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Greenland Turbot *Reinhardtius hippoglossoides* of the Eastern Bering Sea and Aleutian Islands Region

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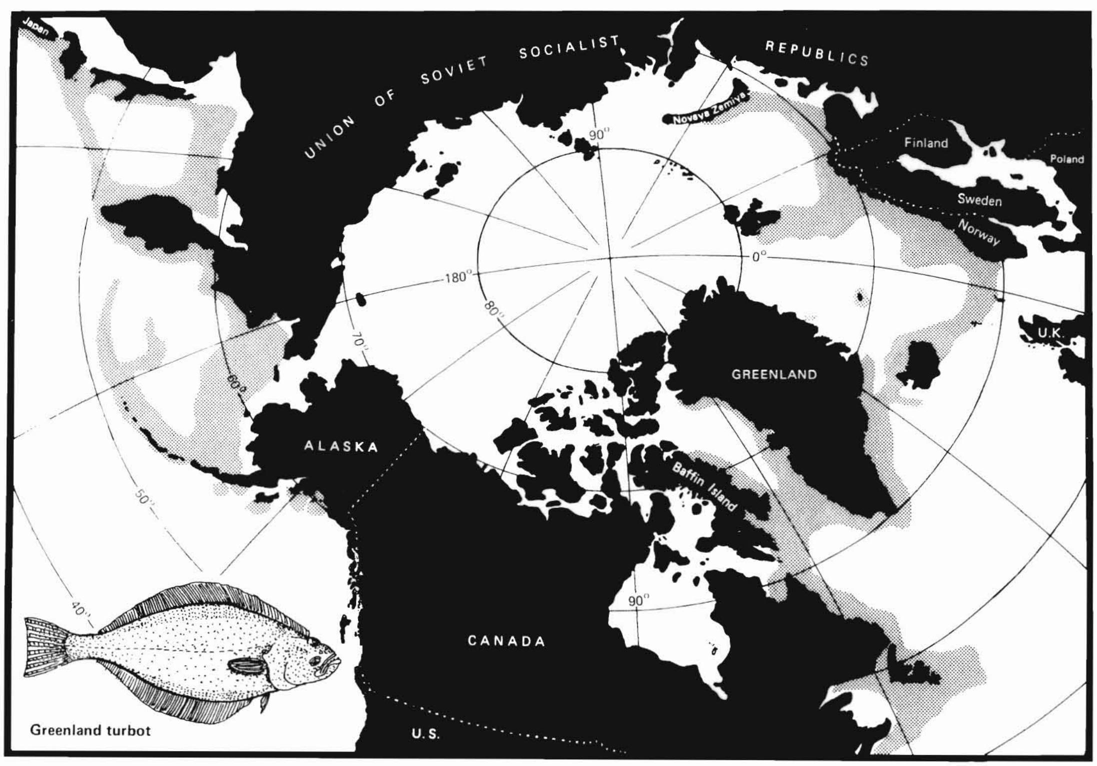

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ABSTRACT

Greenland turbot (*Reinhardtius hippoglossoides*) is a commercially important flounder in both the North Atlantic and North Pacific Oceans. In the latter, its center of abundance is in the eastern Bering Sea and along the Aleutian Islands chain where its population is managed as a single stock. Harvest levels in this region of the North Pacific during the period 1970-81 were comparable with those in the northwest and northeast Atlantic, with annual average catches of 53,000 metric tons (t). However, the catch in 1984 dropped sharply to 23,100 t, in part because of reduced quotas arising from concern over continued poor recruitment and declining catch-per-unit-effort.

Recruitment failure was manifested in 1) the sharp decline in the catch rate of young fish in annual research trawl surveys on the continental shelf of the eastern Bering Sea and 2) an increasing proportion of older and larger fish in the commercial catch from the continental slope of both the eastern Bering Sea and Aleutian Islands. The cause of the decline in recruitment could not be clearly identified.

Greenland turbot of the Bering Sea-Aleutian Islands share certain distributional features with the North Atlantic form. There is an apparent bathymetric change in the size and age of fish, with younger animals occupying continental shelf depths and the older individuals residing at depths of the continental slope. At shallow depths the young are exposed to temperature fluctuations, whereas older animals along the slope are exposed to relatively stable temperatures.

A hypothesis is proposed for describing the temporal and spatial paths by which young animals reach the mature or spawning portion of the population.

Purpose

This report provides a comprehensive treatment of our knowledge of the Greenland turbot,[1] *Reinhardtius hippoglossoides*, stock of the eastern Bering Sea and Aleutian Islands region (hereafter referred to as the Aleutians). It covers the history of harvest and management of this stock and describes the characteristics of the fisheries, such as nations and vessel types involved and the temporal and spatial patterns of harvest and of catch-per-unit-effort. The report also traces changes that have occurred in the abundance and composition of the stock as inferred from both fisheries and research vessel survey data. A hypothesis is proposed for the eastern Bering Sea-Aleutian stock which describes the possible temporal and spatial pathways by which young fish recruit to the adult population.

Background

Distribution of species

Greenland turbot has an amphiboreal distribution, occurring in the North Atlantic and North Pacific, but not in the intervening Arctic Ocean (Fig. 1). Hubbs and Wilimovsky (1964) have suggested that their range was probably continuous through the Arctic Ocean during the last interglacial period and possibly even during the postglacial hypsithermal period when the Arctic Ocean waters were warm. They found no significant morphological differences between representative specimens from the two oceans. Fairbairn (1981), however, using biochemical genetic techniques on muscle, heart, and liver tissues, found genetic divergence approaching the subspecies level between samples from the northwest Atlantic Ocean and the Bering Sea.

In the North Pacific, species abundance is centered in the eastern Bering Sea and, secondly, in the Aleutians. On the Asian side, these fish occur in the Gulf of Anadyr (about lat. 65°N) along the Bering Sea coast of the U.S.S.R., in the Okhotsk Sea, around the Kurile Islands, and along the east coast of Japan to northern Honshu Island (about lat. 38°N) (Hubbs and Wilimovsky 1964, Mikawa 1963, Shuntov 1965). Isolated occurrences have been recorded for the Sea of Japan (Mikawa 1963).

Isolated occurrences have also been recorded along the North American continent outside the distribution described above. In the far north, Greenland turbot has been taken irregularly in Norton Sound of the Bering Sea and in the southwest Chuckchi Sea (about lat. 66°N). Species distribution is light and intermittent in the Gulf of Alaska and southward to about lat. 45°N. Isolated captures have been recorded off British Columbia (Westrheim and Pletcher 1966), Oregon (Niska and Magill 1967), northern and central California, and as far south as northern Baja California in Mexico (about lat. 32°N) (Hubbs and Wilimovsky 1964).

Greenland turbot are distributed across the north Atlantic Ocean (Fig. 1) and are most prevalent from Baffin Island and west Greenland south to the northern Grand Bank (Bowering 1983), off Iceland (Sigurdsson 1981), around Jan Mayen Island (Torheim 1979), and from Spitsbergen Island to the north coast of Norway (Hognestad 1969). They are found as far north as Smith Sound (about lat. 78°N) and as far south as Georges Bank (about lat. 40°N) in the northwest Atlantic (Templeman 1973). In the northeast Atlan-

[1]The common market name is used in this report rather than the scientifically accepted common name, Greenland halibut.

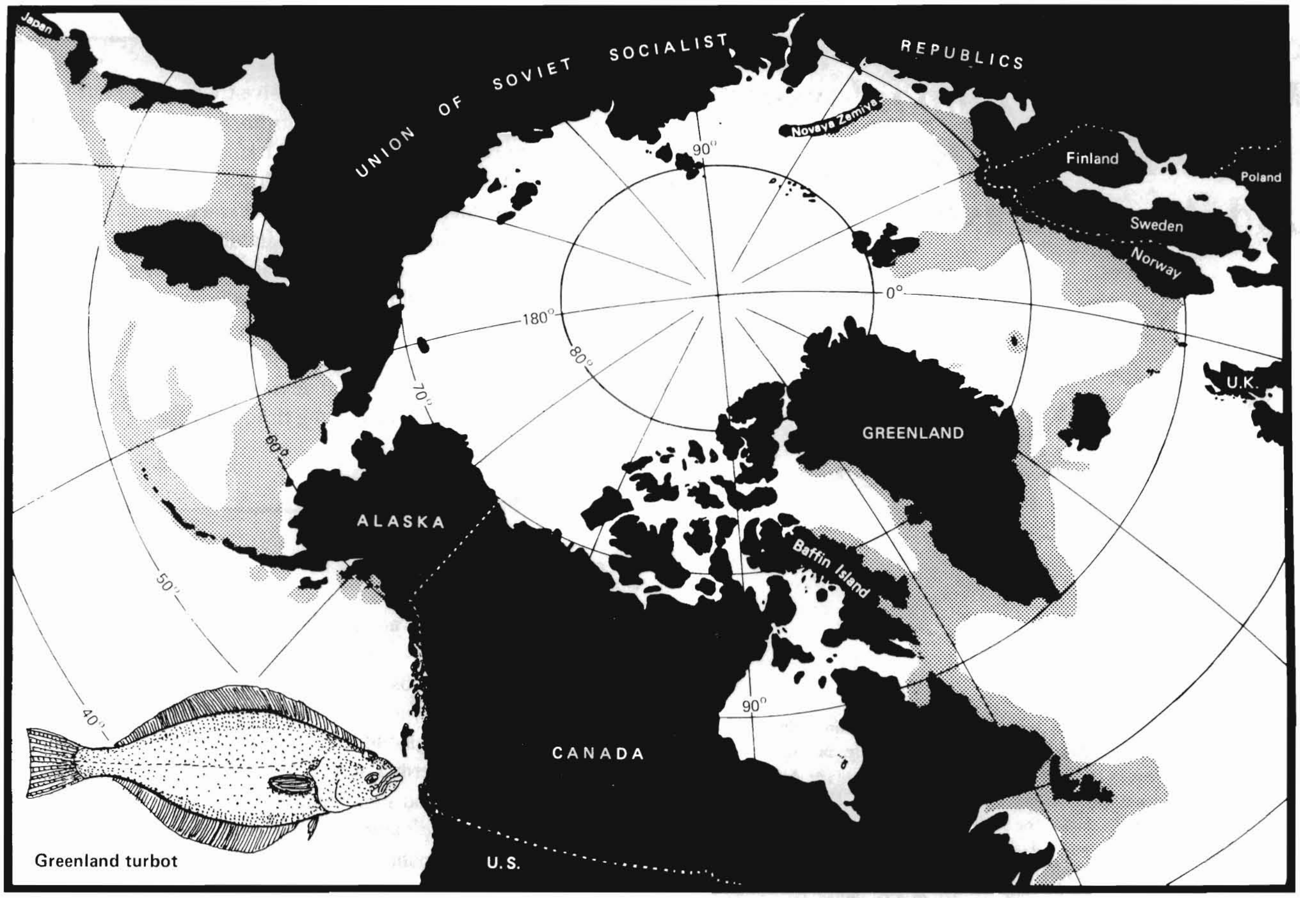

Figure 1
Geographical distribution (shaded areas) of Greenland turbot, *Reinhardtius hippoglossoides*.

tic, they range from Spitsbergen Island in the north (about lat. 80°N) to southern Ireland (about 52°N) (Hubbs and Wilimovsky 1964) and range eastward as far as the southwest coast of Novaya Zemlya (Northland) in the Barents Sea (about long. 100°E) (Hognestad 1969).

General life history features

Most information on life history characteristics of the species has come from studies in the Atlantic, and to a lesser extent from studies in the Pacific Ocean. As will become evident, life history features of turbot appear to be quite similar in the two oceans.

Spawning appears to occur in the eastern Bering Sea in winter and may be protracted starting in September or October and continuing until March with an apparent peak period in November to February (Shuntov 1970, Bulatov 1983). Spawning time in the Atlantic varies by area: February-April off west Iceland (A. Sigurdsson, Mar. Res. Inst., P.O. Box 1390, 121 Reykjavik, Iceland, pers. commun., April 1986), November-January in the Barents Sea (Fedorov 1968), and April-June off west Greenland (Jensen 1935) and in the Norwegian Sea (Hognestad 1969). Spawning appears to occur universally on the continental slope (Bulatov 1983; Hognestad 1969; Sigurdsson 1979). Spawning Greenland turbot have been caught at depths of 1,000 m both off Iceland (Sigurdsson 1979) and in Davis Strait in the northwest Atlantic (Smidt 1969).

Greenland turbot spawn relatively small numbers of eggs. In the Bering sea, fecundity ranged from 23,900 to 149,300 eggs for females 83.3 cm and smaller in length (D'yakov 1982). This range is similar to that of turbot in the Atlantic from southern Labrador and the southeastern Gulf of St. Lawrence (13,000-150,000 eggs; Bowering 1980), southern Labrador and eastern Newfoundland (15,000-215,000 eggs; Lear 1970), and the Barents Sea (6,000-140,000 eggs; Sorokin 1967, cited by D'yakov 1982).

Eggs and early larval stages are bathypelagic in both the Pacific (Musienko 1970) and Atlantic (Smidt 1969, Sigurdsson 1981) forms of Greenland turbot. In the Atlantic, 10-18 mm larvae have been found in bathypelagic waters and were reported to gradually rise to the pelagic zone as they grew and reached 16-24 mm in length (Atkinson et al. 1981). This rise to the pelagic zone appears to correspond to the absorption of the yolk sac which occurs at about 15-18 mm (Pertseva-Ostroumova 1961, Smidt 1969) and the onset of feeding. The period of larval development extends from April or May (Bulatov 1983, Jensen 1935) to August or September (Jensen 1935). This prolonged larval stage results in an extensive period of larval drift and broad dispersal from spawning areas (Haug and Gulliksen 1982, Templeman 1973, Hubbs and Wilimovsky 1964). In August or September, at about 70-80 mm in length, they settle to the bottom by which time the left eye has migrated to the dorsal side of the head (Jensen 1935, Pertseva-Ostroumova 1961, Andriyashev 1954, Hognestad 1969, Sigurdsson 1981, Smidt 1969). Unlike that of most flatfish, the migrating eye does not move completely to one side but stops at the top of the head which presumably results in a greater field of vision (de Groot 1970, Atkinson et al. 1981). This morphological adaptation for vision, plus the equally well-developed musculature of both sides of the body, helps to explain this species' tendency to feed off the sea bottom.

During their first few years as immature fish, Greenland turbot inhabit relatively shallow water. In the eastern Bering Sea, they inhabit continental shelf waters (<200 m) until about age 4 or 5 years, and continental slope waters at older ages. In the Atlantic Ocean, the young immatures tend to occupy deeper water than in the eastern Bering Sea, mainly between 200 and 400 m (Atkinson et al. 1981, Hognestad 1969, Templeman 1973), but even to depths of 700 m (Bowering 1984). The immatures are quite tolerant of cold temperatures, being frequently found in temperatures less than 0°C (Hognestad 1969, Shuntov 1965).

Adults occupy mainly continental slope waters from about 200 to 1,000 m or more. Off Newfoundland, turbot have been found to depths of at least 1,400-1,600 m (Templeman 1973). They appear to undergo seasonal shifts in depth distribution, moving deeper in winter and shallower in summer (Chumakov 1970, Shuntov 1970). Adults also frequently occupy water temperatures below 0°C (Chumakov 1970, Ernst 1974 cited by Haug and Gulliksen 1982, Fedorov 1971, Sigurdsson 1981, Templeman 1973), but at times are found at temperatures well over 0°C (Fedorov 1971); in some regions, such as the Labrador-eastern Newfoundland area (Bowering 1984) and the eastern Bering Sea, adults are most abundant in 3-5°C water.

From spawning areas, the drift of eggs and larvae appears to be mainly northward. In the Norwegian Sea, larvae are believed to be carried from spawning areas between northern Norway and Bear Island to off the western coast of Spitsbergen, which appears to be a nursery area for young Greenland turbot (Haug and Gulliksen 1982). Immature and maturing fish must then migrate southward to reach the spawning area (Godø and Haug 1987). Tagging and other studies have shown that spawning grounds exist off the west coast of Iceland and that migrations take place between this area and the feeding grounds off the northwest, north, and east coasts of Iceland (Sigurdsson 1979). The drift of larvae is mainly westward towards the east coast of Greenland, but to a minor extent to the north coast of Iceland. Shallower areas off the north and east coasts of Iceland are frequented by immature fish. Tagging has also confirmed migration of Greenland turbot from Iceland to the coast of Norway, thus indicating some mixing between the Iceland-Faroe Islands and Norwegian-Barents Sea stocks (Sigurdsson 1981). A northward drift of larvae takes place in the West Greenland Current of the northwest Atlantic, but some larvae are carried southward by the Arctic Current (Bowering 1984). From this drift the young become distributed along the west coast of Greenland and along the coast of Baffin Island, Labrador, and eastern Newfoundland (Atkinson et al. 1981, Bowering 1984). As will be discussed later, the migratory cycle for eastern Bering Sea turbot may be most similar to that of the Norwegian Sea stock, with a drift of larvae from spawning grounds in the southern slope area of the eastern Bering Sea northward to the northern shelf area, and with a gradual shifting of immature and maturing fish to deeper and more southern waters.

Greenland turbot may live more than 20 years and reach sizes as great as 120 cm and 16-17 kg (Moiseev 1953, Vernidub and Panin 1937, Smidt 1969). In the western Pacific, Mikawa (1963) found the maximum life span of turbot to be 15 years for males and 20 years for females. Off Greenland, maximum ages were found to be 13 years for males and 19 years for females (Atkinson et al. 1981). Similar maximum ages (14 years for males and 18 years for females) were derived for turbot off Baffin Island (Bowering 1983). Otoliths have been the structure most frequently used for ageing, although some investigations have had success with vertebrae and scales.

Maturity is reached at 5-10 years in the eastern Bering Sea (D'yakov 1982). In the northwest Atlantic, 50% maturity in females was found to vary from 7.8 years (58 cm) in the Gulf of St. Lawrence to 12 years (81 cm) in more northern areas (Bowering 1983); for males, 50% maturity was reached at 5 years (40 cm) in more southern regions and 7.9 years (56 cm) in the north. Smidt (1969) reported for the west Greenland area that the smallest mature male was 55 cm (about age 7) and the smallest maturing female 66-70 cm (8-10 years), while most males matured at about 60 cm and most females at 70-80 cm. In the Norwegian-Barents Sea, heavy exploitation of Greenland turbot in the 1970's reduced abundance of the stock to such an extent that growth rates increased and maturity was reached at smaller lengths and earlier ages (Kovtsova and Nizovtsev 1985). In the later 1970's and 1980's, large numbers of males matured at 41-55 cm (ages 5-9 years) and large numbers of females at 61-70 cm (ages 10-12 years), while in the 1960's and early 1970's maturity was reached by males at ages 9-10 and by females at ages 12-13 years.

Food consumed by Greenland turbot corresponds to the more semipelagic life of the species and often consists of plankton, nekton, and nektoplankton, while true benthos are of negligible importance (Smidt 1969, de Groot 1970, Livingston et al. 1986, Bowering and Lilly 1985). Off Newfoundland and west Greenland, evidence indicates that turbot ascend 100 m or more off the bottom to feed on capelin, *Mallotus villosus*, and other species (Templeman 1973). Feeding habits vary with water depth and fish length. In continental shelf waters, shrimp are often relatively important prey, along with pelagic or semipelagic species of fish such as capelin in the Atlantic and walleye pollock, *Theragra chalcogramma*, in the Pacific. Squid and bathypelagic or demersal fish become more important in continental slope waters (Smidt 1969, Livingston et al. 1986, Bowering and Lilly 1985). In the eastern Bering Sea the importance of walleye pollock in the diet increased from 3% by total weight of stomach contents in turbot less than 50 cm in length, to 57% in turbot greater than 70 cm, while squid showed a corresponding decrease (Livingston et al. 1986). In samples from off southern Labrador and northeastern Newfoundland, small turbot (<20 cm) preyed mainly on small crustaceans and squids, intermediate size fish (20-69 cm) on capelin, and large size fish (>70 cm) on a variety of demersal fishes, particularly redfish (*Sebastes* spp.) and other Greenland turbot (Bowering and Lilly 1985). Feeding appears to be more intense in summer than winter (Shuntov 1970, Mikawa 1963).

Pelagic and bathypelagic fishes are the main prey of Greenland turbot in the North Pacific, with walleye pollock often a major species in the diet (Mikawa 1963, Shuntov 1970, Livingston et al. 1986). This may result from the availability of pollock in many regions of the North Pacific. Mikawa (1963) found a variety of species (mainly fish) predominating in the diet of Greenland turbot along the Asian coast and suggested that these geographical differences were due to the distribution of prey animals. Squid are also an important component, with euphausiids and shrimp of lesser importance.

