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Structure and Historical Changes in the Groundfish Complex of the Eastern Bering Sea

Richard G. Bakkala

U.S. Department of Commerce

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U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary for Oceans and Atmosphere
National Marine Fisheries Service

Contents

Glossary of Abbreviations

B	biomass
CI	confidence intervals
CL	confidence limits
CPUE	catch per unit of effort
EEZ	Exclusive Economic Zone
fm	fathom
GIFA	Governing International Fisheries Agreement
INPFC	International North Pacific Fisheries Commission
IPHC	International Pacific Halibut Commission
JFA	Japan Fisheries Agency
LME	large marine ecosystems
MFCMA	Magnuson Fisheries Conservation and Management Act
MSY	maximum sustainable yield
NMFS	National Marine Fisheries Service
NPFMC	North Pacific Fishery Management Council
NWAFC	Northwest and Alaska Fisheries Center
OY	optimum yield
SE	standard error
t	metric ton

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ABSTRACT

The eastern Bering Sea is a major marine ecosystem containing some of the largest populations of groundfish, crabs, birds, and marine mammals in the world. Commercial catches of groundfish in this region have averaged about 1.6 million tons (t) annually in 1970-86. This report describes the species and relative importance of species in the eastern Bering Sea groundfish complex, the environment in which they live, and the history of the fisheries and management during the years 1954 - 1985. Historical changes in abundance and the condition of the principal species at the end of this first 30 years of exploitation are also examined. Results suggest that the biomass of the groundfish complex is characterized by variability rather than stability. The most reliable data (1979 to 1985) suggests that the biomass of the complex fluctuated between 11.8 and 15.7 million t. Even greater variability is suggested by the less reliable data from earlier years. Because of its dominance in the complex and wide fluctuations in abundance, walleye pollock (*Theragra chalcogramma*) is primarily responsible for the major variations in abundance of the complex. After 30 years of exploitation, the complex was generally in excellent condition.

Introduction

The eastern Bering sea is one of the most biologically productive marine environments in the world. It contains some of the largest populations of marine mammals, birds, crabs, and groundfish in the world (Hood 1981). The reasons for this high productivity are not completely understood, but one of the primary factors is the size of the continental shelf (Fig. 1), which is one of the largest in the northern hemisphere (Coachman 1986).

The productivity of groundfish in the eastern Bering Sea relative to other northern and temperate seas may be roughly gauged by the magnitude of commercial catches in each of these regions (Table 1). During 1970–81, commercial catches of groundfish in the eastern Bering Sea averaged 1.6 million metric tons (t) annually, which was similar to average annual catches in this period from the northwest Atlantic Ocean (1.6 million t), the Yellow and East China Seas (1.5 million t), and the Barents Sea (1.5 million t). They were exceeded only by those from the North Sea (2.0 million t) and possibly the Okhotsk Sea for which only one year (1979) of catch statistics (2.7 million t) was available. Based on the mean catch of groundfish per unit of shelf area, the productivity of the eastern Bering Sea is exceeded by that in the Yellow and East China Seas, the western Bering Sea and western Pacific Ocean region, the Okhotsk Sea, (productivity in the latter two regions was based on one year of catch data), and the North Sea (Table 1). These comparisons may be biased by incomplete catch statistics, differences in rates of exploitation among the regions, use of total shelf areas rather than the actual areas of fishing, and by the extent to which the total complexes were utilized by the fisheries of each area.

The groundfish in the eastern Bering Sea are a valuable economic resource. Based on ex-vessel prices[1], eastern Bering Sea groundfish landings were valued at $216.3 million in 1986. The dollar values of these resources are of course much larger at the wholesale and retail levels.

In addition to their value to man, groundfish, especially walleye pollock (*Theragra chalcogramma*), are important components of the eastern Bering Sea ecosystem because they provide a food source for other fishes and higher trophic animals such as marine mammals and birds. McAlister and Perez (1987) have estimated that marine mammals consume about 2.27 million t of fish per year, equal to 5.5% of the standing biomass of

[1] Ex-vessel values are based on prices paid to fishermen by U.S. shore-based processing plants and by foreign processing vessels in U.S. joint venture fisheries.

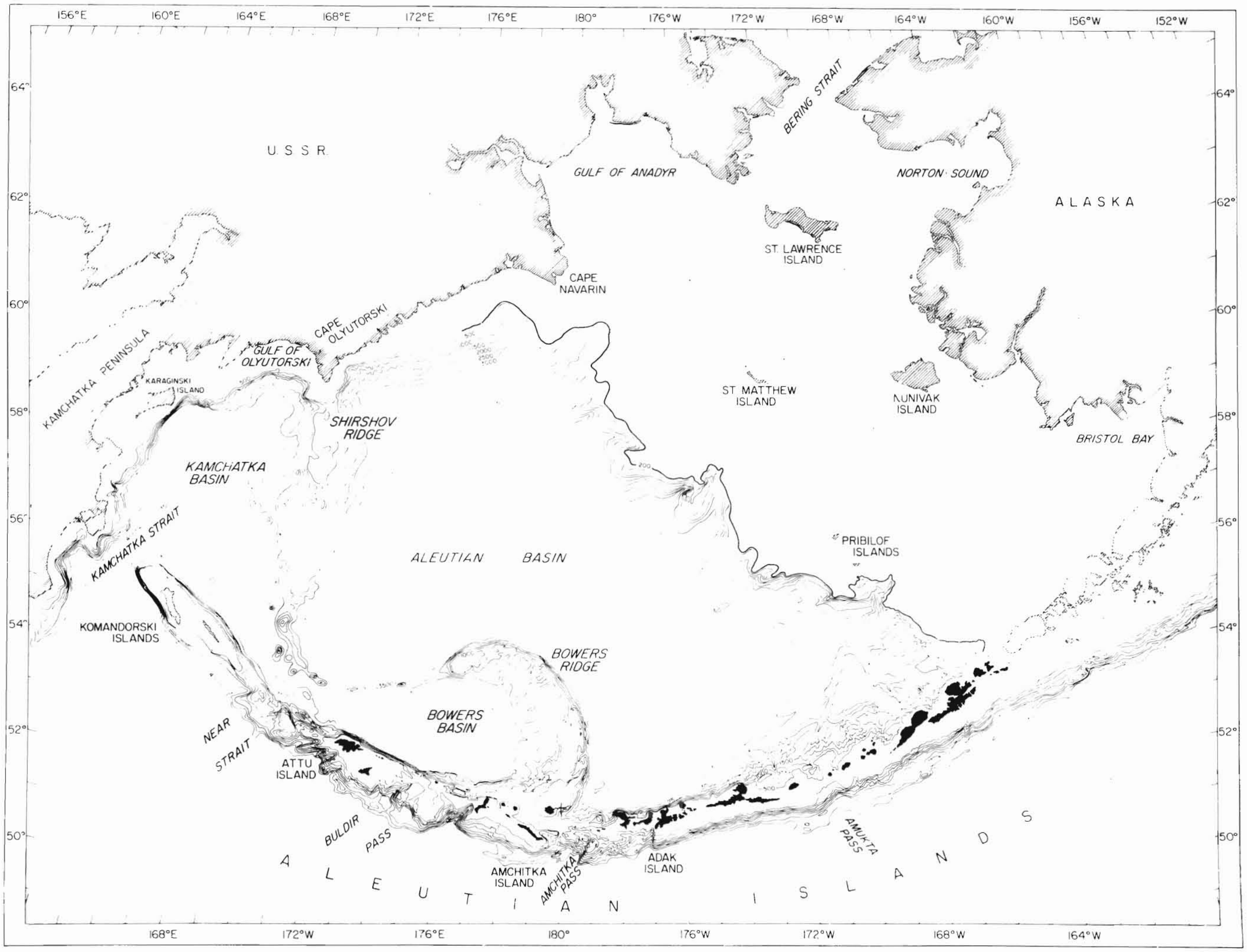


Figure 1
The Bering Sea, giving place names mentioned in the text (Kinder 1981—from a figure prepared by Noel McGary for the atlas by Sayles et al. 1979).

fish and 5.3% of commercially important groundfish. Walleye pollock was the principal commercially important groundfish consumed by marine mammals (520,000 t annually), 84.9% of which were juvenile fish age 1–2 years. Marine birds, which consume mainly small juvenile pollock, take an additional estimated 140,000 t per year (Springer et al. 1986). Interestingly, the predation of pollock by pollock (cannibalism) and by other fishes has been estimated to be even higher than that of marine mammals and birds at almost 3.4 million t annually (Livingston et al. 1986). Thus, the consumption of pollock by fishes, birds, and mammals may be three to four times higher than the level taken by the commercial fishery.

Commercial exploitation of groundfish in the eastern Bering Sea has a history of over 100 years dating back to 1882 when U.S. sailing schooners initiated a handline fishery for Pacific cod (*Gadus macrocephalus*) (Cobb 1927). However, cod and other groundfish in this region have received relatively intense exploitation only since about 1960. Greater utilization of eastern Bering Sea groundfish was initiated by Japanese distant-water fisheries in 1954. Japanese fleets were later joined by those from the U.S.S.R., the Republic of Korea, and other nations. Groundfish catches were dominated by these distant-water fisheries until 1986 when catches by U.S. fishing vessels involved in joint ventures with foreign processing vessels first exceeded those of all other nations. Thus, 1985 marked the end of an era that had seen the development of the fishery and full utilization of groundfish in the eastern Bering Sea primarily by foreign fisheries. Subsequently, U. S. fleets took an ever-increasing proportion of the harvest and presently are the sole participants in the fishery.

The objectives of this study are to describe 1) the species and the relative importance of species in this major groundfish complex, 2) the distribution and abun-

Table 1

Groundfish catches (1,000 metric tons) in the eastern Bering Sea and other northern and temperate regions of the Pacific and Atlantic Oceans.

Year	Yellow and East China Sea[a]	Japan Sea[b]	Okhotsk Sea[c]	Western Bering Sea and Western Pacific Ocean[c]	Eastern Bering Sea[d]	Gulf of Alaska[e]	Northwest Atlantic Ocean[f]	North Sea[g]	Barents Sea[g]
1970	1,182				1,594	118	2,090	2,066	1,721
1971	1,264				2,157	116	2,155	1,939	1,628
1972	1,364				2,249	167	2,099	2,009	1,378
1973	1,470				2,063	160	2,097	1,797	1,631
1974	1,590				1,900	183	1,743	2,457	2,045
1975	1,582	244			1,645	178	1,568	2,093	1,805
1976	1,592	290			1,429	193	1,309	2,229	1,767
1977	1,612	288			1,170	197	1,165	2,095	1,568
1978	1,724	265			1,312	163	1,136	1,924	1,240
1979	1,575	263	2,681	1,038	1,167	167	1,237	1,765	1,004
1980	1,574	251			1,223	204	1,227	2,047	875
1981	1,597	282			1,260	243	1,261	1,740	972
Mean catch 1970–81	1,510	269	—	—	1,597	174	1,591	2,013	1,470
Shelf area[h] (1,000 km^2)	874	250	620	480	1,200	369	1,260	550	1,300
Mean catch (t/km^2)	1.728	1.076[i]	4.324[j]	2.162[j]	1.331	0.472	1.263	3.660	1.131

[a] Catches by Japan, Republic of Korea, and People's Republic of China. Japanese catches from Chikuni (1985); other catches from Hitoshi Fujita, personal communication, Seikai Regional Fisheries Research Laboratory, Nagasaki, Japan, November, 1987.
[b] Catches by Japan and Republic of Korea. Japanese catches from Japanese Ministry of Agriculture, Forestry and Fisheries (1977–83). Korean catches from Korea Ministry of Agriculture, Forestry, and Fisheries (1976–82).
[c] Catch data from Chikuni (1985). Catches not reported for other years.
[d] Catches from Bakkala (1987).
[e] Catches from Major and Wildebuer (1988).
[f] Catches from Northwest Atlantic Fisheries Organization (1985).
[g] Catches from Conseil International pour l' Exploration de la Mer (1972–83).
[h] Shelf areas from Yellow Sea-East China Sea (Inoue 1981), Japan Sea, Okhotsk Sea, western Bering Sea-western Pacific Ocean (Chikuni 1985), eastern Bering Sea (Hood 1981), Gulf of Alaska (Hood 1987), northwest Atlantic Ocean, North Sea, and Barents Sea (Gulland 1971).
[i] Based only on 1975–81 data.
[j] Based only on 1979 data.

dance of major families and species, 3) the history of exploitation and management of the resource, 4) historical changes in abundance of principal individual species and the overall complex since the mid-1960's, 5) factors that may have influenced observed changes in abundance of the complex, and 6) the condition of the resource at the end of the first 30 years of exploitation.

The Eastern Bering Sea Environment

The Bering Sea is a subpolar sea bounded by the Aleutian Island arc in the south and by the Bering Strait in the north (Fig. 1). The Aleutian Islands present only a minor restriction to exchange of waters with the North Pacific Ocean and, oceanographically and biologically, the Bering Sea is largely an extension of the North Pacific Ocean (Hood 1983). The Bering Sea has two major geomorphological features: the deep Aleutian Basin and the extensive eastern Bering Sea shelf, each occupying an approximately equal amount of surface area (McRoy et al. 1986). The eastern Bering Sea shelf is 1,200 km in length, exceeds 500 km in width at its narrowest point, and represents the widest continental shelf outside the Arctic Ocean (Coachman 1986). Only the North Sea and the East China Sea approach its breadth.

The eastern Bering Sea shelf is essentially a large, featureless plain that deepens gradually from the shore to the shelf break at about 170 m where it is indented by several submarine canyons (Coachman 1986). However, there are two zones of enhanced sea floor gradients near the 50 and 100 m isobaths (Askren 1972) that are related to fronts that separate the shelf region into three oceanographic domains.

Oceanographic Fronts and Domains

The primary form of energy on the eastern Bering Sea shelf is the kinetic energy of the tidal currents (Coachman 1986). The interactions between these fluctuating tidal flows and steeper bottom gradients at the 50, 100, and 170 m isobaths, on the otherwise extremely flat shelf, create oceanographic fronts (i.e., zones of specific dynamic activity including upwelling, partial mixing, and small, along-isobath flows), which separate the eastern Bering Sea shelf into three distinct domains: coastal, central, and outer shelf. The domains are separated by the inner and middle shelf fronts at approximately 50 and 100 m; the outer shelf domain is separated from oceanic water of the Aleutian Basin by an oceanic front between 150 and 200 m (Fig. 2). The domains are characterized by their temperature, salinity, vertical structure, and the seasonal changes in these properties (Fig. 3).

The outer shelf domain differs from the others by having both significant mean and subtidally variable flows (Coachman 1986). These flows result in more rapid flushing (perhaps on the order of every two to three months) than that which occurs in the other two domains. The outer shelf domain is a zone of lateral water mass interaction between central shelf water and Aleutian Basin water. These two water masses do not mix evenly or completely, resulting in an interleaving and layering of the partial mixtures. In general, the basin waters intrude shoreward near the bottom while the middle shelf waters extrude seaward above them (Schumacher 1984).

The main feature of the central shelf domain is a general tendency toward two-layered vertical structure (Coachman 1986). During most of the year, a surface layer of 10 to 40 m overlies a relatively homogeneous deep layer. There is little or no significant advection in this domain and heat content is governed by air-sea exchange (Reed 1978). The isolation of the deeper water in this domain from solar heating, combined

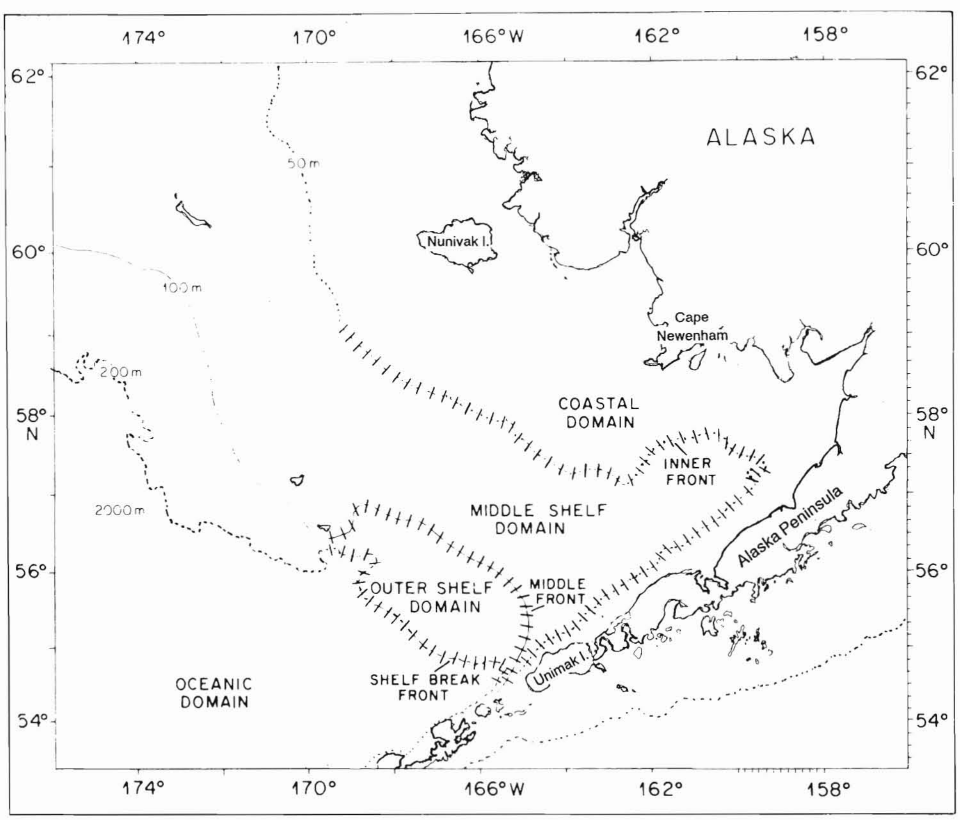


Figure 2
Approximate locations of hydrographic domains and fronts over the southeastern Bering Sea shelf (from Schumacher et al. 1983).

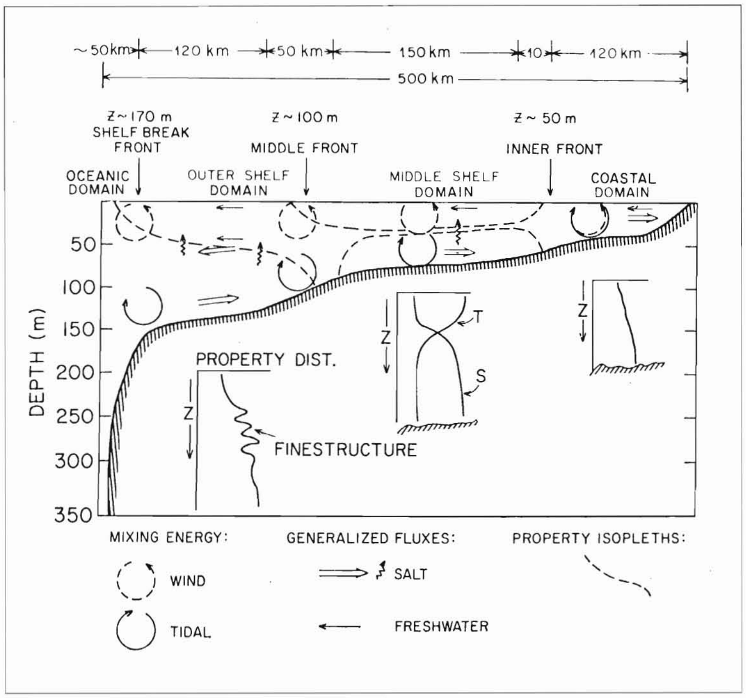


Figure 3
A schematic interpretation on the cross-shelf plane of energy balance, fresh- and saltwater fluxes, and vertical structure; note that the middle shelf domain becomes mixed either during periods of surface cooling (winter) or during extreme storms (from Schumacher et al. 1983).

with the absence of significant advection, leads to a large pool of relatively homogeneous, cold (<0 to 3°C) bottom water in summer, the coldest water on the shelf (Coachman 1986). This large area of cold bottom water is the most distinctive feature of eastern Bering Sea shelf waters. The temperature of this bottom layer is dependent on the severity of winter climatic conditions. Flushing in the central domain is extremely slow and water in this domain has a long residence time (e.g., more than one year and perhaps as much as two years).

The coastal domain is a product of direct mixing of freshwater runoff and saline water and on the average is the least saline of the three domains (Coachman 1986). A distinct feature of the coastal water is a tendency toward homogeneity due to the shallowness of the domain, wind, and strong tidal mixing. Because of the shallow water column and good mixing of this domain, the heat exchange between the water column and the overlying atmosphere is high, resulting in a large seasonal variation in temperature ranging from near freezing (-1.5°C) in winter to average air temperature (10°C) in summer. Flushing time for the coastal domain is about six months and hence intermediate between those of the outer and middle shelf domains (Coachman 1986).

The fronts separating the three domains and the outer shelf domain from Aleutian Basin water are broad zones in which horizontal property gradients are relatively stronger than elsewhere (Coachman 1986). Also, they frequently have long, sloping rather than vertical interfaces. The inner shelf front is about 20 km wide centered at about the 50 m isobath. At this front the two-layered structure of the central domain changes to the nearly homogeneous structure of the coastal domain. The middle and outer fronts are each about 50 km wide and centered at about 100 m depth and over the shelf break.

Circulation

Water circulation over the eastern Bering Sea (Fig. 4) is dominated by the action of the tidal currents (Coachman 1986). Three important types of motion are found on the outer shelf domain: 1) tidal currents, which represent about 80% of the flow field, 2) a mean lateral flow of 5 to 10 cm/sec along the upper continental slope and shelf break, 3) and an onshelf-offshelf flow of 1 to 5 cm/sec. In the middle shelf domain, tidal currents provide the only important type of motion and mean net flows are weak. In the coastal domain there are two types of motion: tidal currents, representing about

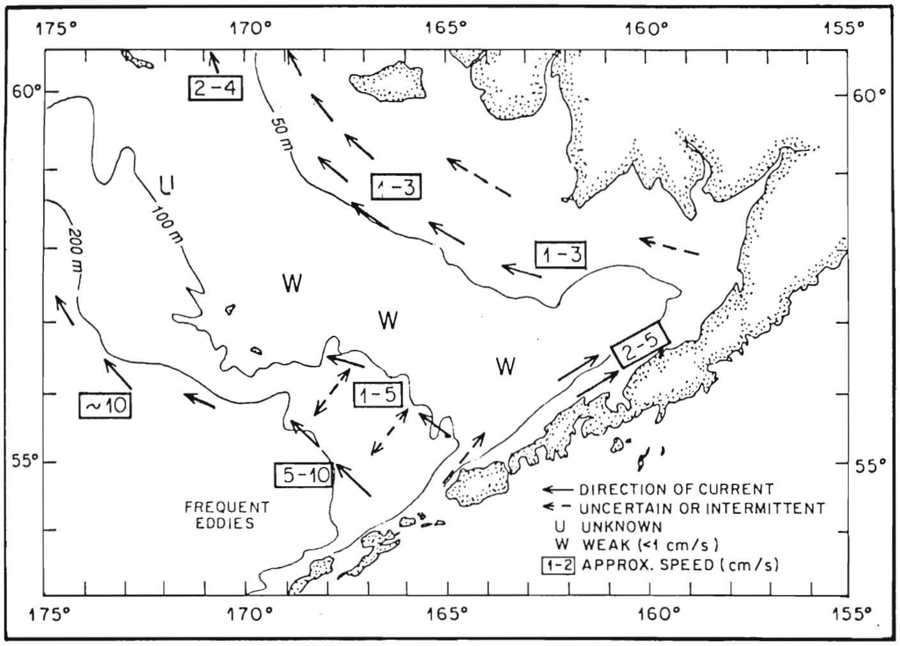


Figure 4

Estimated long-term (mean) circulation. The dashed arrows in the northern coastal regime suggest probable seasonal variability while those off Unimak Island and in the outer shelf domain are a result of subtidal variations, usually lasting 2 to 10 days duration. Flow over the shelf is mostly tidal so that the instantaneous flow is quite different from this depiction; however, it is the instantaneous flow which affects the net advective transport of properties (from Coachman 1986 as adapted from Kinder and Schumacher 1981).

95% of the flow energy, and a small but significant (1 to 5 cm/sec) mean lateral flow following the 50 m isobath.

Sea Ice

Ice cover is a seasonal feature of the eastern Bering Sea shelf, varying from none in summer to greater than 80% coverage during its maximum extent in March (Niebauer 1983). The seasonal advance of ice begins at the Bering Strait in November, reaches its southern maximum in March-April, and is completely melted by early July. Large year-to-year deviations of hundreds of kilometers from the seasonal means have been observed (Figs. 5 and 6). These deviations are generally correlated with either wind fields or storm tracks (Niebauer 1983). For example, during heavy ice years, storms occur predominantly along the Aleutian Islands and eastward into the Gulf of Alaska, staying south of the eastern Bering Sea shelf. This results in more winds from the north and northeast over the eastern Bering Sea, which increases ice production and moves the ice farther south, increasing the extent of ice cover. During light ice years, storms generally move north across the western Bering Sea and a reduced number of storms occur along the Aleutian Islands. This results in a greater incidence of winds from the south and southwest, which produce higher air and sea temperatures and less ice cover in the eastern Bering Sea.

In the mid-to-late 1960's (until 1967) air flow came from the south producing above-normal sea temperatures in the eastern Bering Sea (Niebauer 1983). A change in atmospheric conditions led to a sharp decrease in sea temperatures from 1967 to 1976, with bottom water temperatures being particularly low in 1972, 1975, and 1976 (Fig. 7). The upper air flowed from the south again in 1977, initiating a warming trend that reached a maximum in 1979. Bottom temperatures again declined after 1979 but did not reach the low levels observed in 1972 and 1975–76 through at least 1986 (Fig. 7).

Food Chain Dynamics

Properties of the oceanographic fronts and domains in the eastern Bering Sea divide the shelf into distinct production regions (Alexander 1986; Walsh and McRoy 1986). Over the outer shelf, a large portion of the annual primary production is channeled into a pelagic food web that supports the large population of walleye pollock and other semidemersal species in this region.

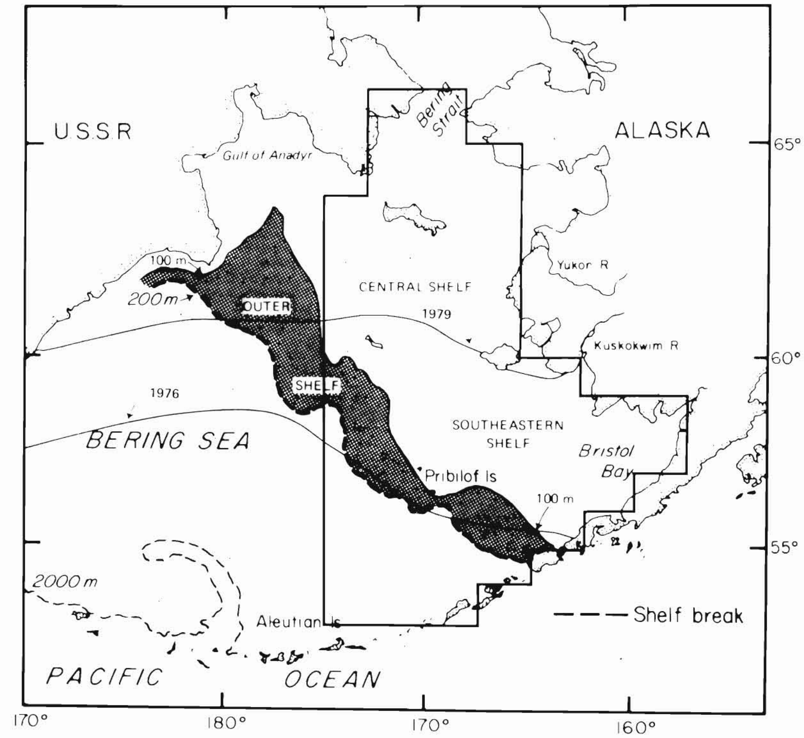


Figure 5
Estimates of the southern ice limit in the eastern Bering Sea in April of a cold year (1976) and a warm year (1979) (Niebauer 1983). Outlined area was used to calculate percent ice cover.

The major portion of the primary production not consumed in the water column is advected off the shelf to the continental slope and a relatively small portion sinks to the sea floor. These processes lead to a relatively low biomass of macrobenthos on the outer shelf domain and reduced abundance of benthic-feeding groundfish.

Almost all of the primary production settles to the sea floor on the central shelf, where the abundance of pelagic grazers is low (Alexander 1986; Walsh and McRoy 1986). The biomass of macrobenthic infauna on the central shelf is 10 times greater than on the outer shelf (Haflinger 1981) and this domain supports the greatest abundance of benthic predators such as yellowfin sole (*Pleuronectes aspera*) and other small flatfishes. Food is not limited for most organisms in the southeast Bering Sea. (Walsh and McRoy 1986)

Sources of Data and Methods

Data on the groundfish complex of the eastern Bering Sea and historical changes in biomass are derived from research vessel surveys and commercial fisheries. Extensive demersal trawl surveys were first conducted in the eastern Bering Sea by the U.S.S.R. in 1957–59. The methods used during these surveys are not well documented and the data from these surveys are used sparingly. In 1965, the International Pacific Halibut Commission (IPHC) conducted an extensive demersal trawl survey using methods and trawls similar to those used in later years by the Northwest and Alaska Fisheries Center (NWAFC). Surveys by the NWAFC have been the principal source of assessment data for eastern Bering Sea groundfish since the mid-1970s. Because of the similarities in methods and trawls, the IPHC survey data were considered reasonably compatible with the later NWAFC survey data. The Japanese Fisheries Agency (JFA) initiated demersal trawl surveys of eastern Bering Sea groundfish in 1966 and continued independently to survey groundfish each year (except 1972) until 1978. The earlier JFA surveys are particularly important for describing historical changes in biomass of groundfish because they provide the only standard series of survey data during the developmental and peak periods of the fishery for walleye pollock.

The NWAFC initiated groundfish trawl surveys in 1971, but those surveys were limited to the southeast Bering Sea continental shelf (<200 m) until 1975, when the first large-scale, systematic demersal trawl survey was conducted. The survey encompassed most of the

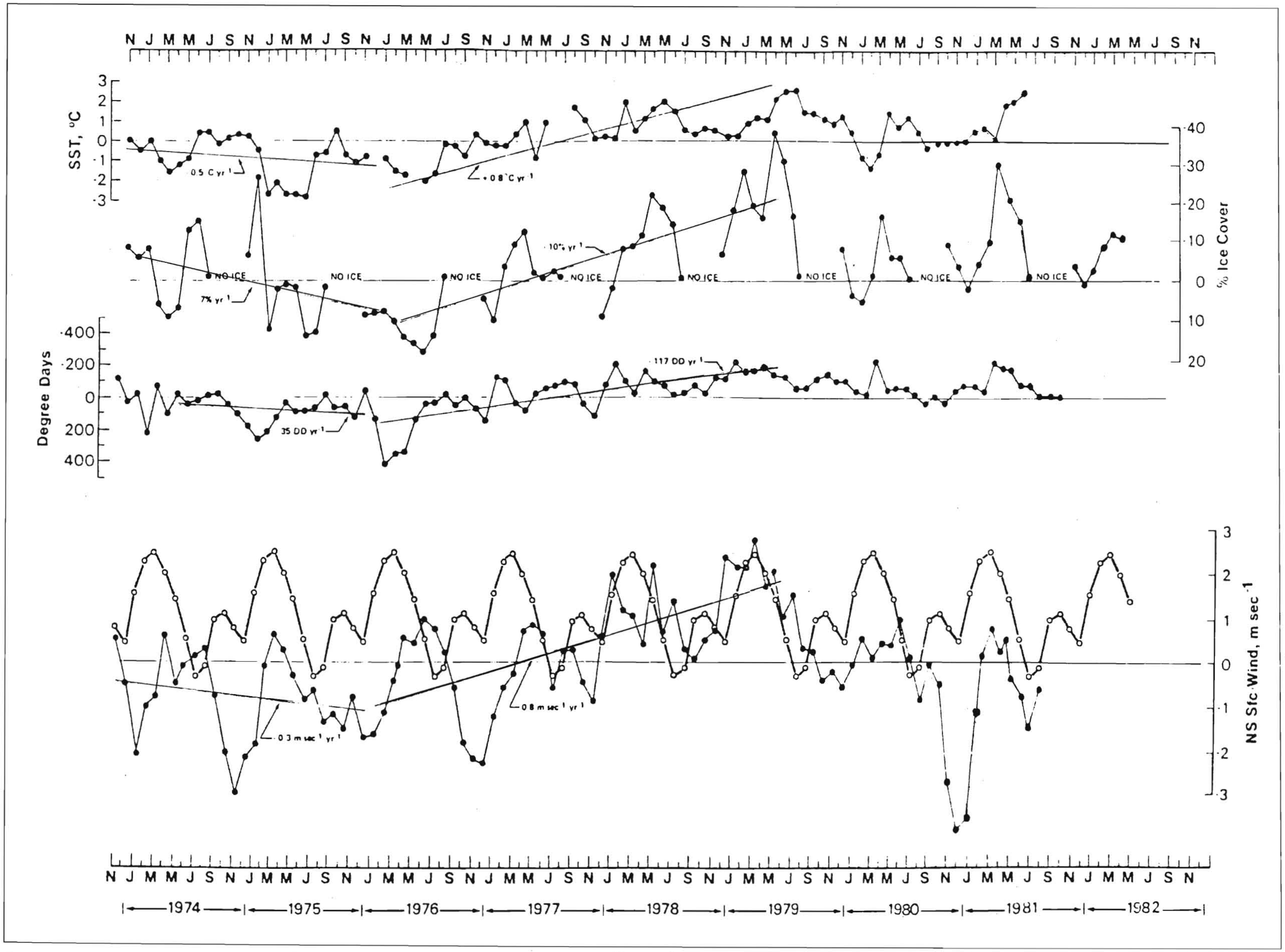


Figure 6

Departures from monthly mean values for ice cover, sea surface temperature (SST), degree days (DD), and north-south component of the surface wind (solid line with solid circles) from the eastern Bering Sea (from Niebauer 1983). In wind panel, open circles with solid lines are seasonal mean winds plotted such that, for a given month, when wind anomalies (solid dot) fall below seasonal mean (open dot), the wind is actually from the north regardless of the sign of the anomaly. When the anomaly rises above, the wind is from the south. Wind data have been smoothed by a 3-month running mean.

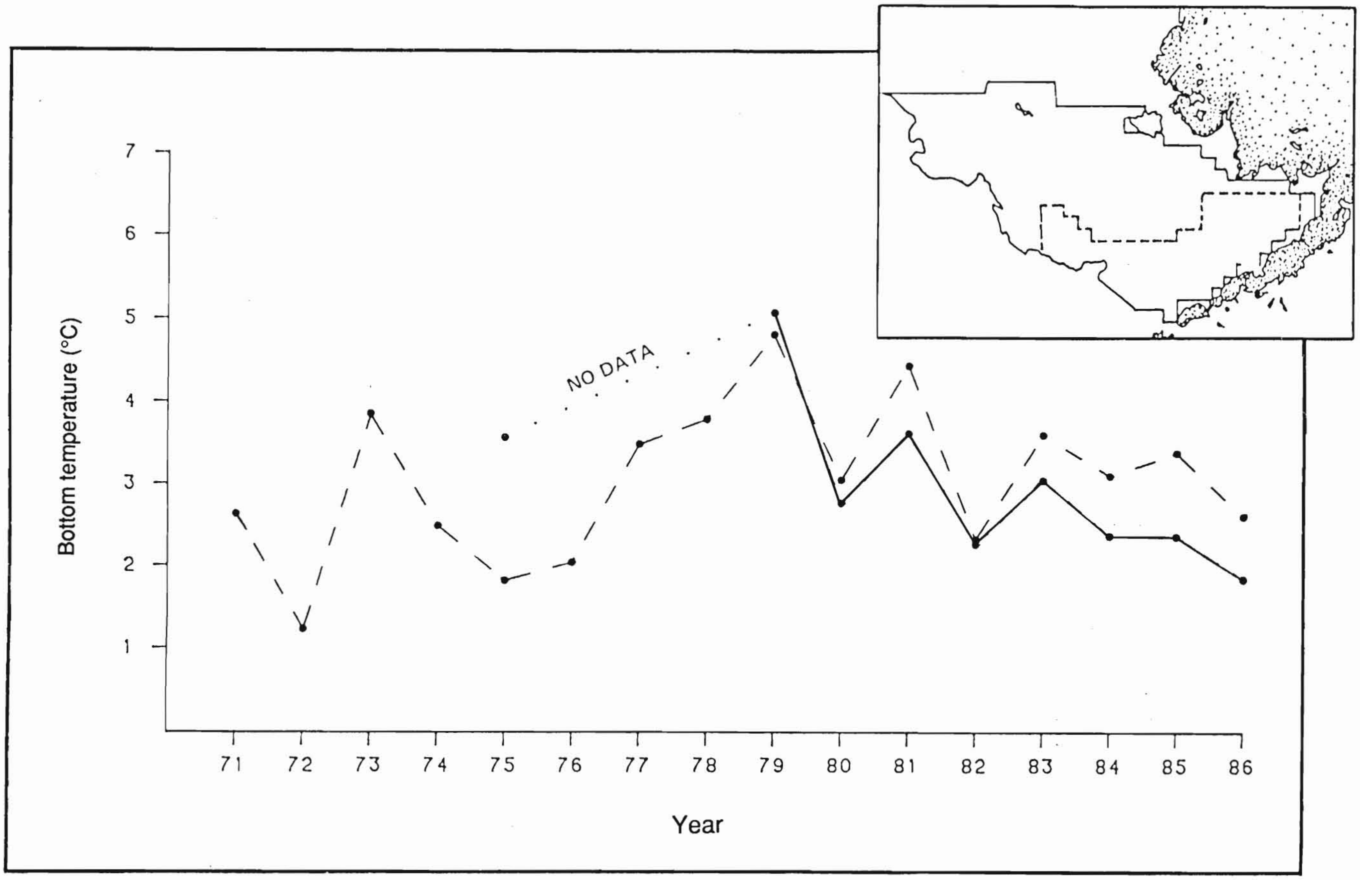


Figure 7

Mean summer bottom water temperatures, based on bathythermograph casts at depths ranging from 20 to 200 m during Northwest and Alaska Fisheries Center groundfish surveys. The dashed line represents data for the southeast Bering Sea only (see inset) 1971-85; the solid line represents data for the entire survey area (1975, 1979-86).

eastern Bering Sea continental shelf and sampled the major portions of the distributions of groundfish on the shelf. Less extensive surveys were again conducted in the eastern Bering Sea in 1976–78, but in 1979 the NWAFC began to sample a major portion of the shelf on an annual basis (Fig. 8). These large-scale surveys have been continued until the present. Also in 1979, the JFA joined the NWAFC in the first of a series of cooperative surveys to provide the first comprehensive assessment of groundfish on the continental slope (200–1,000 m depth) of the eastern Bering Sea (Fig. 9). The 1979 cooperative survey also included a hydroacoustic and midwater trawl survey of walleye pollock to assess the midwater portion of the population. Combined with the demersal trawl data, this survey provided the first assessment of the overall pollock population in the eastern Bering Sea. Cooperative NWAFC and JFA demersal trawl and hydroacoustic surveys were repeated on a triennial basis through 1985; in addition, the JFA surveyed the continental slope in 1981. These cooperative demersal trawl and hydroacoustic surveys provide the most comprehensive assessment of the eastern Bering Sea groundfish and are the main source of information for describing the groundfish complex and the distribution and biomass of the species in the complex. The 1979–86 NWAFC demersal trawl surveys of continental shelf waters also provide eight years of standardized annual estimates of the overall biomass of groundfishes except for walleye pollock and continental slope species. This time series can be extended to a 12-year period by including the 1975 survey data.

Data from IPHC and JFA demersal trawl surveys in 1965–71 were used to examine trends in biomass of groundfish in years prior to the first extensive NWAFC trawl survey in 1975. Although the IPHC conducted annual trawl surveys in most years in 1963–78 as did the JFA for most years in 1966–78, the areas sampled varied considerably from year to year. The variable sampling areas made the data from the complete series of these surveys unsuitable for assessing changes in groundfish biomass. The main objective of the IPHC surveys was to assess the condition of juvenile Pacific halibut

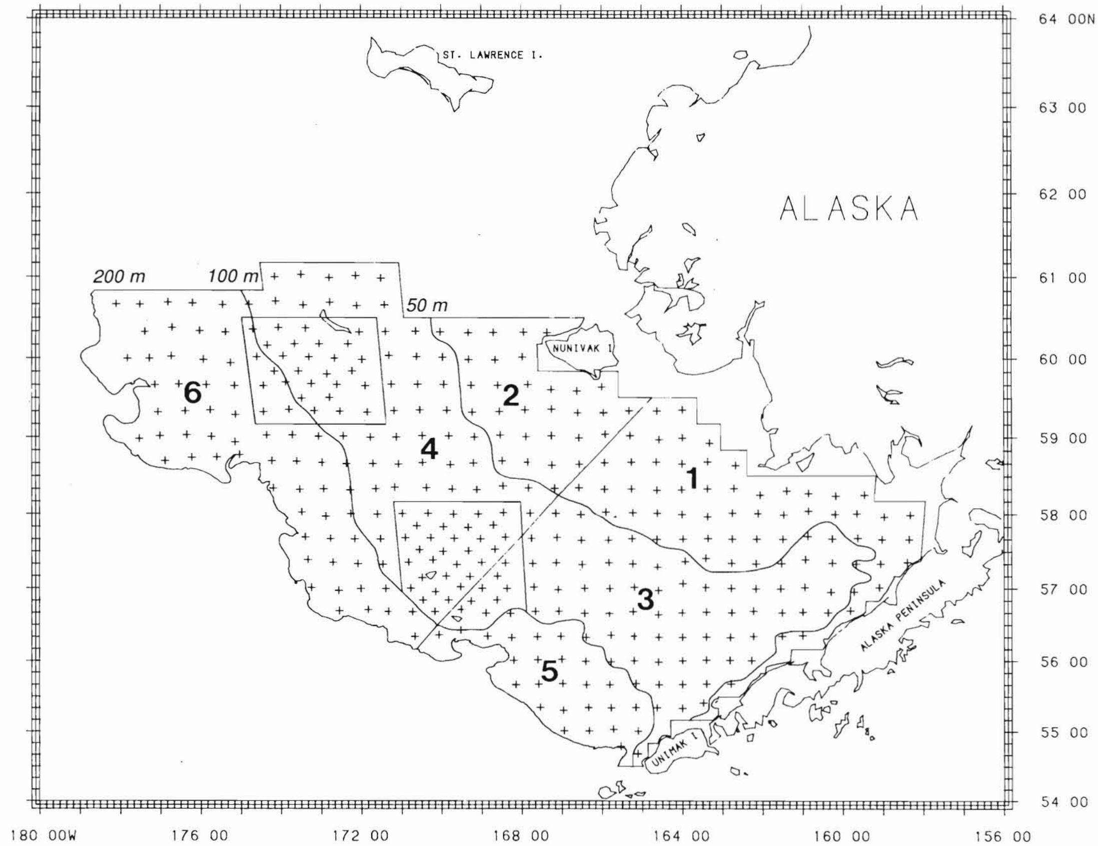


Figure 8
Area of the eastern Bering Sea continental shelf sampled by Northwest and Alaska Fisheries Center vessels in 1975 and 1979-86. Insets show areas of increased sampling density and the numbers 1 to 6 represent subarea numbers.

(*Hippoglossus stenolepis*). Abundance of other groundfish species in the catches were usually only roughly estimated except in 1965 when all species were sorted and weighed. Thus, only the 1965 IPHC survey data were useful for purposes of this study.

Two JFA survey areas were useful for the present study because each of the sampling areas was relatively large and the survey data were likely representative of groundfish populations throughout the eastern Bering Sea shelf area. Each of these areas was also sampled in two different years (one in 1966 and 1971 and the other in 1968 and 1970), thus providing two standardized sets of biomass estimates for this period.

Results from cohort and stock-reduction analyses (Pope 1972; Kimura 1985; Zhang 1987; Kimura 1988) were used to describe historical changes in biomass when available (Table 2); Survey data were used for species not analyzed in that manner. Fishery catch, length-frequency, and age data used in age-structured models and for deriving other information reported here were obtained from two sources. Biological data collected by the Japanese from their fishery were used until about 1973 and catch data reported by the individual fishing nations until about 1977. Most of the biological data used since 1973 were collected by the NWAFC Foreign Fishery Observer Program from the various fisheries. Starting in 1977, the program also began to collect catch data, which have generally been used rather than those reported by foreign sources. In the absence of fishery age data, survey age data have been used in age-structured models for rock sole and Alaska plaice.

Trends in biomass were examined for the principal species and species groups occupying continental shelf waters as well as Pacific ocean perch (*Sebastes alutus*) and sablefish (*Anoplopoma fimbria*), two target species of the continental slope fisheries. These species and species groups represented about 98% of the total sampled groundfish biomass on the eastern Bering Sea shelf and slope, based on results of the 1985 NWAFC-JFA cooperative survey.

Results from cohort analyses were available for describing historical changes in biomass of walleye pollock and yellowfin sole, the two most abundant species, since the early years of the fisheries for those species.

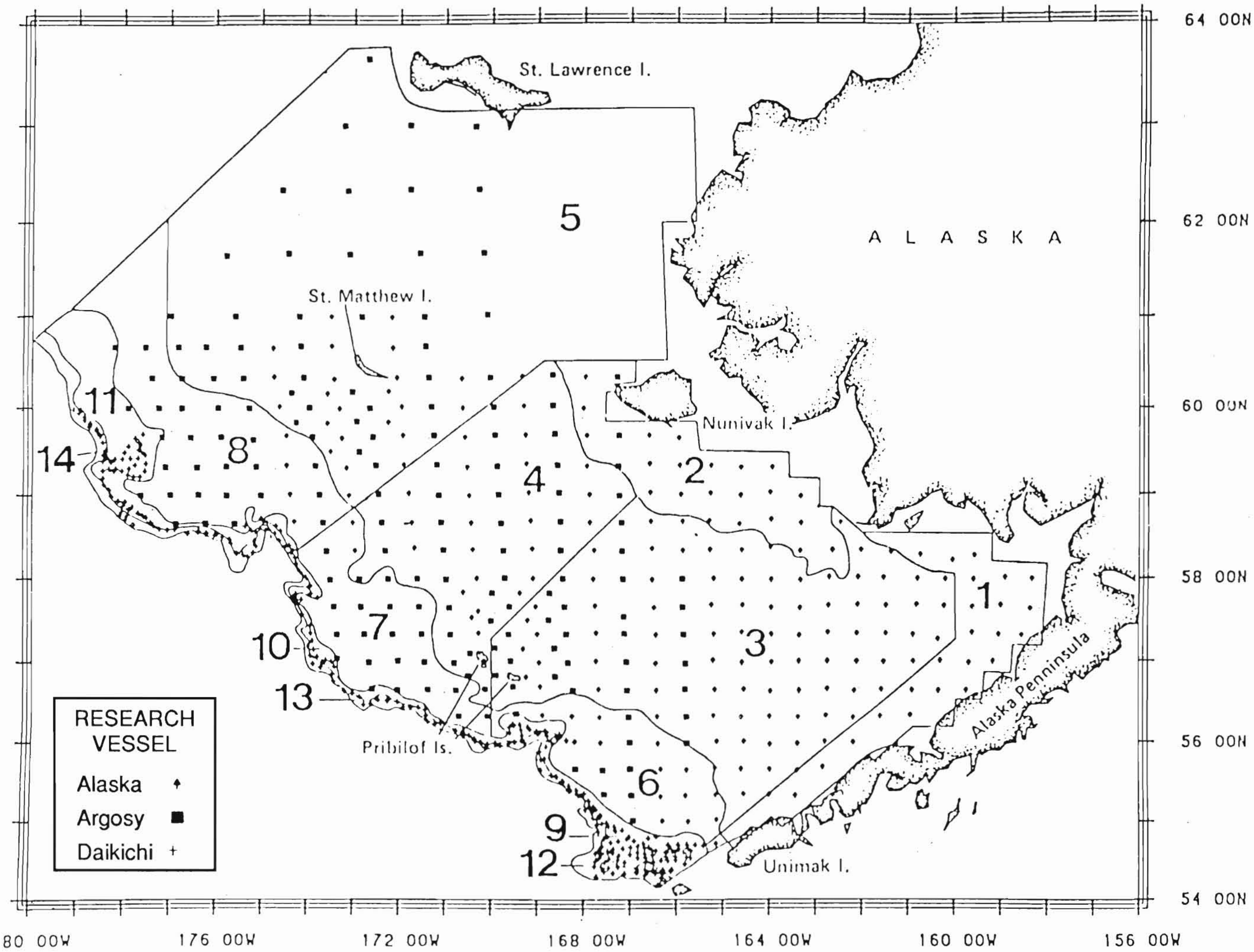


Figure 9

Areas of the continental shelf and slope of the eastern Bering Sea sampled during the Northwest and Alaska Fisheries Center-Japan Fisheries Agency cooperative surveys in 1979-85. Shown is the sampling pattern of survey vessels in 1985. Numbers 1 to 14 represent subarea numbers.

