Studies on the Sablefish Resources of the North Pacific Ocean

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Abstract

The sablefish or blackcod, *Anoplopoma fimbria* (PALLAS), are widely distributed in the North Pacific Ocean and the Bering Sea, and form one of the commercially important groundfish resources in these regions. Sablefish have been exploited since the end of the 19th century by fishermen of the west coast of North America. The Japanese sablefish fishery was initiated in the northern Bering Sea in 1958 and then steadily expanded to other areas of the Bering Sea and Northeast Pacific Ocean. After reaching a peak in 1972, the amount of catch turned to decrease gradually up to 1976, but declined drastically in 1977 when Canada and the United States established 200-mile fishing zones. Consequently, the Japanese sablefish fishery is at a distressful situation. Although the rapid decline in catches was a direct result of more stringent management measures by Canada and the United States based on socio-economic factors, there was also disagreement of opinions between Japan and the United States on the condition of the stock which indirectly affected the situation.

This thesis examines biological features of the sablefish stock, the condition of the resource, and provides estimates of acceptable biological catch. Biological characteristics examined are geographic and bathymetric distribution, migrations, stock structure, age and growth, sexual maturity, sex ratios, feeding habits, and recruitment processes. Trends in stock condition are examined based on statistics from the Japanese longline fishery and results of longline surveys, and biomass estimates derived from longline and trawl survey data. Finally, an acceptable biological catch (ABC) is estimated for the eastern Bering Sea, Aleutian Region, and Gulf of Alaska based on analysis of fisheries statistics, the change in the stock level between 1969 and 1979 and following 1979, and taking into account the recruitment of the extremely strong 1977 year class.

In order to assure sound management of the sablefish fisheries, it will be necessary to clarify the age structure of the populations, the frequency and degree of geographic intermixing, and the mechanisms that result in strong year classes, as well as to improve the accuracy of biomass estimates and biological parameters. At the same time, it will also be important to continue to monitor the stock condition over a broad area of its range and to promote an active exchange of information among the countries concerned with the resource.

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Introduction

The sablefish have been exploited since the end of the 19th century along the western coast of North America. Initially, fishing grounds were quite limited geographically. Demand for sablefish increased temporarily during the World Wars I and II, but annual catches never exceeded 10,000 metric tons during these periods. In the 1960's, Japan and the U.S.S.R. embarked on large-scale groundfish fisheries in the Bering Sea and the northeastern Pacific Ocean, taking with sablefish as one of the main target species. The total catch of sablefish by all nations reached a peak of 66,700 tons in 1972. Thereafter, catches decreased steadily to an estimated 25,000 tons in 1980 because of the intensification of fisheries regulations by Canada and the United States.

Sablefish have been exploited by Canada, the United States, Japan, Republic of Korea, Taiwan, and the U.S.S.R. Japanese fisheries accounted for 50% of the total catch in 1960, but increased to more than 70% during the period from 1961 to 1975. However, after 1977 when Canada and the United States established the 200-mile fishing zone, catch quotas allocated to Japan decreased rapidly. The United States has apparently taken the largest share of the catch in most recent years.

Among the groundfish resources along the coast of North America, sablefish and Pacific halibut have been species traditionally exploited by Canadian and United States fishermen. Sablefish have therefore been of great concern to fishermen of these countries who feared that the stocks might be depleted as a result of the development of large-scale foreign groundfish fisheries, particularly those by Japan. For this reason the United States began to impose regulation on foreign sablefish fisheries in 1973, which were strengthened year by year. In addition, through meetings of the International North Pacific Fisheries Commission (INPFC) and Japan-U.S. and Japan-Canada bilateral meetings, scientific discussions on sablefish stock assessment and fisheries regulations were initiated.

In Japan, systematic studies on groundfish resources in the North Pacific Ocean started in 1963, but it was not until the early 1970's that specific studies on sablefish were initiated. Until 1977, studies on fisheries biology were based on fisheries statistics compiled by commercial fishermen and data collected on research vessels. Because most research vessels operate on continental shelves, they only provide fragmentary information on sablefish which mainly inhabit continental slope waters. Moreover, with the changes in the nature of the commercial sablefish fishery brought about by the implementation of the U.S. 200-mile fishing zone in 1977, the quality of catch and effort statistics were altered and the interpretation of these statistics remains to be studied.

Even before implementation of the 200-mile fishing zone, the United States, for the purpose of the protection and development of domestic coastal fisheries, began to take a conservative approach toward the management of the fisheries resources in which American fishermen had special interest. Due to the limited information on sablefish through the mid 1970's, there were wide differences of opinion between Japan and the United States on the condition of the resource.

In order to improve our knowledge of the fisheries biology of sablefish, which had previously been mainly based on data from the commercial fisheries, a systematic groundfish survey using bottom longline gear was conducted in the Gulf of Alaska for the first time in 1978. Following this first preliminary survey, the survey expanded to the areas including the Aleutian Region in 1979 and the eastern Bering Sea in 1982. Meanwhile, large-scale trawl surveys have been conducted covering continental slope waters as well as shelf waters in the eastern Bering Sea and Aleutian Region since 1979. As a result of these surveys, biological information on sablefish has been remarkably increased. These surveys have been conducted jointly by Japan and the United States, because the survey areas are within the U.S. 200-mile fishing zone.

The author has been involved in the systematic study of groundfish resources in the North Pacific Ocean at the Far Seas Fisheries Research Laboratory of the Fisheries Agency of Japan since 1968 and for much of this time has mainly devoted to studies on sablefish. The purpose of these studies has been to understand the real state of the sablefish fishery in the North Pacific Ocean, the biological characteristics of sablefish, to assess the present condition and the future trend of the resource based on information gathered thus far, and to use the resource more efficiently. This report is a summary of the results of this series of studies.

I. Description of the species

1. Systematics and closely related species

Sablefish was first recorded as *Gadus fimbria* by PALLAS in 1811. JORDAN and GILBERT (1883) proposed the name *Anoplopoma fimbria* (PALLAS) because of the close similarity of sablefish to *Anoplopoma merlangus* which was recorded by AYRES in 1859. At the same time, on the basis of morphological characteristics, JORDAN and GILBERT (1883) established Anoplopomatidae to separate sablefish from other species of related families. The closely related species, skilfish (*Erilepis zonifer*) was first recorded in 1880 by LOCKINGTON (1880). JORDAN and EVERMANN (1898) originally placed skilfish in Anoplopomatidae and later in Erilepidae and considered both families to consist of a single genus and species (JORDAN *et al.*, 1930). MATSUBARA (1955) and CLEMENS and WILBY (1961), however, considered Erilepidae as a synonym for Anoplopomatidae and thus again placed skilfish in Anoplopomatidae.

Based on the findings of these latter authors, Anoplopomatidae is considered to consist of two genera, *Anoplopoma* and *Erilepis* each with a single species. The family with the closest affinity to Anoplopomatidae in Scorpaeniformes is Hexagrammidae.

2. Morphology

In spite of similarity of the exterior form, sablefish differ from those of the Family Hexagrammidae by the presence of two well developed nostrils on each side of the snout and two well separated dorsal fins and in the absence of cirri on the head (MATSUBARA, 1955). It is readily distinguishable from skilfish by the complete separation of the first and second dorsal fins, the presence of spiny rays on the anal fin and the small body depth (OKADA and KOBAYASHI, 1968). Maximum body length exceeds 1 m and body weight 13 Kg. Characteristics of sablefish were described by HART (1973) as follows;

"Body rather elongate about 4.5 into standard length. Head about 3.5 into standard length. Snout tip elongate and mouth terminal. Maxillary reaches to point below anterior margin of pupil of eye. Lower jaw included in upper jaw. Teeth fine and in patches on jaws, vomer and palatines. Eye small. Orbital diameter 6.5 into length of head. Gill membranes united and joined to isthmus. Caudal peduncle slender. Two dorsal fins well separated. Second dorsal mirrors anal fin. Pelvic fins thoracic. Caudal prominently forked. Scales weakly ctenoid, small, elongate covering body and head".

It is difficult to count number of fin rays accurately since the distinction between spiny and soft rays is not clear and the fin rays on the dorsal and anal fins are frequently embedded. Different counts resulted when fin rays of an individual specimen was counted by more than one scientist (PHILLIPS *et al*., 1954). The reported ranges to date (CLEMENS and WILBY, 1961; HART, 1973; JORDAN and EVERMANN, 1898; MATSUBARA, 1955; OKADA and KOBAYASHI, 1968; PHILLIPS *et al*., 1954) are XVII to XXVII for first dorsal fin, I, 13 to 20 for second dorsal fin, and III, 13 to 19 for anal fin.

Body color differs significantly between adult and young fish. Adults are black or dark gray and the outer margin of the pectoral is dark black. The body is slightly lighter on the ventral surface. Adult fish inhabiting water shallower than 300 m are greenish gray on the dorsal surface and silvery white on the ventral surface as in young fish. Occasionally calico and yellow variants are reported (PHILLIPS, 1952). Young fish are greenish gray with dark bars on the dorsal surface and silvery white on the ventral surface. The outer margin of all fins in young fish are white and broad except the first dorsal and pectoral fin which has a black outer margin.

The body color and relative length of the pectoral fin to body length of 21-35 mm long larvae during the pelagic life stage are considerably different than those of adult fish (BROCK, 1940; KOBAYASHI, 1957). The body color of larvae is blue or bluish green on the dorsal surface and silvery white on the ventral surface. All fins are colorless except for the posterior half of the pectoral fin which is pitch-black. The pectoral fin which is about 1/3 of the body length extends beyond anus, almost reaching the front of the anal fin.

3. Geographic and bathymetric distribution

The geographical distribution of larvae and post larvae, one to two year old juveniles, and adults are schematically illustrated in Fig. 1. The distribution of adult fish is reported to extend along the Asian coast from Sagami Bay (ABE, 1966; SHUBNIKOV, 1963) through coastal waters of the Pacific side of northern Honshu Island and along Hokkaido Island (MARUKAWA, 1939; HIKITA, 1950) and the Kamchatka Peninsula (BELL and GHARRETT, 1945) to Cape Navarin. A sablefish measuring 82 cm in fork length was caught in Suruga Bay in August 1979 by bottom longline gear aiming at deep-sea sharks. This is the most southern record on the Asian side. Along the North American coast they extend from the northeastern Bering Sea and Aleutian Islands area through the Gulf of Alaska and along the west coast of Canada, the United States, and Mexico to Cedros Island off Baja California (CLEMENS and WILBY, 1961 ; HART, 1973 ; JORDAN and EVERMANN, 1898 ; ROEDEL, 1953 ; SWAN, 1885). Sablefish have not been reported from the Sea of Japan and Chukchi Seas (ALVERSON *et al.*, 1964 ; MATSUBARA, 1955 ; SHMIDT, 1965). In the Okhotsk Sea, only a few fish of this species were found (NOVIKOF, 1968). Adult fish not only occupy the continental slope, but also appear on seamounts in the northeastern Pacific Ocean (CHIKUNI, 1971 ; HUGHES, 1981 ; KURODA and KUROIWA, 1981 ; MCFARLANE and BEAMISH, 1983a). Water temperatures at the sea bottom in the Aleutian Region and Gulf of Alaska where adult fish were commonly found were 3.6-4.5°C in 400 m and 2.9-3.3°C in 900 m during the summer season (KUROIWA and SASAKI, 1980).

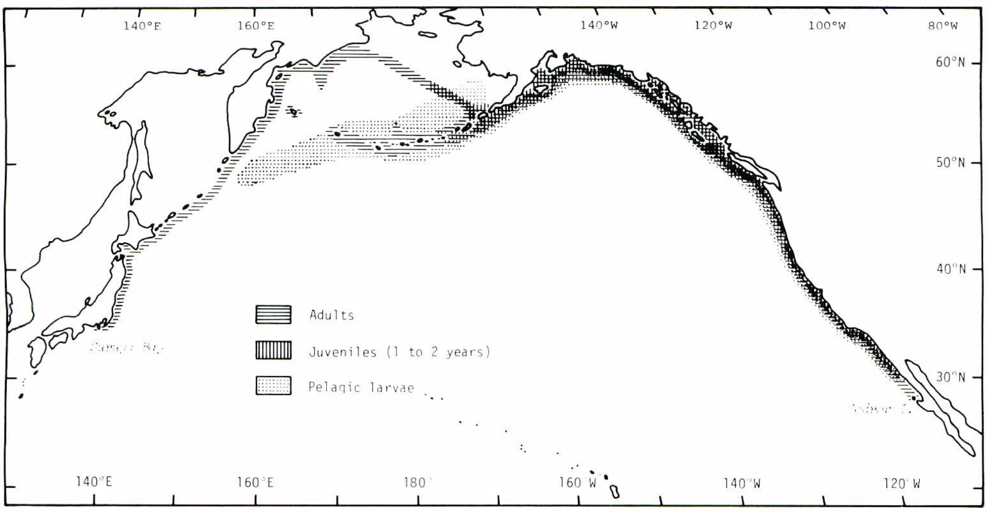

Fig. 1. Geographic distribution of adult, juvenile and larval sablefish in the North Pacific Ocean, revised from KODOLOV (1968).

The distribution of one and two year old juveniles is more limited than that of larvae and adult fish. They are commonly found in surface waters and near the bottom in shallow nearshore water of the northeastern Pacific Ocean extending from the Gulf of Alaska to California (ALVERSON, 1960 ; Anonymous, 1966 ; BELL and GHARRETT, 1945 ; COX, 1947 ; KENNEDY, 1969 ; PRUTER, 1959). In contrast, one and two year old fish are rare in the eastern Bering Sea. In spite of many surveys, the occurrence of these age groups has been limited. In 1978, a relatively extensive distribution of one and two year old fish was observed from Unimak Pass to 59°N centered in the 100 to 200 m depth zone and the shallow water areas less than 100 m along the Alaska Peninsula (UMEDA *et al.*, 1983 ; WAKABAYASHI and FUJITA, 1981 ; WAKABAYASHI and YABE, 1981).

Although survey activity has been limited, it appears unlikely that sablefish younger than age 3 inhabit waters of the eastern Bering Sea north of 59°N, the western Bering Sea, and the Aleutian Islands area. Age 3 and older sablefish, however, are distributed extensively in waters from south of 59°N in the eastern Bering Sea and Aleutian Islands area to waters off California.

Results of ichthyoplankton surveys by Hokkaido University since 1955 have shown that larvae up to 30 mm in length appear in the surface waters east of the Kuril Islands (east of 159°E), in the Aleutian Islands area, in the eastern Bering Sea south of 58°N, and in the Gulf of Alaska (HOKKAIDO UNIVERSITY, 1957-1961; 1964; 1968-1970). They were found when water temperatures were 5.6-8.7°C in July and August. In coastal and offshore waters from the Gulf of Alaska to California larvae larger than 11 mm have been found to occupy surface waters (BROCK, 1940; GRINOLS and GILL, 1968; KODOLOV, 1968; MASON *et al.*, 1983), but post larvae larger than 30 mm have not been found in surface waters on the Asian side of tne North Pacific Ocean, in the Bering Sea, and in the Aleutian Islands area (HOKKAIDO UNIVERSITY, 1957-1961; 1964; 1968-1970). It therefore appears unlikely that these larger larvae are distributed in these waters. Water temperatures at the surface layer in the waters off Washington to California where larvae and juveniles were found were 11.8-13.7°C in May and 11.7-16.5°C in July to September (KODOLOV, 1968).

The absence of standard survey data makes it difficult to compare abundance accurately in various geographical areas. The percentage of the accumulated catch of sablefish by all nations over the 10 year period of 1968 to 1977, when the fishing grounds expanded widest, was 51.6% in the Gulf of Alaska, 18.4% in the eastern Bering Sea, 12.4% in the Washington-California Region, 10.4% in Canadian Waters, 4.4% in the Aleutian Region, and 2.8% in the western

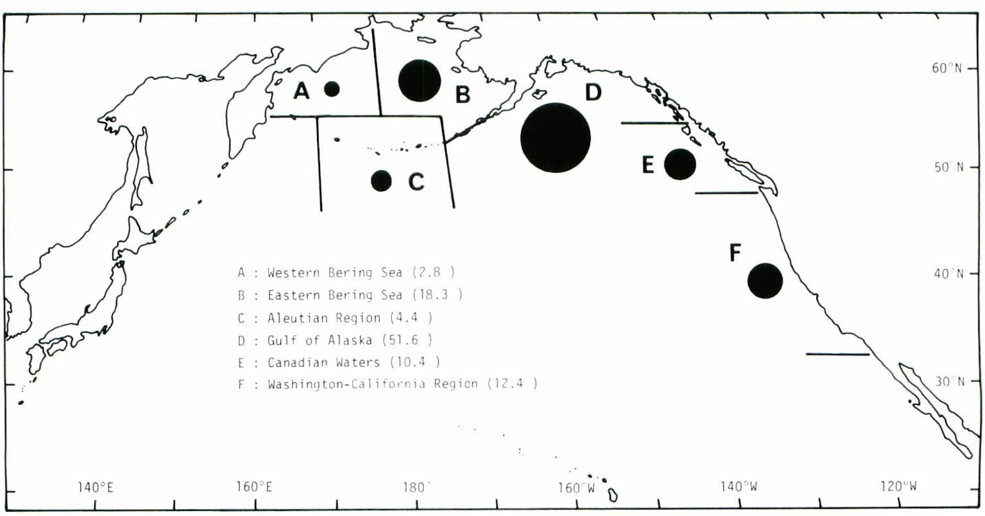

Fig. 2. Percent by region of the all nation cumulated commercial catch of sablefish during the period 1968-1977, as an index of relative geographical abundance of the exploitable biomass in the North Pacific Ocean.

Bering Sea (Fig 2). Although these figures do not accurately reflect the geographical abundance of the stock, it shows that production is the highest in the Gulf of Alaska and is extremely low in Asian waters and waters off Baja California which represent the fringes of distribution.

Based on data from a cooperative Japan-U.S. longline survey in 1982 (Fig. 3), which was conducted in the Bering Sea and Gulf of Alaska, the relative abundance was highest in the Gulf of Alaska which accounted for 83.2% of the total, followed by the eastern Bering Sea (8.7%) and Aleutian Region (8.1%).

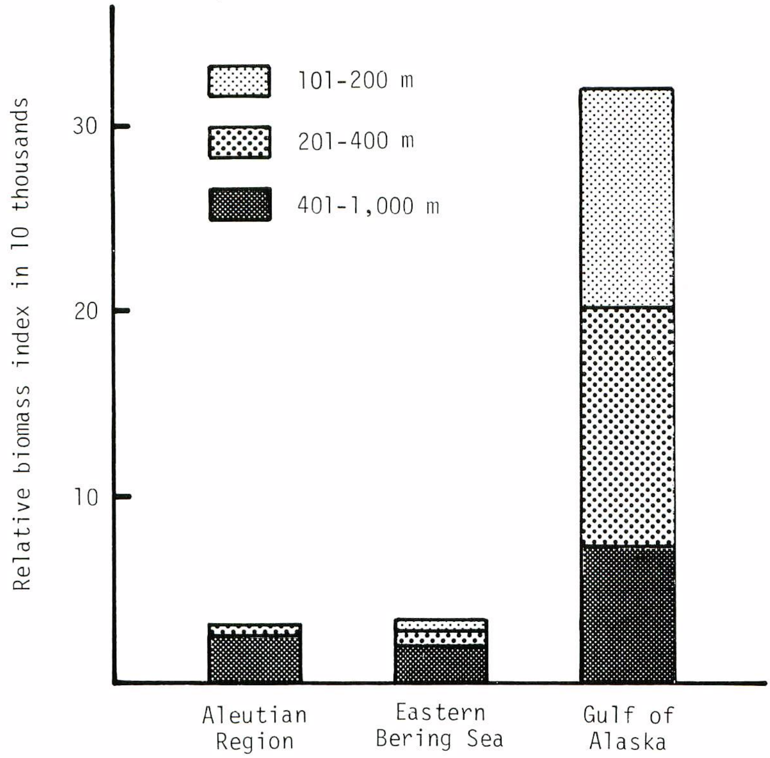

Fig. 3. Relative abundance of sablefish by region and depth in the 101-1,000 m depth range of the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summer of 1982 as shown by the Japan-U.S. cooperative longline survey.

The vertical distribution of sablefish is also extensive. THOMPSON (1941) and MASON *et al.* (1983) reported that eggs are found at depths greater than 300 or 400 m which coincides with the bathymetric distribution of mature fish. Larvae and juveniles less than age 1 are initially distributed in offshore surface waters, and then move to inshore waters as they grow (BROCK, 1940 ; GRINOLS and GILL, 1968 ; KOBAYASHI, 1957 ; KODOLOV, 1968 ; MASON *et al.*, 1983). Young fish often inhabit shallow inshore surface and bottom waters in bays and inlets until ages 3 or 4

(ALVERSON, 1960; BELL and GHARRETT , 1945; COX, 1947; KENNEDY, 1969; PRUTER, 1959). Nearshore waters extending from off southeast Alaska to British Columbia in Canada are known to be one of the most important nursery grounds for young sablefish.

Since the size of fish increases with depth (KULIKOV, 1965; SASAKI *et al.*, 1982), it is assumed that young fish move to deeper waters as they grow and then recruit to the adult stock. Based on data from a survey of the distribution of sablefish in deep waters off British Columbia, the lower limit of the bathymetric distribution is 1,830 m (BEAMISH *et al.*, 1980).

The bathymetric distribution of sablefish by growth stage is summerized in Fig. 4. The following description of the bathymetric distribution in terms of relative abundance for the eastern Bering Sea, Aleutian Region, and Gulf of Alaska is based on results of a cooperative Japan-U.S. longline survey in 1982 (Fig. 3). The majority of the biomass in the eastern Bering Sea and Aleutian Region was located at depths greater than 400 m with 60% in the eastern Bering Sea and 83% in the Aleutian Region distributed at depths of 400 to 1,000 m. In Gulf of Alaska, 77% of the biomass was located at depths of 100 to 400 m and only 23% at depths of 400 to 1,000 m. However, the depth distribution of the biomass in 1982 was influenced by the presence of a strong year class in the population.

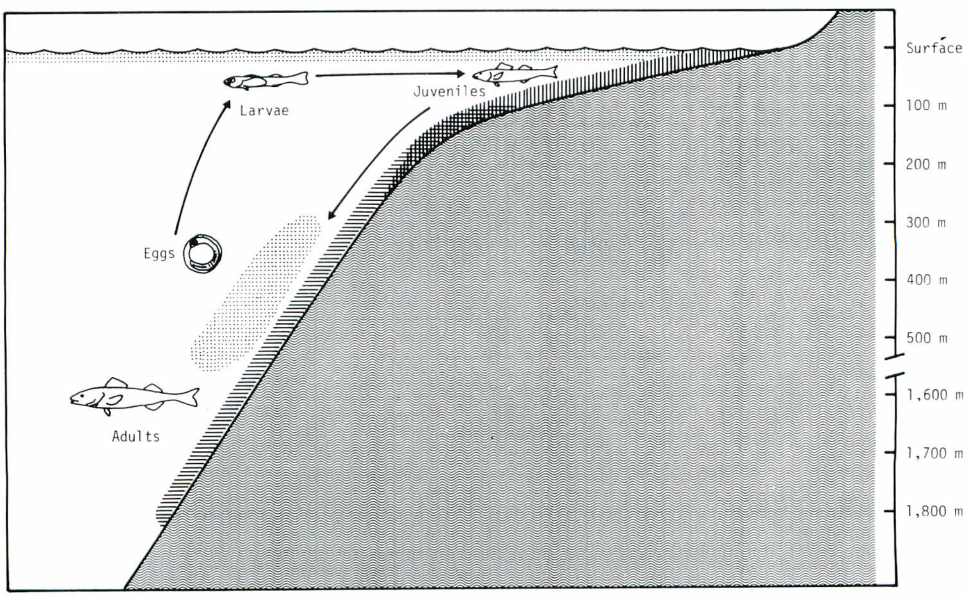

Fig. 4. Bathymetric distribution of sablefish by life stage.

II. Stock structure

As stated in Chapter I, sablefish have an extremely wide geographical distribution. To understand the biology of sablefish it is essential to clarify the stock structure within this distribution. The study of stock structure has focussed on migration and regional intermixing of sablefish as determined by geographical variation in meristic counts (PHILLIPS *et al.*, 1954), tagging experiments (ALASKA DEPARTMENT of FISHERIES, 1953, 1954; BEAMISH *et al.*, 1980; BRACKEN, 1982; EDSON, 1954; HOLMBERG and JONES, 1954; NOVIKOV, 1968; PASQUALE, 1964; PATTIE, 1970; PHILLIPS, 1969; PRUTER, 1959; SASAKI, 1979a, 1980a; WESPESTAD *et al.*, 1983), and biochemical genetic studies (TSUYUKI and ROBERTS, 1969; WISHARD and AEBERSOLD, 1979). Among these studies, most reports on foreign tagging experiments and meristic studies suggest that several isolated stocks probably exist in the distribution area, while biochemical genetic studies show that all sablefish in the northeastern Pacific Ocean are polymorphic and thus identical population. Attaching importance mainly to the results of the Canadian and U.S. tagging experiments, stock assessment and fishery management by the United States and Canada has been conducted by region.