In the Atlantic Ocean, primary prey items are capelin (*Mallotus villosus*), Arctic cod (*Boreogadus saida*), rockfishes (*Sebastes* spp.), grenadiers (Macrouridae), shrimp, euphausiids, and squid (Andriyashev 1954, Chumakov 1970, de Groot 1970, Smidt 1969, Haug and Gulliksen 1982, Bowering 1982, Bowering and Lilly 1985). Turbot are also cannibalistic to some extent (Bowering and Lilly 1985).

Observed predators of Greenland turbot are northern fur seals (*Callorhinus ursinus*) in the Pacific (Kajimura 1984) and Greenland

Table 1

Commercial catches (t) of Greenland turbot from the northeast and northwest Atlantic Ocean and from the eastern Bering Sea and Aleutian Islands region of the Pacific Ocean. (Catch statistics from Int. Counc. Explor. Sea (ICES) 1972-83; Northwest Atl. Fish. Organ. 1983; Bakkala et al. 1985).

Area	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	Accumulative total
Northeast Atlantic													
Barents Sea	4,011	5,399	8,548	5,667	5,251	6,495	2,479	2,273	1,591	945	602	1,230	44,491
Norwegian Sea	12,819	10,504	14,564	8,190	7,852	3,166	3,985	10,396	12,892	10,287	5,473	5,284	105,412
Spitzbergen-Bear Island	53,925	60,182	18,310	16,081	24,660	28,511	29,610	16,221	10,134	6,080	7,209	8,504	279,427
North Sea and English Channel	5		30	49	34	17	21	12	33	21	216	7	445
Iceland	15,043	11,732	10,507	7,386	7,866	3,308	5,448	15,679	11,588	16,976	27,927	15,780	149,240
Faroes, NW Scotland, N. Ireland, and N. of Azores		11	498	403	334	586	333	661	731	566	1,342	580	6,045
East Greenland	841	10,422	8,061	12,719	28,089	19,627	273	241	2,166	6,231	2,148	2,893	93,711
Total	86,644	98,250	60,518	50,495	74,086	61,710	42,149	45,483	39,135	41,106	44,917	34,278	678,771
Northwest Atlantic													
West Greenland	2,000	3,000	4,000	7,000	13,000	23,000	11,000	9,000	11,000	18,000	7,000	6,000	114,000
Baffin Island	+	1,000	10,000	2,000	1,000	2,000	5,000	4,000	1,000	1,000	2,000	+	29,000
Labrador	11,000	11,000	13,000	15,000	16,000	12,000	9,000	11,000	7,000	6,000	2,000	5,000	118,000
Newfoundland	26,000	14,000	17,000	15,000	12,000	17,000	16,000	21,000	32,000	29,000	31,000	26,000	256,000
Gulf of St. Lawrence and Nova Scotian shelf	1,000	1,000	1,000	1,000	1,000	2,000	2,000	4,000	7,000	9,000	7,000	3,000	39,000
Total	40,000	30,000	45,000	40,000	43,000	56,000	43,000	49,000	58,000	63,000	49,000	40,000	556,000
Eastern Bering Sea & Aleutian Islands area	19,976	42,214	77,384	63,946	78,442	67,789	62,590	30,161	42,189	41,409	52,552	57,321	635,973

shark (*Somniosus microcephalus*), white whale (*Delphinapterus leucas*), narwhal (*Monodon monoceros*), and Atlantic cod (*Gadus morhua*) in the Atlantic (Smidt 1969). There are undoubtedly other predators, particularly on early life history stages.

Smidt (1969) noted a decline in turbot abundance in west Greenland waters at the same time cod stocks were increasing. He attributed this to predation on larval and early bottom stages of Greenland turbot. Conversely, W.R. Bowering (1984; pers. commun., March 1986, Can. Dep. Fish. Oceans, Fish. Res. Branch, P.O. Box 5667, St. John's, Newfoundland, A1C 5X1, Canada) has observed exceptionally good year-classes of Greenland turbot in the Labrador-eastern Newfoundland area coincident with a dramatic decline in abundance of cod off west Greenland. Recently, a substantial decline in recruitment of Greenland turbot in the eastern Bering Sea has coincided with a period of high abundance of Pacific cod (*Gadus macrocephalus*).

North Atlantic and North Pacific Greenland turbot fisheries

The stimulus for development of intensive directed fisheries for Greenland turbot in both the Atlantic and Pacific Oceans appears to have been their substantial presence during the 1960's in bycatches of fisheries targeting on redfishes and rockfishes (*Sebastes* spp.) and other deepwater species. Target fisheries for Greenland turbot existed as early as the 1850's off Newfoundland and later in the fjords of west Greenland, but these were always small scale efforts with catches usually less than 1,000 metric tons (t) (Templeman 1973). Following the development of target fishing, catches in the northeast and northwest Atlantic and eastern Bering Sea-Aleutians area (the only known target fishing in the North Pacific) have been of a similar magnitude (Table 1). Cumulative catches in the period 1970-81 were 679,000 t in the northeast Atlantic, 556,000 t in the northwest Atlantic, and 636,000 t in the eastern Bering Sea-Aleutians. Peak annual catches occurred in the northeast Atlantic (98,000 t) and Bering Sea (78,000 t) in the early 1970's and in the northwest Atlantic (63,000 t) in the late 1970's.

As the target fisheries developed, Greenland turbot became important commercially in regions of the Atlantic Ocean such as the Norwegian Sea and Spitsbergen area, off Iceland, and in the Canadian northwest Atlantic (Haug and Gulliksen 1982, Bowering 1983, Sigurdsson 1979, Templeman 1973). In the northeast Atlantic, largest cumulative catches in 1970-81 came from the Spitsbergen-Bear Island grounds (279,400 t), off Iceland (149,200 t), and from the Norwegian Sea (105,000 t). In the northwest Atlantic, largest cumulative catches in this period came from Newfoundland (256,000 t), Labrador (118,000 t), and west Greenland (114,000 t).

Depths of target fisheries for Greenland turbot in both the Atlantic and Pacific Ocean are usually greater than 300 m (Bakkala 1985, Haug and Gulliksen 1982, Hognestad 1969, Templemen 1973). Fishing gear used in the Atlantic has included trawls, longlines, and gillnets. For many years catches were salted, but now fresh and frozen fillets are produced. Trawls have been the primary fishing gear used in the eastern Bering Sea, but longlines have also been used occasionally; the fish are headed, gutted, and frozen.

Management of eastern Bering Sea-Aleutians stock

Meaningful regulation of the Greenland turbot fishery was not established in the eastern Bering Sea until after implementation in 1977 of the Magnuson Fisheries Conservation and Management Act (MFCMA) of 1976 which established the 200-mile fisheries conservation zone (FCZ) off the United States. Some time-area restrictions and catch quotas were established prior to 1977 through bilateral agreements and the International North Pacific Fisheries Commission (INPFC), involving the United States and nations harvesting groundfish in the eastern Bering Sea and Aleutians. However, catch quotas which applied to broad groups of species, such as all flatfish or all species other than walleye pollock, probably had little influence on any target fisheries for Greenland turbot.

Following implementation of the MFCMA and establishment of the fishery conservation zone (FCZ), Greenland turbot of the eastern Bering Sea and Aleutians were managed as part of a group of species for which an annual allowable catch or optimum yield (OY)[2] was set. Greenland turbot was included in a group designated as "other flounders" for the years 1977-79. Other members of this group were arrowtooth flounder (*Atheresthes stomias*), rock sole (*Lepidopsetta bilineata*), flathead sole (*Hippoglossoides elassodon*), and other miscellaneous flatfish species. The OY for this "other flounder" group was 100,000 t in 1977 and 159,000 t for the years 1978 and 1979. Because of similarities in their life histories and distribution, Greenland turbot and arrowtooth flounder were placed in a separate management unit called "turbot" beginning in 1980. The OY of the "turbot" group was 90,000 t for the years 1980-83, then reduced to 59,610 t in 1984, and further reduced to 42,000 t in 1985 because of indications of population decline in Greenland turbot. Since this decline was accompanied by increases in abundance of arrowtooth flounder, each species began to be managed as a separate unit in 1986.

In establishing OY for Greenland turbot, the condition of the stock has been determined from trends in catch-per-unit-effort (CPUE) and young fish abundance and from recent estimates of adult abundance. Stock abundance is estimated to have been reduced from about one million t in the 1960's to about 400-500 thousand t in 1984-85 (Bakkala et al. 1986).

Fisheries and research surveys

Data sources and analysis

Fisheries

Catch and effort—Fisheries from Japan and the U.S.S.R. were the first to harvest substantial amounts of bottomfish from the eastern Bering Sea and Aleutians. Japanese trawl fisheries operated in the eastern Bering Sea as early as the 1930's, but these fisheries were interrupted because of World War II and postwar restrictions. When Japan's fisheries resumed operations in the eastern Bering Sea during 1954, they expanded rapidly in geographic and species coverage as well as in level of harvest, diversifying into a number of distinct fisheries. By 1960 the total catch of bottomfish by Japanese fisheries reached some 449,000 t, of which 36,800 t were identified as "turbot" (Greenland turbot and arrowtooth flounder). This was the first year that Japan had reported turbot as a separate category. As a member of the INPFC, Japan began in 1964 to provide catch-and-effort data for its fisheries operating in U.S. contiguous waters. Such data are given in a manner prescribed by the INPFC (i.e., by species or higher taxa for statistical blocks of 1° longitude by 0.5° latitude, by month, fishery, and vessel class). The catch of turbot was not reported by species until 1977. However, Wakabayashi and Bakkala (1978) using knowledge of how Greenland turbot were classified in catch statistics from the various fisheries, estimated the Japanese turbot catch by species for the years 1970-76.

U.S.S.R. fishing fleets entered the eastern Bering Sea in 1959 and, like the Japanese fisheries, subsequently grew in scope. Reports of the Food and Agricultural Organization of the United Nations began to include Soviet catch statistics in 1965. The Soviet catch was given by a very broad geographical area that encompassed the eastern Aleutian Islands, eastern Bering Sea, and the Gulf of Anadyr. Beginning in 1972, the U.S.S.R. provided statistics on their fisheries in U.S. offshore waters under terms of bilateral agreements. These statistics were reported by species (including turbot) and by broad INPFC statistical areas (Fig. 2). The 1970 and 1971 U.S.S.R. catches of Greenland turbot were estimated by Wakabayashi and Bakkala (1978) by prorating the Soviet statistics reported to FAO based on Japanese catch data.

With implementation of the MFCMA, all nations were required annually to report catch and effort of their fisheries operating in the FCZ of the United States according to INPFC standards. Nations whose catch of turbot was less than 15% of their total groundfish catch were not required to report that catch by species.

In 1977, the U.S. Foreign Fisheries Observer Program instituted procedures for obtaining an independent estimate of the foreign catch in the FCZ. It is called "best blend," since the estimating procedure uses both observer estimates of catch and data reported by the foreign fishing vessels themselves (Nelson et al. 1981). Best blend catch of Greenland turbot is given by INPFC statistical areas.

Fisheries statistics for Greenland turbot can thus be placed into three reporting periods: The first, years 1960-69 (Table 2), gives an incomplete picture of the actual removals and does not provide catches by individual species consistently; the second, 1970-76 (Table 3), is one in which the catch estimate for Greenland turbot is given but by statistical areas that differ among nations; and the third, beginning in 1977 (Table 3), is one in which all nations follow the same reporting format and the U.S. Observer Program provides best blend catch estimates.

In this report, major emphasis is placed on the catch-and-effort data from those fisheries (namely Japanese) which have targeted Greenland turbot or have taken large amounts of Greenland turbot as bycatch. Targeted fisheries include the landbased dragnet fishery, the North Pacific trawl fishery (hereafter, called North Pacific small trawlers), and vessels using longline gear. The nontargeted fishery is comprised of mothership operations where catcher vessels land their catches aboard the processing or mothership vessel.

The landbased dragnet fishery has only operated west of long. 170°W in the Bering Sea and Aleutians region because of licensing restrictions imposed in Japan. Vessels in this fishery cannot transship their catch to Japan, but must offload their processed catch in Japan themselves. Neither the North Pacific small trawlers nor longline vessels have these restrictions.

The fisheries targeting on Greenland turbot operate mainly on the continental slope, whereas the mothership fishery operates mainly on the continental shelf targeting on pollock for the production of surimi.

U.S. Foreign Fisheries Observer Program data have been used almost exclusively to calculate CPUE of targeted fisheries and the incidence rate in the mothership fishery. The exception is the use of Japanese reported statistics for CPUE estimates of their landbased dragnet fishery.

CPUE was not calculated for U.S.S.R. vessels because of the difficulty of identifying targeted effort and the corresponding catch of Greenland turbot, and because of the limited time series of significant annual catches of Greenland turbot (Table 3). Catches of Greenland turbot by fisheries other than those of Japan and the

[2]Optimum yield refers to the annual catch which will provide the greatest overall benefit to the U.S., and which is prescribed on the basis of sustainable yield as modified by any relevant economic, social, or ecological factors. For Greenland turbot, OY is set by the North Pacific Fishery Management Council.

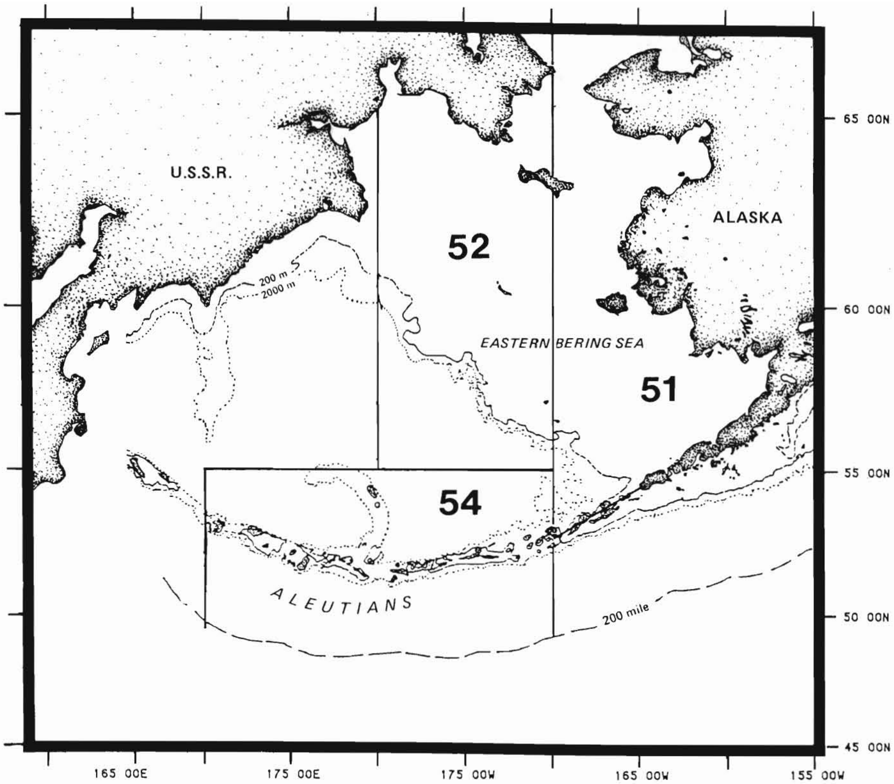

Figure 2

International North Pacific Fisheries Commission statistical areas used in the reporting of catches by the U.S. Foreign Fisheries Observer Program.

Table 2

Estimates of turbot catch (1,000 t) from the eastern Bering Sea and Aleutians[1] by Japanese and U.S.S.R. fisheries, 1960-69.

Nation	Species	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Japan[2]	Greenland turbot and Arrowtooth flounder combined	36.8	57.3	58.2	31.6	33.7	8.0	10.8	21.2	20.0	19.2
USSR[3]	Greenland turbot	NA	NA	NA	NA	NA	1.2	1.5	6.1	17.8	15.0
	Arrowtooth flounder	NA	NA	NA	NA	NA	0.6	0.7	3.2	9.1	7.8
All	All	NA	NA	NA	NA	NA	9.8	13.0	30.5	46.9	42.0

[1]Reported annual catches for the Aleutians ranged from 63 to 504 t.
[2]From Wakabayashi and Bakkala (1978).
[3]From FAO 1975, 1976.
NA = not available.

Table 3

Annual catches (1,000 t) of Greenland turbot in the eastern Bering Sea and Aleutian Islands region as reported by Bakkala et al. (1986) for 1970-76 and made available by the U.S. Foreign Fisheries Observer Program for 1977-86. (tr = catch of 50 t or less.)

Nation	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Eastern Bering Sea																	
Japan	14.7	30.2	49.8	43.4	58.8	52.6	51.6	33.6	54.7	42.4	46.9	50.5	44.0	42.2	21.1	14.6	6.8
USSR	5.0	10.3	14.7	11.9	10.8	12.2	8.9	2.7	4.9	0.5					tr		
Other									0.1	0.2	2.0	2.4	1.8	1.2	0.2	tr	0.9
Total	19.7	40.5	64.5	55.3	69.6	64.8	60.5	36.3	59.7	43.1	48.9	52.9	45.8	43.4	21.3	14.6	7.7
Aleutian Islands region																	
Japan	0.3	1.7	12.7	8.3	8.8	3.0	2.0	1.7	8.2	9.9	3.7	4.4	6.3	4.1	1.8	tr	0.1
USSR			0.2	0.3	tr		0.1	tr	tr	tr							
Others									tr	tr	tr	tr	tr	tr	tr	tr	2.0
Total	0.3	1.7	12.9	8.6	8.8	3.0	2.1	1.7	8.2	9.9	3.7	4.4	6.3	4.1	1.8	tr	2.1
Grand total	20.0	42.2	77.4	63.9	78.4	67.8	62.6	38.0	67.9	53.0	52.6	57.3	52.1	47.5	23.1	14.7	9.8

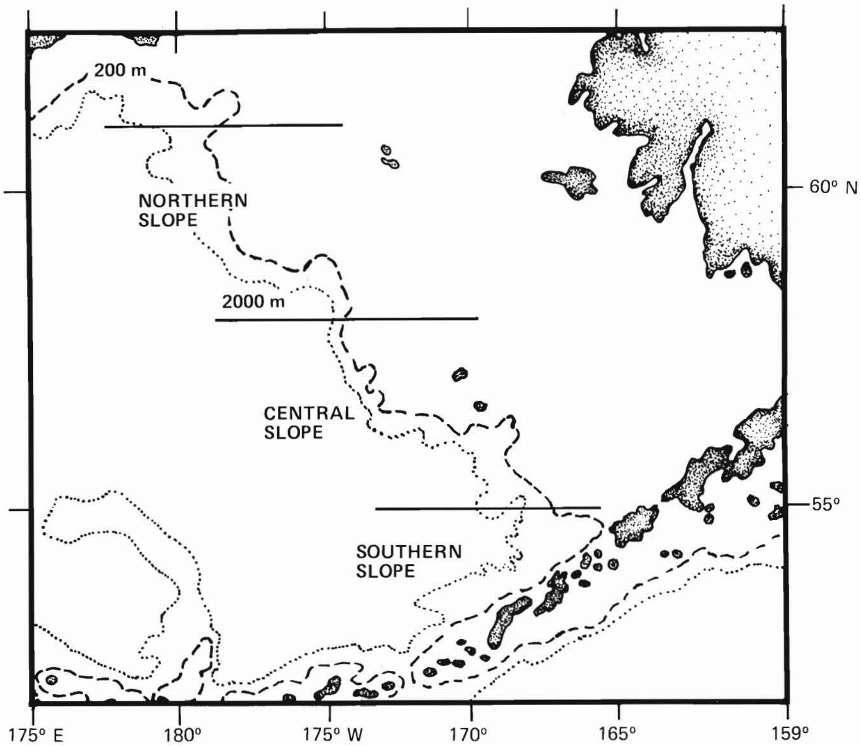

Figure 3
Location of the three eastern Bering Sea continental slope areas referred to in the presentation of fisheries and research survey findings.

U.S.S.R. have been small for most years; hence no attempt has been made to estimate CPUE for such fisheries.

Biological data—All biological data used in this report from the fisheries were collected by U.S. observers aboard Japanese vessels. These data are part of the observer program fisheries database (designated NORPAC) which is stored in the Northwest and Alaska Fisheries Center's (NWAFC) mainframe computer. The data consist, for the most part, of fish lengths by sex for the years 1978-84. Otoliths were collected during these years but were not read because of other priorities placed on the NWAFC Ageing Unit.

