy of trawl survey estimates, then, may refer to either 1) the fidelity of sample estimates to reflect constant proportionality to the real world, 2) the departure of estimates of absolute properties from real world values, or 3) the departure of estimates of absolute properties from true, but indefinable, characteristics of artificial available populations determined by the fishing gear.

Comparison of Results Between Surveys

Two comparisons of the overall results of the 1975 and 1976 surveys are shown in Tables 64 and 65. Table 64 compares indices of relative fish abundances observed during the two surveys. Table 65 compares the absolute population estimates obtained for each species, uncorrected for differences in geographical coverage between surveys. Population estimates are also compared in Table 65 against total commercial catches in the eastern Bering Sea during 1975.

Mean relative abundances showed large differences between surveys, both within individual subdivisions of the survey area and overall (Table 64). Differences in overall apparent densities may have been due to 1) changes in sampling efficiencies and sampling biases, 2) true population growth due to recruitment, or decline due to mortality, and 3) population in-migration to, or out-migration from, the overall survey area. The importance of these potential effects has previously been discussed in the presentation of survey results for each species. Differences in apparent mean densities within individual subdivisions may then have been caused by 1) all of the above potential effects and 2) changes in the geographical distribution of populations between subareas due to seasonal or between-year shifts and migrations.

Comparisons of absolute population estimates between surveys also showed large differences (Table 65), reflecting changes in apparent mean densities (Table 64), and effects due to the reduced area surveyed in 1976 (Table 1). The accuracy of these estimates, relative to either true or available population references, cannot yet be well assessed due to the unavailability of estimates from other sources using independent procedures.

Although comparisons of the 1975 and 1976 survey estimates with the total 1975 commercial fish catches provide perhaps unexpected results (Table 65)—where one year's total removals of walleye pollock, Pacific cod, Greenland turbot, and arrowtooth flounder represent a large proportion of, or exceed, the survey population estimates—these inconsistent results may indicate poor comparability due to differences in space and time dimensions. First, there are questions regarding the degree of geographical overlap between the survey and commercial catch data sets. Secondly, in making comparisons of short-term survey population estimates against a year's total removals, somatic growth, recruitment, and in-migration must also be considered as potential sources of differences. In particular, in-migration processes could be quite important if individuals from outside—such as deep or midwater populations—migrate to replace populations removed from preferred grounds within the survey area.

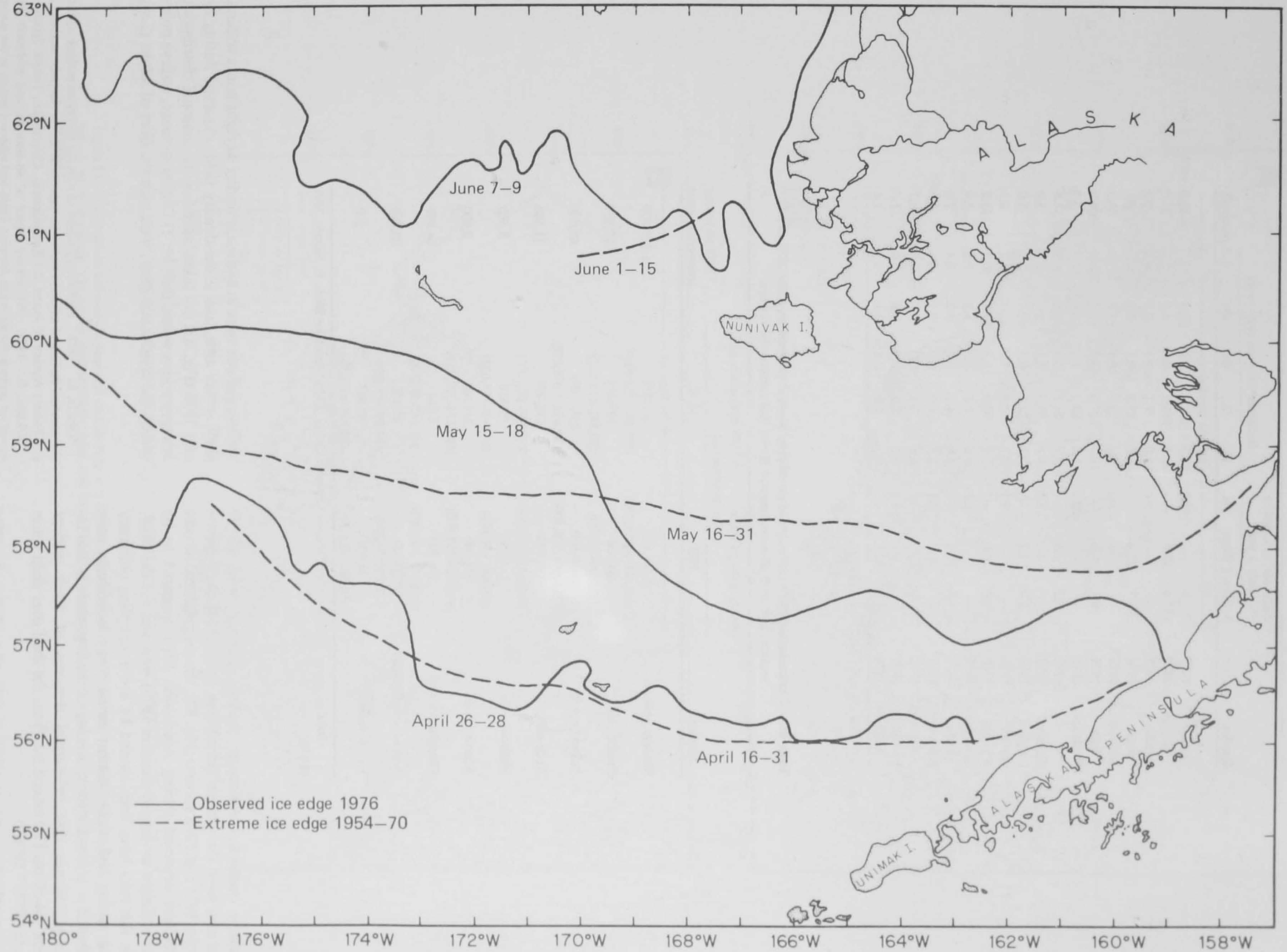

Figure 81.—Ice cover observed during spring 1976 compared to long-term (1954-70) extremes reported by Potocsky (1975). Data for 1976 from shipboard observations and satellite records provided by the Environmental Satellite Services, NOAA, Washington, D.C.

Table 64.—Comparisons of mean catch per unit fishing effort within geographical subdivisions of the 1975 and 1976 study areas in the eastern Bering Sea.

		Subareas[1] sampled in only 1 year			Subareas[1] sampled both years					
Species	Year	3 Slope	2 Slope	3N	3S	2	4N	4S	1	Overall
		kg/km trawled								
Walleye	1975	—	—	198.8	57.7	226.8	0.6	39.5	10.7	80.5
pollock	1976	15.4	90.5	—	36.5	119.2	0.9	1.3	2.8	34.0
Pacific	1975	—	—	3.6	2.0	7.1	<0.1	0.5	0.9	2.7
cod	1976	16.7	27.4	—	4.6	17.2	<0.1	0.1	0.2	5.1
Yellowfin	1975	—	—	<0.1	1.2	15.1	18.9	65.0	103.6	34.3
sole	1976	0.1	0.0	—	21.7	127.0	23.9	47.5	259.0	104.0
Rock sole	1975	—	—	<0.1	3.6	10.4	1.3	6.4	12.9	5.7
	1976	0.3	1.5	—	2.7	29.7	0.4	18.0	6.9	11.8
Flathead	1975	—	—	3.8	3.4	14.9	<0.1	1.0	1.6	3.9
sole	1976	2.4	7.1	—	2.2	22.3	0.1	0.1	0.4	5.0
Alaska	1975	—	—	<0.1	0.1	1.2	7.2	12.5	3.7	4.1
plaice	1976	0.0	0.0	—	1.9	10.0	10.4	29.1	10.7	12.2
Greenland	1975	—	—	16.8	5.6	2.3	0.9	1.3	0.8	4.4
turbot	1976	4.8	19.8	—	4.8	4.1	0.2	0.2	0.4	2.6
Arrowtooth	1975	—	—	0.1	1.1	4.9	0.0	<0.1	0.1	1.0
flounder	1976	7.0	39.0	—	0.6	5.3	0.0	0.0	0.0	2.1
Pacific	1975	—	—	0.1	0.1	2.6	0.9	0.6	2.0	1.0
halibut	1976	1.5	14.6	—	0.2	5.8	0.1	0.1	0.3	1.6

[1]See Figures 2 and 3.