In this chapter, the stock structure of sablefish in the North Pacific Ocean is presented based on results of Japanese and Japan-U.S. joint tagging experiments and geographical variation in number of vertebrae. Furthermore, results of the U.S. and Canadian tagging experiments are reviewed from a point of the detection of tagged fish and non-reporting of recoveries by Japanese commercial vessels. These studies lead us to conclusion that there is no biological basis for geographically dividing this stock.

1. Tagging experiments

1-1. Materials and methods

Japanese sablefish tagging experiments were carried out almost annually from 1962 to 1972 in the Bering Sea and northeastern Pacific Ocean. They were suspended from 1973 to 1977 but were resumed in 1978 in cooperation with the United States. Since then the experiments have been carried out each year in the Aleutian Region and Gulf of Alaska, and since 1982 in the eastern Bering Sea.

Sablefish were caught for tagging by bottom longline or trawl gear during the period from 1962 to 1972, while in 1978 and latter years they were mainly caught by longline gear. During experiments from 1962 to 1965, a stainless strap tag was attached to the outer edge of the left opercle, but from 1966 to 1972 a Petersen disk tag was attached to each side of the base of the first dorsal fin with stainless pins. Since 1978 anchor tags have been attached to the base of the first dorsal fin.

In the 1962-1972 experiments, 5,315 fish were released in the Bering Sea and Aleutian Region and 2,140 fish in the northeastern Pacific Ocean (Fig. 5). By the end of December 1981, 123 sablefish had been recovered for a 1.65% recovery rate. A majority (110) of these fish were

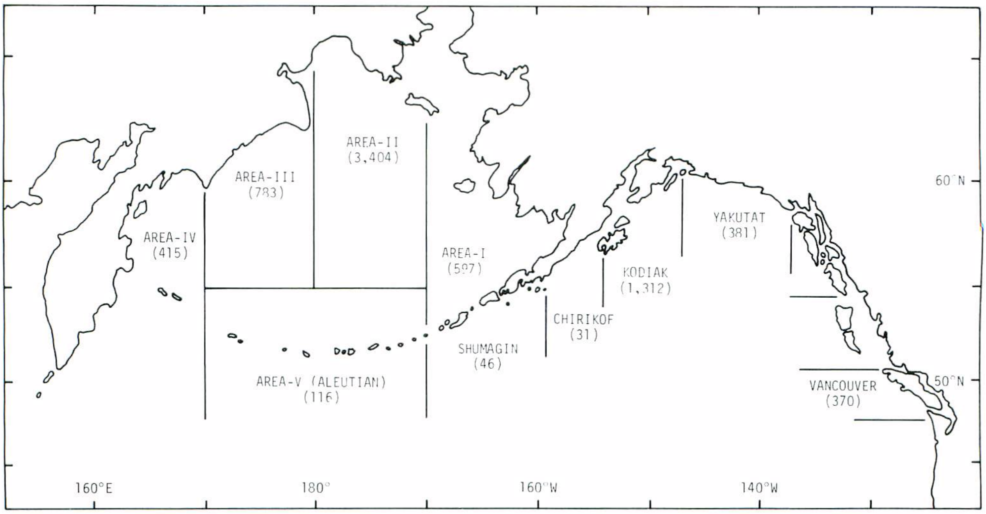

Fig. 5. Number of tagged sablefish released by Japan by INPFC area, 1962-1972.

Table 1. Number of tagged sablefish released during Japanese and Japan-U.S. joint tagging experiments and number of recoveries by country. Number of recoveries are those reported through the end of August 1982.

Year Released	Number released	Recoveries by country					Total
		Japan	U.S.A.	Canada	U.S.S.R.	ROK	
1962	118	2	—	—	—	—	2
1963	316	2	—	—	—	—	2
1964	1,119	9	—	—	—	—	9
1965	601	3	—	—	—	—	3
1966	1,211	16	—	—	—	—	16
1967	704	16	—	—	1	—	17
1968	941	13	1	—	2	—	16
1969	542	15	1	—	—	—	16
1971	1,152	22	1	2	—	—	25
1972	751	12	2	1	—	2	17
(Sub-total)	(7,455)	(110)	(5)	(3)	(3)	(2)	(123)
1978	6,986	75	37	52	—	—	164
1979	16,097	141	111	44	—	1	297
1980	13,540	107	31	21	—	—	159
1981	20,226	71	7	8	—	—	86
(Sub-total)	(56,849)	(394)	(186)	(125)	—	(1)	(706)
Total	64,304	504	191	128	3	3	829

recovered by Japanese fishing vessels (Table 1).

In the experiments from 1978 to 1981, 4,496 tagged sablefish were released in the Aleutian Region and 51,693 in ghe Gulf of Alaska (Fig. 6). By the end of August 1982, 706 fish had been recovered from these latter experiments (Table 1), among which 394 (including 65 by U.S. observers) were recovered on board of Japanese vessels, 186 on U.S. vessels, 125 on Canadian vessels, and 1 on Korean vessel. Longliners took 88% of the tagged fish (347 in number) recovered by Japan.

Tagging data from 1962 to 1972 and those from after 1978 are analyzed separately.

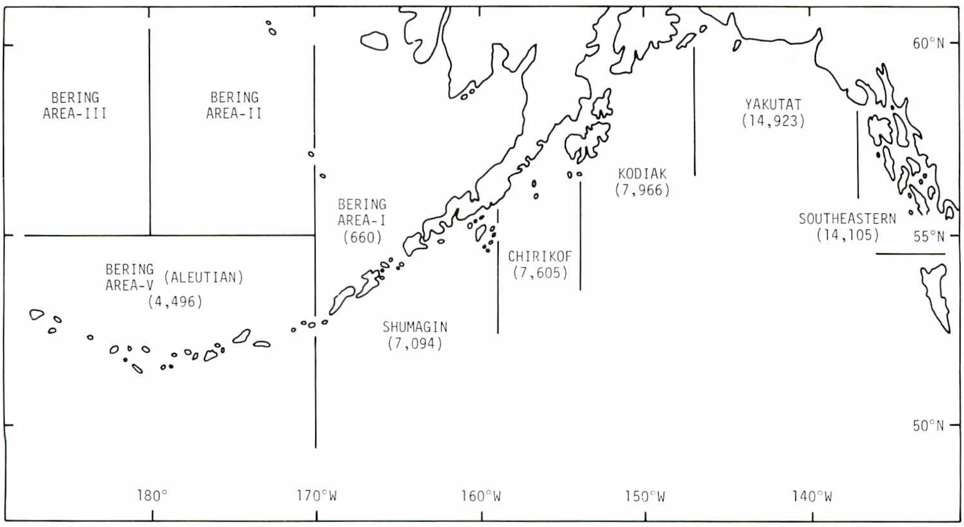

Fig. 6. Number of tagged sablefish released by INPFC area during the Japan-U.S. cooperative longline surveys, 1978-1981.

1-2. Tagging experiments from 1962 to 1972

Ten years have passed since the last sablefish was released from tagging experiments in 1962-72, and there has been no reported recoveries after 1979. Among the recoveries from this tagging period, the longest time at liberty was 9 years and 11 months for a fish released in the northern Bering Sea and recovered on Eickelberg Seamount off Vancouver Island, Canada. The longest distance travelled was 4,376 km, assuming a straight line course, for a fish at liberty for 6 years and 4 months, tagged in the northern Bering Sea and recovered off San Francisco, California.

The recovery rate of tagged fish released in the Bering Sea throughout this period was 1.65% ; it was lower (0.74%) from 1962 to 1965 than in 1966 to 1972 (2.02%). The reason for the lower recoveries in the earlier period was that there was no well-organized sablefish fishery in the northeastern Pacific Ocean until 1967, and thus the chances of recoveries were few for sablefish migrating from the Bering Sea to the northeastern Pacific Ocean.

Among the 123 fish recovered, complete recovery data were available for 113 fish. Table 2 shows the regional movements by INPFC area of 89 tagged fish recovered after four or more months at liberty. The recoveries within three months after release were excluded, because the time at liberty was too short for the fish to make long distance movements. Distances of migrations generally increased in proportion to the time at liberty. Among the 89 fish recovered, 61 fish or 69% of the total were recovered in INPFC areas other than the release area (Table 2).

Table 2. Recoveries of tagged sablefish by INPFC area from Japanese tagging experiments in the North Pacific Ocean during 1962-1972. Recoveries are for fish at liberty 4 months or more.

INPFC area of release	INPFC area of capture														Total
	B-I	B-II	B-III	B-IV	ALEU	SHU	CHI	KOD	YAK	SE	CHA	VAN	MON	Seamount	
Bering Area-I	1	1	—	—	—	—	1	—	—	—	—	—	—	—	3
Bering Area-II	—	10	2	1	—	—	3	4	3	9	2	—	1	1	36
Bering Area-III	—	—	3	—	—	2	—	2	—	2	1	1	—	—	11
Bering Area-IV	—	—	—	3	—	—	—	—	—	—	—	—	—	—	3
Aleutian Region	2	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Kodiak	1	1	—	—	—	—	—	3	6	7	1	1	—	—	20
Yakutat	—	—	—	—	—	—	—	—	4	3	—	—	—	—	7
Vancouver	—	—	—	—	—	—	1	—	1	1	—	4	—	—	7
Total	4	12	5	4	—	2	5	9	14	22	4	6	1	1	89

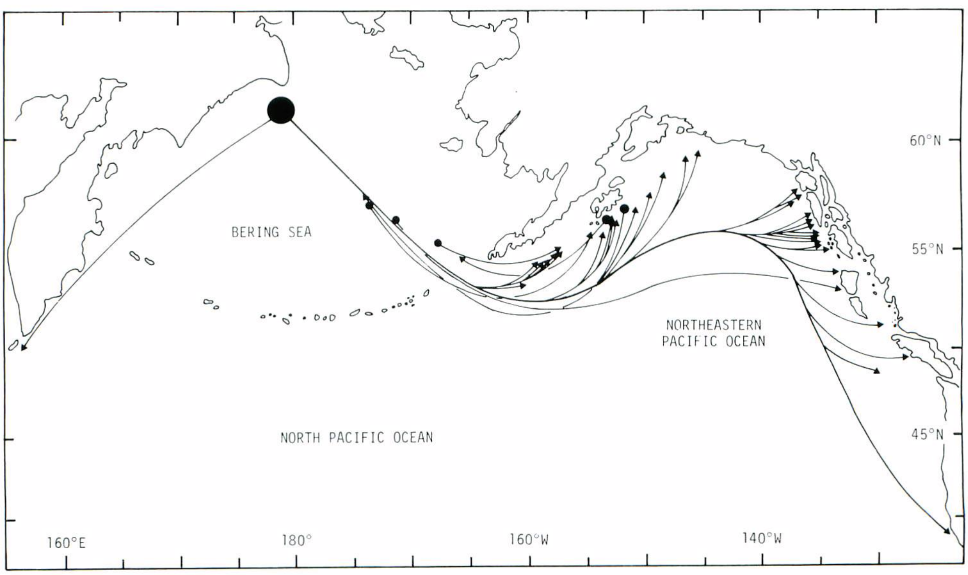

Fig. 7. Regional movements of tagged sablefish released during Japanese tagging experiments from 1962 to 1972 in the Bering Sea and northeastern Pacific Ocean. Black circles indicate the release area and the size of the circle is proportional to the number of releases.

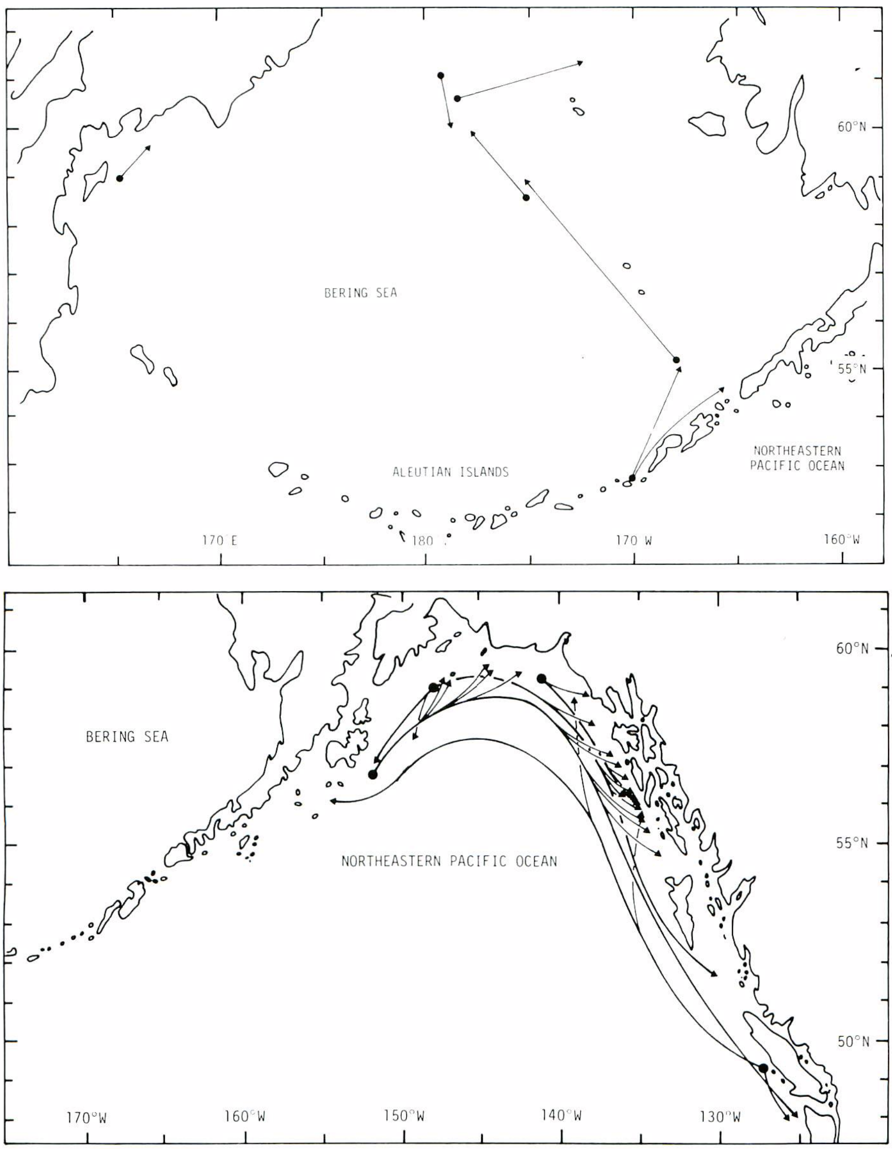

Fig. 8. Movements of tagged sablefish recovered more than 100 km from release sites in the Bering Sea, Aleutian Region, and northeastern Pacific Ocean. These fish were released during Japanese tagging experiments from 1962 to 1972 in the Bering Sea and northeastern Pacific Ocean.

Sablefish released in the Bering Sea were recovered in many areas of the northeastern Pacific Ocean, showing active movements (Fig. 7). Two fish migrated from the northeastern Pacific Ocean to the Bering Sea. Only minor tagging experiments were carried out in the Aleutian Region. However, migration of two fish from the Aleutians to the Bering Sea was shown by the recoveries (Fig. 8). Frequent long distance movements within the northeastern Pacific Ocean were also shown by the recoveries (Fig. 8).

1-3. Tagging experiments in 1978 and later years

From the sablefish tagging experiments started in 1978, 706 recoveries had been reported by the end of August 1982. Of the 548 fish recovered after four or more months from release, 59% were recovered in an INPFC area other than the release area (Table 3). The Southeastern Area, where migrations are less extensive than in western areas, showed the lowest proportion (34%) of fish recovered outside of the release area (Table 3, Fig. 9). Of the fish tagged in the Aleutian Region, 81% were recovered outside this area.

Table 3. Recoveries of tagged sablefish by INPFC area from Japan-U.S. joint tagging experiments conducted in the Aleutian Region and Gulf of Alaska since 1978. Recoveries are for fish at liberty 4 months or more as reported up to the end of August 1982.

INPFC area of release	INPFC area of capture														Total
	B-II	B-I	ALEU	SHU	CHI	KOD	YAK	SE	CHA	VAN	COL	EUR	Seamount	Unknown	
Bering Area-I	—	2	—	—	—	—	—	—	—	—	—	—	—	—	2
Aleutian	2	—	4	2	1	2	—	3	5	—	2	—	—	—	21
Shumagin	1	4	1	19	5	7	4	15	17	8	4	1	1	—	87
Chirikof	—	2	1	6	19	6	2	7	12	13	3	—	—	—	71
Kodiak	—	1	1	3	6	50	10	6	23	7	3	1	—	—	111
Yakutat	—	2	2	10	5	15	38	19	18	4	3	—	—	2	118
Southeastern	—	—	2	1	8	4	12	91	15	4	1	—	—	—	138
Total	3	11	11	41	44	84	66	142	90	36	16	2	1	2	548

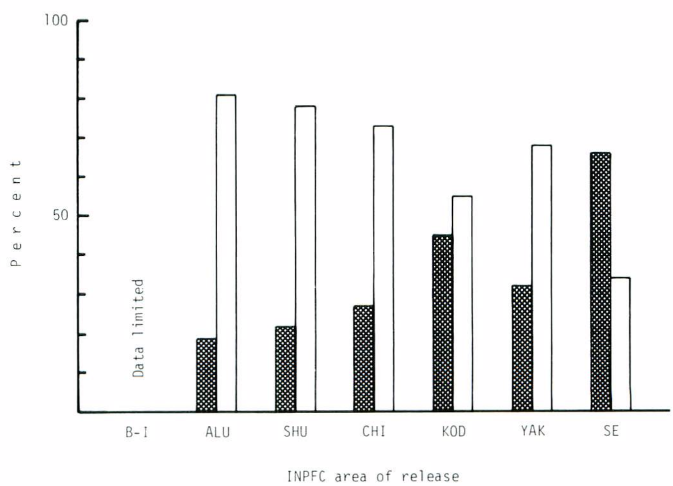

Fig. 9. Percent of tagged sablefish recovered in a release area (shadow) and the fish recovered in the other areas than the release area (blank). These recoveries were from Japan-U.S. joint tagging experiments conducted in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska since 1978.

1-4. Discussion

Sablefish tagging experiments have been actively carried out by Canada, Japan, the United States, the U.S.S.R., and the Republic of Korea. The first experiments were carried out by the United States in 1948 and 1949 along the coast of Oregon State. From 1950 to 1952, systematic tagging experiments were initiated along the North American coast from Alaska to California. Since then, various fishery agencies have carried out tagging experiments in many areas along the North American coast. One of the major experiments in U.S. waters was a joint effort from 1971 through 1976 by the United States, the U.S.S.R., and Republic of Korea in the northeastern Pacific Ocean. Canada has also conducted large-scale tagging experiments since 1977 within 200 miles of their coast.

A number of authors have summarized results of tagging experiments in the 1950's and 1960's, and have concluded that sablefish migrate within only limited areas (ADF, 1953, 1954; EDSON, 1954; HOLMBERG and JONES, 1954; NOVIKOV, 1968; PRUTER, 1959; PHILLIPS, 1969). However, until 1967 there was no major sablefish fishery in the northeastern Pacific Ocean. Thus, longer range migrations could not have been detected, because the only possibilities for recovery were in the limited area fished by North American fishermen. The conclusions reached by these authors was therefore biased by the artificially limited nature of the returns. One notable exception was that five young sablefish released in Puget Sound of the State of Washington, were recovered by Japanese fishing vessels in the Bering Sea (PASQUALE, 1964; PATTIE, 1970).

WESPESTAD *et al.* (1983) reviewed results of the U.S. tagging experiments conducted jointly with the Republic of Korea and the U.S.S.R. since 1971 when the sablefish fishery was operating in all major areas of sablefish distribution. Their conclusions which differed from this paper, were based on tagged fish of which two thirds were released from off Washington to California. However, results of present study were based on release from the Japan-U.S. joint tagging experiments which were carried out in areas west of southeastern Alaska. Therefore, the two different conclusions possibly reflect migration behavior peculiar to each region.

Major considerations in analysis of release-recovery data is how well tagged fish are detected in catches and non-reporting of recoveries. An important part of present study was a detailed examination of the reported recoveries. For instance, reported recoveries from Japanese vessels, which took most of the sablefish catch, were from a limited number of the total vessels. This suggests non-reporting of recoveries and if this was not considered, misleading results might have been produced.

An interim report on Canadian tagging experiments, which were started in 1977, shows that 80% of the reported recoveries (2,385 fish) were within 50 km of the release point and that the distance travelled was greater as the time after release increased (BEAMISH *et al.*, 1980). Japanese fishing vessels recovered fish released by Canada in various parts of the Bering Sea, Aleutian Region and Gulf of Alaska (Fig. 10). Most of the reported recoveries were made by five to six specific longliners. Total recoveries by Japanese vessels, which are still imcomplete were 305 at the end of August 1982. Because there has not been much change in fishimg operations in

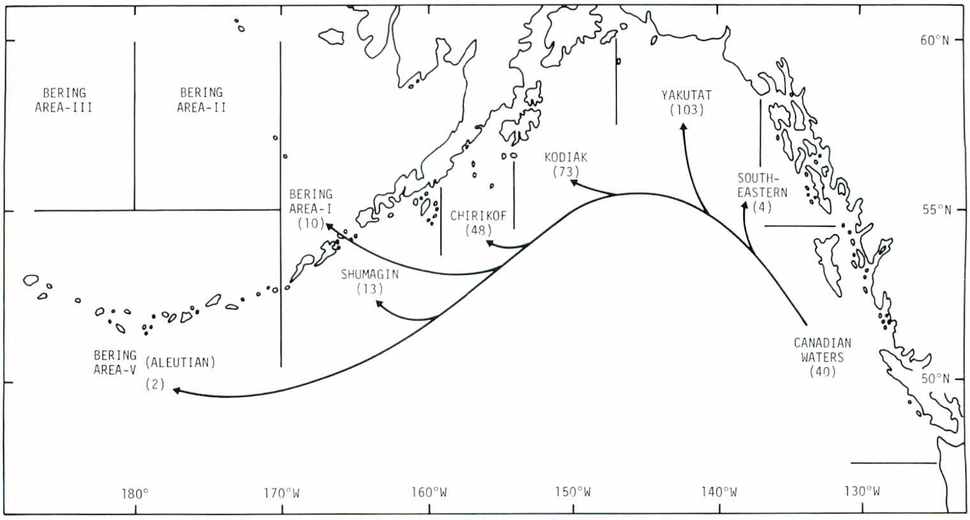

Fig. 10. Japanese recoveries by INPFC area of sablefish tagged in Canadian waters. Releases are from Canadian tagging experiments since 1977. The lack of recoveries in Washington to California waters and the small number of recoveries in the Southeastern Area are due to the closer of these waters to foreign sablefish fisheries since 1977 and 1978 respectively. Canadian waters were also closed to these fisheries in 1980.

recent years, the total of Japanese longline fleet of 22 vessels was estimated to have recovered approximately 1,220 tagged fish released by Canada. This estimate shows that the numbers of sablefish that migrate from Canadian waters to the Gulf of Alaska and as far as the eastern Bering Sea and Aleutian Region in a comparatively short period of time is not negligible.

Analysis of recovery data from the Japan-U.S. joint tagging experiments are not corrected giving consideration to the distribution of the catch and fishing effort by INPFC area and to the variable reporting of recoveries by individual fishing vessels. Similar to the recoveries from the Canadian tagging experiments, however, 88% of the recoveries from the Japan-U.S. joint experiments since 1978 were made by a few specific Japanese longliners. The actual number of recoveries by longline vessels was therefore estimated to be at least four times (approximately 2,500 fish) of the number reported. The evidence that there has not been much difference in fishing operations by longliners in recent years and operations have covered the Gulf of Alaska west of the Yakutat Area leads to the conclusion that the number of tagged fish recovered does not vary among fishing vessels and that the recovery data expanded to the total fleet represents an undistorted picture of the migrations and intermingling of sablefish between areas.

These experiments showed a relatively low rate of migration from the Southeastern Area to other areas (Table 3, Fig. 9). Because foreign fishing for sablefish has been prohibited in this area since 1978, most of the fish were recovered by U.S. fishing vessels. The fairly high reporting of recoveries by U.S. vessels compared to the lower rate on Japanese vessels in waters outside the Southeastern Area distorts the true migration pattern. The proportion of migrating fish from the Southeastern Area to other INPFC areas is, therefore, estimated to be larger than shown by the data.

The results of tagging experiments to date do not show that long range migrations are a phenomenon peculiar to a few sablefish, but rather that intermixing takes place over a large part of their geographical range in a relatively short period of time.