Standard procedures established by the U.S. Observer Program (Nelson et al. 1981) were followed in the collection of length data. When Greenland turbot was a vessel's targeted species, the observers obtained a random sample of some 150 fish from each day's catch of this species. The total length of each fish and its sex were determined. In addition to random samples, a sample stratified by length-groups (5 fish of each sex for each 1-cm interval) was collected in which each fish was weighed to the nearest hundredth of a kilogram and its otolith removed for later age determination. Data from these stratified-by-length collections provided the means of converting catch-in-weight to catch-in-numbers by using length-weight relationships.

Since individual trawl catches were sampled in the targeted fisheries for length information, the observer was able to record important ancillary information so that length data could be related to catch magnitude, fishing effort, area, and depth. Whenever length information was combined into large area-time-depth cells, lengths from individual hauls were weighted by the catch of these hauls and then expanded to the total catch in the cell.

The majority of length data came from the catch of the landbased dragnet fishery or the North Pacific small trawlers. The U.S. Foreign Fisheries Observer Program database does not distinguish between these fisheries, but places vessels from both fisheries into the standard category of small freezer trawlers. Length data were also available from the Japanese longline and mothership fisheries.

Through trial and error, an area-season-depth stratification was constructed, based on similarities and differences in length compositions of fish sampled from small freezer trawlers. The stratification that best described the changes in length composition between area, season, depth, and year was one based on three areas of the eastern Bering Sea continental slope (Fig. 3), three depths (184-450 m, 451-730 m, >730 m), and quarterly periods. For the Aleutians, length data were examined by the same depth intervals as above but by year rather than by quarter because of the limited seasonal data from the region, and for two areas, the eastern and western Aleutians divided at 180°.

Research survey data

In examining temporal and geographic features of the distribution and abundance of Greenland turbot, we have used data gathered from extensive research trawl surveys of the eastern Bering Sea and Aleutians. Annual trawl surveys of crab and bottomfish have taken place beginning as early as 1971, but it was not until 1973 that the surveys began to annually sample a standardized and significant area of the eastern Bering Sea shelf. However, the 1973 and 1974 surveys covered only the southeastern part of the eastern Bering Sea shelf. The first survey to adequately cover much of the eastern Bering Sea shelf occurred in 1975. This extensive survey was done by the NWAFC in response to the need for baseline in-

Table 4
Annual catch (1,000 t) by the Japanese fisheries of the eastern Bering Sea and Aleutian Islands region. Statistics provided by the U.S. Foreign Fisheries Observer Program. (tr = catch of 50 t or less.)

Fishery or vessel class	1978	1979	1980	1981	1982	1983	1984	1985
Eastern Bering Sea								
Small freezer trawlers[1]	38.4	30.1	33.3	41.2	38.1	38.2	19.9	14.2
Mothership	11.9	9.8	9.8	5.4	2.8	1.7	0.7	0.3
Other trawler types	3.1	0.7	0.3	0.5	0.2	0.1	0.1	tr
Longline	1.3	1.8	3.3	3.4	2.9	2.2	0.4	0.1
Total	54.7	42.4	46.7	50.5	44.0	42.2	21.1	14.6
Aleutian Islands region								
Small freezer trawler[1]	6.7	8.9	3.2	4.1	6.0	3.9	1.6	
Other trawler types	0.4	0.1	tr	tr	tr	tr	tr	
Longline	1.1	0.9	0.5	0.3	0.3	0.2	0.2	tr
Total	8.2	9.9	3.7	4.4	6.3	4.1	1.8	tr

[1]Combined catches of two major Japanese fisheries: the North Pacific trawl fishery and the landbased dragnet fishery.

formation to evaluate the potential effects of oil exploration and development on the fishery resources of the region (Pereyra et al. 1976). Surveys of much lesser area coverage occurred in 1976, 1977, and 1978. Another extensive shelf survey took place in 1979 and, for the first time, continental slope waters were comprehensively sampled through a joint effort by the NWAFC and the Fishery Agency of Japan (Bakkala et al. 1985). Following a triennial schedule, Japanese and U.S researchers conducted similar surveys of the shelf and slope in 1982 and 1985. In intermediate years (1980, 1981, 1983, 1984), extensive areas of the shelf were sampled, but the slope was not sampled by the Japanese except in 1981. Thus we have 4 years of slope survey data (1979, 1981, 1982, and 1985), 8 years of extensive shelf coverage (1975, 1979-85), and 13 years (1973-85) of coverage that included the southeastern part of the shelf. We have treated the results of the Japanese survey of the slope separate from that of the shelf area and have not attempted to interrelate data from the two regions. As discussed earlier, trawls and trawl rigging used in the two regions differed, and comparative fishing experiments have not been adequate to measure the relative efficiencies of these trawls. There are the additional problems of marked changes in species composition and bottom topography in the two regions which further complicates interrelating these data.

There have also been changes in trawls and trawl rigging during the NWAFC shelf survey which may have created some bias in the time series of survey results. For example, the standard survey trawl was changed in 1982, and evidence suggests that the newer trawl was more affective in capturing small flatfish than the trawls used prior to 1982. Therefore, the catch efficiency for young Greenland turbot on the shelf has possibly been higher since 1982.

Extensive trawl surveys of the Aleutians, which covered the areas both north and south of the Aleutian chain, began in 1980 and followed a triennial schedule so that a second survey was conducted in the Aleutians in 1983. These surveys have also been a joint effort by the United States and Japan. Because of the relatively small shelf area in the Aleutians, most of the survey effort took place at depths greater than 183 m (Wilderbuer et al. 1985).

Trawling locations were preselected for the eastern Bering Sea and Aleutian surveys so as to cover both depth and area. Locations are given for the eastern Bering Sea by Pereyra et al. (1976), Wakabayashi et al. (1985), Umeda and Bakkala (1983), Sample et al. (1985), Bakkala and Wakabayashi (1985), Hirschberger (1985), and Halliday and Umeda (1986); and for the Aleutians by Wilderbuer et al. (1985). Haul duration was 0.5 hours for U.S. vessels and 1.0 hours for Japanese vessels.

Commercial-type fishing trawls were used. Those fished from U.S. vessels had a small mesh web (32-mm stretched mesh) lining the codend so that small animals such as juvenile fish could be retained. Japanese trawls had no liners but had triple layers of 90-100 mm stretched mesh in the codend. All trawls used in the Aleutians and in the slope area of the eastern Bering Sea were equipped with roller gear to reduce damage and hangups on the sea bottom. Roller gear was not used during shelf surveys in the eastern Bering Sea.

Survey sampling methods are described by Wakabayashi et al. (1985). In general, total catches of less than about 1,150 kg were sorted by species and then weighed and counted. Catches over 1,150 kg were subsampled before sorting. Random samples of Greenland turbot were separated by sex and measured to the nearest centimeter. Otoliths were removed for ageing from at least five fish of each sex per centimeter length-interval during the survey. U.S. age samples through 1982 were read by NWAFC age readers. Due to reservations about methodology and results from these readings, we did not use these data. Samples collected since 1982 have not been read due to higher priorities for other species. However, age and related length data provided by the Fisheries Agency of Japan were used 1) as an age-length key to convert length data collected during the NWAFC 1979 survey to age, and 2) to approximate the age of young fish during NWAFC surveys of the eastern Bering Sea shelf in 1975 and 1980-85. Japanese age data were based on otoliths collected by a Japanese research vessel operating in the shelf and slope region of the eastern Bering Sea in 1979. Approximation of the age of young fish was possible because of the high growth rate of juvenile Greenland turbot, which results in very little overlap in the length ranges of successive ages of young fish.

Results

Analysis of Japanese fisheries information

As mentioned earlier, actual removals of Greenland turbot by foreign fisheries prior to 1970 cannot be adequately estimated. Although estimates of the annual catch of this species became available in 1970, it was not until 1977 that catch of Greenland turbot could be related to specific fisheries and to depth. Information on the length and sex of fish also began to be collected in 1977. However, because of limited observer coverage in 1977, these data

Table 5

Annual Japanese catches (1,000 t)[1] of Greenland turbot by the landbased dragnet fishery and small trawlers of the North Pacific trawl fishery in the eastern Bering Sea and Aleutian Islands region, 1970-84.

Fishery or vessel class	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Eastern Bering Sea															
Landbased	9.6	7.1	25.1	14.2	21.2	20.6	17.6	13.3	19.2	13.7	13.1	16.2	17.9	17.2	14.9
N. Pacific trawl fishery[2]	—	—	—	—	—	—	—	3.0	3.8	6.7	8.1	10.0	10.0	11.5	8.2
Total								16.3	23.0	20.4	21.2	26.2	27.9	28.7	23.1
Aleutian Islands region															
Landbased	0.3	0.5	12.0	7.3	7.8	2.2	1.1	2.0	4.1	5.6	4.8	2.5	3.3	2.6	1.6
N. Pacific trawl fishery[2]	—	—	—	—	—	—	—	0.4	0.2	0.2	0.1	0.2	0.1	0.1	0.0
Total								2.4	4.3	5.8	4.9	2.7	3.4	2.7	1.6

[1]As reported by Japan through INPFC.
[2]Format of reported statistics prevents identification of catch by this fishery for the years 1970-76.

Table 6

Catch in numbers of animals and average weight of Greenland turbot by the Japanese mothership fisheries, 1977-84.

	1977	1978	1979	1980	1981	1982	1983	1984
Catch (millions of fish)	36.6	49.6	40.5	38.9	9.1	2.0	1.8	0.7
Average individual weight (kg)	0.235	0.240	0.242	0.252	0.593	1.421	0.921	0.937

were not considered in some of the analyses concerned with changes in availability and length of fish by area and depth. This section, therefore, emphasizes findings from the Japanese fisheries for the years 1978-84. Other nations' catches of Greenland turbot have been inconsequential compared with those taken by the Japanese fisheries (Table 3), and very little biological information was collected for other fisheries.

Annual catch by region and fishery—The all-nation annual catch of Greenland turbot in the combined regions of the eastern Bering Sea and Aleutians has ranged from 9,800 t to 78,400 t during the period 1970-84 (Table 3). Most of the catch has come from the eastern Bering Sea, where annual catch reached levels of 60 to 70 thousand t from 1972 through 1978. This was followed by a general decline, so that in 1986 only 7,700 t were taken. Annual catch in the Aleutians has fluctuated between less than 50 t to as much as 13,000 t (Table 3).

Japanese fisheries have accounted for the majority of the Greenland turbot catch from both the eastern Bering Sea and Aleutians. Among these fisheries, the landbased dragnet trawlers, North Pacific small trawlers, the surimi mothership fishery, and the longline fishery have been the most important in terms of harvest magnitude or targeting on Greenland turbot (Table 4). Estimates of catch for the landbased dragnet fishery and that of the North Pacific small trawlers are not distinguished, but have been combined under the designation Japanese "small freezer trawlers" (Table 4).

The small freezer trawlers' annual catch does not correspond very closely with the Japanese reported combined catch of landbased dragnet and North Pacific small trawlers (Table 5) for either the eastern Bering Sea or Aleutians. The U.S. observer best blend estimate of catches by small freezer trawlers almost consistently exceeds that reported by the Japanese. For the eastern Bering Sea, the correspondence between best blend and Japanese reported catch

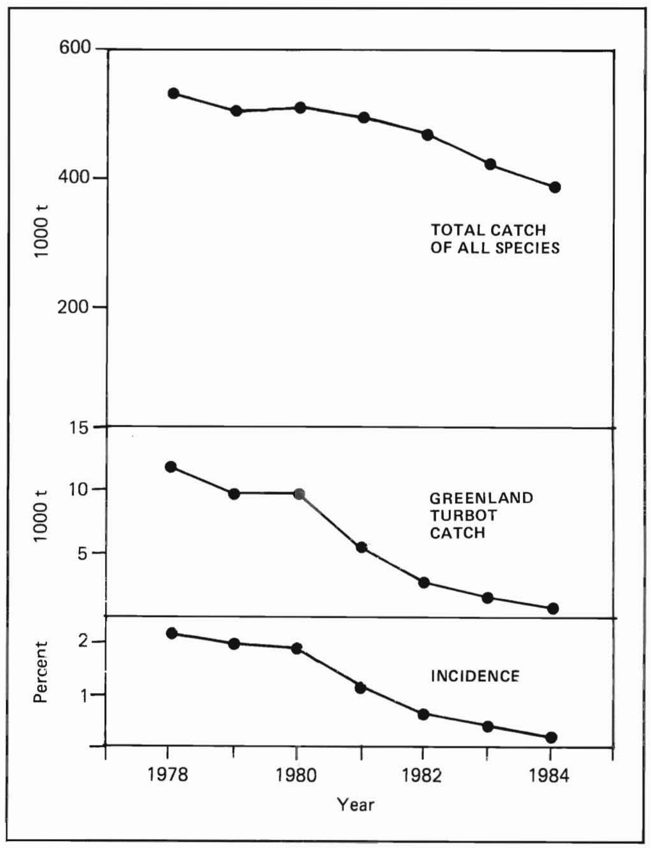

Figure 4

Annual catch and incidence (percent by weight of the annual catches of all species) of Greenland turbot by the Japanese surimi mothership fishery in the eastern Bering Sea, 1978-84. (Information from U.S. Foreign Fisheries Observer Program database.)

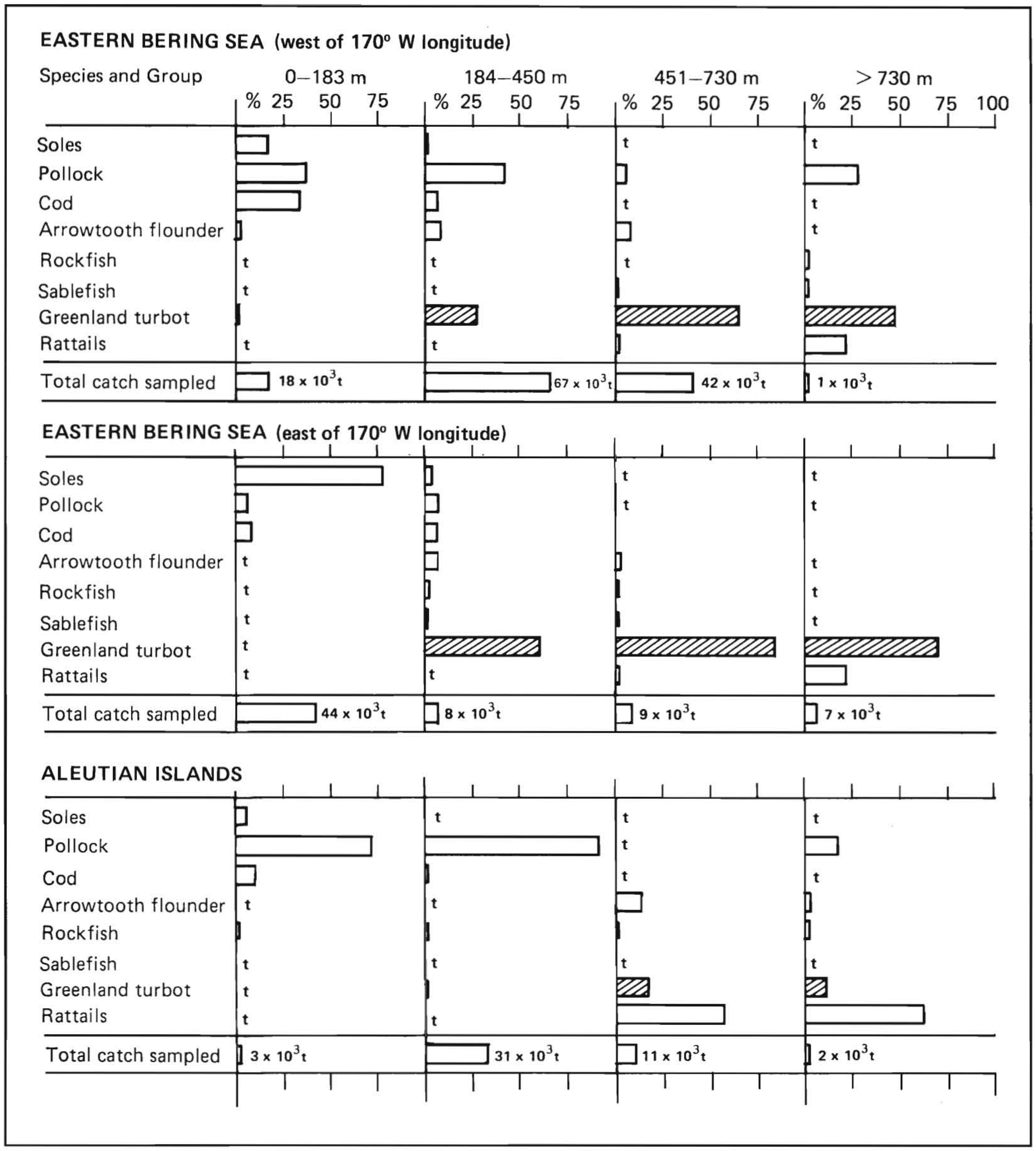

Figure 5

Importance of Greenland turbot relative to other species in the catch by Japanese small trawlers in the eastern Bering Sea and Aleutians, 1980-84. Total catch refers to that taken by trawlers with U.S. observers aboard. (Information from U.S. Foreign Fisheries Observers Program database.)

improves with time, so that by 1984 the best blend catch approximates that of the Japanese reported catch:

Ratio (Best blend/Reported catch)

78	*79*	*80*	*81*	*82*	*83*	*84*
1.7	1.5	1.6	1.6	1.4	1.3	0.9

Annual catch of the landbased fishery, as reported by Japan for the eastern Bering Sea, rose sharply in 1972 to 25,100 t and then fluctuated between 13 and 21 thousand t in subsequent years. In the Aleutians, the 1972-74 period was particularly productive for these fisheries, with annual catch ranging from 7.3 to 12.0 thousand t. However, since then there has been a downward trend in the level of catch, so that by 1984 the catch was only 1,600 t (Table 5).

Prior to 1977, we could not determine the Greenland turbot catch for the North Pacific small trawlers, the surimi mothership fishery, and the longline fishery. Since 1977 the catch of this species by North Pacific small trawlers in the Aleutians has been insignificant, but in the eastern Bering Sea such catches have risen, peaking at 11,500 t in 1983 and then dropping to 8,200 t in 1984 (Table 5). The mothership fishery operates only in the eastern Bering Sea and mainly on the continental shelf. Although there is no known targeting of Greenland turbot by this fishery, the incidental catch of this species was as high as 11,900 t in 1978 (Table 4). The catch dropped to 9,800 t in 1979 and 1980 and then rapidly declined in subsequent years, so that by 1984 less than 1,000 t were taken. The number of turbot estimated to have been caught by the mothership fisheries during the years of high catches (1978-80) ranged from 36.6 to 49.6 million (Table 6). In contrast to the mothership fishery, the Japanese longline fishery mainly operates in the slope region and does target Greenland turbot in both the eastern Bering Sea and the Aleutians. Its catch in the eastern Bering Sea has consistently been higher than that in the Aleutians. In the former region,

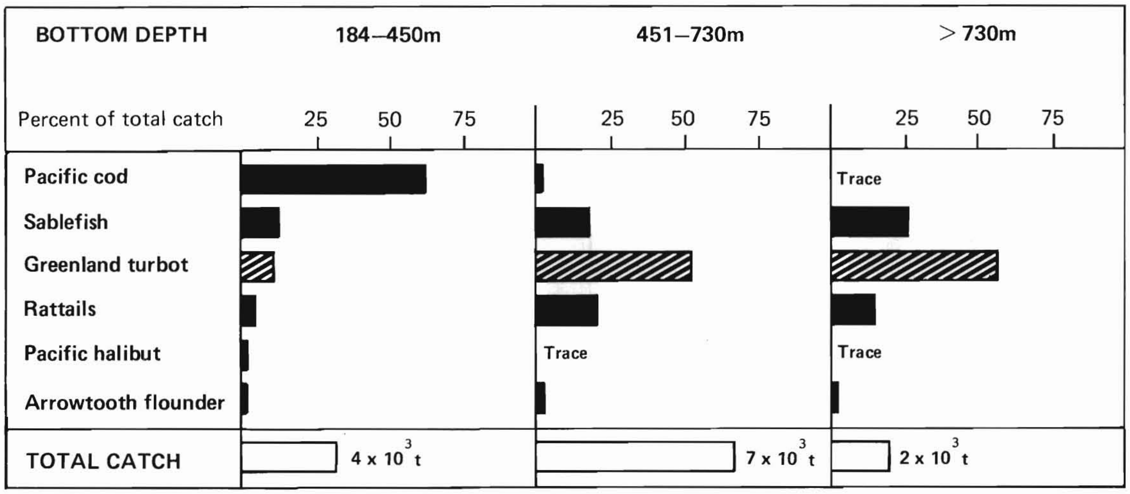

Figure 6

Importance of Greenland turbot relative to other species in the catch by Japanese longline vessels in the eastern Bering Sea. Total catch refers to the amount landed on vessels with U.S. observers aboard. (Information from U.S. Foreign Fisheries Observer Program database.)

the catch reached high levels (2,900 to 3,400 t) in the 1980-82 period and then declined to as low as 100 t in 1985. For the Aleutians, the catch by the longline fishery has steadily declined since 1978, so that less than 100 t were taken in 1985 (Table 4).