Table 65.—Comparisons between estimates of population biomass obtained from the 1975 and 1976 surveys, and 1975 all-nation eastern Bering Sea commercial catches.

	Survey biomass estimates and 95% confidence limits (in parentheses)		
Species	1975	1976	1975 all-nation[1] commercial catch
	Metric tons		
Walleye pollock	2,426,400	679,492	1,285,000
	(2,001,600-2,851,100)	(480,060-878,925)	
Pacific cod	64,500	102,282	57,300
	(51,500-77,500)	(70,581-133,983)	
Yellowfin sole	1,038,600	2,094,589	65,800
	(870,800-1,206,400)	(1,170,499-3,018,678)	
Rock sole	170,300	236,067	11,100
	(138,300-202,200)	(79,984-392,151)	
Flathead sole	113,000	99,430	5,500
	(93,900-132,100)	(63,848-135,012)	
Alaska plaice	127,100	243,662	2,600
	(101,800-152,800)	(190,174-297,150)	
Greenland turbot	126,700	51,013	64,800
	(112,700-140,700)	(43,247-58,778)	
Arrowtooth flounder	28,000	40,822	20,800
	(22,700-33,300)	(29,990-51,654)	
Pacific halibut	30,600	30,947	300
	(18,700-42,600)	(20,755-41,138)	

[1]Data on file at Northwest and Alaska Fisheries Center, 2725 Montlake Blvd. E, Seattle, WA 98112.

Walleye pollock.—Although walleye pollock was widely distributed over the eastern Bering Sea continental shelf during both the 1975 and 1976 surveys (Fig. 82), the geographical density distribution observed during April-June 1976 appeared to be shifted (relative to August-October 1975) west and off the shelf. While this may have been caused by lower sampling efficiency during spring and early summer when more individuals were distributed in midwater for spawning or feeding, there is also increasing evidence that substantial densities of adult walleye pollock (44-50 cm FL) extend out from the shelf over deep water (Okada 1977,[10] 1978[11]).

Because the few echosounding records taken during the 1976 survey do not support the hypothesis that large abundances of walleye pollock were in midwater during daylight hours within the shelf survey area, and if the density fields observed during 1975 and 1976 (Fig. 82) are taken as indicating seasonal distributions, interpretations would then be: 1) During summer, walleye pollock invade the continental shelf, with high densities of adults (2-6 yr)

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[10] Okada, K. 1977. Preliminary report of acoustic survey on pollock stocks in the Aleutian Basin and adjacent waters in summer of 1977. Unpubl. manuscr., 3 p. Fishery Agency of Japan, 2-1 Kasumigaseki, Chiyoda-ku, Tokyo, Japan.

[11] Okada, K. 1978. Preliminary report of an acoustic and midwater trawl survey on pollock stocks in the Aleutian Basin and adjacent waters in the summer of 1978. Unpubl. manuscr., 6 p. Fishery Agency of Japan, 2-1 Kasumigaseki, Chiyoda-ku, Tokyo, Japan.

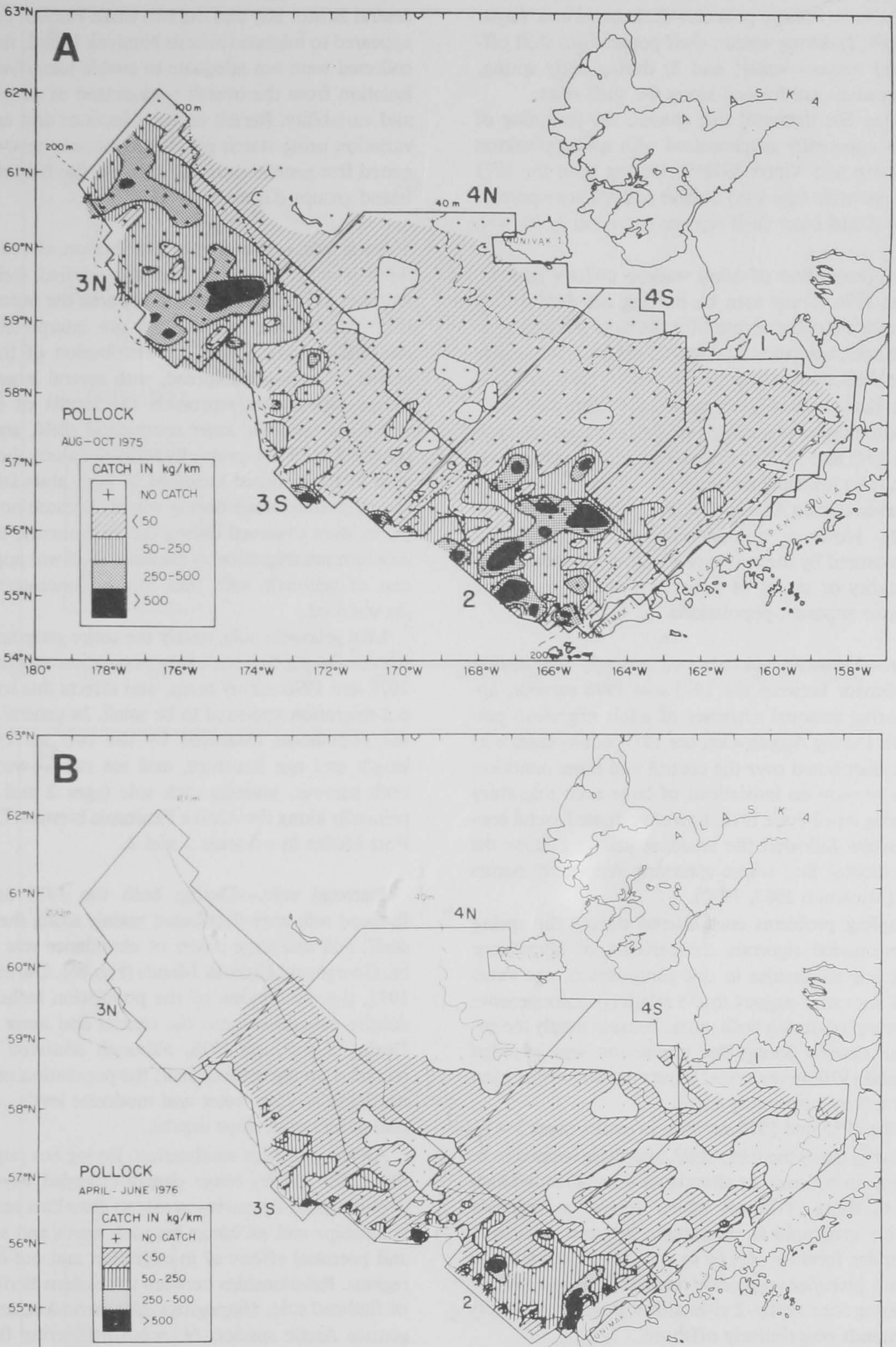

Figure 82.—Comparison between the apparent distributions and relative abundance of walleye pollock in the Bering Sea: A) 1975 survey; B) 1976 survey. The survey area boundary lines used in 1975 are superimposed upon both illustrations as a common reference.

concentrating along the outer shelf where food abundances—euphausiids and juvenile walleye pollock—(Takahashi and Yamaguchi 1972) are high; 2) during winter, shelf populations shift offshore to deep and warmer water; and 3) during early spring, spawning concentrations are formed along the shelf edge.

Like most Bering Sea demersal fish species, the spawning of walleye pollock is apparently synchronized with spring plankton production (Waldron and Vinter 1978[12]). During both the 1975 and 1976 surveys, juvenile (age 1 yr) walleye pollock were primarily found in central and inner shelf regions (subareas 1, 4S, 4N, and 3S).

If a substantial proportion of adult walleye pollock had migrated out of the 1976 survey area by moving off-shelf during winter, these movements could account for the large differences in size and age structures, sex ratios, and length-weight relationships measured for the shelf populations by the two surveys.

The hypothesis that genetically distinct north and south walleye pollock populations may exist was not well supported by data collected during the 1975 and 1976 surveys, although rigorous testing was not possible. Two principal centers of abundance, north and south, were observed during August-October 1975 in subareas 3N and 2 (Fig. 82). However, comparisons of the population characteristics measured by the two surveys were not adequate to evaluate the integrity or extent of behavioral and reproductive isolation of the two apparent populations.