Cohort analysis results were also available for rock sole (*Pleuronectes bilineatus*) and Alaska plaice (*Pleuronectes quadrituberculatus*) since the early or mid-1970's. Survey data and stock-reduction analyses (described below) were used for the remaining species and species groups.

Survey Methods and Analyses

Survey Areas—The standard NWAFC survey area was larger than the 1965 IPHC and 1966–71 JFA survey areas (Figs. 10–12, Table 3). Some of the stations sampled during the IPHC and JFA surveys were not used in order to provide uniform sampling densities within the survey areas. In the case of the JFA surveys, some stations were omitted to standardize the areas sampled between years.

During the 1975 and 1979–86 time series of NWAFC standard bottom trawl surveys on the continental shelf (Fig. 8), 465,000 km^2 were sampled at a density of 1,314 km^2 per station. The 1979, 1982, and 1985 NWAFC-JFA cooperative bottom trawl surveys expanded the sampling effort of these surveys (Fig. 9) with NWAFC survey vessels extending bottom trawl sampling to the north shelf between St. Matthew and St. Lawrence Islands and JFA vessels sampling continental slope waters. The JFA also sampled continental slope waters in 1981. The station pattern used in 1985 is representative of sampling during the earlier NWAFC-JFA cooperative bottom trawl surveys in 1979, 1981, and 1982 although there were some modifications (Bakkala and Wakabayashi 1985; Bakkala et al. 1985; Sample et al. 1985). Except for 1979, NWAFC vessels sampled all shelf stations and JFA vessels all slope stations. The total

Table 2
Species and species groups of groundfish of the eastern Bering Sea for which historical changes (1965–85) in biomass were examined and the methods of deriving these estimates.

Species	Sources of biomass estimates
Walleye pollock	Cohort analysis
Pacific cod	Surveys
Pacific ocean perch	Stock-reduction analysis
Sablefish	Stock-reduction analysis
Yellowfin sole	Cohort analysis
Rock sole	Surveys 1965-74 and 1985, Cohort analysis 1975-84
Flathead sole	Surveys
Alaska plaice	Surveys 1965-70, cohort analysis 1971-85
Greenland turbot	Surveys
Arrowtooth flounder	Surveys
Pacific halibut	Surveys
Sculpins	Surveys
Eelpouts	Surveys
Skates	Surveys

shelf area sampled in 1985 was 627,400 km^2 at a density of 1,684 km^2 per station. The area of the slope sampled was 37,300 km^2 with a mean of 123 km^2 per station.

The 1985 hydroacoustic-midwater trawl survey covered 368,000 km^2 over bottom depths of approximately 30 to 500 m (Fig. 13) and from about 15 m below the surface to within 3 m of the bottom (Walters et al. 1988). The 1985 hydroacoustic survey area was larger than that covered in 1982 (294,500 km^2) (Bakkala et al. 1985) and 1979 (132,300 km^2) (Traynor and Nelson 1985).

Vessels and Fishing Gear — A variety of vessels and sampling trawls have been used during the various surveys (Table 4). Differences in size and horsepower of vessels and trawl characteristics undoubtedly influence any between-year comparison of bottom trawl survey results. The 1965 IPHC survey used the 400–mesh eastern trawl, which was the standard trawl used during most NWAFC bottom trawl surveys until 1982. This trawl has a small vertical opening (about 1.5 m) and was fished without roller gear. The trawls used during the 1966–71 Japanese surveys had similar characteristics: a low vertical opening (2.0–2.5 m) and only light roller gear. Thus, the trawls used by the three agencies are assumed to have sampled groundfish in a similar manner.

The 83–112 trawl, a larger version of the 400–mesh eastern trawl, was used for the 1975 NWAFC survey and on one of the survey vessels in 1981. Comparative fishing experiments using the 400–mesh eastern and 83–112 trawls in 1981 showed that differences in catch rates were not significant for most species; significant differences were found for yellowfin sole, Alaska plaice, Greenland turbot (*Reinhardtius hippoglossoides* [Greenland halibut of Robins et al. 1991]), and skates (Rajidae) (Sample et al. 1985).

In 1982, the NWAFC adopted the 83–112 trawl as the standard trawl for its eastern Bering Sea surveys. Prior to the 1982 survey, test fishing operations were conducted to determine how well the footrope of the 83–112 trawl made contact with the bottom. Unsatisfactory contact with the seabed resulted in rerigging of the trawl. Dandylines were changed from a single 46–m section branching into two 27–m bridles for an overall length of 73 m to double dandylines having an overall length of 55 m. In addition, 61–cm chain extensions were attached between each end of the footrope and lower dandyline. The presence of bottom debris in the catches indicated that the new rigging resulted in good bottom contact of the footrope.

These changes in rigging apparently resulted in a significant increase in the efficiency of the 83–112 trawl over the trawls used previously, based on large increases in abundance for some flatfishes between the 1981 and 1982 surveys that could not be explained by population increases alone. The catch-per-unit-effort (CPUE) val-

Table 3
Characteristics of demersal trawl surveys for groundfish in the eastern Bering Sea by the Northwest and Alaska Fisheries Center (NWAFC), the International Pacific Halibut Commission (IPHC) and the Japan Fisheries Agency (JFA), 1965–86.

Agency	Survey year(s)	Area Sampled (km^2)	Proportion of NWAFC survey area	Number of stations	Sampling density (km^2/station)
NWAFC	1975, 1979-86	465,035	1.000	354	1,314
IPHC	1965	201,849	0.434	92	2,194
JFA	1966	222,014	0.477	132	1,682
JFA	1971	222,014	0.477	121	1,835
JFA	1968	162,407	0.349	120	1,353
JFA	1970	162,407	0.349	100	1,624

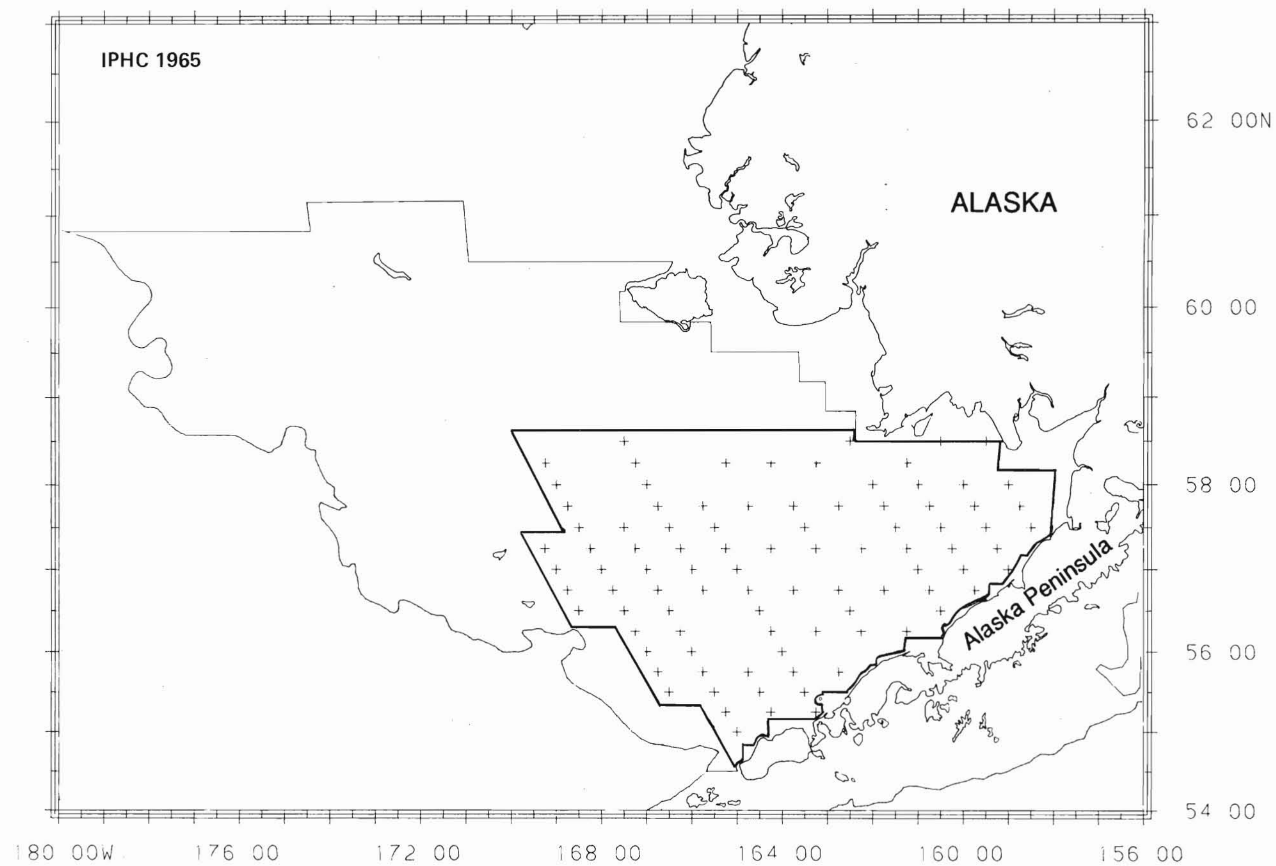


Figure 10

Area and stations sampled in the eastern Bering Sea by the International Pacific Halibut Commission (IPHC) in 1965 (boldline) within the larger Northwest and Alaska Fisheries Center (NWAFC) survey area in 1975 and 1979-86.

ues increased from 51.5 to 70.4 kg/ha for yellowfin sole, 6.5 to 12.3 kg/ha for rock sole, 11.5 to 15.1 kg/ha for Alaska plaice, and 3.5 to 4.2 kg/ha for flathead sole (*Hippoglossoides elassodon*). Although the abundances of these species were known to be increasing during the early 1980's, the magnitude of the increases between the period 1981 and earlier and the period 1982 and later was probably less than indicated by the survey data owing to the change in the sampling gear. As will be shown below from comparisons of survey estimates with results of cohort analyses, the pre-1982 trawls may have underestimated the biomass of at least some flatfishes.

The design of the JFA and NWAFC trawls used during the 1979–85 cooperative surveys differed as did their effectiveness for various species. The NWAFC trawls were designed to fish on the relatively smooth sea floor of the continental shelf and to be efficient at capturing benthic organisms while the JFA trawls were designed to fish continental slope waters where the sea floor may be irregular. There was no roller gear on the footrope of the NWAFC trawls which was designed to fish hard on the bottom, and the trawl had a relatively small vertical opening of 1.5–2.3 m. The JFA trawls had a greater vertical opening (2.3–3.4 m) and lengths of chain between the upper and lower groundrope resulted in an opening of 20–28 cm between the bottom of the trawl and the lower groundrope. The lower groundrope was also equipped with 45–55 cm diameter steel bobbins. Results of comparative fishing experiments between the JFA and NWAFC vessels and trawls were generally similar each year. The NWAFC trawls were more efficient for most species, particularly for species more closely associated with the bottom such as the flatfishes. The Japanese trawls were usually more efficient for semidemersal species such as herring (*Clupea pallasii*) and walleye pollock.

Data Collection and Station Sampling Procedures—

Demersal trawl surveys—Detailed methods of data collection and sampling of catches during cooperative NWAFC-JFA surveys were described by Wakabayashi et al. (1985). These methods have been used on all NWAFC surveys since 1975. The methods of sorting and weighing catches on the early JFA and IPHC surveys are compatible with those on NWAFC surveys. Briefly, the data collected at each station included haul-position information, distance trawled, species composition by weight and number, and water temperature profiles.

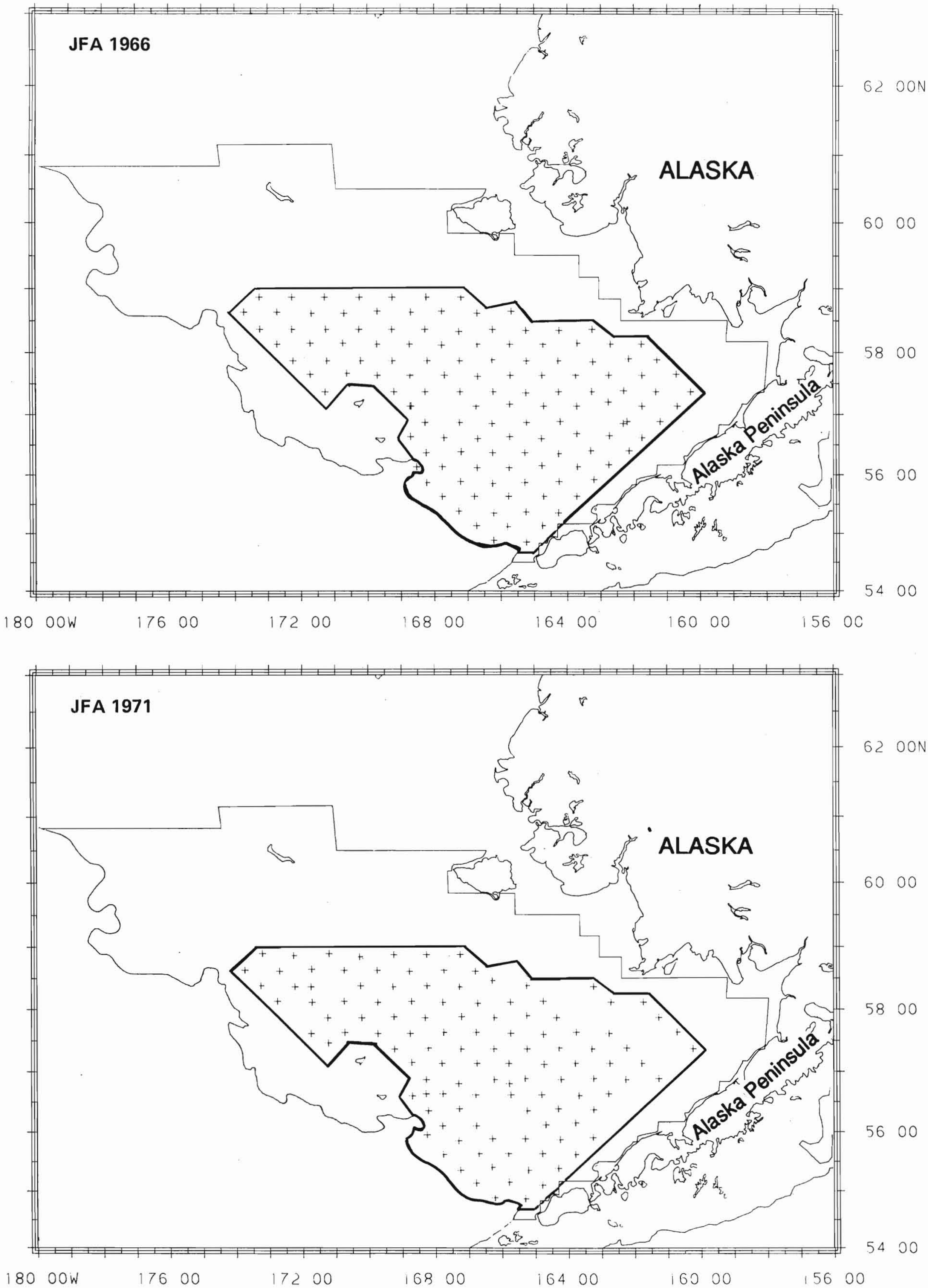


Figure 11

Area and stations sampled in the eastern Bering Sea in 1966 and 1971 by the Japan Fisheries Agency (JFA) (boldline) within the larger Northwest and Alaska Fisheries Center (NWAFC) survey area in 1975 and 1979-86.

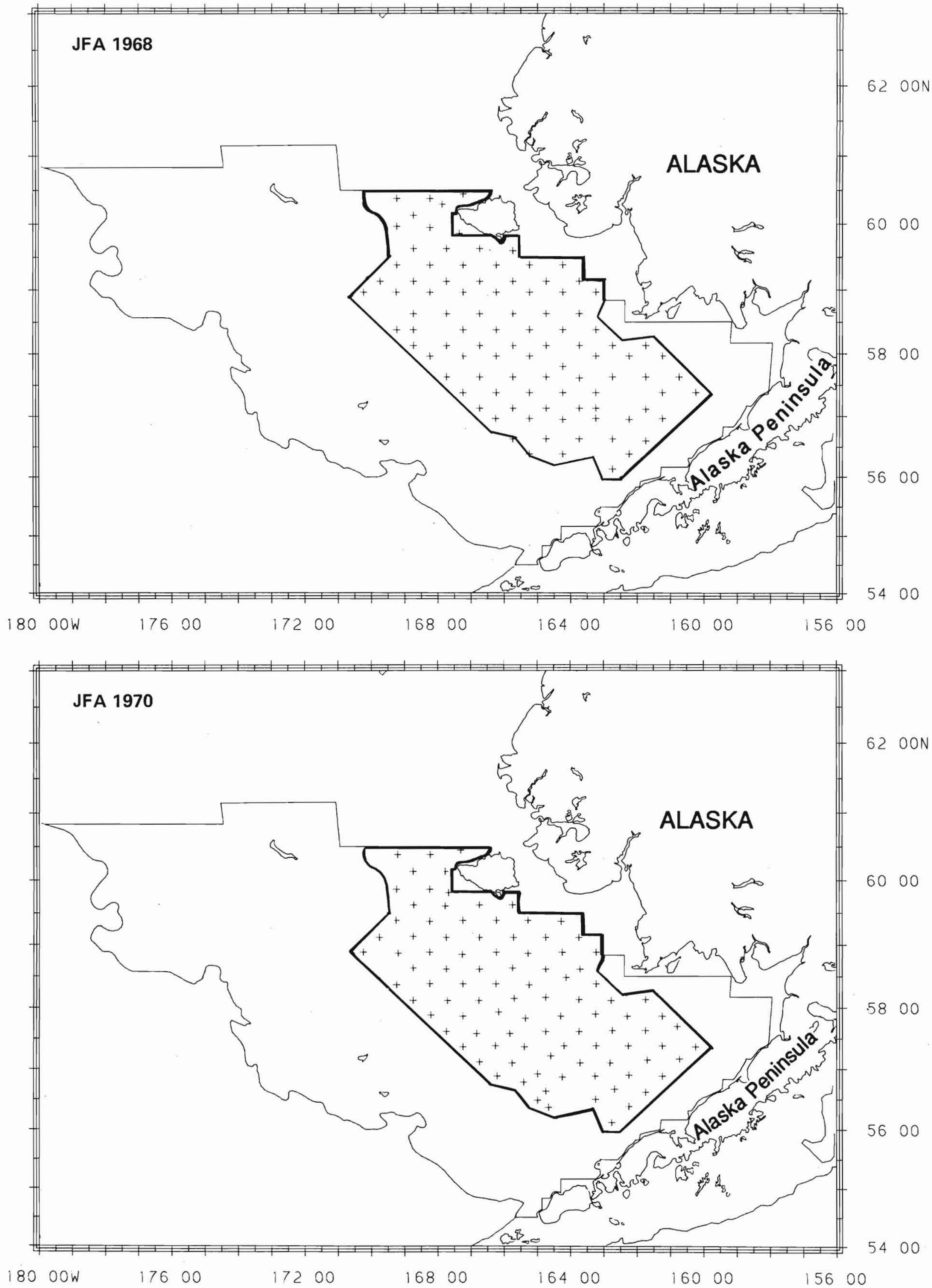


Figure 12

Area and stations sampled in the eastern Bering Sea in 1968 and 1970 by the Japan Fisheries Agency (JFA) (boldline) within the larger Northwest and Alaska Fisheries Center (NWAFC) survey area in 1975 and 1979-86.

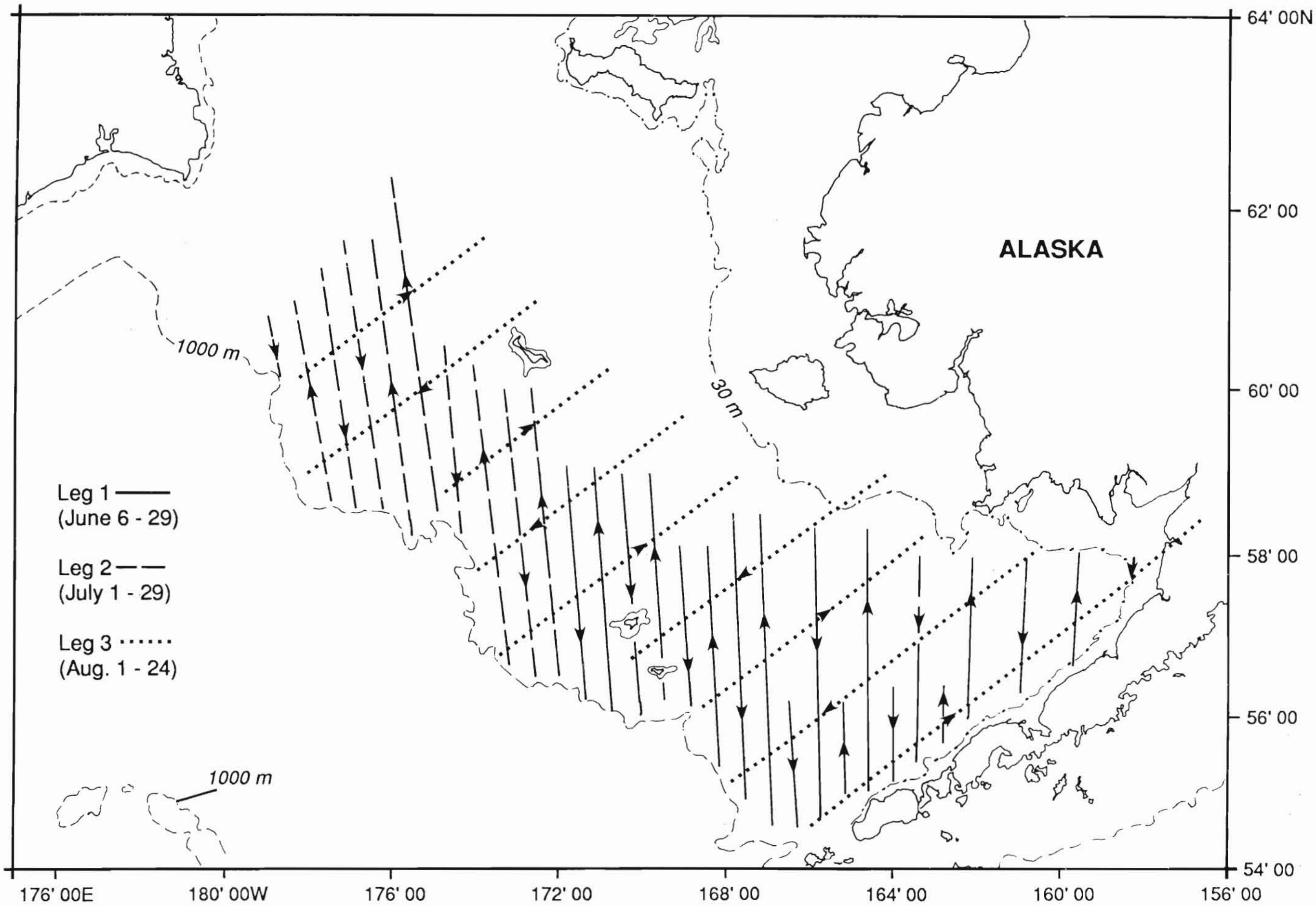


Figure 13
Transects of the charter fishing vessel *Morning Star* during the 1985 midwater survey. Age-1 and older walleye pollock (*Theragra chalcogramma*) were sampled on legs 1 and 2 and age 0-pollock on leg 3.

Random samples of principal species were measured for length at most stations where they appeared in catches. An age-structure sample, stratified by sex and length class, was also collected for commercially important species.

Methods of measuring wing spread for deriving areas swept by the trawls have varied. The wing spreads of NWAFC trawls were initially derived by diver observations and later by intermittent measurements with trawl mensuration equipment developed at the NWAFC (Wathne 1977). In most recent years these measurements have been obtained for most hauls by a commercial trawl mensuration system (Scanmar).

Until 1985, Japanese scientists used an indirect method of measuring wing spread based on the angle of the trawl warps (Koyama 1974). During the 1985 NWAFC-JFA cooperative surveys, measurements were made both indirectly by the Koyama method and directly using a net monitor transducer (FNR-80, Furuno Electric Co.). For deriving biomass estimates from JFA survey data prior to 1979, an average wing spread of 20.9 m was used based on indirect measurements taken in 1974 (Wakabayashi, pers. comm. National Research Institute of Fisheries Science, Fisheries Agency of Japan, 5–5–1 Kachidaki, Chuo-ku, Tokyo, 104 Japan, Nov. 1988).

Distances trawled were also not recorded during the early Japanese surveys and an average distance of 3.13 km for a 30-minute tow was used based on recorded values from 1976, 1977, and 1978 JFA surveys.

Hydroacoustic surveys—Hydroacoustic data were collected by means of a computerized echo-integration and target-strength measurement system installed in a portable van, which was located on the deck of the vessel (Traynor and Nelson 1985). The hydroacoustic system operated at 38 kHz and was designed to collect integration data and target-strength information using dual- and split-beam techniques.

Echo-integration density estimates (in kg/m^3) were obtained for up to 400 1–m depth intervals from the transducer and in each of forty 1–m bottom referenced intervals. Density outputs were obtained at 1–min intervals along the survey transects. Estimates of walleye pollock target strength were obtained when conditions suitable for single-target recognition were encountered.

Walleye pollock and other species were sampled along the acoustic transects by midwater trawling. For each midwater haul the total weight was determined for all species and the total number for each species of fish. Sex and length composition and age-structure samples were collected for each catch of walleye pollock.

Data Analyses—

Demersal trawl surveys—The methods of data analysis for all of the bottom trawl surveys were the same and are described in detail by Wakabayashi et al. (1985). In

Table 4

Vessels and trawl gear used during demersal trawl and hydroacoustic surveys in the eastern Bering Sea.

			Vessel characteristics			
Year	Agency	Vessel name	Overall length (m)	Gross tonnage (t)	Engine horsepower	Trawl gear
1965	IPHC[a]	*Tordenskjold*	20.4	60	220	400-mesh eastern
1966	JFA[b]	*Kawachi maru*	—	300	700	2-seam trawl
1968	JFA	*Chosui maru*	—	365	1,050	2-seam trawl
1970	JFA	*Inase maru No. 3*	—	313	1,000	2-seam trawl
1971	JFA	*Tanshu maru*	—	291	800	2-seam trawl
1975	NWAFC[c]	*Oregon*[d]	30.5	219	600	400-mesh eastern
	NWAFC	*Anna Marie*	26.2	177	665	83-112
	NWAFC	*Pat San Marie*	30.0	200	765	83-112
	NWAFC	*Miller Freeman*	65.5	1,500	2,200	83-112
1979	NWAFC	*Oregon*	30.5	219	600	400-mesh eastern
	NWAFC	*Paragon II*	33.5	196	850	400-mesh eastern
	NWAFC	*Discovery Bay*	32.9	196	850	400-mesh eastern
	NWAFC	*Miller Freeman*[e]	65.5	1,500	2,200	Norsenet
	JFA	*Yakushi maru No. 21*	48.4	350	2,500	Commercial trawl
	JFA	*Shotoku maru No. 35*	50.8	350	3,000	Commercial trawl
1980	NWAFC	*Oregon*	30.5	219	600	400-mesh eastern
	NWAFC	*Ocean Harvester*	32.9	199	1,125	400-mesh eastern
1981	NWAFC	*Chapman*	38.7	427	1,250	83-112
	NWAFC	*Alaska*	30.5	219	600	400-mesh eastern
	JFA	*Ryoan maru No. 31*	50.7	350	2,700	Commercial trawl
1982	NWAFC	*Chapman*	38.7	427	1,250	83-112
	NWAFC	*Pat San Marie*	30.0	200	765	83-112
	NWAFC	*Miller Freeman*	65.5	1,500	2,200	83-112
	NWAFC	*U.S. Dominator*[e]	37.8	199	1,450	Gourock rope wing and Diamond 1000
	JFA	*Ryujin maru No. 8*	54.4	350	2,500	Commercial trawl
1983	NWAFC	*Chapman*	38.7	427	1,250	83-112
	NWAFC	*Alaska*	30.5	193	600	83-112
1984	NWAFC	*Chapman*	38.7	427	1,250	83-112
	NWAFC	*Alaska*	30.5	219	600	83-112
1985	NWAFC	*Alaska*	30.5	219	600	83-112
	NWAFC	*Argosy*	38.1	200	1,125	83-112
	NWAFC	*Morning Star*[e]	37.5	188	1,125	Diamond 1000
	JFA	*Daikichi maru No. 32*	50.4	350	2,500	Commercial trawl
1986	NWAFC	*Alaska*	30.5	219	600	83-112
	NWAFC	*Morning Star*	37.5	188	1,125	83-112

[a] International Pacific Halibut Commission.
[b] Japanese Fisheries Agency.
[c] Northwest and Alaska Fisheries Center.
[d] Independently surveyed southeast Bering Sea Shelf.
[e] Hydroacoustic survey vessel.

general terms, catches at each station were standardized to a basic sampling unit (kg/ha) trawled or CPUE. Mean CPUE by species and strata were then computed from the standardized catch rates and summed over strata after being weighted by the size of each stratum to obtain mean catch rates for the overall survey area. Standing stock (biomass) estimates were derived using the "area swept" method of Alverson and Pereyra (1969). Vulnerability (the proportion of the population that is available to the fishing gear and is caught when encountered by the gear) of all species was assumed to be 1.0, except when fishing power adjustments were made as described below.

In estimating the length composition of the sampled populations, the number of individuals within sex and size classes for each station was derived by expanding the length-frequency subsample to the total catch per standard sampling unit. The individual station data were then expanded to the total strata area and summed over strata to obtain estimates for the total survey area. Age composition was estimated by proportioning the computed population length-frequency distributions to ages with age-length keys that were stratified by sex and size categories.

During the NWAFC surveys since 1975, the relative fishing powers of vessels within a survey period have been determined through side-by-side trawling or by alternate-row fishing. In the latter method, the vessels fished alternate north-south rows of stations throughout the survey area or a large portion of the survey area. CPUE values from the two vessels fishing either method were compared to determine the relative fishing powers for each species or species group taken. The Geisser and Eddy (1979) technique was used to determine whether the CPUE distributions were the same or different. If CPUE distributions were the same for a given species, or there were insufficient data to test for differences, the vessels were assumed to have the same fishing powers for that species. If CPUE distributions were different, then the CPUE values of the less efficient vessel were adjusted to that of the more efficient vessel for that species using the CPUE ratio of the two vessels. The rationale for this procedure was based on the assumption that CPUE values of the more efficient vessel more nearly reflected the true abundance of the species. No attempt has been made to estimate between-year relative fishing powers among the vessels. Relative fishing powers between NWAFC and JFA vessels were determined during each of the cooperative surveys in 1979–85, but mainly in shelf waters. In this study, adjustments in abundance estimates for relative fishing powers between NWAFC survey data on the shelf and JFA survey data on the slope were not made because of differences in trawls used and the species assemblages and size composition of species in the two areas.

To examine historical changes in biomass of groundfish an effort was made to derive estimates from the 1965–71 IPHC and JFA survey data of groundfish that were compatible with estimates from the 1975 and 1979–85 NWAFC survey data. The procedure was to determine initially if the biomass estimates from the IPHC and JFA survey areas were representative of the estimates from the larger NWAFC survey area (Figs. 10–12). This was accomplished by first deriving biomass estimates within the IPHC and JFA survey areas using NWAFC survey data from 1975 and 1979–85. Linear regression analyses were then used to determine if the relationship between the estimates in the IPHC and JFA survey areas and the larger NWAFC survey area was significant. If the relationship was significant, the regression equations were used to expand the biomass estimates from the 1965–71 IPHC and JFA survey data to the larger NWAFC survey area. Standard errors (SE) of the predicted mean biomass (B) were used to calculate 95% confidence intervals (CI) around the predicted values (Zar 1984):

$$SE(B) = \sqrt{Var(B)} = \sqrt{\frac{\sum (x_{ij} - \bar{x}_j)^2}{n_j}}$$

Where x_{ij} = CPUE from station i in stratum j, x_j = mean CPUE from stratum j, and n_j = sample size from stratum j. If the estimator is approximately normally distributed, then the upper and lower confidence intervals are distributed symmetrically about the mean as follows:

$$95\%\ CI = \text{Mean biomass} \pm 1.96\ SE(B)$$

In those cases where the relationship was not significant, the mean ratio of biomass estimates from the NWAFC survey in the IPHC and JFA survey area and the larger NWAFC survey area was used to expand the IPHC and JFA survey estimates. Standard errors of the mean ratios were used to calculate 95% confidence limits (CL) around the estimated biomass as follows:

$$CL = \frac{B}{\bar{x} \pm 1.96(SE)}$$

where B is the biomass in the IPHC or JFA survey areas and x is the mean ratio of biomass estimates in the IPHC or JFA survey areas relative to the larger NWAFC survey area based on the 1975 and 1979–85 NWAFC survey data.

For most species the relationship between the biomass estimates in the IPHC and JFA survey areas and the larger NWAFC area were highly significant (P=0.01) (Table 5). The only species and areas for which the relationship was not significant were walleye pollock in the 1968 and 1970 JFA survey area, Greenland turbot in the 1966 and 1971 JFA survey area, arrowtooth flounder (*Atheresthes stomias*) in the 1968 and 1970 JFA survey area, and sculpins (*Cottidae*) in all of the survey areas. Results from cohort analyses were mainly used to examine historical trends in biomass of walleye pollock, yellowfin sole, rock sole, and Alaska plaice; any errors in expanding biomass estimates for other species would have a relatively minor influence on biomass estimates for total groundfish.

Hydroacoustic surveys —The proportion of fish in three size categories collected by midwater trawl were used to calculate biomass estimates for each stratum from the hydroacoustic surveys. A target-strength value was assigned to each size category as follows: -23.6 dB (decibels)/kg for 1–18 cm fish, -27.0 dB/kg for 18–29 cm fish, and -30 dB/kg for fish >29 cm (Traynor and Williamson 1983). Mean target-strength estimates for the size distribution estimated for each strata were applied to data collected during both daylight and darkness. The use of target-strength estimates and the echo-integration scaling procedure are described by Traynor and Nelson (1985).

Mean fish density (kg/m^2) was calculated for each echo integrator output. Biomass was calculated as the product of mean density and area. Age-specific biomass and population estimates were calculated from midwater trawl length-frequency samples, a length-weight relationship, and an age-length key (Traynor and Nelson 1985).

Age-structured Models

Results from age-structured models given in this report are derived from other reports. Biomass estimates for walleye pollock (Bakkala et al. 1987b; Wespestad and Traynor 1988) and yellowfin sole (Bakkala and Wespestad 1986, 1987) are based on cohort analysis using the methods of Pope (1972). Estimates for rock sole (Walters and Halliday 1988) and Alaska plaice (Zhang 1987) are from a biomass-based cohort analysis (Zhang 1987).

Historical trends in biomass of sablefish and Pacific ocean perch, for which age data are lacking, were derived from stock-reduction analysis (Kimura 1985, 1988). Stock-reduction analysis represents one method of implementing the delay-difference equation of Deriso (1980) as generalized by Schnute (1985). The delay-difference equation is a biomass-based production function that approximates the behavior of an age-structured model exhibiting knife-edge recruitment, age-invariant mortality rates (above the age of recruitment), a Brody (1945) weight-age relationship, and an arbitrary spawner-recruit relationship. As it is usually applied, stock-reduction analysis employs a set of life his-

Table 5

Regression analyses of the relationship between biomass estimates in the International Pacific Halibut Commission (IPHC) and Japan Fisheries Agency (JFA) survey areas and the larger Northwest and Alaska Fisheries Center (NWAFC) survey area based on NWAFC survey data in 1975 and 1979–85.

	IPHC survey			JFA survey area 1966 and 1971			JFA survey area 1968 and 1970		
Species	*t* statistic	r^2	Level of significance	*t* statistic	r^2	Level of significance	*t* statistic	r^2	Level of significance
Walleye pollock	10.13	0.945	**	13.73	0.969	**	1.91	0.377	—
Pacific cod	4.19	0.745	**	3.64	0.688	*	4.47	0.769	**
Yellowfin sole	18.11	0.982	**	6.99	0.891	**	8.84	0.929	**
Rock sole	20.51	0.986	**	10.82	0.951	**	21.08	0.987	**
Flathead sole	12.77	0.965	**	20.60	0.986	**	7.08	0.893	**
Alaska plaice	5.75	0.896	**	9.12	0.933	**	6.87	0.887	**
Greenland turbot	3.83	0.709	**	0.41	0.027	—	4.35	0.759	**
Arrowtooth flounder	16.57	0.979	**	18.50	0.983	**	0.37	0.022	—
Pacific halibut	5.02	0.808	**	3.56	0.679	*	2.73	0.553	*
Sculpins	0.08	0.090	—	1.32	0.225	—	0.04	<0.001	—
Eelpouts	3.71	0.697	**	6.58	0.878	**	5.47	0.833	**
Skates	6.96	0.890	**	8.61	0.925	**	3.00	0.601	*
Total Fishes	17.46	0.981	**	12.68	0.964	**	6.31	0.869	**

— Not significant
* Significant at the 0.05 level, t 6, 0.05 = 2.447
** Significant at the 0.01 level, t 6, 0.01 = 3.705

tory parameter estimates and a time series of catch data to solve the delay-difference equation and the catch equations simultaneously. This is typically accomplished by assuming that the stock is in equilibrium prior to the second year of the time series and by assuming either a known biomass estimate for some year during the time series or a known biomass ratio for some pair of years during the time series.

Species in the Groundfish Complex

Species Encountered During Trawl Surveys

Wilimovsky (1974) recorded 235 species of fish in the eastern Bering Sea. During the four cooperative U.S.-Japanese surveys in the eastern Bering Sea between 1979 and 1985, 207 species were identified among 40 families (Table 6). Some specimens were only identified to genus or family, and may have represented specimens identified to species within that family or genus on other occasions. There is also the possibility of some of the species being misidentified because of inadequate taxonomic keys for some families in this region. Species indicated in Table 6 as frequently identified are believed to be accurately identified.

During the 1979 U.S.-Japan cooperative survey in this region three new species of eelpouts (Zoarcidae) were identified: *Lycodapus leptus*, *L. poecilus*, and specklemouth eelpout (*L. psarostomatus*) (Peden and Anderson 1981). The first observations of shortnose swallower (*Kali indica*) and Sakhalin sole (*Pleuronectes* [= *Limanda*] *sakhalinensis*) in the Bering Sea were also recorded during this and subsequent surveys (Yabe et al. 1981; Walters et al. 1988).

Relative Importance of Individual Species

The 20 most abundant species of groundfish in the eastern Bering Sea, ranked in order of relative abundance based on U.S.-Japan bottom trawl survey data in 1979–85, are listed in Table 7. These 20 species represented from 98.1 to 99.2% of the total estimated abundance by weight of all groundfish caught during these surveys. Three species were consistently the most abundant during the 1979–85 period: walleye pollock, the top ranking species each year, followed by yellowfin sole and Pacific cod. These three species represented from 70.1 to 75.1% of the overall sampled weight of all groundfish. This percentage would be even higher if the midwater portion of the walleye pollock population were included, as demonstrated below.

There was much less consistency in the ranking of the remaining 20 most abundant species. The populations of a number of the flatfish increased in this period, including rock sole, Alaska plaice, flathead sole, and arrowtooth flounder, and by 1985 these were the fourth through seventh ranked species in CPUE. Exceptions were Pacific halibut, which had relatively constant CPUE, and Greenland turbot, which showed a decline in CPUE. Some of the species groups also showed declines, such as the eelpouts, other cods (Gadidae) (saffron *Eleginus gracilis* and Arctic *Boreogadus saida* cods), snailfishes (Cyclopteridae), and the Irish lords (*Hemilepidotus* spp., family Cottidae).

The relative importance of species over all depths sampled and by depth zones during the 1985 bottom trawl survey is illustrated in Figure 14. The flatfishes, particularly yellowfin sole but also rock sole and Alaska plaice, dominated catches at depths less than 110 m (60 fm). Walleye pollock and Pacific cod were important over a wide range of depths from less than 37 m (20 fm) to 730 m (400 fm). Pollock were highly dominant over the outer continental shelf (110–183 m [60–100 fm]).

Important species on the slope, in addition to walleye pollock and Pacific cod on the upper slope, were arrowtooth flounder, Pacific ocean perch, sablefish, Greenland turbot, and grenadiers (Macrouridae). Greenland turbot and grenadiers, in particular, dominated at depths greater than 730 m (400 fm).

Commercially Important Species

A high proportion of the total weight of groundfish, ranging from 82.7 to 93.9% in the four survey years, represents commercially important species. These are, in order of their relative abundance based on the 1985 survey data, walleye pollock, yellowfin sole, Pacific cod, rock sole, Alaska plaice, flathead sole, arrowtooth flounder, Greenland turbot, Pacific halibut, sablefish, and Pacific ocean perch (Fig. 15). Pacific herring is also a commercially valuable species and one of the 20 most abundant species taken during the 1985 survey; however, herring are mainly pelagic and not considered a groundfish.

Biological characteristics of the commercially important species are listed in Table 8.

Exploitation and Management of the Groundfish Complex

Commercial exploitation of groundfish in the eastern Bering Sea has a history of more than 100 years. The first commercial venture was an exploratory effort by a single U.S. sailing schooner in 1864 to investigate the Pacific cod resource in this region (Cobb 1927). A fishery for cod started on a regular, annual basis in 1882. It was nearly 50 years later before a second ground-

Table 6
Fishes encountered during U.S.-Japan cooperative surveys in the Bering Sea, 1979–85.

Taxon[a]	English common name	Japanese standard name	Species frequently identified[b]
MYXINIDAE			
Myxinidae	Hagfish unident.	Mekuraunagi-rui	
PETROMYZONTIDAE			
Lampetra tridentata (Gairdner)	Pacific lamprey	Yufutsuyatsume	X
LAMNIDAE			
Lamna ditropis Hubbs & Follett	Salmon shark	Nezumizame	
SQUALIDAE			
Somniosus pacificus Bigelow & Schroeder	Pacific sleeper shark	Ondenzama	X
Squalus acanthias Linnaeus	Spiny dogfish	Aburatsunozame	X
RAJIDAE			
Bathyraja sp.[c]	Skate unident.	Sokogangiei-rui	X
Bathyraja abyssicola (Gilbert)[d]	Deepsea skate	Chihirokasube	
Bathyraja aleutica Gilbert	Aleutian skate	Arasukakasube	X
Bathyraja interrupta (Gill and Townsend)	Sandpaper skate	Sokogangiei-rui	
Bathyraja lindbergi Ishiyama & Ishihara[e]	Commander skate	Komandorukasube	
Bathyraja maculata Ishiyama & Ishihara[e]	Skate	Montsukikasube	
Bathyraja minispinosa Ishiyama & Ishihara[e]	Whitebrow skate	Subesubekasube	
Bathyraja parmifera (Bean)[c]	Alaska skate	Kitatsunokasube	X
Bathyraja trachura (Gilbert)[c]	Roughtail skate	Yasudakasube	
Raja sp.	Skate unident.	Gangiei-rui	X
Raja binoculata Girard	Big skate	Gangiei-rui	X
Raja rhina (Jordan & Gilbert)	Longnose skate	Gangiei-rui	X
Raja stellulata (Jordan & Gilbert)	Starry skate	Kohoshikasube	X
CLUPEIDAE			
Clupea pallasi Valenciennes	Pacific herring	Nishin	X
ENGRAULIDAE			
Engraulis mordax Girard	Northern anchovy	Katakuchiiwasi-rui	
SALMONIDAE			
Oncorhychus keta (Walbaum)	Chum salmon	Sake	X
Oncorhynchus kisutch (Walbaum)	Coho salmon	Ginsake	X
Oncorhynchus nerka (Walbaum)	Sockeye salmon	Benizake	X
Oncorhynchus tshawytscha (Walbaum)	Chinook salmon	Masunosuke	X
OSMERIDAE			
Mallotus villosus (Muller)	Capelin	Karafutoshishamo	X
Osmerus mordax (Mitchill)	Rainbow smelt	Kyuriuo	X
Thaleichthys pacificus (Richardson)	Eulachon	Yuurakon	X
BATHYLAGIDAE			
Bathylagus sp.[f]	Black smelt unident.	Sokoiwashi-rui	X
Bathylagus milleri Jordon & Gilvert[d]	Robust blacksmelt	Kurosokoiwashi	
Bathylagus ochotensis Schmidt[d]	Popeye blacksmelt	Sokoiwashi	
Bathylagus pacificus Gilbert[f]	Pacific blacksmelt	Yasesokoiwashi	X
Leuroglossus schmidti Rass	Northern smoothtongue	Togariichimonjiiwashi	X
OPISTHOPROCTIDAE			
Macropinna microstoma Chapman	Barreleye	Demenigisu	
GONOSTOMATIDAE			
Cyclothone sp.[f]	Bristlemouth unident.	Onihadaka-rui	
STOMIIDAE			
Stomiidae	Viperfish unident.	Hooraieso-rui	

Table 6 — Continued
Fishes encountered during U.S.-Japan cooperative surveys in the Bering Sea, 1979–85.