2. Geographical variation in number of vertebrae

2-1. Materials and methods

A total of 1,986 fish (Table 4) was sampled from the Bering Sea and northeastern Pacific Ocean from 1967 to 1971 for meristic and morphological studies (Fig. 11). Most of these samples were collected by research vessels of the Fisheries Agency of Japan, and the rest was supplied by commercial fishing vessels. All samples were frozen, and various measurements were taken after the specimens were thawed in the laboratory. Flesh was then removed, and the vertebrae were soaked in hot water after which the remaining flesh was removed with a tweezer or brush. Vertebrae including urostyles were then counted.

2-2. Results and discussion

Vertebrae counts ranged from 61 to 66 with a mode of 64 (Table 5). Mean values showed no geographical cline, although a significant difference in values was found between Areas Unimak Pass (D) in the eastern Bering Sea and off Prince of Wales Island (H) in the Gulf of Alaska (Table 5, Fig. 12). The frequency distribution of number of vertebrae by area also showed

Table 4. Sample data for sablefish collected for racial studies using vertebrae counts.

Area	Date collected		Locality of catch	Number of fish	Range in fork length in cm
A	September,	1967	off Cape Navarin, Bering Sea	177	46-76
	August,	1969		73	52-74
B	August,	1969	NW of Pribilof Is., Bering Sea	56	44-70
C	July,	1967	SE of Pribilof Is., Bering Sea	32	46-60
	August,	1969		44	48-72
D	Mar.-June,	1969	Unimak Pass, Bering Sea	121	36-60
	May,	1971		368	38-60
E	August,	1970	Patton Seamount, Gulf of Alaska	33	56-72
F	August,	1970	off Kodiak I., Gulf of Alaska	264	40-78
	May,	1971		134	46-78
G	Mar.-Aug.,	1967	off Montague I., Gulf of Alaska	24	42-78
	May-Aug.,	1970		120	42-76
	May,	1971		339	40-98
H	Apr.-Dec.,	1967	off Prince of Wales I., Gulf of Alaska	30	40-66
	Nov.-Dec.,	1968		36	40-60
	January,	1969		23	40-48
I	July,	1969	off Queen Charlotte Sound, Gulf of Alaska	104	36-62
	June,	1970		8	44-58
Total				1,986	

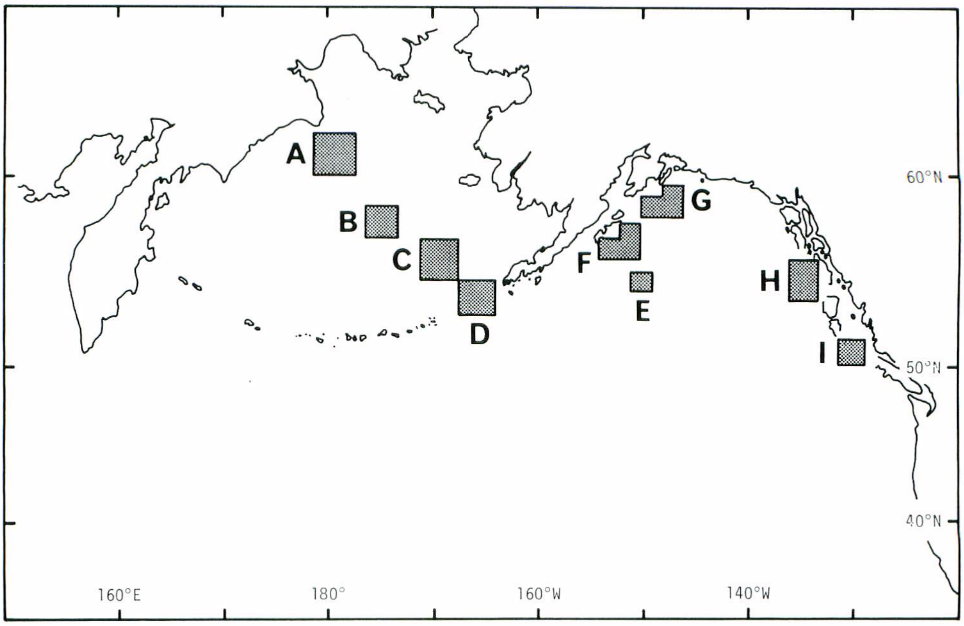

Fig. 11. Sampling areas in the Bering Sea and northeastern Pacific Ocean for collection of sablefish during 1967 to 1971 used in racial studies based on vertebra counts.

Table 5. Total number of vertebrae (including urostyle) from sablefish collected in the Bering Sea and northeastern Pacific Ocean from 1967 to 1971.

Number of vertebrae	Sampling area									Total
	A	B	C	D	E	F	G	H	I	
61	2	—	—	—	—	2	—	2	—	6
62	12	8	—	8	2	16	21	13	5	85
63	80	13	20	77	12	121	119	39	48	529
64	111	25	43	252	13	182	237	26	44	933
65	41	10	11	138	6	68	95	9	14	392
66	4	—	2	14	—	9	11	—	1	41
Total	250	56	76	489	33	398	483	89	112	1,986
Mean	63.76	63.66	63.93	64.15	63.70	63.82	63.91	63.30	63.63	63.88
Variance	0.7555	0.8828	0.5156	0.5986	0.7178	0.7396	0.7012	0.8501	0.6329	0.7301

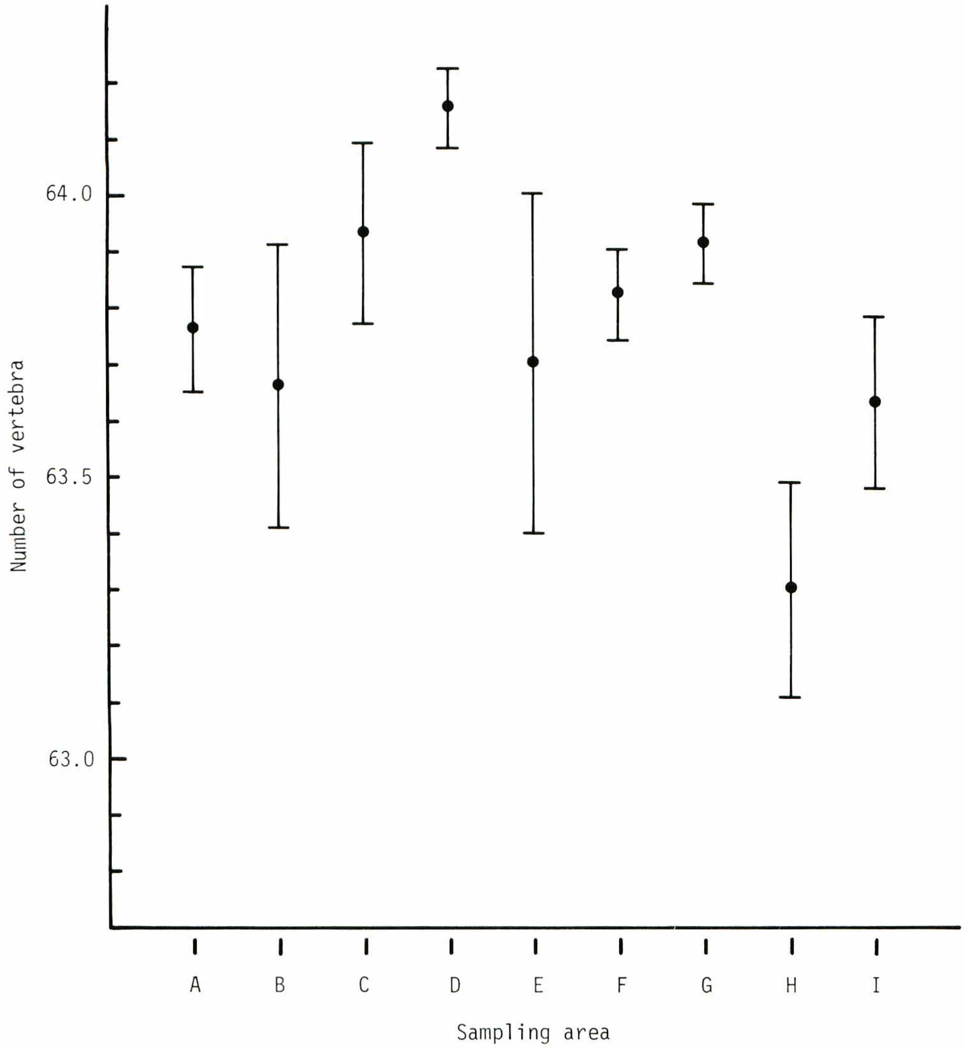

Fig. 12. Means and 95 % confidence intervals of number of vertebrae of sablefish collected in the Bering Sea and Gulf of Alaska from 1967 to 1971.

significant difference between these two Areas based on a chi-square test, but no geographical difference were detected in samples from the other seven areas (Table 6).

NAKAI (1938) pointed out that in order to use geographical variation in number of vertebrae to reach valid conclusions on the stock structure of fish, it is necessary to collect sufficient numbers of samples to test for differences statistically and to analyze data by life stages. Body lengths of the sampled fish from Areas Unimak Pass and off Prince of Wales Island were conspicuously samller than those from other areas (Table 7). The peculiarity of the mean lengths and length compositions suggest that fish in these areas were in a diffrent life stage than those from other areas, while the similarity in lengths among the other seven areas, having mostly large fish, might suggest that fish stocks intermingle as they grow.

Table 6. Results of chi-square tests for differences in distribution of vertebrae counts and t-tests for differences in mean vertebrae counts from sablefish taken in various areas of the Bering Sea and northeastern Pacific Ocean.

Area		Sampling area									
		A	B	C	D	E	F	G	H	I	
A			N	N	HS	N	N	N	HS	N	
B		N		S	HS	N	QS	N	N	N	
C		N	N		N	N	N	N	HS	N	
D		HS	HS	QS		S	HS	HS	HS	HS	chi-square test
E	t-test	N	N	N	S		N	N	N	N	
F		N	N	N	HS	N		N	HS	N	
G		QS	QS	N	HS	N	N		HS	S	
H		HS	QS	HS	HS	QS	HS	HS		N	
I		N	N	S	HS	N	QS	S	S		

N : Not significant ($P>0.05$)
QS : Questionable significant ($0.05>P>0.01$)
S : Significant ($0.01>P>0.001$)
HS : Highly significant ($P<0.001$)

PHILLIPS *et al.* (1954) studied the geographical variation in number of vertebrae, gill rakers, and fin rays from sablefish taken from southeastern Alaska to southern California and concluded that there were four geographically separated stocks. Length compositions of specimens used in this study, however, varied widely by the locality of catch. Thus the geographical variation in meristic counts does not mean that there was no intermixing of fish between the stock areas.

In summary, the above information indicates that there is no geographical variation in number of vertebrae in widely distributed population of sablefish in the Bering Sea and northeastern Pacific Ocean, and thus no indication of geographically separated stocks.

3. Discussion on the stock structure

Analyses of recoveries from tagging experiments and of the geographical variation in number of vertebrae have given no indication of the existance of geographically separated populations in the major area of distribution of sablefish.

Using biochemical genetic methods, TSUYUKI and ROBERTS (1969) and WISHARD and AEBERSOLD (1979) examined polymorphism of enzymes from sablefish samples taken from various regions of the northeastern Pacific Ocean. These studies show that all sablefish in the northeastern Pacific Ocean were polymorphic and thus identical populations.

Sablefish larvae less than 30 mm in body length have been identified in surface waters of

Table 7. Length frequencies of sablefish sampled for vertebral counts.

Fork length in cm	Sampling area								
	A	B	C	D	E	F	G	H	I
30～	—	—	—	—	—	—	—	—	—
32	—	—	—	—	—	—	—	—	—
34	—	—	—	14	—	—	—	—	2
36	—	—	—	35	—	—	—	—	5
38	—	—	—	37	—	1	1	5	6
40	—	—	—	21	—	3	2	14	3
42	—	1	—	17	—	1	13	17	2
44	4	—	3	46	—	8	55	14	2
46	6	2	5	63	—	12	47	9	5
48	7	3	9	101	—	13	25	4	8
50	18	4	8	79	—	15	14	3	12
52	17	7	7	49	—	17	20	3	17
54	31	3	7	18	2	21	25	5	14
56	47	4	6	6	4	53	36	4	16
58	42	6	6	3	5	58	30	4	12
60	34	9	5	—	8	48	30	4	8
62	20	6	4	—	7	47	39	2	—
64	11	7	7	—	1	33	26	1	—
66	3	1	3	—	3	32	26	—	—
68	5	3	3	—	1	15	10	—	—
70	1	—	3	—	2	12	15	—	—
72	2	—	—	—	—	5	13	—	—
74	2	—	—	—	—	1	16	—	—
76	—	—	—	—	—	3	12	—	—
78	—	—	—	—	—	—	10	—	—
80	—	—	—	—	—	—	6	—	—
82	—	—	—	—	—	—	5	—	—
84	—	—	—	—	—	—	—	—	—
86	—	—	—	—	—	—	2	—	—
88	—	—	—	—	—	—	2	—	—
90	—	—	—	—	—	—	—	—	—
92	—	—	—	—	—	—	2	—	—
94	—	—	—	—	—	—	—	—	—
96	—	—	—	—	—	—	1	—	—
98	—	—	—	—	—	—	—	—	—
Total	250	56	76	489	33	398	483	89	112
Average	57.79	58.25	56.63	46.90	61.79	59.71	58.87	47.58	51.84
Variance	28.21	38.77	52.56	30.14	17.23	44.73	125.56	47.84	47.97

the Bering Sea and Aleutian Region, but not post larvae larger than 30 mm and juvenile fish less than age 1. Juvenile age 1 and older sablefish are usually found between the 100 and 200 m isobaths from Unimak Pass to the Pribilof Islands, but their density is in general extremely low.

KODOLOV (1968) concluded from the distribution of larvae and juvenile sablefish in the Bering Sea and Aleutian Region that reproduction is not sufficient to maintain the populations in these regions and that their numbers are sustained by immigration from the northeastern Pacific Ocean. The extremely strong 1977 year class appeared in a limited area of the south-eastern part of the Bering Sea in 1978 (BAKKALA *et al.*, 1982; UMEDA *et al.*, 1983; WAKABAYASHI and FUJITA, 1981; WAKABAYASHI and YABE, 1981) and Aleutian Region in 1980 (SASAKI, 1980b). Young fish have seldom been identified during previous surveys and never as abundant as in recent years (UMEDA *et al.*, 1983). Good chaches of young sablefish were also in the northeastern Pacific Ocean in the same years as those in the Bering Sea starting from 1978 (MCFARLANE and BEAMISH, 1983b; SASAKI, 1979b; ZENGER, 1981). These findings can result in conclusion that the young sablefish found in the eastern Bering Sea and Aleutian Region might be immigrants from the northeastern Pacific Ocean.

The distribution area of this year class in the Bering Sea expanded to the northwest area of the Pribilof Islands by 1981 (data exchange between Northwest and Alaska Fisheries Center and Far Seas Fisheries Research Laboratory). In the northwestern part of the Bering Sea, some small assemblages were observed in 1982 following a period of very low abundance during the 1970's (TUPONOGOV and KODOLOV, 1983). It is highly possible that this abrupt increase was caused by 1977 year class migrated there from the southeastern Bering Sea.

As mentioned earlier, five young tagged sablefish released in inland water of Washington State in the 1950's were recovered several years later in the Bering Sea (PASQUALE, 1964; PATTIE, 1970). This shows that young sablefish can in fact immigrate from the northeastern Pacific Ocean to the Bering Sea.

BRACKEN (1982), analyzing ten years of tagging data, concluded that sablefish migrate frequently and that some of the young sablefish from inland waters of southeastern Alaska migrate to the western Gulf of Alaska, and then make homing migrations to the eastern Gulf of Alaska as they become mature. However, if homing migrations of larger fish from the western Gulf of Alaska to the eastern Gulf of Alaska occur regularly, the size of sablefish in the western Gulf would be expected to be smaller than those in the eastern Gulf. There was no significant difference, however, in the size composition of sablefish among the areas in the Gulf of Alaska taken by research vessels since 1979. Therefore, it is indistinct whether a homing migration to the eastern Gulf of Alaska is regarded as a common phenomenon or not.

In the northeastern Pacific Ocean, juvenile fish during their surface life and prior to their recruitment to the adult stocks, move widely in shoals in offshore surface waters and in shallow coastal waters (COX, 1947; GRINOLS and GILL, 1968; KODOLOV, 1968). This shows that relatively active regional movements are made at young stages. Annual changes in abundance of sablefish among areas based on results of Japan-U.S. joint longline surveys since 1979 also show that extensive westward movements of young fish in the Gulf of Alaska may occur in a relatively short period of time. Results from studies of geographical variation in number of vertebrae, biochemical genetics, and tagging show that sablefish in the northeastern Pacific Ocean represent a single stock. Thus, there is no biological basis to divide geographically this stock. There is insufficient data to discuss the relationship of sablefish in the Washington to California area to those in other areas.

The above study on stock structure may be summarized as follows. Sablefish in the North Pacific Ocean consist of a single large stock. It is highly possible that sablefish in the Bering Sea and Aleutian Region originate from the northeastern Pacific Ocean. The degree of intermingling between INPFC areas or regions has been previously underestimated and it has been shown by this study to be relatively extensive and rapid. The remaining task is to present a clearer picture of the actual degree and speed of intermingling of populations between areas or regions.

III. Age and growth

A key element of fisheries biology is the study of age and growth. These biological parameters are important to an understanding of age composition, survival and recruitment rates, and provides some bases for an analytical study of populations.

The age determination of sablefish is based on examination of scales or otoliths. However, it is generally difficult to determine age of fish older than 5 years. SHUBNIKOV (1963) and KENNEDY and PLETCHER (1968) compared counts of annuli from an otolith and scale taken from the same fish, and found that the annuli on the otolith were easier to count than those on the scale. PRUTER (1954) and KODOLOV (1967) determined the age of sablefish using scales, while FUNK and BRACKEN (1983) and SHIPPEN (1974) used otoliths and MAEDA and HANKIN (1983) used both scales and otoliths. In recent years a new technique has been tested. It involves burning sectioned otoliths from which counts of annual rings are made (BEAMISH and CHILTON, 1982).

In this chapter, sablefish age and growth will be discussed from results of age determination using scales, tagging experiments, and information from other biological sources.

1. Materials and methods

Age determinations were made from a sample of 782 sablefish taken from the eastern Bering Sea in 1966. The relationship between the length of fish and radius of the scale was also determined from this sample together with additional 104 scales taken from sablefish in the eastern Bering Sea during the period of 1965 to 1969. To determine the portion of the body that provided the best scales, the size and shape of scales were compared in various portions of the body from one male and one female sablefish taken from the Bering Sea in June 1968.

Regenerated or broken scales were removed from the samples and the normal scales were placed in a praparat after washing. The scales were magnified, and a shadowgraph was used to measure the radius. The longest axis of the scale was used for measurements. Radius of the annuli (r_i) was the distance from the center to the extreme outer edge of the resting zone. Data used for estimating annual growth were from all tagged sablefish recovered in 1977 and later which had been identified by sex and were at liberty for one to four years. However, because the precision of measurements taken on fishing vessels might be questionable, only those length measurements taken at research laboratories were used. Annual growth was also estimated from length compositions of the abundant 1977 year class which were collected during research vessel surveys.

A length-weight relationship was derived from the sample of 886 fish mentioned previously and from 3,199 fish taken from the eastern Bering Sea, Aleutian Region and Gulf of Alaska during the period from 1978 to 1981.

2. Variation in scales from various portions at the body

The male and female sablefish used in this study had fork lengths of 54.1 and 50.1 cm, respectively. Of the twelve body portions sampled (Fig. 13), the scales taken from area *L* (base

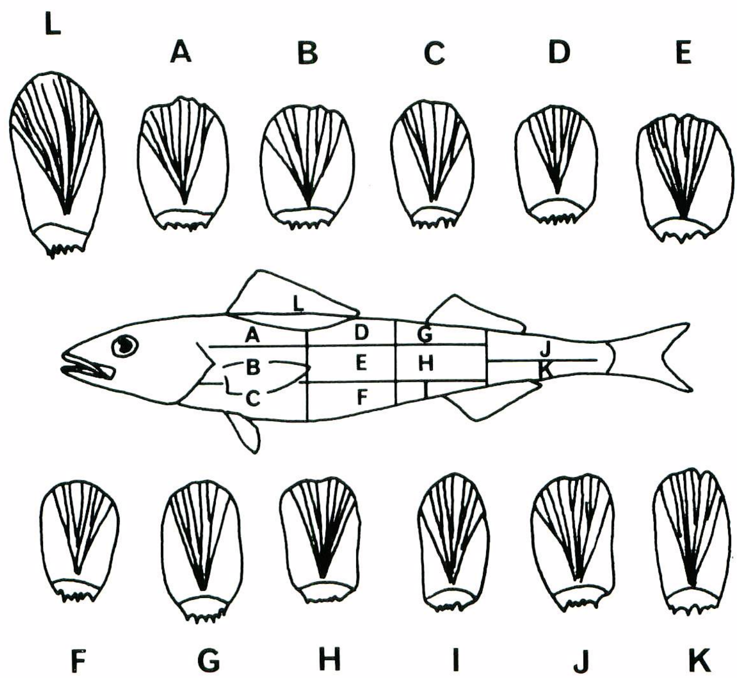

Fig. 13. Comparison of the size and shape of sablefish scales collected from various areas of the body. The scale taken from area *L* is the best for age determination.

of the first dorsal fin) were the largest and easiest to read. The scales are ctenoid, with the exposed part completely covered by numerous small spines. On the covered portion, a number of concentric circuli are formed with a central plate in the center. These circuli are bisected by ten to nineteen grooves radiating from the front edge of the central plate. Alternating wide and narrow spaces between circuli form the concentric annuli. Four annuli were found on the scale from the male and three on the scale from the female. This number of annuli were found regardless of the portion of the body from which the scale was taken, however the annuli were most clearly apparent on scales taken from area *L*.

In order to determine the similarity in annuli from a single fish, the relationship between the radius of the scale (R) and of the annulus (r_i) was examined for scales from each portion of the body (Fig. 14). The results show a direct relationship between the radius of the scales and

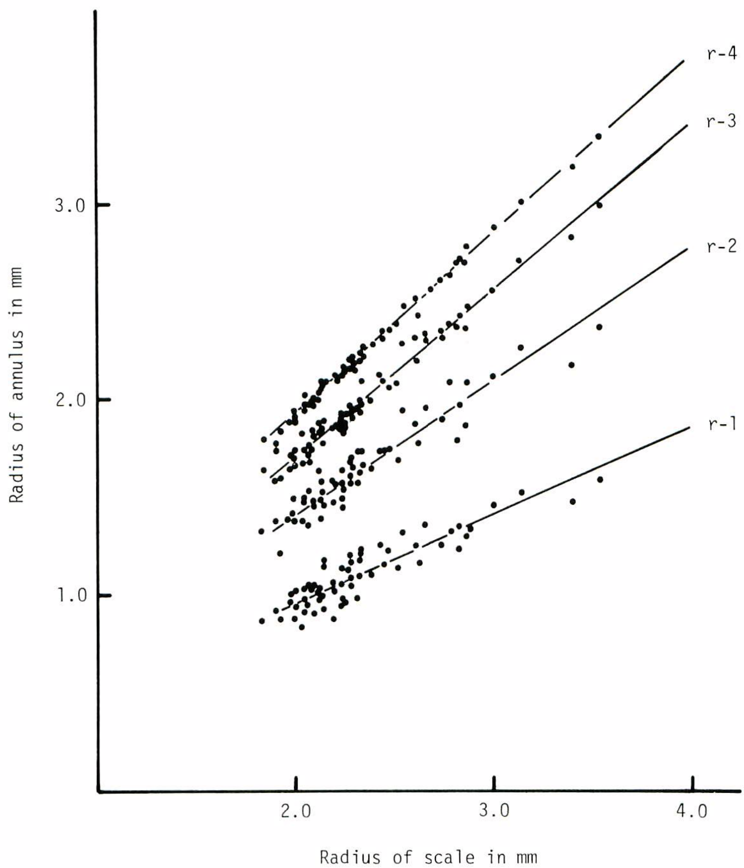

Fig. 14. Similarity in relationships between radius of annuli and radius of scales in scales from various areas of the body. The scales were from a 54.1 cm male captured in the Bering Sea in June 1968.

that of the annulus, indicating that the formation of the scale and annulus are similar in all portions of the body of a single fish.

A zone covered with dense circuli is regarded as a resting zone formed during periods of slow growth. Although the difficulty of distinguishing resting zones varies, they are formed on scales from all portions of the body. As PRUTER (1954) has pointed out, scales from the base of the first dorsal fin are largest and the annuli distinctive and they are best suited for age determination.