Yellowfin sole.—Yellowfin sole showed strongly contrasting distributional behavior between the 1975 and 1976 surveys, apparently representing seasonal extremes of adult migration patterns (Fig. 83, 84). During August-October 1975, adults (ages 6-13 yr) were broadly distributed over the central and inner continental shelf, and there were no indications of large-scale migratory movements. During April-June 1976, however, dense frontal concentrations of adults followed the receding pack ice from the outer shelf into Bristol Bay where spawning reportedly occurs during summer (Musienko 1963, 1970).

Although sampling problems encountered during the spring 1976 survey confounded rigorous comparisons of abundance estimates, the strong similarities in size composition, age structure, and overall sex ratios suggest that a relatively homogeneous population was sampled during both years. Because nearly the entire range of the eastern Bering Sea population was included within the 1975 and 1976 survey areas, effects due to in-migration and out-migration were apparently small.

During both the 1975 and 1976 surveys, juveniles (ages 2-4 yr) were found primarily along the inner shelf, and there seemed to be a positive relationship between the abundance of small individuals and proximity to shore. Whereas adults appear to regularly undergo extensive geographical migrations between seasons—perhaps to maximize food supply, or as an adaptive response to cold temperatures, juveniles apparently remain in shallow inshore nursery areas during their first 1-2 yr and then develop migratory behavior that extends progressively offshore.

The hypothesis that eastern Bering Sea yellowfin sole might also have genetically distinct north and south populations was not well supported by the survey data. Although three principal centers of abundance were recognized during the April-June 1976 survey—the large Unimak Island concentration that moved into central Bristol Bay and the two small Pribilof concentrations that appeared to migrate towards Nunivak Island, the population data collected were not adequate to enable identifying potential stock isolation from the overall background of geographical gradients and variability. Recent tissue collections and analyses of protein variation using starch gel electrophoresis have subsequently suggested free genetic exchange between the Bristol Bay and Pribilof Island groups (Grant et al. 1978[13]).

Rock sole.—The density distribution of rock sole during the April-June 1976 survey had also shifted (relative to August-October 1975) southwest and towards the outer continental shelf (Fig. 85). If the two surveys are interpreted as representing seasonal extremes, then the distribution of the population observed in 1975—widespread, with several large centers of abundance—apparently represents the results of extensive summer migration onto the inner continental shelf, and the distribution observed in 1976—primarily restricted along the outer continental shelf, with scattered locations of high abundance—represents a retreat to deep water during winter. Because no large-scale movements were observed during the 1976 survey, the timing of rock sole summer migration to the inner shelf was apparently later than that of yellowfin sole, and frontal concentrations were not as pronounced.

Like yellowfin sole, nearly the entire geographical range of the eastern Bering Sea rock sole population was included within the 1975 and 1976 survey areas, and effects due to in-migration and out-migration appeared to be small. In general, characteristics of the population measured by the two surveys—absolute size, length and age structure, and sex ratio—were similar. During both surveys, juvenile rock sole (ages 2 and 3 yr) were taken primarily along the Alaska Peninsula between Unimak Island and Port Moller in subareas 1 and 2.

Flathead sole.—During both the 1975 and 1976 surveys, flathead sole were distributed mainly along the outer continental shelf, and one large center of abundance was observed between St. George and Unimak Islands (Fig. 86). During August-October 1975, the distribution of the population included relatively low density extensions onto the central and inner continental shelf. During April-June 1976, although scattered occurrences were recorded on the central shelf, the population range was primarily restricted to deep water and moderate levels of abundance were also observed at slope depths.

Although a large southeastern Bering Sea population was identified, the species range clearly extended beyond the northern boundaries of the survey areas; so questions remain regarding relationships and exchange between north and south populations, and potential effects of in-migration and out-migration between regions. Relationships between the eastern Bering Sea population of flathead sole, *Hippoglossoides elassodon,* and that of the congeneric Arctic species, *H. robustus* (Bering flounder), are also unclear (Forrester et al. 1977).

Population characteristics that showed similarity between the 1975 and 1976 surveys included overall mean density, estimated

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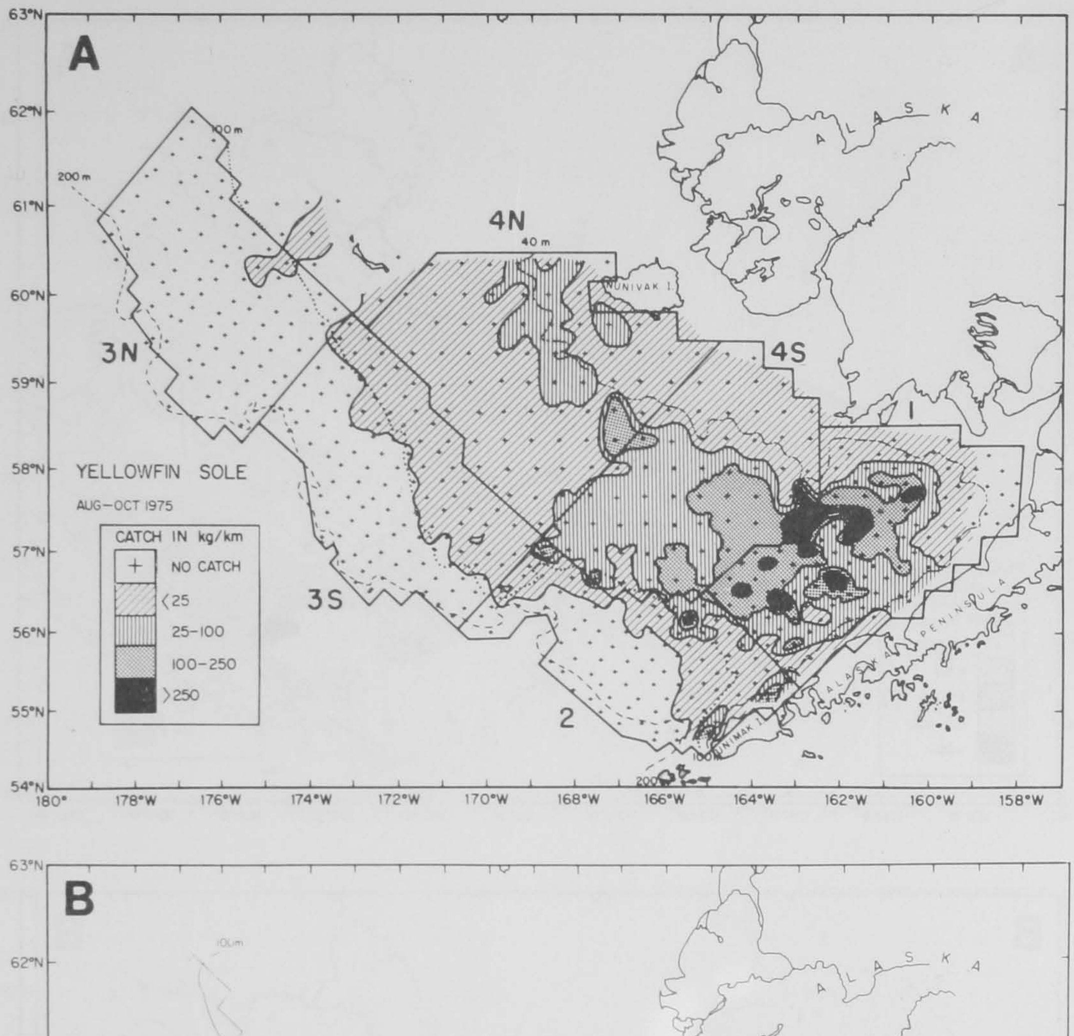

Figure 83.—Comparison between the apparent distributions and relative abundance of yellowfin sole in the Bering Sea: A) 1975 survey; B) April 1976.