Relative importance of Greenland turbot in the Japanese fisheries—The importance of Greenland turbot relative to other species in the fisheries of the eastern Bering Sea and Aleutians increases with increasing bottom depth. On the shelf, the proportion of Greenland turbot in the catch is insignificant in comparison with that of targeted species such as pollock, cod, and the various species of sole. In the Japanese mothership fishery, the incidence of Greenland turbot was slightly more than 2% in 1978, but since then the incidence has declined to less than 0.3% in 1984 (Fig. 4). Catches by the Japanese small freezer trawlers and longline vessels are inconsequential at depths less than 183 m in both the eastern Bering Sea and Aleutians. In the slope region of the eastern Bering Sea, however, the importance of this species in the catch of these fisheries increases with depth, so that at the deepest depths (>450 m) it is the predominant species caught (Figs. 5 and 6). This is not the situation in the slope region of the Aleutians, where pollock predominates in the catch of small freezer trawlers from upper slope depths (183-450 m), and where rattails comprise most of the catch from lower slope depths (>450 m).

Since 1980 the importance of Greenland turbot relative to sablefish in the longline fishery has been declining, so that by 1984 it was no longer the dominant species in the annual catch.

Catch patterns of Greenland turbot by area, season, and depth—In this section we rely considerably on information provided by the U.S. Observer Program best blend estimate of catch. We place most of our emphasis on findings for the eastern Bering Sea because of the greater sampling coverage by time, depth, and area. For the Aleutians, the desultory nature of the fishing by time and area and the paucity of observer coverage prevent an adequate identification of area-time-depth catch patterns for this region.

In the eastern Bering Sea, Japanese small freezer trawlers have consistently taken a greater tonnage of Greenland turbot from the northern slope area than from either the central or southern slope area (Fig. 7). In turn, removals from the central slope area have been greater than from the southern slope area except in 1984 when the reverse occurred. By 1984 the catch was more evenly distributed among the three areas.

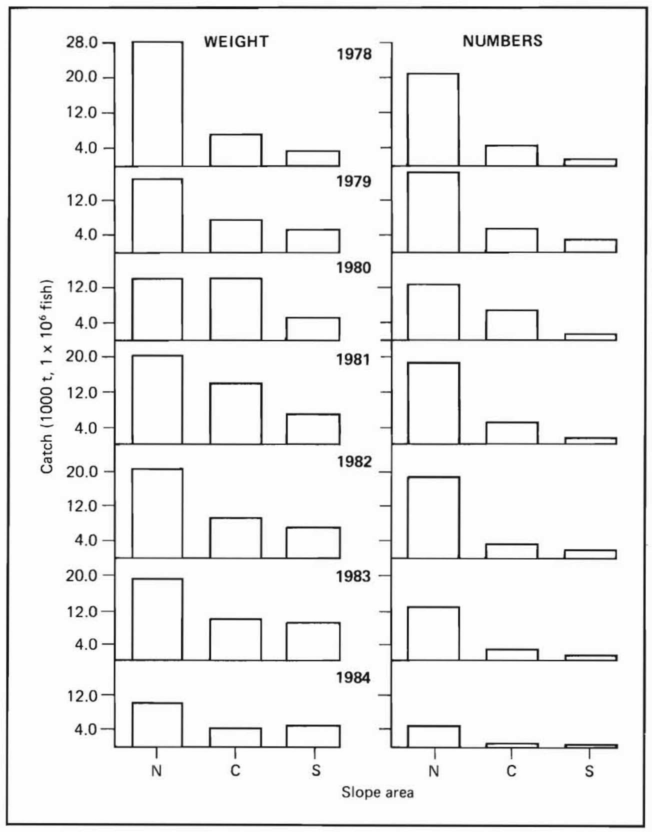

Figure 7

Annual Greenland turbot catch by Japanese small trawlers in the continental slope region of the eastern Bering Sea, 1978-84 (N = northern slope area, C = central slope area, and S = southern slope area).

When the catch of Greenland turbot by the small freezer trawlers is examined in terms of numbers of fish, the importance of the northern slope area becomes even more pronounced because of the smaller weight of individual Greenland turbot in the northern slope relative to the other slope areas (Fig. 8). In 1978, the estimated

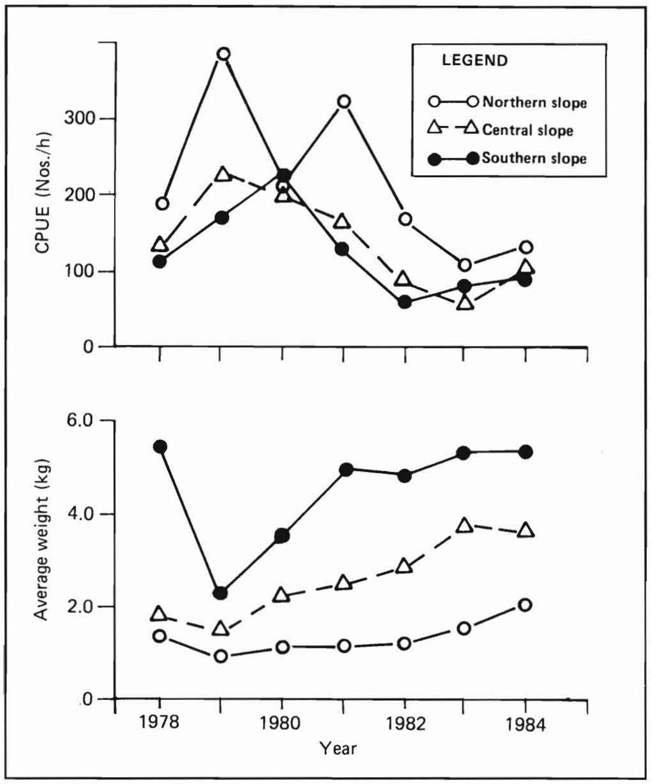

Figure 8
Annual changes in CPUE and average weight of Greenland turbot by Japanese small trawlers in the slope areas of the eastern Bering Sea, 1978-84.

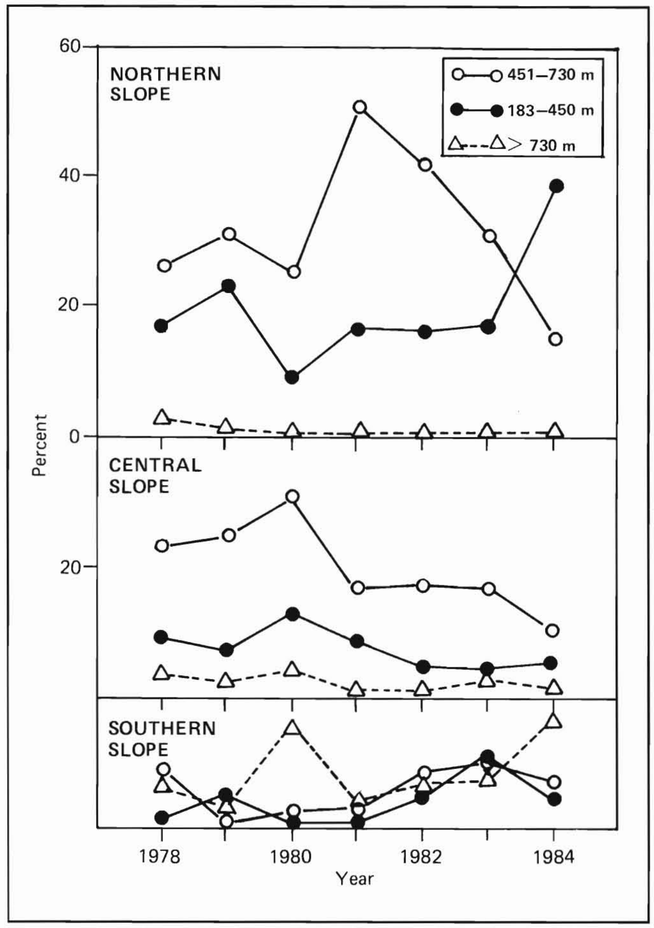

Figure 9
Distribution of annual Greenland turbot catch by Japanese small trawlers by depth and area in the continental slope area of the eastern Bering Sea, 1978-84.

number of fish taken by these trawlers from the northern slope was in excess of 20 million, and average annual removals for the years 1978-82 were about 17 million fish. In contrast, the average annual removals for the same period for the central slope were about 5 million fish and for the southern slope about 2 million fish.

In the northern and central slope areas most of the catch has come from shallow (184-450 m) and intermediate (451-730 m) bottom depths, with intermediate depths having the highest catch (Fig. 9).

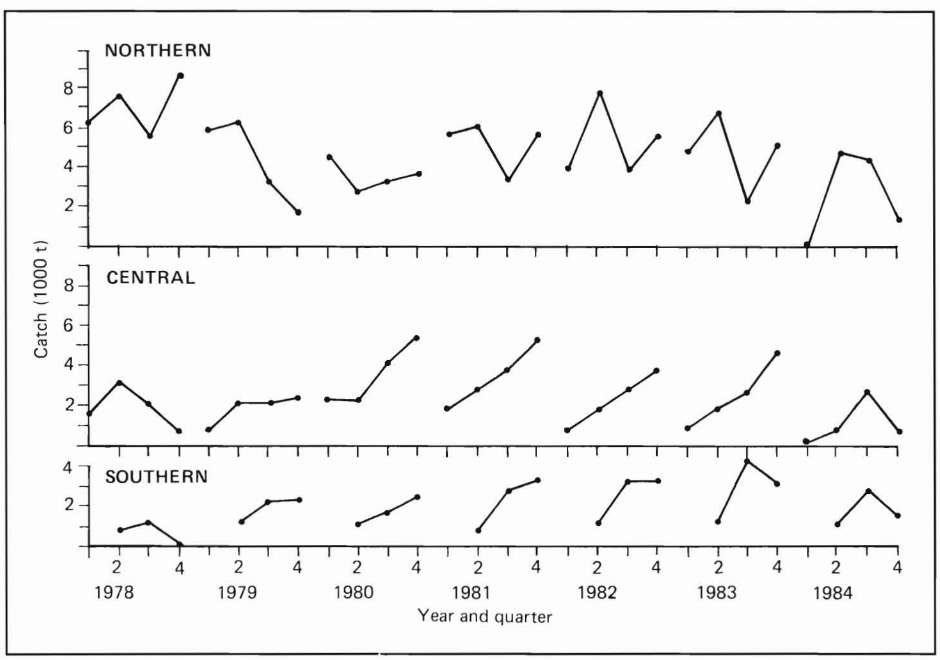

Figure 10
Quarterly catch of Greenland turbot by Japanese small trawlers in the continental slope region of the eastern Bering Sea, 1978-84.

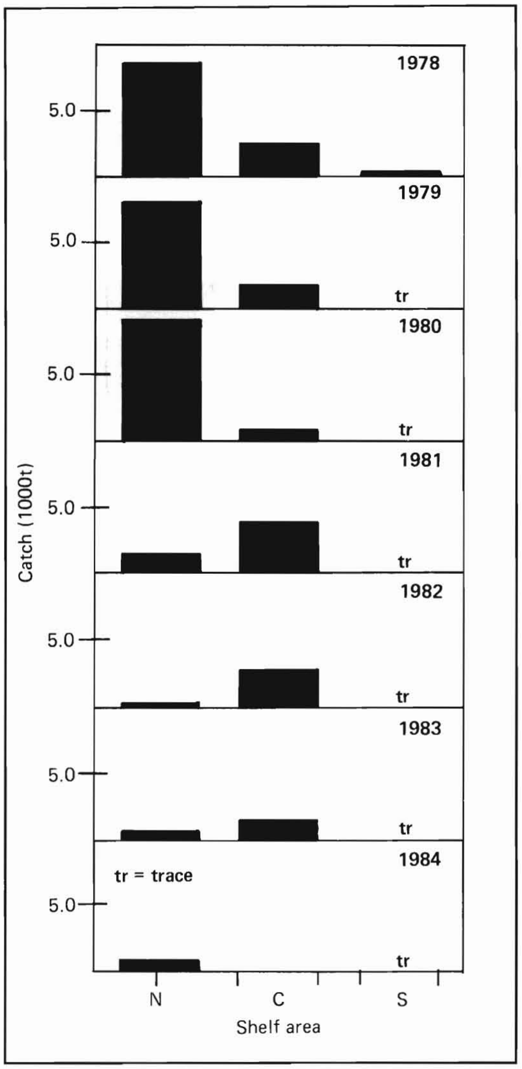

Figure 11
Annual catch (1978-84) of Greenland turbot by the Japanese surimi mothership fishery by area of the eastern Bering Sea shelf (N=north of 58°, C=55°-58°N lat., and S=south of 55°N lat.).

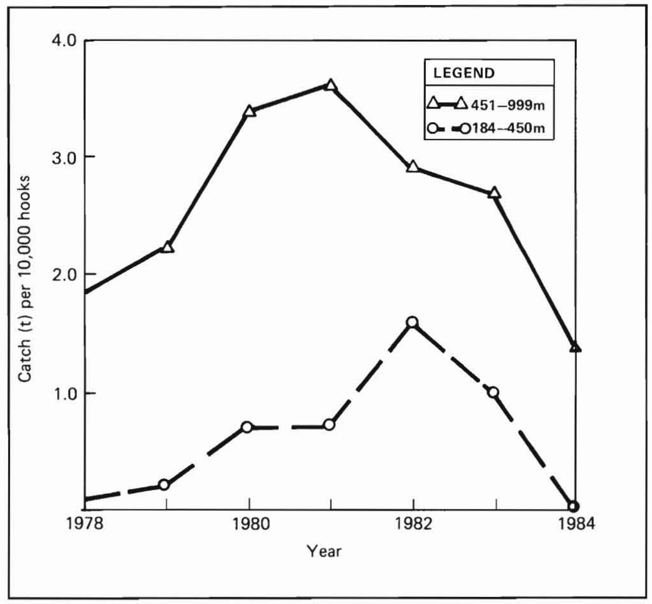

Figure 12
Catch-per-unit-effort of Greenland turbot by Japanese longline vessels operating in the eastern Bering Sea, 1978-84.

However, in 1984 the proportion of catch from intermediate depths sharply declined, and, for the first time, the proportion from shallow depths exceeded that of intermediate depths in the northern slope area. For the southern slope, the distribution of catch has tended to be more evenly distributed among the three depth zones.

A seasonal catch pattern was apparent for the small freezer trawlers in both the central and southern slope areas which was most pronounced after 1980 (Fig. 10). In the central slope area the catch for most years was lowest in the first quarter and then increased, usually reaching its highest level in the fourth quarter. In the southern slope area no catch was recorded for the first quarter; fishing began in the second quarter, with the catch increasing in the third quarter, and then either leveling off or declining in the fourth quarter. For the northern slope area the highest catch tended to be taken in the second quarter.

The Japanese surimi mothership fishery is active mainly during the summer and early fall months and operates for the most part on the continental shelf. Since 1980 there has been a marked decline in magnitude of the catch from the northern shelf (Fig. 11). By 1984 very few Greenland turbot were taken anywhere on the shelf.

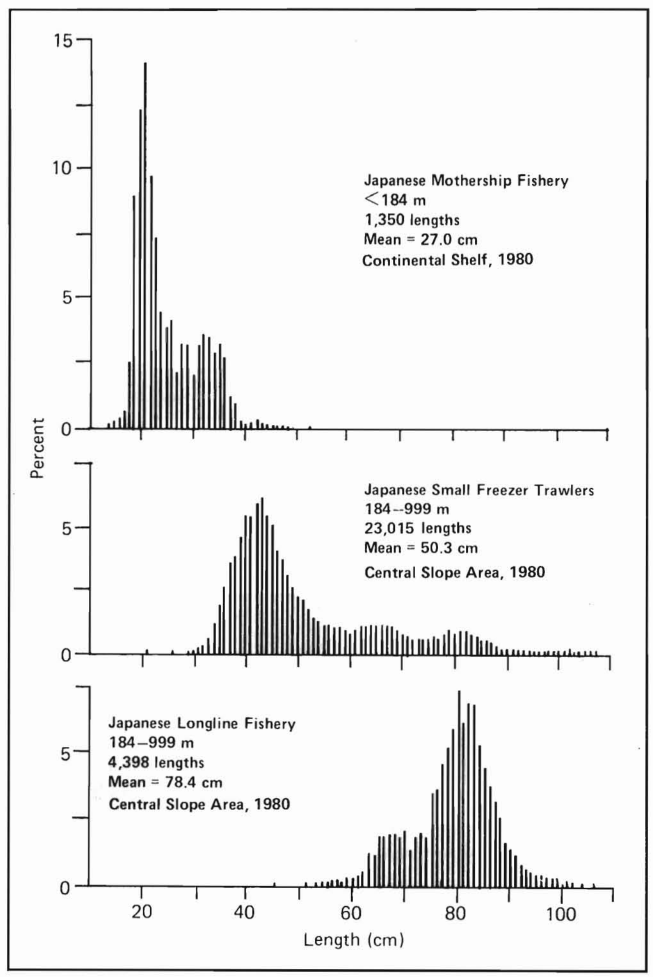

Figure 13
Length composition of Greenland turbot taken by various Japanese fisheries in the eastern Bering Sea, 1980.

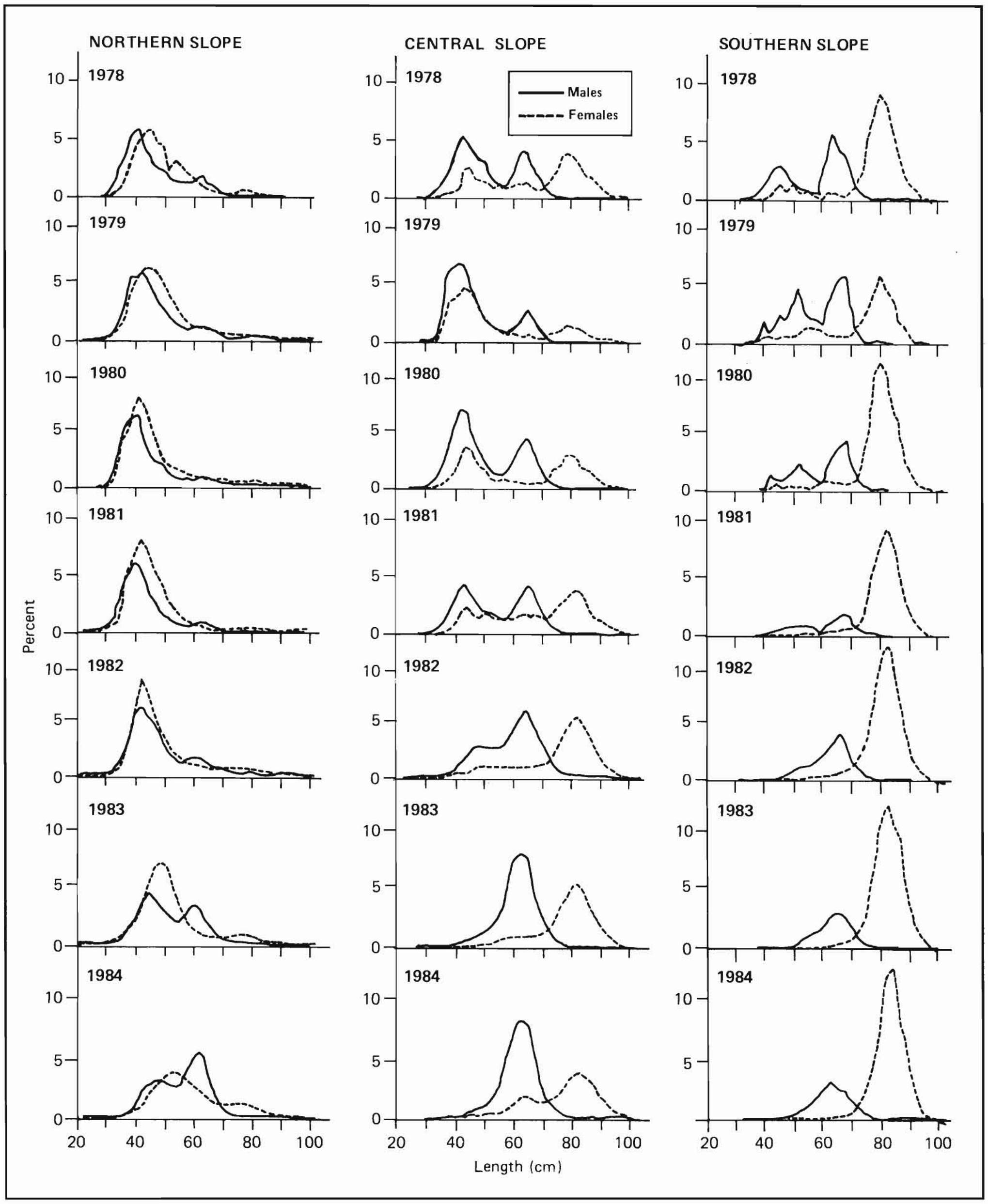

Figure 14
Length composition by sex of Greenland turbot taken by Japanese small trawlers in the continental slope region of the eastern Bering Sea, 1978-84.