3. Age determination and growth based on radius of scales

The relationship between fork length (FL) and the radius of scales (R) is the same for

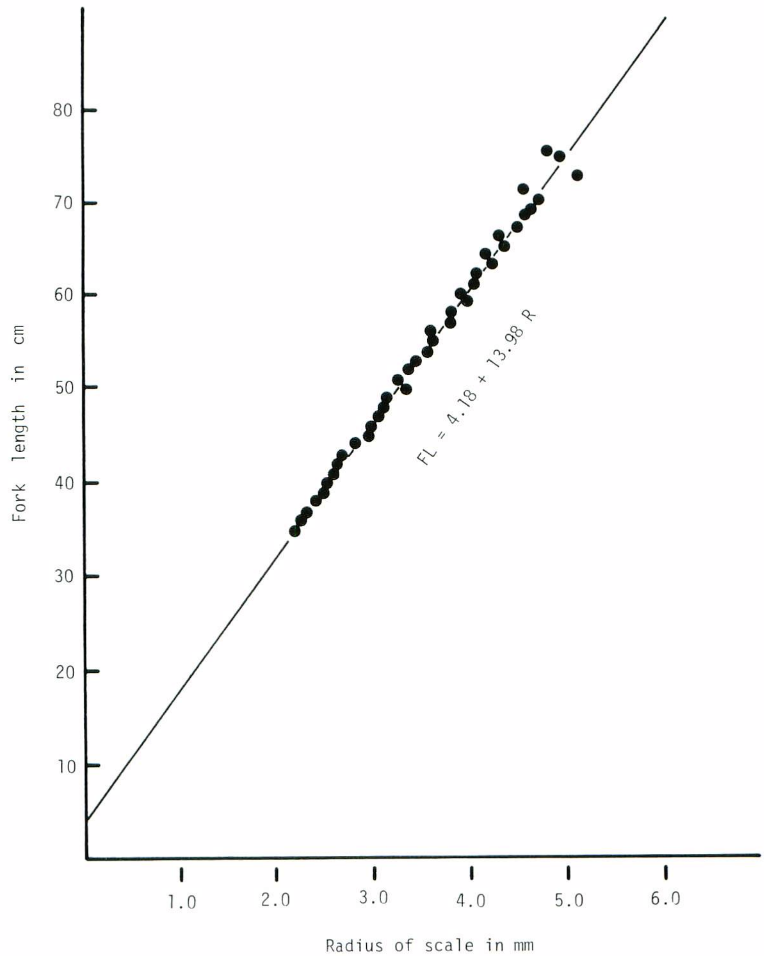

Fig. 15. Relationship between radius of scale and fork length of 886 sablefish collected from the Bering Sea from 1965 to 1969.

male and female sablefish and is described by the following equation (Fig. 15):

$$FL = 4.18 + 13.98\,R$$

where, FL is in cm, and R is in mm.

To back calculate length at age from the radius of the annuli, the outer edge of the resting zone was regarded as the radius of the annuli and average values were determined for each annulus from the sample of fish collected in the Bering Sea in 1966 (Table 8, Fig. 16). Since neither males or females showed the LEE-phenomenon which the length at age back calculated

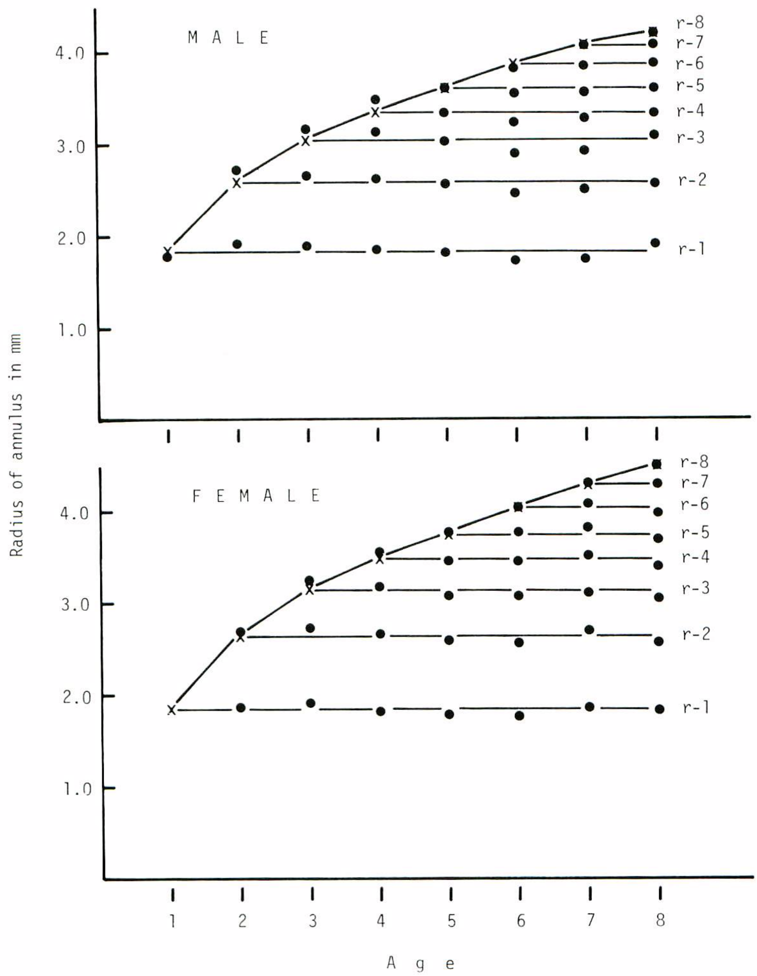

Fig. 16. Average radius of annuli by age from scales of sablefish collected from the Bering Sea in 1966. The x symbol represents the mean values of the radius for each annulus.

Table 8. Average radius of annuli by age from scales of sablefish collected from the Bering Sea in 1966.

A) Male

Age	Average radius of annuli in mm							
	r-1	r-2	r-3	r-4	r-5	r-6	r-7	r-8
1	1.778	—	—	—	—	—	—	—
2	1.914	2.709	—	—	—	—	—	—
3	1.882	2.653	3.149	—	—	—	—	—
4	1.839	2.618	3.106	3.471	—	—	—	—
5	1.803	2.559	3.006	3.337	3.632	—	—	—
6	1.712	2.461	2.880	3.224	3.537	3.819	—	—
7	1.735	2.481	2.908	3.268	3.552	3.836	4.063	—
8	1.893	2.552	3.090	3.331	3.592	3.876	4.055	4.193
Mean	1.820	2.576	3.023	3.326	3.578	3.844	4.059	4.193

B) Female

Age	Average radius of annuli in mm							
	r-1	r-2	r-3	r-4	r-5	r-6	r-7	r-8
1	—	—	—	—	—	—	—	—
2	1.872	2.693	—	—	—	—	—	—
3	1.907	2.719	3.253	—	—	—	—	—
4	1.809	2.647	3.174	3.564	—	—	—	—
5	1.776	2.582	3.062	3.451	3.760	—	—	—
6	1.772	2.561	3.072	3.454	3.770	4.040	—	—
7	1.880	2.696	3.140	3.516	3.817	4.092	4.333	—
8	1.832	2.648	3.136	3.489	3.777	4.061	4.293	4.486
Mean	1.835	2.637	3.126	3.479	3.762	4.040	4.292	4.486

from the relationship between length of fish and the radius of scales become small at the older fish compared with the younger fish (LEE, 1912), mean radii for age 1 to 8 were determined by sex for each average radius of annulus (Fig. 16). These mean radii for ages 1 to 8 were substituted into the above equation to calculate mean length at age (Table 9).

The Walford graph, using the calculated lengths at age, showed an inflection in the growth pattern of sablefish at 44.6 cm for males and 48.0 cm for females (Fig. 17). Based on the point of intersection between the Walford line and the 45° line, maximum lengths were estimated to be 75.1 cm for males and 90.2 cm for females.

From the Walford graph test, it is known that age and length relationship of sablefish fits into following Bertalanffy growth equation:

$$L_t = L_\infty \left\{ 1 - e^{-k(t-t_0)} \right\}$$

where, L_∞ is the maximum length, k is the growth coefficient, and t_0 is a corrective constant of age.

Table 9. Age-length relationship of sablefish taken from the Bering Sea in 1966 based on back-calculated fork lengths from radius of annuli (R-FL), and from calculations using the von Bertalanffy equation.

Age	Fork length in cm					
	Back-calculated from R-FL relationship		Calculated from the von Bertalanffy equation		Annual increase	
	Male	Female	Male	Female	Male	Female
1	29.6	29.8	29.5	29.7	29.5	29.7
2	40.2	41.0	40.1	40.9	10.6	11.2
3	46.4	47.9	46.6	48.1	6.5	7.2
4	50.7	52.8	50.8	52.8	4.2	4.7
5	54.2	56.8	54.6	57.0	3.8	4.2
6	57.9	60.7	57.8	60.7	3.2	3.7
7	60.9	64.2	60.6	64.0	2.8	3.3
8	62.8	66.9	62.9	66.9	2.3	2.9
9	—	—	64.8	69.5	1.9	2.6
10	—	—	66.4	71.8	1.6	2.3
11	—	—	67.8	73.9	1.4	2.1
12	—	—	68.9	75.7	1.1	1.8
13	—	—	69.9	77.3	1.0	1.6
14	—	—	70.7	78.7	0.8	1.4
15	—	—	71.4	80.0	0.7	1.3
16	—	—	72.0	81.2	0.6	1.2
17	—	—	72.5	82.2	0.5	1.0
18	—	—	72.9	83.1	0.4	0.9
19	—	—	73.2	83.9	0.3	0.8
20	—	—	73.5	84.6	0.3	0.7
25	—	—	74.4	87.1		
30	—	—	74.8	88.5		
35	—	—	75.0	89.2		
40	—	—	—	89.7		
45	—	—	—	89.9		
50	—	—	—	90.0		

Then, following four equations are obtained from relationship between age (t) and age ($t+1$) for each one of younger and older ages divided at the point of growth inflection:

Male : $L_t = 57.3 \left\{ 1 - e^{0.48(t+0.52)} \right\}$ $t \leqq 2.6$

$L_t = 75.1 \left\{ 1 - e^{0.17(t+2.57)} \right\}$ $t > 2.6$

Female : $L_t = 61.4 \left\{ 1 - e^{0.43(t+0.53)} \right\}$ $t \leqq 3.0$

$L_t = 90.2 \left\{ 1 - e^{0.12(t+3.46)} \right\}$ $t > 3.0$

where, L is fork length in cm, and t is age in years.

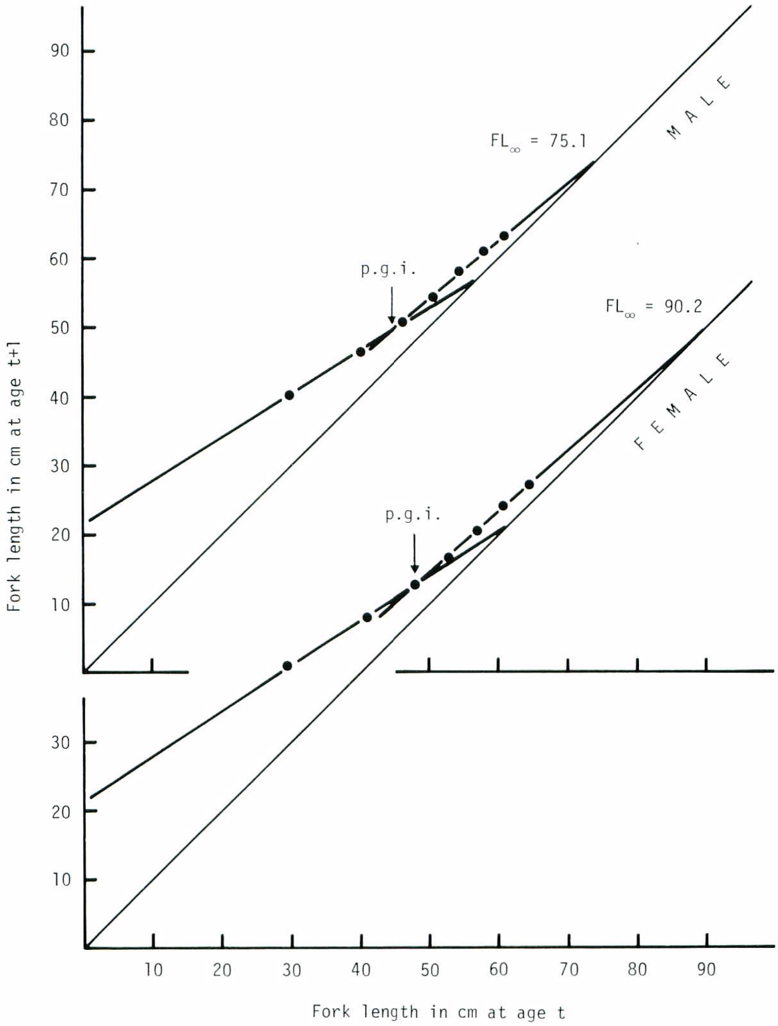

Fig. 17. Walford graph test for sablefish collected from the Bering Sea in 1966. The Walford line is divided into two parts by the point of growth inflection (p. g.i).

It is found that the age at the point of growth inflection corresponds to age 2.6 for males and age 3.0 for females to substitute 44.6 cm and 48.0 cm of the length at the point of growth inflection for *L*. Therefore, age-length relationships for the two periods of growth for sablefish of the Bering Sea are described by the above equations.

For both male and female sablefish, the coefficient of growth (*k*) differed substantially for the two growth phases with a much slower growth rate after the point of growth inflection. Calculated fork lengths at age and annual growth increments as estimated from the above procedures are shown in Table 9 and Fig. 18. There was no difference in growth between the sexes at age 1, but for age 2 and older fish, females were larger and the differences in lengths between the sexes increased with age. Annual growth also decreases exponentially with age.

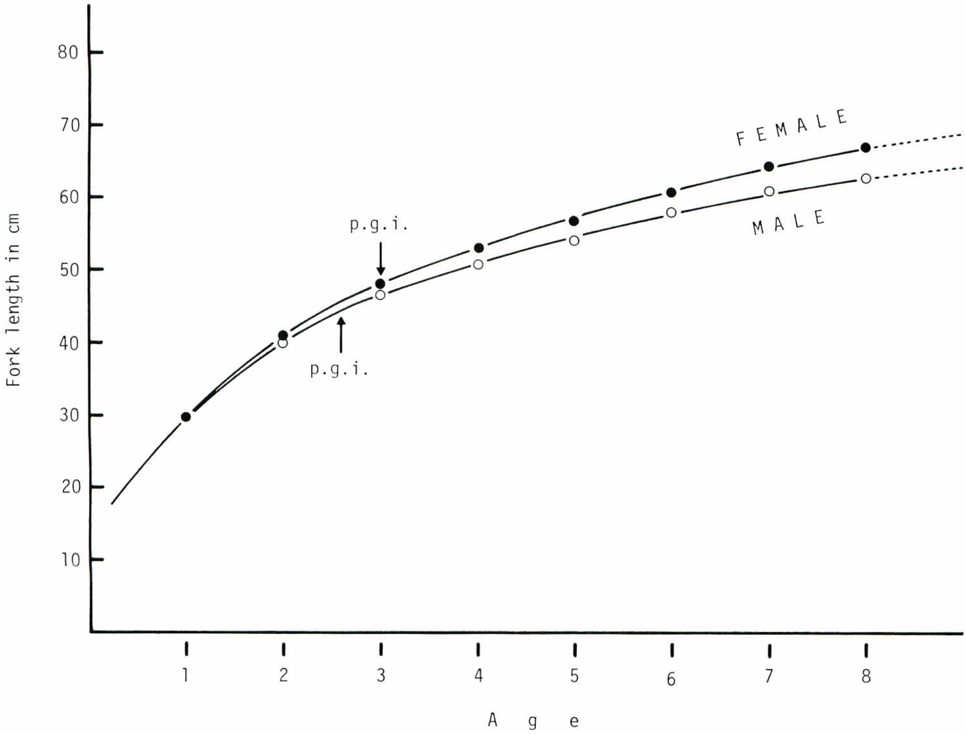

Fig. 18. Age-length relationship of sablefish collected from the Bering Sea in 1966. The relationship is divided into two parts by the point of growth inflection (p.g.i.) derived from the Walford graph test as shown in Fig. 17. White and black dots are the fork lengths estimated from R-FL relationship as shown in Fig. 15.

4. Estimated growth from tagging experiments and size composition

4-1. Tagging experiments

Data suitable for growth studies from tagged fish were available from 344 of the 1,011 recoveries. Of these, 138 or 40% were measured as smaller in length at the time of recovery than that of release. However, measurement errors may have occurred for both those fish showing an increase in size and those showing a decrease, so the analysis included all of the data. Growth by years at liberty from the tag recovery data are shown by sex and length at release in Table 10. Although growth varied widely, negative growth was often observed in males larger than 60 cm and in females larger than 70 cm. Annual growth was generally lower from these data than that estimated from the Bertalanffy growth equation (Table 9).

Table 10. Average growth by size class of sablefish recovered from tagging experiments during joint Japan-U.S. longline surveys and by Canada and Alaska Department of Fish and Game since 1977.

A) Male

Fork length at release (cm)	Growth after one year at liberty			Growth after two years at liberty			Growth after three years at liberty			Growth after four years at liberty		
	Number of fish	Range in growth (cm)	Average growth (cm)	Number of fish	Range in growth (cm)	Average growth (cm)	Number of fish	Range in growth (cm)	Average growth (cm)	Number of fish	Range in growth (cm)	Average growth (cm)
41	—	—	—	—	—	—	—	—	—	—	—	—
42	—	—	—	1	—	10.7	—	—	—	—	—	—
43	—	—	—	—	—	—	—	—	—	—	—	—
44	—	—	—	3	(+)5.5−(+)6.9	6.2	—	—	—	—	—	—
45	1		0.6	1		6.8	—	—	—	—	—	—
46	2	(+)2.3−(+)7.0	4.7	1		9.0	—	—	—	—	—	—
47	1		0.6	4	(+)4.5−(+)11.0	8.4	—	—	—	—	—	—
48	1		2.2	—	—	—	—	—	—	—	—	—
49	1		3.2	—	—	—	—	—	—	—	—	—
50	—	—	—	—	—	—	—	—	—	—	—	—
51	—	—	—	—	—	—	—	—	—	—	—	—
52	4	(+)0.2−(+)2.8	1.9	—	—	—	—	—	—	—	—	—
53	—	—	—	1		4.6	—	—	—	—	—	—
54	4	(+)1.4−(+)2.6	2.2	1		2.0	—	—	—	—	—	—
55	3	(+)0.4−(+)1.6	1.0	—	—	—	—	—	—	—	—	—
56	1		0.6	—	—	—	—	—	—	—	—	—
57	1		0.6	1		1.4	1		3.0	—	—	—
58	1		2.9	1		0.7	—	—	—	—	—	—
59	4	(−)0.6−(+)1.6	0.3	—	—	—	—	—	—	—	—	—
60	10	(−)0.8−(+)3.0	0.8	1		1.1	1		0.3	—	—	—
61	3	(−)1.7−(+)0.5	−0.6	3	(±)0.0−(+)1.0	0.5	1		−0.8	—	—	—
62	4	(−)0.3−(+)2.7	0.9	1		1.0	1		−0.6	2	(−)0.5−(+)4.5	2.0
63	4	(−)3.0−(±)0.0	−1.3	4	(−)1.7−(+)1.0	−0.6	1		−1.6	—	—	—
64	2	(+)1.0−(+)3.0	2.0	—	—	—	—	—	—	—	—	—
65	7	(−)1.9−(+)1.0	−0.7	4	(−)3.0−(−)0.3	−2.0	—	—	—	—	—	—
66	3	(−)1.1−(±)0.0	−0.5	5	(−)2.7−(−)0.2	−1.4	4	(−)3.5−(+)3.0	+0.5	—	—	—
67	1		−0.3	—	—	—	2	(−)3.0−(−)0.8	−1.9	—	—	—
68	—	—	—	—	—	—	—	—	—	—	—	—
69	1		0.5	—	—	—	—	—	—	—	—	—
70	4	(−)2.0−(−)1.0	−0.6	1		−1.2	—	—	—	—	—	—
71	1		−1.0	—	—	—	—	—	—	—	—	—
72	—	—	—	2	(−)1.8−(+)0.5	−0.7	—	—	—	—	—	—
73	1		±0.0	—	—	—	—	—	—	—	—	—
74	—	—	—	—	—	—	—	—	—	—	—	—
75	—	—	—	—	—	—	—	—	—	—	—	—

Table 10. Continued.

B) Female

Fork length at release (cm)	Growth after one year at liberty			Growth after two years at liberty			Growth after three years at liberty			Growth after four years at liberty		
	Number of fish	Range in growth (cm)	Average growth (cm)	Number of fish	Range in growth (cm)	Average growth (cm)	Number of fish	Range in growth (cm)	Average growth (cm)	Number of fish	Range in growth (cm)	Average growth (cm)
41	—	—	—	—	—	—	—	—	—	—	—	—
42	—	—	—	—	—	—	—	—	—	—	—	—
43	—	—	—	1		10.0	—	—	—	—	—	—
44	1		3.8	1		11.1	—	—	—	—	—	—
45	—	—	—	—	—	—	—	—	—	—	—	—
46	—	—	—	1		8.3	—	—	—	—	—	—
47	1		1.9	—	—	—	—	—	—	—	—	—
48	2	(+)1.0−(+)4.2	2.6	1		6.0	—	—	—	—	—	—
49	—	—	—	—	—	—	—	—	—	—	—	—
50	4	(+)3.0−(+)3.9	3.6	3	(+)3.0−(+)13.0	8.0	—	—	—	—	—	—
51	3	(+)3.0−(+)4.0	3.5	3	(+)6.1−(+)8.8	7.5	—	—	—	—	—	—
52	2	(+)1.0−(+)2.0	1.5	—	—	—	—	—	—	—	—	—
53	4	(+)2.0−(+)3.6	2.8	2	(+)1.5−(+)8.1	4.8	—	—	—	—	—	—
54	3	(+)0.5−(+)6.0	3.3	1		1.0	—	—	—	—	—	—
55	7	(−)2.7−(+)7.0	2.9	1		7.0	—	—	—	—	—	—
56	—	—	—	—	—	—	—	—	—	—	—	—
57	1		−0.5	2	(+)0.2−(+)6.0	3.1	—	—	—	—	—	—
58	—	—	—	1		9.0	1		5.5	—	—	—
59	2	(±)0.0−(+)4.5	2.3	—	—	—	—	—	—	—	—	—
60	5	(−)2.0−(+)3.0	0.9	—	—	—	—	—	—	—	—	—
61	8	(+)0.5−(+)4.9	2.9	3	(−)0.5−(+)5.0	2.3	—	—	—	—	—	—
62	8	(−)0.4−(+)4.0	1.1	3	(−)0.7−(+)7.2	3.3	—	—	—	1		4.5
63	6	(+)1.7−(+)3.3	2.8	—	—	—	1		−1.2	—	—	—
64	6	(−)0.3−(+)2.0	0.6	1		−1.0	1		0.5	—	—	—
65	4	(−)1.0−(±)0.0	−0.4	8	(−)0.5−(+)1.5	0.3	—	—	—	—	—	—
66	2	(±)0.0−(+)0.2	0.1	4	(+)2.9−(+)5.1	3.7	1	—	−3.0	—	—	—
67	2	(−)2.0−(−)1.0	−1.5	2	(−)0.3−(+)0.7	0.2	3	(−)1.2−(+)4.0	1.4	3	(+)4.0−(+)10.9	7.5
68	5	(−)2.0−(+)1.5	0.4	7	(−)1.0−(+)4.0	1.7	3	(+)4.0−(+)5.0	4.5	2	(−)2.0−(+)6.4	2.2
69	9	(−)2.0−(+)0.5	−1.2	4	(+)2.8−(+)3.0	2.9	—	—	—	—	—	—
70	6	(−)2.1−(+)0.4	−0.9	8	(−)2.4−(+)4.5	1.3	3	(−)2.4−(±)0.0	−1.2	—	—	—
71	4	(−)1.0−(+)1.3	±0.0	7	(−)2.0−(+)2.0	0.1	4	(−)1.4−(+)5.0	2.5	—	—	—
72	2	(−)2.5−(−)0.8	−1.7	2	(−)0.5−(−)0.2	−0.4	3	(+)0.1−(+)1.5	0.8	—	—	—
73	1		±0.0	5	(−)2.0−(+)1.3	−0.4	1		−0.1	—	—	—
74	2	(−)2.0−(−)1.0	−1.5	4	(−)4.0−(−)1.0	−2.3	4	(−)1.7−(+)3.0	1.0	—	—	—
75	2	(−)3.2−(−)2.8	−3.0	1		1.6	—	—	—	—	—	—
76	1		±0.0	—	—	—	—	—	—	—	—	—
77	—	—	—	2	(−)2.4−(+)0.2	−1.1	1		−1.3	—	—	—
78	—	—	—	—	—	—	2	(−)2.7−(−)0.5	−1.6	—	—	—
79	1		±0.0	2	(−)2.0−(+)5.4	1.7	—	—	—	—	—	—
80	—	—	—	1		−3.2	—	—	—	—	—	—
81	2	(−)2.0−(±)0.0	−1.0	—	—	—	—	—	—	—	—	—
82	—	—	—	1		±0.0	1		−2.3	—	—	—
83	1		−1.5	1		1.6	—	—	—	—	—	—
84	—	—	—	—	—	—	—	—	—	—	—	—
85	—	—	—	—	—	—	—	—	—	—	—	—
86	—	—	—	—	—	—	1		0.2	—	—	—
87	—	—	—	—	—	—	1		−1.8	—	—	—

4-2. Size composition

Size composition data taken from sablefish samples by research vessels in 1978 and later years clearly show the recruitment of a strong year class over a wide geographical area. This is considered to be the 1977 year class. The prominent modes formed by this year class provide another method of estimating annual growth. The best size composition data for estimating growth from samples fo the 1977 year class in the Gulf of Alaska was from the 101 to 200 m depth zone. In the Aleutian Region, sablefish have not occupied the 101 to 200 m depth zone since 1981 so data from the 201 to 400 m depth zone were used. In the eastern Bering Sea, the 1977 year class was abundant in a wide range of depths and size composition data was used from all depth zones. Table 11 and Figure 19 show the mean length and the annual growth of the 1977 year class estimated from the modes in the size compositions.