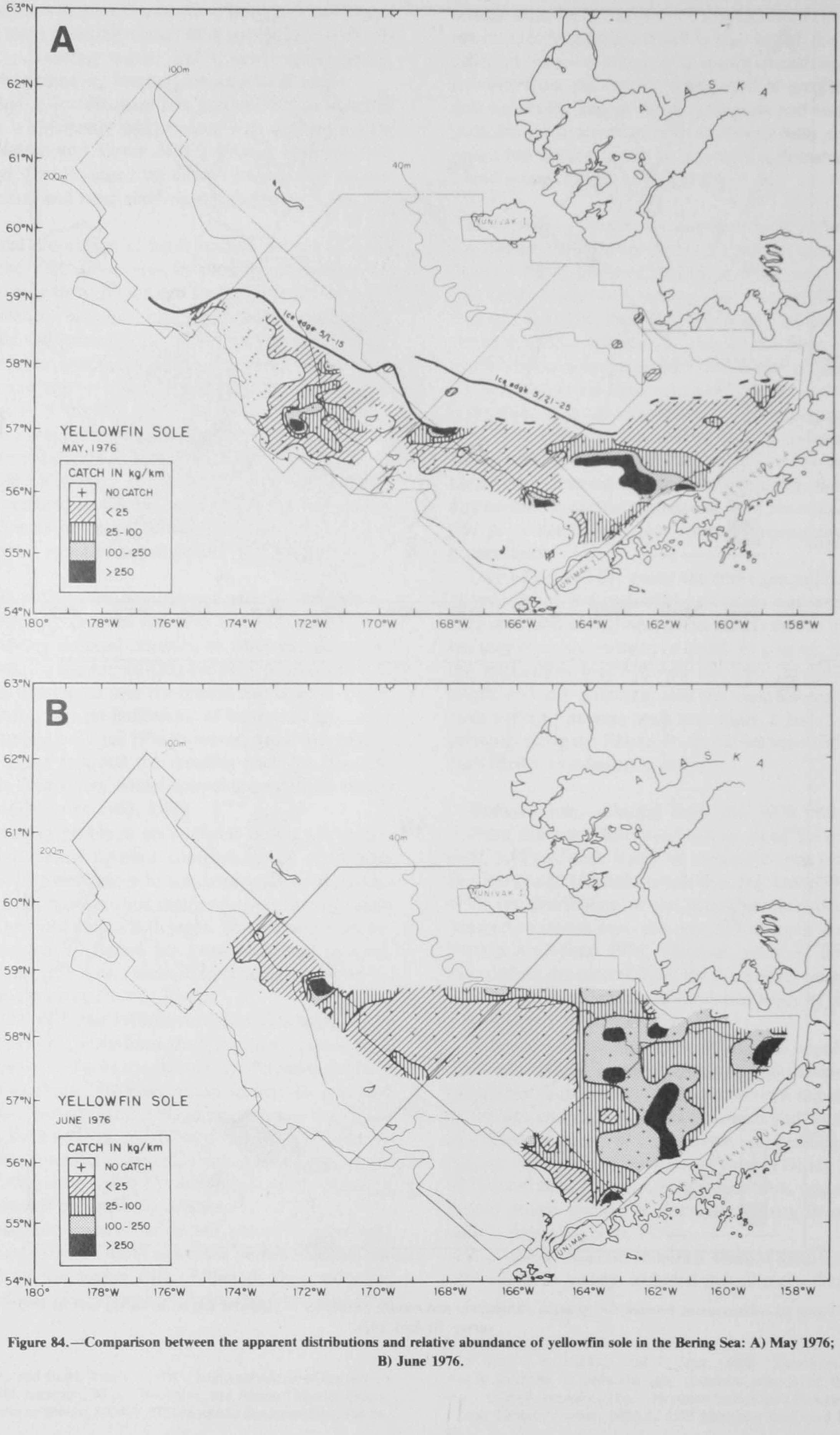

Figure 84.—Comparison between the apparent distributions and relative abundance of yellowfin sole in the Bering Sea: A) May 1976; B) June 1976.

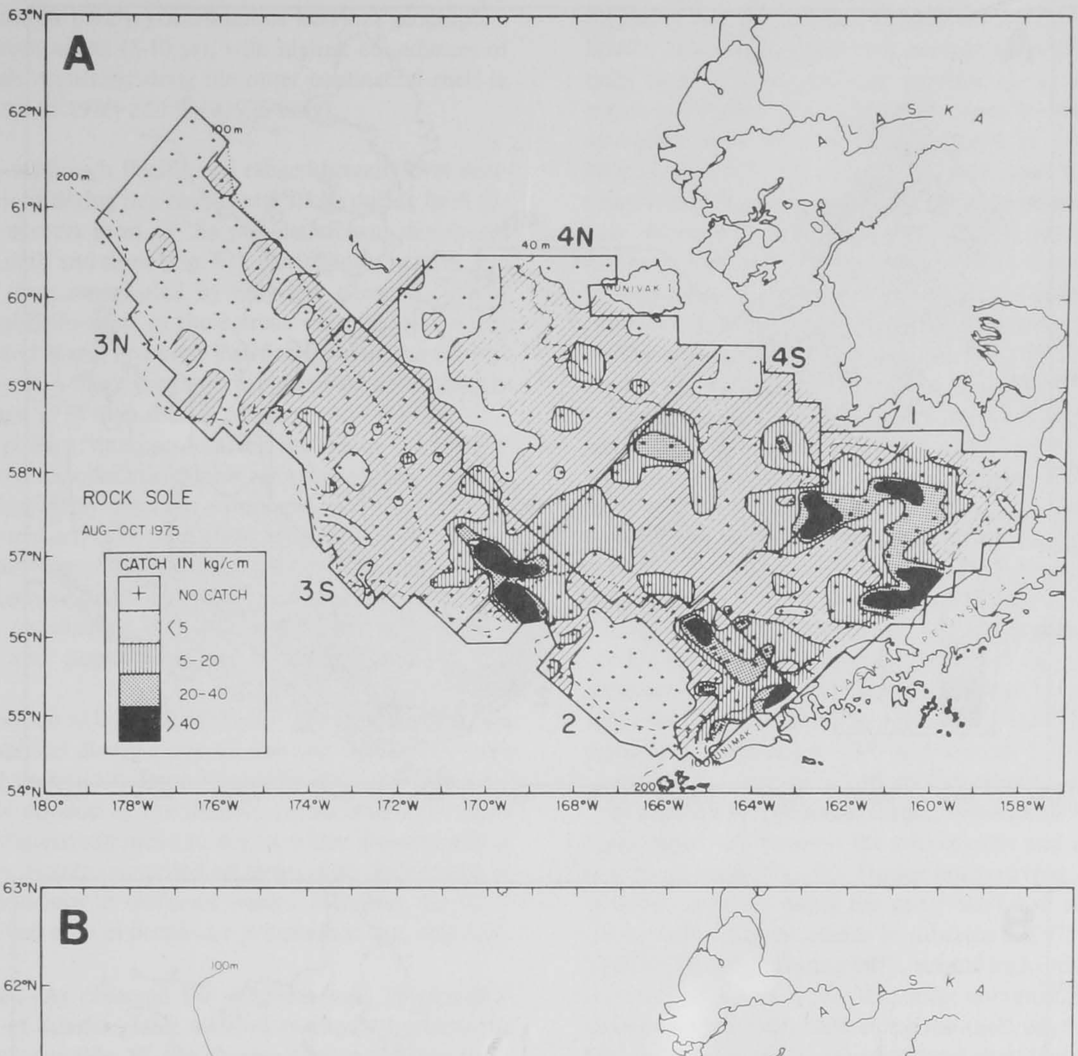

Figure 85.—Comparison between the apparent distributions and relative abundance of rock sole in the Bering Sea: A) 1975 survey; B) 1976 survey.