Taxon[a]	English common name	Japanese standard name	Species frequently identified[b]
STOMIIDAE — Continued			
Aristostomias scintillanas (Gilbert)[d]	Shiny loosejaw	Houkiboshieso-rui	
Chauliodus macouni Bean	Pacific viperfish	Higashihooraieso	X
Tactostoma macropus Bolin	Longfin dragonfish	Hadakahoteieso	
MYCTOPHIDAE			
Myctophidae	Lanternfish unident.	Hadakaiwashi-rui	X
Diaphus theta Eigenmann & Eigenmann	California headlightfish	Todohadaka	
Lampanyctus sp.	Lanternfish	Tongarihadaka-rui	
Lampanyctus jordani Gilbert[d]	Brokenline lampfish	Mamehadaka	X
Lampanyctus regalis (Gilbert)	Pinpoint lampfish	Mikadohadaka	X
Stenobrachius leucopsarus (Eigenmann & Eigenmann)	Northern lampfish	Kohirehadaka	
Stenobrachius nannochir (Gilbert)[d]	Garnet lampfish	Sekkihadaka	
ONEIRODIDAE			
Oneirodes sp.[f]	Dreamer unident.	Yumeanko-rui	X
Oneirodes bulbosus Chapman[f]	Dreamer	Yumeanko	
Oneirodes thompsoni (Schultz)[g]	Dreamer	Togerakudaanko	
CERATIIDAE			
Ceratiidae	Seadevil unident.	Mitsukurienagachochinankou-rui	
MORIDAE			
Antimora microlepis Bear[h]	Pacific flatnose	Kanadadara	X
Laemonema longipes Schmidt[i]	Threadfin hakeling	Itohikidara	
GADIDAE			
Boreogadus saida (Lepechin)	Arctic cod	Hokkyokudara	X
Eleginus gracilis (Tilesius)	Saffron cod	Komai	X
Gadus macrocephalus Tilesius	Pacific cod	Madara	X
Theragra chalcogramma (Pallas)	Walleye pollock	Suketodara	X
MACROURIDAE			
Albatrossia pectoralis (Gilbert)[j]	Giant grenadier	Munedara	X
Coryphaenoides acrolepis (Bean)[f]	Pacific grenadier	Ibarahige	X
Coryphaenoides cinereus (Gilbert)[i]	Popeye grenadier	Karafutosokodara	X
Coryphaenoides longifilis Gunther[i]	Filamented grenadier	Himodara	X
MELAMPHAEIDAE			
Melamphaes lugubris Gilbert[d]	Highsnout bigscale	Honkabutouo-rui	X
Melamphaes polylepis Ebling[k]	Melamphaeid	Urokokabutouo-rui	
Poromitra crassiceps (Gunther)[f]	Crested bigscale	Kabutouo	
OREOSOMATIDAE			
Allocyttus folletti Myers[d]	Oxeye oreo	Oomematodai	X
TRACHIPTERIDAE			
Trachipterus altivelis Kner	King-of-the-salmon	Sakegasira	
GASTEROSTEIDAE			
Pungitius pungitius (Linnaeus)[f]	Ninespine stickleback	Kitanotomiyo	
TRICHODONTIDAE			
Trichodon trichodon (Tilesius)	Pacific sandfish	Ezohatahata	X
CHIASMODONTIDAE			
Kali indica Lloyd[d]	Shortnose swallower	Kurobouzugisu-rui	

Table 6 — Continued
Fishes encountered during U.S.-Japan cooperative surveys in the Bering Sea, 1979–85.

Taxon[a]	English common name	Japanese standard name	Species frequently identified[b]
BATHYMASTERIDAE			
Bathymaster signatus Cope	Searcher	Sokomedamauo	X
ZOARCIDAE			
Zoarcidae	Eelpout unident.	Genge-rui	X
Allolepis sp.[c]	Eelpout unident.	Norogenge-rui	
Bothrocara sp.[f]	Eelpout unident.	Shirogenge-rui	X
Bothrocara brunneum (Bean)[f]	Twoline eelpout	Yawagenge	X
Embryx crotalinus (Gilbert)[d]	Snakehead eelpout	Genge-rui	X
Gymnelus viridis (Fabricius)	Fish doctor	Hadakagenge	
Lycenchelys sp.	Eelpout unident.	Hebigenge-rui	X
Lycenchelys camchaticus (Gilbert & Burke)[d]	Kamchatka eelpout	Hebigenge-rui	
Lycodapus sp.	Eelpout unident.	Ashinashigenge-rui	X
Lycodapus endomoscotus Peden & Anderson[d]	Deepwater eelpout	Ashinashigenge-rui	
Lycodapus fierasfer Gilbert	Blackmouth eelpout	Ashinashigenge-rui	
Lycodapus leptus Peden & Anderson[l]	Eelpout	Ashinashigenge-rui	
Lycodapus poecilus Peden & Anderson[l]	Eelpout	Ashinashigenge-rui	
Lycodapus psarostomatus Peden & Anderson[l]	Specklemouth eelpout	Ashinashigenge-rui	
Lycodes sp.	Eelpout unident.	Mayugaji-rui	X
Lycodes brevipes Bean	Shortfin eelpout	Asibosogenge	X
Lycodes concolor Gill & Townsend[f]	Ebony eelpout	Mayugaji-rui	X
Lycodes diapterus Gilbert	Black eelpout	Mayugaji-rui	X
Lycodes mucosus Richardson[f]	Saddled eelpout	Numerigenge	
Lycodes palearis Gilbert	Wattled eelpout	Hakusengaji	X
Lycodes polaris (Sabine)	Canadian eelpout	Mayugaji-rui	
Lycodes raridens Taranetz & Andriashev	Marbled lycod	Kitanogenge	
Lycodes turneri Bean	Polar eelpout	Hokkyokugenge	X
Puzanovia rubra Fedorov[c]	Eelpout	Akagenge	
STICHAEIDAE			
Stichaeidae	Prickleback unident.	Tauegaji-rui	X
Chirolophis decoratus (Jordan & Snyder)	Decorated warbonnet	Fusaginpo-rui	
Chirolophis snyderi (Taranetz)[d]	Bearded warbonnet	Hanabusaginpo	
Eumesogrammus praecisus (Kroyer)	Fourline snakeblenny	Togeginpo	
Lumpenella longirostris (Evermann & Goldsborough)	Longsnout prickleback	Nezumiginpo	X
Lumpenus fabricii (Valenciennes)	Slender eelblenny	Koorimedamaginpo	
Lumpenus maculatus (Fries)	Daubed shanny	Unagigaji-rui	X
Lumpenus medius (Reinhardt)	Stout eelblenny	Unagigaji-rui	
Lumpenus sagitta Wilimovsky	Snake prickleback	Unagigaji	X
Poroclinus rothrocki	Whitebarred prickleback	Tauegaji-rui	
Stichaeus punctatus (Fabricius)	Artic shanny	Nisetauegaji	
ANARHICHADIDAE			
Anarhichas orientalis Pallas	Bering wolffish	Ookamiuo	X
Anarhichthys ocellatus Ayers	Wolf-eef	Ribonookami	X
CRYPTACANTHODIDAE			
Cryptacanthodes aleutensis (Gilbert)	Dwarf wrymouth	Hadakaookamiuo-rui	X
ZAPRORIDAE			
Zaprora silenus Jordan	Prowfish	Bouzuginpo	X
AMMODYTIDAE			
Ammodytes hexapterus Pallas	Pacific sand lance	Kitaikanago	X

Table 6 — Continued

Fishes encountered during U.S.-Japan cooperative surveys in the Bering Sea, 1979–85.

Taxon[a]	English common name	Japanese standard name	Species frequently identified[b]
ICOSTEIDAE			
Icosteus aenigmaticus Lockington	Ragfish	Irezumikonnyakuaji	X
SCORPAENIDAE			
Sebastes sp.	Rockfish unident.	Mebaru-rui	X
Sebastes aleutianus (Jordan & Evermann)	Rougheye rockfish	Aramenuke	X
Sebastes alutus (Gilbert)	Pacific ocean perch	Arasukamenuke	X
Sebastes babcocki (Thompson)	Redbanded rockfish	Hatazoi	X
Sebastes borealis Barsukov	Shortraker rockfish	Hireguromenuke	X
Sebastes ciliatus (Tilesius)	Dusky rockfish	Nagamenuke	X
Sebastes crameri (Jordan)	Darkblotched rockfish	Yotsujimamenuke	X
Sebastes mystinus (Jordan & Gilbert)	Blue rockfish	Aomenuke	
Sebastes polyspinis (Taranetz & Moiseev)	Northern rockfish	Kitanomenuke	X
Sebastes variegatus Quast	Harlequin rockfish	Madaraakauo	X
Sebastolobus alascanus Bean	Shortspine thornyhead	Arasukakichiji	X
Sebastolobus altivelis Gilbert	Longspine thornyhead	Hirenagakichiji	X
Sebastolobus macrochir (Gunther)[f]	Broadbanded thornyhead	Kichiji	X
ANOPLOPOMATIDAE			
Anoplopoma fimbria (Pallas)	Sablefish	Gindara	X
HAXAGRAMMIDAE			
Hexagrammos sp.	Greenling unident.	Ainame-rui	X
Hexagrammos decagrammus (Pallas)	Kelp greenling	Arasukaainame	X
Hexagrammos lagocephalus (Pallas)	Rock greenling	Usagiainame	X
Hexagrammos octogrammus (Pallas)	Masked greenling	Sujiainame	
Hexagrammos stelleri Tilesius	Whitespotted greenling	Ezoainame	X
Pleurogrammus monopterygius (Pallas)	Atka mackerel	Kitanohokke	X
COTTIDAE			
Cottidae	Sculpin unident.	Kajika-rui	
Artediellus sp.	Sculpin unident.	Okikajika-rui	X
Artediellus pacificus Gilbert[f]	Hookhorn sculpin	Okikajika-rui	
Artediellus scaber Knipowitsch	Hamecon	Okikajika-rui	
Artediellus uncinatus (Reinhardt)	Arctic hookear sculpin	Okikajika-rui	
Blepsias bilobus Cuvier	Crested sculpin	Hokakeanahaze	X
Dasycottus setiger Bean	Spinyhead sculpin	Ganko	X
Enophrys diceraus (Pallas)	Antlered sculpin	Onikajika	X
Enophrys lucasi (Jordan & Gilbert)	Leister sculpin	Onikajika-rui	
Eurymen gyrinus Gilbert & Burke[f]	Smoothcheek sculpin	Yagishirikajika	
Gymnocanthus sp.	Sculpin unident.	Tsumagurokajika-rui	X
Gymnocanthus galeatus (Bean)	Armorhead sculpin	Chikamekajika	X
Gymnocanthus pistilliger (Pallas)[f]	Threaded sculpin	Hagekajika	X
Gymnocanthus tricuspis (Reinhardt)	Arctic staghorn sculpin	Shiberiatsumagurokajika	X
Hemilepidotus sp.	Irish lord unident.	Yokosujikajika-rui	X
Hemilepidotus hemilepidotus (Tilesius)	Red Irish lord	Honyokosujikajika	X
Hemilepidotus jordani Bean	Yellow Irish lord	Nameyokosujikajika	X
Hemilepidotus papilio (Bean)[f]	Butterfly sculpin	Kujakukajika	X
Hemilepidotus zapus Gilbert & Burke	Longfin Irish lord	Yokosujikajika-rui	
Hemitripterus bolini (Myers)	Bigmouth sculpin	Kemushikajikamodoki	X
Icelinus borealis Gilbert	Northern sculpin	Kajika-rui	
Icelus sp.	Sculpin unident.	Koorikajika-rui	X
Icelus canaliculatus Gilbert	Blacknose sculpin	Kurokoorikajika	X
Icelus spatula Gilbert & Burke	Spatulate sculpin	Koorikajika-rui	X
Icelus uncinalis Gilbert & Burke[f]	Uncinate sculpin	Himekoorikajika	
Leptocottus armatus Girad	Pacific staghorn sculpin	Kajika-rui	X
Malacocottus kincaidi Gilbert & Thompson	Blackfin sculpin	Montsukikajika	X

Table 6 — Continued
Fishes encountered during U.S.-Japan cooperative surveys in the Bering Sea, 1979–85.

Taxon[a]	English common name	Japanese standard name	Species frequently identified[b]
COTTIDAE — Continued			
Malacocottus zonurus Bean[m]	Darkfin sculpin	Kobushikajika	X
Megalocottus platycephalus (Pallas)	Belligerent sculpin	Ojigikajika	
Microcottus sellaris (Gilbert)	Brightbelly sculpin	Ohotsukutsunokajika	X
Myoxocephalus sp.	Sculpin unident.	Gisukajika-rui	X
Myoxocephalus jaok (Cuvier)	Plain sculpin	Okukajika	X
Myoxocephalus polyacanthocephalus (Pallas)	Great sculpin	Togekajika	X
Myoxocephalus quadricornis (Linnaeus)	Fourhorn sculpin	Gisukajika-rui	
Myoxocephalus scorpioides (Fabricius)	Arctic Sculpin	Nezumikajika	
Myoxocephalus scorpius (Linnaeus)	Shorthorn sculpin	Gisukajika-rui	
Myoxocephalus stelleri Tilesius[i]	Frog sculpin	Anakajika	
Myoxocephalus verrucosus (Bean)[f]	Warty sculpin	Ibogisukajika	X
Nautichthys pribilovius (Jordan & Gilbert)	Eyeshade sculpin	Okozekajika	
Psychrolutes phrictus Stein & Bond[n]	Blob sculpin	Nyudookajika	X
Rastrinus scutiger (Bean)[o]	Roughskin sculpin	Koorimatsukajika	
Triglops sp.	Sculpin unident.	Hokkyokukajika-rui	X
Triglops forficatus (Gilbert)	Scissortail sculpin	Futamatakajika	X
Triglops macellus (Bean)	Roughspine sculpin	Yasekarafutokajika	X
Triglops metopias Gilbert & Burke[f]	Sculpin	Hokkyokukajika-rui	
Triglops pingeli Reinhardt	Ribbed sculpin	Hokkyokukajika	X
Triglops scepticus Gilbert	Spectacled sculpin	Niramikajika	X
Zesticelus profundorum (Gilbert)[d]	Flabby sculpin	Kajika-rui	
AGONIDAE			
Agonidae sp.	Poacher unident.	Tokubire-rui	X
Anoplagonus inermis (Gunther)	Smooth alligatorfish	Nametokubire-rui	X
Aspidophoroides bartoni Gilbert	Aleutian alligatorfish	Tatetokubire	X
Aspidophoroides olriki Lutkin	Arctic alligatorfish	Tatetokubire-rui	
Bathyagonus alascanus (Gilbert)	Gray starsnout	Tokubire-rui	X
Bathyagonus infraspinatus (Gilbert)	Spinycheek starsnout	Tokubire-rui	
Bathyagonus nigripinnis GIlbert	Blackfin poacher	Sokotokubire	X
Leptagonus decagonus Bloch & Schneider	Atlantic poacher	Chigotokubire	
Occella dodecaedron (Tilesius)	Bering poacher	Kamutosachiuo	X
Occella verrucosa (Lockington)	Warty poacher	Saburoo-rui	X
Pallasina barbata (Steindachner)	Tubenose poacher	Yagiuo	X
Percis japonicus (Pallas)[f]	Dragon poacher	Inugochi	X
Podothecus acipenserinus (Tilesius)	Sturgeon poacher	Kitanotokubire	X
Sarritor frenatus (Gilbert)	Sawback poacher	Yasetengutokubire	X
Sarritor leptorhynchus (Gilbert)	Longnose poacher	Tengutokubire	
CYCLOPTERIDAE			
Cyclopteridae sp.	Snailfish unident.	Dangouo-rui	X
Aptocyclus ventricosus (Pallas)	Smooth lumpsucker	Hoteiuo	X
Careproctus sp.	Snailfish unident.	Konnyakuuo-rui	X
Careproctus bowersianus Gilbert & Burke[f]	Snailfish	Konnyakuuo-rui	
Careproctus colletti Gilbert[f]	Snailfish	Arasukabikunin	
Careproctus cypselurus (Jordan & Gilbert)[p]	Blackfinned snailfish	Aibikunin	
Careproctus furcellus Gilbert & Burke[f]	Emarginate snailfish	Ogurokonnyakuuo	X
Careproctus gilberti Burke[f]	Smalldisk snailfish	Misakibikunin	
Careproctus melanurus Gilbert	Blacktail snailfish	Konnyakuuo-rui	X
Careproctus rastrinus Gilbert & Burke[f]	Salmon snailfish	Sakebikunin	X
Careproctus scottae Chapman & Delacy[f]	Peachskin snailfish	Konnyakuuo-rui	X
Crystallichthys cyclospilus Gilbert & Burke	Blotched snailfish	Zenigatasuishoouo	
Elassodiscus sp.[f]	Snailfish unident.	Fuuraikusauo-rui	
Elassodiscus tremebundus Gilbert & Bure[f]	Snailfish	Fuuraikusauo	
Eumicrotremus birulai Popov[f]	Siberian lumpsucker	Konpeito	
Eumicrotremus orbis (Gunther)	Pacific spiny lumpsucker	Ibodango	X

Table 6 — Continued
Fishes encountered during U.S.-Japan cooperative surveys in the Bering Sea, 1979–85.

Taxon[a]	English common name	Japanese standard name	Species frequently identified[b]
CYCLOPTERIDAE — Continued			
Liparis sp.	Snailfish unident.	Kusauo-rui	X
Liparis dennyi Jordan & Starks	Marbled snailfish	Kusauo-rui	X
Liparis gibbus Bean[f]	Variegated snailfish	Sentopourukusauo	
Liparis megacephalus (Burke)[f]	Bighead snailfish	Ryumonkusauo	
Liparis pulchellus Ayres	Showy snailfish	Kusauo-rui	
Liparis rutteri (Gilbert & Snyder)	Ringtail snailfish	Kusauo-rui	
Nectoliparis pelagicus Gilbert & Burke	Tadpole snailfish	Kantenuo	
Paraliparis sp.	Snailfish undient.	Inkiuo-rui	X
Paraliparis cephalus Gilbert[d]	Swellhead snailfish	Inkiuo-rui	
Paraliparis dactylosus Gilbert[f]	Red Snailfish	Kokuteninkiuo	
Paraliparis ulochir Gilbert[f]	Broadfin snailfish	Inkiuo-rui	
Rhinoliparis sp.[f]	Snailfish unident.	Shirohigekonnyakuuo-rui	
Rhinoliparis attenuatus Burke[f]	Slim snailfish	Shirohigekonnyakuuo-rui	
PLEURONECTIDAE			
Atheresthes evermanni Jordan & Starks	Kamchatka flounder	Aburagarei	X
Atheresthes stomias (Jordan & Gilbert)	Arrowtooth flounder	Arasukaaburagarei	X
Clidoderma asperrimum (Temminck & Schlegel)[f]	Roughscale sole	Samegarei	X
Embassichthys bathybius (Gilbert)	Deepsea sole	Shimofurigarei	X
Errex zachirus Lockington	Rex sole	Hirenaganameta	X
Hippoglossoides elassodon Jordan & Gilbert	Flathead sole	Umagarei	X
Hippoglossoides robustus Gill & Townsend	Bering flounder	Dorogarei	X
Hippoglossus stenolepis Schmidt	Pacific halibut	Ohyo	X
Microstomus pacificus (Lockington)	Dover sole	Babagarei-rui	X
Platichthys stellatus (Pallas)	Starry flounder	Numagarei	X
Pleuronectes asper (Pallas)	Yellowfin sole	Koganegarei	X
Pleuronectes bilineatus (Ayres)	Rock sole	Shumushugarei	X
Pleuronectes glacialis Pallas	Arctic flounder	Kurogarei-rui	
Pleuronectes isolepis (Lockington)	Butter sole	Karei-rui	X
Pleuronectes proboscideus (Gilbert)	Longhead dab	Hanagarei	X
Pleuronectes quadrituberculatus Pallas	Alaska plaice	Tsunogarei	X
Pleuronectes sakhalinensis Hubbs[q]	Sakhalin sole	Karafutogarei	X
Psettichthys melanostictus Girard	Sand sole	Karei-rui	
Reinhardtius hippoglossoides (Walbaum)	Greenland turbot[r]	Karasugarei	X

[a] Nomenclature from Robins (1991), unless otherwise noted.
[b] Some species not frequently identified may be misidentified.
[c] Nomenclature from Fedorov (1973).
[d] Nomenclature from Hubbs et al. (1979).
[e] Nomenclature from Ishiyama and Ishihara (1977).
[f] Nomenclature from Quast and Hall (1972).
[g] Nomenclature from Pietsch (1974).
[h] Nomenclature from Hart (1973).
[i] Nomenclature from Ichthyological Society of Japan (1981).
[j] Nomenclature from Iwamoto and Stein (1974).
[k] Nomenclature from Ebeling and Weed (1973).
[l] Nomenclature from Peden and Anderson (1981).
[m] Nomenclature from Matsubara (1955).
[n] Nomenclature from Stein and Bond (1978).
[o] Nomenclature from Nelson (1984).
[p] Nomenclature from Allen and Smith (1988).
[q] Nomenclature from Sakamoto (1984).
[r] This species is Greenland halibut in Robbins (1991) but commonly called Greenland turbot in the North Pacific Ocean.

Table 7

Rank order of abundance (CPUE in kg/ha) of the 20 most abundant species of groundfish in the eastern Bering Sea based on U.S.-Japan bottom trawl surveys in 1979–85.

1979			1981			1982			1985		
Species	CPUE	Proportion[a] of total CPUE	Species	CPUE	Porportion[a] of total CPUE	Species	CPUE	Porportion[a] of total CPUE	Species	CPUE	Proportion[a] of total CPUE
Walleye pollock	53.92	0.394	Walleye pollock	63.18	0.370	Walleye pollock	61.35	0.321	Walleye pollock	83.09	0.449
Yellowfin sole	30.05	0.220	Yellowfin sole	44.92	0.263	Yellowfin sole	57.50	0.301	Yellowfin sole	38.34	0.207
Pacific cod	11.91	0.087	Pacific cod	20.14	0.118	Pacific cod	18.07	0.094	Pacific cod	16.98	0.092
Eelpouts	10.94	0.080	Alaska plaice	9.90	0.058	Alaska plaice	11.95	0.062	Rock sole	11.96	0.065
Greenland turbot	5.29	0.039	Rock sole	6.15	0.036	Rock sole	10.36	0.054	Alaska plaice	9.83	0.053
Alaska plaice	4.15	0.030	Greenland turbot	3.96	0.023	Marbled eelpout	6.24	0.033	Flathead sole	5.79	0.031
Myoxocephalus spp.	2.83	0.021	Flathead sole	3.55	0.021	Flathead sole	3.70	0.019	Arrowtooth flounder	3.44	0.019
Rock sole	2.68	0.020	Skates	3.31	0.019	Butterfly sculpin	2.75	0.014	Skates	2.54	0.014
Flathead sole	1.95	0.014	Arrowtooth flounder	1.79	0.010	Skates	2.70	0.014	Butterfly sculpin	2.50	0.014
Butterfly sculpin	1.66	0.012	Giant grenadier	1.65	0.010	Greenland turbot	2.11	0.011	Myoxocephalus spp.	2.26	0.012
Skates	1.44	0.011	Myoxocephalus spp.	1.41	0.008	Longhead dab	2.09	0.011	Giant grenadier	1.45	0.008
Giant grenadier	1.28	0.009	Longhead dab	1.24	0.007	Myoxocephalus spp.	2.08	0.011	Greenland turbot	1.33	0.007
Arrowtooth flounder	1.09	0.008	Marbled eelpout	1.20	0.007	Giant grenadier	1.45	0.008	Pacific halibut	1.20	0.006
Other cods	1.06	0.008	Shortfin eelpout	1.13	0.007	Arrowtooth flounder	1.40	0.007	Sablefish	0.78	0.004
Pacific halibut	1.02	0.007	Pacific halibut	1.10	0.006	Plain sculpin	1.19	0.006	Pacific herring	0.59	0.003
Snailfishes	0.73	0.005	Sablefish	1.00	0.006	Pacific halibut	1.09	0.006	Pacific ocean perch	0.50	0.003
Sablefish	0.69	0.005	Wattled eelpout	0.87	0.005	Sablefish	0.75	0.004	Marbled eelpout	0.35	0.002
Irish lords	0.56	0.004	Irish lords	0.79	0.005	Irish lords	0.73	0.004	Bigmouth sculpin	0.23	0.001
Longhead dab	0.51	0.004	Plain sculpin	0.46	0.003	Shortfin eelpout	0.42	0.002	Starry flounder	0.20	0.001
Pacific herring	0.42	0.003	Great sculpin	0.30	0.002	Bigmouth sculpin	0.34	0.002	Irish lords	0.19	0.001

[a] Total CPUE (kg/ha) of all fish combined was 136.68 in 1979, 170.95 in 1981, 191.27 in 1982, and 184.96 in 1985.

fish fishery, the U.S. fishery for Pacific halibut, began to develop in 1928. This was soon followed by a Japanese fishery in 1933–41 for walleye pollock, yellowfin sole, and other flatfishes. These were all small-scale operations relative to the modern-day fishery, which started in 1954. The resources have only been exploited intensively since about 1960. Management of these fisheries, with the exception of the Pacific halibut fishery, was not initiated until 1977.

History of the Fishery

Pacific Cod Fishery—The initial U.S. Pacific cod fishery in the eastern Bering Sea spanned the period from 1882 to 1950. Throughout this period, the fishery was mainly conducted by sailing schooners and the actual fishing was performed by handlines from one-man dories (Cobb 1927). Fishing areas extended along the north side of Unimak Island and the Alaska Peninsula into Bristol Bay. The fishery peaked during World War I when catches ranged from 12,000 to 14,000 t annually (Pereyra et al. 1976).

Pacific Halibut Fishery—Pacific halibut were taken commercially in only four years during the 1930s and 1940's and catches were small (3–62 t per year; Myhre et al. 1977). The fishery started on a regular, annual basis in 1952, but significant catches were not taken until the late 1950's (Table 9). During this latter period, Canadian and Japanese fishing vessels joined U.S. vessels in taking halibut. These three fisheries initially used setlines or longlines for capturing halibut although Japan also used trawling gear at times. In 1953, Canada, Japan, and the United States formed the International North Pacific Fisheries Commission (INPFC) for the purpose of ensuring the maximum sustained productivity of fishery resources of the North Pacific Ocean (Forrester et al. 1978). One provision of the treaty was that Japan would abstain from fishing for Pacific halibut in waters east of long. 175° W as long as the stocks were under substantial exploitation by two or more of the contracting parties. In 1962, the three nations agreed that halibut no longer qualified for exclusion and Japan was allowed to fish east of long. 175° W in the Bering Sea. Nevertheless, Japan continued to take most of its catch of halibut between long. 175° W and 180° W in the eastern Bering Sea.

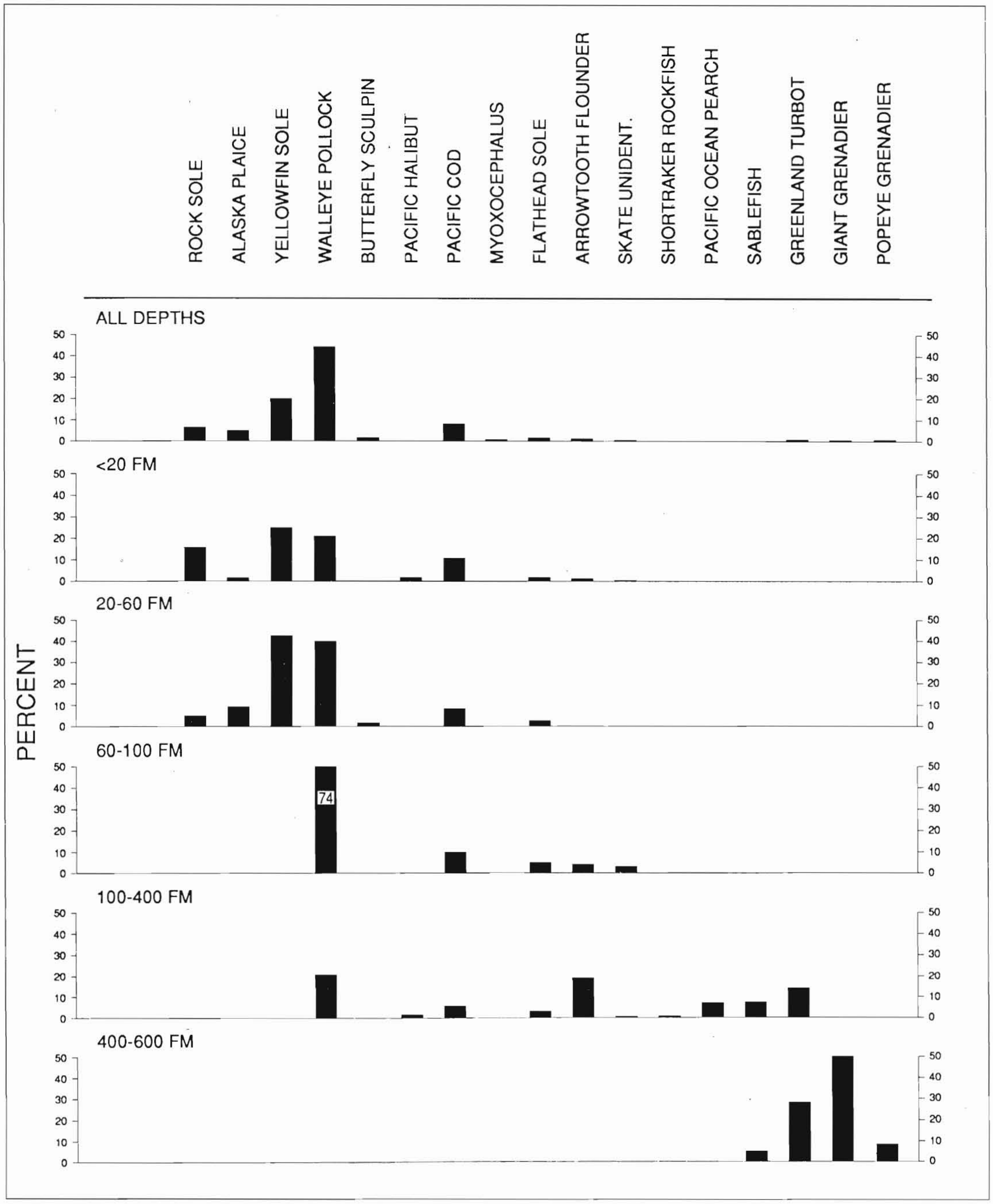


Figure 14
Relative abundance of principal species and species groups of groundfish by depth and for all depths combined based on data from the 1985 U.S.-Japan bottom trawl survey.

During the period from 1960 to 1963, catches of halibut in the eastern Bering Sea by the three nations increased to an average of about 10,000 t annually with peak catches of about 12,300 t in 1962 and 1963. In subsequent years, catches declined abruptly suggesting a decline in stock abundance. Another development that may have influenced the halibut stock in the late 1960's was the buildup of the Japanese and Soviet trawl fisheries for walleye pollock and other species that took halibut as a bycatch. These bycatches of halibut were estimated to range between 5,800 and 11,500 t annually in the period from 1967 to 1973 (Hoag and French 1976). These incidental catches plus those of the directed fisheries for halibut indicate that total removals may have continued to range between 7,900 and 16,900 t in 1967–73.

With implementation of the Magnuson Fishery Conservation and Management Act in March 1977, groundfish resources in the eastern Bering Sea came under exclusive management jurisdiction of the United States (see section below on management). One of the provisions of the Act was to create a category of "prohibited species" consisting of certain species traditionally harvested by U.S. fishermen that could not be retained by U.S. trawlers or any foreign fishing vessels. As a consequence of this provision, time-area closures and other management efforts reduced incidental catches of halibut, to about a range of 1,500–4,600 t after 1977 (Berger et al. 1987). Catches by the U.S.-directed longline fishery for halibut were also reduced, ranging from 250 to 1,800 t in 1973–86 (Table 9). The directed halibut fishery has been conducted exclusively by U.S. vessels since 1979.

Japanese Pre-World War II Groundfish Fishery—Japanese distant-water fisheries initiated operations in the east-

Table 8

Life history characteristics of principal species of groundfish in the eastern Bering Sea. Estimates are from various literature and survey data.

Life history characteristics	Walleye pollock	Pacific cod	Sablefish	Pacific ocean perch	Yellowfin sole	Rock sole	Flathead sole	Alaska plaice	Greenland turbot	Arrowtooth flounder	Pacific halibut
Bottom depths (meters) of main concentrations	100–200	50–200	400–1,000	200–300	10–100	10–100	50–200	40–110	400–1,000	100–500	50-250
Feeding habitat	pelagic	bentho-pelagic	bentho-pelagic	pelagic	bentho-pelagic	benthic	bentho-pelagic	benthic	pelagic	bentho-pelagic	bentho-pelagic
Maximum age (years)	16	14	55	90	22	19	20	17	19	15	42
Age at 50% maturity (females)	3–4	6	5	8	9	—	—	6–7	7–8	—	12
Average size at maturity (females) (cm)	36	62	58	28	26	—	—	31	65	—	120
Age at recruitment to fishery (years)	2–3	3	3	9	3–12	3	3	6	3–4	5–10	7
Spawning period	Feb.–Jul.	Jan.–Mar.	Jan.–Apr.	Mar.–Jun.	Jun.–Sep.	Mar.–Jun.	Feb.–May	Apr.–Jun.	Dec.–Mar.	Dec.–Feb.	Nov.–Mar.
Spawning location	shelf edge & off-shelf	shelf edge	continental slope	continental slope	inner shelf	mid-shelf	mid-shelf	mid-shelf	continental slope	—	continental slope
Fecundity (millions)	0.06–1.21	1.4–6.4	0.06–1.0	0.01–0.21	0.1–2.9	0.15–0.4	0.05–0.16	0.06–0.31	0.002–0.145	—	0.10–2.80
Instantaneous natural mortality rate (m)	0.45 age 2 0.30 ages >2	0.22–0.45	0.10	0.05	0.12	0.20–0.23	0.20–0.23	0.20–0.23	0.18	0.20	0.20
Growth completion rate (k) males	0.180	0.203	0.326	0.106	0.130	0.140	0.100	0.150	0.140	0.230	0.290
females	0.175	0.203	0.276	0.106	0.110	0.090	0.070	0.140	0.140	0.140	0.290
Length-weight relationships a	0.0075	0.00608	0.0043	0.02602	0.0113	0.006959	0.003965	0.008841	0.000405	0.0098	0.000069
b	2.977	3.1635	3.220	2.813	2.998	3.170	3.259	3.111	3.732	3.006	3.240
Estimated biomass in 1986 (1,000 t)	8800	1100	45	64	1870	1014	369	551	429	352	87
Maximum sustainable yield (1,000 t)	1,500	201–224	3.0–5.3	4.8	150–175	112.5	36–42	76	46.5	—	6.6

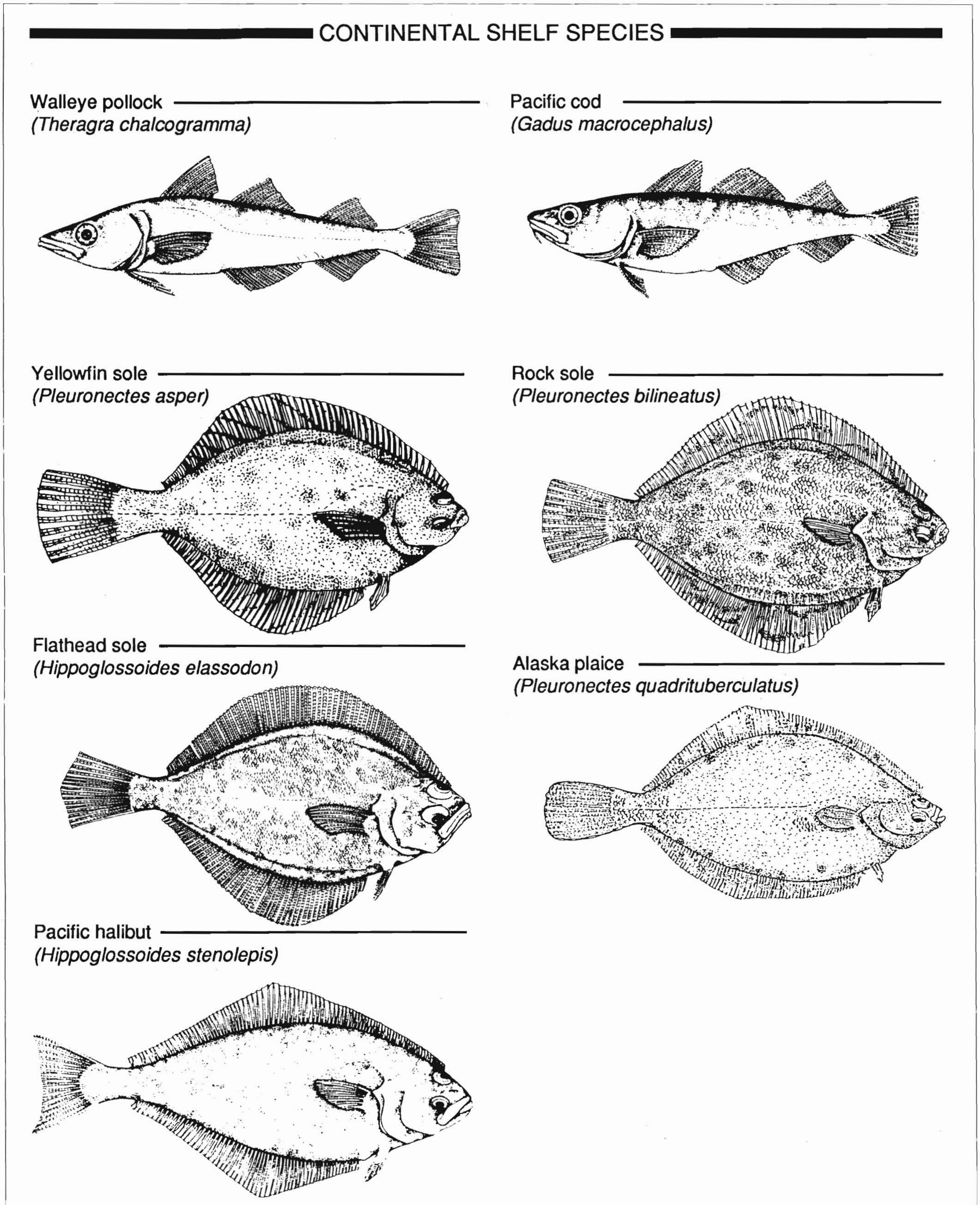


Figure 15
Commercially important species of the eastern Bering Sea.

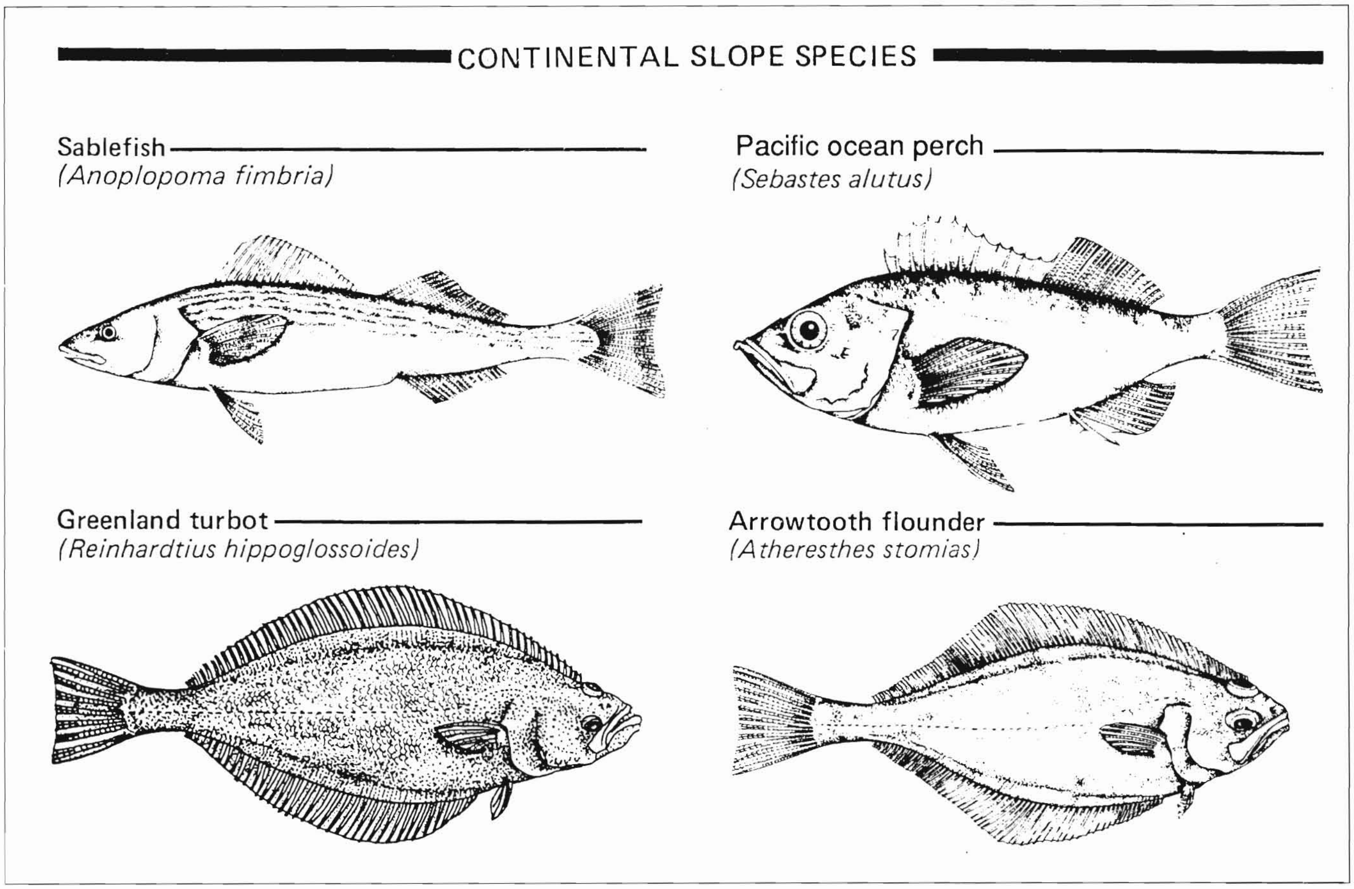


Figure 15 — Continued

ern Bering Sea through an exploratory effort involving two trawlers in 1930 (Forrester et al. 1978). This was followed in 1933 by a mothership-catcher boat operation targeting walleye pollock and flatfishes off Bristol Bay for processing into fish meal. This operation continued until 1937 when a decline in the price of fish meal caused a termination of the fishery. From five to 13 catcher boats operated from May to September in this fishery and catches of pollock ranged from 11,600 to 31,300 t annually in 1934–37 and total catches from 3,300 to 43,400 t in 1933–37.

In 1940–41 the Japanese resumed fishing in the eastern Bering Sea with another mothership operation, this time targeting yellowfin sole for processing as frozen fish. The eight to 10 catcher boats in this fishery took 9,600 and 12,200 t (6,900 and 9,800 t were unspecified flatfish) in the two years. The outbreak of war between the United States and Japan in December 1941 brought an end to this early Japanese fishery for eastern Bering Sea groundfish.

Groundfish Fisheries, 1954–86—With the signing of the peace treaty between Japan and the United States in 1952, restrictions on Japanese distant-water fisheries were removed, and in 1954, they resumed groundfish operations in the eastern Bering Sea. The initial (1954–57) post-World War II Japanese fishery consisted of two to four freezer motherships and 200–300 ton side trawlers as catcher boats, which operated for about one month in late summer off Bristol Bay for flatfishes, mainly yellowfin sole (Forrester et al. 1978). From one to three independent factory trawlers also operated during this period. Annual catches (reported as frozen) in 1954–57, ranged from about 13,000 to 25,000 t (Table 9).

The 1958 to 1962 period saw a major growth in the Japanese groundfish fishery and the initiation of Soviet fisheries in the eastern Bering Sea. The main target species continued to be yellowfin sole, which was used primarily for the production of fish meal. Catches of yellowfin sole reached a historic peak of 554,000 t in 1961, and during the four-year period of 1959–62 averaged 404,000 t annually. Catches abruptly declined after 1962 (Table 9) because of reduced abundance of yellowfin sole, which, as will be discussed below, was believed to be the result of the intense exploitation in 1959–62.

Table 9
Groundfish catches (metric tons) in the eastern Bering Sea, 1954–86.

Year	Walleye pollock	Pacific cod	Sablefish	Pacific ocean perch	Other rockfish	Yellowfin sole	Turbots[a]	Other flatfishes[b]	Atka mackerel	Pacific halibut	Other species	Total all species
1954						12,562				24		12,586
1955						14,690				27		14,717
1956						24,697				158		24.855
1957						24,145				24		24,169
1958	6,924	171	6			44,153				1,509	147	52,910
1959	32,793	2,864	289			185,321				3,181	380	224,828
1960			1,861	6,100		456,103	36,843			10,339		511,246
1961			15,627	47,000		553,742	57,348			5,874		679,591
1962			25,989	19,900		420,703	58,226			12,282		537,100
1963			13,706	24,500		85,810	31,565	35,643		12,360		203,584
1964	174,792	13,408	3,545	25,900		111,177	33,729	30,604		2,676	736	396,567
1965	230,551	14,719	4,838	16,800		53,810	9,747	11,686		2,174	2,218	346,543
1966	261,678	18,200	9,505	20,200		102,353	13,042	24,864		2,920	2,239	455,001
1967	550,362	32,064	11,698	19,600		162,228	23,869	32,109		5,200	4,378	841,508
1968	702,181	57,902	14,374	31,500		84,189	35,232	29,647		3,572	22,058	980,655
1969	862,789	50,351	16,009	14,500		167,134	36,029	34,749		3,508	10,459	1,195,528
1970	1,256,565	70,094	11,737	9,900		133,079	32,289	64,690		2,419	15,295	1,596,068
1971	1,743,763	43,054	15,106	9,800		160,399	59,256	92,452		5,384	33,496	2,162,710
1972	1,874,534	42,905	12,758	5,700		47,856	77,633	76,813		1,397	110,893	2,250,489
1973	1,758,919	53,386	5,957	3,700		78,240	64,497	43,119		817	55,826	2,064,461
1974	1,588,390	62,462	4,258	14,000		42,235	91,127	37,347		344	60,263	1,900,426
1975	1,356,736	51,551	2,766	8,600		64,690	85,651	20,393		454	54,845	1,645,686
1976	1,177,822	50,481	2,923	14,900		56,221	78,329	21,746		403	26,143	1,428,968
1977	978,370	33,335	2,718	2,654	1,678	58,373	37,162	14,393		474	35,902	1,165,059
1978	979,431	42,543	1,192	2,211	12,155	138,433	45,781	21,040	832	412	61,537	1,305,567
1979	913,881	33,761	1,376	1,718	10,048	99,017	42,919	19,724	1,985	574	38,767	1,163,770
1980	958,279	45,861	2,206	1,097	1,367	87,391	62,618	20,406	4,697	257	34,633	1,218,812
1981	973,505	51,996	2,604	1,222	1,111	97,301	66,394	23,428	3,028	570	35,651	1,256,810
1982	955,964	55,040	3,184	224	863	95,712	54,908	23,809	328	250	18,200	1,208,482
1983	982,363	83,212	2,695	221	460	108,385	53,659	30,454	116	880	15,465	1,277,910
1984	1,098,783	110,944	2,793	1,569	327	159,526	29,294	44,286	41	1,027	8,508	1,457,098
1985	1,178,759	132,736	2,248	784	82	227,107	21,986	71,179	5	1,163	11,503	1,647,552
1986	1,189,355	134,373	3,189	849	71	208,597	14,471	77,669	12	1,786	10,471	1,640,843

[a] Greenland turbot and arrowtooth flounder.
[b] Rock sole, flathead sole, Alaska plaice, and miscellaneous species of flatfishes.

During the 1960's, Japanese and Soviet vessels expanded considerably the areas, duration of fishing, and the number of target species. By 1967, these fisheries had encompassed most of the eastern Bering Sea and fishing occurred throughout much of the year. In the early 1960's, trawl fisheries began to take Pacific halibut, Pacific ocean perch, and sablefish; Japanese longline fisheries also began operations, targeting sablefish. Catches of these species generally peaked in the early 1960's: sablefish catches peaked at 26,000 t in 1962, Pacific ocean perch at 47,000 t in 1961, and Pacific halibut at 12,000 t in 1962–63 (Table 9). These species, in addition to other flatfishes, have continued to be exploited but at lower levels than those in early years of the fishery, in some cases owing to declining abundance of the stocks.

A major development in the eastern Bering Sea fisheries was the implementation by Japan in 1964 of shipboard methods for processing minced fish (surimi) from pollock. As a result, the main emphasis of the

Japanese fishery shifted to walleye pollock and catches of this species increased rapidly from 175,000 t in 1964 to 1.9 million t in 1972. Total groundfish catches also peaked in 1972 at 2.2 million t (Table 9).