The Japanese longline fishery has operated mainly in the central and southern slope region. Its main harvest of Greenland turbot and highest catch rates have come from depths greater than 450 m (Fig. 12).

In the Aleutians, Greenland turbot is also taken mainly at depths greater than 450 m by both the small freezer trawlers and longliners. Since the catch of Greenland turbot in this region has not been of much significance, we have not given any breakdown of the annual catch by area.

Length and sex composition—There are marked differences among the Japanese fisheries in terms of the length of fish captured (Fig. 13). On the continental shelf of the eastern Bering sea where the motherships operate, the catcher vessels take only small, immature fish. The larger juveniles and older fish tend to occur in the slope region, where they are subject to harvest by the Japanese small freezer trawlers and longline vessels. The small freezer trawlers capture a broader size range of fish than the longline vessels in the same region of the slope. The latter vessel type takes only the large fish, which are predominantly females. This difference in gear selectivity also occurs in the Aleutians.

Information from the small freezer trawlers provides the best indication of patterns in the length composition of Greenland turbot catches by area, depth, and season. Length data from the longline and mothership fisheries are incomplete. For the eastern Bering Sea slope there were consistent differences by area in the length of fish captured by small freezer trawlers (Fig. 14). The length of fish increased from north to south and exhibited distinctive modal distributions by sex. Annual changes in length composition were also evident. Obvious changes over time were 1) decline in the pro-

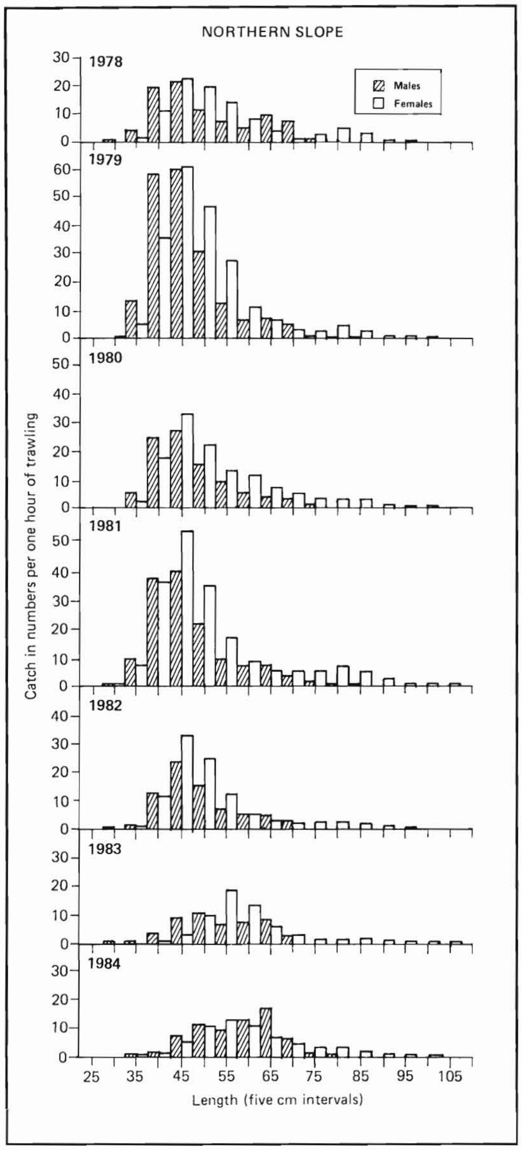

Figure 15

Catch rate by Japanese small trawlers of Greenland turbot by sex and 5-cm length intervals in the northern slope area of the eastern Bering Sea, 1978-84.

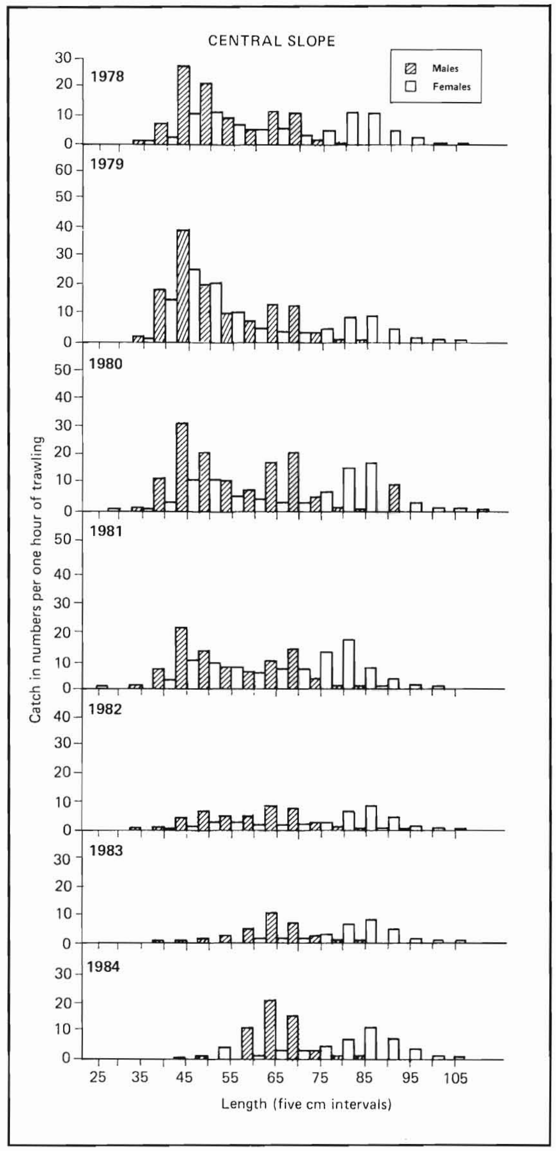

Figure 16

Catch rate by Japanese small trawlers of Greenland turbot by sex and 5-cm length intervals in the central slope area of the eastern Bering Sea, 1978-84.

portion of small fish in the length range of 30-50 cm in all areas, but which was most pronounced in the northern slope, and 2) emergence of sharply defined modal groups by sex in the central and southern slope areas.

Not only had there been a decline in the proportion of small fish in all areas of the slope, but the availability of fish of most length groups, as indicated by annual catch rates of freezer trawlers, also declined (Figs. 15-17). A decline in the proportion of smaller fish (in this instance, less than 60 cm) was also observed in the Aleutians in 1983 and 1984 (Fig. 18).

To examine seasonal patterns in the catch by length, we partitioned both the males and females into two length groups, with the dividing line at 55 cm and 70 cm, respectively. This grouping simplified the presentation and was based on the annual length distributions (Fig. 14) and the suggestion from length-at-maturity information (D'yakov 1982, Smidt 1969) that the larger groups are mostly mature fish and the smaller length groups are mostly immatures.

The availability of fish in the smaller length groups was examined for both the northern and central slopes, though not for the southern area because of the small number of animals of these lengths taken there. The CPUE of these small length groups was consistently much higher in the northern than in the central area, particularly in the shallowest depth interval (Fig. 19). The importance of smaller length groups in both the northern and central areas and at all depths declined markedly in 1983 and 1984.

In both the northern and central slope areas the availability of the smaller length groups showed a pattern of high catch rates in the first two quarters, with the lowest catch rates usually occurring in the fourth quarter of the year. Females showed a tendency to be more available than males, particularly on the northern slope.

Some general tendencies were observed in the availability of fish in the larger length groups. In all slope areas at the shallowest depth interval (184-450 m), the availability of both sexes tended to decline in the fourth quarter, whereas in the deepest depth interval (>730

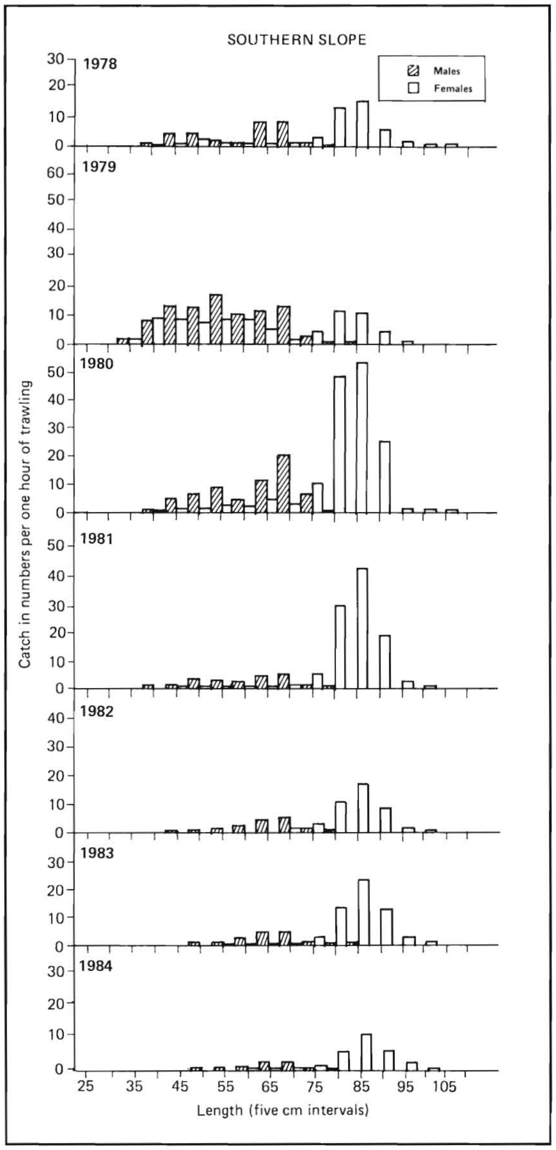

Figure 17
Catch rate by Japanese small trawlers of Greenland turbot by sex and 5-cm length intervals in the southern slope area of the eastern Bering Sea, 1978-84.

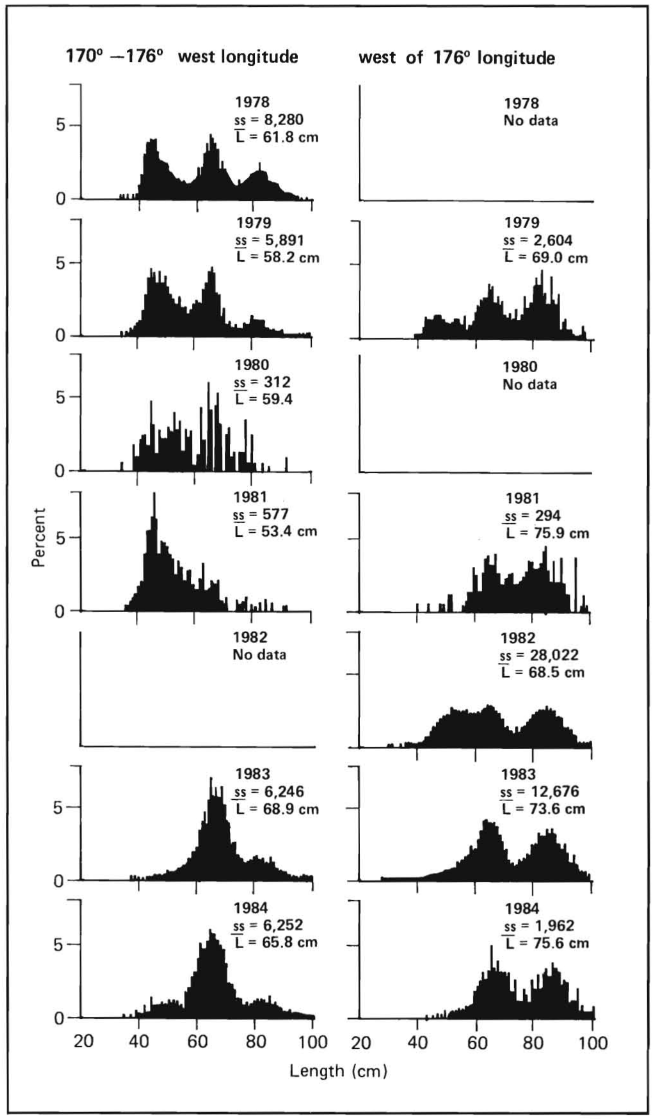

Figure 18
Length composition of Greenland turbot taken by Japanese small trawlers in the Aleutians, 1978-84.

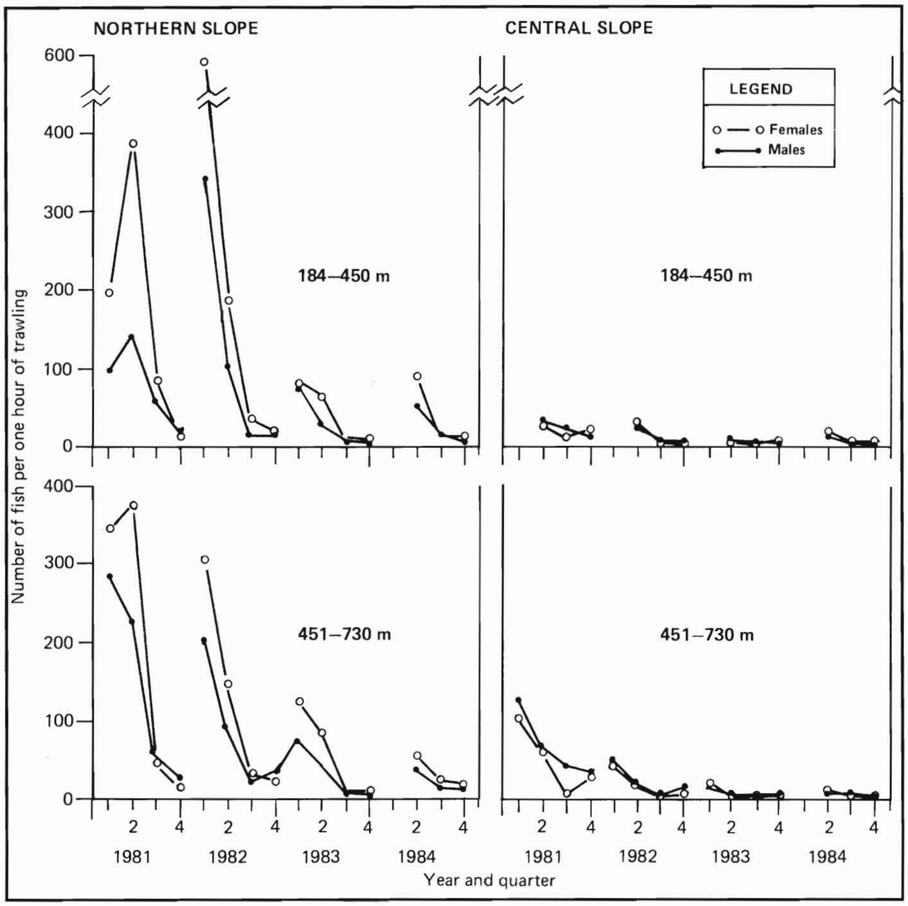

Figure 19

Catch-per-unit-effort of Greenland turbot by Japanese small trawlers by sex, depth, quarter, and area of the continental slope region of the eastern Bering Sea, 1981-84 (length groups: males <55 cm, females <70 cm).

m) their availabilities tended to increase in the fourth quarter (Fig. 20). Another tendency was the decrease in the availability of males from the northern to southern slope area, with the converse occurring among females.

Changes in CPUE and incidence rate—Bakkala et al. (1986) showed that the annual Greenland turbot CPUE of the landbased dragnet fishery has generally declined in the eastern Bering Sea since the early 1970's (Fig. 21). They assumed that CPUE is a relative measure of biomass and viewed these annual CPUE changes as reflecting a decline in Greenland turbot biomass in the eastern Bering Sea.

The CPUE of small freezer trawlers having U.S. observers aboard showed a trend similar to that of the landbased fishery from 1978 to 1984 (Fig. 21). However, CPUE of the small freezer trawlers was much higher than that of the landbased dragnet vessels during the earlier years of that period (1978-81). The match in CPUE between the small freezer trawlers and landbased vessels became quite good in the years 1982-84.

Regression analysis using dummy variables was performed to determine effects due to differences in area, season, and depth in CPUE (tons per hour trawled). A regression model with no interaction terms was used as a basis for the analysis (Table 7). Though interactions may well exist, they were not included in the model since there were enough empty cells to cause the hat matrix to appear nonsingular due to rounding error; tolerances for interaction terms were too low to allow their inclusion in the model (Draper and Smith 1981, Weisberg 1985). Results of the regression analysis suggest that all effects were both meaningful and significant (Table 8). Statistical significance of a factor depends on the significance of its representative dummy variables as a group, not the significance of individual coefficients representing separate levels of a factor. For the regression model results in Table 8, all factors were statistically significant at $\alpha = 0.05$; the p-value for each group effect was always less than 0.025. By area, the highest regression coefficient was found for the southern slope area (Fig. 22), where CPUE for most years was greater than that of other areas for comparable years. By quarter, the greatest deviation of the regression coefficient from the standard (third quarter) was estimated for the first quarter when the CPUE tended to be consistently higher annually than in the other quarters. By depth the greatest deviation of the regression coefficient was estimated for the shallowest interval fished (184-450 m), where the CPUE was almost invariably less than at the greater depths for each of the slope areas. Whether we look at CPUE by area, quarter, or depth, it is obvious that CPUE tended to peak in 1980 and then reach a low point in 1982 or 1983 (Fig. 23). The regression coefficient for annual effect reflects this tendency by being the highest in 1980 and lowest in 1982 and 1983.

When the CPUE in weight was converted to CPUE in numbers, a somewhat different annual trend was found. For the northern and

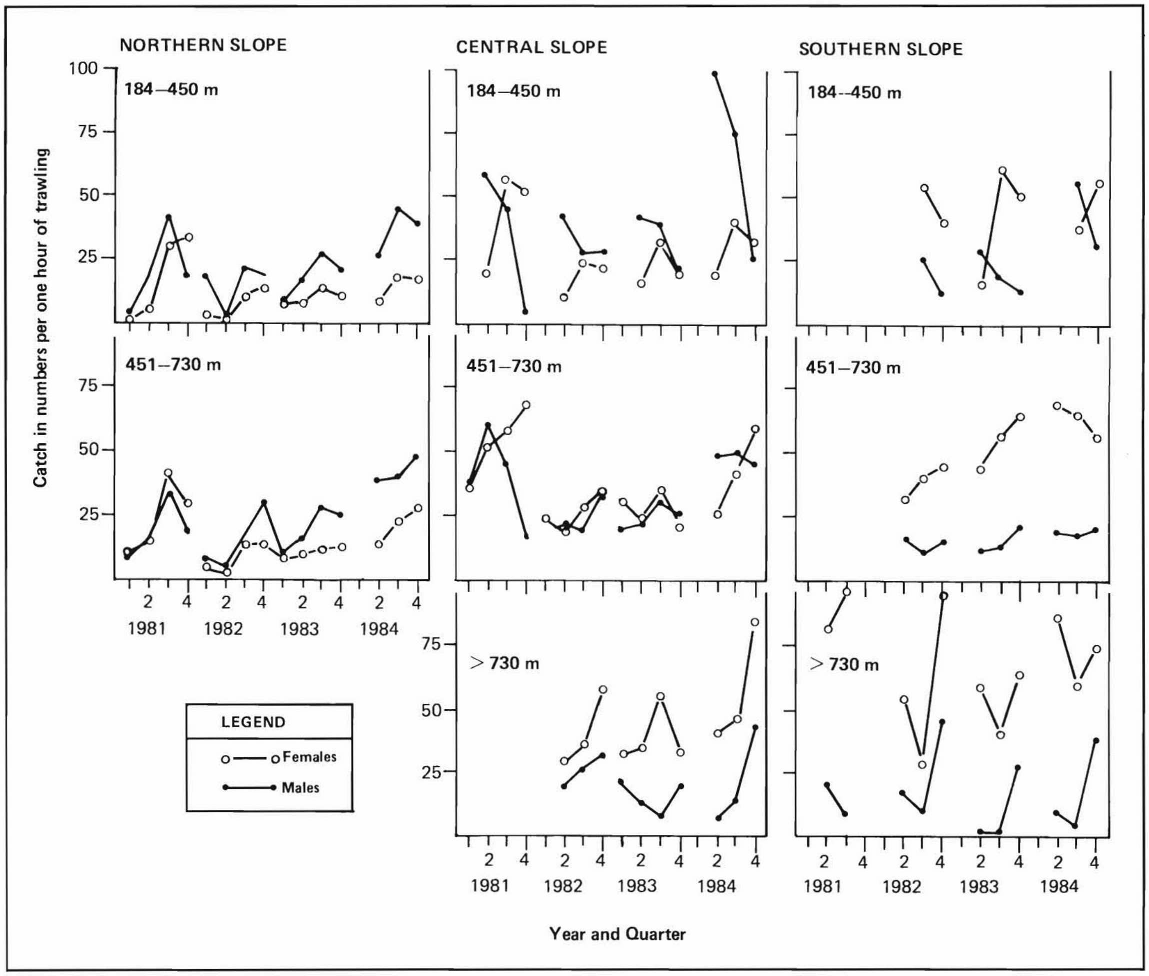

Figure 20
Catch-per-unit-effort of Greenland turbot by Japanese small trawlers by sex, depth, quarter, and area of the continental slope region of the eastern Bering Sea, 1981-84 (length groups: males ≥55 cm, females ≥70 cm).