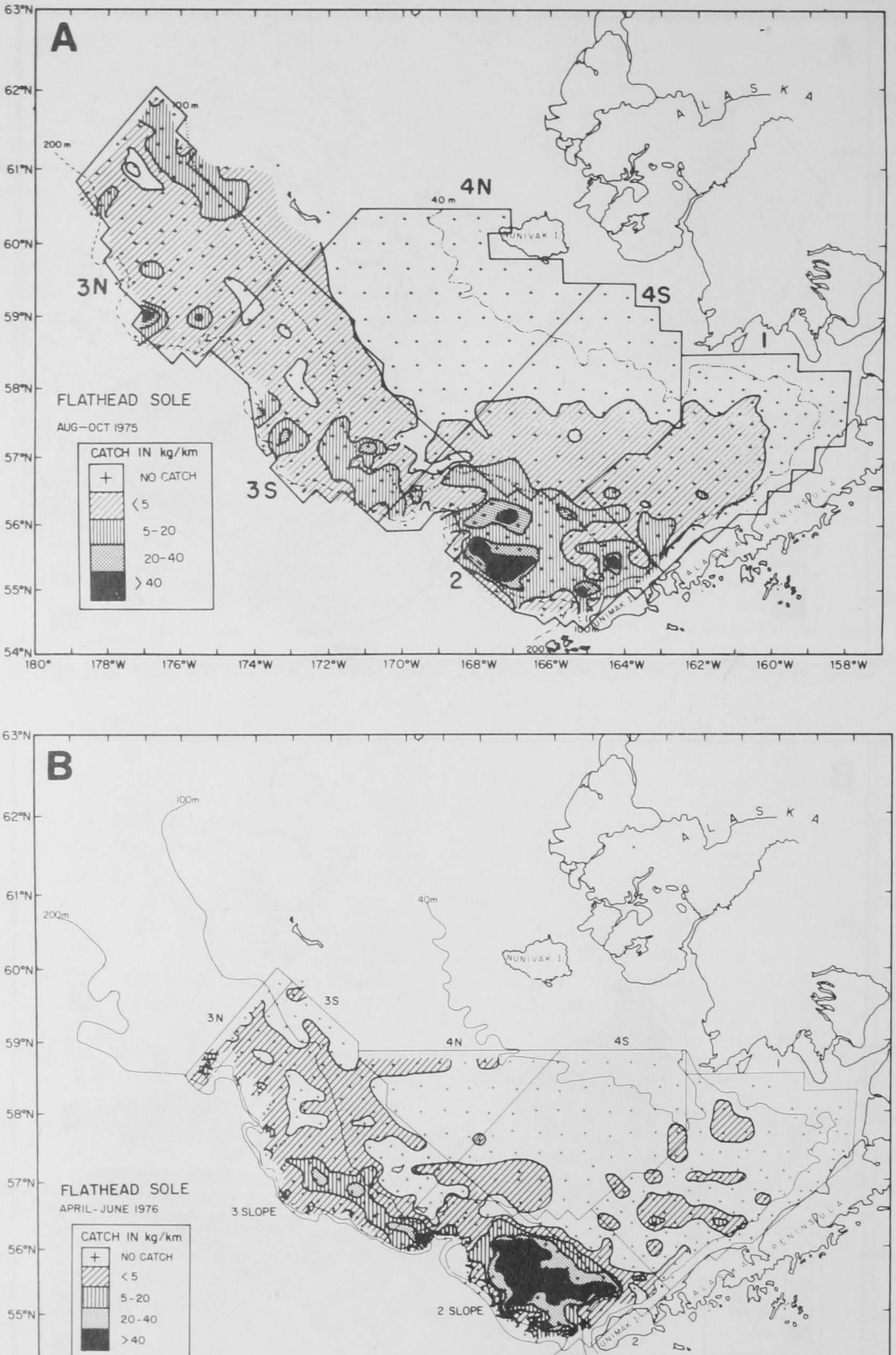

Figure 86.—Comparison between the apparent distributions and relative abundance of flathead sole in the Bering Sea: A) 1975 survey; B) 1976 survey.

absolute size, length composition, and overall sex ratio. During both surveys, juvenile (≤2 yr) distributions were not geographically separated from adults (5-10 yr), with highest abundances of young individuals occurring along the outer continental shelf in subareas 2 (1975 and 1976) and 3N (1975 only).

Pacific cod.—Although Pacific cod ranged broadly over nearly the entire eastern Bering Sea continental shelf, during both the 1975 and 1976 surveys most of the population was distributed along the outer shelf and slope (Fig. 87). Occurrences in inner and central regions were represented by only low densities, and in general, seasonal differences in these areas were unclear. Along the outer shelf and slope, however, Pacific cod abundances were higher and showed a more continuous pattern of high densities during April-June 1976 than during August-October 1975.

Like walleye pollock, attempts to assess the Bering Sea population of Pacific cod included formidable sampling problems due to unknown semidemersal behavior, potential trawl avoidance, dense shoal formation, and potentially large effects due to in-migration and out-migration. Although midocean pelagic populations have not been reported, substantial migratory exchange may occur between populations over the continental slope (depths 180-1,000 m) and populations on the outer shelf (depths 100-180 m).

A feature common to both the 1975 and 1976 survey results was that the geographical distributions of size and age classes were strongly related to bottom depth. Juveniles (0-group and 1-yr-olds) apparently develop in the shallow central and inner shelf regions, then progressively move to deeper water. Populations in deep water were mainly composed of large, older individuals in contrast to populations in shallower waters. However, the maximum age observed even in deepwater populations was only 6 yr.

Alaska plaice.—As observed for yellowfin sole, the distributional patterns of Alaska plaice differed markedly between the 1975 and 1976 surveys (Fig. 88, 89). During August-October 1975, Alaska plaice ranged broadly over the central and inner shelf, with two principal centers of abundance. During April-June 1976, a relatively high-density front of migrating individuals appeared to move from a winter retreat in deep water, approaching a large-scale pattern similar to the late-summer distribution observed during 1975.

Although sampling problems resulting from the population's movements in 1976 prevented meaningful comparisons of abundance estimates, there were similarities in size and age structure, and overall sex ratio between the two surveys. During both 1975 and 1976, juvenile Alaska plaice were most abundant in the northern, central region of the continental shelf (subareas 4S and 4N).

Other flounders.—The three pleuronectid species—Greenland turbot, arrowtooth flounder, and Pacific halibut—provided similar population assessment problems, and survey results for the three species showed many parallels. All three species have extensive geographical ranges, occurring along the entire Pacific rim from southern California to the Kamchatka Peninsula and along all continental shelf regions of the Bering Sea (Hart 1973). In addition, the regional populations of all three species appear to undergo regular seasonal migrations to the upper continental slope or shelf in summer and then return to deep water during winter where spawning occurs (Novikov 1964; Musienko 1970; Shuntov 1970).

Population assessment problems included the following: 1) Because the vertical range of all three species may extend to bottom depths of 500 to 1,000 m—beyond normal trawl sampling capabilities, then in-migration and out-migration effects were potentially large due to seasonal movements between bathymetric zones, particularly in regions with steep bottom slope; 2) trawl avoidance may have been substantial by the large, strong-swimming adults; and 3) tagging studies have indicated that out-migration to, and in-migration from, populations in other regions may be significant (Dunlop et al. 1964; International Pacific Halibut Commision 1973). Additionally, relationships between the southeastern Bering Sea population of arrowtooth flounder, *Atheresthes stomias,* and reported northwestern Bering Sea population of the congeneric Asian arrowtooth flounder, *A. evermanni,* are unclear (Wilimovsky et al. 1967).

During August-October 1975, Greenland turbot were broadly distributed over central and outer regions of the continental shelf at low densities, and one large northern center of abundance represented over one-half the total apparent population (Fig. 90). During April-June 1976, population densities were high along the southwest shelf edge (subarea 2 Slope) in deep water (Table 66), and extension onto the shelf was restricted.

In general, shelf populations of Greenland turbot during both surveys were primarily juveniles (≤4 yr of age). One-year-old-individuals were most abundant in subareas 4S and 4N (1975 and 1976) and subarea 3 (1976 only). Deepwater populations (particularly in subarea 2 in 1975 and subarea 2 Slope in 1976) were composed of large, old (3-16 yr) individuals.

In contrast to Greenland turbot, arrowtooth flounder distributions varied less between the two surveys and northern populations were small (Fig. 91). During both surveys, most arrowtooth flounder occurred along the outer shelf and slope between St. George and Unimak Islands in subareas 2 (1975 and 1976) and 2 Slope (1976 only). During 1975, several high-density locations occurred at intervals along the outer continental shelf. In 1976, abundance was high only along the shelf edge and slope (Table 67). Juveniles (ages 1-3 yr) were most abundant in subarea 2 during both years.

Of the three deepwater flounder species, Pacific halibut showed the most extreme differences in geographical distributions between the two surveys (Fig. 92). During August-October 1975, the apparent population was broadly distributed in Bristol Bay with scattered occurrences on the central and outer shelf. During April-June 1976, Pacific halibut were distributed primarily along the southwest continental shelf between St. George and Unimak Islands and were abundant at slope depths (Table 68). Although large individuals may have been underestimated due to avoidance, trawl catches during both surveys indicated that shelf populations were mainly juveniles (20-50 cm FL).

Table 66.—Apparent bathymetric distribution of Greenland turbot abundance within the 1976 Bering Sea slope subarea.[1]

Bottom depths (m)	No. of samples	Mean CPUE[2] (kg/km)
200-249	10	5.2 (0.0-18.4)
250-299	8	10.6 (0.3-42.6)
300-349	9	10.5 (0.3-29.9)
350-399	7	32.9 (5.0-98.4)
400-449	7	24.0 (0.0-105.2)
450-460	3	66.2 (31.8-133.9)

[1] See Figure 3.

[2] Mean catch per unit fishing effort, with range in parentheses.