Other nations began to fish for groundfish in the late 1960's and 1970's: the Republic of Korea (ROK) began operations in 1968, Polish vessels fished briefly in 1973 and resumed fishing in 1979, Taiwan initiated a small operation with 1 or 2 independent trawlers in 1974, fisheries from the Federal Republic of Germany started in 1980, and Portugal sent one vessel to the region in 1984. Catches (mainly walleye pollock) by these other nations have been relatively small in relation to those by Japan (Fig. 16). A U.S. trawl fishery for Pacific cod was started in 1977 and U.S. joint venture trawl fisheries for walleye pollock and other species began in 1980; joint ventures involved U.S. vessels delivering catches to foreign vessels for processing. The expansion of the U.S. joint venture fishery was very rapid, and by 1986 the U.S. joint venture and domestic fisheries began to take the major share of the catch (Fig. 16).

Following the peak period of the groundfish fishery in the early 1970's, catches began to decline (Fig. 16) as some restrictions were placed on the fisheries through bilateral agreements between the United States and foreign fishing nations and through discussions of the INPFC. Catches were further reduced to about 1.2 million t in the period immediately following the implementation of the Magnuson Fisheries Conservation and Management Act of 1976, which extended U.S. fisheries jurisdiction to 200 miles. In the mid-1980's, catches again increased reaching 1.6 million t in 1985 and 1986.

Walleye pollock has been the principal target species of all nations fishing in the eastern Bering Sea and has been the main component of catches since Japan initiated their target fishery for pollock in 1964 (Fig. 16). Pollock formed over 70% of the total groundfish catches in 1968–86 and usually contributed about 80% of the total. Throughout the 1954–85 period, Japan took by far the majority of the catch, often over 80% of the total

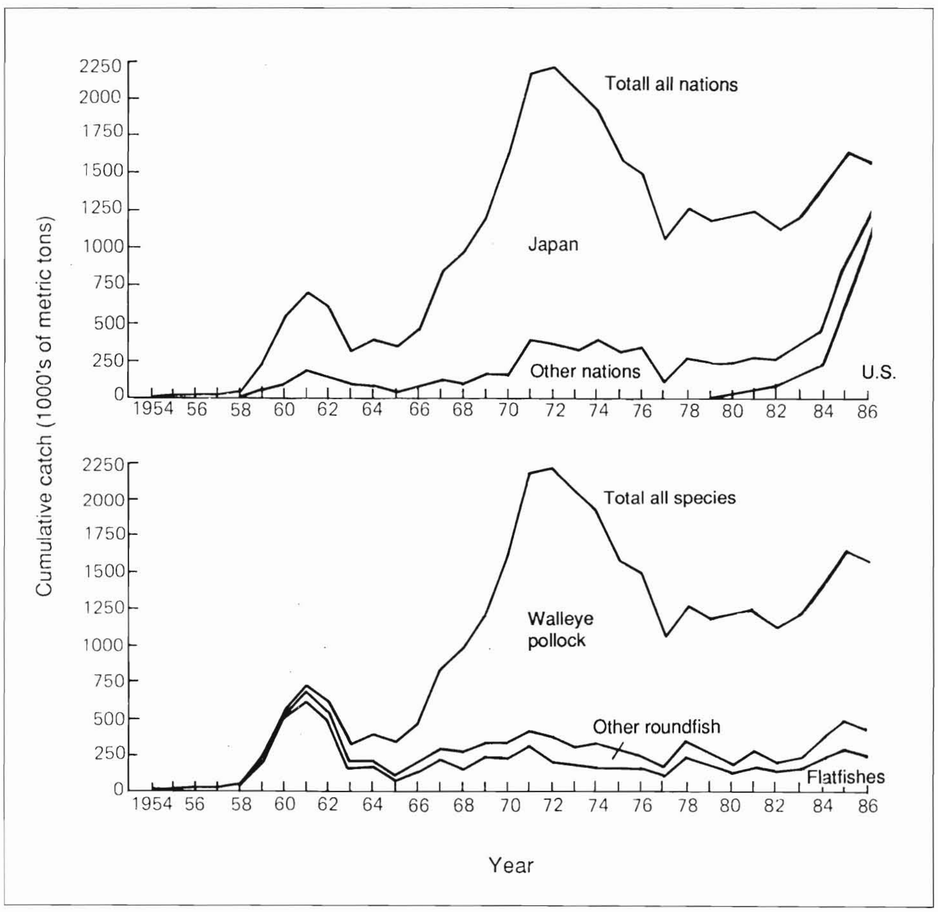


Figure 16

Catch of groundfish in the eastern Bering Sea by nation and species group, 1954-86. Other roundfish are Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*) and rockfishes (Scorpaenidae) and flatfishes include all species of Pleuronectidae found in the eastern Bering Sea.

(Fig. 16). In 1986 for the first time, U.S. fisheries began to dominate the catches.

Throughout the 1954–85 period, Japan, the Soviet Union, and the Republic of Korea employed trawl and longline mothership fleets and larger trawlers and longliners operating independent of motherships. The mothership fleets and independent trawlers were usually supported by cargo vessels and oil tankers, although vessels in the Japanese North Pacific longline-gillnet and land-based (Hokuten) trawl fisheries were prohibited by Japanese domestic regulations from transferring products at sea and had to return to port for unloading their catches. Characteristics of vessels and fishing gear in the Japanese, Soviet, and ROK fisheries are given in Tables 10–15.

Trawl and longline effort by these fisheries as estimated by Fredin (1987a) is illustrated in Figure 17. Trawl effort began to increase sharply in 1959 reaching an initial peak of 400,000 hours in 1961–62, which corresponds to the period of intense exploitation of yellowfin sole. Effort then declined considerably as trawl effort was diverted to the Aleutian Islands region and the Gulf of Alaska. With the development of the walleye pollock fisheries, effort again increased reaching a second peak of slightly over 400,000 hours in 1971. Since 1971, effort has remained about 300,000 to 375,000 hours but somewhat lower levels occurred in 1977 (the first year of U.S. extended fisheries jurisdiction) and in 1980–81.

Longline effort in the eastern Bering Sea by Japanese vessels peaked at 1.3 million hachi[2] in early years of the fishery (1963) when these vessels were targeting sablefish and Pacific halibut (Fig. 17). Longline effort dropped sharply in 1964 owing mainly to a decline in abundance of Pacific halibut (Fredin 1987a). The effort remained at much reduced levels through the mid-1960's as longline vessels were diverted to the Gulf of Alaska where they targeted sablefish. Effort increased in the late 1970's and 1980's reaching 600,000 hachis in 1984 and reflecting effort for Pacific cod by this fishery. (Effort data is not available for ROK longline vessels, the only other foreign nation employing this gear type, but their role was relatively minor.)

History of Management

Management Prior to U.S. Extended Fisheries Jurisdiction —The groundfish fishery in the eastern Bering Sea

[2] The hachi is a unit of Japanese longline which has varied in dimensions but averaged about 75 m in length with gangions spaced about 1.9 m apart.

Table 10

Range in size of fishing vessels and gear in the Japanese mothership and North Pacific trawl fisheries based on a sample of the fleets in 1976 (Japan Fisheries Agency 1976).

		Vessels			Gear			
Fishery	Target species	Type	Gross tons	Horsepower	Head-rope length (m)	Ground-rope length (m)	Codend mesh size (cm)	Otter board size (m)
Mothership	Walleye pollock	Danish seine	96–125	450–1,450	90–130	100–143	7.5–9.0	—
		Pair trawl	115–214	650–1,400	57–130	70–160	8.0–9.0	—
		Stern trawl	299–349	1,200–1,900	48–52	57–63	8.0–8.5	1.9 x 3.2–3.0 x 4.8
	Yellowfin sole	Pair trawl	214	1,400	127	160	9.0	—
		Stern trawl	314	1,200	36	48	9.0	1.8 x 2.8
North Pacific trawl	Walleye pollock	Stern trawl	2,455–5,470	3,500–5,700	64–80	65–111	9.0–10.0	2.4 x 3.8–3.2 x 5.0
	Yellowfin sole	Stern trawl	349–3,500	1,600–4,000	52–74	60–89	9.0–13.0	2.0 X 3.1–2.4 X 3.8
	Rockfishes	Stern trawl	349–3,914	1,420–4,400	40–74	51–89	8.0–13.0	2.0 x 3.2 – 2.7 x 3.6

Table 11
Range in size of North Pacific longline-gillnet vessels and gear used in the fishery in 1976 (Japan Fisheries Agency 1977).

Vessels		Gear					
Gross tons	Horsepower	Groundline			Gangion		
		Hachi[a] length (m)	Diameter (mm)	Hooks per hachi	Length (m)	Size hook (mm) or size number	Bait
382–500	540–1,110	70–75	8–12	35–44	1.0–1.6	18–20	Frozen squid

[a] The hachi is a unit of Japanese longline which has varied in dimensions but which had averaged about 75 m in length with gangions spaced about 1.9 m apart.

during its development and peak years was largely unrestricted. Japan imposed some domestic regulations on its fishery as it expanded but primarily in the interest of avoiding gear conflicts within its own fishery. For example, in 1959, Japan closed an area off the north side of the Alaska Peninsula to trawling to avoid gear conflicts with the Japanese red king crab (*Paralithodes camtschaticus*) fishery. They also established in 1961 a system of limiting areas of operation of each of their fleets to avoid chaos in fishing activities, and in 1967 they limited the number of licensed vessels in the fishery.

Although the U.S. Bureau of Commercial Fisheries issued some regulations regarding trawling as early as the 1930's (as did the Alaska Department of Fish and Game in 1960) (Fredin 1987b), the first significant regulation stemmed from legislation passed by the U.S. Congress in 1964, which made it unlawful for foreign vessels to fish within the 3–mile territorial waters of the United States or to fish for designated fishery resources of the adjacent U.S. continental shelf. In 1966, the U.S. Congress passed additional legislation that established a 9–mile contiguous fishery zone adjacent to the 3–mile territorial sea. Enactment of this law led to a series of bilateral agreements between the United States and nations involved in fisheries in the eastern Bering Sea and other U.S. waters. The main purpose of these bilateral agreements was to restrict Soviet and Japanese

Table 12
Characteristics of Japanese land-based (Hokuten) stern trawlers and fishing gear based on land-based vessels participating in the 1982 Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative trawl survey (Bakkala et al. 1985).

Vessels		Gear			
Gross tons	Horse-power	Headrope length (m)	Groundrope length (m)	Codend mesh size (cm)	Otter door size (m)
350	2,700	56.4	64.6	10	2.2 x 3.4

Table 13
Basic types of fishing vessels employed by the U.S.S.R. in groundfish fisheries off Alaska (Pruter 1976).

Vessel type	Gross tons	Length (m)	No. in crew	Descriptive remarks
SRT	265-335	38	22-26	Small side trawler of older type.
SRTR	505-630	52	26-28	Medium side trawler — usually transships catch to factory ship but may operate independently and process and freeze own catch.
SRTM	700	54	30	Large side trawler — frequently operates independent of factory ships and processes and freezes own catch.
BMRT	3,170	85	90	Factory trawler which normally processes and freezes own catch.
RTM	2,657	82	—	Newer type of factory trawler having increased deck area aft for more efficient handling of gear and catch.

Table 14
Size of Soviet (BMRT) factory stern trawlers and trawl dimensions used for fishing walleye pollock as shown by data of U.S. observers in 1976 and 1977 (Bakkala et al. 1979).

Range in vessel size			Typical trawl dimensions			
Length (m)	Gross tons	Horsepower	Head-rope length (m)	Ground-rope length (m)	Cod-end mesh size (cm)	Otter boards
78-87	2,657-3,837	2,000-2,320	77.4	77.4	3.0-6.0	Round to oval, variable in size. 1,600–1,800 kg.

Table 15
Vessel size and fishing gear dimensions of three Republic of Korea independent stern trawlers fishing off Alaska in 1977 (Bakkala et al. 1979).

	Vessels				Gear				
Name	Length (m)	Gross tons	Horse power	No. in crew	Head-rope length (m)	Ground-rope length (m)	Vertical opening (m)	Cod-end mesh size (cm)	Otter board size (m)
Salvia	84	2,285	3,200	58	59	78	6	10	2.5 x 3.8
Shin An Ho	106	5,680	6,000	157	80	75	7	10	3.0 x 5.0
Heung Yang Ho	104	5,377	5,800	92	74	105	38	10	3.0 x 4.8

groundfish fisheries to certain areas within and outside the U.S. contiguous fisheries zone to prevent damage to U.S. fishing gear and to reserve fishing grounds for the traditional U.S. Pacific halibut fisheries.

With the rapid growth of the groundfish fishery in the eastern Bering Sea followed by the sharp decline in catches of some species such as yellowfin sole and Pacific ocean perch, and with the concern by U.S. scientists about the condition of these and other stocks, the concept of establishing catch quotas began to be introduced by U.S. negotiators at the bilateral meetings. Catch quotas were first implemented for Japanese fisheries in 1973 and for Soviet fisheries in 1974. Quotas imposed through bilateral agreements through 1976 are listed in Table 16. Enforcement of quota regulations was the responsibility of the nation upon which the quota was imposed.

As previously mentioned, many of the restrictions on trawl fisheries were to protect Pacific halibut, a high-value species traditionally harvested by U.S. fishermen. Some of these regulations originated through the INPFC. Before 1963 the U.S. halibut fishery was managed by the International Pacific Halibut Commission (IPHC). From 1963 to 1977, the IPHC recommended regulations, but these had to be approved by the INPFC. Regulations developed by these commissions for the U.S. halibut fishery were mainly designed to achieve a desired distribution of fishing effort and to facilitate enforcement. Except for a period in the late 1940's and early 1950's and again in 1963–64, length of seasons rather than quotas has been used to manage halibut. Other regulations have included vessel licensing, gear restrictions (set lines only), minimum size limits, and area closures. Through INPFC negotiations in 1974–76 and through U.S.-Japan and U.S.-U.S.S.R. bilateral meetings, agreements were reached on time-area closures to protect Pacific halibut from trawl fisheries (Fig. 18).

Management Under U.S. Extended Fisheries Jurisdiction—In March 1976, the U.S. Congress enacted Public Law 94–265, the Magnuson Fishery Conservation and Management Act (MFCMA). The Act took effect on 1 March 1977. Under the MFCMA the United States gained exclusive management authority over all fishery resources except "highly migratory" species (such as tunas, Scombridae) in an Exclusive Economic Zone (EEZ) between 3 and 200 miles offshore. This zone encompasses all waters of the eastern Bering Sea continental

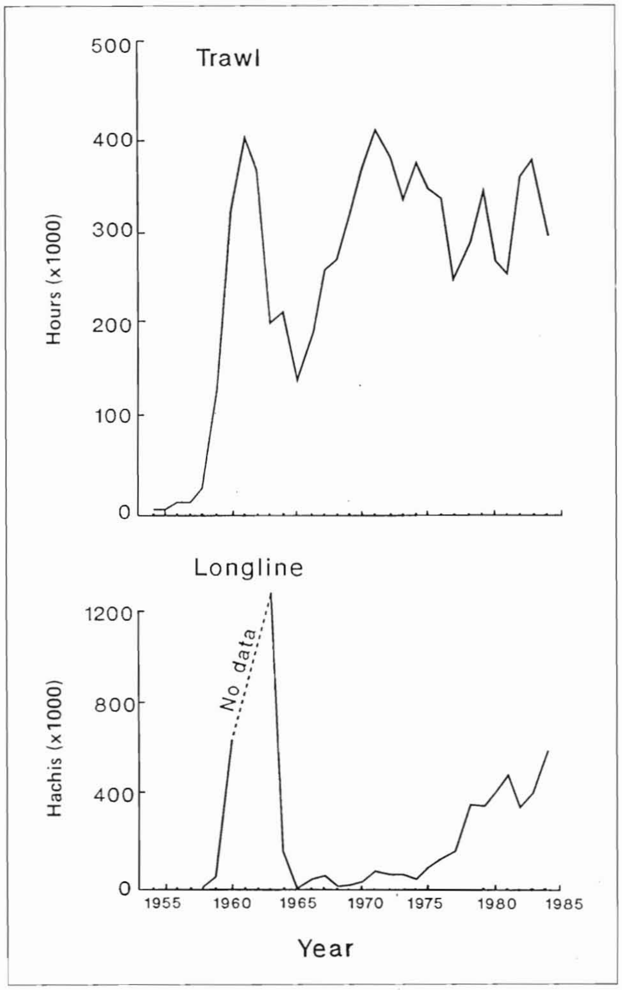


Figure 17
Estimated annual fishing effort for groundfish in the eastern Bering sea by all trawlers and by Japanese longline vessels (after Fredin 1987a). The hachi is a unit of Japanese longline which has varied in dimensions but averaged about 75 m in length with gangions spaced about 1.9 m apart.

shelf and slope and beyond. The Act also prohibits fishing by all non-U.S. nations in the EEZ except as authorized under certain conditions and in accordance with permits issued by the U.S. Secretary of Commerce through a governing international fisheries agreement (GIFA) or by the U.S. Secretary of State in the case of existing international fishery agreements. Foreign fishing under the GIFA's is limited to that portion of the optimum yield (OY) not harvested by U.S. fishermen. The OY is defined as the quantity of fish prescribed on the basis of maximum sustainable yield (MSY) as modified by any relevant economic, social, or ecological factors.

The MFCMA mandated the implementation of fishery management plans to determine and maintain OY for each fishery. Objectives of the management plans (North Pacific Fishery Management Council 1983) are to

- Promote conservation while providing for OY from the region's groundfish resources in terms of
  - a) providing the greatest overall benefit to the nation with particular reference to food production and recreational opportunities;
  - b) avoiding long-term or irreversible adverse effects on fishery resources and the marine environment; and
  - c) insuring availability of a multiplicity of options with respect to future uses of these resources.
- Promote, where possible, efficient use of the fishery resources but not solely for economic purposes.
- Promote fair and equitable allocation of identified available resources in a manner such that no particular group acquires an excessive share of the privileges.
- Base the plan on the best scientific information available.

The MFCMA also established regional councils consisting of U.S. Government and State officials and sci-

Table 16
Catch quotas (metric tons) applicable to Japanese and Soviet fisheries in the eastern Bering Sea, 1973–76.

			Year		
Nation	Fishery	Species	1973	1974	Annually in 1975–76
Japan	Mothership-North Pacific trawl	Walleye pollock	1,500,000	1,300,000	1,100,000
		Groundfish other than walleye pollock			160,000
	Land-based dragnet	All groundfish			35,000
Soviet Union		Flatfishes	100,000	100,000	— [a]
		Walleye pollock			210,000
		Other species			120,000

[a] Included in other species.

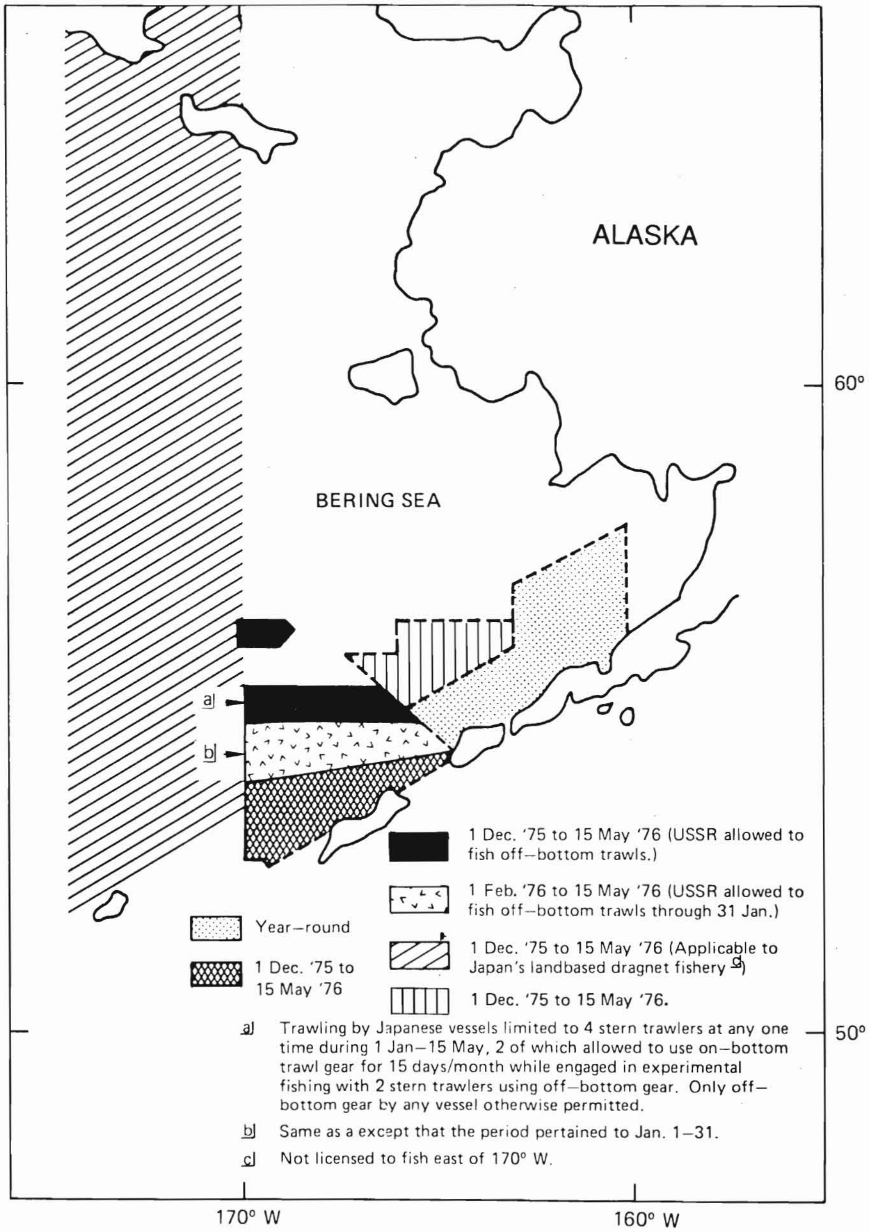


Figure 18

Areas closed to trawling by Japanese and Soviet vessels in the eastern Bering Sea during 1 December 1975 to 31 December 1976 under Japanese domestic regulations and the U.S.-U.S.S.R. bilateral agreement of July 1975 (from International North Pacific Fisheries Commission 1977; Forrester et al. 1983).

entists and commercial fisheries representatives, which were charged with developing management policies for groundfish. The North Pacific Fishery Management Council (NPFMC) has jurisdiction over Bering Sea and Gulf of Alaska groundfish resources. Management actions are recommended by the NPFMC and approved by the Department of Commerce. Regional Directors of the U.S. National Marine Fisheries Service (NMFS) have the responsibility of implementation and enforcement of these fishery regulations.

The primary goal of U.S. management for Bering Sea fisheries as stated in the management plan was to 1) arrest the decline in abundance of overfished stocks and to allow the stocks to rebuild to levels that would produce MSY, 2) to rebuild the Pacific halibut resource of the region to a level that would allow a viable U.S. setline fishery, and 3) to prevent healthy stocks from being overfished.

In line with this policy, numerous restrictions were imposed on groundfish fisheries in the eastern Bering

Sea. Many of the time-area restrictions negotiated through the INPFC and bilateral meetings were retained. Time-area closures applicable to non-U.S. fisheries in 1984 are illustrated in Figure 19.

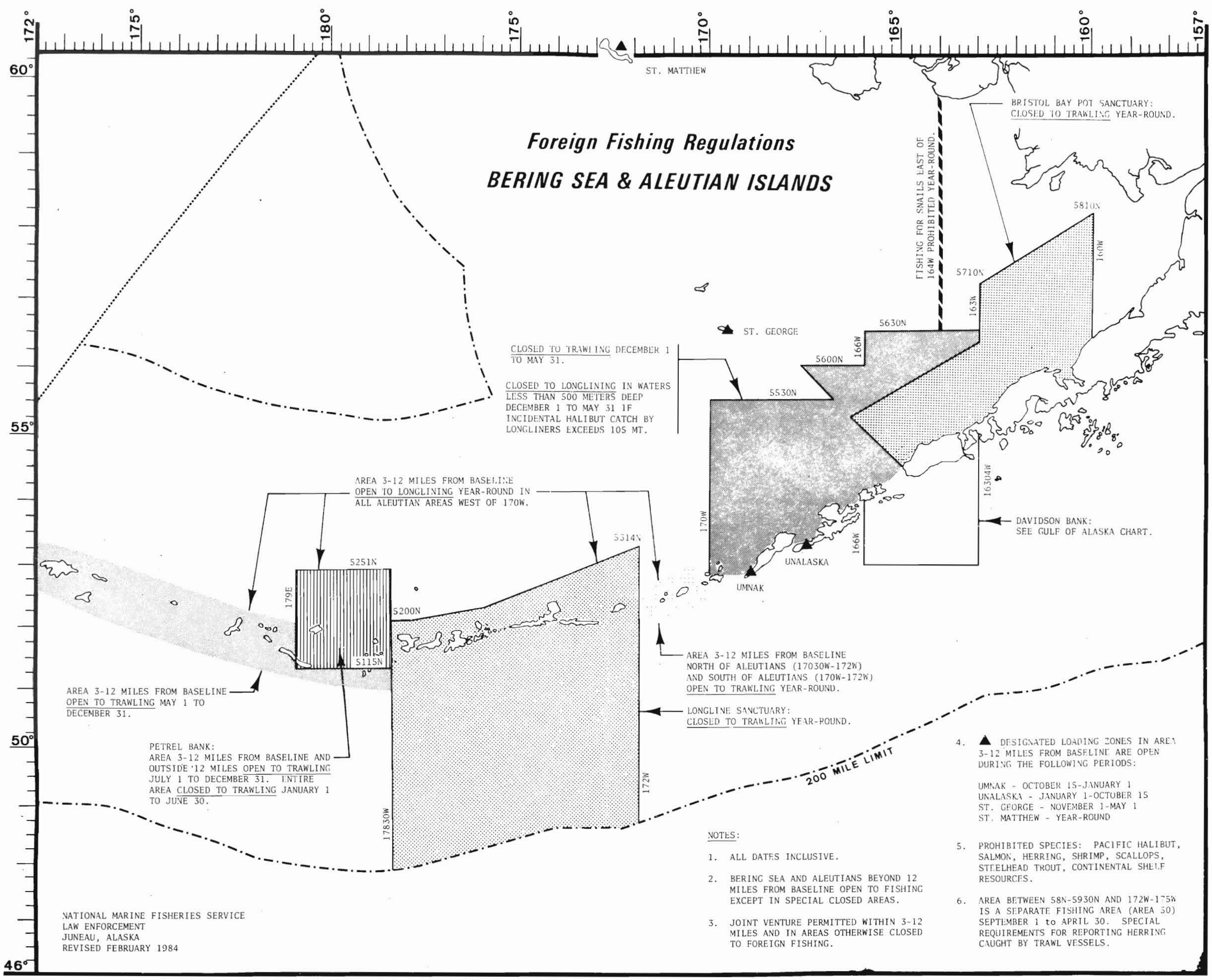


Figure 19
Time-area restrictions applicable to non-U.S. groundfish fisheries in the eastern Bering Sea and Aleutian Islands regions in 1984.

Other key provisions of the management plan for groundfish fisheries included 1) establishment of total allowable catches by species, 2) the closure of a region for the remainder of the calendar year to a nation's fishery when its allocation of a species or species complex was taken, 3) the requirement that all vessels accommodate U.S. observers at no cost to the U.S. Government, and 4) reporting of monthly and annual catch and effort statistics.

The main purpose of the time-area restrictions was to protect high-value species such as Pacific halibut and crab, although they have also served to protect other groundfish, particularly juvenile flatfish. The conservation of exploitable stocks of groundfish has been addressed largely through the use of catch limits on the fisheries. Catch limits have been based on OY's derived from studies of the condition of stocks in which survey and fisheries data and other deliberations by the NPFMC are evaluated. Annual OY's established by the council since implementation of the MFCMA in 1977 are given in Table 17. The management plan (approved in 1979) dictates that the sum of OY's for all species combined must fall within the range of 1.4 to 2.0 million t.

Total catches of groundfish in the eastern Bering Sea had been reduced from the peak level of 2.2 million t in 1972 to 1.4 million t by 1976 through agreements reached in INPFC and bilateral meetings (Table 9). The OY's established by the NPFMC (Table 17) maintained groundfish catches below this level through 1983 (Table 9). Because of the improved condition of many of the stocks, OY's were increased to over 1.8 million t in the eastern Bering Sea region in 1984–86, resulting in catches exceeding 1.6 million t in this region in 1985 and 1986.

Distribution and Stock Structure of Principal Species

Data from the U.S.-Japan cooperative surveys in 1979–85 were the main source of data used to illustrate the distribution of groundfish because of the comprehensive nature of those surveys. The surveys were conducted mainly during the summer from June to August. Comprehensive surveys have not been conducted in fall and winter but data from a spring 1976 NWAFC survey, when the environment was severely cold, was used to illustrate for certain species what is believed to represent winter distributions.

For purposes of management, principal groundfish species in the eastern Bering Sea are considered as unit

Table 17

Optimum yields (metric tons) for groundfish of the eastern Bering Sea and Aleutian Islands region 1977–86.

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Eastern Bering Sea[a]										
Walleye pollock	950,000	950,000	950,000	1,000,000	1,000,000	1,000,000	1,000,000	1,200,000	1,200,000	1,200,000
Yellowfin sole	106,000	126,000	126,000	117,000	117,000	117,000	117,000	230,000	226,900	209,500
Greenland turbot	—	—	—	90,000	90,000	90,000	90,000	59,610	42,000	33,000
Arrowtooth flounder[b]	—	—	—	—	—	—	—	—	—	20,000
Other flounders[c]	100,000	159,000	159,000	61,000	61,000	61,000	61,000	111,490	109,900	124,200
Pacific cod	58,000	70,500	70,500	70,700	78,700	78,700	120,000	210,000	220,000	229,000
Sablefish	5,000	3,000	3,000	3,500	3,500	3,500	3,500	3,740	2,625	2,250
Pacific ocean perch	6,500	6,500	6,500	3,250	3,250	3,250	3,250	1,780	1,000	825
Other rockfish	—	—	—	7,727	7,727	7,727	7,727	1,550	1,120	825
Squid	10,000	10,800	10,000	10,000	10,000	10,000	10,000	8,900	10,000	5,000
Other species	59,600	66,600	66,600	74,249	74,249	74,249	77,314	40,000	37,580	27,800
Aleutian Islands Region[a]										
Walleye pollock	—	—	—	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Sablefish	2,400	1,500	1,500	1,500	1,500	1,500	1,500	1,600	1,875	4,200
Pacific ocean perch	15,000	15,000	15,000	7,500	7,500	7,500	7,500	2,700	3,800	6,800
Other rockfish	—	—	—	—	—	—	—	5,500	5,500	5,800
Atka mackerel	—	24,800	24,800	24,800	24,800	24,800	24,800	23,130	37,700	30,800
Other species	34,000	34,000	34,000	—		—	—	—	—	—
Total all areas	1,346,500	1,467,700	1,466,900	1,571,226	1,579,226	1,579,226	1,623,591	2,000,000	2,000,000	2,000,000

[a] Optimum yields are for the eastern Bering Sea and Aleutian Islands areas combined for pollock in 1977–79, other rockfish 1980–83, other species in 1980–86, and in all years for yellowfin sole, Greenland turbot and arrowtooth flounder, other flounders, Pacific cod and squid.

[b] Combined with Greenland turobt until 1986.

[c] Includes Greenland turbot and arrowtooth flounder until 1980.

stocks. The distributions of Pacific cod, yellowfin sole, Greenland turbot, arrowtooth flounder, rock sole, Alaska plaice, and flathead sole stocks are considered to also encompass the Aleutian Islands region. The distributions of the principal species also extend into the Gulf of Alaska and into Asian waters of the Bering Sea and North Pacific Ocean. The stock structure and relationship of eastern Bering Sea and Aleutian Islands populations to those in other regions is not well understood. The following describes the distribution of total groundfish and principal species within the eastern Bering Sea and what is known or hypothesized about the stock structure of these populations.

Total Groundfish

The distribution of total groundfish based on the 1982 U.S.-Japan cooperative bottom trawl and hydroacoustic-midwater trawl survey data is shown in Figure 20. High densities of groundfish were located along the outer shelf (100–200 m), along the north side of the Alaska Peninsula, and on the inner (0–50 m) to mid-shelf area (50–100 m). The outer, high-density area consisted mainly of walleye pollock whereas the other high-density areas consisted mainly of flatfishes, particularly yellowfin sole. Lower densities of groundfish were observed in some central and northern shelf areas.

Groundfish were distributed throughout the slope region to the maximum depths sampled (914 m, 500 fm) with intermittent areas of high concentrations, particularly on the southeast portion of the slope (Fig. 20).

Walleye Pollock

Walleye pollock is primarily a semidemersal species that inhabits continental shelf and slope waters along the northern rim of the North Pacific Ocean extending from southern Oregon (about lat. 43°30' N) (Allen and Smith 1988) into the southern Chukchi Sea (about lat. 68°00' N) and south along the Asian coast to the southern Sea of Japan (about lat. 34°00' N) (Hart 1973). It is also found pelagically throughout the Aleutian Basin in the Bering Sea. In North American waters it is most abundant in the eastern Bering Sea.

Biochemical studies have revealed major genetic differences between populations of walleye pollock in the Okhotsk Sea and those in the eastern Bering Sea and Gulf of Alaska (Iwata 1975, a and b; Johnson 1977) suggesting that pollock in North American waters and in the Okhotsk Sea are independent stocks. Within North American waters, small but detectable genetic differences were found between samples of walleye pol-

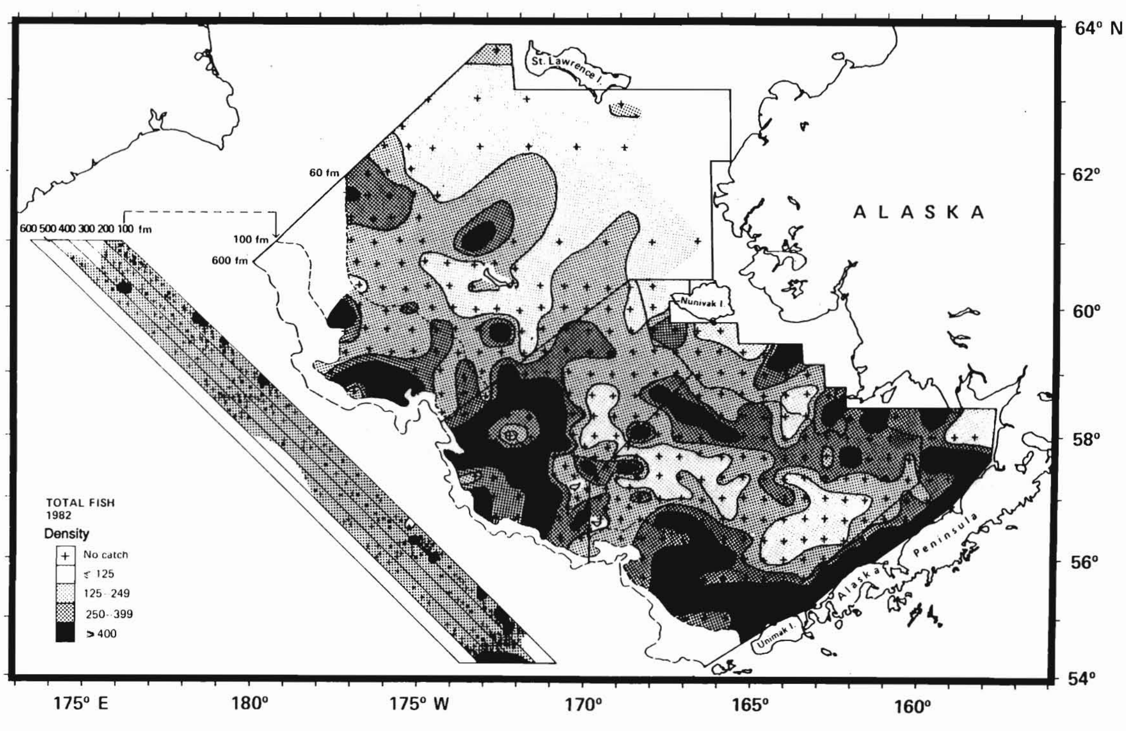


Figure 20
Distribution and relative abundance of total fish as shown by the 1982 U.S.-Japan bottom trawl and midwater-hydroacoustic surveys.

lock from the eastern Bering Sea and Gulf of Alaska (Grant and Utter 1980), possibly due to restricted migrations between these regions, homing to discrete spawning areas, or a combination of these two factors. The relationships between walleye pollock from the eastern Bering Sea, Aleutian Islands region, Aleutian Basin, and western Bering Sea (Fig. 1) are less clear. Some morphometric and morphological studies (Hashimoto and Koyachi 1969; Maeda 1979) have suggested differences in eastern Bering Sea and western Bering Sea populations but this evidence is not conclusive.

The relationship between walleye pollock in the Aleutian Basin and eastern Bering Sea is of special interest. Only large, older pollock (mainly ages 4–8) occupy the pelagic waters of the basin (Okada 1986). The absence of juveniles in the basin suggests that these pollock originate from other areas, presumably from one or more of the shelf areas surrounding the basin. The biomass of the basin population, based on midwater trawl data, has been estimated to range from 1.3 million t to 5.4 million t (Okada 1986). Concentrations of pollock have been encountered by commercial fishing vessels in international waters of the central basin and in the southeast portion of the basin in winter months. The pollock taken in the central basin are believed to be migrants on their way to the southeast basin where they spawn (Dawson 1989). These respective areas produced catches on the order of 1.0 million t in 1986 and 400,000 t in 1987, which together exceed the 1987 catch of 1.18 million t in the eastern Bering Sea proper. An important and intriguing question concerns the origin of these spawners and the ultimate fate of offspring from this spawning. Do the spawners or their offspring contribute to the exploitable population in the eastern Bering Sea, to those in other regions, or to a combination of shelf areas?

The existence of two stocks of walleye pollock within the eastern Bering Sea has been hypothesized. This hypothesis was based on observations of isolated spawning concentrations in the northwest and southeast Bering Sea and on differences in larval feeding habits and growth of larvae and adults from these areas (Dwyer et al. 1983; Walline 1983). However, biochemical genetic studies have given no evidence of multiple stocks in the eastern Bering Sea (Grant and Utter 1980).

The typical summer distribution of pollock in the eastern Bering Sea is illustrated by the 1982 U.S.-Japan cooperative survey data (Fig. 21). Highest densities occur along the outer continental shelf with two major concentrations: 1) between Unimak Island and the Pribilof Islands and 2) northwest of the Pribilof Islands. This distribution is particularly evident in data from combined bottom trawl and hydroacoustic-midwater trawl surveys (Fig. 21). During the 1982 survey, 39% of the population biomass was estimated to be near the sea bottom and 61% in midwater.

Walleye pollock also occupy continental slope waters (Fig 21.). Based on the bottom trawl survey data, it appears that higher concentrations of pollock are mainly limited to less than 365 m (200 fm) on the slope.

Pacific Cod

Pacific cod also have a broad distribution in the North Pacific Ocean extending along the North American coast from southern California (about lat. 34° N) to Norton Sound in the Bering Sea (about lat. 63° N) and along the Asian Coast south to the southern tip of the Korean Peninsula (about lat. 34° N) and into the Yellow Sea (Hart 1973). The abundance of Pacific cod is highest in the eastern Bering Sea.

As with walleye pollock, two major genetic groups of Pacific cod have been detected in the North Pacific Ocean with biochemical genetic techniques: a North American group extending from the eastern Bering Sea to at least off Washington, and an Asian group including at least those cod in Korean and Japanese waters (Grant et al. 1987). The northern boundary between these groups has not been delineated. Virtually no regional genetic differentiation was found among North American populations of Pacific cod. In this regard, ongoing tagging studies by the NWAFC have shown migrations of Pacific cod between the eastern Bering Sea and the Aleutian Islands region and the Gulf of Alaska. Thus, Pacific cod in the eastern Bering Sea do not appear to represent a discrete stock but intermingle with populations in other areas.

The overall distribution of Pacific cod in the eastern Bering Sea appears to be well defined by demersal trawl survey data. Very few Pacific cod have been observed in midwater during hydroacoustic-midwater trawl surveys in the Bering Sea. Their distribution is mainly governed by the abundance and age composition of the population. From 1979 to 1985, the recruitment and growth of strong year classes of Pacific cod spawned in 1977 and 1978 were monitored by NWAFC surveys. Prior to the recruitment of these strong year classes, the abundance of Pacific cod was low and they were infrequently encountered. They occurred mainly in schools on the outer shelf of the eastern Bering Sea.

The strong recruitment of age-1 Pacific cod was first noted on the inner shelf of the eastern Bering Sea in 1978. These young fish shifted to mid-shelf waters at age 2 in 1979 (Fig. 22). When the abundance of Pacific cod was at an observed peak level during the 1980's, the summer distribution of older fish was broad, extending throughout the eastern Bering Sea shelf but at relatively low densities. Some persistent areas of somewhat higher densities have been noted each year during the 1980's: northwest of the Pribilof Islands, along the north side of the Alaska Peninsula, and at some locations along the inner shelf of the Alaska mainland (lower panel of Fig. 22). Pacific cod also occupy continental slope waters but mainly at depths of 183–365 m (100–200 fm).

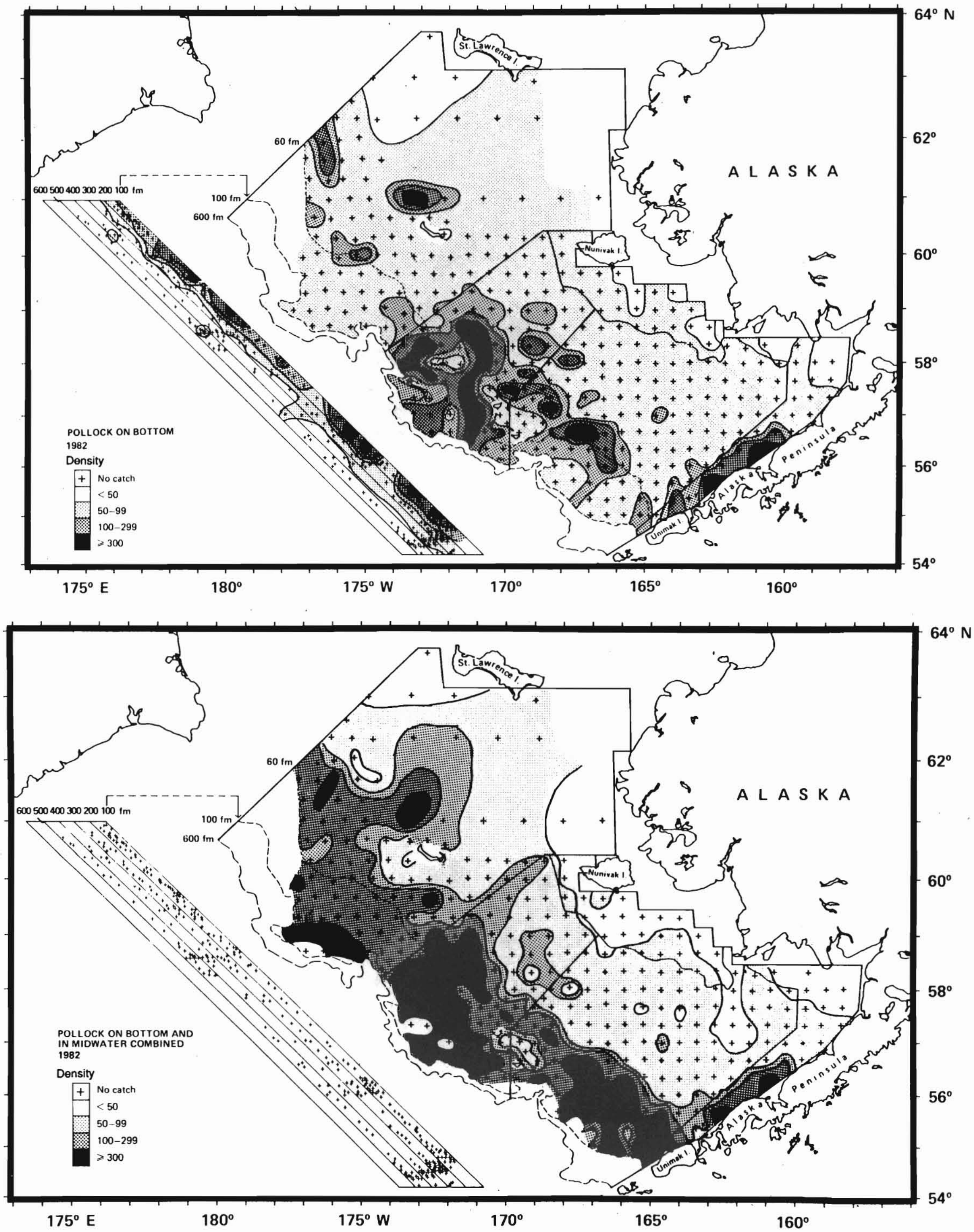


Figure 21

Distribution and relative density of walleye pollock (*Theragra chalcogramma*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative bottom trawl and combined bottom trawl and hydroacoustic-midwater trawl survey data in summer 1982.

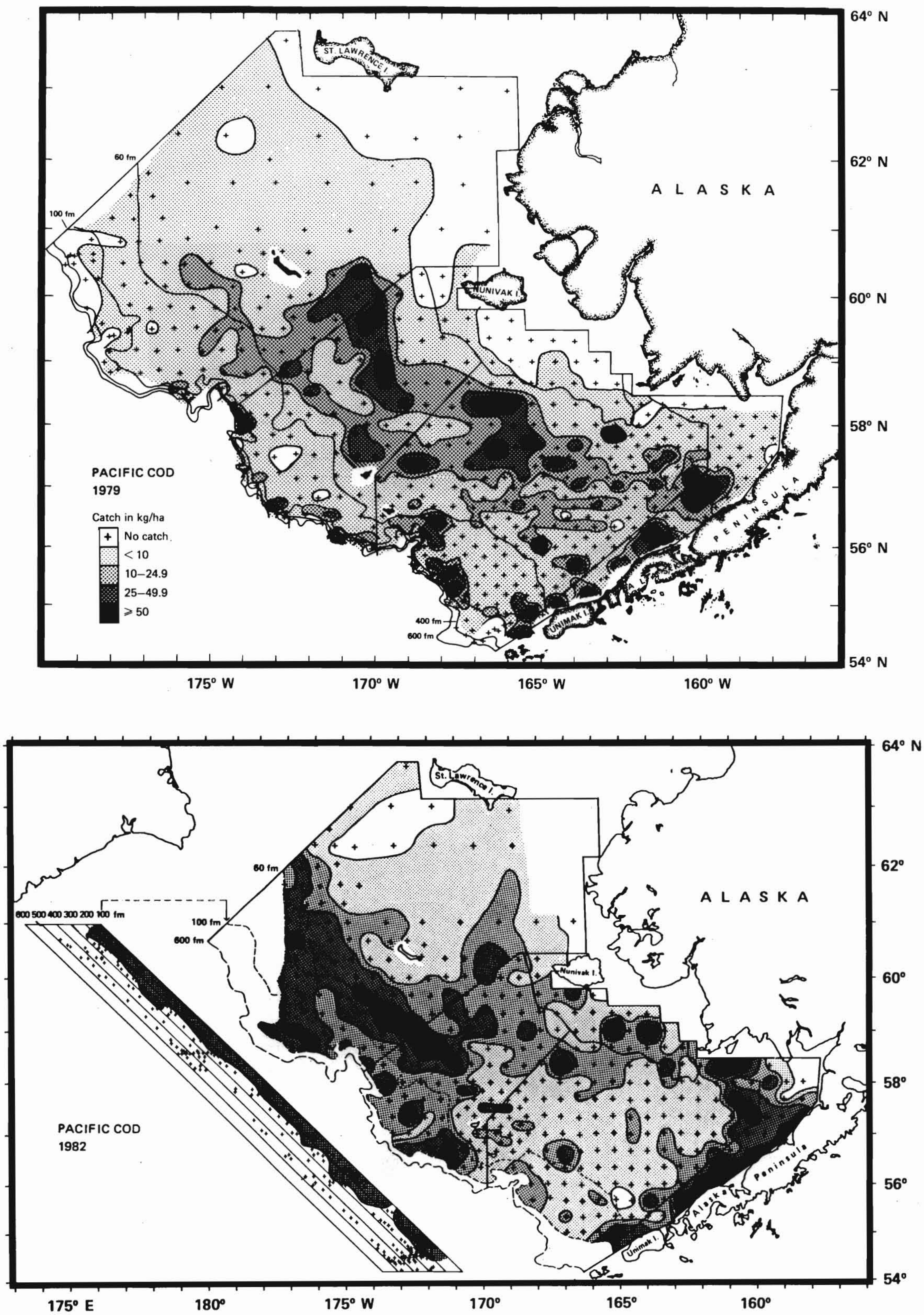


Figure 22
Distribution and relative abundance of Pacific cod (*Gadus macrocephalus*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1979 and 1982.