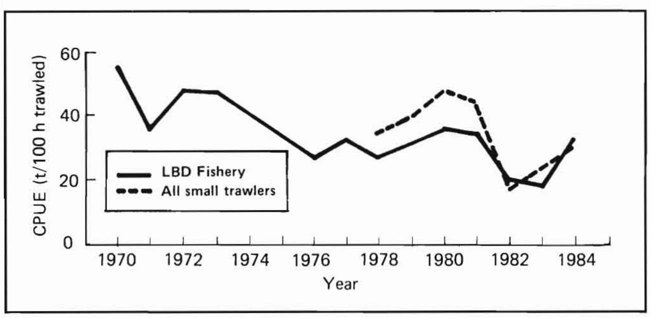

Figure 21
Annual catch-per-unit-effort of Greenland turbot by the Japanese landbased dragnet fishery and that of Japanese small trawlers operating in the eastern Bering Sea, 1970-84.

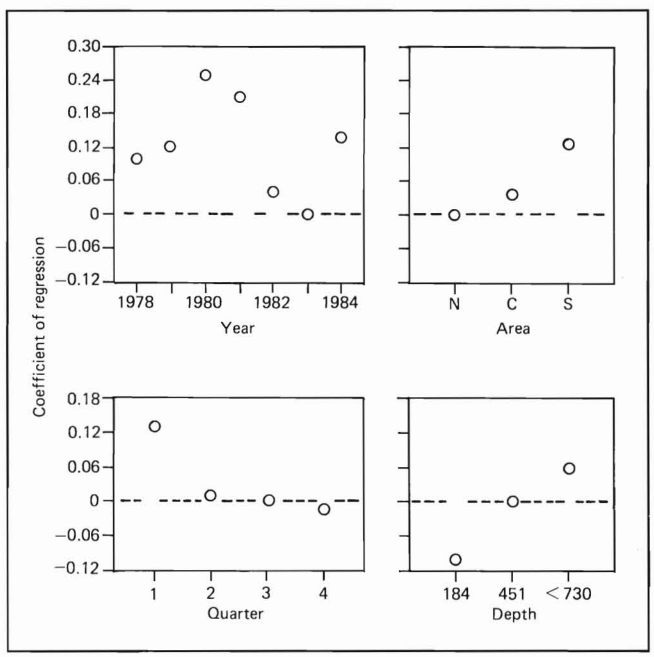

Figure 22
Results of regression analysis of Greenland turbot catch-per-unit-effort, 1978-84, showing regression coefficients by main effects (year, area, quarter, and depth).

Table 7

Regression model (no interactions) applied to Greenland turbot catch-per-unit-effort of the eastern Bering Sea.

Model	Effects
CPUE = B_0*	
+ B_1D1 + B_2D2	Depth
+ B_3Y1 + B_4Y2 + B_5Y3 + B_6Y4 + B_7Y5 + B_8Y6	Year
+B_9Q1 + $B_{10}Q2$ + $B_{11}Q3$	Quarter
+ $B_{12}A1$ + $B_{13}A2$	Area

Definitions of dummy variables

Depth	D1	D2
451-730	0	0
184-450	1	0
>730	0	1

Year	Y1	Y2	Y3	Y4	Y5	Y6
83	0	0	0	0	0	0
78	1	0	0	0	0	0
79	0	1	0	0	0	0
80	0	0	1	0	0	0
81	0	0	0	1	0	0
82	0	0	0	0	1	0
84	0	0	0	0	0	1

Quarter	Q1	Q2	Q3
July-Sept.	0	0	0
Jan.-March	1	0	0
Apr.-June	0	1	0
Oct.-Dec.	0	0	1

Area	A1	A2
Northern	0	0
Central	1	0
Southern	0	1

*B_0 is the intercept or standard, and b_i (not included in the model) is the departure from the standard because of a specific main effect.

Table 8

Results of analysis of variance and regression analysis of Greenland turbot catch-per-unit-effort by Japanese small freezer trawlers operating in the eastern Bering Sea, 1978-84. (Data from U.S. Foreign Fisheries Observer Program.)

Source	df	Partial sum of squares	Partial *F*-value
Depth	2	1.7824	20.63**
Year	6	2.9486	11.38**
Quarter	3	0.8793	6.78**
Area	2	0.9534	11.03**
Error	437	18.8572	

**Significant at α = 0.05

Parameter	Range	Estimate	SE of estimate
Intercept		0.195	
Depth	184-450 m	0.103	0.022
	451-730 m	0[a]	—
	>730	0.058	0.026
Year	1978	0.096	0.034
	1979	0.121	0.035
	1980	0.254	0.038
	1981	0.214	0.036
	1982	0.040	0.033
	1983	0[a]	—
	1984	0.140	0.036
Quarter	Jan.-March	0.130	0.032
	April-Jan.	0.014	0.026
	July-Sept.	0[a]	—
	Oct.-Dec.	0.011	0.026
Area	Northern	0[a]	—
	Central	0.045	0.023
	Southern	0.134	0.029

[a]Zero by definition, because the cell represents the standard.

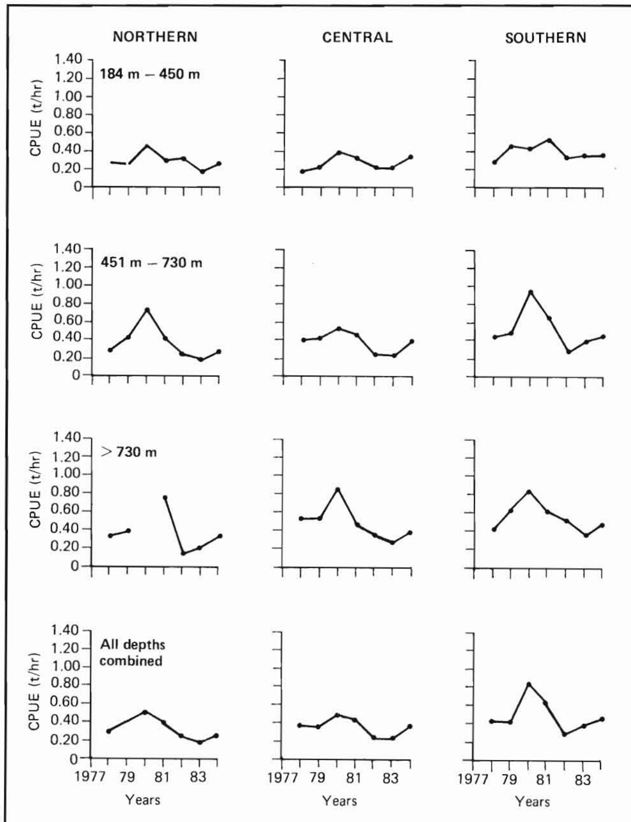

Figure 23

Annual changes in Greenland turbot catch-per-unit-effort by Japanese small trawlers given by depth and area of the continental slope of the eastern Bering Sea, 1978-84.

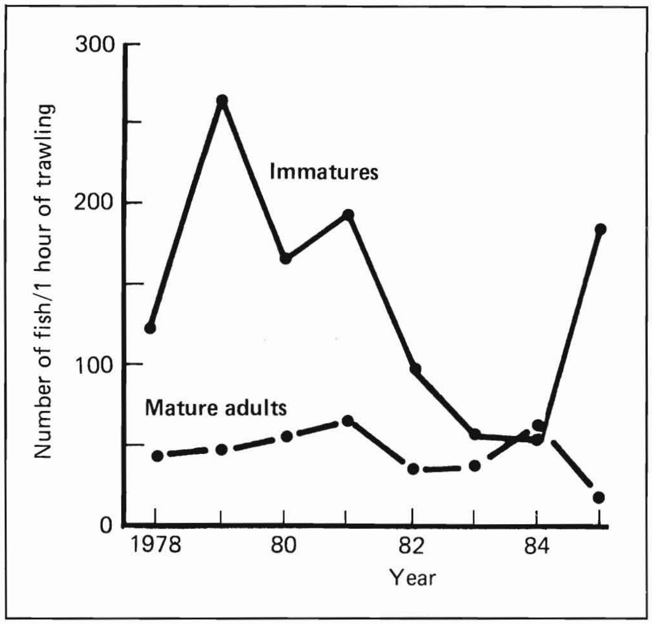

Figure 24
Annual changes in catch-per-unit-effort of mature and immature Greenland turbot by Japanese small trawlers in the eastern Bering Sea, 1978-84.

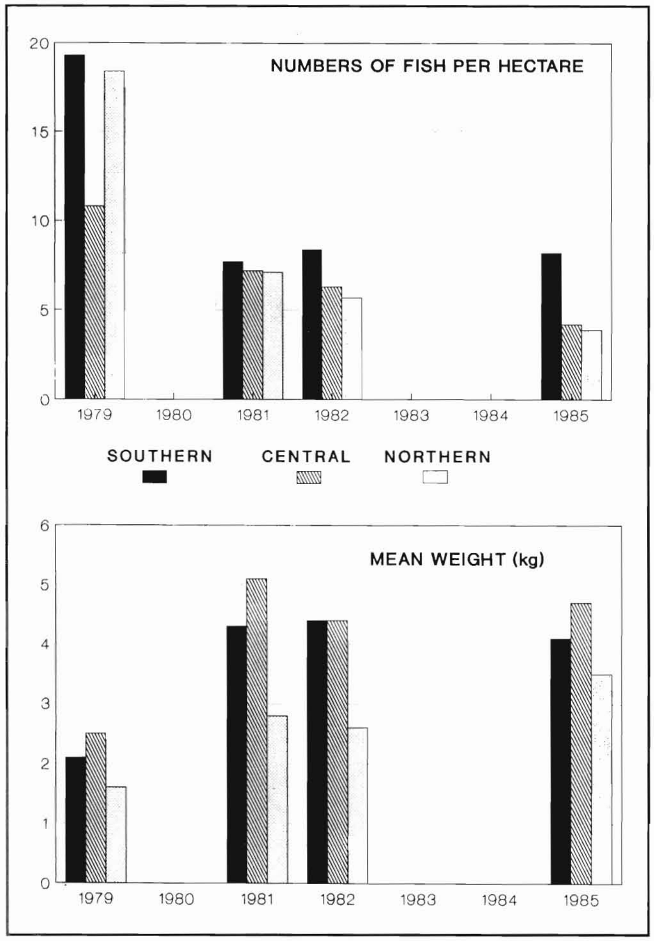

Figure 25
Catch rates and average weight of Greenland turbot taken by Japanese research trawlers in the continental slope region of the eastern Bering Sea in 1979, 1981, 1982, and 1985.

central slope areas CPUE in numbers peaked in 1979, but for the southern slope areas CPUE in numbers peaked in 1980 (Fig. 8). Following these peaks, the CPUE in numbers fell to low levels in 1983 and 1984.

Corresponding to this general decline in CPUE by weight and number since 1979 or 1980, there has been an increase in the average weight of the fish caught (Fig. 8). These corresponding but opposite trends in CPUE and average fish weight may reflect an aging and declining population, since the CPUE of smaller size fish has been decreasing, whereas that of larger fish shows little change since 1978 (Fig. 24).

The CPUE (by weight) of Japanese longline vessels also shows a decline in recent years. At depths greater than 450 m where most of the Greenland turbot catch is taken by these vessels and where CPUE is the highest, CPUE peaked in 1981 and then sharply declined in subsequent years (Fig. 12). At shallower depths of the upper slope, CPUE peaked in 1982 and then declined.

Since the Japanese mothership fishery does not target Greenland turbot, we did not examine CPUE trends but instead looked at the incidence of this fish in the fishery by year. The declining trend in incidence (Fig. 4) cannot be attributed entirely to the decreasing number of animals on the shelf as inferred from the results of research trawl surveys. The Japanese modified the trawls used in their mothership fisheries in 1980 to reduce the catch of crab and halibut. This gear change, which raised the footrope of the net off the sea bottom, may have contributed to the catch reduction of Greenland turbot.

Research vessel survey findings

Continental slope region of the eastern Bering Sea—Findings presented here are based on data provided by the Fisheries Agency of Japan on their research trawling surveys for the summers of 1979, 1981, 1982, and 1985. They are given by the three areas (northern, central, and southern slope) similar to those used in presenting the findings from the fisheries.

Relative density in numbers of fish per hectare declined sharply between the 1979 and 1981 surveys in all slope areas, while mean weight of the fish increased (Fig. 25). Density continued to decline in both the northern and central slope areas from 1981 to 1985, but for the southern slope area no marked change in density could be discerned between 1981 to 1985. As for mean weight of the fish, no well-defined trend is apparent from 1981 to 1985.

The above changes in density and mean weight can be accounted for in part by the decline in small fish less than 55 cm in length in all slope areas (Fig. 26). By 1985 length samples showed two distinct modal groups in both the central and southern areas, with the lesser length modal group (55-69 cm) being comprised mainly of mature males and the large length modal group (75 cm and greater) of mainly mature females. For the northern slope area only one distinct modal group was found in 1985 that corresponded to the lesser length modal groups observed from samples of fish from the other two slope areas in 1985. These survey findings for 1985 correspond with the length compositions obtained from sampling of the fisheries in 1984 (Fig. 14).

Age data were available for only 1979. Individuals 4-7 years in age were dominant and comprised a considerable proportion of fish caught in the northern slope at depths of 184-450 m and in the cen-

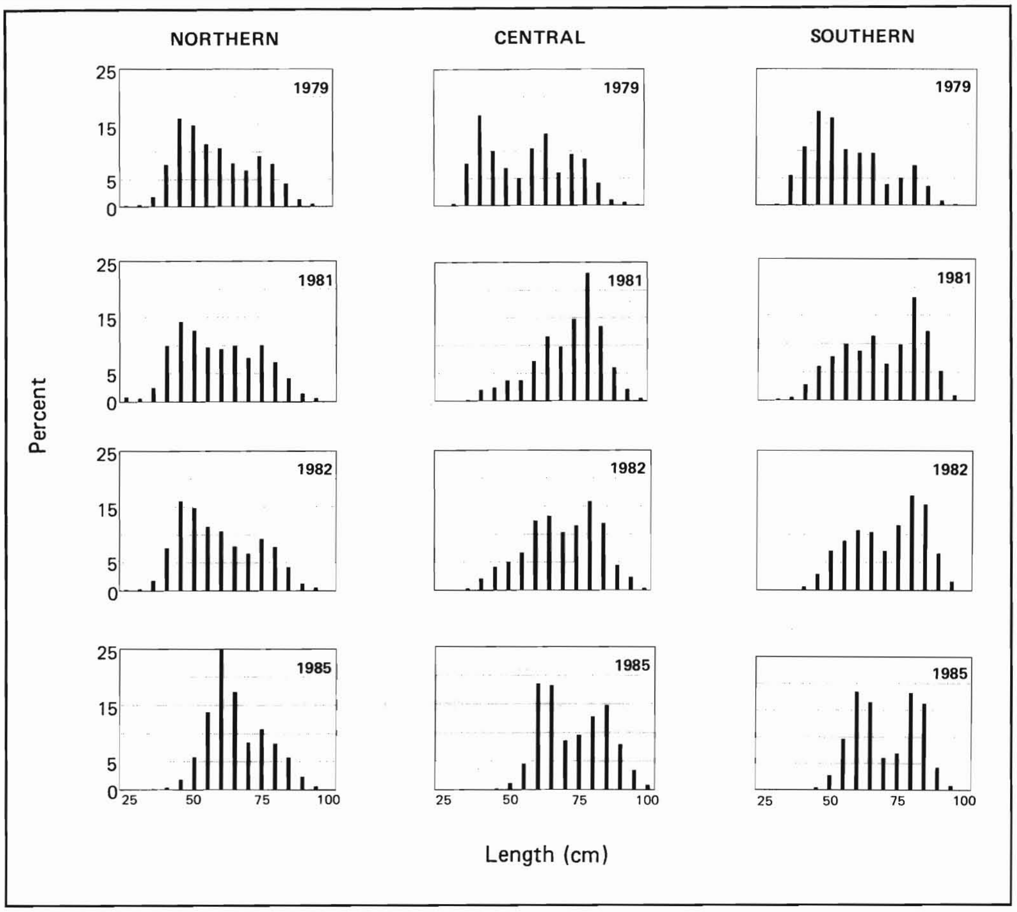

Figure 26
Length composition of Greenland turbot by 5-cm length groups from sampling by Japanese research trawlers in the continental slope region of the eastern Bering Sea in 1979, 1981, 1982, and 1985.

tral and southern slope at intermediate depths (451-730 m). In the deepest zone, females of age 10 and older were most frequently captured.

Temperatures near the sea bottom along the slope generally were 3-5°C, with a slight tendency to decrease from the shallowest to the deepest depth zone (Fig. 27). The widest temperature ranges tended to occur in the shallowest depth zone because of the occasional influence of warm or cold water near the interface of shelf and slope. Mean water temperatures in the two deepest zones almost always fell within a very narrow range of 1°C (3-4°C).

Continental shelf region of the eastern Bering Sea—Results given here are from two sets of survey data: the longer time series (1973-85) that consistently covered the southeastern part of the shelf, and the time series (1975, 1979-86) of survey data which covered a major part of the shelf.

The availability distribution of Greenland turbot by survey year shows some obvious patterns by time and area. For those surveys that covered much of the eastern Bering Sea shelf, the highest concentration of animals was found in the northwestern part of the shelf west and south of St. Matthew Island (Fig. 28). In the early years of the shelf surveys Greenland turbot were caught throughout the region, though mainly at intermediate (50-100 m) and outer shelf depths (101-200 m) (Table 9). However, with time the geographical catch distribution shrank so that by 1985 and 1986 only the area west and south of St. Matthew Island was yielding any amount of fish (Fig. 28), but the magnitude of catches within this area has decreased over time. Survey findings from the 1973-86 southeastern portion of the shelf suggest that young fish were abundant as early as 1973 and that their decline began noticeably in 1980 (Fig. 29 and Table 10).

With the decline in number of fish on the shelf, the average age and size of the fish increased. This can readily be seen when tracking changes in abundance by age (Table 10) and size groups (Fig. 30). In 1979, when the greatest number of fish was found on the shelf during the surveys, fish of ages 1 through 4 were abundant, but by 1981 their numbers had greatly declined. The decline continued in subsequent years so that by 1985 mainly age-5 and older animals were dominant on the shelf, though present only in low numbers. By size, there has been a noticeable shift to large size groups over the period of the surveys, so that in recent years (1984-85) fish greater than 30 cm have become the most important component of survey catches.