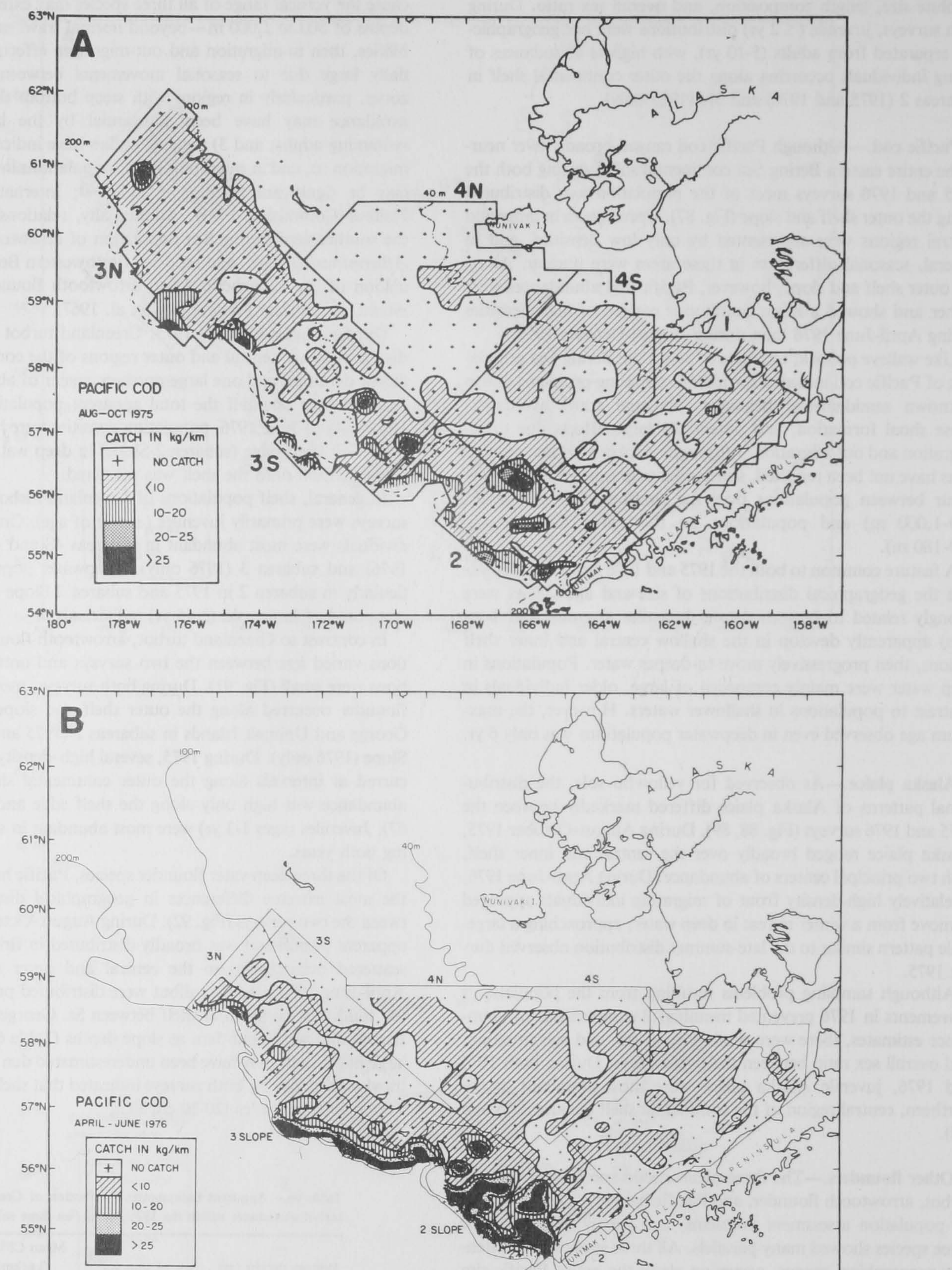

Figure 87.—Comparison between the apparent distributions and relative abundance of Pacific cod in the Bering Sea: A) 1975 survey; B) 1976 survey.

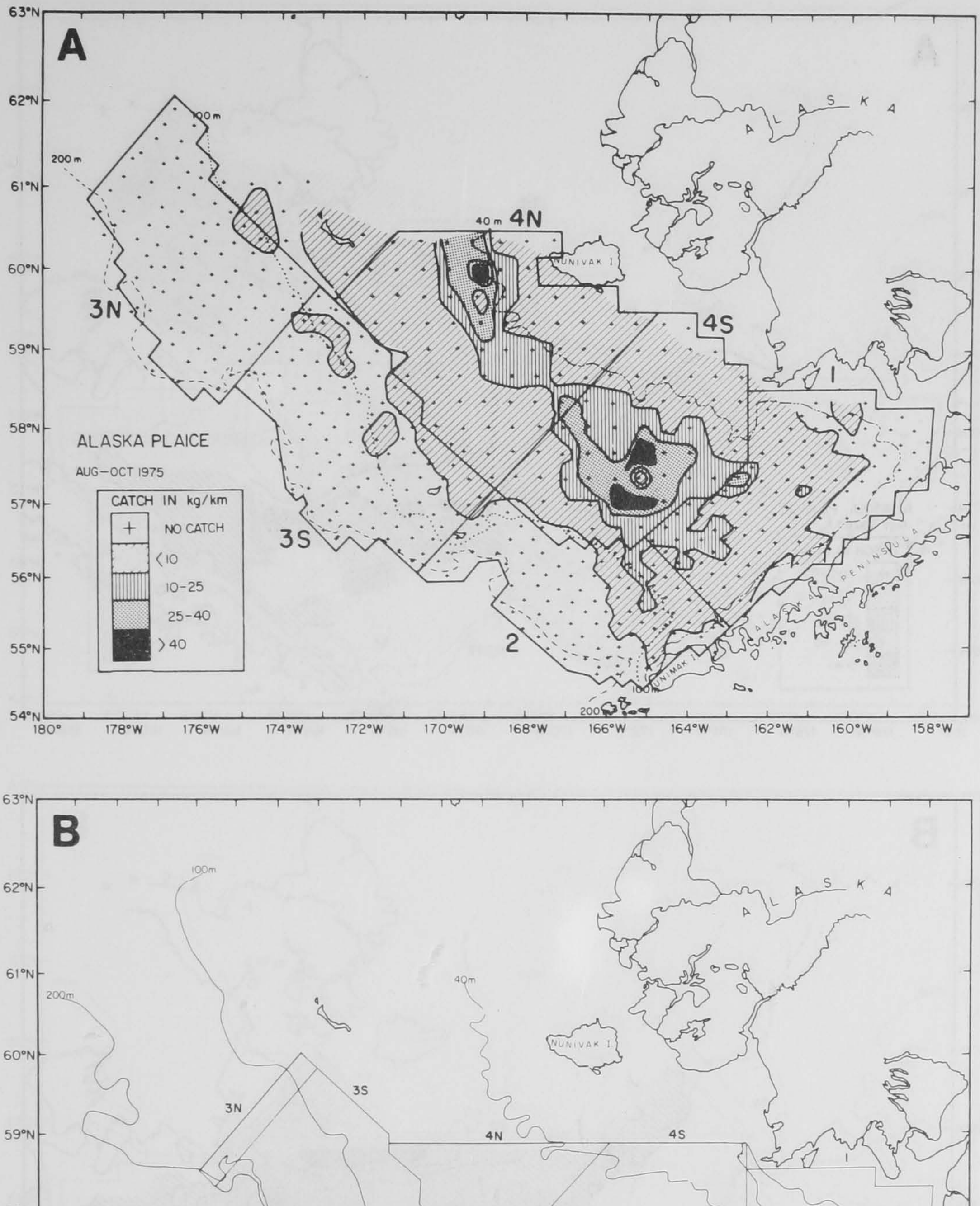

Figure 88.—Comparison between the apparent distributions and relative abundance of Alaska plaice in the Bering Sea: A) 1975 survey; B) April 1976.