Sablefish

Sablefish range in North America from the waters off northern Mexico to the northern Bering Sea and south into Asian waters to the northeast coast of Japan (Hart 1973). Tagging studies, which have shown extensive movements between regions, biochemical genetic, and meristic studies suggest that sablefish in North American waters consist of a single genetic stock (Sasaki 1985). Maximum abundance of the stock occurs in the Gulf of Alaska. Eastern Bering Sea and Aleutian Islands sablefish may originate from spawning in the Gulf of Alaska (Sasaki 1985), based on the observed interchange of sablefish between these regions and the apparent absence or low level of spawning activity in the eastern Bering Sea and Aleutian Islands area (Kodolov 1968).

Within the eastern Bering Sea, only older juvenile and adult sablefish are regularly taken during trawl and longline surveys, and their distribution is almost entirely restricted to continental slope waters. Young (1- to 3-year-old) sablefish have been observed in relatively large numbers on the continental shelf of the eastern Bering Sea in only three (1978–80) of 14 (1973–86) survey years. These young juveniles (see Fig. 23 for their distribution in 1979) were from the strong 1977 year class, suggesting that they may occupy shelf waters of the eastern Bering Sea only in years of stronger recruitment.

More typically, sablefish distribution on the shelf is limited as observed in 1985 (Fig. 23). During the 1985 survey, sablefish were distributed throughout the slope waters sampled (183–914 m, 100–500 fm) and the greatest concentrations occured on the southeast Bering Sea slope.

Pacific Ocean Perch

Pacific ocean perch ranges from southern California to the northern Bering Sea and south to northern Honshu Island in Japan (Hart 1973). It is more abundant in the Aleutian Islands region and particularly in the Gulf of Alaska than in the eastern Bering Sea. Considering the differences in growth rates and length-weight, age-length, and length-frequency relationships, Chikuni (1975) suggested that discrete stocks of Pacific ocean perch existed in the Aleutian Islands region and eastern Bering Sea but these have not been detected by biochemical genetic studies (Wishard and Gunderson 1981).

The distribution of Pacific ocean perch, like that of sablefish, is almost entirely limited to continental slope waters of the eastern Bering Sea (Fig. 24). Schools were occasionally encountered on the shelf during summer surveys and by commercial fishing vessels in other seasons. They mainly occupy upper slope waters (183–549 m , 100–300 fm) and during the 1985 U.S.-Japan survey were found in highest concentrations west and northwest of the Pribilof Islands.

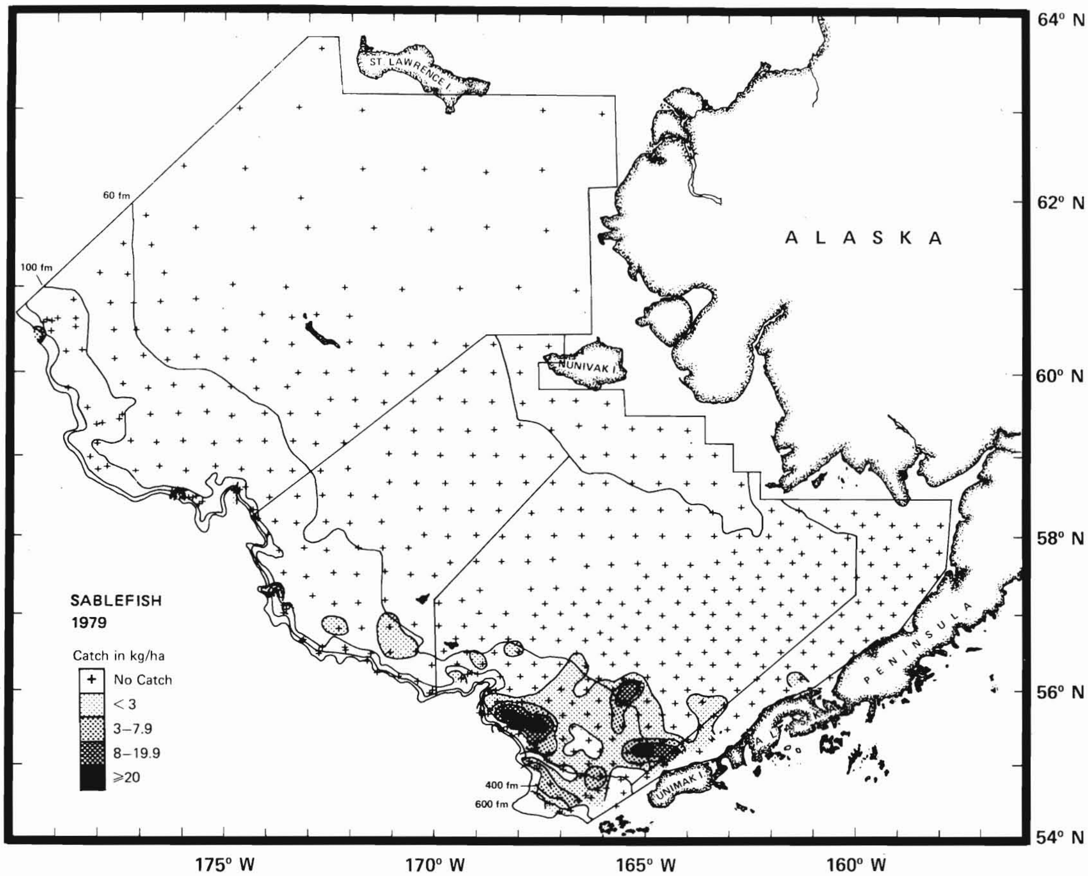
Yellowfin Sole

Yellowfin sole are rarely found south of the northern Gulf of Alaska and range through the eastern Bering Sea to the southern Chukchi Sea (Allen and Smith 1988) and south along the Asian coast to Hokkaido Island in Japan and Peter the Great Bay on the U.S.S.R. coast (Hart 1973). They are most abundant in the eastern Bering Sea and range into the Aleutian Island region and the Gulf of Alaska to a limited extent.

No genetic differences have been found within the yellowfin sole population of the eastern Bering Sea, but significant differences occur between populations in the eastern Bering Sea and Gulf of Alaska (Grant et al. 1983). The degree of intermingling between the eastern Bering Sea and northern and western Bering Sea fish is unknown, but because of the low abundance in these latter regions, the eastern Bering Sea population can probably be considered a unit stock.

Main concentrations of yellowfin sole are typically located on the inner shelf to mid-shelf in summer between the Alaska Peninsula and Nunivak Island (Fig. 25). They occupy outer shelf waters only to a limited extent in summer.

The distribution of yellowfin sole during severe winter-type conditions is illustrated by data from the 1976 NWAFC survey conducted when ice cover in the eastern Bering Sea was extensive in April and May (Fig. 26). An extremely dense concentration of yellowfin sole was observed just north of Unimak Island in April, when ice cover was maximum. As the ice retreated in May, this concentration moved inshore in a northeasterly direction toward Bristol Bay (Fig. 26). Two smaller concentrations, which may have occupied waters under the ice in April were also observed to the east and west of the Pribilof Islands in May. These three concentrations have been observed in winter by earlier investigators (Fadeev 1970; Wakabayashi et al. 1977). The main concentration of yellowfin sole located off Unimak Island in April had apparently moved to inner shelf waters off Bristol Bay by June. The smaller concentration located west of the Pribilof Islands in May apparently moved toward Nunivak Island in June (Fig. 27); these fish are believed to occupy waters around Nunivak Island in summer. In summer 1975 the largest concentration of yellowfin sole occurred off Bristol Bay, a lesser concentration off Nunivak Island, and there were only low densities or yellowfin sole were absent in areas occupied at high densities in April and May 1976 (Fig. 27).



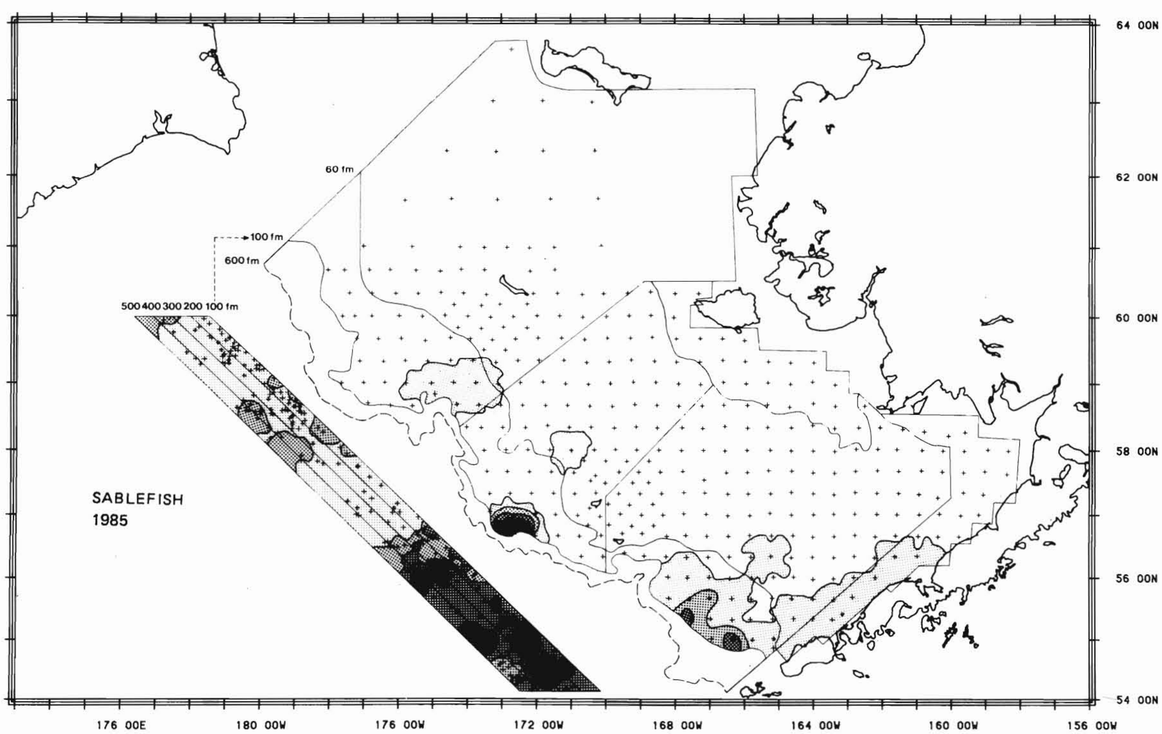


Figure 23

Distribution and relative abundance of sablefish (*Anoplopoma fimbria*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1979 and 1985.

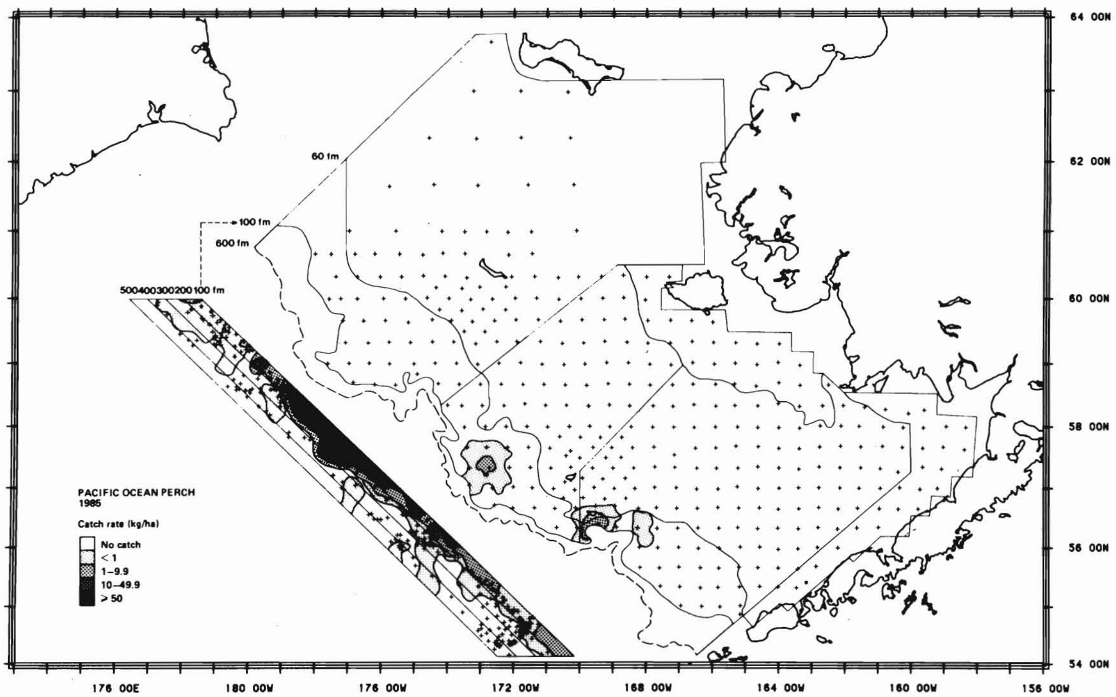


Figure 24
Distribution and relative abundance of Pacific ocean perch (*Sebastes alutus*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1985.

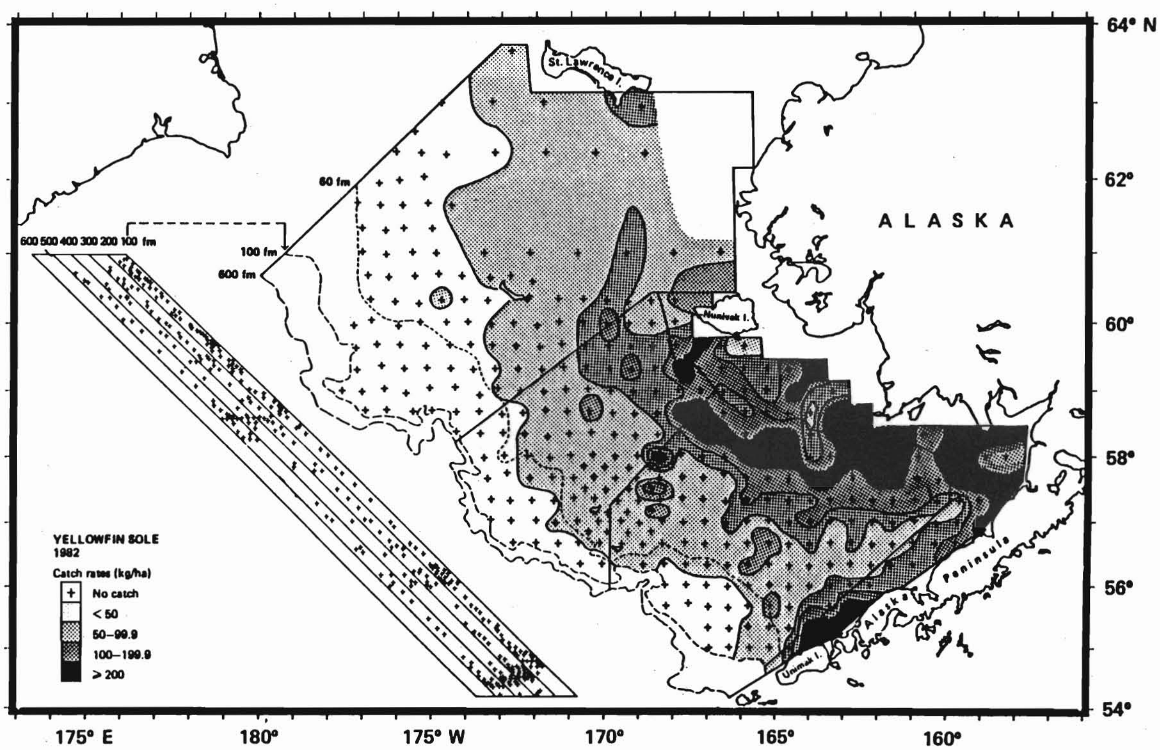


Figure 25
Distribution and relative abundance of yellowfin sole (*Pleuronectes asper*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1982.

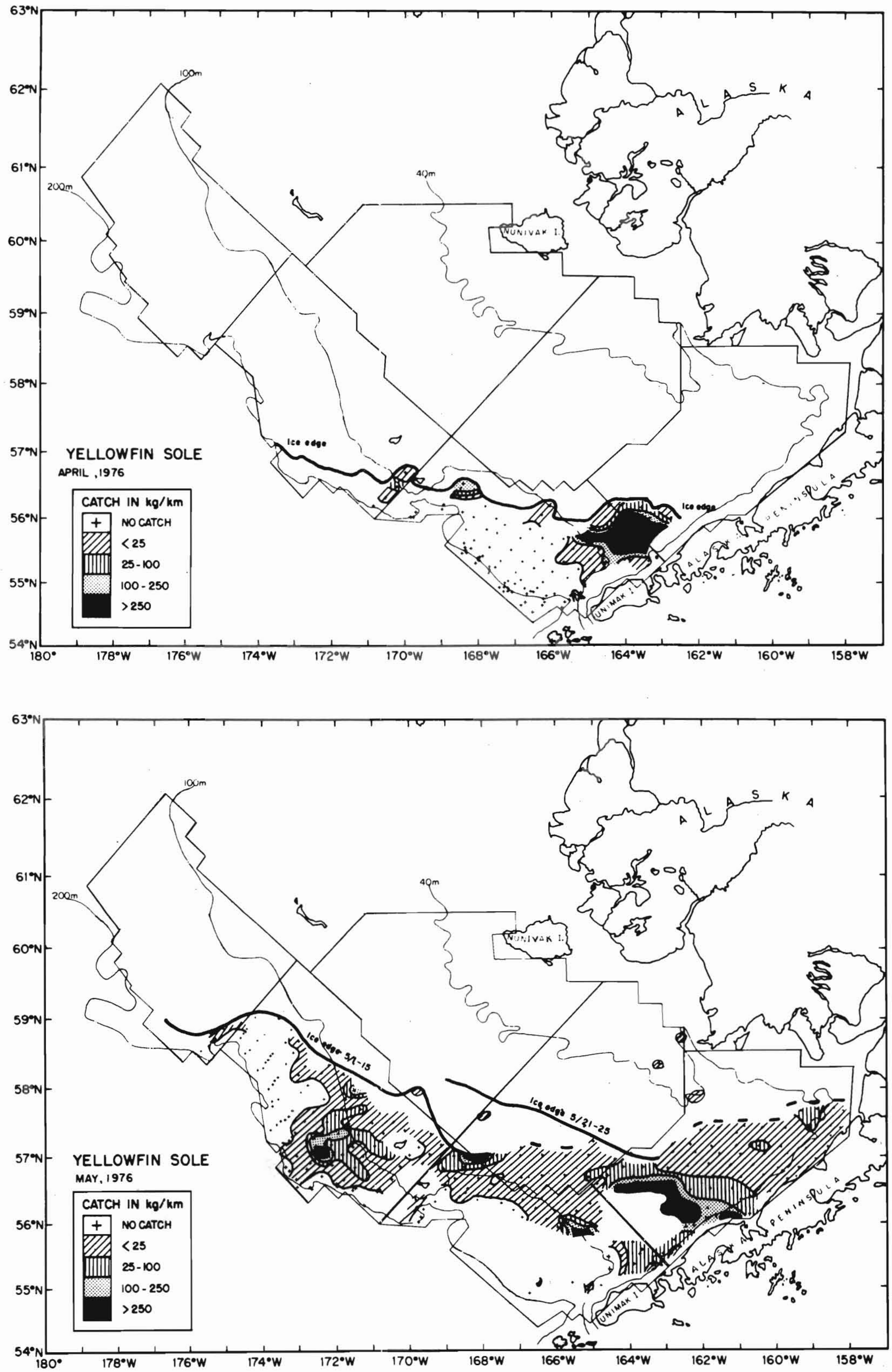


Figure 26
Distribution and relative abundance of yellowfin sole (*Pleuronectes asper*) in April and May 1976 as shown by Northwest and Alaska Fisheries Center survey data.

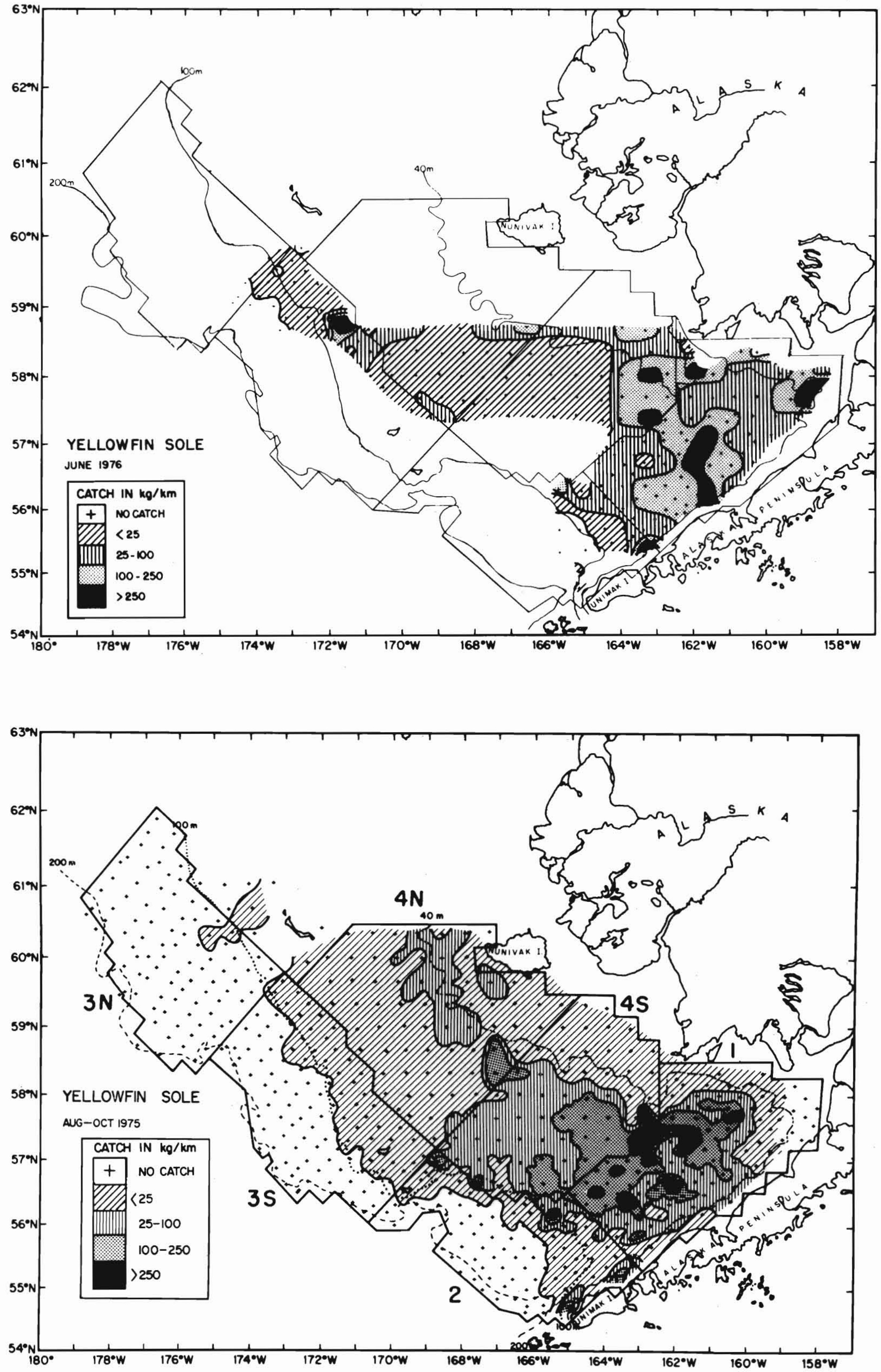


Figure 27

Distribution and relative abundance of yellowfin sole (*Pleuronectes asper*) in June 1976 and August to October 1975 as shown by Northwest and Alaska Fisheries Center survey data.

Thus yellowfin sole move offshore in winter, apparently to avoid cold bottom water and ice cover, and migrate inshore in spring. The extent of the offshore movements probably depends on the severity of winter environmental conditions. The locations of high concentrations in April and May 1976 may represent an extreme in the offshore movements of yellowfin sole.

Rock Sole

Rock sole range from southern California northward through the Bering and Okhotsk Seas and southward to the waters off Korea and the Sea of Japan (Hart 1973). Rock sole have recently been most abundant in the eastern Bering Sea, but in some years they may be more abundant in other regions such as the Gulf of Alaska. Their abundance is low in the Aleutian Islands region. The structure of rock sole stocks has not been studied and the relationship between populations in the eastern Bering Sea and other regions is unknown.

Rock sole abundance increased substantially during the early to mid-1980's. Figure 28 illustrates the distribution of this species in 1979 when the biomass was estimated to be about 200,000 t and in 1985 when the biomass was estimated at about 700,000 t. In 1985, the distribution expanded as abundance increased; compared with 1979, areas of relatively high concentrations were much broader and the overall distribution more extensive.

There were two main concentrations of rock sole in summer, the largest extending north from the Alaska Peninsula in inner shelf waters and a smaller concentration around the Pribilof Islands. As with yellowfin sole, the larger of these concentrations moves offshore in winter, and the extent of this movement may depend on the severity of winter sea temperature and ice conditions. When environmental conditions were extremely cold, in the spring of 1976, the major concentration of rock sole was located north of Unimak Island and along the north side of the outer Alaska Peninsula (Fig. 29). This was a major westward shift from the typical summer location. Although cold environmental conditions were a factor, this offshore movement may have been related to spawning, which occurs in March and April in mid-shelf waters (Shubnikov and Lisovenko 1964).

Alaska Plaice

In North American waters, Alaska plaice occur mainly from the southeastern Bering Sea to the southern Chukchi Sea. In Asian waters they range south from the southern Chukchi Sea to the Sea of Japan and Peter the Great Bay (Pertseva-Ostroumova 1961; Quast and Hall 1972). They also range into the Gulf of Alaska and Aleutian Island waters to a limited extent. Abundance is centered in the eastern Bering Sea. Although the stock structure has not been studied, the species is much less abundant in adjacent regions, and the eastern Bering Sea population can be considered a unit stock (Zhang 1987).

Alaska plaice is a relatively small flatfish occupying inner and mid-shelf waters during the summer (Fig. 30). Its distribution is most similar to that of yellowfin sole and is centered in more northerly waters than that of rock sole. Alaska plaice is generally absent from outer shelf waters in summer. A concentration of Alaska plaice was also observed off the southeastern St. Lawrence Island in summer 1982 (Fig. 30).

An offshore winter distribution and an onshore migration in spring similar to that of yellowfin sole was observed in spring 1976 from NWAFC survey data (Fig. 31). A major concentration of Alaska plaice was observed just outside the ice edge north of Unimak Island and smaller concentrations along the ice edge near the Pribilof Islands in April; however, by May, these concentrations had moved northeast toward areas occupied in summer. By June (Fig. 32), Alaska plaice had reached summer feeding areas on the middle and inner shelf.

Flathead Sole

This species, or a similar form, the Bering flounder (*Hippoglossoides robustus*) range from off northern California to the northern Bering Sea and south to the waters of Japan (Hart 1973). Morphometric and biochemical genetic studies have suggested that two species, subspecies, or races may exist within this range (Forrester et al. 1977). Flathead sole is found along the North American coast as far north as the Bering Sea, and the Bering flounder may occupy the northern and western Bering Sea. Two concentrations of *Hippoglossoides* have been consistently observed during eastern Bering Sea surveys (upper panel of Fig. 33). Studies at the NWAFC indicate that the more southern of these concentrations probably represents flathead sole, the northern concentration probably represents Bering flounder, and the distributions of these two forms overlap between these concentrations (unpubl. data, NWAFC).

The summer distribution of flathead sole differs from other small shelf flatfishes, being centered nearer the outer shelf (Fig. 33); major concentrations of other flatfishes are located on the inner and middle shelves. From a comparison of distributions of flathead sole in spring 1976 and summer 1982 (Fig. 33), some offshore movement occurs in winter, at least in cold years like

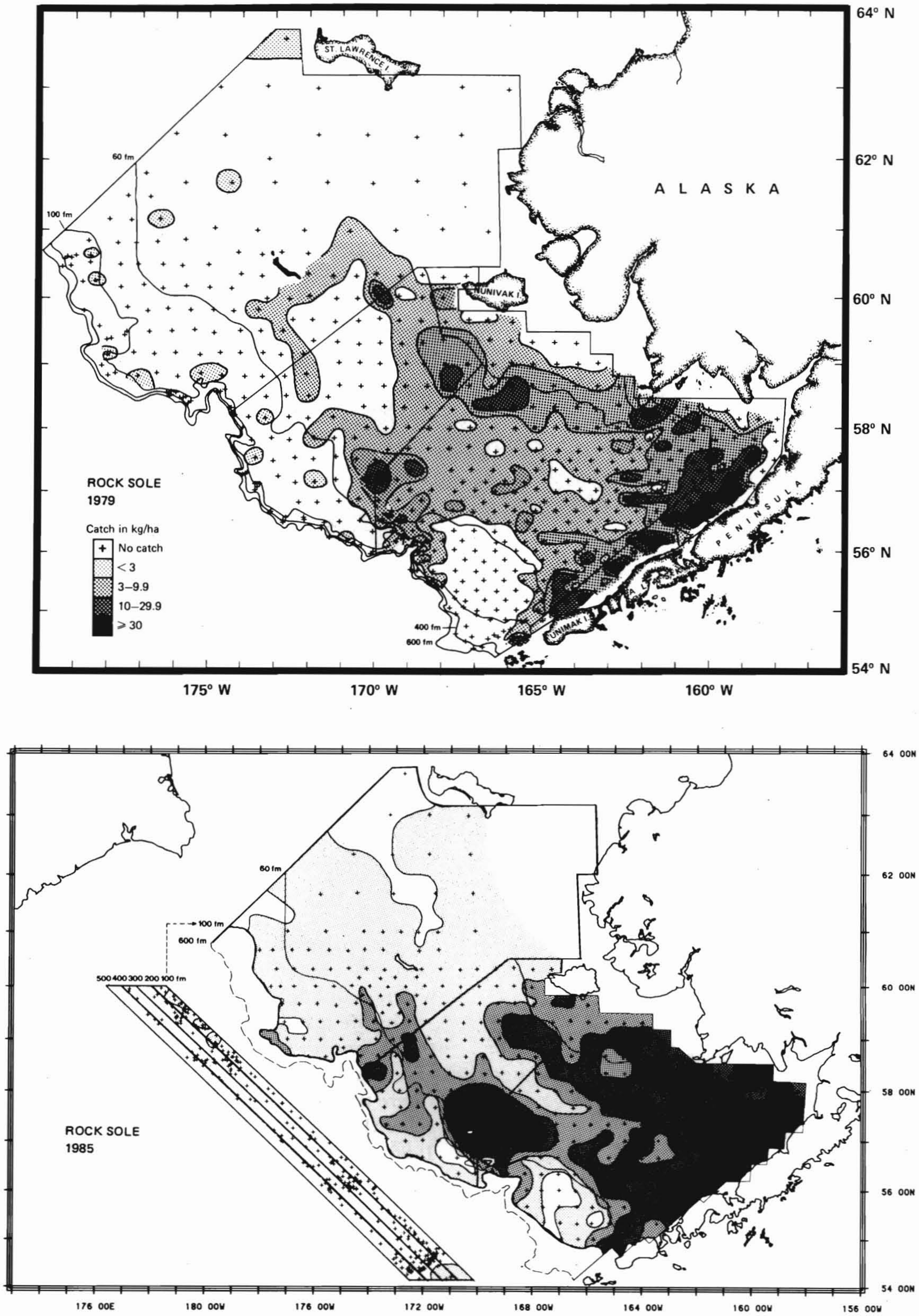


Figure 28
Distribution and relative abundance of rock sole (*Pleuronectes bilineatus*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1979 and 1985.

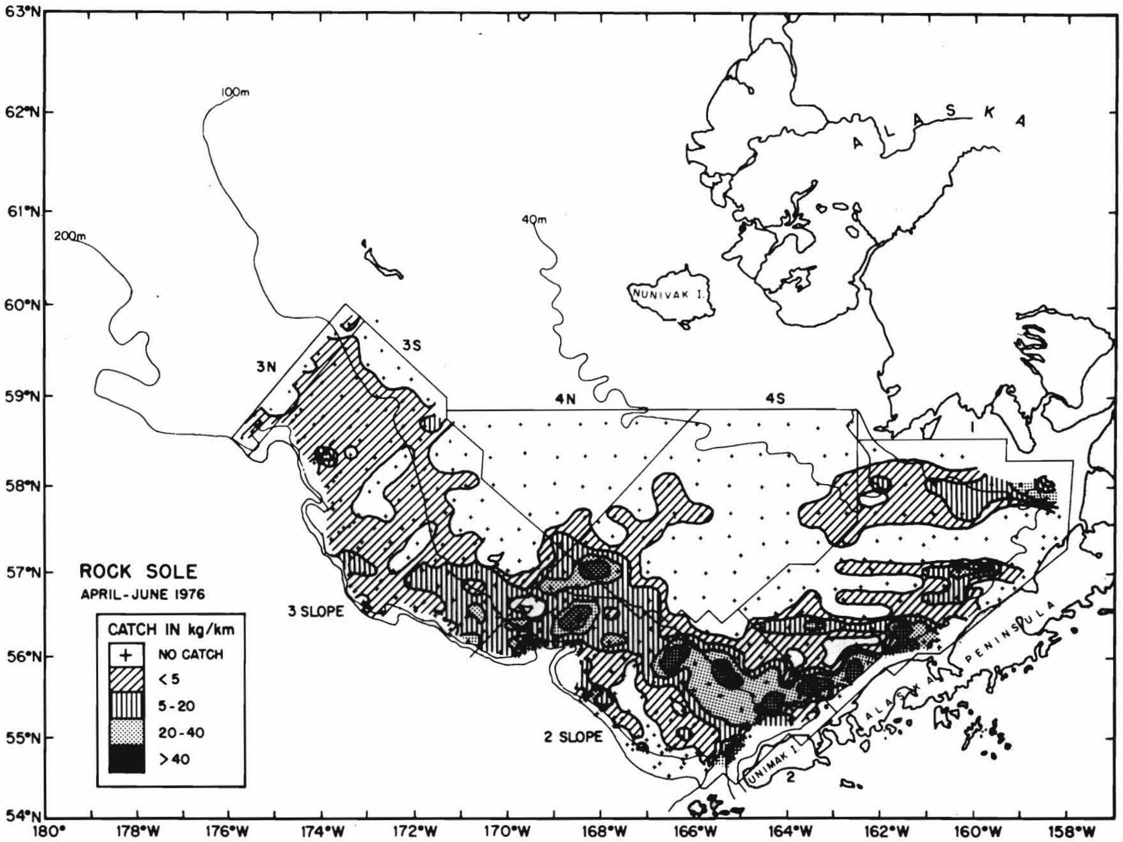


Figure 29

Distribution and relative abundance of rock sole (*Pleuronectes bilineatus*) as shown by Northwest and Alaska Fisheries Center survey data in April-June 1976.

1976. The location of the main concentration on the outer shelf of the southeast Bering Sea did not change between the two seasons, but fish appeared to withdraw from the inner and middle shelf areas in spring 1976.

Flathead sole is more abundant on the continental slope than other small shelf flatfishes. However, it occurs mainly on the upper slope (Fig. 33), and the proportion of the total population on the slope is small. For example, only 3% of the total biomass was located on the slope in 1985 (Walters et al. 1988).

Greenland Turbot

Greenland turbot occurs continuously from the northern Gulf of Alaska through the Aleutian Islands region and eastern and northern Bering Sea into Asian waters south to the Sea of Japan (Hart 1973; Allen and Smith 1988). Isolated occurrences have been recorded along North America as far south as northern Baja California in Mexico (about lat. 32° N) (Hubbs and Wilimovsky 1964). Young juvenile Greenland turbot have not been observed in the Aleutian Islands region suggesting that adults found there originate from spawning in the eastern Bering Sea. Thus, populations in these two regions are managed as a unit stock. Whether intermingling occurs between Greenland turbot from the eastern Bering Sea and those from the Gulf of Alaska and Asian waters is unknown.

The life history of Greenland turbot is unique in that they spend the first three or four years of life on the continental shelf and move to the continental slope where the older juveniles and adults reside. Survey data show that recruitment was extremely low during the 1980's, which was accompanied by a shrinkage of the area of the shelf occupied by young juveniles (Fig. 34). When the young juveniles were abundant in 1979, they ranged over much of the eastern Bering Sea shelf and the main concentrations were located northwest of the Pribilof Islands. As abundance declined, however, the area occupied by juveniles decreased and by 1986 was limited to the northwest corner of the NWAFC survey area.

The poor recruitment of the 1980's did not cause any apparent changes in the distribution of the older juveniles and adults on the slope through 1985. Greenland turbot were caught over all depths sampled on the slope during U.S.-Japan cooperative surveys, and high catch rates at the maximum depths sampled (914 m, about 500 fm) suggest that they ranged to even greater depths (Fig. 35). They were distributed along the entire length of the eastern Bering Sea slope with intermittent areas of high density throughout the slope area.

Arrowtooth Flounder

Arrowtooth flounder and a closely related species, Kamchatka flounder (*Atheresthes evermanni*), are both found in the eastern Bering Sea (Utter et al. 1986). Because of the difficulty of differentiating these species in the field, they have usually been grouped in survey and presumably commercial catches and identified as arrowtooth flounder. The distribution of these species in the Bering Sea and the areas where they overlap may be confused by misidentification of the two species. In general, arrowtooth flounder extends from the waters off central California to the northern Bering Sea where Kamchatka flounder becomes the more dominant species (Hart 1973). The two species may overlap considerably in the eastern Bering Sea and Aleutian Islands region (Allen and Smith 1988). The Kamchatka flounder extends south along the Asian coast to the Sea of Japan.

The life history of arrowtooth flounder is similar to that of Greenland turbot in that young juveniles, until about age 4, reside in continental shelf waters. Unlike Greenland turbot, however, at older ages they occupy both shelf and slope waters. Data from the 1979 and 1982 U.S.-Japan cooperative surveys indicate that the proportion of a given age occupying slope waters gradually increases from ages 5 to 9, but that some older fish continue to occupy shelf waters at even the oldest ages.

Arrowtooth flounder occurs primarily on the outer continental shelf and slope (Fig. 36). On the shelf it is most abundant in the southeast; in some years it was abundant on both the north and south slope. Slope depths inhabited in summer are not as great as those of Greenland turbot and are limited mainly to 183–732 m (100–400 fm); higher densities are located at depths of 183–549 m (100–300 fm).

Pacific Halibut

Pacific halibut ranges from off southern California to as far north as the southern Chukchi Sea along the

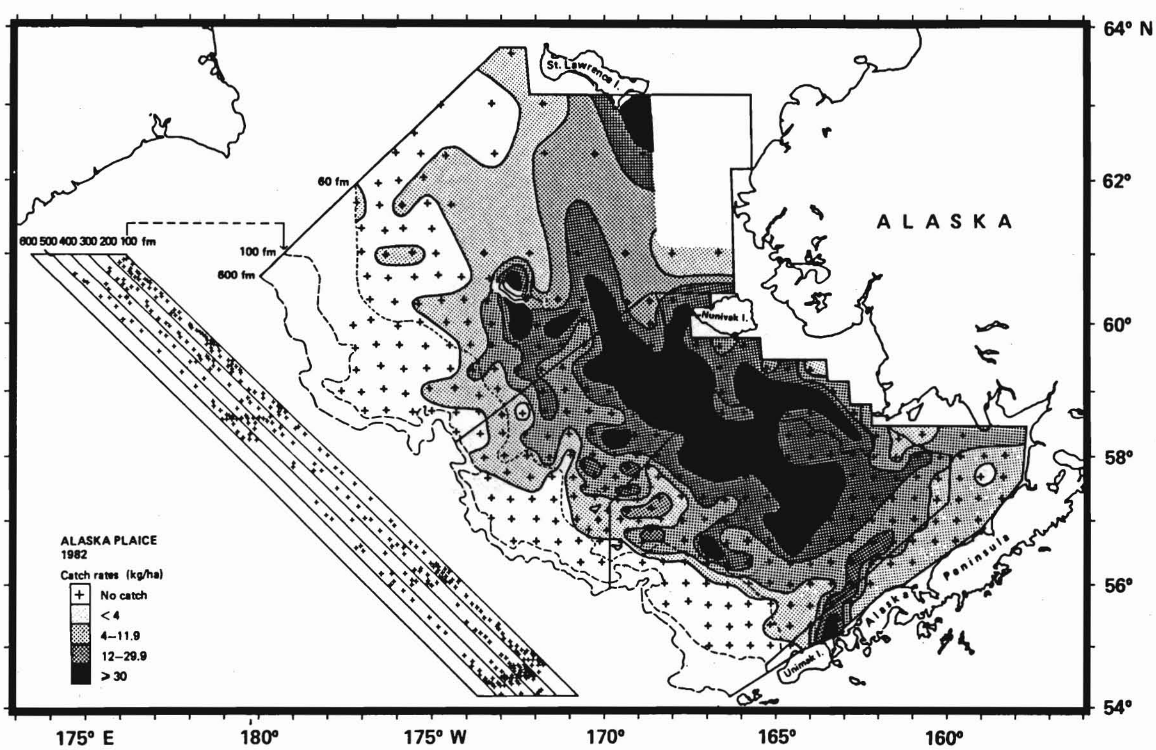


Figure 30
Distribution and relative abundance of Alaska plaice (*Pleuronectes quadrituberculatus*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1982.

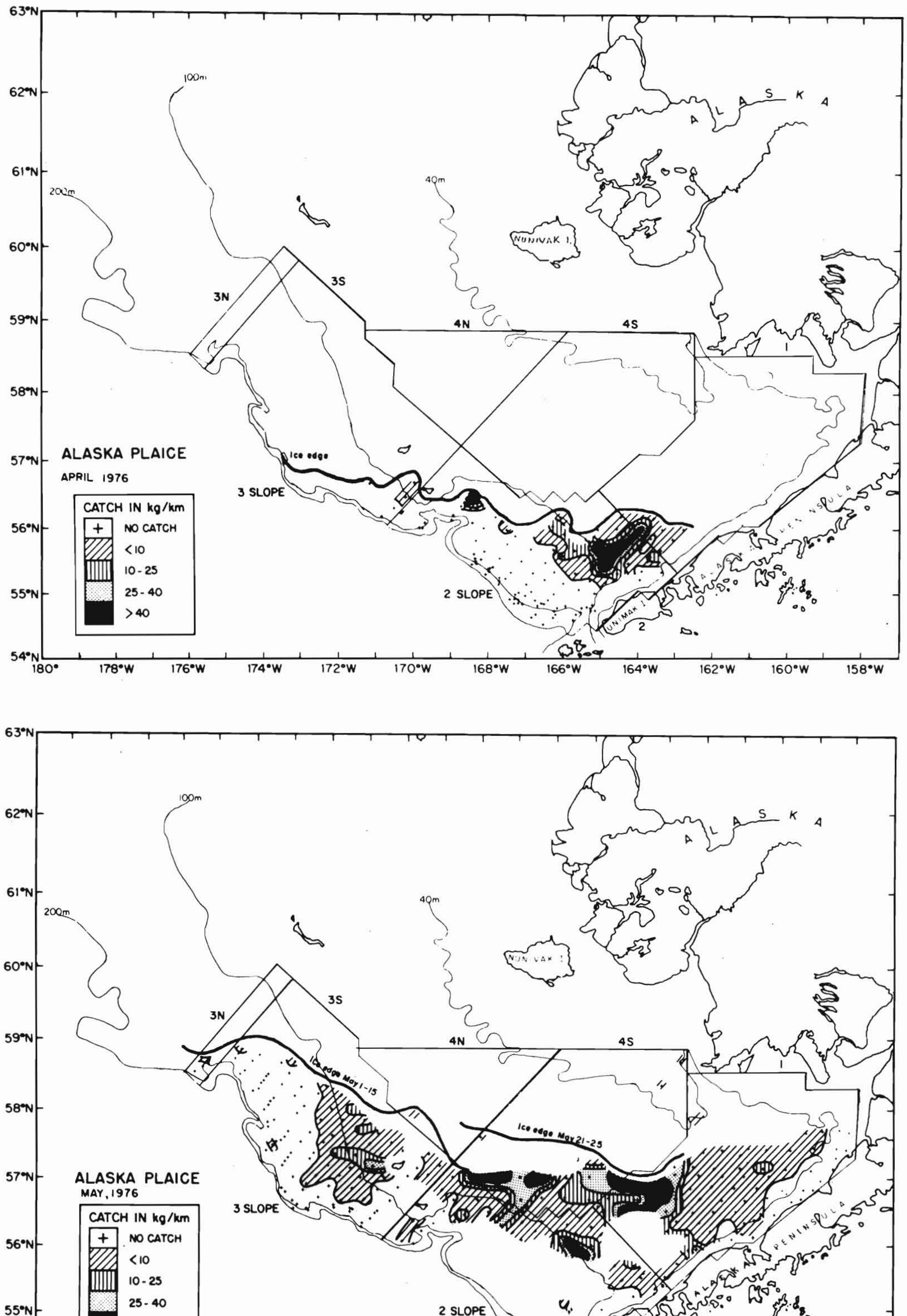


Figure 31

Distribution and relative abundance of Alaska plaice (*Pleuronectes quadrituberculatus*) as shown by Northwest and Alaska Fisheries Center survey data in April and May 1976.

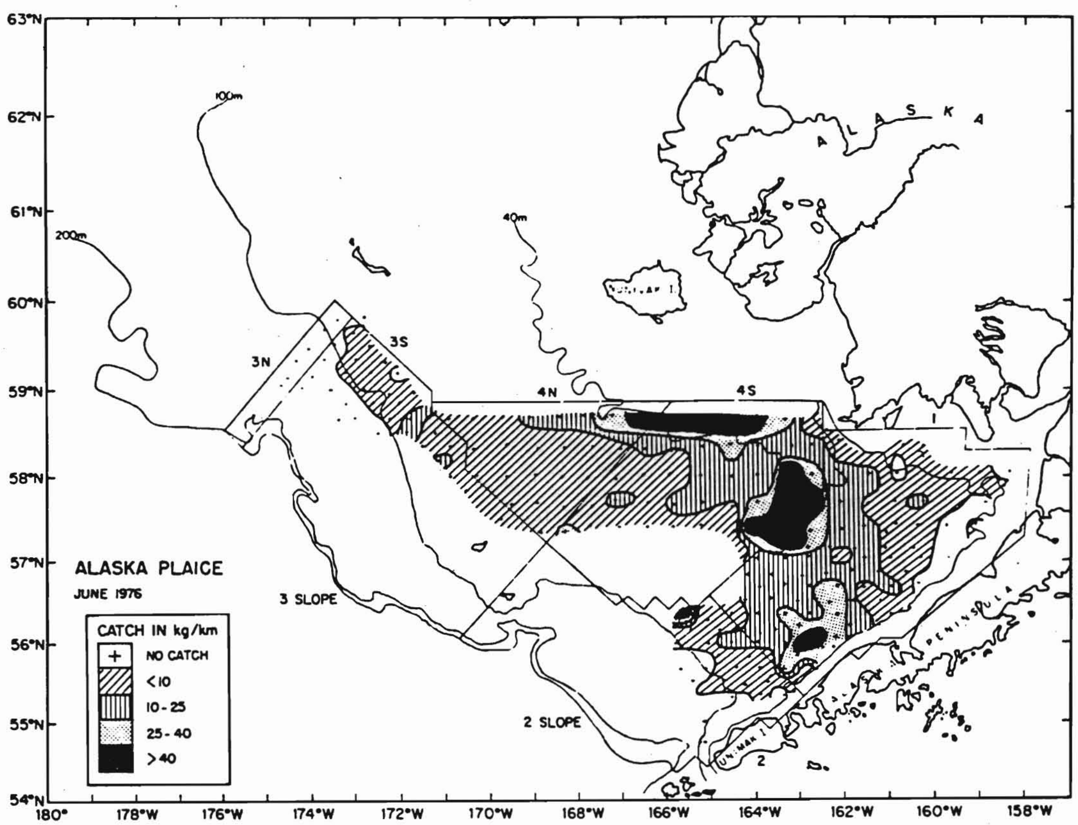


Figure 32

Distribution and relative abundance of Alaska plaice (*Pleuronectes quadrituberculatus*) as shown by Northwest and Alaska Fisheries Center survey data in June 1976.