In contrast to the findings from research surveys and samplings of the fisheries catch in the slope region, where most of the animals were greater than 35 cm and of ages 4 and older, the shelf surveys encountered relatively small, young fish. Fish on the shelf are not substantially recruited to the survey gear at sizes below 10 cm or at age-0. Age-0 fish have never been prominent in survey catches because of their small size which allows them to pass through the mesh of the net and because many of them have probably yet to settle to the sea bottom from their pelagic stage. The sharp decline

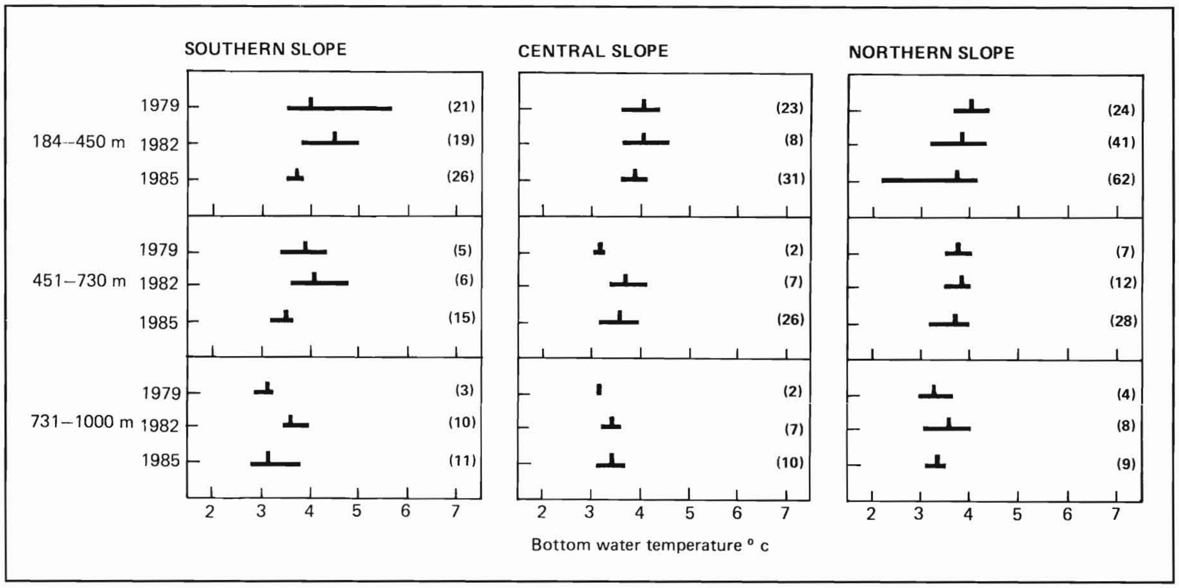

Figure 27
Water temperatures near the sea bottom as observed during Japanese research trawl surveys of the continental slope region of the eastern Bering Sea (1979, 1982, and 1985). Numbers of observations are given in parentheses.

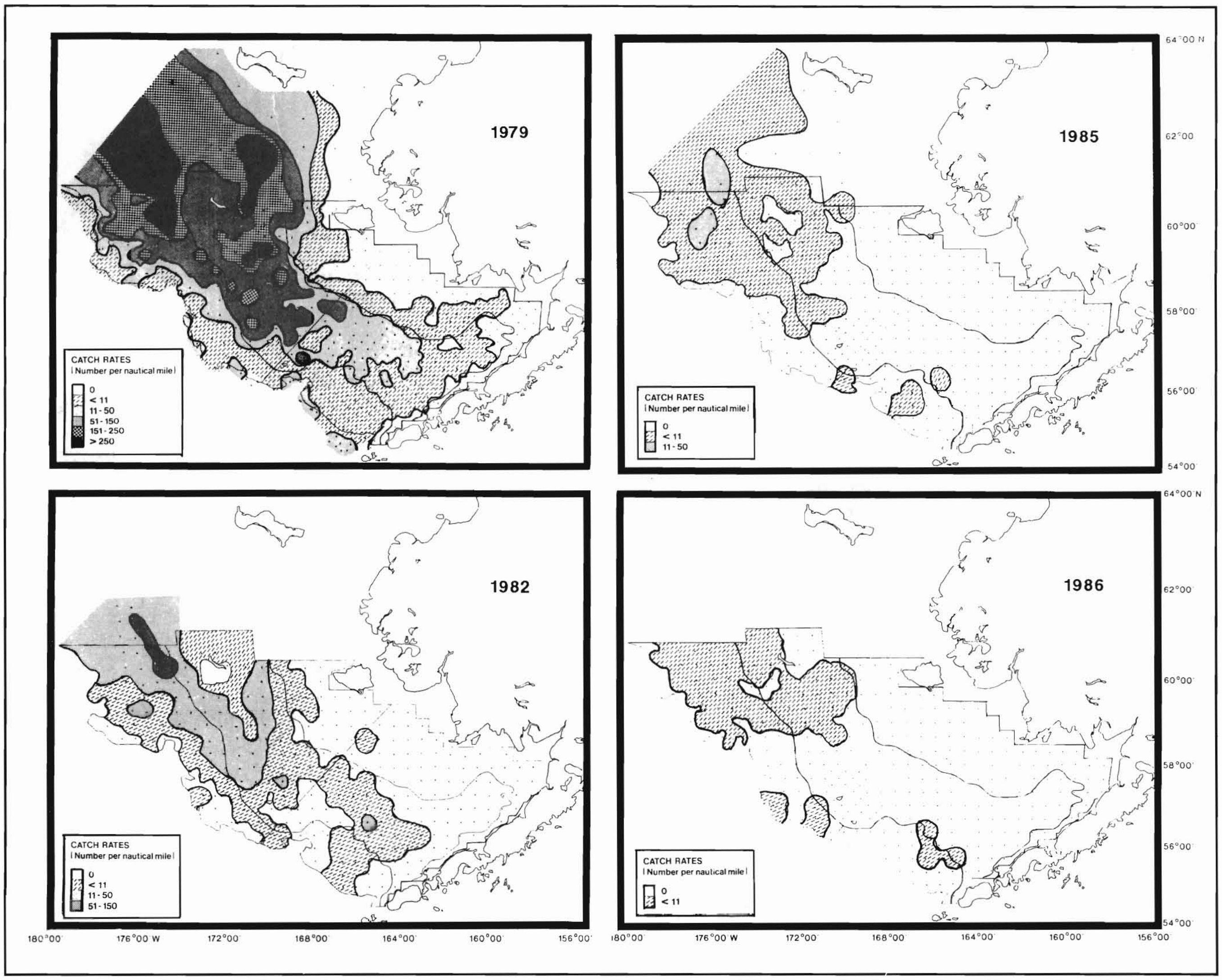

Figure 28
Estimated density distribution of Greenland turbot during summer bottom-trawl surveys by the National Marine Fisheries Service in the shelf region of the eastern Bering Sea in 1979, 1982, 1985, and 1986.

Table 9

Catch rate of Greenland turbot in weight (kg) and numbers (parentheses) per hectare trawled by area and depth in the shelf region of the eastern Bering Sea during annual bottom trawl surveys by the Northwest and Alaska Fisheries Center, 1979 and 1981-85.

Area	Depth (m)	1979	1981	1982	1983	1984	1985
Northern shelf	1-50	0.8 (40.5)		0.0 (0.2)			0.0(0.1)
(>61° N. lat.)	51-100	8.9(131.0)		1.1 (6.4)			0.2(0.7)
	101-200	13.9(137.3)	4.1(26.5)	6.7(19.4)			
Central shelf	1-50	0.3 (5.0)	0.2 (0.6)	0.0 (0.1)	0.0(0.0)	0 (0)	0.0(0.0)
(58°-61° N. lat.)	51-100	7.2 (52.3)	2.2 (9.0)	0.8 (3.9)	0.5(1.4)	0.1(0.2)	0.0(0.2)
	101-200	6.5 (44.2)	7.2(26.2)	2.7 (5.6)	2.4(4.5)	2.0(2.6)	0.8(1.3)
Southern shelf	1-50	0.0 (0.4)	0.0 (0.0)				
(<58° N. lat.)	51-100	1.6 (9.7)	0.3 (0.8)	0.3 (0.4)	0.4(0.9)	0.0(0.0)	0.0(0.0)
	101-200	1.4 (14.7)	0.6 (0.4)	0.3 (0.2)	0.5(0.4)	0.2(0.1)	0.2(0.4)

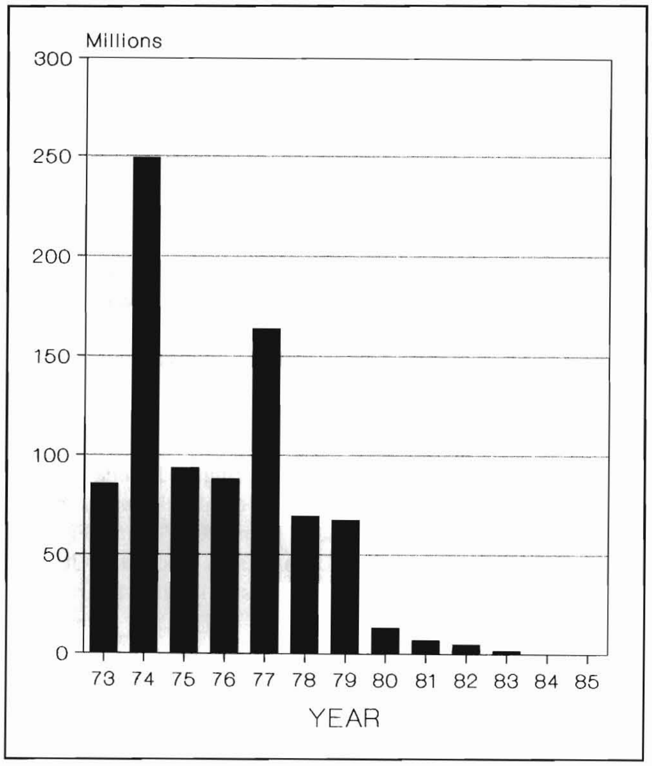

Figure 29

Annual estimates of the relative population numbers of Greenland turbot in an area of the southeastern Bering Sea shelf which has been consistently surveyed since 1973.

Table 10

Number of Greenland turbot (million fish) by age groups (estimated from bottom trawl surveys) in two areas of the eastern Bering Sea shelf with consistently good survey coverage and relatively high abundance. Area N lies between lat. 58°N and 61°N; area S is south of 58°N. Both areas are within bottom depths of 50 to 184 m.

		Ages						
Year	Area	0	1	2	3	4	5+	All
1975	N	0.05	34.54	275.58	210.15	44.13	2.72	567.12
	S	0	19.46	14.03	50.74	14.05	2.05	100.33
	Both	0.05	54.00	289.61	260.89	58.18	4.77	667.45
1979	N	0.52	257.27	173.14	205.03	114.02	18.61	768.59
	S	0	33.01	29.38	41.97	23.67	9.34	137.37
	Both	0.13	290.28	202.52	247.00	137.69	27.95	905.57
1980	N	0	70.57	229.01	183.75	183.60	12.56	679.49
	S	0	4.74	18.58	8.76	11.45	2.67	46.20
	Both	0	75.31	247.59	192.51	195.05	15.23	725.69
1981	N	0.04	16.40	35.90	99.41	101.90	17.90	271.55
	S	0	0.67	0.61	1.69	2.67	3.14	8.78
	Both	0.04	17.07	36.51	101.10	104.57	21.04	280.33
1982	N	0	8.59	9.00	11.90	29.05	16.06	74.60
	S	0	0.67	0.67	1.12	0.93	3.12	6.51
	Both	0	9.26	9.67	13.02	29.98	19.18	81.11
1983	N	0.09	4.70	1.91	8.49	17.23	13.15	45.57
	S	0	0	0.13	1.75	0.59	0.83	3.30
	Both	0.09	4.70	2.04	10.24	17.82	13.98	48.87
1984	N	0	0.34	0.68	1.21	7.12	11.96	21.31
	S	*	*	*	*	*	*	0.67
	Both							21.98
1985	N	0.15	2.17	0.86	1.34	1.54	5.18	11.24
	S	0	0.84	1.70	0.85	0	0.95	4.34
	Both	0.15	3.01	2.56	2.19	1.54	6.13	15.58

*No length data available for conversion to age.

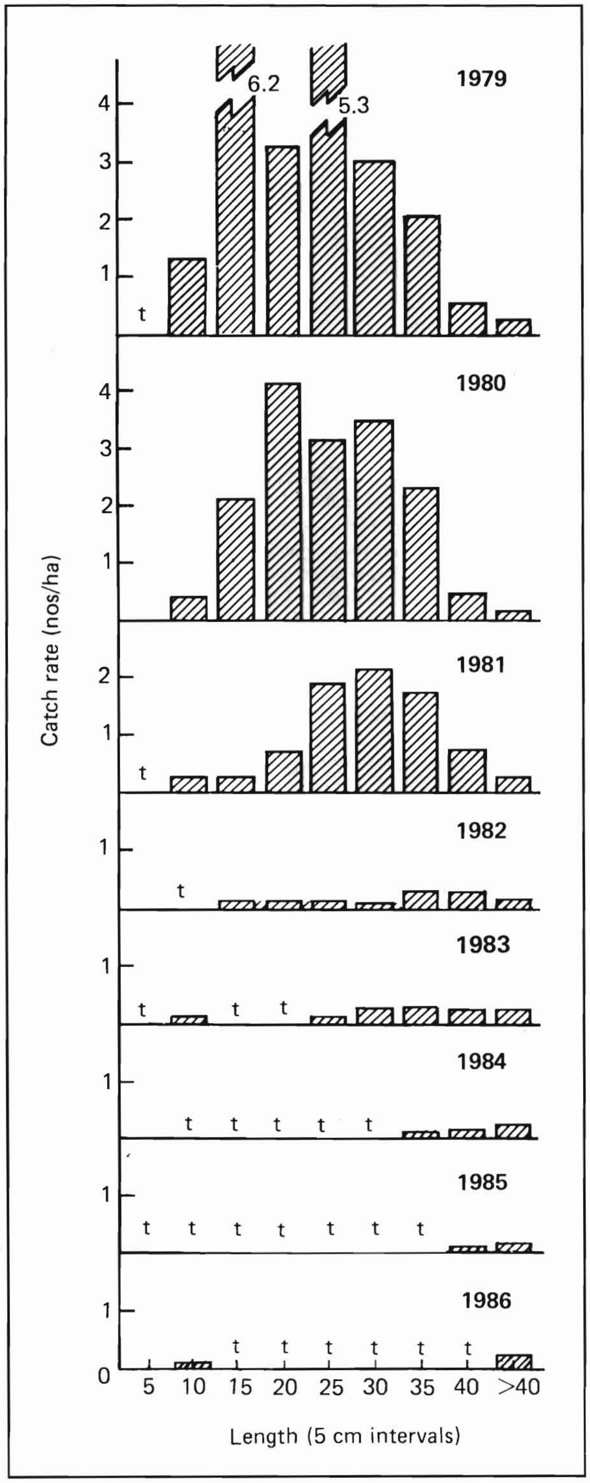

Figure 30
Catch rate of Greenland turbot by 5-cm length groups during annual summer bottom-trawl surveys by the National Marine Fisheries Service in the shelf region of the eastern Bering Sea, 1979-86.

in numbers of fish older than age-4 on the shelf may be accounted for by movements of these animals into the slope region.

Using the estimated abundance of age-1 fish as a measure of year-class strength (Table 10), we can conclude that there has been a continuing decline in year-class abundance since the strong showing of the 1978 year-class as age-1 fish in 1979. The 1979 through 1984 year-classes are therefore considered weak relative to the 1978 year-class.

In the shelf region, trawl catches of Greenland turbot were associated with a wide range of bottom water temperatures, but there was generally a low incidence of turbot where water temperatures were below 0°C.

Aleutian Islands—In both 1980 and 1983 the highest catch rates of Greenland turbot occurred in the northeast area of the Aleutians, whereas the lowest rates were observed in the southeast and southwest areas (Fig. 31). There was a definite declining trend in magnitude of the catch rates from east to west along the Aleutian Island chain. The most pronounced difference between the two surveys in terms of catch rates was observed in the northeast area, where the 1983 average catch of 17.0 kg/ha was twice that of 1980 (8.4 kg/ha).

Relative biomass was greater in 1983 than in 1980, but relative population numbers were greater in 1980 (Fig. 31). Although the number of animals declined, their average weight increased (Fig. 31) so that biomass actually increased as well. The increase in average weight of fish occurred in all but the northwest area. The increase in average weight of fish in 1983 corresponds to an increase in the average length of fish (Fig. 32).

Highest catch rates or apparent densities occurred in the slope region at depths greater than 300 m (Fig. 33).

Bottom water temperatures recorded during the Aleutian surveys tended to decrease by depth zone and to exhibit the widest ranges in the shallowest depth zones (<200 m and 201-300 m) (Fig. 34). Where Greenland turbot was most available by depth (>300 m), mean temperatures of the bottom waters fell within the range of 3 to 4°C.

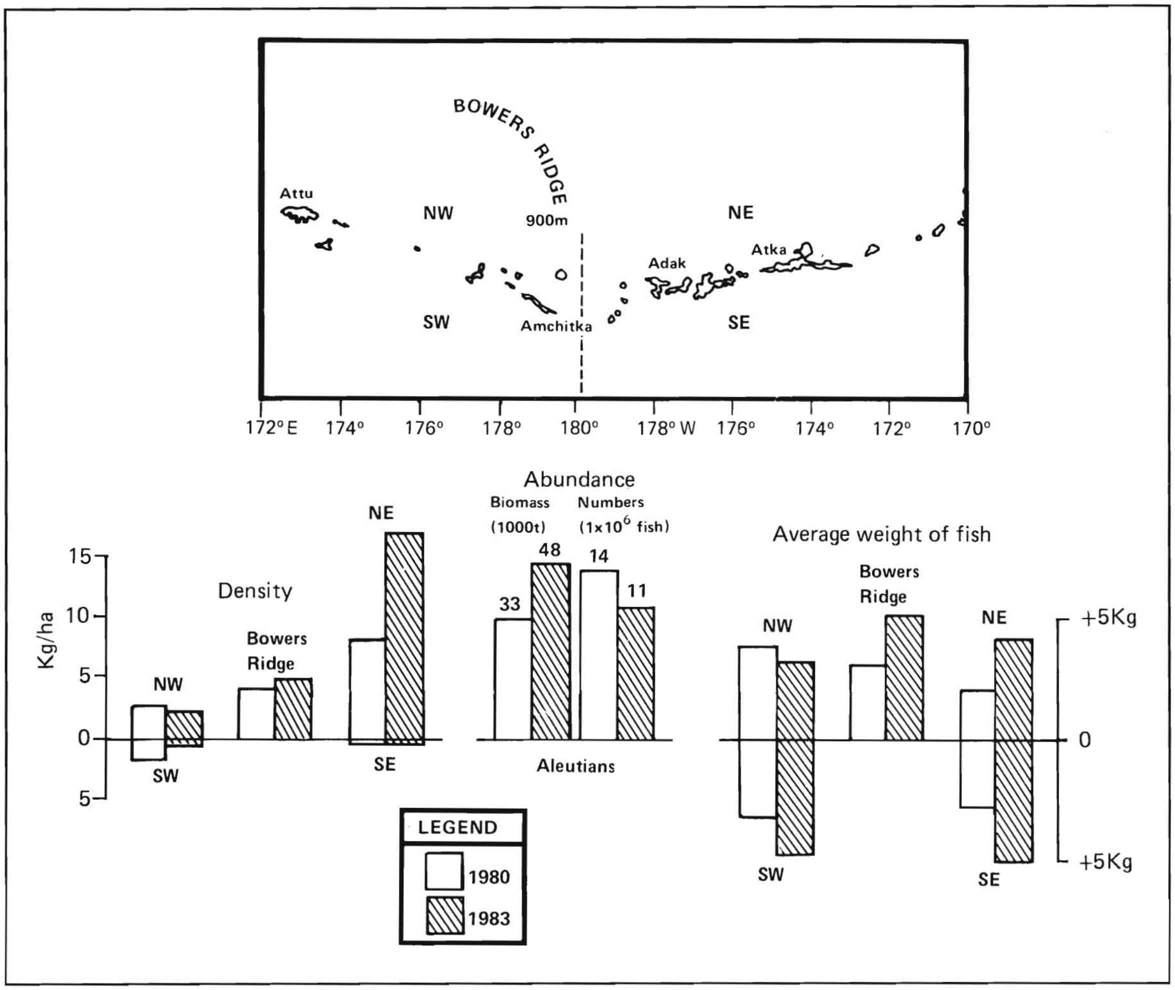

Figure 31

Relative density, abundance, and average weight of Greenland turbot as found during the 1980 and 1983 U.S.-Japan cooperative trawl surveys in the Aleutian Islands region.