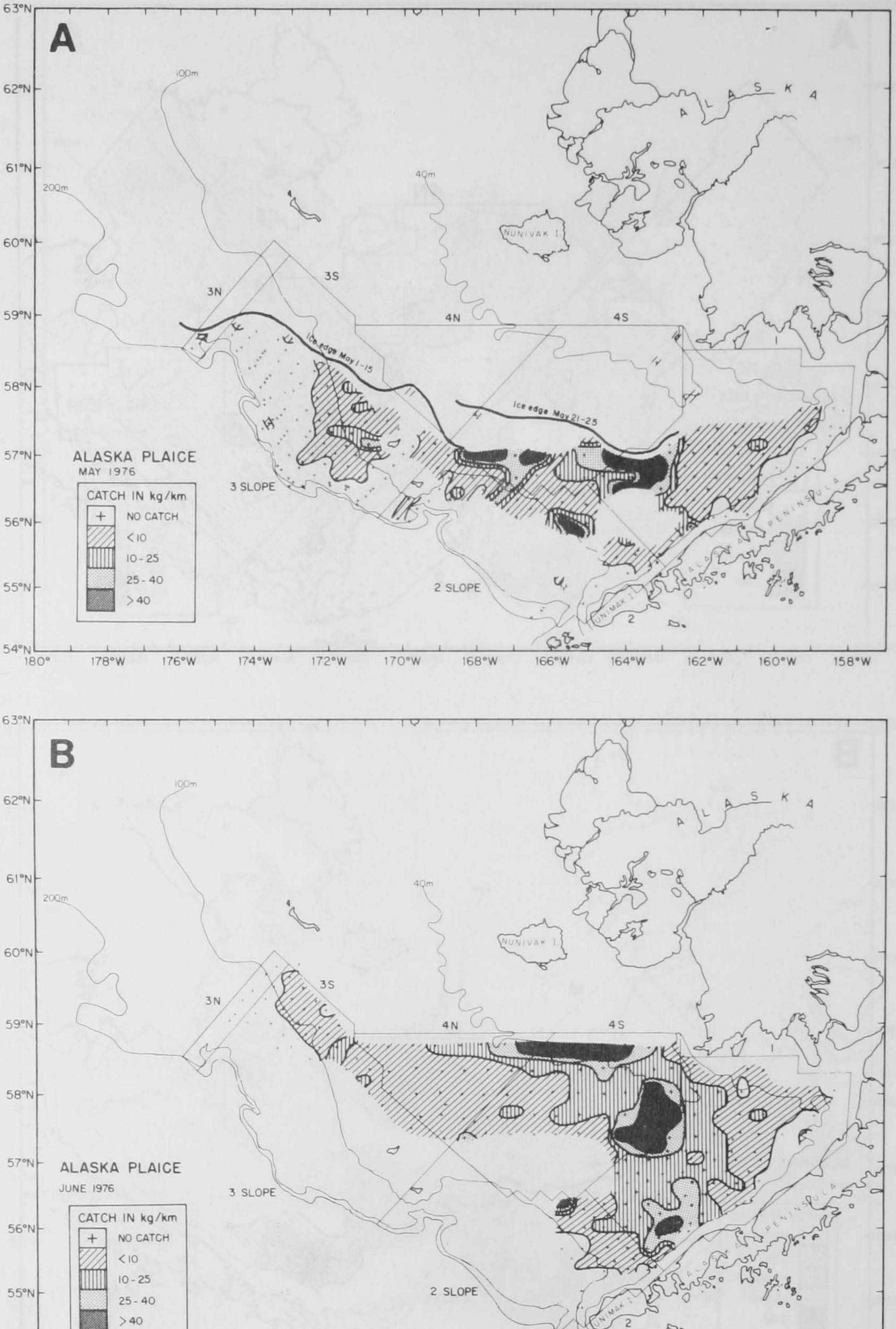

Figure 89.—Comparison between the apparent distributions and relative abundance of Alaska plaice in the Bering Sea: A) May 1976; B) June 1976.

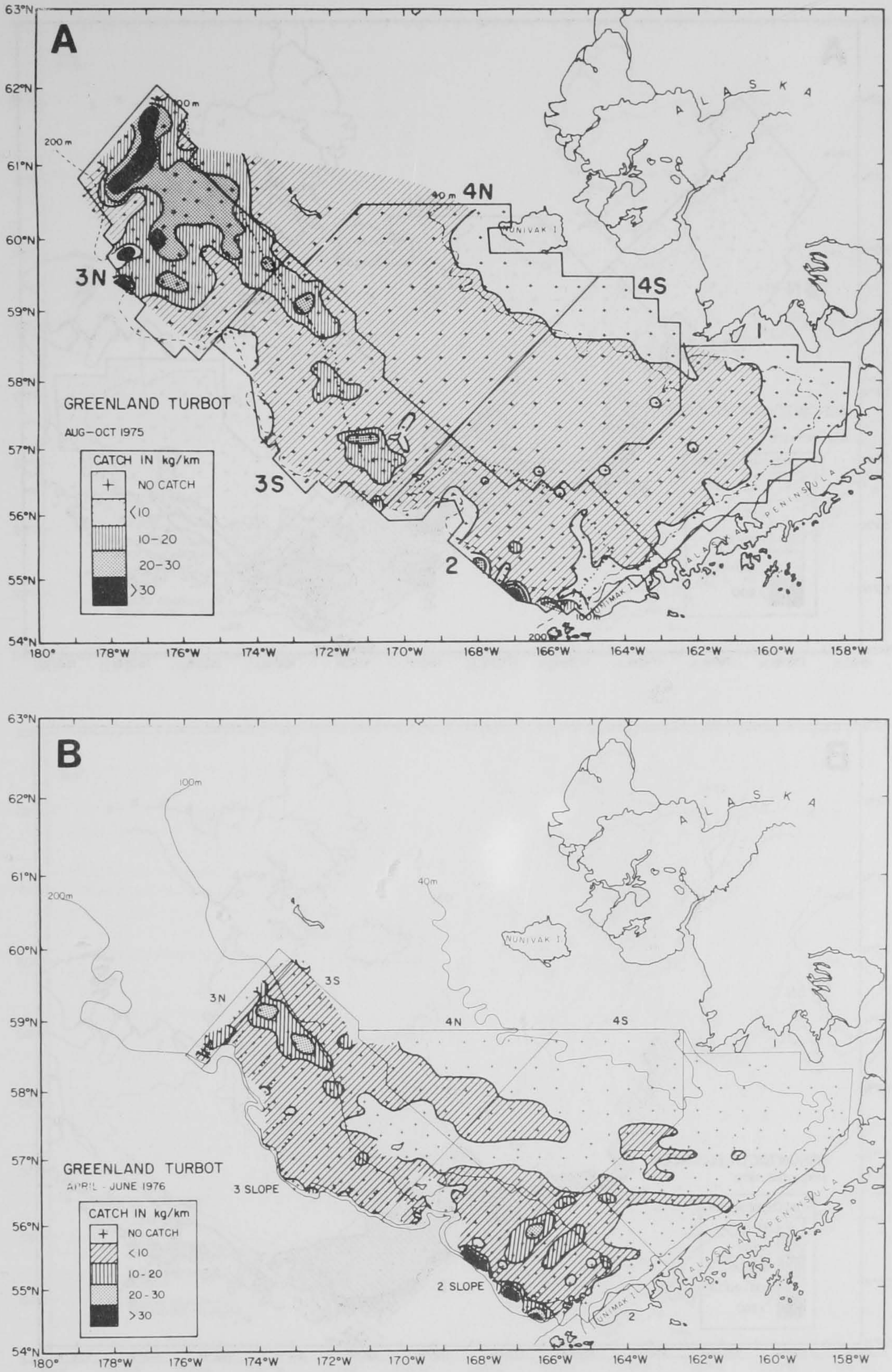

Figure 90.—Comparison between the apparent distributions and relative abundance of Greenland turbot in the Bering Sea: A) 1975 survey; B) 1976 survey.