Differences in mean lengths between regions varied depending on the year. In 1982, sablefish in the eastern Bering Sea grew somewhat faster than those in the Aleutian Region and Gulf of Alaska. Based on a comparison of mean lengths by age of sablefish in the eastern Bering Sea with the mean lengths determined through growth equations (Table 9), it was found that mean lengths at age 1 were similar, but at older ages mean lengths at a given age approximate the mean length of fish one year older. Annual growth between ages 1 and 2 was considerably higher from the size composition data than that determined through growth equations. For age 4 and older fish there was not much difference in estimates of annual growth between the two methods.

Table 11. Average growth (cm) of sablefish of the 1977 year class as shown by increments in mean annual fork lengths estimated from data taken during groundfish surveys in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska since 1978.

Year	Eastern Bering Sea				Aleutian Region				Gulf of Alaska			
	Mean length		Avg. growth		Mean length		Avg. growth		Mean length		Avg. growth	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
1978	29.9[a]	29.9[a]			—	—			—	—		
			15.8	16.3			—	—			—	—
1979	45.7	46.2			—	—			—	—		
			—	—			—	—			—	—
1980	—	—			50.4	51.4			50.4	52.5		
			—	—			3.0	2.6			3.8	4.2
1981	54.5	57.0			53.4	54.0			54.2	56.7		
			3.3	4.0			2.4	4.9			1.5	2.3
1982	57.8	61.0			55.8	58.9			55.7	59.0		

a Unsexed.

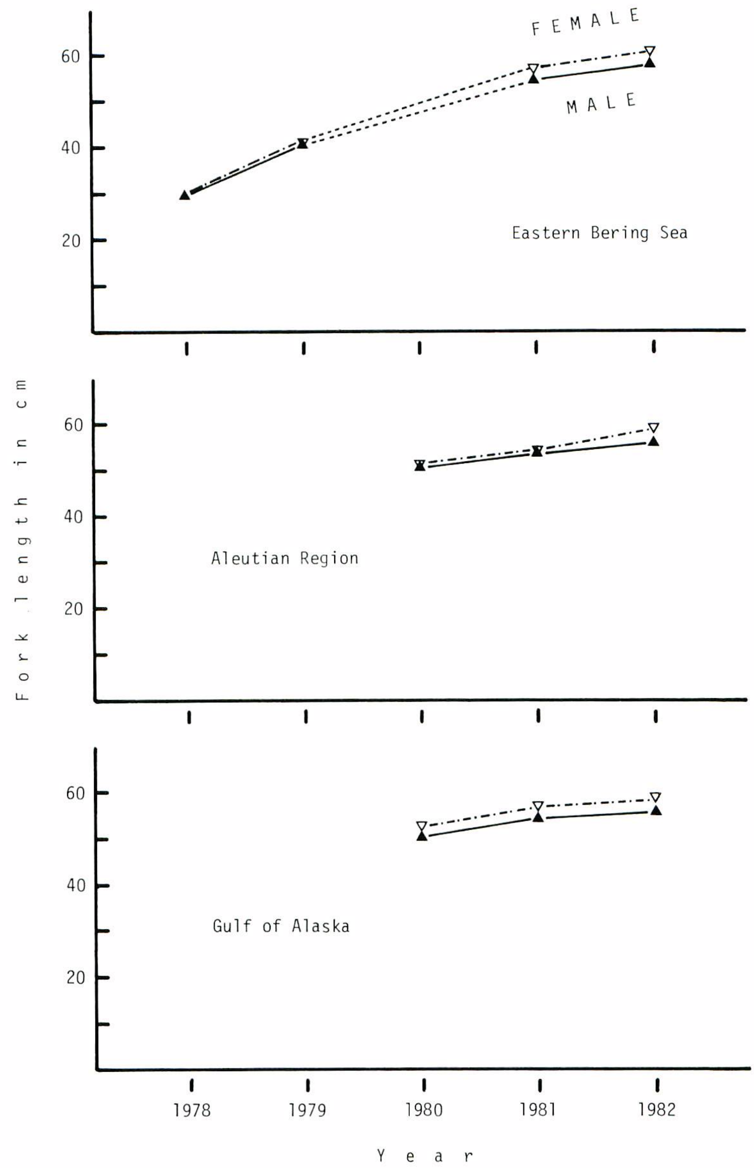

Fig. 19. Mean fork length of 1977 year class of sablefish estimated from the size composition collected during groundfish surveys since 1978.

5. Length-weight and age-weight relationships

Sablefish taken from the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the late 1970's were used to develop length-weight relationships by region and sex. Resulting equations were as follows:

Eastern Bering Sea :		Size range	Number of specimens
Male	: $BW = 5.32 \times 10^{-6} \times FL^{3.17}$	30−74 cm	558
Female	: $BW = 2.94 \times 10^{-6} \times FL^{3.32}$	30−80 cm	589
Sexes combined	: $BW = 3.21 \times 10^{-6} \times FL^{3.30}$	30−80 cm	1,147

Aleutian Region :		Size range	Number of specimens
Male	: $BW = 2.29 \times 10^{-6} \times FL^{3.35}$	44−77 cm	441
Female	: $BW = 1.99 \times 10^{-6} \times FL^{3.40}$	41−88 cm	418
Sexes combined	: $BW = 2.14 \times 10^{-6} \times FL^{3.38}$	41−88 cm	859

Gulf of Alaska :		Size range	Number of specimens
Male	: $BW = 2.28 \times 10^{-6} \times FL^{3.36}$	41−77 cm	514
Female	: $BW = 3.15 \times 10^{-6} \times FL^{3.29}$	41−87 cm	679
Sexes combined	: $BW = 2.99 \times 10^{-6} \times FL^{3.30}$	41−87 cm	1,193

where, BW is weight in kg, and FL is fork length in cm.

The equations show that sablefish in the eastern Bering Sea are heavier at a given size than those in the Aleutian Region and Gulf of Alaska, but there was no significant difference statistically. Female sablefish were somewhat heavier than males in the eastern Bering Sea and Aleutian Region, but there was little difference between sexes in the Gulf of Alaska where the majority of sablefish biomass is located (Fig. 20). Length-weight relationships for both regions and sexes combined were therefore used for subsequent analyses in this study.

The length-weight relationship for sablefish combined from the three regions and by sex is described by the following equation:

$$BW = 4.74 \times 10^{-6} \times FL^{3.19}$$

The length-weight relationship of sablefish in the Bering Sea during the 1960's was as follows:

$$BW = 2.11 \times 10^{-6} \times FL^{3.39}$$

The above equation shows that sablefish of given size in the eastern Bering Sea weighed less in the 1960's than those in the late 1970's. However, all these differences are minor and considered of no significance. The von Bertalanffy growth equation in terms of weight for fish of the eastern Bering Sea taken in the 1960's is as follows:

$$\begin{array}{llll} \text{Male} & : & W_t = 1.92 \left\{ 1 - e^{-0.48(t+0.52)} \right\}^{3.39} & t \leqq 2.6 \\ & : & W_t = 4.82 \left\{ 1 - e^{-0.17(t+2.57)} \right\}^{3.39} & t > 2.6 \\ \text{Female} & : & W_t = 2.43 \left\{ 1 - e^{-0.43(t+0.53)} \right\}^{3.39} & t \leqq 3.0 \\ & : & W_t = 8.96 \left\{ 1 - e^{-0.12(t+3.46)} \right\}^{3.39} & t > 3.0 \end{array}$$

where, W is weight in kg, and t is age in years.

These relationships are graphed in Fig. 21.

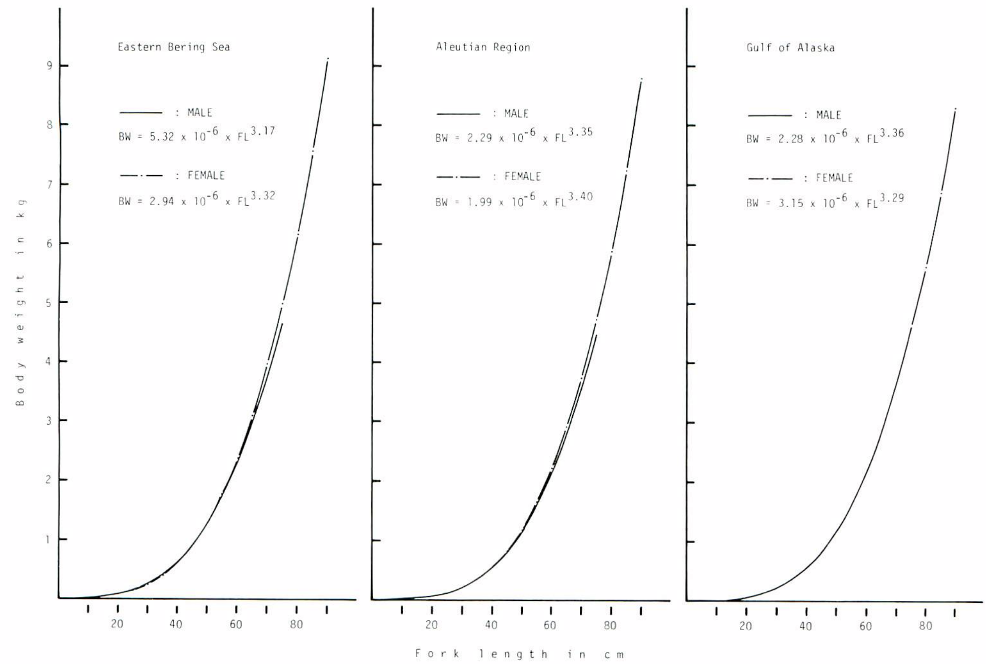

Fig. 20. Length-weight relationship of sablefish collected in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska from 1978 to 1981.

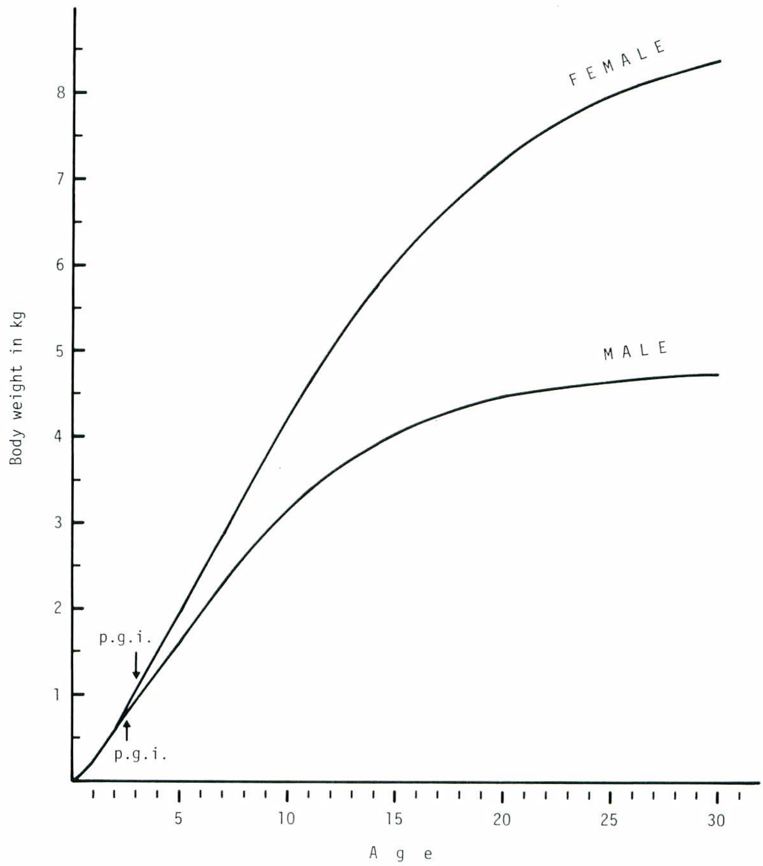

Fig. 21. Relationship between age and body weight of male and female sablefish collected in the Bering Sea from 1965 to 1969. The relationship is divided into two parts by the point of growth inflection (p.g.i) corresponding to the age-length relationship shown in Fig. 18.

6. Discussion

Sablefish of the eastern Bering Sea were found to have a change in growth pattern at approximately age 2.6 for males and 3.0 for females. KODOLOV (1967) has also observed this characteristic in the Bering Sea sablefish. CHIKUNI (1975) has shown that Pacific ocean perch changes its growth pattern, and believes this change occurs during the transition from a pelagic to benthic life. This is also the case for sablefish with the juveniles living in offshore surface or shallow coastal waters and then changing habitats to offshore bottom layers deeper than 100 m. The change in growth pattern is considered to occur with this change in habitat.

Annual growth rates derived from results of age determination using scale was generally larger than that estimated from tag recovery data. While tagging fish, it is usually difficult to measure their length precisely. The lengths taken at recovery are measured after the fish have died or from frozen and thawed fish. Both of these methods produce different lengths than those measured from live fish. It is difficult to detect the small amounts of growth in older sablefish unless lengths are measured accurately. A future task is to accumulate the basic data necessary to convert measurements of frozen and thawed fish to those of live fish and at the same time to clarify the influence of tagging on sablefish growth, so that the accuracy of growth increments from release-recovery data can be improved.

Regional differences in mean sizes of young sablefish considered to be from the 1977 year class were detected. In addition, compared with calculated lengths at age determined from the von Bertalanffy growth equation for the eastern Bering Sea sablefish, mean sizes estimated from modes in size compositions were larger. Regional differences in mean sizes may result from a variety of complex elements. One is that there are considerable differences in sizes even among fish of the same year class due to comparatively long spawning seasons and regional differences in time of spawning. Another factor is that recruitment to the adult stocks is considered to take several years. The third factor is that the abundance of food organisms differs by region and depth zone.

The season of annulus formation in sablefish was not identified in this study. However, since fish scales taken during summer months often show a growth zone at the extreme outer edge of the annulus, the annulus is considered to be formed in winter. MAEDA and HANKIN (1983) suggested that the annulus on scales sampled at Eureka in California is formed during fall and winter months. These lead to the conclusion that the mean size of young sablefish taken during summer is actually greater than the size calculated from the growth equation during the season of annulus formation. However, it is difficult to determine the precise difference between the actual and calculated mean lengths (Tables 9 and 11) at present, because age determination of the sampled fish have not been completed.

Results of age and growth studies have been reported for the Bering Sea sablefish by KODOLOV (1967) and SHUVNIKOV (1963), from the Gulf of Alaska and Canadian waters by KENNEDY and PLETCHER (1968), and from the Washington-California Region by HEYAMOTO (1962), PRUTER (1954) and SHIPPEN (1974). More recent studies have been made by BEAMISH and CHILTON (1982) for sablefish from Canadian waters, from the southeastern Alaska by FUNK and BRACKEN (1983), and from the California waters by MAEDA and HANKIN (1983). Comparison of these studies (Fig. 22) shows that the results of KENNEDY and PLETCHER (1968), KODOLOV (1967), MAEDA and HANKIN (1983), and PRUTER (1954) are consistent despite the difference in regions of study. On the other hand, results of study by FUNK and BRACKEN (1983) were different to the other reports and the growth was much slow till age 20 for both sexes. Results of study by SHUVNIKOV (1963) for individual sexes and sexes combined were consistent with those of SHIPPEN (1974) so far as the growth of females age 6 and older is concerned. In SHUVNIKOV's report, however, sablefish younger than age 6 grew far less than shown by other studies. KODOLOV (1967) considered this a bias attributable to the limited number of samples used by SHUVNIKOV (1963).

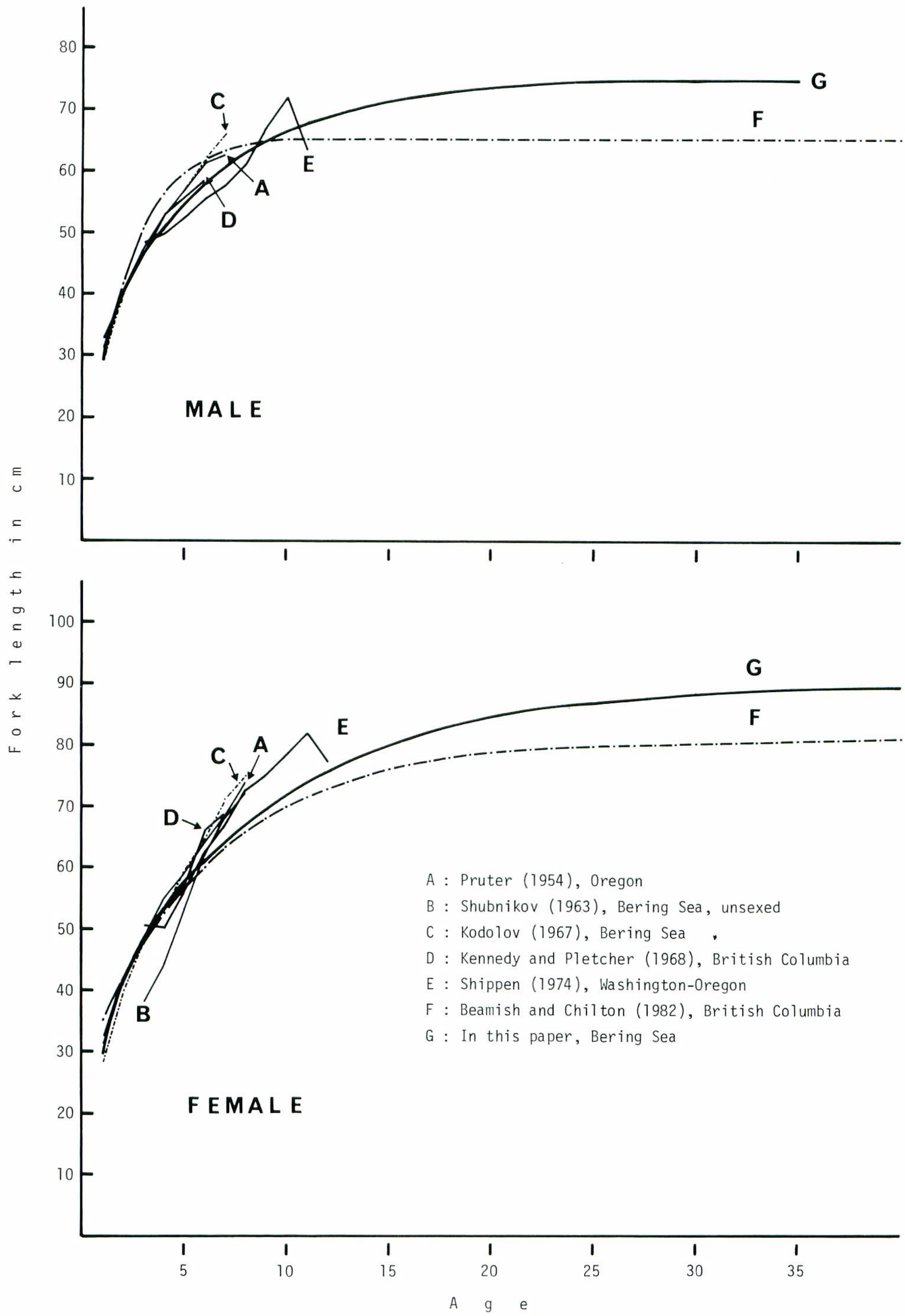

Fig. 22. Comparison of age-length relationships of sablefish from different regions of the Bering Sea and northeastern Pacific Ocean.

Most of the above reports including the results from present study were based on observations of annuli on scales or surfaces of otoliths. BEAMISH and CHILTON (1982), on the other hand, based their observations on sectioned otoliths. Results from present study are not consistent with those from BEAMISH and CHILTON (1982) for male sablefish. Results for females age 7 or younger were relatively consistent in the latter study, but present study shows a higher growth for age 8 and older fish indicating a wider discrepancy between the two methods at older ages (Fig. 22). Age determination from surface observations of scales and otoliths of sablefish age 7 or older are only marginally feasible. Age determination for fish of ages 6 to 8 are only possible for fish with comparatively large scales and distinct annuli. Scales with these characteristics are considered to be from faster growing fish of a year class. As a result, it is highly likely that growth studies based on age readings from scales or surfaces of otoliths overestimate the growth of older fish.

BEAMISH and CHILTON (1982), FUNK and BRACKEN (1983), KENNEDY and PLETCHER (1968), KODOLOV (1967), MAEDA and HANKIN (1983), PRUTER (1954), and SHIPPEN (1974) have demonstrated differences in growth between male and female sablefish and faster growth in females. This study showed similar results. Differences in size cannot be identified at age 1, but the difference increases with age. According to BEAMISH and CHILTON (1982) and FUNK and BRACKEN (1983) growth rates decrease after sablefish reach maturity. They also report that sablefish live to more than 30 or 40 years. Ages of approximately 35 years for males and 50 years for females were estimated from age-growth relationships in present study, and they are much older than age 20 which has long been thought to be the maximum age of sablefish.

Since growth of older sablefish is less than had been anticipated, conventional techniques of age determination are not feasible for sablefish older than age 7 or 8 and the break-burn technique advocated by BEAMISH and CHILTON (1982) may be a worthwhile technique for age determination, although the adequacy of this technique still needs verification.

Length-weight relationships of sablefish do not show any distinguishing differences between regions and years or by sex. Data in this study had some deficiencies such as differences in length ranges, and a future task is to conduct a more detailed analysis. Nevertheless, the relationships are considered accurate enough to use as basic data for the study of population dynamics and management. The overall length-weight relationship derived from this study is therefore used in the population study in the later chapter.

IV. Other biological information

This chapter will present results of studies on size at maturity, feeding habits, sex ratios, and recruitment of sablefish to the exploitable stock.

1. Materials and methods

Samples discussed in this chapter are all from research vessel catches in the eastern

Bering Sea, Aleutian Region, and Gulf of Alaska since 1978. Most samples were taken from May to September and at depths of 101-1,000 m by trawl and longline gear. Biological data was taken aboard the research vessel immediately after landing or from frozen samples in the laboratory.

The relationship between sexual maturity and fork length was studied from a sample of 4,784 sablefish. Maturity is usually not easy to judge in fishes from an external examination of the gonads. This is particularly true for samples taken during periods other than the spawning season, which is generally considered to be in winter for sablefish. The samples were classified as follows: (I) immature, (II) transition from immature to mature stage, and (III) mature. Males were classified as immature (I) when the gonad was thread-like and the females when the ovary formed a slender bag without any swelling or ovum. Gonads in the transition period from immature to mature (II) are fairly large in both the males and females, and minute ova are visible with the unaided eye in the ovaries. Fish of this stage were considered to be in the reproductive process for the first time during the next spawning season. Since the mature (III) stage includes sablefish that have spawned one or more times previously and are expected to reproduce in future spawning seasons, fish with spent gonads and those recovering from spawning were also classified as mature (III).

Stomach contents were analyzed from a total of 6,296 specimens. There were differences in the proportion of empty stomachs depending on the fishing gear used to capture the fish, and it was therefore necessary to analyze the samples by type of fishing gear. The samples were also analyzed by region and length class. The proportion of empty stomachs in sablefish is generally high and much of the food is highly digested even while the fish are feeding. For this reason, the composition of stomach contents is reported by percentage occurrence of food organisms rather than by weight.

Sex ratios are reported as percent females of the total sample. These data were collected while measuring fish aboard the research vessels. In order to compare sex ratios by region in the same year, data from the 1982 longline survey in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska were used. The number of fish examined was 11,886 in the eastern Bering Sea, 5,272 in the Aleutian Region, and 45,776 in the Gulf of Alaska, for a total sample of 62,934 fish. Data sufficient to determine whether sex ratios differed by depth were only available from the Gulf of Alaska.

Based on research vessel data obtained after 1978, a strong 1977 year class has been observed entering the population. An analysis was made to examine the recruitment process of this year class to these regional populations.