North American coast and south to Hokkaido Island, Japan, along the Asian coast (Hart 1973; Allen and Smith 1988). Little genetic differentiation has been detected in Pacific halibut within North American waters (Grant et al. 1984). This homogeneity may result from its long-distance migrations, shown by tagging studies (Skud 1977).

Pacific halibut differs from other species of groundfish in being found intermittently along the outer continental shelf and on the inner shelf along the Alaska Peninsula and mainland (Fig. 37). Halibut occur at only very low densities or are absent in mid-shelf waters. On the continental slope in summer they are mainly found at depths of 183–549 m (101–300 fm).

Principal Species Groups

Sculpins—A total of 41 species of sculpins have been identified during U.S.-Japan cooperative surveys in the eastern Bering Sea (Table 6). These species of sculpins have a variety of life history characteristics and distributions in the eastern Bering Sea. Based on 1979 and 1982 survey data, the distribution of the complex may be quite variable from year to year (Fig. 38). In 1979, a warm year, they were most abundant on the middle and outer shelves. In 1982, a colder year, they were more heavily concentrated on the inner and middle shelves and the northern portions of the eastern Bering Sea. The sculpin complex has not been studied in detail to explain the causes of this apparent change in distribution, but the changes may be related to environmental variables or to the relative abundance of species comprising the complex.

Data from the NWAFC survey of spring 1976, which may be representative of severely cold winter-type conditions, showed offshore movement of various species of flatfishes during winter months, but such an offshore movement was not evident for sculpins (Fig. 39). During the April to June 1976 survey, sculpins were found in middle and inner shelf waters suggesting that at least some species of sculpins can tolerate extreme cold-water conditions. Sculpins also occupy continental slope waters of the eastern Bering Sea; highest densities are found at depths of 183–549 m (100–300 fm) (Fig. 38).

Eelpouts—There are three principal species of eelpouts in the eastern Bering Sea: the marbled (= sparse-

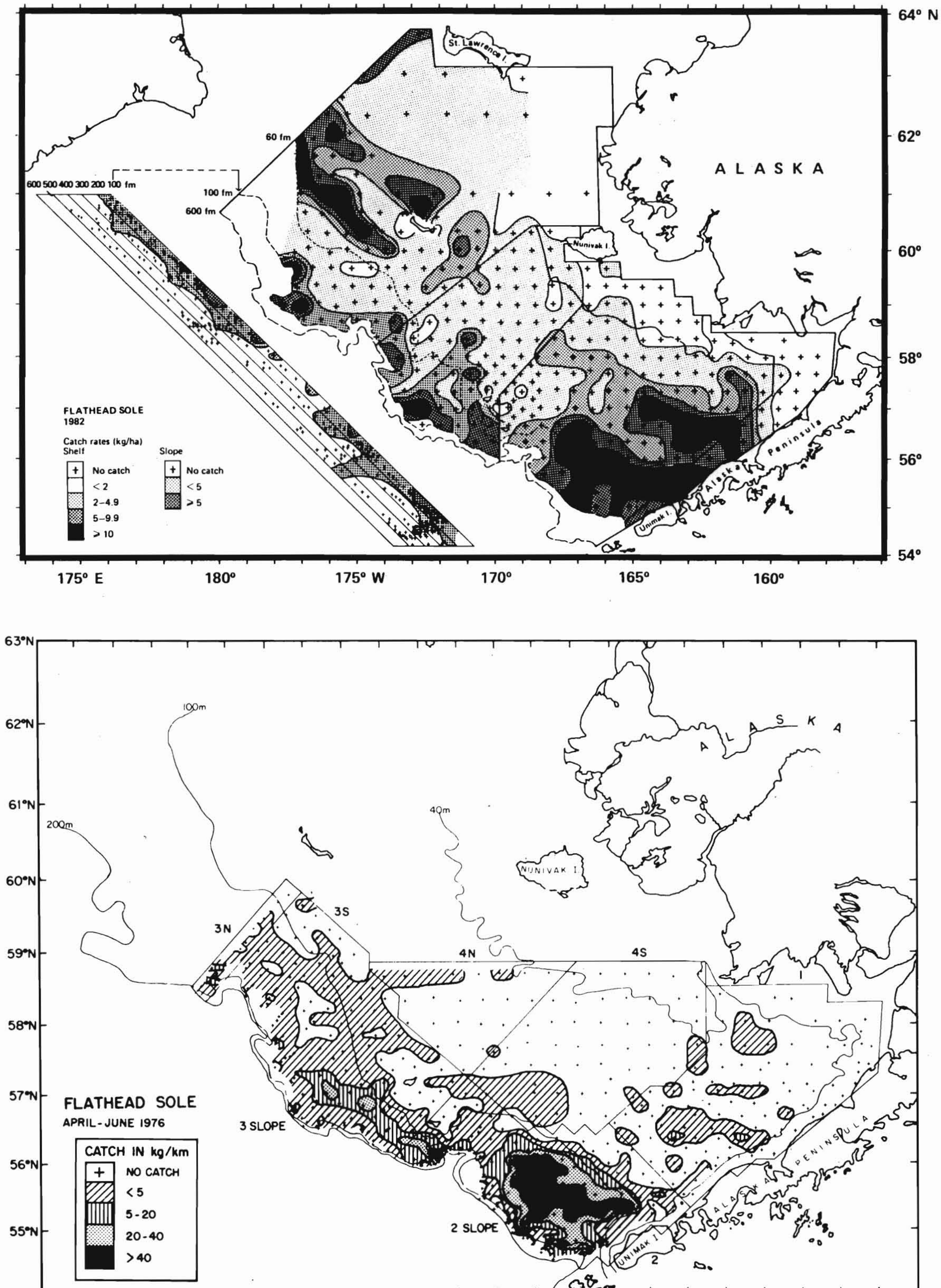


Figure 33

Distribution and relative abundance of flathead sole (*Hippoglossoides elassodon*) and Bering flounder (*H. robustus*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in 1982 and Northwest and Alaska Fisheries Center survey data in April–June 1976.

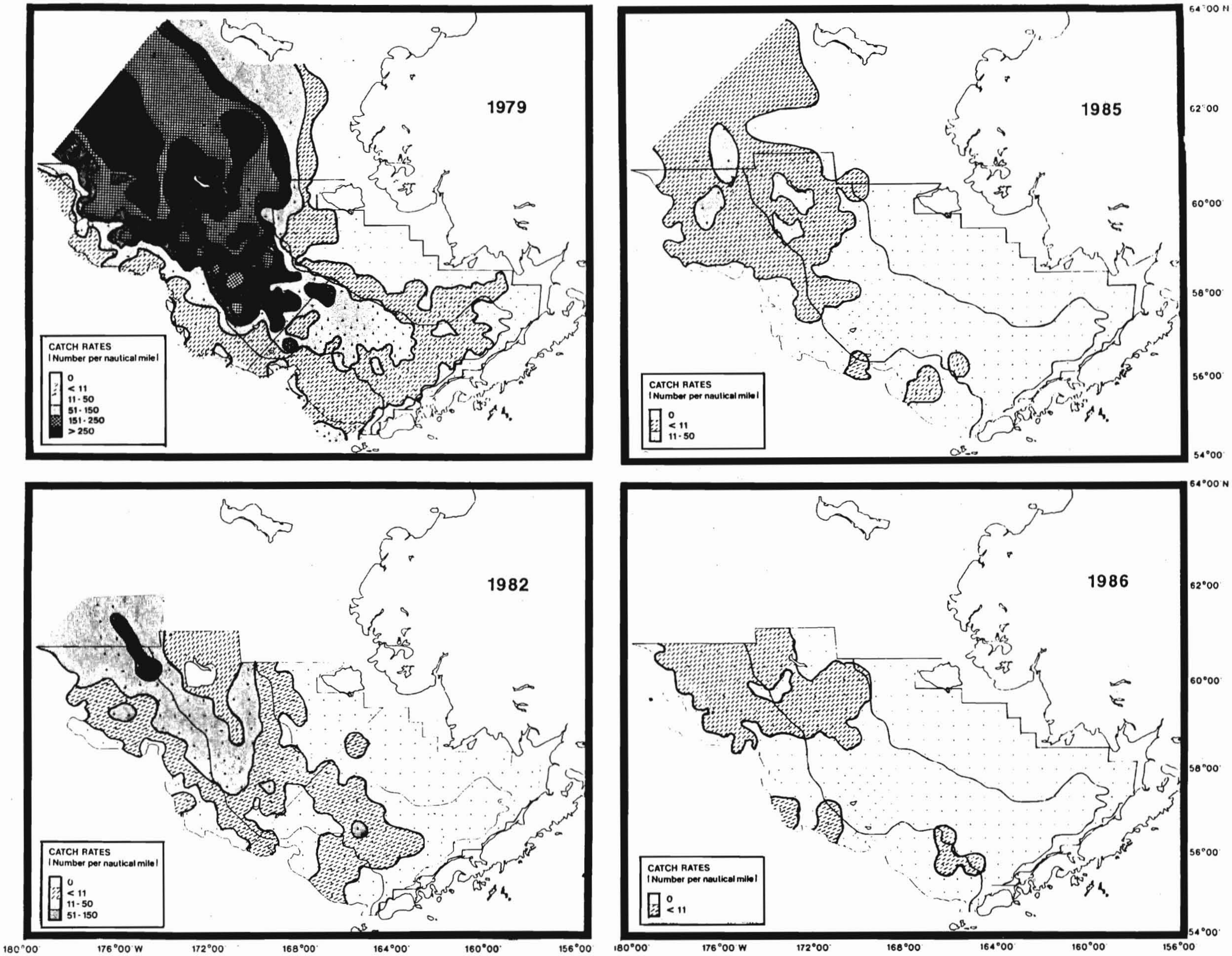


Figure 34

Distribution and density of juvenile Greenland turbot (*Reinhardtius hippoglossoides*) on the continental shelf of the eastern Bering Sea as shown by Northwest and Alaska Fisheries Center survey data, 1979-86.

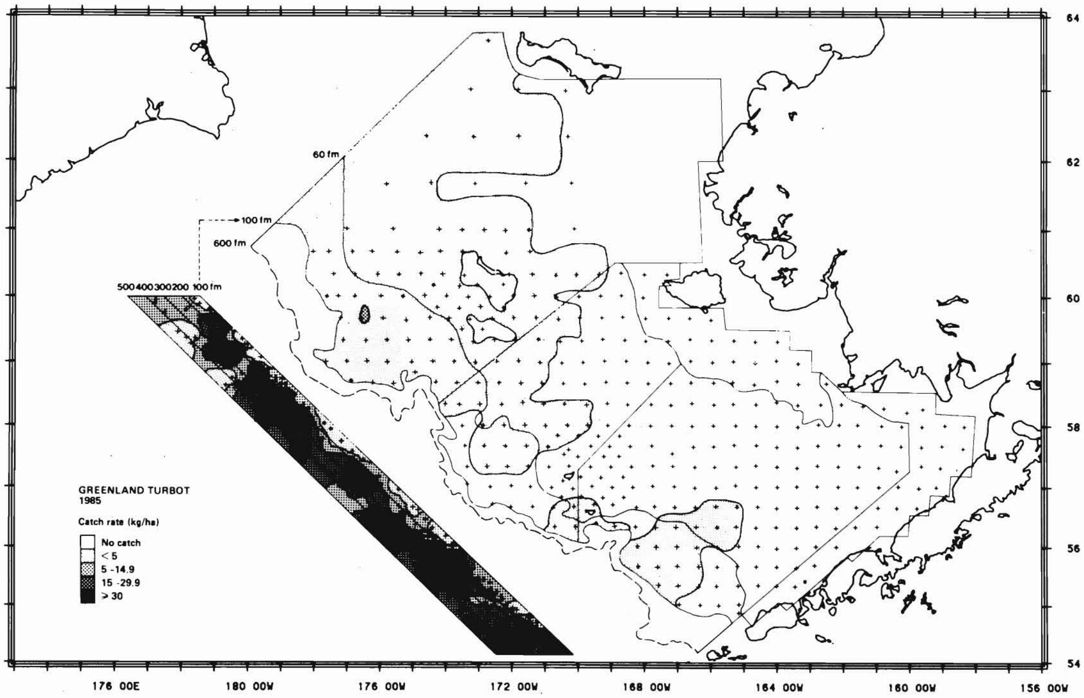


Figure 35
Distribution and relative abundance of Greenland turbot (*Reinhardtius hippoglossoides*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1985.

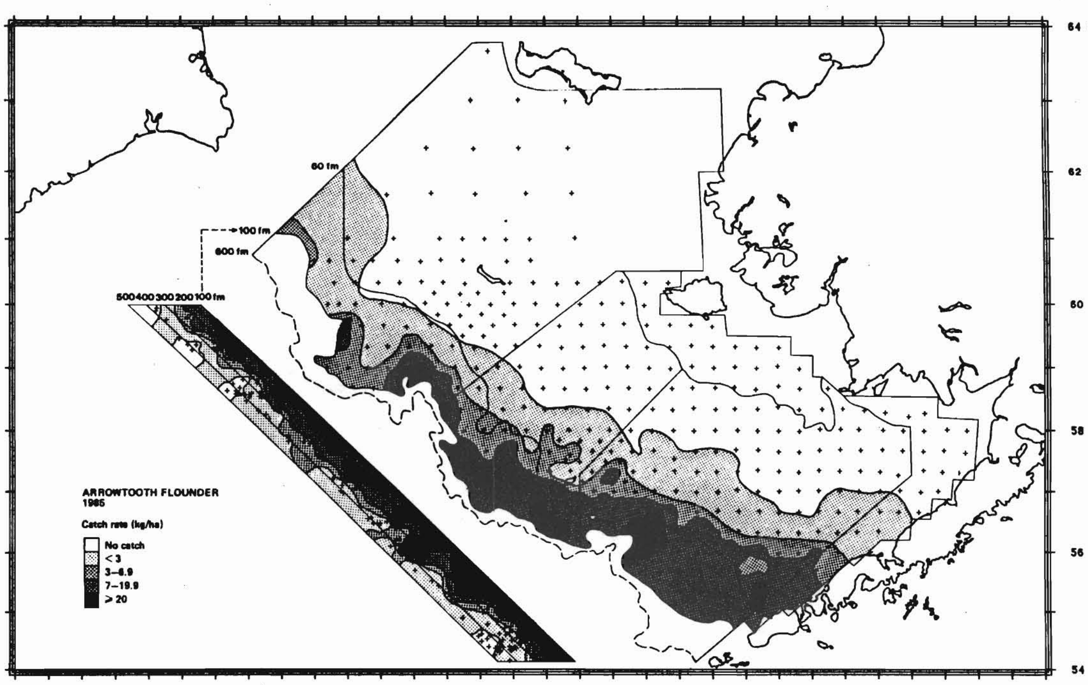


Figure 36
Distribution and relative abundance of arrowtooth flounder (*Atheresthes stomias*) and Kamchatka flounder (*A. evermanni*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1985.

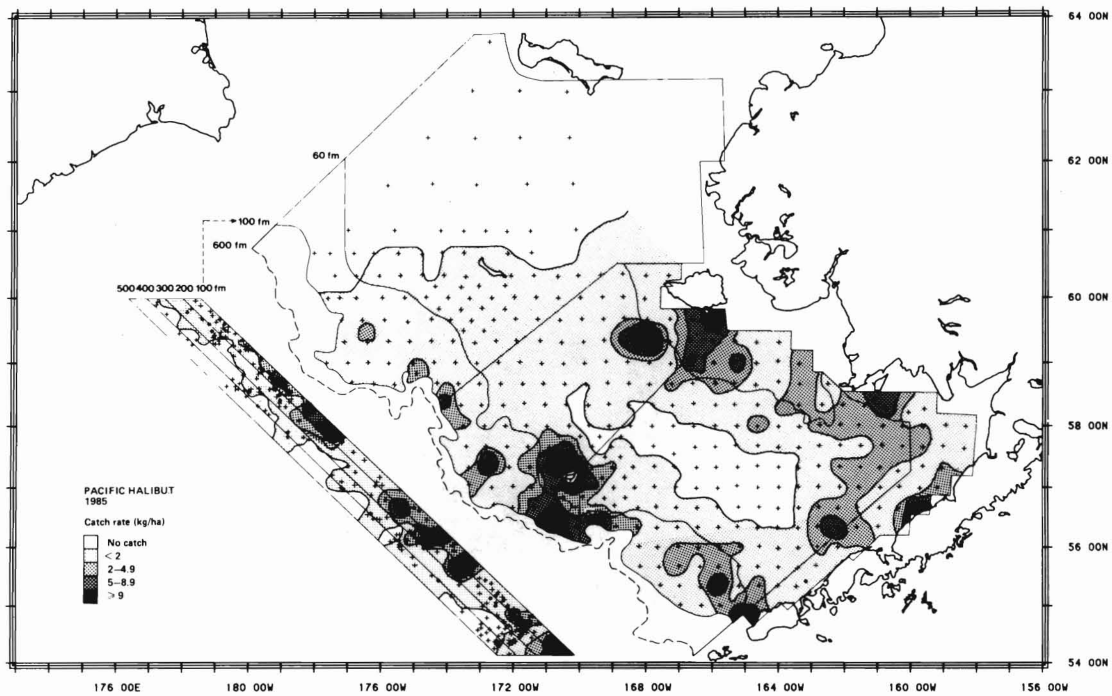


Figure 37
Distribution and relative abundance of Pacific halibut (*Hippoglossus stenolepis*) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1985.

toothed) eelpout (*Lycodes raridens*) of more northerly central shelf waters; the wattled eelpout (*L. palearis*) of the outer shelf; and the shortfin eelpout (*L. brevipes*) of the outer shelf and continental slope (Fig. 40). Eelpout abundance was substantially lower in 1985 than in 1979.

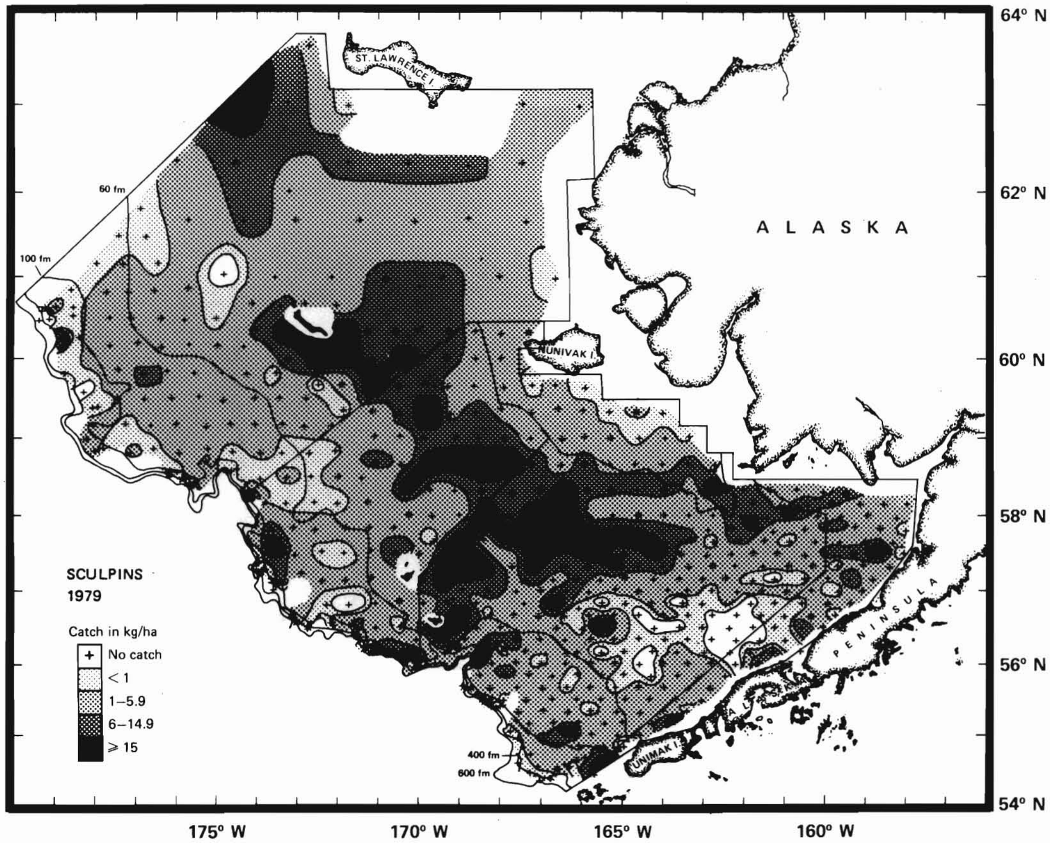
Skates—The summer distribution of skates has shown little variation. Their distribution has extended further inshore in recent years as their abundance has increased. However, they occur mainly on the middle and outer shelves; highest concentrations occur on the outer shelf (Fig. 41). They are also found in relatively low densities on the slope to at least 914 m (500 fm). The spring 1976 NWAFC survey data suggest that skates move to deeper water in winter (Fig. 41).

Estimated Biomass of the Groundfish Complex

Biomass estimates for principal species and species groups of groundfish and for all species combined are presented in Table 18. These estimates are derived from the 1979, 1981, 1982, and 1985 U.S.-Japan cooperative surveys when both continental shelf and slope waters of the eastern Bering Sea were sampled with bottom trawls. Biomass estimates for midwater populations of walleye pollock are also available from hydroacoustic surveys of 1979, 1982, and 1985 to provide assessments of the total pollock population and the overall groundfish complex. Proportions of all species and species groups comprising the total complex in a representative year (1985) during the above period are given in Table 19.

These data illustrate that a high proportion of the biomass of groundfish in the eastern Bering Sea, ranging from about 93 to 96%, is located in continental shelf waters (Table 18). The density of groundfish in the shelf and slope regions was similar; densities ranged from about 16 to 22 t/km^2 in shelf waters and from 12 to 18 t/km^2 in slope waters based on data from the four years of bottom trawl data. Thus, the distribution of biomass on or near bottom was nearly proportional to the area of shelf and slope waters sampled.

The gadids, primarily walleye pollock, dominated the groundfish complex, representing from 60 to 75% of total fish biomass based on combined bottom trawl and acoustic survey data (Tables 18 and 19). The Pleuronectidae was the second most abundant family, representing 19 to 34% of the total fish biomass. The Gadidae and Pleuronectidae together represent a high proportion (94 to 96%) of the total fish weight. Other families representing most of the remainder (3 to 5%) of the total fish biomass were the Cottidae (sculpins), Zoarcidae (eelpouts), Rajidae (skates), and the Macrouridae (grenadiers).



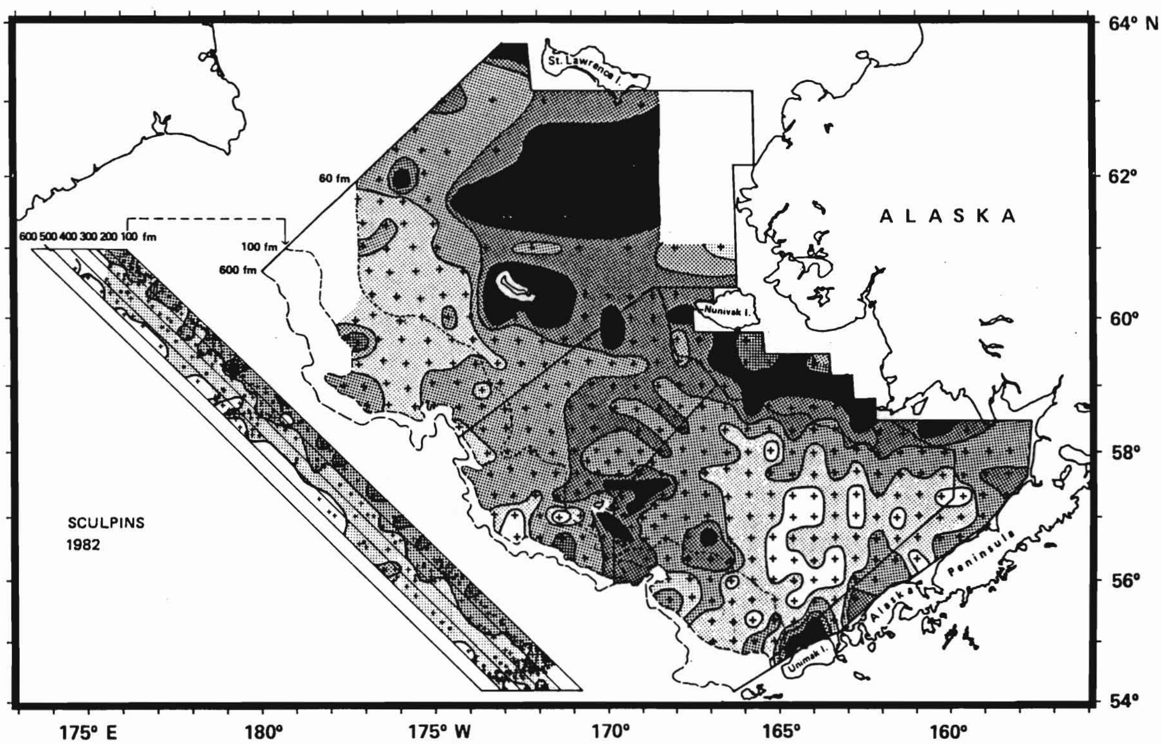


Figure 38

Distribution and relative abundance of sculpins (Cottidae) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1979 and 1982.

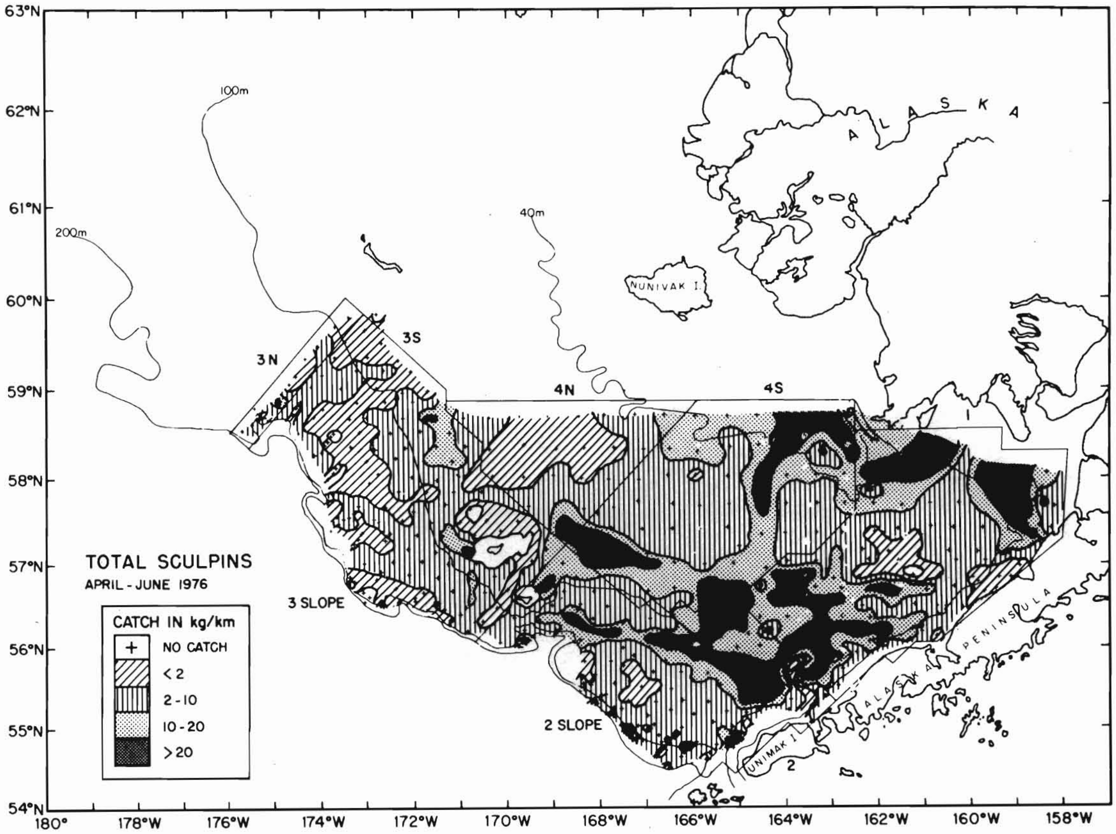


Figure 39

Distribution and relative abundance of sculpins (Cottidae) as shown by Northwest and Alaska Fisheries Center survey data in April–June 1976.

The single most important species in the complex for the overall sampling area was walleye pollock, which represented from 53 to 69% of the groundfish biomass based on combined bottom trawl and hydroacoustic data (Tables 18 and 19). The next most abundant species was yellowfin sole (12 to 22%) followed by Pacific cod (5 to 7%). Several species of flatfishes were ranked below Pacific cod; rock sole (1 to 5%) and Alaska plaice (2 to 5%) were the most abundant of these species.

Differences in species composition and relative importance of species in shelf and slope waters are readily apparent from data in Table 18. The relative importance of species in shelf waters is the same as described above for the overall survey area. In slope waters, walleye pollock, Greenland turbot, and grenadiers, mainly giant grenadier (*Albatrossia pectoralis*), were the three dominant species. Walleye pollock was probably the most abundant species in slope waters in all years, but that is difficult to confirm because the near-bottom and midwater estimates were not available each year. Other important species on the slope were sablefish, the rockfishes (*Sebastes* spp.), and arrowtooth flounder. These latter species, in addition to Greenland turbot, occupy mainly the slope region during adult stages.

Based on the combined bottom trawl and hydroacoustic survey data, the estimated biomass of the overall groundfish complex remained quite constant from 1979 to 1985 at about 15 million t (Table 18). However, some notable changes in biomass occurred in principal species and families within the complex. For example, the biomass of walleye pollock decreased by about 1 million t between 1979 and 1985. An interesting feature of the estimates for pollock was the decrease in the proportion of the biomass in midwater. Age data, presented below, shows that this decrease resulted from a change in the age composition of the population. About 70% of the pollock biomass occurred in midwater in 1979. At that time, age-1 and age-2 pollock were very abundant, and a high proportion of these young prerecruit fish occupied midwater. With a decline in abundance of these young pollock and an increase in abundance of older pollock, which occur more frequently near-bottom, the proportions of the overall population occupying midwater and near-bottom water was nearly equal by 1985.

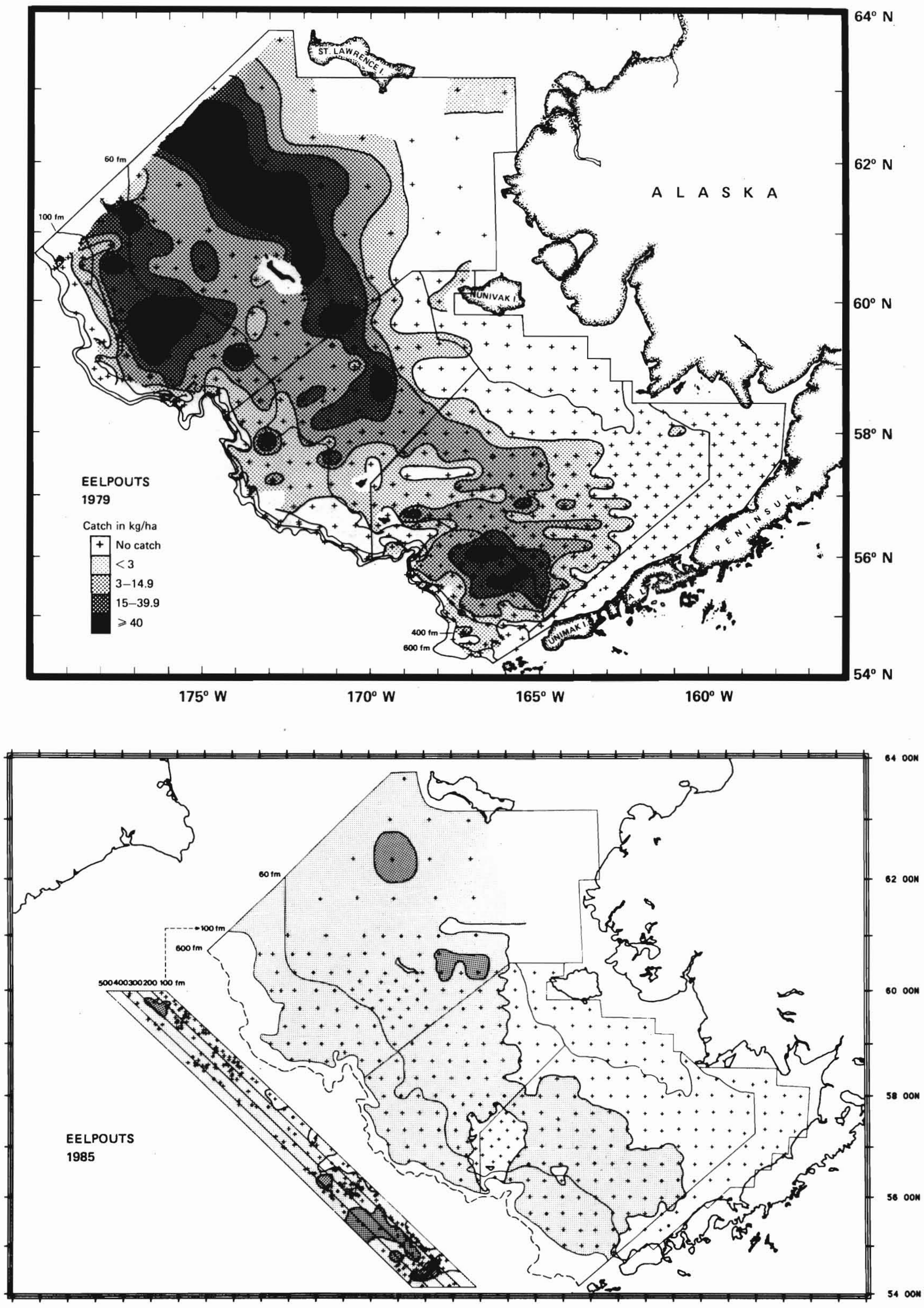


Figure 40
Distribution and relative abundance of eelpouts (Zoarcidae) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in summer 1979 and 1985.

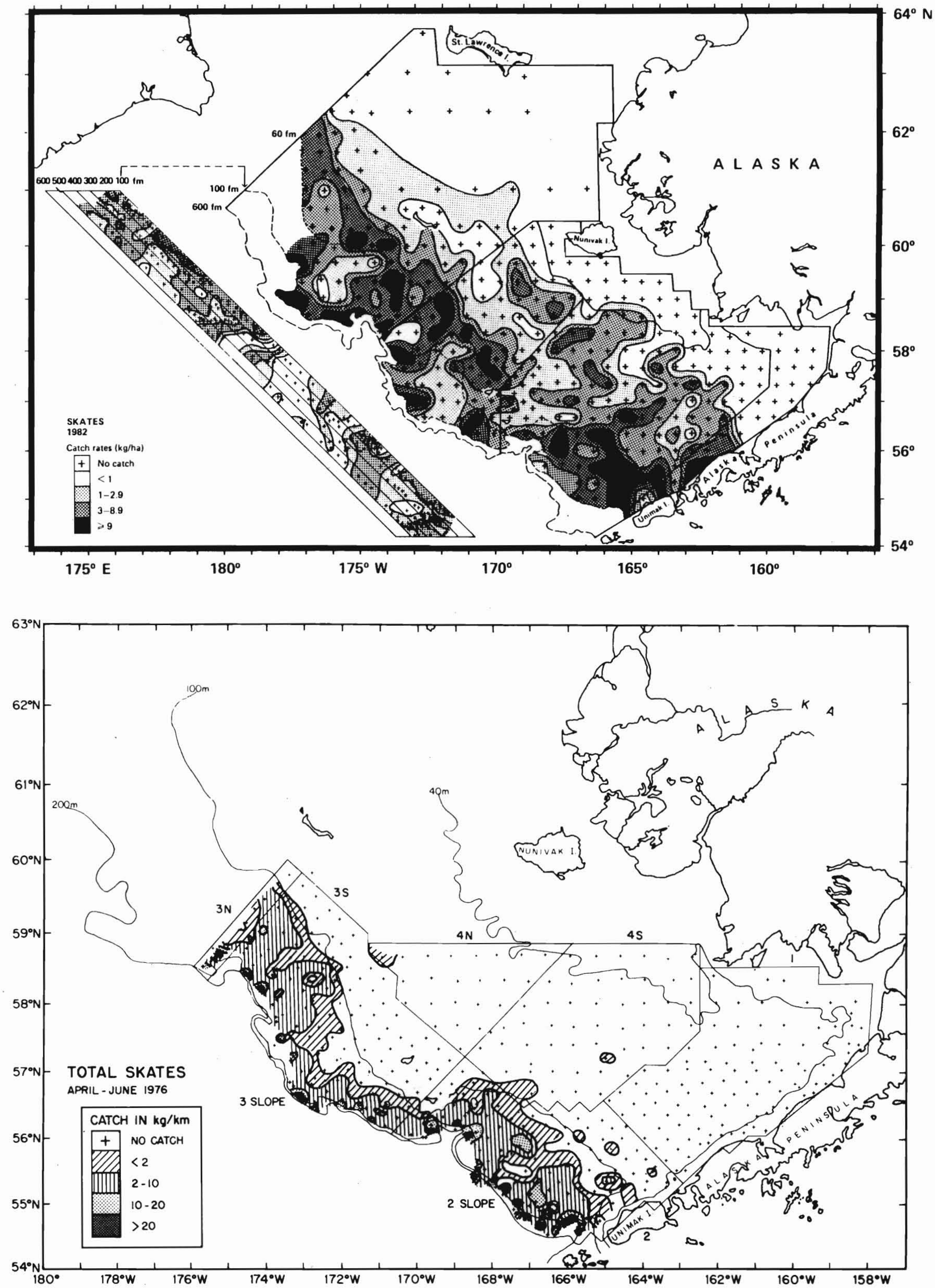


Figure 41

Distribution and relative abundance of skates (Rajidae) as shown by Northwest and Alaska Fisheries Center-Japanese Fisheries Agency cooperative survey data in 1982 and Northwest and Alaska Fisheries Center survey data in April–June 1976.

Table 18

Estimated biomass (metric tons) of principal species and species groups and the overall groundfish complex of the eastern Bering Sea based on Northwest and Alaska Fisheries Center and Japanese Fishery Agency cooperative demersal trawl and hydroacoustic surveys.

	Shelf				Slope				Total survey area			
Species	1979	1981	1982	1985	1979	1981	1982	1985	1979	1981	1982	1985
Walleye pollock												
(Demersal)	2,939,029	2,648,920	2,908,130	4,524,947	87,842	273,493	204,542	79,741	3,026,871	2,922,413	3,112,672	4,604,688
(Midwater)	—	—	4,513,290	4,528,363	—	—	369,010	270,163	7,457,573	—	4,882,300	4,798,526
Pacific cod	754,314	1,034,629	1,020,550	961,049	11,133	23,825	34,708	22,143	765,447	1,058,454	1,055,258	983,192
Other cods	29,951	2,033	2,170	146	105	43	50	22	30,056	2,076	2,220	168
Sablefish	42,508	9,350	7,497	18,485	12,818	39,442	42,944	34,720	55,326	48,792	50,441	53,208
Pacific ocean perch	5,247	0	162	844	4,460	9,822	5,948	32,392	9,707	9,822	6,110	33,236
Other *Sebastes* rockfishes	388	690	5,758	42	2,456	4,417	5,833	5,735	2,844	5,107	11,591	5,777
Thornyheads	0	0	0	0	3,190	4,970	4,353	5,119	3,190	4,970	4,353	5,119
Yellowfin sole	1,866,523	2,394,713	3,275,351	2,277,423	<1	0	0	0	1,866,523	2,394,713	3,275,351	2,277,423
Rock sole	194,734	302,354	572,233	720,309	61	82	55	36	194,795	302,436	572,288	720,345
Flathead sole	104,894	162,899	197,450	329,919	2,936	3,920	6,212	10,474	107,830	166,819	203,662	340,393
Alaska plaice	277,198	535,827	700,245	553,294	<1	0	0	0	277,198	535,827	700,245	553,294
Greenland turbot	146,123	77,208	31,443	7,533	127,525	99,624	90,601	79,247	273,648	176,832	122,044	86,780
Arrowtooth flounder	42,109	53,543	73,178	163,562	33,815	34,881	24,749	74,392	75,924	88,424	97,927	237,954
Pacific halibut	66,862	54,338	61,562	69,109	2,541	2,386	1,835	7,105	69,403	56,724	63,397	76,214
Other flatfishes	50,916	88,041	147,770	33,044	392	377	1,709	987	51,308	88,418	149,479	34,031
Pacific herring	12,648	2,067	3,643	32,109	8	0	0	0	12,656	2,067	3,643	32,109
Smelts	10,386	5,724	10,658	2,626	29	12	4	60	10,415	5,736	10,662	2,686
Sculpins	287,828	193,919	331,481	171,805	7,847	7,494	4,623	2,939	295,675	201,413	336,104	174,744
Snailfishes	17,292	1,006	2,410	2,875	637	382	905	606	17,929	1,388	3,315	3,481
Poachers	21,803	14,928	13,908	3,176	51	16	23	20	21,854	14,944	13,931	3,196
Eelpouts	321,887	163,304	109,265	12,127	2,593	1,334	4,681	4,713	324,480	164,638	113,946	16,840
Skates	70,006	159,754	169,322	148,309	4,301	4,033	3,927	5,658	74,307	163,787	173,249	153,967
Sharks	401	0	0	48	0	77	36	360	401	77	36	408
Grenadiers	0	0	0	0	91,470	90,492	104,728	107,624	91,470	90,492	104,728	107,624
Other fishes	18,446	9,981	10,934	7,119	1,547	1,781	2,138	3,466	19,993	11,762	13,072	10,585
Total fishes												
(Demersal)	7,281,493	7,915,229	9,655,120	10,039,899	397,758	602,903	544,604	477,559	7,679,250	8,518,131	10,199,724	10,517,459
(Demersal & midwater)			14,168,410	14,568,262	—	—	913,614	747,722	15,136,823	—	15,082,024	15,315,985

In 1979–85 Pacific cod biomass increased from 765,000 t to about 1 million t. This was a continuation of a five-fold or greater increase in biomass of cod resulting from strong recruitment from the 1977–78 year classes.

During the 1979–85 period, there was a relatively small increase in the biomass of sablefish and the rockfishes, the latter mainly due to greater biomass of Pacific ocean perch (Table 18). Biomass of noncommercial species declined about 364,000 t during 1979–85. The decline was persistent and severe for some of the representative families (e.g., eelpouts and poachers (Agonidae)) (Table 18).

Increases in flatfish biomass of about 1.4 million t offset the declines in walleye pollock and other species to maintain the biomass of the overall groundfish complex at about 15 million t during 1979–1985. With the exception of Greenland turbot and Pacific halibut, increases in biomass of all the flatfishes can be noted, although the biomass of some species peaked prior to 1985. As discussed earlier, a change in the standard NWAFC survey trawls in 1982 may have overemphasized the increase in biomass of flatfishes between 1979–81 and 1982–85. The trawls used prior to 1982 may have been less efficient for flatfish than the standard trawls used in later years.

Historical Changes in Abundance

Walleye Pollock

Because walleye pollock can occur in midwater, the population is only partially sampled by bottom trawls; thus estimates of total biomass are not available from these assessment surveys, but have been derived from cohort analysis and combined bottom trawl and hydroacoustic surveys. Estimates of biomass of eastern Bering Sea pollock from both bottom trawl and hydroacoustic surveys are only available for three years (1979, 1982, and 1985). However, Japanese data collections from their walleye pollock fishery provide biomass estimates of the exploitable stock through cohort analysis back to the start of the fishery in the mid-1960's. Methods and results of these cohort analyses are described by Bakkala et al. (1987a) and Wespestad and Traynor (1988). Data used in these analyses are probably most questionable for 1964–72. In these earlier years, age data were inadequate and pooled age-length keys from 1978 to 83 were applied to the catch and length-frequency data for 1964–72. Other inadequacies in data from this period may have biased the results from the cohort analyses; for example, the accuracy and representativeness of the reported catch and length-frequency data are not known. Catch data reported by fishing nations were also used in 1964–77, as were length-frequency data in 1964–72. Length and age data collected by the NWAFC Foreign Fishery Observer Program was available for 1973–85. All catch and biological data used in the analysis for 1979–85 were collected by the NWAFC Observer Program.

Table 19

Estimated biomass of principal species and families in the eastern Bering Sea groundfish complex as shown by the 1985 U.S.-Japan cooperative demersal trawl and hydroacoustic surveys.

		Proportion of total	
Species	Estimated biomass (metric tons)	Individual species and families	Groups
Pollock	9,403,214	0.614	
Pacific cod	983,192	0.064	
Other cods	168	<0.001	0.678
Sablefish	53,208	0.004	
Pacific ocean perch	33,236	0.002	
Other rockfishes	5,777	<0.001	
Thornyheads	5,119	<0.001	0.006
Yellowfin sole	2,277,423	0.149	
Rock sole	720,345	0.047	
Flathead sole	340,393	0.022	
Alaska plaice	553,294	0.036	
Greenland turbot	86,780	0.006	
Arrowtooth flounder	237,954	0.016	
Pacific halibut	76,214	0.005	
Other flatfishes	34,031	0.002	0.283
Pacific herring	32,109	0.002	
Smelts	2,686	<0.001	
Sculpins	174,744	0.011	
Snailfishes	3,481	<0.001	
Poachers	3,196	<0.001	
Eelpouts	16,840	0.001	
Skates	153,967	0.010	
Sharks	408	<0.001	
Grenadiers	107,624	0.007	
Other fishes	10,585	0.001	0.032
Total	15,315,985	1.000	

Results of cohort analysis for walleye pollock (Wespestad and Traynor 1988) indicated that the exploitable population (ages 2–9) underwent a major increase in abundance during the late 1960's (Fig. 42). The biomass was estimated to be as low as about 2 million t in 1964 but then increased four- to six-fold over the following seven years reaching a peak of 12.4 million t in 1971. Following this peak, biomass declined in the mid-1970's to around 8 million t, increased to 10.5 million t in 1982, and then declined again to 8.6 million t in 1985. Biomass estimates from the bottom trawl-hydroacoustic surveys (for fish age 1 and older) were of the same magnitude as those from cohort analysis, although the trends in abundance shown by the two methods were opposite from 1979 to 1985 (Fig. 42). The 1985 estimates from the survey (9.4 ± 1.6 million t) and cohort analysis (8.6 million t) were reasonably similar, but this may be due in part to the use of age composition data from the 1985 survey and trends in biomass from the 1979 to 1985 bottom trawl-hydroacoustic surveys to adjust the cohort analysis. Results from earlier years of the cohort analysis may be the most questionable because catch-at-age data were less reliable, particularly during the 1960's when the analysis showed a major increase in abundance of walleye pollock.