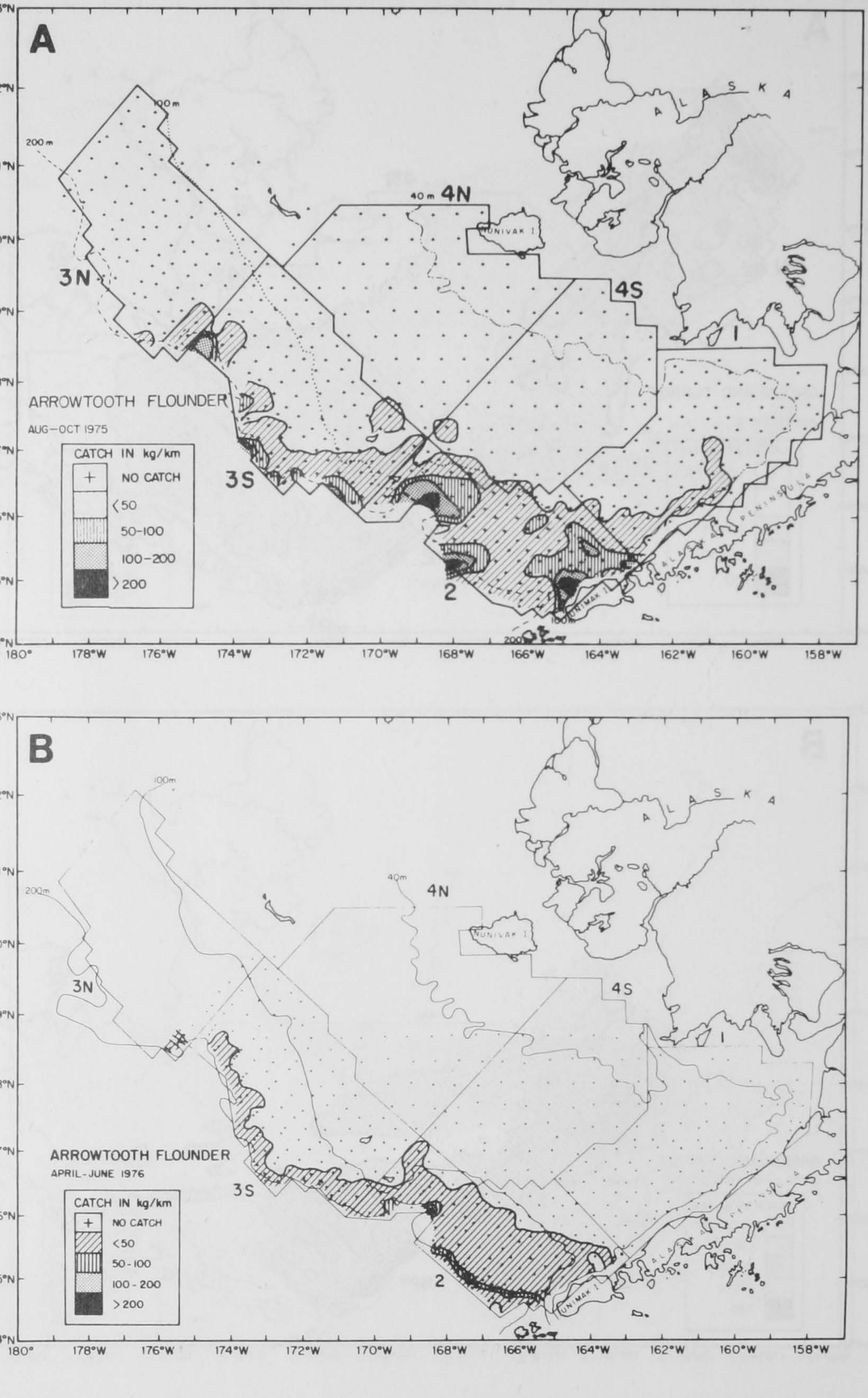

Figure 91.—Comparison between the apparent distributions and relative abundance of arrowtooth flounder in the Bering Sea: A) 1975 survey; B) 1976 survey.

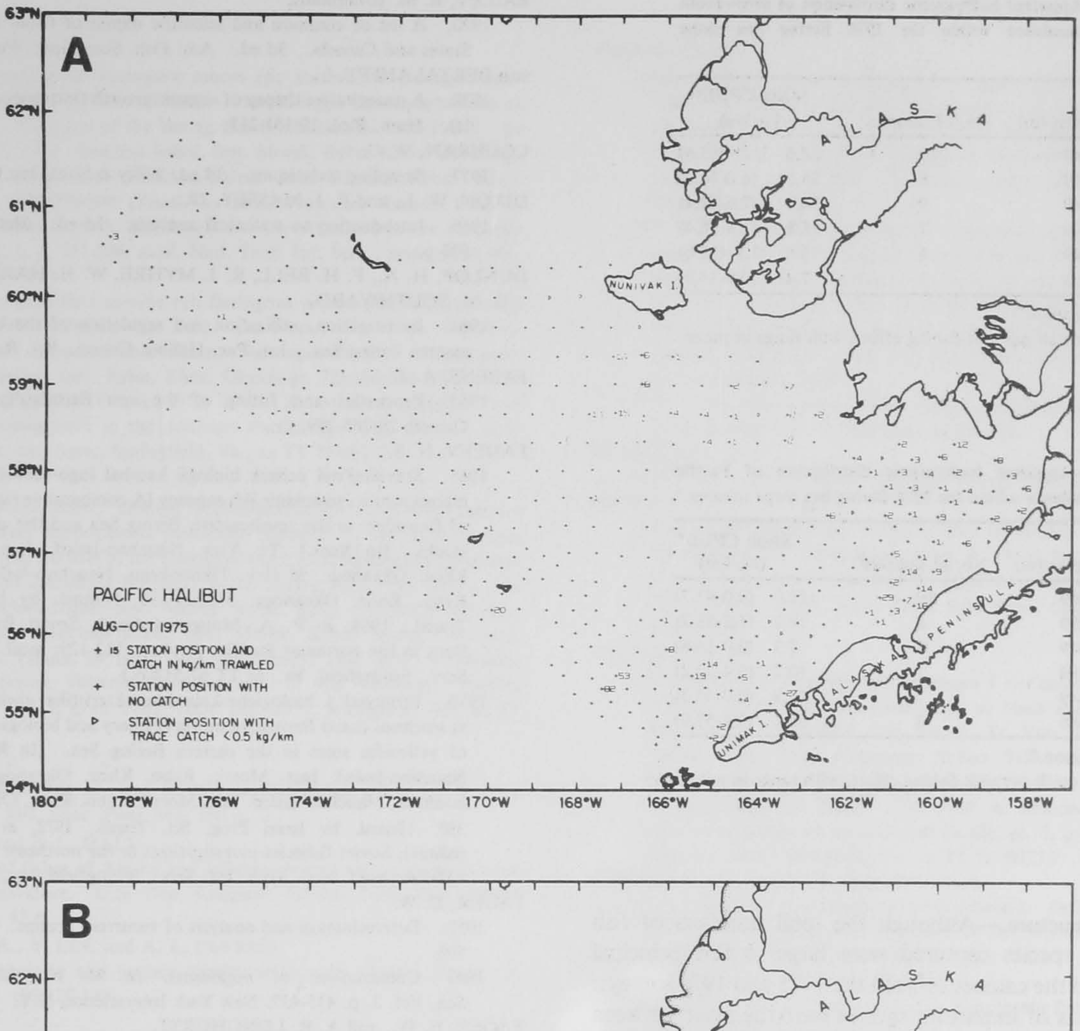

Figure 92.—Comparison between the apparent distributions and relative abundance of Pacific halibut in the Bering Sea: A) 1975 survey; B) 1976 survey.

Table 67.—Apparent bathymetric distribution of arrowtooth flounder abundance within the 1976 Bering Sea slope subarea.[1]

Bottom depths (m)	No. of samples	Mean CPUE[2] (kg/km)
200-249	10	27.6 (1.0-103.8)
250-299	8	28.5 (6.0-76.0)
300-349	9	34.8 (7.6-62.1)
350-399	7	15.8 (2.4-58.4)
400-449	7	75.5 (2.8-425.0)
450-460	3	7.4 (0.0-14.7)

[1] See Figure 3.

[2] Mean catch per unit fishing effort, with range in parentheses.

Table 68.—Apparent bathymetric distribution of Pacific halibut abundance within the 1976 Bering Sea slope subarea.[1]

Bottom depths (m)	No. of samples	Mean CPUE[2] (kg/km)
200-249	10	12.0 (0.0-47.7)
250-299	8	10.1 (1.2-33.7)
300-349	9	7.3 (0.0-16.8)
350-399	7	10.2 (0.4-22.2)
400-449	7	14.9 (0.0-45.3)
450-460	3	32.1 (9.1-57.0)

[1] See Figure 3.

[2] Mean catch per unit fishing effort, with range in parentheses.

Community structure.—Although the total numbers of fish and invertebrate species captured were large, a few principal species dominated the catches of both the 1975 and 1976 surveys. In general, the lists of important species were the same between surveys. And importantly, relationships within the lists of principal species from each survey, as measured by the extent of co-occurrence between species and regional distributions of co-occurring species groups, were also remarkably similar.[1]

Despite partial predictability of principal species and their organization over large geographical areas, at any specific location on the eastern Bering Sea continental shelf the relative species composition of the demersal fish community may be expected to undergo large seasonal variations. These changing relationships presumably result from seasonally driven variations in the overlapping distributions of resident (nonmigrating) and transient (migrating) species populations, and changes in their relative density distributions.

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