2. Size at maturity

Results of maturity investigations from 4,618 of the total sample of 4,784 sablefish, excluding 166 specimens for which maturity could not be accurately determined, are shown in Fig. 23 by region in terms of percent mature fish (maturity stage II and III). In all regions, males reached maturity at a smaller size than females. The fork length at which 50% of the population reaches maturity in the Aleutian Region is 61 cm for males and 65 cm for females, and in the

Gulf of Alaska 57 cm for males and 65 cm for females. Maturity was reached at larger size in the eastern Bering Sea than in the other two regions for both sexes, and it is estimated that 50% of the eastern Bering Sea population matures at a fork length of 65 cm for males and 67 cm for females, respectively. The investigation also indicates that the proportion of mature fish does not increase rapidly in this region, which is different from those in other regions, and that up to a fork length of 60 cm, immature fish predominate.

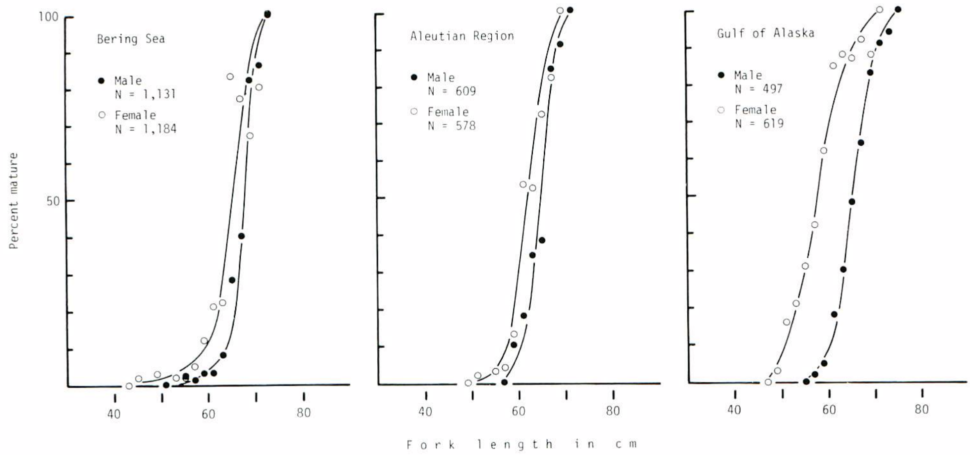

Fig. 23. Size at maturity for sablefish in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska taken during groundfish surveys in the summers of 1978, 1979, 1980, and 1981.

3. Feeding habits

The proportion of empty stomachs in sablefish was as high as 77 to 85% in fish caught by longline gear, but the proportion in fish caught by trawl gear was lower at 25 to 36% (Table 12). The proportion of empty stomachs in sablefish taken by longline gear was high regardless of body length, but in fish caught by trawl gear there was a trend toward lower proportions of empty stomachs in larger sablefish. Even in fish that had been feeding, stomach fullness was generally low in frequency.

In addition to a variety of prey organisms, some inanimate objects such as stones, sand, mud, and vinyl products were observed in the stomachs. Among the prey organisms, fish appeared most frequently, although their frequency varied by region (Fig. 24). Their frequency was relatively high (about 50%) in sablefish from the eastern Bering Sea and Gulf of Alaska, but it was low (about 30%) in fish from the Aleutian Region. Prey items other than fish were normally squids, octopuses, crabs, shrimps, amphipods, euphausiids, and ophiuroidea.

Among the prey fish identified, walleye pollock (*Theragra chalcogramma* (PALLAS)) were found most frequently (33-74%), followed by grenadiers, lanternfishes, eelpouts, flatfishes, poach-

Table 12. Percentage occurrences of food items in the stomachs of sablefish by size class sampled during groundfish surveys in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summers of 1978, 1979, 1980, and 1981.

Eastern Bering Sea (Trawl)

	Size class (FL in cm)							Total
	20—29	30—39	40—49	50—59	60—69	70—79	80—89	
Sample size	10	123	619	1,326	303	33	—	2,414
No. empty stomachs	—	38	187	311	70	6	—	612
Food items								
Fishes	8(40%)	60(51%)	309(57%)	728(55%)	160(54%)	21(58%)	—	1,286(55%)
Crustacea								
Shrimps	—	4(3%)	26(5%)	133(10%)	24(8%)	—	—	187(8%)
Crabs	2(10%)	6(5%)	35(7%)	29(2%)	18(6%)	2(6%)	—	92(4%)
Euphausiids	—	4(3%)	13(2%)	1(0%)	1(0%)	—	—	19(1%)
Amphipods	—	—	3(1%)	16(1%)	3(1%)	—	—	22(1%)
Others	2(10%)	—	11(2%)	31(2%)	8(3%)	—	—	52(2%)
Mollusca								
Squids and Octopus	—	—	66(12%)	204(15%)	49(17%)	6(17%)	—	325(14%)
Others	—	3(3%)	2(0%)	15(1%)	2(1%)	—	—	22(1%)
Annelida								
Echiuroidea	4(20%)	23(20%)	—	3(0%)	—	—	—	30(1%)
Others	2(10%)	1(1%)	6(1%)	16(1%)	1(0%)	—	—	26(1%)
Ophiuroidea	—	—	8(2%)	66(5%)	10(3%)	1(3%)	—	85(4%)
Others	2(10%)	16(14%)	63(12%)	92(7%)	21(7%)	6(17%)	—	200(9%)

Gulf of Alaska (Longline)

	Size class (FL in cm)							Total
	20—29	30—39	40—49	50—59	60—69	70—79	80—89	
Sample size	—	1	236	782	1,063	351	37	2,470
No. empty stomachs	—	1	192	681	898	320	29	2,121
Food items								
Fishes	—	—	14(29%)	44(41%)	79(52%)	17(57%)	5(71%)	159(46%)
Crustacea								
Shrimps	—	—	2(4%)	4(4%)	4(3%)	—	—	10(3%)
Crabs	—	—	—	2(2%)	2(1%)	1(3%)	—	4(1%)
Euphausiids	—	—	2(4%)	1(1%)	5(3%)	—	—	8(2%)
Amphipods	—	—	8(17%)	8(7%)	9(6%)	—	—	25(7%)
Others	—	—	2(4%)	—	2(1%)	—	—	5(1%)
Mollusca								
Squids and Octopus	—	—	4(8%)	17(16%)	14(9%)	5(17%)	1(14%)	41(12%)
Others	—	—	1(2%)	1(1%)	2(1%)	—	—	4(1%)
Annelida								
Echiuroidea	—	—	—	—	—	—	—	—
Others	—	—	—	—	—	—	—	—
Ophiuroidea	—	—	—	2(2%)	—	—	—	2(1%)
Others	—	—	15(31%)	29(27%)	36(24%)	7(23%)	1(14%)	88(25%)

Table 12. Continued.

Aleutian Region (Trawl)

	Size class (FL in cm)							Total
	20—29	30—39	40—49	50—59	60—69	70—79	80—89	
Sample size	—	—	327	404	39	14	1	785
No. empty stomachs	—	—	147	119	15	3	1	285
Food items								
Fishes	—	—	84(33%)	138(33%)	12(36%)	7(54%)	—	241(33%)
Crustacea								
Shrimps	—	—	7(3%)	21(5%)	1(3%)	—	—	29(4%)
Crabs	—	—	4(2%)	6(1%)	—	—	—	10(1%)
Euphausiids	—	—	10(4%)	16(4%)	2(6%)	1(8%)	—	29(4%)
Amphipods	—	—	50(20%)	94(23%)	3(9%)	—	—	147(20%)
Others	—	—	9(4%)	19(5%)	2(6%)	—	—	31(4%)
Mollusca								
Squids and Octopus	—	—	24(9%)	41(10%)	4(12%)	1(8%)	—	70(10%)
Others	—	—	1(0%)	2(0%)	—	—	—	3(0%)
Annelida								
Echiuroidea	—	—	—	—	—	—	—	—
Others	—	—	3(1%)	6(1%)	1(3%)	—	—	10(1%)
Ophiuroidea	—	—	3(1%)	7(2%)	—	2(15%)	—	12(2%)
Others	—	—	62(24%)	67(16%)	8(24%)	2(15%)	—	139(19%)

Aleutian Region (Longline)

	Size class (FL in cm)							Total
	20—29	30—39	40—49	50—59	60—69	70—79	80—89	
Sample size	—	—	111	243	203	56	14	627
No. empty stomachs	—	—	96	187	150	44	11	488
Food items								
Fishes	—	—	1(7%)	17(26%)	20(33%)	10(63%)	3(100%)	51(32%)
Crustacea								
Shrimps	—	—	1(7%)	8(12%)	4(7%)	—	—	13(8%)
Crabs	—	—	—	4(6%)	1(2%)	—	—	5(3%)
Euphausiids	—	—	—	—	—	—	—	—
Amphipods	—	—	1(7%)	4(6%)	4(7%)	—	—	9(6%)
Others	—	—	1(7%)	2(3%)	2(3%)	—	—	5(3%)
Mollusca								
Squids and Octopus	—	—	2(13%)	15(23%)	8(13%)	1(6%)	—	26(16%)
Others	—	—	—	—	—	—	—	—
Annelida								
Echiuroidea	—	—	—	—	—	—	—	—
Others	—	—	—	—	—	—	—	—
Ophiuroidea	—	—	—	2(3%)	4(7%)	2(13%)	—	8(5%)
Others	—	—	9(60%)	14(21%)	17(28%)	3(19%)	—	43(27%)

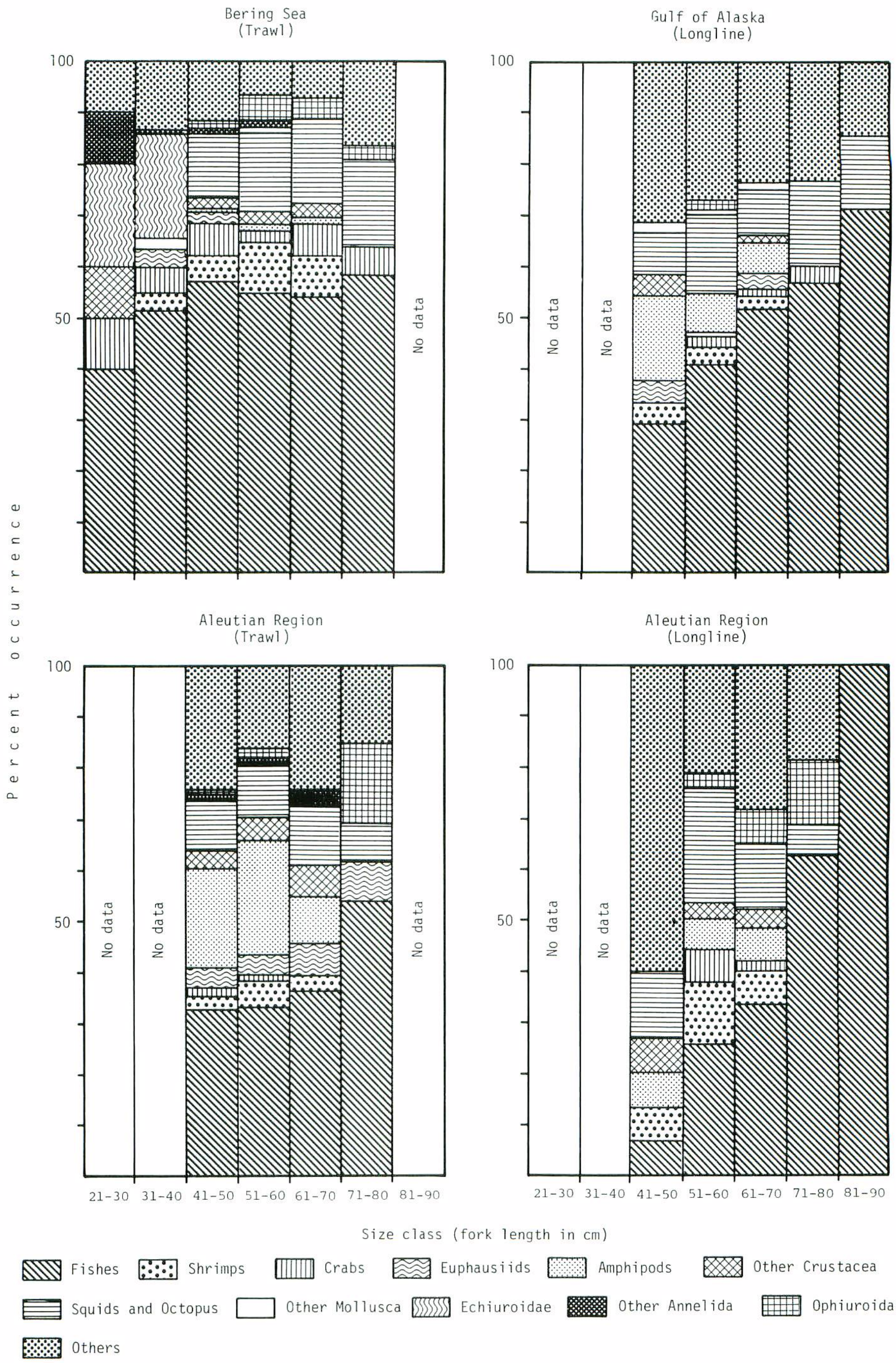

Fig. 24. Percentage occurrences of food items in the stomachs of sablefish by size class taken in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska during groundfish surveys in the summers of 1978, 1979, 1980, and 1981.

ers, Pacific herring (*Clupea harengus pallasi* VALENCIENNES), and shortspine thornyhead (*Sebastolobus alascanus* BEAN). Crabs preyed on were tanner crabs (*Chionoecetes* spp.) including deep-sea tanner crabs, golden king crab (*Lithodes aequispina* BENEDICT) and deep-sea red king crab (*Lithodes couesi* BENEDICT). Shrimps taken were pink shrimp of the family Pandalidae and deep-sea red shrimp of the family Oplophoridae. There were numerous other items in the stomachs including starfishes, sea cucumbers, sea anemones, jellyfishes, sea urchins, sponges, seaweeds, as well as bird feathers and parts of infant sea mammals.

The analysis of data by size class indicates that fishes were more frequent in stomachs of larger sablefish. It appears that young sablefish smaller than 40 cm prey on benthos such as Echiurida and Polychaeta.

4. Sex ratio

Sex ratios (in percent females) of sablefish were 56% in the eastern Bering Sea, 51% in the Aleutian Region, and 55% in the Gulf of Alaska, showing that the proportion of females was somewhat higher than males in all regions (Table 13).

Sex ratios by size class differed by region, but the proportion of females was found to increase in all regions as the size increased (Table 13, Fig. 25). The fork length at which the proportion of females surpassed 50% was 60 cm in the eastern Bering Sea, 64 cm in the Aleutian Region, and 66 cm in the Gulf of Alaska ; at greater lengths the percentage of females increased rapidly as size increased. Males larger than 80 cm in fork length were seldom observed.

In the Aleutian Region and Gulf of Alaska, the proportion of females decreased with depth, but in the eastern Bering Sea no particular trend was observed (Table 14). The primary analysis of sex ratio by size class and depth was made in the Gulf of Alaska where the main body of sablefish is distributed. It was found that the change in sex ratios by size was altered at a depth of 400 m (Fig. 26). That is, at depths less than 400 m, the proportion of females increased with size, however, at depths greater than 400 m the proportion decreased because the percentage of males increases in the population of fish 60 cm and larger, which is the size occupying these depths.

5. Recruitment processes

During the trawl surveys in the eastern Bering Sea in summer 1978, one-year-old fish of the 1977 year class were observed in catches (UMEDA *et al*., 1983 ; WAKABAYASHI and FUJITA, 1981 ; WAKABAYASHI and YABE, 1981). They were found over relatively large areas but the majority were distributed in the 101-200 m depth zone between the Pribilof Islands and Unimak Pass, and the shallow water areas less than 100 m along the Alaska Peninsula. A large number of this year class appeared as two-year-old fish in almost this same area in 1979 (BAKKALA *et al*., 1982 ; UMEDA *et al*., 1983). The abundance of this year class was extremely high representing 90% of the total estimated population in the eastern Bering Sea. A survey in the eastern Bering Sea was conducted by the United States in 1980. These data show that the majority of the 1977 year class was still distributed in the continental shelf waters between the Pribilof

Table 13. Sex ratios (in percent females) of sablefish by region and size class taken during the Japan-U.S. joint longline survey in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in 1982.

Length class (cm)	Eastern Bering Sea			Aleutian Region			Gulf of Alaska		
	Frequency		Sex ratio	Frequency		Sex ratio	Frequency		Sex ratio
	Male	Female		Male	Female		Male	Female	
30～	—	—	—	—	—	—	—	—	—
32	—	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—	—
36	—	—	—	—	—	—	—	1	100
38	—	—	—	—	—	—	4	—	0
40	1	1	50	1	—	0	12	5	29
42	—	2	100	1	1	50	56	23	29
44	9	2	18	3	—	0	186	101	35
46	31	10	24	48	10	17	362	232	39
48	100	36	26	136	52	28	730	456	38
50	283	139	33	249	143	36	1,129	667	37
52	568	354	38	381	236	38	1,571	1,058	40
54	715	595	45	361	303	46	1,692	1,319	44
56	983	820	45	301	326	52	1,840	1,501	45
58	902	841	48	207	311	60	2,249	1,668	43
60	740	971	57	222	238	52	2,346	1,720	42
62	466	902	66	230	184	44	2,499	1,697	40
64	214	839	80	135	163	55	2,243	1,820	45
66	91	588	87	114	142	55	1,687	1,962	54
68	42	331	89	94	122	56	1,055	2,117	67
70	17	150	90	56	85	60	610	2,197	78
72	6	73	92	30	80	73	260	1,821	88
74	2	22	92	21	77	79	141	1,395	91
76	1	19	95	7	46	87	53	1,162	96
78	1	7	88	6	42	88	24	764	97
80	—	8	100	1	29	97	9	550	98
82	—	3	100	—	21	100	3	312	99
84	—	—	—	—	15	100	2	188	99
86	—	—	—	—	12	100	—	131	100
88	—	—	—	—	10	100	—	69	100
90	—	—	—	—	5	100	—	35	100
92	—	1	100	—	4	100	—	12	100
94	—	—	—	—	7	100	—	13	100
96	—	—	—	—	1	100	—	6	100
98	—	—	—	—	2	100	—	4	100
100	—	—	—	—	1	100	—	4	100
102	—	—	—	—	—	—	—	1	100
104	—	—	—	—	—	—	—	1	100
106	—	—	—	—	—	—	—	1	100
108	—	—	—	—	—	—	—	—	—
110	—	—	—	—	—	—	—	—	—
Total	5,172	6,714	56	2,604	2,668	51	20,763	25,013	55

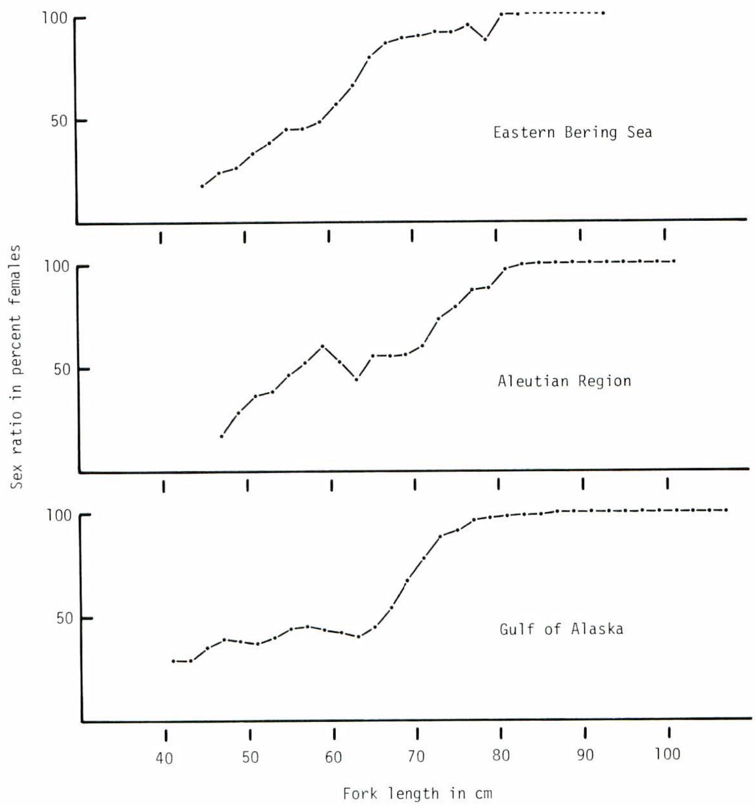

Fig. 25. Sex ratios of sablefish by size class taken during the Japan-U.S. joint longline survey in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in 1982.

Table 14. Sex ratios (in percent females) of sablefish by depth taken during the Japan-U.S. joint longline survey in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in 1982.

Depth zone (m)	Eastern Bering Sea			Aleutian Region			Gulf of Alaska		
	Number of fish		Sex ratio	Number of fish		Sex ratio	Number of fish		Sex ratio
	Male	Female		Male	Female		Male	Female	
101- 200	709	754	52	1	4	80	1,393	2,122	60
201- 400	938	1,300	58	229	369	62	4,139	6,780	62
401- 600	814	1,257	61	832	1,001	55	5,201	6,185	54
601- 800	2,155	2,747	56	1,311	1,096	46	6,788	6,632	49
801-1,000	556	656	54	231	198	46	3,242	3,294	50
Total	5,172	6,714	56	2,604	2,668	51	20,763	25,013	55

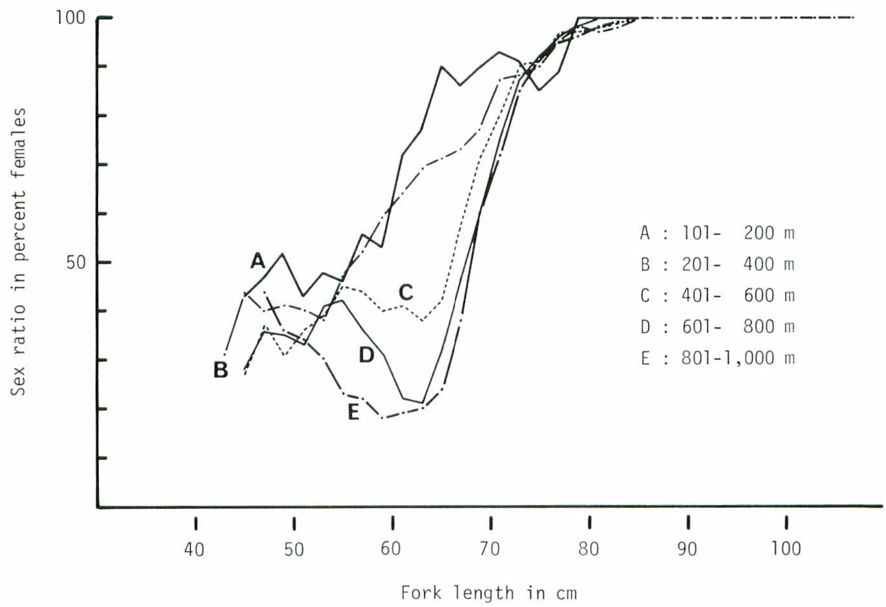

Fig. 26. Sex ratios of sablefish by size class and depth taken during the Japan U.S. joint longline survey in the Gulf of Alaska in 1982.

Islands and Unimak Pass (UMEDA *et al*., 1983). Analysis of 1981 trawl survey data demonstrated that the distribution of the 1977 year class had expanded to northwest of the Pribilof Islands by 1981, with 40% of the eastern Bering Sea population occupying this area (data exchange between Northwest and Alaska Fisheries Center and Far Seas Fisheries Research Laboratory). The majority was distributed in the 101-400 fathom (183-732 m) depth zone. A longline survey (SASAKI *et al*., 1983) as well as a trawl survey in this region in 1982, showed an almost uniform distribution of the 1977 year class in the 146-800 m depth range.

In the Aleutian Region, the 1977 year class was seldom found in abundance in 1979 (SASAKI, 1979b), but there was an unexpected appearance of this year class in the 101-600 m depth zone in 1980 (SASAKI, 1980b). A trawl survey in this area in 1980 showed that there was almost no occurence of this year class at depths less than 100 m (data exchange between NWAFC and FSFRL). They had practically disappeared from 101-200 m depth zone by 1981 (SASAKI *et al*., 1982).

The 1978 longline survey in the Gulf of Alaska did not reveal any strong year classes in depths greater than 100 m (SASAKI, 1978b), although during the 1979 survey the 1977 year class appeared to be abundant (SASAKI, 1979b). Most of them were distributed in the 101-200 m depth zone. Since 1980, this year class has appeared at depths greater than 200 m (SASAKI, 1981 ;

SASAKI *et al.*, 1982 ; 1983).