Survey data from this period can be examined to provide some evaluation of the results from cohort analysis. All surveys prior to 1979 used bottom trawling techniques; therefore, comparisons between survey data and the results of cohort analysis can only be made in

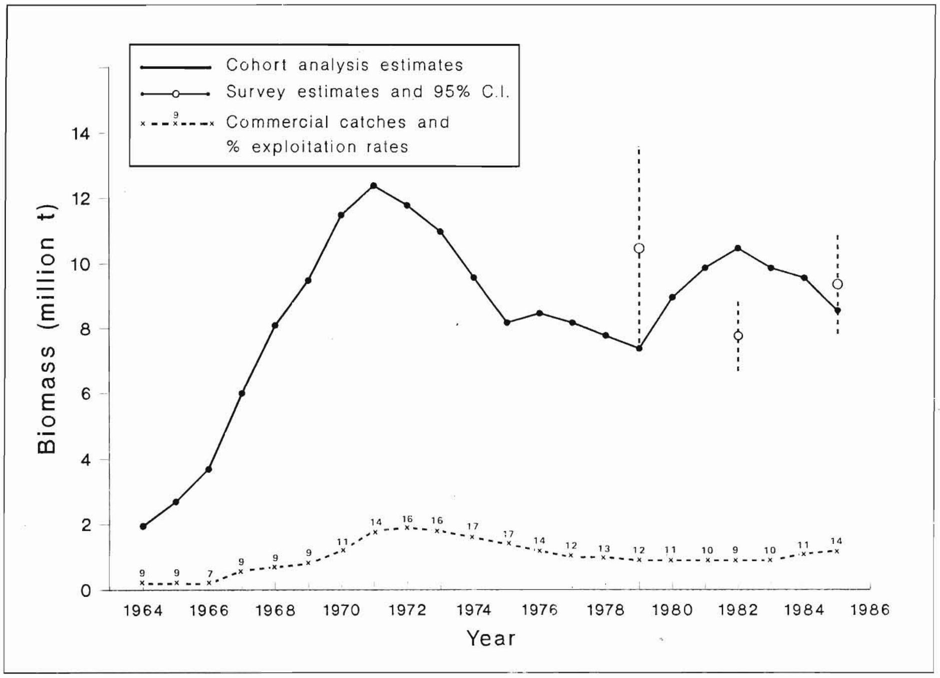


Figure 42
Historical trends in biomass (metric tons) of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea as shown by results from cohort analysis (1964-85) (Wespestad and Traynor 1988) and combined hydroacoustic and demersal trawl surveys (1979, 1982, and 1985). Commercial catches are also shown; numbers above line indicate percent exploitation rates.

terms of relative changes in abundance. An important assumption in making these comparisons is that the bottom trawl data reflect the abundance of the overall population. Evidence from combined bottom trawl and hydroacoustic surveys by the NWAFC suggest that this is not always the case and that the proportion of the overall population sampled by bottom trawls is dependent on the age composition of the population. A higher proportion of older than younger age groups occupy waters near bottom and are thus more vulnerable to bottom trawling. For example, in 1979 when age-1 and age-2 fish were very abundant, only about 30% of the total estimated pollock biomass in the eastern Bering Sea was derived from bottom-trawl data. In 1982 and 1985, when older ages formed a higher portion of the population, 39 and 49% respectively of the estimated total biomass were derived from bottom trawl data. Thus the bottom trawl data may primarily detect relative changes in the abundance of older age groups.

To evaluate results from cohort analysis in earlier years, survey data that may be representative of the relative changes in biomass of walleye pollock in the mid-1960's to early or mid-1970's were compared with relative changes in biomass from cohort analysis over the same or similar time periods (Table 20). Some of the biomass estimates from survey data support the results from cohort analysis while others do not. Results from the cohort analysis agreed best with the 1957–59 Soviet and 1975 NWAFC data, data sets which may be the least comparable. There was less agreement between cohort analysis results and the 1965 IPHC and 1975 NWAFC data, and poorest agreement with the 1966–71 JFA survey data which is assumed to be the most compatible. Thus, results from the surveys do not provide consistent evidence in support of results from cohort analysis.

In support of the results from cohort analysis, the percentage volume of pollock in stomach contents of northern fur seals (*Callorhinus ursinus*) in the vicinity of the Pribilof Islands was consistently high in 1973–74 (>48%). In years prior to 1968, however, pollock comprised a variable and usually low percentage of the seal's diet (<20% in eight of the months sampled) (Swartzman and Haar 1983).

Another consideration in evaluating results from cohort analysis is the estimates of natural mortality used. The results from cohort analysis in the late 1960's correspond to the years in which the walleye pollock fisheries first developed. Fishing mortality in this early period was thus lower than in later years when the fishery was fully developed. Theoretically, natural mortality decreases when fishing mortality increases

Table 20
Relative changes in biomass estimates for walleye pollock (*Theragra chalcogramma*) from survey data and cohort analysis over the same or similar time periods.

Initial survey			Later survey			Relative change in biomass estimates (%)	
Year	Nation or agency	Biomass estimate	Year	Nation or agency	Biomass estimate[b]	Initial and later survey	Cohort analysis estimates
1957–59	USSR	114,100	1975	NWAFC	471,400	+313	+332 (1964–75)
1965	IPHC[a]	1,113,600	1975	NWAFC	1,958,400	+76	+203 (1965–75)
1966	JFA	1,304,000	1971	JFA	956,200	-27	+235 (1966–71)

[a] International Pacific Halibut Commission.
[b] Estimates from the same areas sampled during the initial survey areas.

(Wakabayashi 1975). Because the constant natural mortality values used in the cohort analysis were derived after the fishery had fully developed, natural mortality during the late 1960's may have been underestimated. If this were the case, then back- calculations through cohort analysis would have underestimated the biomass of cohorts during the late 1960s and overestimated the increase in biomass between the late 1960's and early 1970's.

In summary, evidence to support the results from cohort analysis in the late 1960's is mixed. Some increase in biomass of pollock probably occurred in this period, but perhaps not of the magnitude shown by cohort analysis.

Historical fluctuations in biomass of walleye pollock appear to be the result of variation in recruitment. Recruitment of age-2 pollock, as shown by cohort analysis, was apparently far below average in the early 1960's, but improved in subsequent years, with a series of five stronger than average year classes produced in 1965–69 (Fig. 43). The decline in biomass after 1972, despite the recruitment of the strong 1972 year class, was apparently caused by the declining abundance of the strong 1965–69 year classes, the poor recruitment from the 1970 and 1971 year classes, and the accumulative removals by the fishery in 1970–75, which totaled 9.6 million t. Biomass remained relatively stable in 1976–79, which corresponded to a period of near-average

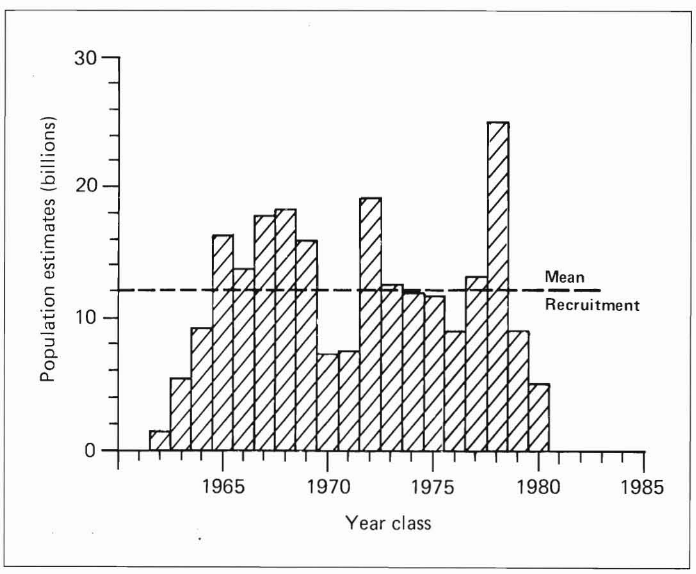


Figure 43
Recruitment of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea at age 2 based on cohort analysis.

recruitment (1973–77 year classes). The 1978 year class, which appears to be the strongest year class yet observed (Fig. 43), resulted in an increase in biomass between 1979 and 1982 to 10.5 million t. From 1982 to 1985, recruitment and biomass declined, but biomass was still relatively high in 1985 at approximately 9.0 million t.

In addition to these changes in walleye pollock biomass between the late 1970's and mid-1980's, there was also a major change in the age composition of the population. Age-composition data during the late 1970's showed a rather consistent pattern of principal age groups in survey and fishery catches (Fig. 44). Survey catches were composed primarily of age groups 1–4, and fishery catches were mainly ages 2–4 with age-3 fish usually dominating the catch. The abundance of age-5 and older pollock was much lower than that of these younger ages. Since 1982, this pattern has changed with the older 4– to 8-year fish becoming important components of the survey and fishery catches. In part, this has been the result of the strength of the 1978 year class, which continued to contribute significantly to survey and fishery catches at age 8 in 1986. However, other factors are probably involved in the aging of the population because less abundant year classes are also becoming important components of the catches at advanced ages.

Pacific Cod

Because Pacific cod from the Bering Sea are difficult to age and in the past were usually taken by commercial fisheries as a bycatch species, time series of age data and CPUE estimates from the fisheries are not available. Thus, it has not been possible to use cohort analysis to examine historical changes in biomass. Data from NWAFC surveys have documented a major increase in biomass of Pacific cod since 1975 (Fig. 45). Between 1975 and the early 1980's, a several-fold increase in biomass was shown by these data. The 1975 estimate of about 53,000 t is obviously low because the commercial catch in that year was about 52,000 t so the actual increase was somewhat less. Nevertheless, the population biomass had increased substantially and during the 1980's was at an all-time observed high of approximately 1 million t (Fig. 45). This increase in biomass was due to the recruitment of two strong year classes spawned in 1977 and 1978. Although the biomass of these year classes had declined, better than average recruitment from the 1982–85 year classes maintained the biomass near 1 million t through 1986.

Biomass point estimates from IPHC and JFA survey data from 1965 to 1971, standardized to the NWAFC survey area of 1975 and 1979–86, suggest that the biomass of Pacific cod was also high in the mid-1960's, perhaps about 1 million t, but declined in the late 1960's and early 1970's. The validity of this trend is questionable because of the wide 95% confidence intervals around the point estimates. The 1975 NWAFC survey data suggest that biomass remained at a lower level until the late 1970's when the strong 1977–78 year classes appeared.

Pacific Ocean Perch

This species primarily occurs in continental slope waters of the eastern Bering Sea, and because assessment surveys of slope waters were not conducted prior to 1979, historical trends in biomass are not available from survey data. However, long-term trends in abundance of Pacific ocean perch have been followed through indices of relative abundance from Japanese commercial trawl fisheries (Ito 1987). These CPUE estimates showed a persistent long-term decline in excess of 90% over the period from the early 1960's to the late 1970's.

Results from stock-reduction analysis show a similar trend (Fig. 46) with a decline in biomass from near 250,000 t in the mid-1960's to less than 50,000 t in the mid-1970's. Since 1977, the stock has shown some recovery with biomass reaching an estimated 61,000 t in 1986. Survey biomass estimates have been lower than those from stock-reduction analysis, but they also reflect an improvement in the condition of the stock during the 1980's (Fig. 46).

Sablefish

This species also occurs primarily in continental slope waters, for which survey biomass estimates are not available prior to 1979. However, data from the Japanese longline fishery showed a steady decline in CPUE of eastern Bering Sea sablefish through 1979 when it was 20% of the level in 1970 (McDevitt 1987). Between 1979 and 1985, biomass increased because of the recruitment of a strong year class spawned in 1977. This increase was documented by JFA longline survey data (Sasaki 1987) and by mean biomass estimates from cooperative NWAFC-JFA trawl survey data (Table 21).

Although the abundance of sablefish had increased, the biomass during the mid-1980's was believed to be lower than that in the early 1960's. Based on stock-reduction analysis for the combined eastern Bering Sea and Aleutian Islands populations (results are not available for the eastern Bering Sea alone), the biomass in 1986 was estimated to be from 59 to 67% of the virgin biomass depending on the recruitment coefficient used in the analysis (Fig. 47).

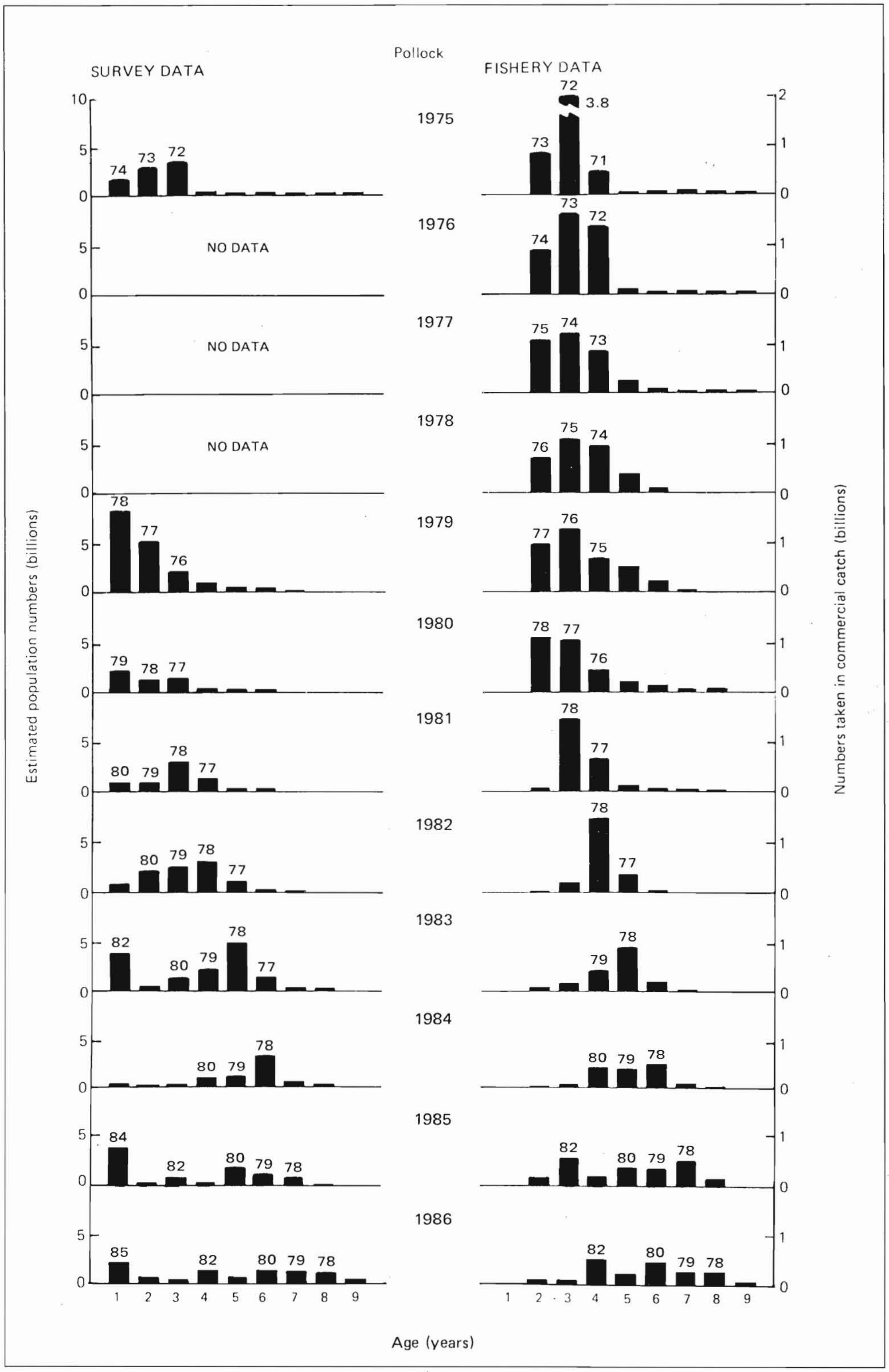


Figure 44
Age composition of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea based on data from Northwest and Alaska Fisheries Center bottom trawl surveys and the commercial fishery. Principal year classes are shown above the bars.

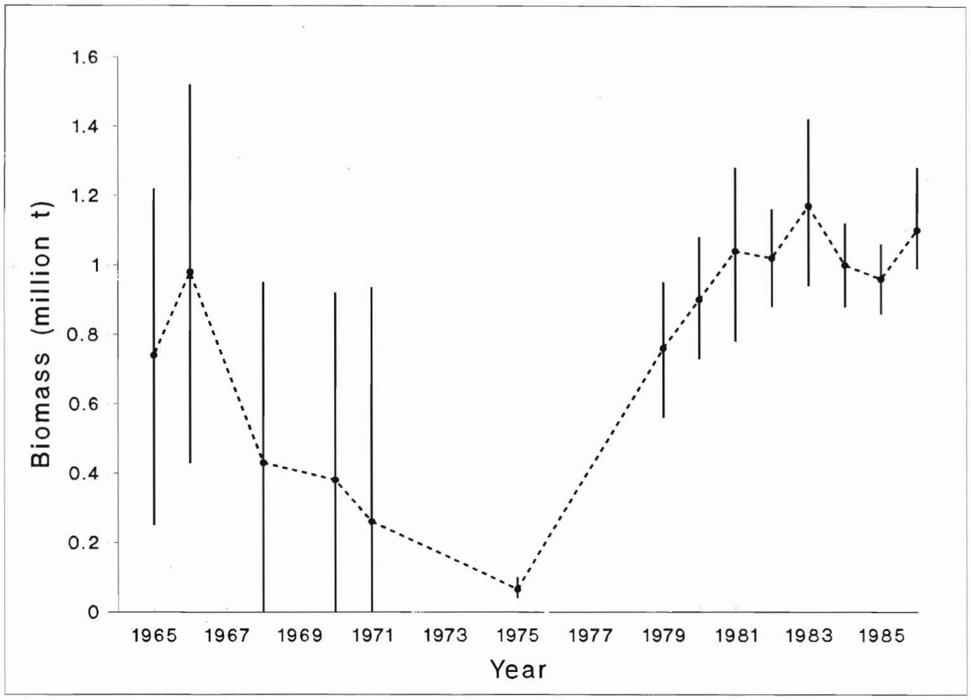


Figure 45

Biomass estimates (metric tons) and 95% confidence intervals for Pacific cod (*Gadus macrocephalus*) of the eastern Bering Sea as shown by 1965 International Pacific Halibut Commission survey data, Japanese Fisheries Agency survey data in 1966–71 and Northwest and Alaska Fisheries Center survey data in 1975 and 1979–86.

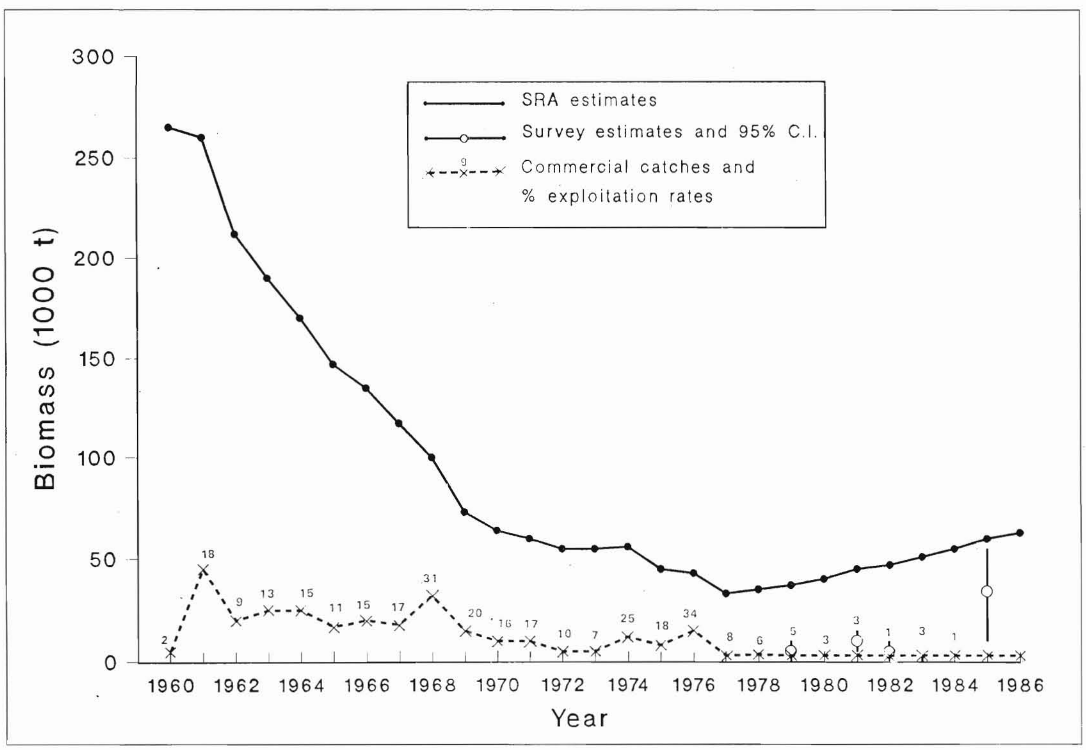


Figure 46

Biomass estimates (metric tons) for Pacific ocean perch (*Sebastes alutus*) of the eastern Bering Sea from stock-reduction analysis (SRA) (after Ito 1987) and Japanese Fisheries Agency and Northwest and Alaska Fisheries Center survey data. Commercial catches are also shown; numbers above line indicate percent exploitation rates.

Yellowfin Sole

Because biological data on yellowfin sole had been collected by Japanese scientists since the early years of their fisheries, historical trends in biomass can be examined by cohort analysis. Survey data are also available to provide periodic independent estimates of biomass.

Cohort analyses (Bakkala and Wespestad 1986, 1987) adjusted with the 1985 survey age composition and trends in fishery CPUE, have indicated that the biomass of yellowfin sole (ages 7–17) may have been approximately 1.2 million t in 1959–60 at the time the fishery for this species intensified (Fig. 48). The intense exploitation, which continued through 1962, apparently reduced the population biomass to less than half the 1959–60 level.

Cohort analysis indicated that biomass remained low from 1963 through the early 1970's. Biomass estimates from the IPHC and Japanese surveys for 1965–71, which were standardized to the NWAFC survey area of 1975 and 1979–86, agree quite well with results of the cohort analysis and suggest that biomass may have been about 500,000 t (Fig. 48).

Both cohort analysis and NWAFC survey data show that the yellowfin sole population began to recover in the early 1970's. Biomass of the population continued to increase through the early 1980's as a result of the recruitment of a series of strong (1968–77) year classes (Figs. 49 and 50). Cohort analysis indicated that the biomass of yellowfin sole peaked in 1983 at about 2 million t, thus the population in 1983 was as high or higher than in 1959–60.

There was reasonably good agreement in the magnitude of biomass estimates for yellowfin sole between the survey data and cohort analysis in 1975–81. In 1982–

Table 21

Biomass estimates (metric tons) and 95% confidence intervals of the estimates for sablefish (*Anoplopoma fimbria*) of the eastern Bering Sea continental slope based on results of cooperative Northwest and Alaska Fisheries Center and Japan Fisheries Agency bottom trawl surveys.

Year	Mean biomass estimate	95% Confidence interval
1979	12,600	0 – 56,900
1981	39,400	23,800 – 55,100
1982	42,900	35,800 – 50,100
1985	34,700	28,400 – 41,100

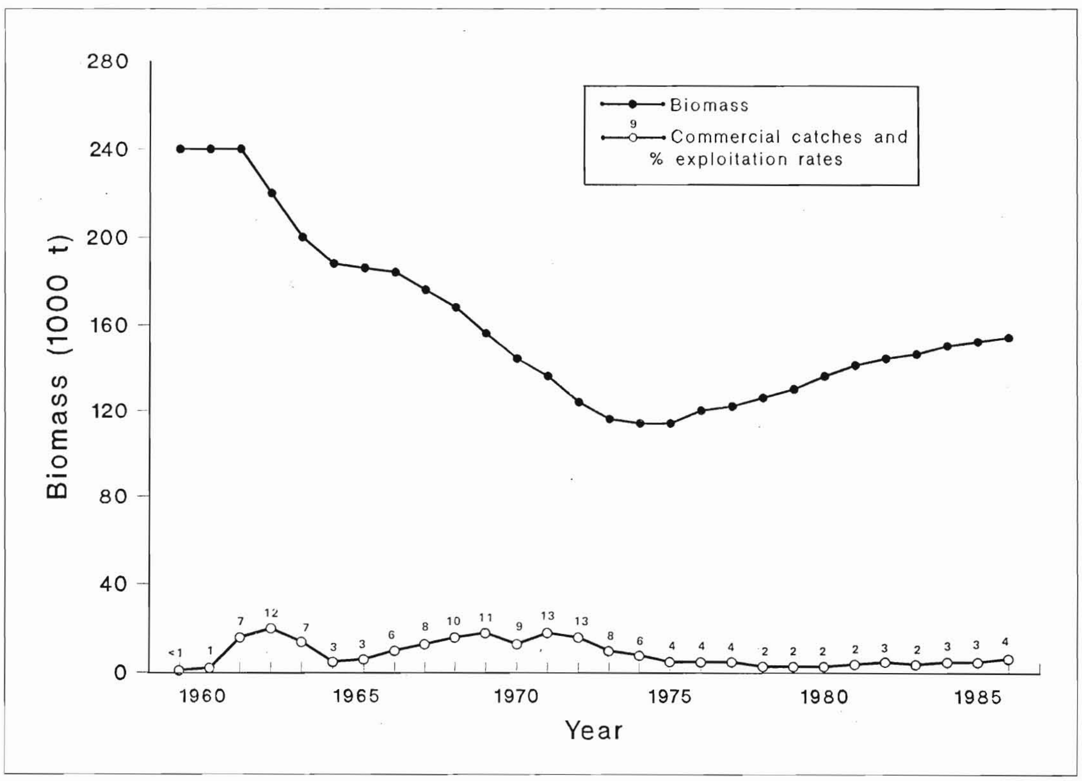


Figure 47

Biomass estimates (metric tons) for sablefish (*Anoplopoma fimbria*) of the eastern Bering Sea and Aleutian Islands regions combined based on stock-reduction analysis (after McDevitt 1981). Commercial catches are also shown; numbers above line indicate percent exploitation rates.

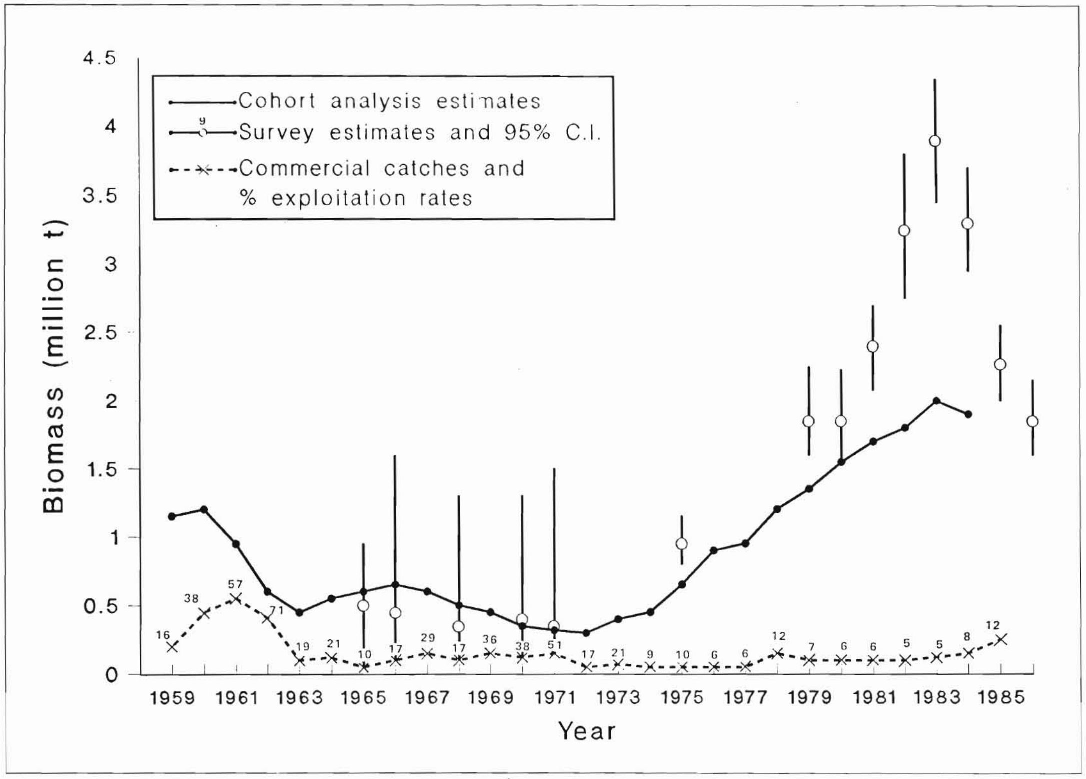


Figure 48

Biomass estimates (metric tons) for yellowfin sole (*Pleuronectes asper*) of the eastern Bering Sea from cohort analysis (ages 7–17) (Bakkala and Wespestad 1986, 1987) and estimates from 1965 International Pacific Halibut Commission survey data, 1966–71 Japan Fisheries Agency survey data, and 1975–86 Northwest and Alaska Fisheries Center trawl survey data. Commercial catches are also shown; numbers above line indicate percent exploitation rates.

84, the survey biomass estimates were highly variable and were much higher than those from cohort analysis. The survey estimates (for ages 7–17) increased from 2.1 million t in 1981 to 3.7 million t in 1983 but then decreased to 2.1 million t in 1985—an estimate similar to that of 1983–84 from cohort analysis. Variations of this magnitude are unlikely for a long-lived and slow-growing species like yellowfin sole; hence the biomass trends shown by cohort analysis for 1981–85 are probably more accurate. As discussed above, a change in the standard NWAFC survey trawls in 1982 may have contributed to the high variability of the survey biomass estimates in this period. Other, as yet unexplained, factors may have also been involved.

Rock Sole, Flathead Sole, and Alaska Plaice

Like yellowfin sole, these three species of small flatfish, are found mainly in continental shelf waters. Although distributions of the three species overlap, they occur in highest density in different areas (Figs. 28, 30, and 33). Of the inner shelf species, Alaska plaice has a more northerly distribution, and rock sole is distributed mainly farther south. Flathead sole is most concentrated on the outer shelf.

Based on survey data and cohort analysis, the biomass of these species was relatively low during the late 1960's and 1970's but increased during the 1980's (Figs. 51–53). The biomass of rock sole may have increased during the late 1960s based on mean estimates from the 1966–71 JFA survey data; however, the 95% confidence intervals around the mean estimates overlapped broadly (Fig. 51). The highest mean estimate in this period was about 300,000 t in 1971. Commercial catches of rock sole also peaked at that time reaching a reported 61,000 t in 1972. Biomass of rock sole apparently declined after 1971, but increased sharply during the early 1980's reaching an estimated 1 million t in 1986 based on NWAFC survey data. Results from cohort analysis (Walters and Halliday 1988) support the survey results, also showing a sharp increase in biomass during the late 1970's and early 1980's (Fig. 51). Biomass estimates from NWAFC survey data were considerably lower than those from cohort analysis in 1979–81, but were closer to the estimates from cohort analysis

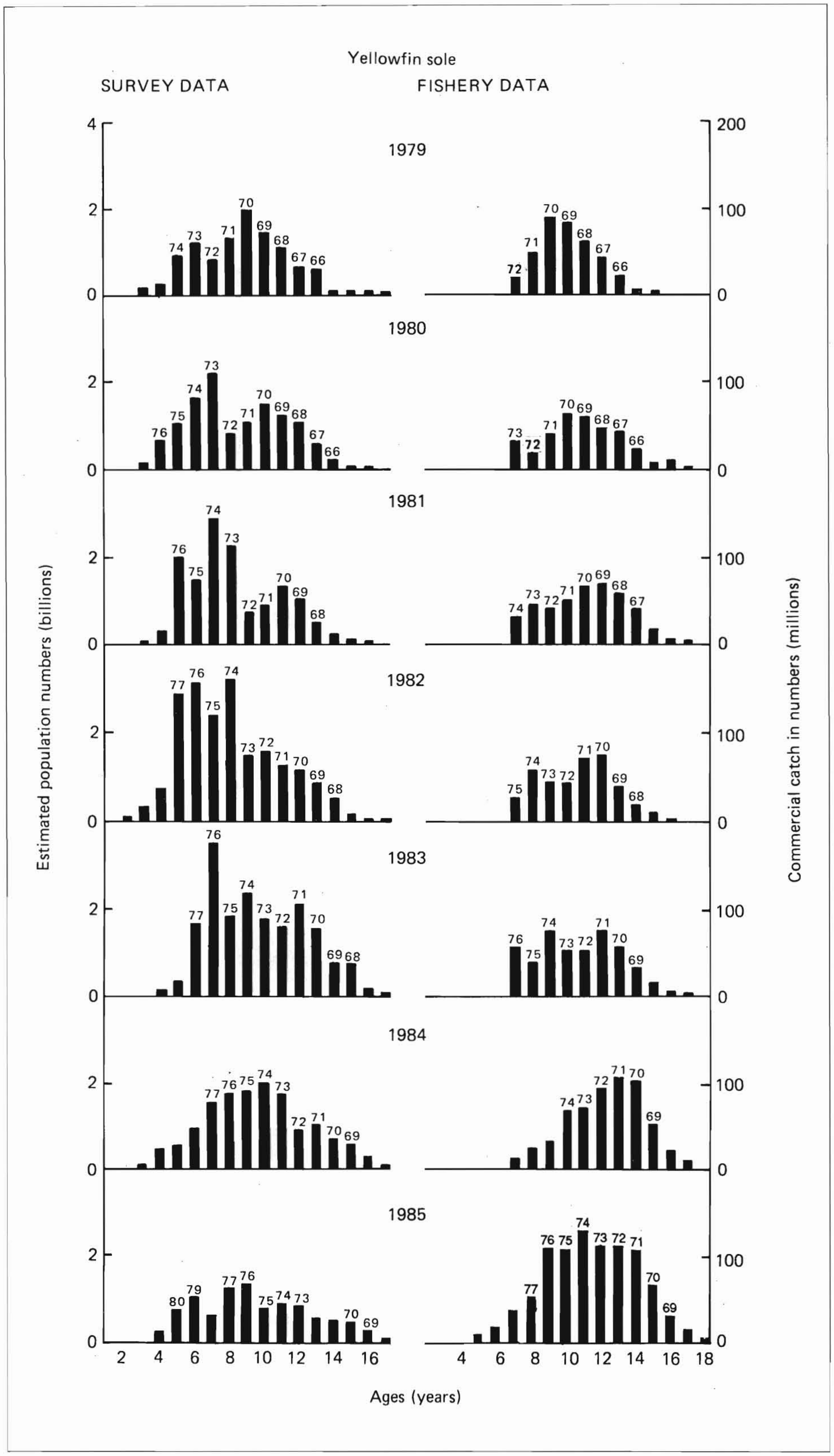


Figure 49

Age composition of yellowfin sole (*Pleuronectes asper*) of the eastern Bering Sea as shown by data from Northwest and Alaska Fisheries Center surveys and the commercial fishery. Year classes for more abundant ages are shown above the appropriate bars.

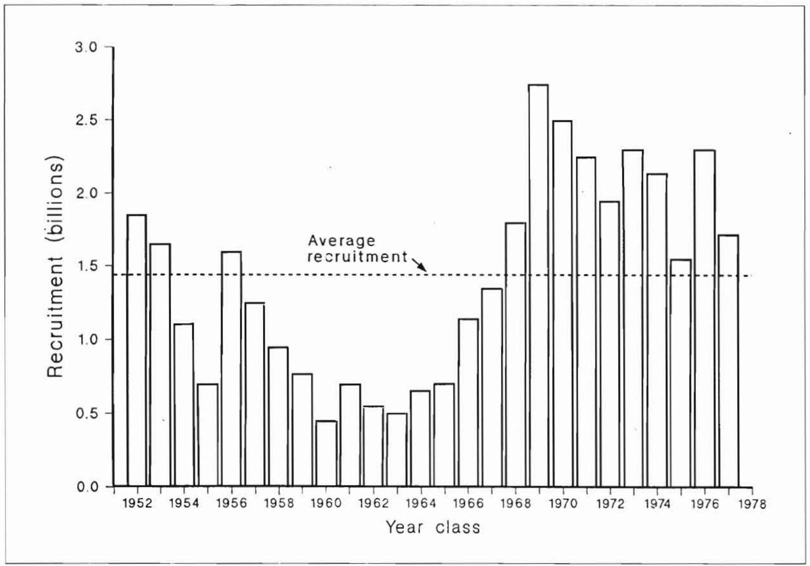


Figure 50
Year-class strength at age 7 for yellowfin sole (*Pleuronectes asper*) of the eastern Bering Sea as shown by cohort analysis (Bakkala and Wespestad 1986, 1987).

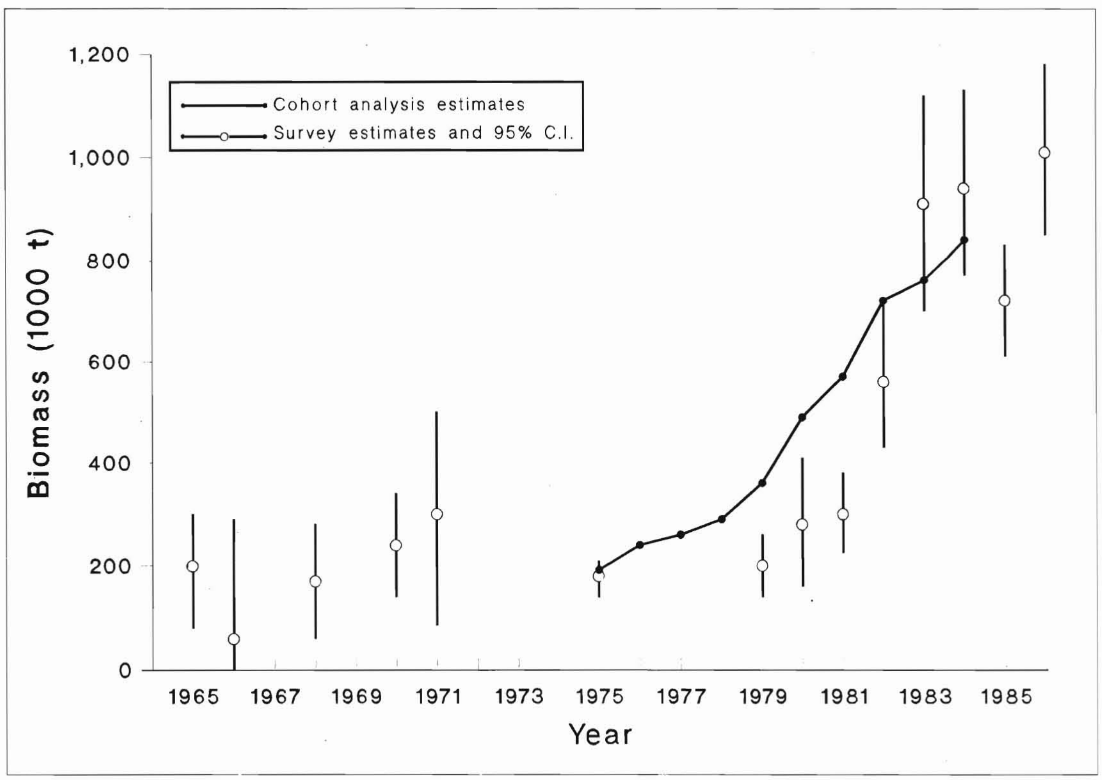


Figure 51
Biomass estimates (metric tons) for rock sole (*Pleuronectes bilineatus*) of the eastern Bering Sea from cohort analysis for 1975–84 (Walters and Halliday 1988) and from trawl survey data: 1965, International Pacific Halibut Commission; 1966-71, Japan Fisheries Agency; and 1975–86, Northwest and Alaska Fisheries Center. Bars indicate 95% confidence intervals.

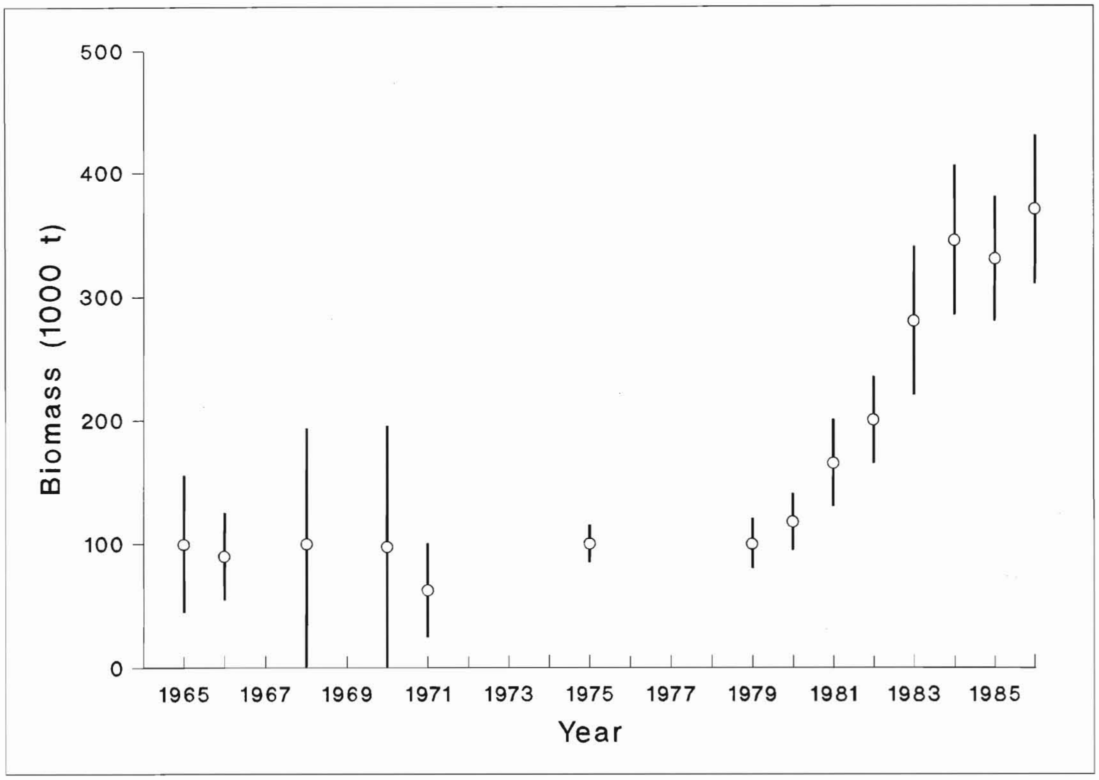


Figure 52

Biomass estimates (metric tons) and 95% confidence intervals for flathead sole (*Hippoglossides elassodon*) and Bering flounder (*H. robustus*) of the eastern Bering Sea as shown by trawl survey data: 1965, International Pacific Halibut Commission; 1966–71, Japan Fisheries Agency; and 1975–86, Northwest and Alaska Fisheries Center.

after the new standard trawl began to be used by the NWAFC in 1982.

Survey biomass estimates for flathead sole remained relatively stable during the late 1960's and 1970's, but increased during the 1980s (Fig. 52). Biomass estimates prior to 1980 ranged around 100,000 t but increased to 370,000 t in 1986. Reported commercial catches of about 41,000 t in 1970 and 51,000 t in 1971, if accurate, would suggest that biomass may have been underestimated by survey data prior to the 1980's.

The biomass of Alaska plaice was also consistently low in the late 1960's but increased in the 1970's. Results from cohort analysis (Zhang 1987) indicate that this increase began in the early 1970s although it was not apparent from survey data until the late 1970's (Fig. 53). Both cohort analysis and survey data show that the biomass of Alaska plaice peaked in the early 1980's at about 700,000 t and then declined to about 550,000 t in the mid-1980's.

The cohort analysis developed by Zhang (1987) is a biomass-based model that incorporates growth. Interestingly, results from this model show a decline in biomass in 1975 and 1976, although it generally increased before and after this period. Water temperatures in the eastern Bering Sea were especially cold in those years (Fig. 7), and reduced growth during these cold years may have caused the decline in biomass. Estimates from cohort analysis suggest that biomass was underestimated by NWAFC survey data from 1975 to 1981 but was more accurate after 1982 when the NWAFC adopted the new standard survey trawl.

Greenland Turbot, Arrowtooth Flounder, and Pacific Halibut

As described earlier, these three large flatfish are unique in that they occupy continental shelf waters during their first few years as juveniles, but mainly occupy deeper waters of the shelf and the continental slope as older juveniles and adults. This behavior is most marked in the case of Greenland turbot, which occur in continental slope waters almost exclusively as older juveniles and adults; arrowtooth flounder and Pacific halibut occur in both shelf and slope waters at older ages. Because historical biomass estimates of these species

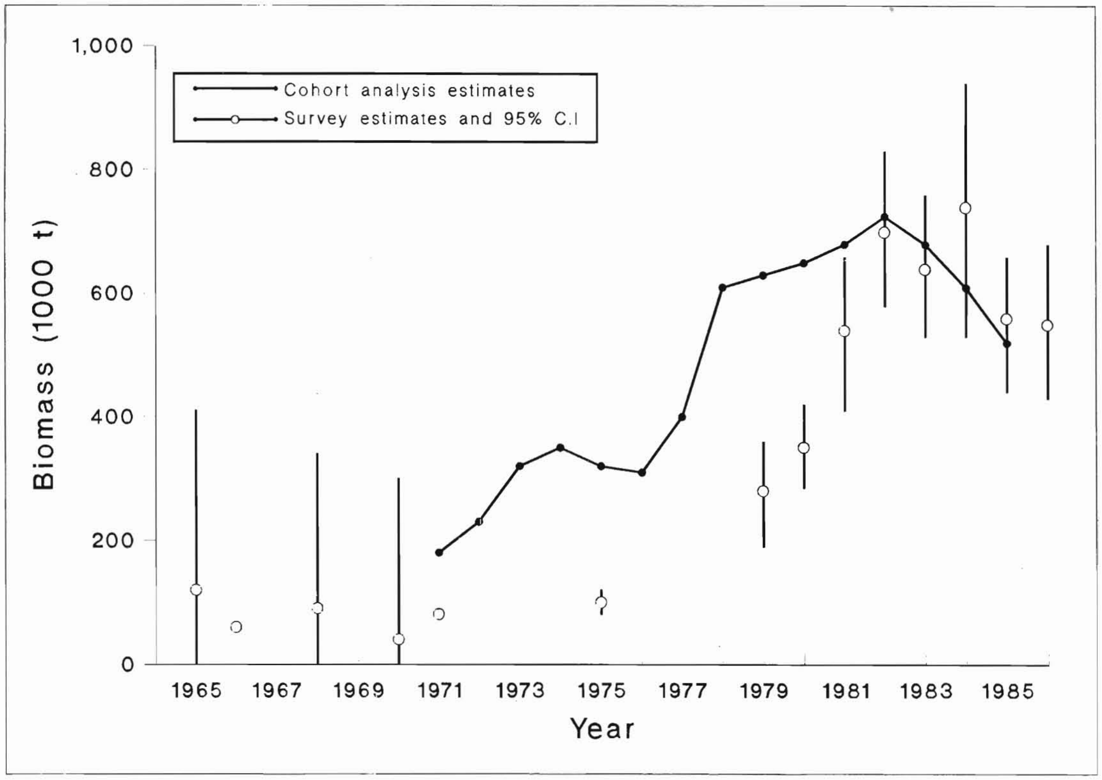


Figure 53
Biomass estimates (metric tons) for Alaska plaice (*Pleuronectes quadrituberculatus*) of the eastern Bering Sea from cohort analysis for 1971-85 (Zhang 1987) and from trawl survey data: 1965, International Pacific Halibut Commission; 1966–71 Japan Fisheries Agency; and 1975-86, Northwest and Alaska Fisheries Center.

was based on shelf trawl surveys, they represent younger juveniles of Greenland turbot and only a portion of the adults of arrowtooth flounder and Pacific halibut.