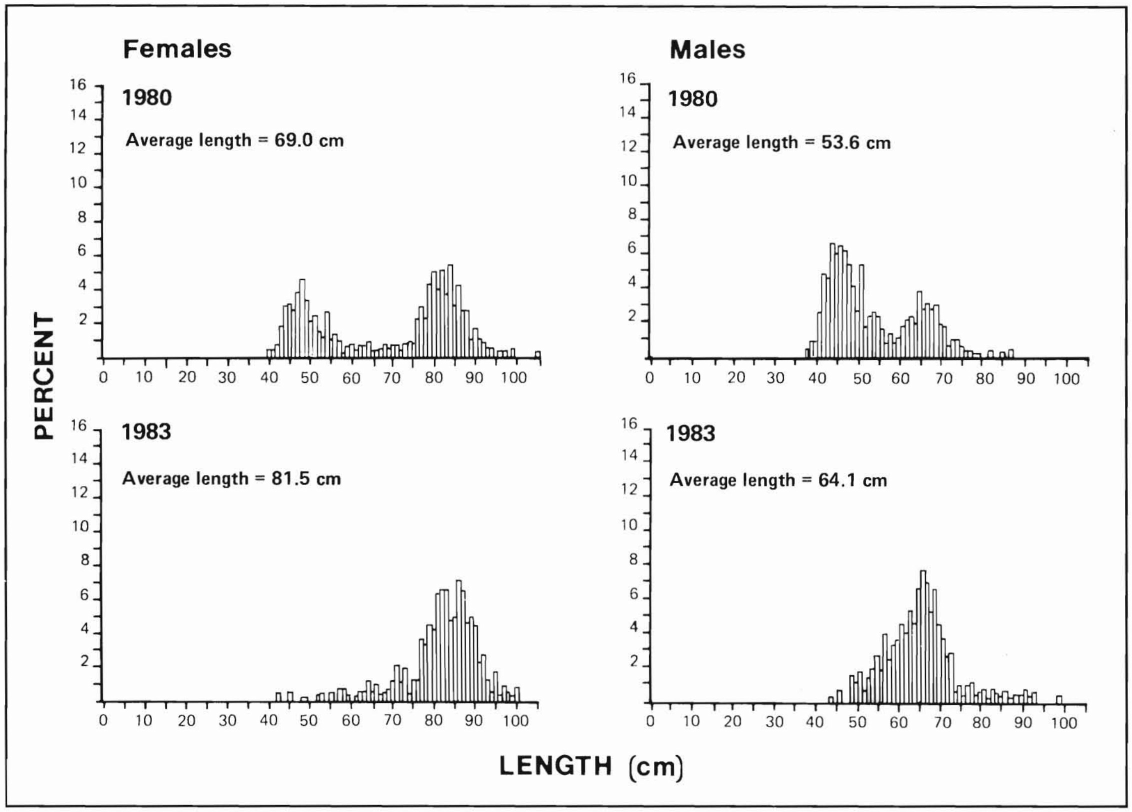

Figure 32
Length composition of Greenland turbot taken during U.S.-Japan cooperative bottom-trawl surveys in the Aleutian Islands region in 1980 and 1983.

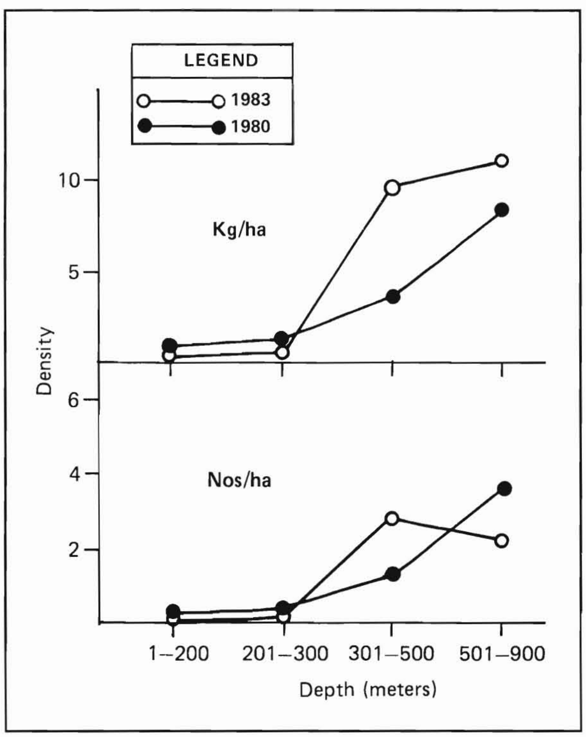

Figure 33
Catch rate of Greenland turbot by depth during U.S.-Japan trawl surveys in the Aleutian Islands region in 1980 and 1983.

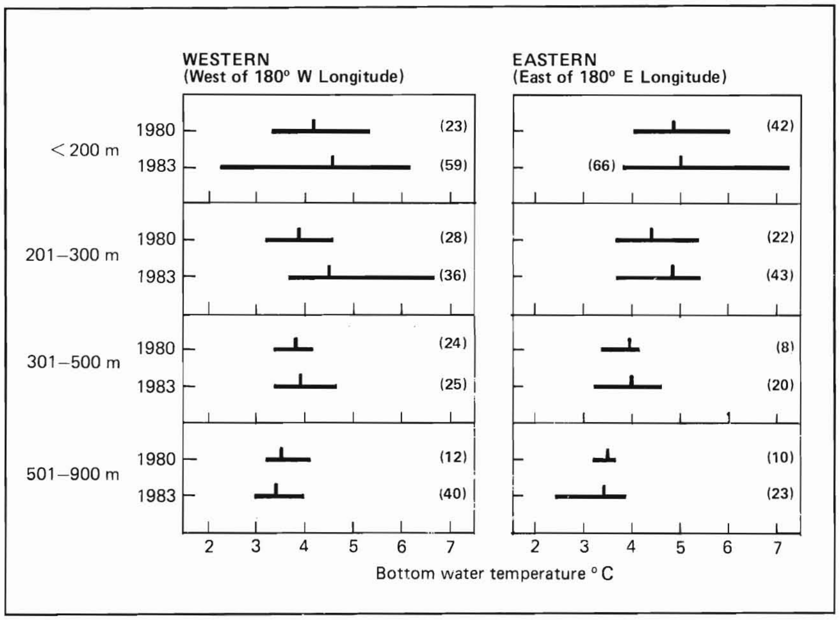

Figure 34

Water temperatures near the sea bottom as observed during U.S.-Japan research trawl surveys in the Aleutian Islands region, 1980 and 1983. Numbers of observations are given in parentheses.

Discussion

Distribution and migrations

Greenland turbot has certain distributional features throughout its range which are also manifested in our findings for this species in the eastern Bering Sea and Aleutians. There is an apparent bathymetric gradient involving fish size and age with the younger animals tending to occupy shallower depths, and the older animals being more likely to reside at depths of the continental slope. At shallow depths the young are exposed to a wide range of temperature conditions, whereas older animals along the slope live where temperatures are relatively stable. Seasonal movements are also suggested from our findings and the observations of other investigators.

For the eastern Bering Sea, Shuntov (1970) discussed seasonal depth movements of both young and older animals. Movement of young fish is confined to the continental shelf. In spring the movement is from deep parts of the shelf to shallower parts, followed by another movement to even shallower depths in summer. By fall the fish have returned to deeper waters of the shelf. The spring and fall movements are believed to occur in response to changes in water temperatures, whereas the summer movement is believed to be a response to feeding. For adults, Shuntov (1970) showed two concentrations of animals along the slope—one west and southwest of St. Matthew Island, and the other farther south between the Pribilof Islands and the Unimak Pass. He found that both concentrations of fish exhibited a spring to summer, feeding-related movement from deeper parts of the slope to shallow parts, followed by a return movement to deeper waters in October.

For animals occupying the slope, our findings suggest seasonal depth changes. If we interpret seasonal shifts in availability by depth as indicative of movements, then there is some suggestion, particularly in the southern slope area, that movements of large fish into deeper water occur in the fall (Fig. 20).

We were not able to discern any long-distance migrations related to spawning and feeding as reported for the northwestern Atlantic stock (Bowering 1984) and the Icelandic stock (Sigurdsson 1979). However, our findings for the eastern Bering Sea do suggest a long-term movement of maturing fish from the northwest slope towards the predominantly mature population in the central and southern slope regions, where the majority of spawning is believed to take place. Similar movements of maturing animals towards the spawning region have been alluded to for the Greenland turbot stock of the northwestern Atlantic and the stock off Norway. Bowering (1984) has presented evidence that maturing fish move from the Newfoundland-Labrador area to the spawning grounds in Davis Strait, and he raises the possibility that these fish may remain in that vicinity, namely off West Greenland. Based on north-south changes in fish size for the stock off Norway, Godø and Haug (1987) hypothesize a movement of animals from the vicinity of the nursery grounds off Spitsbergen south to the spawning grounds along the continental slope between Spitsbergen and northern Norway.

Recruitment hypothesis

We propose for the eastern Bering Sea-Aleutian Islands population of Greenland turbot the following hypothesis for describing the temporal and spatial paths by which young animals reach the mature portion of the population. We begin with the assumption that most spawning occurs in the deep part of the slope region between Unimak Pass and the vicinity of Pribilof Islands in the late fall and early winter. Several Soviet investigations (Pertseva-Ostroumova 1961, Musienko 1970, Shuntov 1970, Bulatov 1983) have indicated a spawning period in the Bering Sea that begins as early as September and ends as late as March, with peak spawning in November-December. As for location, Bulatov (1983) places spawning on the slope off Unimak Pass, whereas others (Musienko 1970, Pertseva-Ostroumova 1961) refer to a more northern location in the Bering Sea from off St. Matthew Island to the Gulf of Anadyr. It is likely that spawning occurs throughout the range of the adult fish, an area including the Aleutians, but we argue that the heaviest spawning occurs between Unimak Pass and the

Pribilofs. This is based on 1) Waldron (1981), who shows the highest occurrences of larvae in this region, and 2) our findings, which indicate that most adult fish were found in the central and southern slope regions.

Eggs and early larvae are bathypelagic, but with growth the larvae become epipelagic (Musienko 1970, Jensen 1935 cited by Atkinson et al. 1981). Larvae are in midwater from early winter to early fall before they settle to the sea bottom. Waldron (1981) shows highest catches of larvae in plankton surveys during the spring-summer period in the vicinity of the shelf's edge and slope, with small catches scattered in the shelf region and a few occurrences over deep water; larvae were found as far north as the vicinity of St. Matthew Island. A fall settling of the larvae is suggested from the reports of Hognestad (1969), Smidt (1969), and Atkinson et al. (1981) for the North Atlantic form of the species. However, in the eastern Bering Sea, a few 0-age fish were found during July and August surveys of the shelf, implying that some larvae apparently settle earlier than the fall in this region.

Young-of-the-year were found mainly in the central and northern areas of the shelf, occurring most densely in the northern area. They apparently spend their early years at shelf depths, but by age 4 and particularly by age 5, many of them have moved into the slope region. The fish on the shelf were consistently found at highest densities in an area west and southwest of St. Matthew Island. We believe that this high-density area is an important pathway by which young animals move from the shelf into the slope region. The area lies adjacent to the northern and central slope regions where we find the highest catch rates as well as the highest proportions of older immatures. We assume these fish move south as they age, toward the southern slope region where mature fish are predominant.

For the Aleutian Islands region, we hypothesize that spawning takes place there because of the presence of large, adult fish year-round. However, due to the lack of any extensive shelf, and perhaps because of currents, there is little settling of the larvae in this region as suggested from the infrequent encounters of small fish (<35 or 40 cm in length) in this region by research surveys and fisheries. The eastward current on the northern side of the Aleutians (Kitani 1983) could be a means by which eggs and larvae are transported towards the broad shelf area of the southern part of the eastern Bering Sea. We, therefore, assume that most adult fish in the Aleutians spend their juvenile stages in the shelf region of the eastern Bering Sea.

In summary, we believe that the main spawning area lies in the slope region between Unimak Pass and the Pribilof Islands. Larvae produced from spawning in this area tend to be transported towards the central and northern portions of the continental shelf where they settle on the sea bottom in the summer and fall. The young begin to move from the shelf to the deeper water of the slope by ages 4 and 5. As they mature they move towards the spawning area. Most fish in the Aleutians are believed to have spent their early years on the eastern Bering Sea shelf. We propose this recruitment hypothesis as a framework for future investigations. In 1986 a tagging program was begun to test this hypothesis.

Current condition of eastern Bering Sea-Aleutians stock

Our findings suggest that since 1981 the population has been declining and ageing. The number of small fish (<40 cm) on the shelf and intermediate-size fish (40-55 cm) on the slope has decreased. This is evident from the changes in catch rates by size on the shelf (Fig. 30) and in CPUE by size in the slope region of the eastern Bering Sea (Figs. 15-17). Fish in the intermediate size range of 40-55 cm were much more available to the Japanese small freezer trawlers in 1979 and 1980 than in subsequent years. By 1982 their availability declined; these fish were either dying (natural and fishing mortality) or growing into the next size category with insufficient younger fish to replace their numbers. This decline in intermediate-size fish was also evident in the Aleutians by their decreasing proportion in the total size composition of animals taken in the commercial (Fig. 18) and research (Fig. 32) catches. Our findings suggest that this decline was brought about by a succession of weak year-classes spawned between 1979 and 1984.

Causes of recruitment failure

We assume that recruitment failure is real based on research survey and fisheries findings. Our reservations to this assumption arise because of the absence of 1) research trawl surveys in the northern part of the eastern Bering Sea shelf and 2) data on recruitment prior to 1973 because of no sampling. The decline in young fish abundance may in actuality be the result of a distributional shift of the young fish towards the north and beyond the research trawl survey area. We raise this as a possibility, although the decline of intermediate-length fish (30 to 55 cm) on the slope would argue against this. We have been assuming that the abundance of young fish on the shelf during the years 1973-79 was typical, when, in fact, it may be the result of some unusual conditions bringing about strong year-classes. What we perceive as a decline in recruitment may in fact be a retreat to normal recruitment levels.

Assuming that recruitment failure is real, several possibilities may account for it. Recruitment failure may be the result of an insufficient number of spawners. The spawning stock has been declining, but we have no understanding as to the relationship of spawners to the number of recruits to give us any guidelines for considering this possibility.

An obvious potential source of mortality of the young would be the trawl fisheries on the shelf. In the years 1977-79 the Japanese mothership fishery took a considerable number of Greenland turbot as a bycatch in their pollock fisheries. This bycatch amounted to an average of some 41 million animals a year. Yet these removals (Table 6) were only a small fraction (<5%) of the animals estimated to be in the shelf area by National Marine Fisheries Service surveys in 1979 and 1980 (Table 10) and should have had no serious impact on the abundance of young fish in those years.

One source of mortality that could potentially account for the decline of young fish would be increases in predator populations or a predator shift toward Greenland turbot. Here we are faced with a wide choice of potential predators from carnivorous zooplankters, to fish, to marine mammals. Unfortunately, we can say nothing about zooplankters except that they could do damage at the egg and early larval stages.

Observations of Greenland turbot in stomachs of fish are rare. The Trophic Interactions Program at the NWAFC has examined over 15,000 stomachs of fish from the eastern Bering Sea, including Pacific cod, walleye pollock, Greenland turbot, arrowtooth flounder, and others. Yet the only instances of predation on Greenland turbot were by adult yellowfin sole (*Limanda aspera*) and flathead sole on young-of-the-year fish. In the five occurrences of turbot in yellowfin sole stomachs, the prey ranged in length from 22 to 33 mm, a size which suggest that the turbot had not yet settled to the sea bottom. The single occurrence of turbot predation by a flathead sole was on a young fish whose length was not recorded. Potentially, yellowfin sole could have an impact on young-of-the-year Greenland turbot, since yellowfin sole is one of the most abundant flatfish of the eastern Bering Sea and is distributed at shelf depths. The biomass of yellowfin sole as estimated from NMFS trawl surveys almost doubled between 1975 and 1979 (from 1.0 to 1.9 million t), and peaked at over 2.0 million t in 1983 (Bakkala et al. 1985).

There has not only been an increase in the abundance of yellowfin sole, but Pacific cod and other fish populations have also increased during the period of Greenland turbot year-class decline.

Atlantic cod is known to prey on young Greenland turbot in the northwest Atlantic (Jensen 1935, Hansen 1949, Dunbar and Grainger 1952, Lear and Pitt 1975). Smidt (1969) has even suggested that the decline of the Greenland stock of turbot in the 1930's may have been due to cod, which were abundant in those years. Although we have no evidence that Pacific cod is an important predator of turbot, we know that cod biomass in the eastern Bering Sea increased four- to fivefold between 1976 and 1979 and then continued to increase, reaching 1.13 million t in 1986 (Thompson and Shimada 1986). In regions of the shelf where Greenland turbot has historically been abundant, cod abundance, as assessed by the NWAFC's annual surveys, increased dramatically between 1975 and 1979, and exceeded Greenland turbot abundance after 1981. Pacific cod is therefore suggested as possibly being an important predator of Greenland turbot based on overlapping distributions, an inverse relational change in abundance, and the inference that if Atlantic cod preys on young turbot its congener may also have the potential to feed on them. However, findings by Shimada et al. (1986) based on the examination of over 1,850 cod stomachs collected in 1981 from the eastern Bering Sea, suggest that Greenland turbot is of little consequence in the cod's diet. This may be a reflection of the narrow time and area window of their sampling. There were no samples collected from the fall period when most settling of young turbot is believed to occur.

Arrowtooth flounder and sablefish (*Anoplopoma fimbria*) are other species in the eastern Bering Sea whose abundance increased during the period of turbot decline. As arrowtooth flounder abundance on the shelf rose beginning in 1980, Greenland turbot abundance declined so that by 1983-85 arrowtooth flounder abundance exceeded that of Greenland turbot (Bakkala et al. 1986). High-density areas of arrowtooth flounder lie at outer shelf depths (100-200 m) and on the continental slope. In 1978 sablefish were encountered in unusual numbers during an NWAFC survey on the shelf (Umeda et al. 1983). These fish, belonging to the 1977 year-class, shifted from the shelf to the slope region in 1979, and by 1981 their abundance on the slope was exceptionally high compared with earlier surveys. Both arrowtooth flounder and sablefish are potential predators of young Greenland turbot in its pelagic stage or after it settles on the sea bottom.

Among marine mammals, Kajimura (1984) has found that juvenile Greenland turbot was the fourth-ranking finfish (in volume of food) in stomachs of fur seals captured near the Pribilof Islands. One animal had as many as 500 Greenland turbots in its stomach. Samples of these juveniles were 45-60 mm in length and of a size which suggested that they had either settled to the sea bottom or were approaching that stage. Presumably, the fur seal had captured them off the sea bottom, since fur seals tend to feed on nektonic fishes and invertebrates. In the 3 years (1964, 1973, 1974) for which detailed information on the feeding of fur seals in the eastern Bering Sea is available, Greenland turbot comprised from 1.1 to 2.1% of the total volume of fur seal stomach contents (Fiscus and Kajimura 1965, Kajimura et al. 1974, Kajimura and Sanger 1975). This could translate to a substantial number of turbot, considering the energy needs of the fur seals and assuming that fur seals consume mainly juvenile turbot. The population of female seals alone has been estimated at 570×10^3, (Briggs and Fowler 1984). They forage and feed their young during the period when the turbot larvae are in the water column or settling to the sea bottom (June to November).

Fur seals have been in the Bering Sea in large numbers for a long time, but why should they suddenly begin to seriously reduce the abundance of young Greenland turbot? Perhaps predation by fur seals, along with that of increased predation by other species, could be accounting for the year-class decline.

As in many attempts to explain changes in the year-class strength of a species, there is no concrete evidence here for a particular causative factor or factors. Several possibilities have been discussed for the purpose of evaluating either their plausibility or their promise as avenues for further study. We have emphasized predation by fish and fur seals in our discussion, but that is because most of our data on abundance changes, and predation of eastern Bering Sea biota deal with these animals. If we knew more about the predatory habits of zooplankon, squid, or bottom invertebrates along with their temporal-spatial changes in abundance, our discussion would have been more extensive. The same could be said about parasitism, disease, and changes in the physical environment. Therefore, we are left with a considerable degree of uncertainty as to the causes of the continuing decline in year-class abundance of Greenland turbot. There is also the possibility alluded to earlier that the decline may be a return to more normal levels of recruitment from high levels during the 1970's and not the result of a recruitment failure.

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