6. Discussion

KODOLOV (1970) has reported that male sablefish in the Bering Sea reach maturity only when they reach a larger size than females. BRACKEN (1982) for Gulf of Alaska waters and MASON *et al.* (1983) for Canadian waters both report that 50% of the male sablefish reach sexual maturity at 50 cm, while PHILLIPS and IMAMURA (1954) for Washington to California waters report that this stage is reached at 60 cm. For females, these authors reported that 50% maturity was reached at 58 cm (BRACKEN, 1982), 52 cm (MASON *et al.*, 1983), and 71 cm (PHILLIPS and IMAMURA, 1954). HEYAMOTO and ALTON (1964) reported for Washington to California waters that all male and female sablefish less than 45 cm were immature and those 56 cm or larger were mature. The size at 50% maturity for sablefish in the Gulf of Alaska reported in this study was 57 cm for males and 67 cm for females, neither of which corresponds to sizes reported by the above authors except for those reported by PHILLIPS and IMAMURA (1954).

All of the above reports except that by KODOLOV (1970) shows that sexual maturity of male sablefish is reached at a relatively small size and that the size at maturity differs considerably among both males and females. These differences can be regarded as the result of differences in areas, years, and season sampling. Also, there are some questions about the accuracy of the maturity scale used and a detailed evaluation of this scale is a task that must be carried out in the future. A standardized maturity scale derived from a histological study is eagerly awaited.

Because samples were unavailable from October to April, there was no estimation of spawning season based on an examination of gonads from throughout the year. Instead, known spawning habits of sablefish will be summarized from the literatures. Authors have reported substantially different spawning seasons in the Bering Sea and Aleutian Region. SHUVNIKOV (1963) estimated spawning to occur in February, while KODOLOV (1968) reported it to peak in fall. Since larvae in the pelagic stage, 11-30 mm in length, have been taken in July-August in the Aleutian Islands area (KOBAYASHI, 1957), MASON *et al.* (1983) suggested that these larvae might be spawned there in May. Reported spawning season in the northeastern Pacific Ocean are not as variable as those for the Bering Sea and Aleutian Region. In Canadian waters the spawning season is in January-April with a peak in February (MASON *et al.*, 1983 ; THOMPSON, 1941), and in California it is in December-April with a peak in January-February (PHILLIPS and IMAMURA, 1954).

Sablefish do not have specific spawning grounds, but rather spawn in the 300-400 m depth zone or deeper which is the usual habitat of adults. The eggs are free-floating of the pelagic type and have no oil globule, and they develop in waters above the depths of spawning (MASON *et al.*, 1983 ; THOMPSON, 1941). Fecundity is estimated at about 100,000 eggs at 53 cm and 1 million eggs at 101 cm fork length in California waters (PHILLIPS and IMAMURA, 1954), and 195,000 eggs at 70 cm females off British Columbia in Canada (MASON *et al.*, 1983).

Observations of sablefish stomach contents revealed high rates of empty stomachs. SHUBNIKOV (1963) pointed out that this resulted from regurgitation while the fish were being raised from the sea bottom. The fact that sablefish taken by longline gear had higher rates of empty stomachs than those taken by trawl gear is believed to be the result of the longer time required to retrive longline gear compared to trawls.

Pelagic sablefish, 8-30 cm in fork length, which are widely distributed in summer in offshore surface waters of the northeastern Pacific Ocean, were reported to have fed on young Pacific saury (*Cololabis saira* (BREVOORT)), lanternfishes, and euphausiids. The sablefish had been attracted by and were concentrated under lights on a research vessel (GRINOLS and GILL, 1968; KODOLOV, 1968). Juvenile sablefish in southern California waters mainly consumed copepods, amphipods, euphausiids, fish eggs and larvae, and the larvacea of Oikopleura (FREY, 1971).

Our findings on the feeding habits of sablefish conforms well with those of SHUBNIKOV (1963) for the Bering Sea, KENNEDY and PLETCHER (1968) for the Gulf of Alaska, and BEAMISH *et al*. (1980) for Canadian waters. All of these studies show that sablefish are not selective feeders but consume a wide variety of food organisms and can thus be classified as euryphagous fish.

Females were found to be slightly out number males (51-55% females) in the overall population. There was a trend towards decreasing proportions of females with depth. These latter results correspond to those reported by SHIPPEN (1974) for sablefish off the Washington-Oregon coast. The data also showed an increase in percent females with size. However, this trend changed at 400 m with the proportion of females decreasing sharply at depths greater than 400 m where fish 60 cm and larger predominated. As mentioned in Chapter III, this is because the proportion of males for some size classes in the 60 cm range exceeds than for females's due to the slower growth and longer time it takes males to reach 60 cm. Few males exceeded 80 cm in fork length and their maximum length was 86 cm. The maximum length of females caught during longline surveys was 108 cm.

A large scale groundfish survey, which corresponds in timing with the appearance of a strong year class of sablefish, would provide a chance to measure the actual recruitment over a wide area. As was mentioned in Chapter I, sablefish inhabit surface or shallow coastal waters before they recruit to the adult stock. The recruitment process of the 1977 year class differed by region. In the eastern Bering Sea, they appeared in the continental shelf at age 1 and had stayed there by age 2 or 3, and then recruit to the adult stock in the slope waters (UMEDA *et al*., 1983). In the Aleutian Region and Gulf of Alaska, there was no evidence of appearance of age 1 fish in the 101-200 m depth zone. It is clear, however, that this is not the result of the selectivity of hook size used during the longline surveys because many fish with much smaller mouths than young sablefish, such as flatfishes and sculpins, have been taken by longline gear. Appearance of the 1977 year class in the Aleutian Region occurred in the 101-600 m depth range in 1980 when they are age 3, which was later than the other regions. This may be the result of those fish that appeared in the shelf waters in the eastern Bering Sea or the Gulf of Alaska later moving to the Aleutian Region. In the Gulf of Alaska, they appeared partially in the shelf waters at age 2, but a majority of them appeared both in the shelf and slope waters at age 3. Since large population of this year class still remained in the shelf waters at ages 4 and 5, recruitment of a sablefish to the adult stock is not believed to occur suddenly at a specific age or size, but over several years. Future analysis of abundance data by age from the longline surveys will show the recruitment process of the 1977 year class in quantitative terms.

V. Trend of stock condition based on fisheries statistics

Until the present time, trend of sablefish stock has been examined by researchers including those from Canada and the United States, based on fisheries statistics of Japanese commercial longline vessels targeting on mainly sablefish. However, results of analysis are different among them, especially the U.S. researchers consider that stock condition of sablefish has taken a turn for the worse in recent years and they have established fairly conservative management strategy since 1977 (U.S. DEPARTMENT of COMMERCE, 1978). As various kinds of factors produce an effect on catch per unit of effort (CPUE) of longline gear, it is necessary to examine into fisheries statistics when we use CPUE data obtained from commercial longliners to analyze the trend of stock condition, but it seems that the U.S. researchers do not take this point into their consideration.

In this study, statistics of commercial longline fishery were examined closely to obtain CPUE data representing stock abundance of sablefish and it was clarified that stock condition appears to be good. Furthermore, it was ascertained that available statistics for this study are limited to those until 1976, because operations of the Japanese longline fishery are thought to have changed after 1977 when Canada and the United States established their 200-mile fishing zones.

1. Materials and methods

Groundfish fisheries conducted by Japan in the North Pacific Ocean are a mothership fishery, north Pacific independent trawl fishery, north Pacific longline-gillnet fishery, and the land-based dragnet fishery. However, the collection of statistics from these fisheries was started in different years and are only available for all fisheries since 1968 (TAKAHASHI, 1978). The sources of data mainly used are from the North Pacific Groundfish Fisheries Statistics and the Landbased Dragnet Fishery Statistical Year Book. Statistics of foreign countries used were from Statistical Year Book of the International North Pacific Fisheries Commission (INPFC), BAKKALA *et al.* (1981), BALSIGER and ALTON (1981), FORRESTER *et al.* (1978), FORRESTER *et al.* (1983), and STOCKER (1981).

Names and locations of INPFC Areas and Regions referred to in this chapter are shown in Fig. 27.

Among the Japanese vessels engaged in the north Pacific groundfish fishery, stern trawl and longline vessels most frequently catch sablefish (SASAKI, 1984). The stern trawlers which mainly catch sablefish are the small less than 500 gross ton vessels. However, the main target species of these vessels are rockfishes, Greenland turbot and Pacific cod, and only a few target

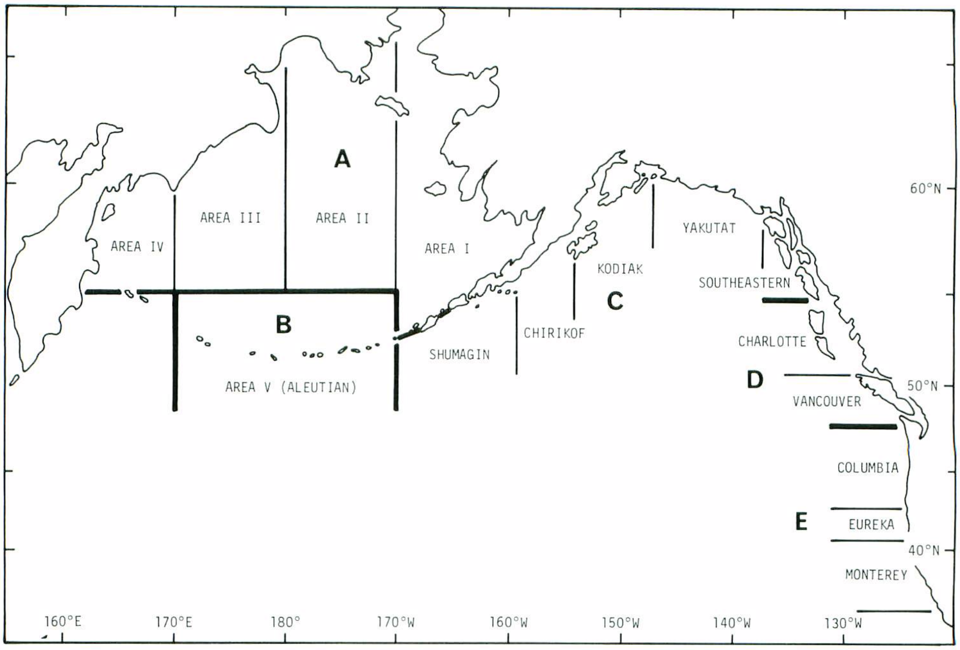

Fig. 27. INPFC areas in the Bering Sea and northeastern Pacific Ocean.

specifically on sablefish. Therefore, CPUE values from these vessels are not representative of the abundance of sablefish. Also, because the available catch records from trawl vessels are tabulated by day rather than by haul it is not possible to separate the fishing effort directed to sablefish from that directed to other species. Considering these points, it is difficult to evaluate the stock condition of sablefish from statistics of the stern trawl vessels.

On the other hand, longline vessels consistently target on sablefish, and after 1968 data from a broad area extending from the eastern Bering Sea to Canadian waters are available. There are some longline vessels which target on Pacific cod as well as sablefish, and after 1978 the effort for Pacific cod has been larger than that for sablefish. Because Pacific cod inhabit depths mainly less than 400 m and longline vessels are prohibited from operating for sablefish at depths less than 400 m in summer and 500 m in winter in the Gulf of Alaska, both species cannot be targetted on at the same time. Additionally fisheries statistics from longline vessels are reported by each operation and it is therefore comparatively easy to separate the effort directed toward sablefish from the raw data. But there are cases in deeper waters of the eastern Bering Sea and on the north side of the Aleutian Islands where Greenland turbot predominate in catches. However, because sablefish and Greenland turbot inhabit nearly the same depths, and it is impossible to catch sablefish exclusively in these areas, effort for catches having large amounts of Greenland turbot could not be excluded from the effort used to calculate CPUE values for sablefish.

It is believed that CPUE from longline gear is largely influenced by the structure of the gear, the kinds of bait used, and the soaking time. Therefore, if these factors change from year to year between vessels, standardization of effort is required. Only minor differences have been observed in the structure of fishing gear and the fishing technique used by Japanese commercial longline vessels (SASAKI, 1984). There were small differences in the length of hachis and in the number of hooks among vessels, but hook spacing has remained at about 1.6 m. These differences do not require that effort is standardized. The use of squid as bait by vessels has also remained unchanged. For a certain period of time when prices of squid increased markedly, some limited number of vessels used Pacific saury as bait. It is likely that the species of squid used as bait deffered by vessel and throughout the years because of variation in cost of various species. Recently most vessels have used squid of the family Ommastrephidae which is imported from the Atlantic Ocean. Numbers of hachi per set have been increasing yearly and along with this, average soaking time has increased. However, from results of a longline survey in 1979 during which the relation between soaking time and CPUE was experimentally examined, there were no differences in CPUE when average soaking time ranged from 6 to 18 hours (SASAKI, 1979b). This indicates that since quality of bait decreases rapidly after 6 hours, further increases in CPUE cannot be expected for soaking times in excess of 6 hours.

From the above observations, it can be seen that no standardization or revision of the effort statistics are required except for the separation of fishing effort by target species.

Size composition data was obtained from both trawl and longline vessels. The two vessel types operate at different depths, and the trawl data is representative of the size composition of sablefish for depths from 100 to 500 m and that of the longline vessels for depths from 400 to 800 m. There are many complications in the analysis of data for this species. For example, there are differences in the size composition of males and females and these data are not collected by sex on commercial vessels. The data is therefore not adequate for detailed analysis and it only examined on a yearly basis to show gross changes in the size composition for sexes combined. Data were grouped for this analysis by the Bering Sea (including the Aleutian Region) and northeastern Pacific Ocean.

The maximum sustainable yield (MSY) was estimated by the general production model (GULLAND, 1961). Since independent populations cannot be recognized geographically in the waters from the eastern Bering Sea to California as discussed in Chapter II, the population throughout these waters were considered as a single stock. In order to use the general production model, 3 to 7 year running averages of fishing effort was used, with the number of years involved varying by area, to produce an equilibrium condition between CPUE and effort.

Table 17 shows the converted effort for longline gear in terms of CPUE for all waters. In order to obtain the total converted effort for longline gear, effort by each region was first estimated from CPUE values shown in Table 16, and from the total catch of sablefish by region and fishing nation as shown in Table 15. The estimated regional effort was then summed up.

Table 15. Historical catches of sablefish in tons by region and nation in the North Pacific Ocean, 1958—1981.

Year	Bering Sea			Aleutian Region				Gulf of Alaska						Canadian Waters						Wash-Cal.[a]			Grand total
	Japan	USSR	Total	Japan	USSR	ROK	Total	Japan	USA	Canada	USSR	ROK	Total	Japan	USA	Canada	USSR	ROK	Total	Japan	Others	Total	
1958	32	—	32	b	—	—	b	—	700	98	—	—	798	—	c	167	—	—	167	—	c	c	997
1959	393	—	393	b	—	—	b	—	967	52	—	—	1,019	—	c	251	—	—	251	—	c	c	1,663
1960	1,861	—	1,861	b	—	—	b	—	1,348	17	—	—	1,365	—	c	423	—	—	423	—	c	c	3,649
1961	26,183	—	26,183	b	—	—	b	—	606	31	—	—	637	—	c	322	—	—	322	—	c	c	27,142
1962	29,830	—	29,830	b	—	—	b	—	684	47	—	—	731	—	c	267	—	—	267	—	c	c	30,828
1963	17,791	—	17,791	639	—	—	639	1,819	617	109	—	—	2,545	—	c	288	—	—	288	—	c	c	21,263
1964	7,681	—	7,681	1,534	—	—	1,534	1,047	1,173	238	—	—	2,458	—	83	398	—	—	481	—	2,486	2,486	14,640
1965	6,638	—	6,638	1,248	—	—	1,248	2,217	1,048	194	—	—	3,459	—	92	455	—	—	547	—	2,255	2,255	14,147
1966	12,219	—	12,219	1,338	—	—	1,338	3,778	1,051	335	—	—	5,164	174	95	635	—	—	904	—	2,096	2,096	21,721
1967	13,680	274	13,954	1,651	—	—	1,651	5,030	947	199	—	—	6,176	1,189	65	393	—	—	1,647	1,311	1,461	2,772	26,200
1968	13,544	4,256	17,800	1,673	—	—	1,673	14,767	112	128	—	—	15,007	2,390	65	465	—	—	2,920	419	2,669	3,088	40,488
1969	17,079	1,579	18,658	1,673	—	—	1,673	19,051	302	72	—	—	19,425	4,720	43	312	—	—	5,075	905	1,619	2,524	47,355
1970	10,091	2,874	12,965	1,247	—	—	1,247	24,530	369	68	—	—	24,967	5,142	104	257	—	—	5,503	138	4,370	4,508	49,190
1971	13,427	2,830	16,257	2,766	170	—	2,936	25,228	270	15	—	—	25,513	3,050	161	314	—	—	3,525	10	3,241	3,251	51,482
1972	12,440	2,137	14,577	2,999	269	—	3,268	35,558	1,387	15	535	308	37,803	4,236	582	1,086	—	—	5,904	759	4,340	5,099	66,651
1973	6,078	1,220	7,298	2,740	134	—	2,874	27,264	867	16	109	58	28,314	2,950	82	938	—	—	3,970	21	4,967	4,988	47,444
1974	4,730	77	4,807	2,463	14	—	2,477	24,176	771	10	38	2,431	27,426	3,866	70	482	65	129	4,612	315	5,939	6,254	45,576
1975	3,685	38	3,723	1,630	79	—	1,709	22,072	1,088	16	33	3,000	26,209	4,702	126	892	0	1,263	6,983	151	7,383	7,534	46,158
1976	2,952	29	2,981	1,558	61	—	1,619	21,924	803	22	41	3,700	26,490	3,494	217	771	0	2,335	6,817	134	14,465	14,599	52,506
1977	2,796	0	2,796	1,761	0	86	1,847	14,326	828	3	4	1,594	16,755	2,961	345	1,088	0	168	4,562	—	8,000	8,000	33,960
1978	937	0	937	732	0	23	755	6,918	1,813	0	4	665	9,400	2,103	319	831	—	—	3,253	—	c	c	c
1979	1,061	49	1,110	638	0	164	802	5,901	2,341	0	152	759	9,153	1,005	399	2,031	—	—	3,435	—	c	c	c
1980	1,709	0	1,709	303	0	26	329	4,543	2,204	0	416	891	8,054	181	c	3,793	—	—	3,974	—	c	c	c
1981	2,108	c	2,108	227	c	c	227	6,792	c	c	c	c	c	1	c	3,888	c	c	3,889	—	c	c	c

a Catches for nations other than Japan are unavailable, but almost all of the catch was by U.S.A..
b Included in the Bering Sea catch totals.
c Unavailable.

Data sources for catches by :

Japan ; 1958—70, FORRESTER *et al.* (1978) ; 1971—76, FORRESTER *et al.* (1983) ; 1977—81, Data on file, Far Seas Fish. Res. Lab., Shimizu, Japan.

U.S.A. ; 1958, pers. comm., H. Gangmark, NWAFC, NMFS, Seattle ; 1959—80 in the Gulf of Alaska, BALSIGER and ALTON (1981) ; 1964—79 in Canadian Waters, STOCKER (1981).

Canada ; 1958—62 in the Gulf of Alaska, pers. comm., B. Leaman, Pacific Biological Station, Nanaimo ; 1963—70 in the Gulf of Alaska, FORRESTER *et al.* (1978) ; 1971—76 in the Gulf of Alaska, FORRESTER *et al.* (1983) ; 1977—80 in the Gulf of Alaska, BALSIGER and ALTON (1981) ; 1958—80 in Canadian Waters, STOCKER (1981) ; 1981 in Canadian Waters, Leaman (1982).

U.S.S.R. and R.O.K. ; Bering Sea and Aleutian Region, BAKKALA *et al.* (1981) ; Gulf of Alaska, BALSIGER and ALTON (1981) ; Canadian Waters, STOCKER (1981).

Table 16. Sablefish catches[a], fishing effort[b], and CPUE values[c], from the Japanese longline fishery in the North Pacific Ocean, 1964 – 1981. Fishing effort is from only those operations where sablefish was the target species.

Year	Bering Sea			Aleutian Region			Gulf of Alaska			Canadian Waters			Wash-Cal. Region		
	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE
1964	2,231	23,947	93	888	6,297	141	—	—	—	—	—	—	—	—	—
1965	1,043	9,938	105	217	1,183	183	—	—	—	—	—	—	—	—	—
1966	2,270	13,696	166	1,123	4,811	233	—	—	—	—	—	—	—	—	—
1967[d]	1,839	8,532	216	783	2,851	275	570	2,690	212	—	—	—	—	—	—
1968	310	2,215	140	438	2,728	161	10,351	39,349	263	1,488	5,725	260	155	658	236
1969	589	3,143	187	320	1,752	183	14,414	61,462	235	4,243	20,542	207	864	4,513	191
1970	1,253	5,202	241	627	2,599	241	20,478	83,417	245	4,938	23,024	214	80	519	154
1971	1,156	6,238	185	602	2,974	202	20,903	100,897	207	2,717	16,771	162	4	91	44
1972	268	2,299	117	485	2,337	208	26,914	129,463	208	3,494	16,910	207	—	—	—
1973	294	1,984	148	798	3,914	204	21,266	101,853	209	2,585	12,367	209	—	—	—
1974	799	4,880	164	969	4,659	208	20,061	105,811	190	3,724	17,790	209	315	1,559	202
1975	487	3,733	130	1,041	6,205	168	18,103	102,254	177	4,458	22,981	194	151	771	196
1976	673	4,571	147	1,136	9,987	114	17,905	96,536	185	3,246	16,971	191	134	1,049	128
1977[e]	1,191	8,819	135	1,256	11,651	108	13,333	96,077	139	2,855	19,129	149	—	—	—
1978[f]	556	10,622	52	519	13,052	40	6,553	48,617	135	2,103	13,040	161	—	—	—
1979[g]	561	11,774	48	387	10,016	39	5,284	48,485	109	1,004	7,718	130	—	—	—
1980	435	6,793	64	117	1,761	66	2,940	24,022	122	181	1,507	120	—	—	—
1981[h]	627	8,360	75	134	1,396	96	4,796	31,762	151	—	—	—	—	—	—

a Catch in tons.
b Effort in 10 hachi longline units.
c CPUE in kg per 10 hachis.
d Data are available for only the two months of November and December in the Gulf of Alaska.
e Washington-California Region was closed to foreign sablefish fisheries starting in 1977.
f Southeastern Area of the Gulf of Alaska was closed to foreign sablefish fisheries starting in 1978.
g East of 140°W in the Gulf of Alaska was closed to foreign sablefish fisheries starting in 1979.
h Canadian Waters were closed to foreign sablefish fisheries starting in 1981.

Table 17. Catches, fishing effort, and estimates of CPUE for sablefish from the longline fishery in the North Pacific Ocean, 1964-1976.

Year	Catch (tons)	Effort (1,000 hachis)	CPUE (kg/hachi)	Effort[a] (1,000 hachis)
1964	14,640	1,165	12.6	—
1965	14,147	960	14.7	—
1966	21,721	1,123	19.3	—
1967	26,200	1,135	23.1	—
1968	40,488	2,204	18.4	1,317
1969	47,355	2,290	20.7	1,542
1970	49,190	2,071	23.8	1,765
1971	51,482	2,704	19.0	2,081
1972	66,651	3,756	17.7	2,605
1973	47,444	2,406	19.7	2,645
1974	45,576	2,367	19.3	2,661
1975	46,158	2,617	17.6	2,770
1976	52,506	2,924	18.0	2,814

a Five year average effort including the year listed and 4 previous years.

CPUE was calculated by dividing the total catch by the total effort previously obtained. For the Washington-California Region, CPUE data was not adequate, and thus CPUE from the longline fishery in the neighboring Vancouver Area was used as a substitute to obtain effort. The reason statistics after 1977 were excluded is that these later data are not representative of abundance.

2. Trend in CPUE from the Japanese longline fishery

Yearly changes in regional catches, fishing effort, and CPUE from the Japanese longline fishery when sablefish was the main target species are shown in Table 16, and Figs. 28 and 29. Catches and fishing effort in each region show almost identical fluctuations (Fig. 28). However, in the Bering Sea and Aleutian Region in 1978 and in the Gulf of Alaska and Canadian Waters in 1977 there were large decreases in catches despite little change in fishing effort.

Trends in CPUEs (Fig. 29) from the longline fishery indicate that abundance declined almost continuously in the Bering Sea and Aleutian Region after 1970 and in the Gulf of Alaska and Canadian Waters from 1968 to 1979. For the latter regions, a small recovery was shown in 1980. The annual decline in CPUEs was in general relatively small. However, CPUEs showed a sharp drop in the Bering Sea and Aleutian Region in 1978 and in the Gulf of Alaska and Canadian Waters in 1977.