Biomass estimates are not available for 1965 because Greenland turbot and arrowtooth flounder were not separated by species during the IPHC survey. Biomass estimates for Greenland turbot from the 1966–71 JFA surveys had extremely wide 95% confidence intervals (Fig. 54). These wide confidence intervals probably result from a poor correspondence of the JFA survey areas with the distribution of Greenland turbot. The main concentrations of juvenile Greenland turbot were located on the northwest portion of the eastern Bering Sea shelf (Fig. 34), whereas the survey areas were on the southern and eastern portion of the shelf (Figs. 11 and 12). Point estimates suggest that biomass of juveniles was low during the late 1960s and early 1970's but increased in the mid- to late 1970s, and decreased through 1986 owing to a severe decline in recruitment of juveniles. The decline is reflected not only in survey biomass estimates, but also by a reduction in juvenile distribution (Fig. 34). This sustained recruitment failure has been alarming.

Abundance of the older juveniles and adults on the continental slope (Table 18) also declined from 127,500 t in 1979 to 79,240 t in 1985, but the rate of decline was not as severe as for the young juveniles. The slope population of 1985 was probably still being sustained by good recruitment of the late 1970's.

Confidence intervals for the 1968 and 1970 JFA survey biomass estimates for arrowtooth flounder were also extremely wide (Fig. 55) because these data were from inner and mid-shelf waters and arrowtooth flounder occupy mainly the outer shelf. Confidence intervals for the 1966 and 1971 JFA data were relatively narrow and hence more precise. Based on the 1966 and 1971 estimates from JFA data and later NWAFC survey estimates, the biomass of arrowtooth flounder was relatively high in the mid-1960's, declining to a much lower level during the 1970's, and then increasing substantially during the 1980's before reaching its highest level of 232,000 t in 1986 (Fig. 55). Thus, arrowtooth flounder is another example of a flatfish showing a substantial increase in abundance during the 1970's and 1980's. Data from NWAFC-JFA cooperative surveys also show an increase in arrowtooth flounder biomass on the

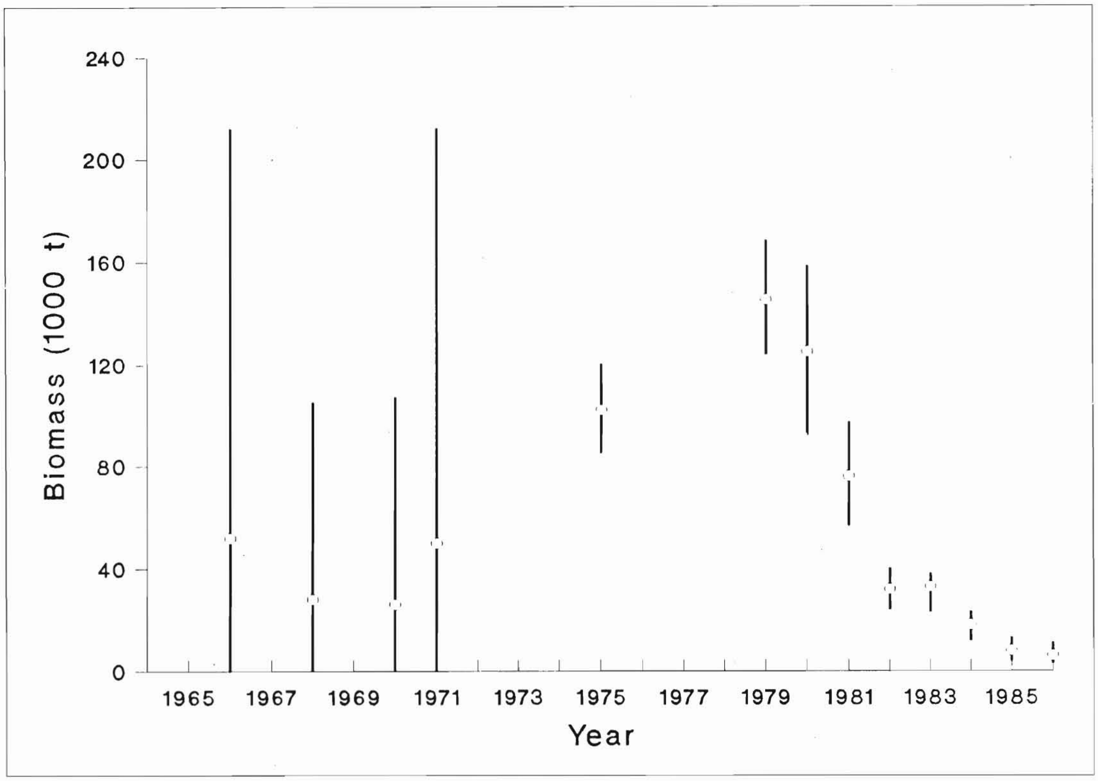


Figure 54
Biomass estimates (metric tons) and 95% confidence intervals for juvenile Greenland turbot (*Reinhardtius hippoglossoides*) on the continental shelf of the eastern Bering Sea as shown by trawl survey data: 1966–71, Japan Fisheries Agency; 1975-86, Northwest and Alaska Fisheries Center.

continental slope, increasing from 33,800 t in 1979 to 74,400 t in 1985 (Table 18).

The biomass of juvenile Pacific halibut also fluctuated during 1965–86 but apparently to a lesser degree than Greenland turbot and arrowtooth flounder (Fig. 56). Again, the 95% confidence intervals for the early 1966–71 survey data were extremely wide. Point estimates suggest a decline in biomass during the late 1960's and early 1970's, which corresponds to the period of intense exploitation of this species by the commercial fishery (Table 9). The later NWAFC survey data show an increasing trend in biomass during the late 1970's and early 1980's, reaching a peak in 1983 or 1984. The overall trends shown by the data in Figure 56 are quite similar to those from IPHC surveys of juvenile Pacific halibut along the north side of the Alaska Peninsula from 1966 to 1982 (International Pacific Halibut Commission 1986).

Sculpins, Eelpouts, and Skates

The historical survey data suggest that the biomass of sculpins has remained relatively stable at about 200,000 to 300,000 t during 1965–86 except for a low of 110,000 t in 1975 (Fig. 57). The biomass of eelpouts has varied widely, with relatively low estimates of about 100,000 t or less from 1965 to 1975, and a sharp increase in 1979 and 1980 at over 300,000 t, and a sharp decline to less than 20,000 t in 1985 and 1986 (Fig. 58). The larger number of species of sculpins relative to the eelpouts may account for the greater stability in biomass of sculpins.

Skate biomass estimates increased to 190,000 t during the 1980's after a long period of relatively low estimates (12,600 to 81,600 t) from at least 1965 to 1979 (Fig. 59).

Overall Groundfish Complex

The overall combined biomass of the principal species and species groups of groundfish in 1965–85 is shown in Figure 60. These estimates do not include species occupying continental slope waters because estimates for most slope species are not available prior to 1979. The estimates are summations of the biomasses of individual species from sources believed to be the most accurate. For example, estimates from cohort analysis

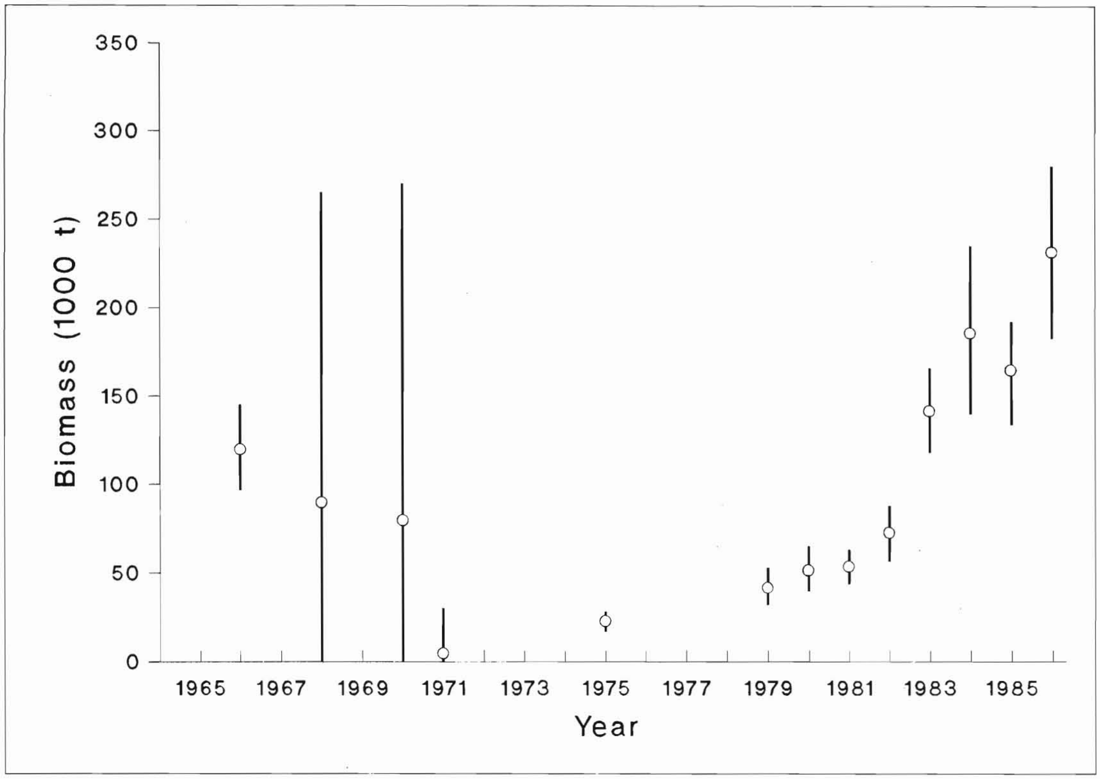


Figure 55
Biomass estimates (metric tons) and 95% confidence intervals for arrowtooth flounder (*Atheresthes stomias*) and Kamchatka flounder (*A. evermanni*) of the eastern Bering Sea as shown by trawl survey data: 1966-71, Japan Fisheries Agency; 1975–86, Northwest and Alaska Fisheries Center.

were used when available and those from survey data in other cases (Table 22). Results from cohort analysis were available throughout this period for walleye pollock and yellowfin sole, the two most abundant species in the complex and the species which have the greatest influence on the variability in abundance of the overall groundfish complex.

Two biomass peaks occurred between 1965 and 1985, an initial peak in 1971 of almost 14 million t and a second in 1982 of nearly 16 million t (Fig. 60). These peaks correspond to biomass peaks for walleye pollock and it is thus apparent that the major fluctuations in biomass of the groundfish complex are caused by pollock. The biomass of the total groundfish complex was higher in 1982 than 1971 because of the higher biomass of Pacific cod and flatfishes. Groundfish biomass ranged between 10 and 16 million t from 1975 to 1985.

The data indicate a much lower biomass of groundfish prior to 1971. The 1965 estimate was 4.8 million t, followed by a near three-fold increase to 13.9 million t in 1971. Based on results from cohort analysis, this increase was due entirely to an apparent major increase in biomass of walleye pollock. As discussed above however, the increase in abundance of pollock between 1965 and 1971 was not supported by all survey data. For example, the JFA survey data, which is assumed to be the most reliable for estimating changes in abundance for this period, showed little change in abundance of pollock between 1966 and 1971. Thus, it is uncertain that the biomass of the overall groundfish complex was as low as shown by the available data during the mid-1960's.

Influence of Fishery on Target Species

Exploitation rates on principal commercial species were examined to determine if removals by the fishery is an important component of variation in abundance. The species considered were walleye pollock, yellowfin sole, Pacific ocean perch, and sablefish. Pacific halibut may have been overfished in the early 1970's, but exploitation rates are not available for this species because survey biomass estimates only represent a portion of the population. Most other species are generally only taken as bycatch in the fishery and hence are generally lightly exploited, and observed fluctuations in their biomass probably result from variability in recruitment.

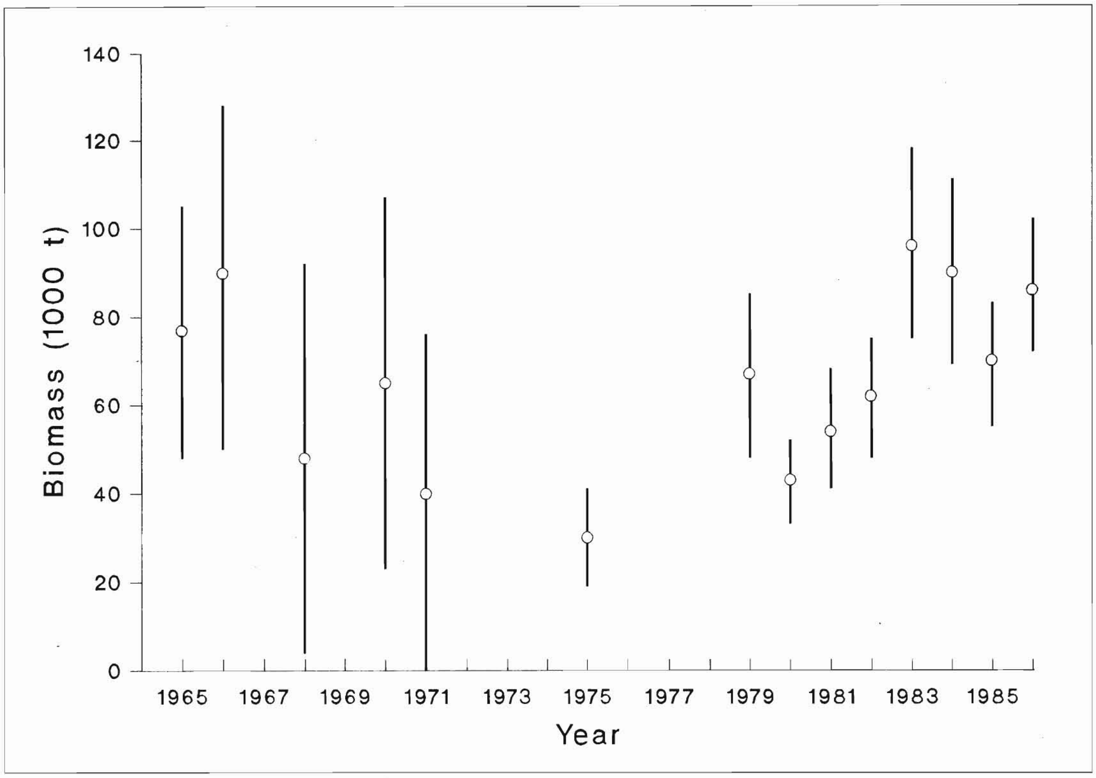


Figure 56
Biomass estimates (metric tons) and 95% confidence intervals for Pacific halibut (*Hippoglossus stenolepsis*) of the eastern Bering Sea as shown by trawl survey data: 1965, International Pacific Halibut Commission; 1966-71, Japan Fisheries Agency; and 1975–86, Northwest and Alaska Fisheries Center.

Exploitation rates for walleye pollock during 1964–85 have varied from 7 to 17% and were greatest (14–17%) during the peak years of the fishery in 1971–75 (Fig. 42). Over this 5-year period, the fishery took 8.3 million t of pollock and the biomass declined from 12.4 to 8.2 million t, based on cohort analysis. Cohort analysis has also shown that prior to the peak period of the fishery, biomass of the population increased substantially from recruitment of five relatively strong year classes originating in 1965–69 (Fig. 43). The following two year classes (1970 and 1971) were relatively weak. Thus, the effects of natural mortality acting on the aging 1965–69 year classes in conjunction with the weak recruitment from the 1970 and 1971 year classes may have resulted in a decline in biomass without fishing. The exploitation rates during 1971–75 were apparently not excessive for a relatively fast-growing and short-lived species like the walleye pollock. Recent analyses suggest that walleye pollock can sustain an exploitation rate of 0.23 (Wespestad and Traynor 1988). Thus, natural causes were probably the major factor in the decline of pollock biomass in 1971–75.

Exploitation rates have been even lower since 1975, ranging from 9 to 14%, and have probably had little influence on the fluctuations in abundance of walleye pollock since 1975. The primary factor in the rise and fall of biomass in 1979–85 was the recruitment and decay of the 1978 year class, the strongest year class yet observed (Fig. 43).

It has generally been recognized that yellowfin sole was overfished in the early period of the target fishery for this species (Fadeev 1965; Wakabayashi 1975; Bakkala et al. 1982). The relationship between trends in biomass and exploitation rates clearly supports this conclusion (Fig. 48). The exploitable biomass (those age groups partially or fully recruited to the commercial fishing gear) of yellowfin sole declined sharply during the early 1960's from an estimated 1.2 million t in 1960 to 463,000 t in 1963. Catches in the 4-year period from 1959 to 1962 averaged 404,000 t annually, representing exploitation rate estimates of 16 to 71% of the biomass derived from cohort analysis (Bakkala and Wespestad 1986). It is unlikely that exploitation rates reached 70% or even 50%, but if the biomass was as high as 2 million t in 1960 as estimated from another cohort analysis (Wakabayashi et al. 1977), exploitation rates would have still ranged from 23 to 42% during 1960–63. The sharp decline in abundance of yellowfin sole in this

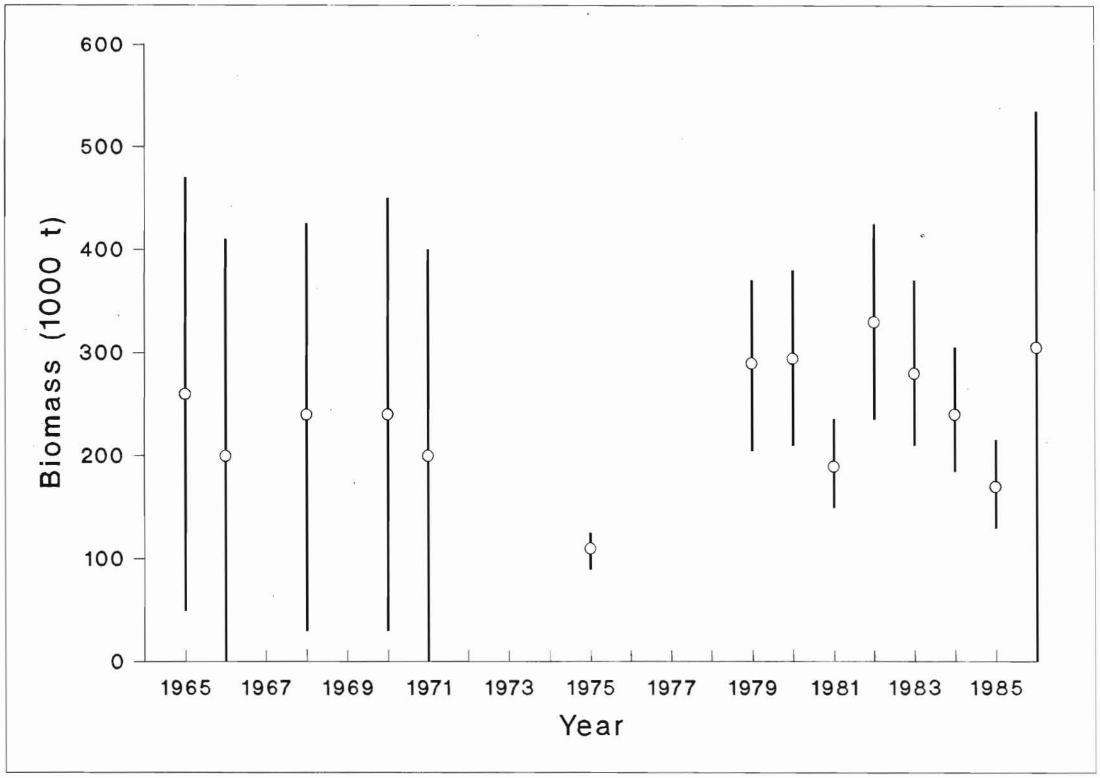


Figure 57
Biomass estimates (metric tons) and 95% confidence intervals for sculpins (Cottidae) of the eastern Bering Sea as shown by trawl survey data: 1965, International Pacific Halibut Commission; 1966-71, Japan Fisheries Agency; and 1975–86, Northwest and Alaska Fisheries Center.

period suggest that these rates were well above a sustainable level. Exploitation rates were also excessive in 1966–71, ranging from 17 to 51%. These rates were accompanied by a further decline in abundance of yellowfin sole.

Since the early 1970s when the abundance of yellowfin sole began a sustained increase (Fig. 48), exploitation rates have been low, ranging from 5 to 12%. An optimal fishing mortality rate for yellowfin sole may be 12–14% (Bakkala and Wespestad 1987).

Although the sustained increase in abundance of yellowfin sole from 1972 to 1984 was due to the recruitment of a series of strong year classes (Fig. 50), the low exploitation rates during this period of strong recruitment undoubtedly contributed to this increase. Conversely, there was generally poor recruitment during the period of decline and low levels of biomass in 1960–72 (Fig. 50).

Pacific ocean perch may also have been overexploited during the early target fishery for this species (Ito 1982). Results of stock-reduction analysis (Ito 1987) show a persistent and substantial decline in the population between 1960 and 1977 (Fig. 46). This decline has also been documented by CPUE data from the commercial fishery and by cohort analysis (Ito 1987). Based on commercial catches in this period and biomass estimates from stock-reduction analysis, exploitation rates ranged from 7 to 34% in 1961–76 and averaged 17%.

Ageing studies have indicated that Pacific ocean perch may be very long lived, reaching 40 years or more (Beamish 1979; Archibald et al. 1981; Chilton and Beamish 1982). In accordance with the long life and slow growth of Pacific ocean perch, the exploitation rate at maximum sustainable yield has been estimated at 6% (Ito 1987). Therefore, the exploitation rates of 7 to 34% during the 1961–76 period were likely excessive.

Managers have maintained exploitation rates at 1–8% since 1977 to rebuild the population. The population appears to be responding to these measures and shows signs of recovery (Fig. 46), resulting from improved recruitment (Ito 1987).

Abundance trends for sablefish have been examined for the combined eastern Bering Sea and Aleutian Islands region populations (McDevitt 1987). Sablefish populations in these regions experienced a sustained decline as shown by stock- reduction analysis (Fig. 47). The biomass had declined by 1974 to about 50% of its level prior to increased fishing pressure in the early

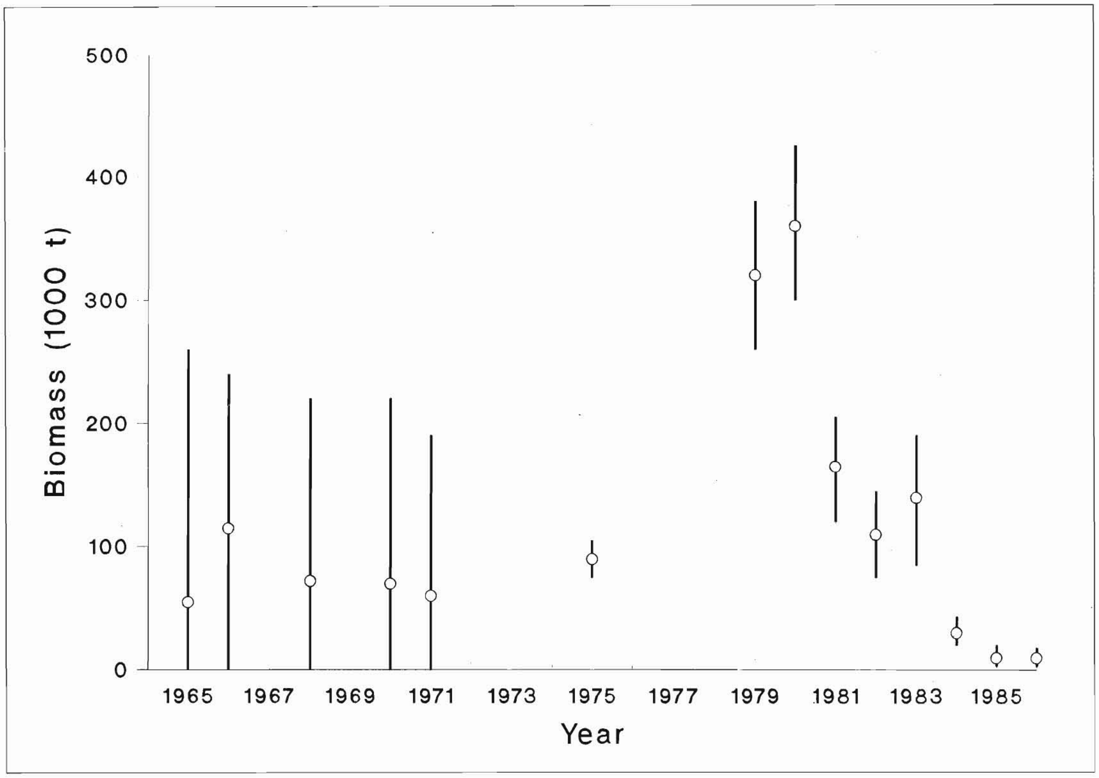


Figure 58

Biomass estimates (metric tons) and 95% confidence intervals for eelpouts (Zoarcidae) of the eastern Bering Sea as shown by trawl survey data: 1965, International Pacific Halibut Commission; 1966–71, Japan Fisheries Agency; and 1975-86, Northwest and Alaska Fisheries Center.

1960's. This decline has also been documented by CPUE data from the commercial fishery (McDevitt 1987). During most years in this period of decline, exploitation rates varied between 6 and 13%.

Recent ageing studies have suggested that sablefish may be a long-lived species reaching ages of 40 years or more (Beamish and Chilton 1982). Because of its long life span and slow growth during adult stages, population levels may only be maintained at low exploitation rates in the absence of strong recruitment. Sasaki (1985) has suggested that an exploitation rate of 5% is sustainable. If this is the case, the exploitation rates of 6 to 13% during the period of decline in abundance of sablefish may have been too high.

Discussion

Variability of Fish Stocks in Large Marine Ecosystems

Variability and management of fish stocks in large marine ecosystems (LME's) was the topic of a 1984 symposium sponsored by the American Association for the Advancement of Science (Sherman 1986a). The LME's were defined as regions with unique hydrographic regimes, submarine topography, and trophically linked populations. Examples of LME's are the North Sea, U.S. northeast Atlantic shelf, California current system, and the eastern Bering Sea.

Papers presented at the 1984 symposium demonstrated that variability, rather than stability, is characteristic of fish populations in LME's. This instability is not only pronounced among individual species but appears to occur in fish complexes as a whole. Sources of this variability may be fishing mortality or natural perturbances or both. Brown et al. (1976) documented a 55% decline in abundance of the fish community off the U.S. northeast Atlantic coast caused by overfishing. Multispecies virtual population analysis suggests that the biomass of commercially exploited species in the North Sea declined about 40% between 1965 and 1978 (Gislason and Helgason 1985).

Other studies suggest quite dramatic changes in abundance in periods prior to exploitation as discussed by Beddington (1986). Analysis of the anaerobic sediments off California by Soutar and Isaacs (1974) showed major changes in the abundance of pelagic fishes over the past 2,000 years. Similarly, studies of sediment cores in

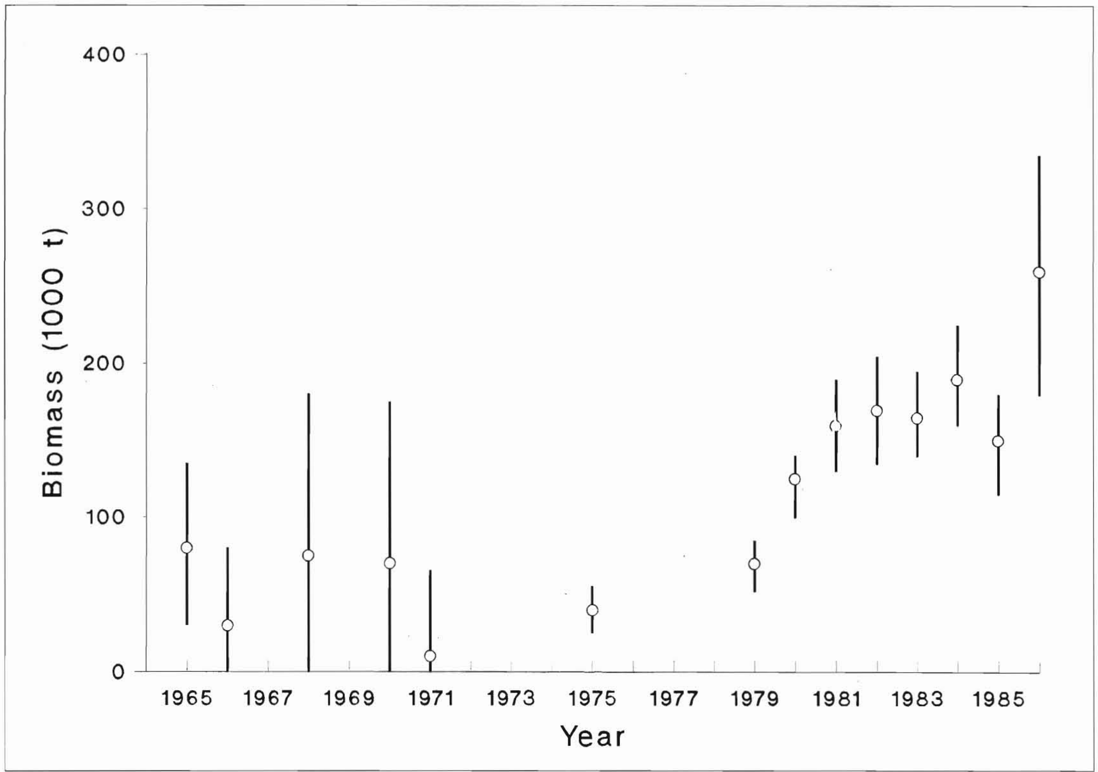


Figure 59
Biomass estimates (metric tons) and 95% confidence intervals for skates (Rajidae) of the eastern Bering Sea as shown by trawl survey data: 1965, International Pacific Halibut Commission; 1966–71, Japan Fisheries Agency; and 1975–86, Northwest and Alaska Fisheries Center.

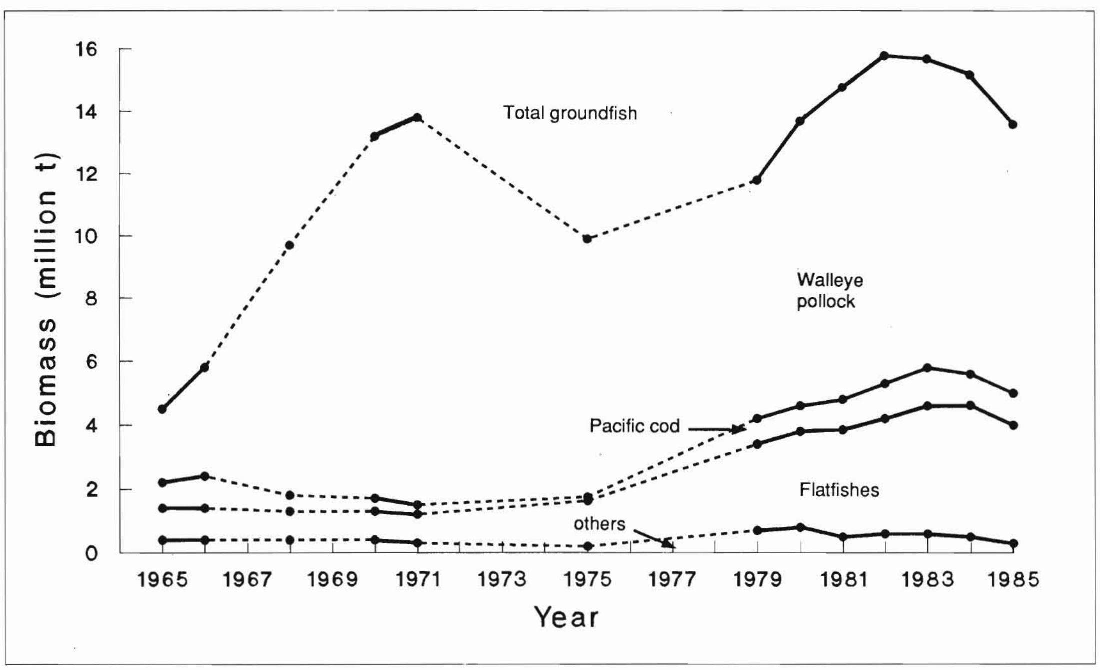


Figure 60
Historical trends in biomass (metric tons) of groundfish on the eastern Bering Sea continental shelf (see Table 22 for sources of data and species included).

the Peruvian upwelling region show complicated patterns of shifting species abundance prior to exploitation (DeVries and Pearcy 1983). Smith (1978) has also produced evidence that the total biomass of pelagic fish stocks in the California current system may have been as much as several times higher in the early part of this century than at present or even in the late 1930's when heavy exploitation commenced.

Some studies have suggested that although there may be changes in fish biomass within LME's, the carrying capacity of the ecosystem may be relatively stable. The abundance of phytoplankton and zooplankton on the U.S. northeast continental shelf was observed to be relatively stable at the time of considerable reduction in the fish biomass in the region. This provides further evidence that the decline in these stocks was not related to a lack of food at the lower end of the food chain, but rather to fishing mortality (Sherman 1986b). Other studies have suggested that ecosystems are sufficiently buffered to allow large increases in abundance of fish stocks. As evidence of this, Ursin (1982) cites the case of the emergence of an extremely abundant year class of haddock (*Melanogrammus aeglefinus*) in the North Sea that exhibited normal rates of growth. Another example also suggestive of this pattern is the emergence of a sequence of several strong year classes of Atlantic cod (*Gadus morhua*) in the North Sea during the 1960's that allowed a sudden doubling of catches after they had remained relatively constant at a lower level for many years (Daan 1986).

If the carrying capacity of LME's remains relatively constant, then the decline in one fish stock may allow others to increase and replace the declining stock through reduced predation or competition. However, there have been very few documented cases of the replacement phenomenon (Daan 1980; Ursin 1982). Examples of at least partial replacement are the population explosion of American sand lance (*Ammodytes americanus*) coincident with a decline in Atlantic herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*) on the U.S. northeast Atlantic shelf (Sherman 1986b) and the declines in Atlantic herring and mackerel stocks of the North Sea accompanied by a rapid increase in recruitment of most other stocks (Ursin 1982). In other cases, however, the collapse of one stock (e.g., Pacific sardine stock of Japan [or Japanese

Table 22

Estimated biomass (metric tons) of principal species and species groups of groundfish of the eastern Bering Sea based on cohort analyses and demersal trawl data.

Year	Walleye pollock[a]	Pacific cod[b]	Yellowfin sole[a]	Rock sole[c]	Flathead sole[b]	Alaska plaice[d]	Greenland turbot[b]	Arrowtooth flounder[b]	Pacific halibut[b]	Sculpins[b]	Eelpouts[b]	Skates[b]	Total all species combined
1965	2,700,000	717,000	541,000	195,200	100,400	123,200	—	—	77,200	260,000	54,300	81,600	4,849,900
1966	3,700,000	977,300	593,000	65,100	89,900	61,600	62,700	121,300	89,900	200,300	113,200	30,000	6,104,300
1967	6,000,000	—	562,000	—	—	—	—	—	—	—	—	—	—
1968	8,100,000	428,000	489,000	170,600	95,200	93,500	25,500	89,400	42,700	240,000	72,800	76,200	9,922,900
1969	9,900,000	—	468,000	—	—	—	—	—	—	—	—	—	—
1970	11,500,000	384,100	353,000	237,700	115,400	38,700	26,800	81,200	65,000	239,600	71,100	67,400	13,180,000
1971	12,400,000	238,800	317,000	295,500	62,900	177,400	60,300	3,400	39,400	198,300	62,400	12,600	13,868,000
1972	11,800,000	—	274,000	—	—	231,600	—	—	—	—	—	—	—
1973	11,000,000	—	370,000	—	—	318,500	—	—	—	—	—	—	—
1974	9,400,000	—	456,000	—	—	351,200	—	—	—	—	—	—	—
1975	8,200,000	53,100	630,000	192,800	100,700	323,400	106,000	22,400	29,800	109,800	87,300	31,800	9,887,100
1976	8,500,000	—	896,000	234,000	—	312,100	—	—	—	—	—	—	—
1977	8,200,000	—	962,000	260,100	—	397,000	—	—	—	—	—	—	—
1978	7,800,000	—	1,198,400	292,000	—	610,100	—	—	—	—	—	—	—
1979	7,700,000	754,300	1,338,800	360,000	104,900	631,700	146,100`	42,100	66,900	287,800	321,900	70,000	11,824,500
1980	9,000,000	905,300	1,541,600	489,600	117,500	652,700	125,400	52,500	42,600	294,400	360,800	123,100	13,705,500
1981	9,900,000	1,034,600	1,722,500	572,600	162,900	682,900	77,200	53,500	54,300	193,900	163,300	159,800	14,777,500
1982	10,500,000	1,020,600	1,808,800	703,700	197,400	721,700	31,400	73,200	61,600	331,500	109,300	169,300	15,728,500
1983	9,900,000	1,176,300	1,984,800	763,000	279,900	678,600	30,500	142,200	96,500	289,700	138,900	166,000	15,646,400
1984	9,600,000	1,001,900	2,061,600	844,700	344,800	609,000	17,500	187,600	89,900	242,900	31,900	190,500	15,222,300
1985	8,600,000	961,500	1,880,000	720,300	329,900	524,800	7,500	163,600	69,100	171,800	12,100	148,300	13,588,900

[a] Biomass estimates based on cohort analyses for all years.
[b] Biomass estimates based on survey data for all years.
[c] Biomass estimates based on survey data 1965–74 and 1985, cohort analysis 1975–84.
[d] Biomass estimates based on survey data 1965–70, cohort analysis 1971–85.

pilchard *Sagax melanostictus*]) or group of stocks (e.g., U.S. northeast shelf groundfish and pelagic species, Gulf of Thailand groundfish) were not coincident with major increases in other species (Daan 1980). However, as Ursin (1982) notes, lack of evidence of replacement may be the result of insufficient information. In these cases, fish stocks for which information is available may only represent a portion of the total animal biomass; for example, the removals may have been replaced by undetected increases in abundance of pelagic species of fish or invertebrates such as jellyfish or squid.

Variability in Abundance of Eastern Bering Sea Groundfish

The studies of fish stocks in LME's suggest that instability in fish biomass is the rule rather than the exception, even in the absence of fishing. The studies also indicate that the carrying capacity of marine ecosystems may not be taxed at normal levels of fish biomass but can accommodate substantial increases in abundance. With this background, the observed fluctuations in biomass of groundfish in the eastern Bering Sea seem for the most part to be reasonable.

The better assessment data available after 1979 from comprehensive bottom trawl and hydroacoustic surveys (Table 18) suggest that the biomass of the overall groundfish complex in the eastern Bering Sea remained stable at 15 million t during the 7-year period of 1979–85 even though there was considerable variation in abundance of individual species and species groups. Gadid biomass declined about 1 million t; other groundfish species, excluding flatfishes, about 300,000 t. These declines were offset by an increase of about 1.4 million t in the biomass of flatfishes that maintained the nearly constant biomass of the complex. However, this is not an entirely realistic picture because, as described above, the bottom trawls used in 1982 and later years were more efficient for flatfishes than the trawls used earlier, which probably overemphasized the increase in flatfish biomass. Thus, the biomass estimates from cohort analysis for the principal species of flatfish are believed to be more representative of the actual trend in biomass between 1979 and 1985 than those from the surveys. The survey results also show that the biomass of walleye pollock declined from about 10.5 million t in 1979 to 8.0 million t in 1982 and then increased to 9.4 million t in 1985. However, overlapping 95% confidence intervals (Fig. 42) suggest that these estimates were not significantly different. Cohort analysis showed an increasing trend from 1979 (7.7 million t) to 1982 (10.5 million t) and then a decline (8.6 million t) in 1985. This latter trend appears more realistic because the increase in 1979–82 coincides with the recruitment and growth of the very large 1978 year class of pollock.

Thus, the trend in biomass of the overall groundfish complex in 1979–85 is believed to be better described by the combined results from cohort analysis and the surveys (Fig. 60). These data suggest a fluctuating biomass for the complex ranging from 11.8 million t in 1979, increasing to a peak of 15.7 million t in 1982, and then declining to 13.6 million t in 1985.

Less confidence can be placed in the biomass trends for the groundfish complex prior to 1979 and particularly prior to the mid-1970's because of the unknown quality of the available data. The data indicate that biomass of the complex ranged between 10 and 14 million t during the 1970's (Fig. 60). The earlier peak of 14 million t in 1971 was of a similar magnitude to that in 1982.

The data for the period prior to 1971 suggested even greater variations in biomass of the groundfish complex than during the 1970's. The available data indicated that biomass in 1965 may have been as low as 5 million t before increasing sharply to 14 million t in 1971. This nearly three-fold increase in biomass of the groundfish complex over the relatively short time interval from 1965 to 1971 seems questionable, and information was presented earlier to suggest that the magnitude of this increase may have been overestimated. However, the approximately 1.5-fold variation in biomass of the complex between 1971 and 1982 seems plausible, and this degree of change does not seem unreasonable in view of findings from research on other LME's.

Fluctuations in biomass of the overall groundfish complex are primarily governed by walleye pollock because of their dominance and large variations in abundance. Therefore, it seems unlikely that fluctuations in pollock biomass are compensated for by changes in biomass of other species of fish to maintain a constant biomass of fish in the eastern Bering Sea. Bakkala et al. (1987a) discussed the replacement phenomenon as a possible explanation for the sharp increase in abundance of pollock between 1965 and 1971 as shown by cohort analyses. Species that may be competitors of pollock and show a major decline in abundance during this period were Pacific herring and Pacific ocean perch. Wespestad and Fried (1983) reported that the abundance of Pacific herring decreased from 1.7 million t to 250,000 t between 1963 and the mid-1970's, while Ito (1987) estimated that the abundance of Pacific ocean perch declined from 200,000 t to 30,000 t in the eastern Bering Sea and from 450,000 to 40,000 t in the Aleutian Islands area between the mid-1960's and mid-1970's. The sum of decreases in biomass for these two species and regions amounts to 2 million t, whereas, the increase in biomass of walleye pollock may have considerably exceeded this amount. Thus, the magnitude of the decline in Pacific herring and Pacific ocean perch biomass would not appear to account for the increase in the pollock population through replacement.

A better hypothesis (Ursin 1982) to explain the fluctuations in abundance of walleye pollock suggests that ecosystems are sufficiently buffered to allow large fluctuations in abundance of fish stocks.

Causes of Fluctuations in Abundance

During the late 1970's and early 1980's, the abundance of most principal species of groundfish increased in the eastern Bering Sea (Fig. 60). The biomass of the total complex may have increased from about 10 million t in 1975 to more than 15 million t in the early 1980's. One factor accounting for this increase was improved recruitment. There was at least one, but usually several stronger-than-average year classes for each of the principal species during the 1970's. Some striking patterns are revealed by arranging stronger-than-average year classes of the 1970's by species and areas of spawning (Table 23). The outer shelf and slope spawners, which primarily reproduce in late winter, appear to be characterized by single or short 2–3 year series of stronger-than-average year classes in contrast to the middle and inner shelf spawners that had longer series (usually 5–6 year). These findings suggest that the environmental conditions influencing the reproductive success of middle and inner shelf spawners are different from those influencing the outer shelf and slope spawners and that improved conditions in each region often result in greater abundance of most species in that region.

The causes of these fluctuations in year-class strength are probably governed by interrelated environmental processes rather than by single environmental features such as temperature. Bottom temperature data routinely taken during surveys have shown temperature cycles in the eastern Bering Sea. The period 1971–76 was cold and the period 1977–80 was warmer with temperatures peaking in 1979 (Fig. 7). Strong and weak year classes were produced in both cold and warm years, particularly by the middle and inner shelf spawners. The strong year classes of gadids and other outer shelf-slope spawners during the 1977–78 period were produced during the warming period immediately following a cold period. Saetersdal and Loeng (1987) noted that most strong year classes in Atlantic cod of the Barents Sea during 1900–83 were produced when the environment shifted from a cold to a warm period. They also noted coincident abundant year classes among three species (Atlantic cod, haddock, and Atlantic herring) in this region.

There may be factors other than favorable environmental conditions involved in the increases in abundance of so many species in the eastern Bering Sea during the late 1970's and early 1980's. One of these may be reduced fishing mortality. During the peak period of the fishery in 1971–73, reported catches ranged from 2.1 to 2.2 million t. In 1977–83, following the establishment of the U.S. 200–mile EEZ, catches were reduced to 1.2 to 1.3 million t. Thus, exploitation in this latter period may have been only about 50% of that at the peak of the fishery. This reduced exploitation undoubtedly contributed to the increases in abundance and may be a relatively important factor, particularly if catches were higher than actually reported in earlier years when the fishery was largely unregulated.

Current Condition of Eastern Bering Sea Groundfish

The groundfish resources of the eastern Bering Sea were generally in good condition at the end of the first

Table 23
Years of stronger-than-average year classes of groundfish in the eastern Bering Sea during the 1970's.

Spawning area	Species	Spawning period	Year class 1973	1974	1975	1976	1977	1978	1979
Outer shelf and slope	Walleye pollock	Feb.–July					x	x	
	Pacific cod	Jan.–Mar.					x	x	
	Sablefish	Jan.–Apr.					x		
	Greenland turbot	Dec.–Mar.				x	x	x	
Middle and inner shelves	Yellowfin sole	June–Sept.	x	x	x	x	x		
	Rock sole	Mar.–June			x	x	x	x	x
	Flathead sole	Feb.–May		x	x	x	x	x	x
	Alaska plaice	Apr.–June		x	x				

30 years of the fishery. There was evidence of overfishing for some species but these species had fully or partially recovered. The abundance of walleye pollock, although below peak levels, remained high and the age structure of the population improved, consisting of a series of older age groups than existed following the peak of the fishery. The abundance of Pacific cod and most of the flatfishes were at observed historical high levels. The only species of concern was Greenland turbot, which had undergone a sustained recruitment failure during the 1980's. However, the spawning stock was believed to be still healthy and was being protected by management restrictions on rates of exploitation.

During most of the first 30–year period of intense exploitation of eastern Bering Sea groundfish, the fishery was largely unrestricted. Only during about the last 10 years of this period was a structured management policy implemented. It was during the unrestricted period of exploitation that overfishing occurred. The levels of exploitation causing overfishing should provide some guidance for prevention of similar occurrences in the future.

Conclusions

1 The eastern Bering Sea is a major marine ecosystem containing some of the largest populations of groundfish in the world; the biomass of the complex was estimated to range between 11.8 and 15.7 million t in 1979–85.

2 Gadids, primarily walleye pollock, dominate the groundfish complex (60 to 75% by weight) followed by the pleuronectids (19 to 30%).

3 Full commercial utilization of groundfish in the eastern Bering Sea has a relatively brief history, beginning in the 1960's and early 1970's after development of the modern-day fishery which started in 1954; catches averaged 1.6 million t in 1970–86.

4 Walleye pollock has been the main target species of the fisheries starting in the mid-1960's with annual catches ranging from 0.9 to 1.9 million t in 1969–1986.

5 Fluctuations in abundance of pollock appear to be caused mainly by variations in recruitment rather than by the fishery.

6 Evidence suggests that yellowfin sole, Pacific ocean perch, and sablefish were overfished in early years of the fishery, but these species had partially or fully recovered by the mid-1980's.

7 Data suggests that the biomass of the eastern Bering Sea groundfish complex is variable rather than stable which also appears to be the case in other large marine ecosystems.

8 Fluctuations in biomass of the overall groundfish complex are primarily governed by walleye pollock because of their dominance and large variations in abundance.

9 The biomass of the complex increased substantially in the late 1970's and early 1980's because of strong recruitment in many of the principal species; this increase may have been enhanced by lower fishing mortality in this period compared to that during the peak of the fishery in the early 1970s.

10 The principal species of groundfish of the eastern Bering Sea were generally in good condition at the end of the first 30 years of the modern-day fishery: the abundance of walleye pollock remained high and that of Pacific cod and most of the flatfishes were at observed high levels.

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