3. Trend in size composition of fish taken by Japanese vessels

For the Bering Sea, size composition data are available from trawl vessels for the period from 1966 to 1971. During this period average size increased each year (Fig. 30). However, compared to catches by longline vessels, the size of sablefish in trawl catches is quite small with

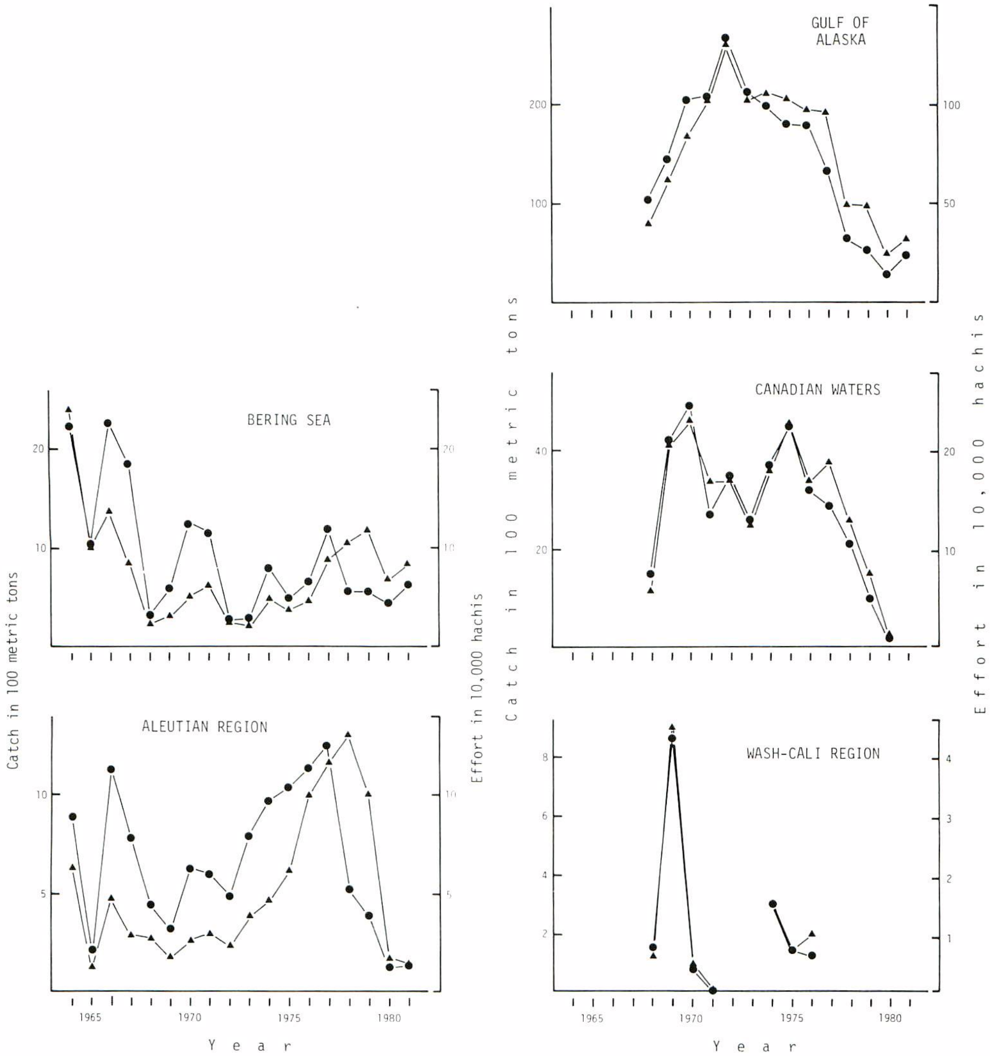

Fig. 28. Trends in catch and effort of Japanese longline vessels targetting on sablefish in the North Pacific Ocean, 1964-1981.

few fish exceeding 70 cm in fork length. The size compositions of sablefish caught by longline vessels do not show a particular trend, though average sizes were large in 1965, 1971, and 1978.

Sablefish caught by the trawl fishery in the northeastern Pacific Ocean are also much smaller than those caught by the longline fishery. For the trawl fishery, sizes decreased from 1964 to 1966, but increased in 1967 and 1968. Changes from 1969 to 1973 in the trawl catches are the result of an increase in abundance of young fish. There were no apparent trends in the size

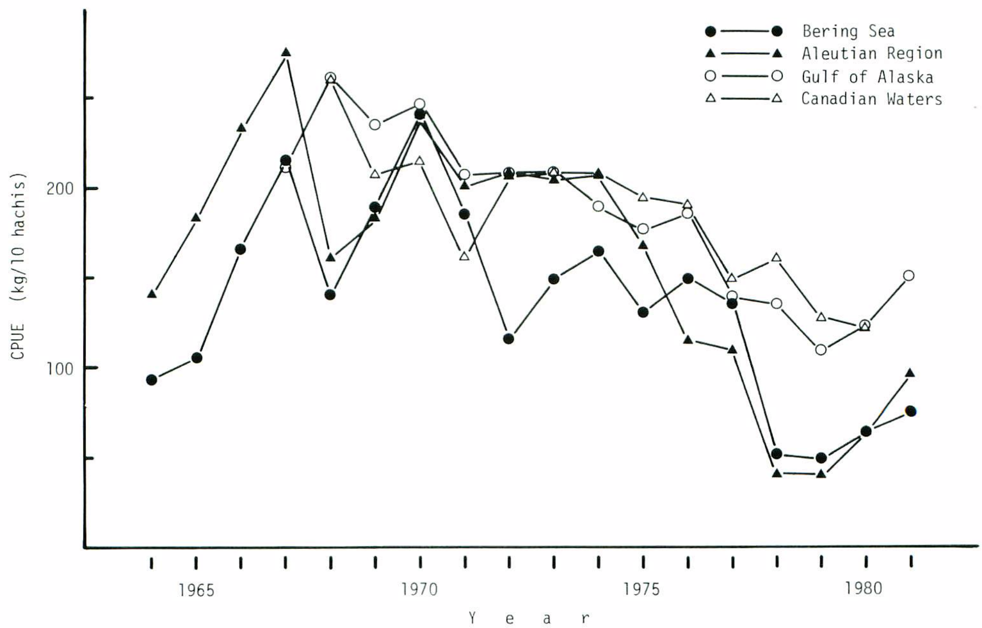

Fig. 29. Trends in CPUE from the Japanese longline fishery when sablefish was the target species.

composition of sablefish taken by the longline fishery. The abundance of young fish observed in the trawl catches was not apparent in catches by the longline fishery.

4. Maximum sustainable yield (MSY)

The MSY and the fishing effort required to acheive this MSY was estimated for the waters from the Bering Sea to off California from regression of CPUE on effort using the assumption of a single stock in these waters. Running 5 year averages of effort and CPUE used to determine the relationship between effort and yield as shown in Fig. 31. Estimates were as follows:

$$Y/f = 22.97 - 0.001611f \qquad (r = -0.73)$$
$$fs \ : \ 7{,}129 \ (1{,}000 \text{ hachis})$$
$$Ys \ : \ 81{,}878 \ (\text{tons})$$

where, Y/f is CPUE in kg per hachi, f is average effort in 1,000 hachis, r is correlation coefficient, fs is optimum effort, and Ys is maximum sustainable yield.

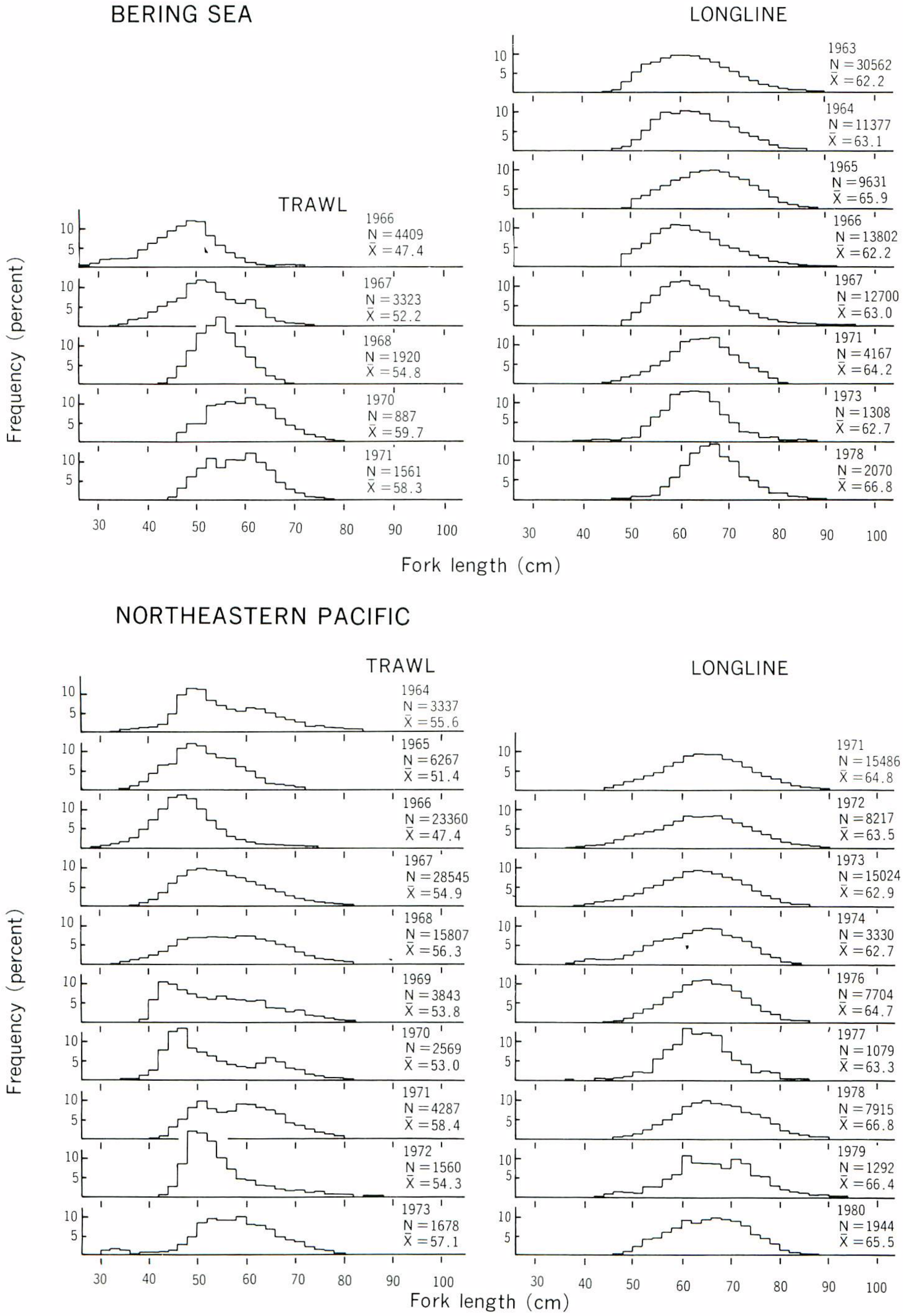

Fig. 30. Size composition of sablefish (sexes combined) taken by Japanese fishing vessels operating in the Bering Sea and northeastern Pacific Ocean.

As is clear in Fig. 31 the range of annual values was extremely narrow.

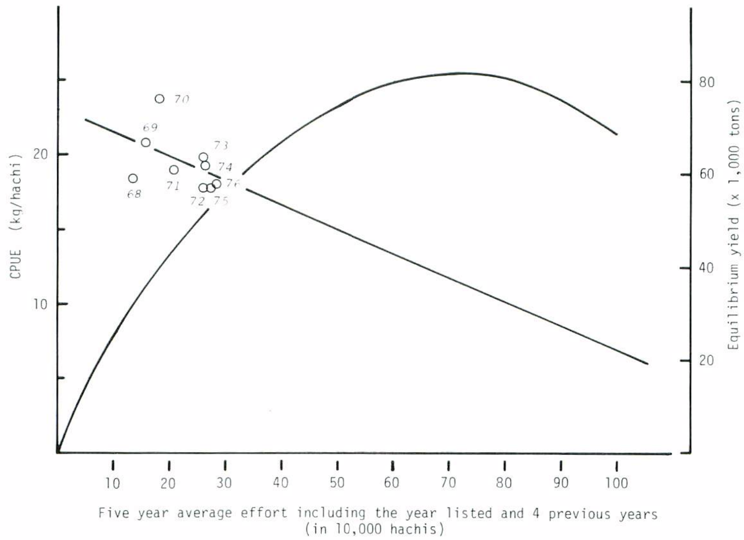

Fig. 31. Relationship between fishing effort and CPUE for sablefish in the North Pacific Ocean and estimated equilibrium yields.

5. Discussion

Estimates of CPUE for sablefish in the Bering Sea and Aleutian Region reported by BAKKALA *et al.* (1981) are quite low compared with values shown in this study (Table 18). These differences are the result of these authors including effort directed toward Pacific cod. For the Gulf of Alaska the CPUE values reported in this paper are not different from those of BALSIGER and ALTON (1981) through 1976. After 1977, U.S. scientists estimated CPUE for sablefish based on data collected by their observers aboard Japanese longline vessels (Table 18). Since these data have inconsistencies in seasons fished, fishing areas and fishing depths and the amount of data is limited, the CPUE values cannot be regarded as an appropriate estimates of abundance. For Canadian Waters, the values reported here are not different than those reported by STOCKER (1981).

Yearly changes in catch and effort from the Japanese longline fishery targetting on sablefish mainly fluctuated when increases in effort were followed by corresponding increases in catch (Fig. 28). Furthermore, declines in CPUE until 1976 were generally moderate and based on these points it is concluded that stock abundance decreased slowly until 1976. The CPUEs after 1977 decreased by 40-60% compared with the previous levels. Since 1977, when Canada and the United States implemented 200-mile fishing zones and established catch quotas which reduced the Japanese catch to about half that prior to 1977, the nature of the Japanese sablefish fishery changed. For example, CPUE values which had been decreasing relatively slowly took an unnatural sharp drop despite a reduction in catches to about half those prior to 1977 and it is

Table 18. Trends in CPUE values of sablefish by region in the North Pacific Ocean, 1964—1981.

Year	Bering Sea		Aleutian Region			Gulf of Alaska		Canadian Waters			
	CPUE 1	CPUE 2	CPUE 1	CPUE 2	CPUE 3	CPUE 1	CPUE 4	CPUE 1	CPUE 5	CPUE 6	CPUE 7
1964	93	61	141	139	—	—	—	—	—	—	—
1965	105	54	183	110	—	—	—	—	—	—	—
1966	166	139	233	229	—	—	—	—	—	—	—
1967	216	210	275	277	—	212	—	—	—	—	—
1968	140	143	161	165	—	263	—	260	261	—	—
1969	187	189	183	184	—	235	—	207	207	—	—
1970	241	231	241	189	—	246	—	215	215	—	—
1971	185	120	202	165	—	207	—	162	162	38	—
1972	117	50	208	203	—	208	—	207	207	61	—
1973	148	47	204	192	—	209	—	209	209	52	—
1974	164	141	208	187	—	190	—	209	210	62	—
1975	131	68	168	98	—	177	—	194	194	36	—
1976	147	69	114	71	—	186	—	191	194	55	—
1977	135	73	108	70	37	139	109	149	170	53	—
1978	52	16	40	24	34	135	86	161	180	58	18
1979	48	17	39	18	27	109	80	130	133	32	16
1980	64	21	66	17	—	122	110	121	132	—	15
1981	75	a	96	a	a	151	a	b	b	—	19

a Data not available.
b Area was closed to the Japanese longline fishery.

Data sources : CPUE 1 (kg/10 hachis) ; Japanes estimates for the Japanese longline fishery targetting on sablefish, 1964—76, SASAKI (1978), 1977—81, data on file, Far Seas Fish. Res. Lab., Shimizu.

CUPE 2 (kg/10 hachis) ; U.S. estimates for Japanese longline fishery from Japanese fisheries Statistics, BAKKALA *et al.* (1981).

CPUE 3 (kg/10 hachis) ; U.S. estimates for Japanese longline fishery from U.S. observer data, BAKKALA *et al.* (1981).

CPUE 4 (kg/10 hachis) ; U.S. estimates for Japanese longline fishery from U.S. observer data, BALSIGER and ALTON. (1981).

CPUE 5 (kg/10 hachis) ; Canadian estimates for Japanese longline fishery from several data sources, STOCKER (1981).

CPUE 6 (kg/trap) ; Canadian sablefish trap fishery using Canadian rectangular collapsible traps, STOCKER (1981).

CPCU 7 (kg/trap) ; Canadian sablefish trap fishery using Korean conical traps, STOCKER (1981).

difficult to regard these abrupt changes in CPUE as actual changes in abundance.

With regard to the size composition of sablefish caught by the commercial fishery, there were observed differences between those taken by trawl and longline vessels. Sablefish taken by trawl vessels were smaller than those taken by longline vessels, because the trawl vessels operate at shallower depths where small fish are mainly distributed.

Size composition data from commercial longline vessels operating in the Bering Sea are available for the years 1963-1967, 1971, 1973, and 1978. The size composition in 1978 showed a similar range, but the modal size was larger than sablefish taken at the beginning stages of the fishery in 1963 and 1964. In the northeastern Pacific Ocean no changes in size composition were recognized in fish taken by the longline fishery.

Thus far, assessment and management of the sablefish stock has been based on the MSY theory and the production model (BAKKALA *et al.*, 1981 ; BALSIGER and ALTON, 1981 ; LOW *et al.*, 1976 ; LOW and WESPESTAD, 1979 ; SASAKI, 1978a ; SASAKI *et al.*, 1975 ; STOCKER, 1981 ; U.S. DEPARTMENT of COMMERCE, 1978). In this study, the MSY for sablefish was estimated as 82,000 tons and optimum effort 7.1 million hachis for the area ranging from the Bering Sea to off California. Based on fishery statistics (Table 15), neither effort nor catch has ever exceeded these levels.

The above estimates were based on regression analysis in which effort and CPUE varied within a relatively small range. Therefore, if the effort was doubled or tripled from the present level for the time being, it is uncertain whether CPUE will drop along the estimated regression line or not. Although this uncertainty exists in the estimates, it should be emphasized that the stock is presently in good condition which is supported by yearly changes in CPUE, size composition and the remarkable appearance of the strong 1977 year class. However, in the marginal areas of distribution for this species such as the eastern Bering Sea and Aleutian Region, many immigrants from main areas of concentration are caught as the stock is exploited and as a result of this accumulated catch, the stock size decreases and the level of biomass is thought to become quite low. For this reason fishing effort in these regions decreases.

LOW and WESPESTAD (1979) estimated MSY for the area from the Bering Sea to off California as 50,300 tons and apportioned MSY by region according to the ratios between the accumulated regional catches and the total catch. Furthermore, they estimated MSY for each region by applying the production model to data from each region and determined the final regional MSY based on a comparative evaluation of the MSYs obtained by the two methods. The results were 13,000 tons for the eastern Bering Sea, 2,100 tons for the Aleutian Region, 25,100 tons for the Gulf of Alaska, 12,600 tons for waters from off Canada to off California. The total MSY by adding the regional MSYs was 52,800 tons. Although these authors stated that the estimated value for the Washington to California region was underestimated, their MSY is quite low compared to that estimated in present study. The reason for the low estimate by LOW and WESPESTAD (1979), as already mentioned, was that their study was based on CPUE data which included effort directed to species other than sablefish.

Canadian scientists assume that sablefish within Canadian Waters are an independent stock, and by applying the production model to catch and effort statistics from the Japanese longline fishery, they estimated MSY for their waters to range from 4,800 to 5,200 tons (STOCKER, 1981).

The United States scientists believed that MSY was realized in 1970 and have determined annual equilibrium yields (EY) by region based on the rate of decline in the CPUE from the Japanese longline fishery in each region from that in 1970 (U.S. DEPARTMENT of COMMERCE, 1978). However, since there are several problems in the method used by U.S. scientists to estimate EY their values can be regarded as underestimated. These problems are: 1) estimating MSY by region, 2) validity of using 1970 as the year when MSY was realized, 3) applying a linear function in the estimation of EY, 4) using CPUE data does not exclude effort directed to species other than sablefish, and 5) using CPUE data that loses the continuity after 1977.

If it is necessary to set allowable catches by region for management purposes, it is more logical to estimate EY for the whole region and allocate EY by region according to the proportion of the total biomass in each region (IKEDA, 1979). To do this, biomass estimates for all of the major distributional areas is needed. However, the estimate of total biomass in the whole distribution area are still unavailable. Because major fishing grounds south of southeast Alaska have been closed to the foreign sablefish fishery after 1977, fishery data is no longer available from this part of the overall distribution. Therefore, it is difficult to estimate EY for the whole stock in recent years. As already mentioned, operations of the Japanese longline fishery are thought to have changed after 1977. Thus it is believed inappropriate to use recent data from the longline fisherv to judge trends in stock condition of sablefish.

VI. Present stock condition based on results of groundfish surveys

As noted in Chapter V, it is difficult to analyze the trend of stock condition of sablefish from statistics of Japanese longline fishery after 1977. Because of these limitations, the recent stock condition is examined in this chapter based on results of various groundfish surveys conducted by longline and trawl research vessels.

The Fisheries Agency of Japan and the U.S. National Marine Fisheries Service launched joint systematic groundfish surveys using bottom longline gear in the Gulf of Alaska in 1978. The purpose was to continue the collection of abundance and biological data on sablefish that was previously available from the commercial fishery, but that was becoming more limited because of increasing restrictions on the fishery. From 1979, the longline surveys were expanded to sample the Aleutian Region and from 1982 to sample the eastern Bering Sea. The most important objective of this systematic survey is to collect data on and monitor changes in distribution, abundance, and size compostition of sablefish in the survey area. Large-scale trawl survey has been also conducted by jointly Japan and the United States in the eastern Bering Sea and Aleutian Region since 1979, and biomass estimates of sablefish were obtained for the first time. In addition, longline survey data taken in 1969 in the Gulf of Alaska provide us an important clue to know the unexploited stock level.

1. Groundfish surveys

1-1. Japan-U.S. joint longline survey

(1). Data collection

The survey in 1978 was a preliminary investigation intended to measure variation in catch rate with depth, number of hachis, and type of bait used (SASAKI, 1978b). Based on results of this initial survey, plans for future assessment surveys were established. The utmost care has been taken to prevent introducing any qualitative variations in the data by altering survey methods.

The surveys have been conducted each year in the period from May to September and in the area as shown in Fig. 32 aboard a chartered Japanese North Pacific longline vessel. The longline vessels used for these surveys were all 500 gross tonnage vessels of essentially the same structural characteristics. The number of survey stations was 32 in 1978, 57 in 1979, 76 in 1980 and 1981, and 108 in 1982. Numbers of survey stations were less in the first two years than in later years because the survey in 1978 was of a preliminary nature and experiments on fishing efficiency were carried out in 1979 in addition to the standard survey. Survey stations were distributed as uniformely as possible in each geographic area. One station per day was fished, and normally 160 hachis were fished at each station. The longline was set at right angles to the isobaths in a manner to cover the depth range of 101–1,000 m. However, the distance between 101 and 1,000 m varied at each survey station. Thus, this complete depth range could not be covered at stations where this distance exceeded the 16 km length of the longline gear. The longline was usually set from shallow to deep waters and was retrieved in the same direction. Hauling the longline started 2 hours after the set was completed.

A standard hachi consisted of a 100 m groundline with 45 hooks spaced 2 m apart on 1.2 m gangions. The hook was 74 mm in length and 21 mm in width. Ring-cut short-finned squid imported from the Atlantic Ocean were used as bait. The soaking time was on the average 5 to 6

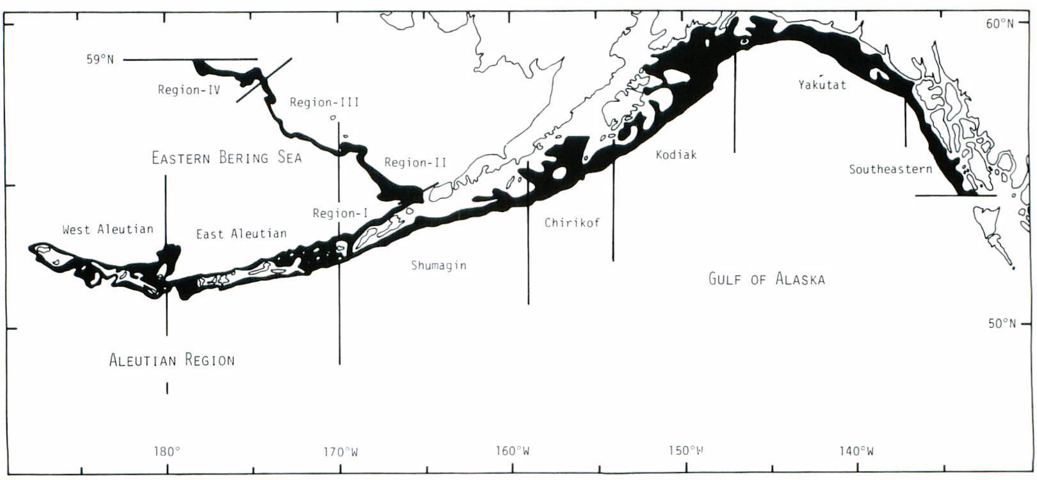

Fig. 32. Regions and areas used for summarizing data from the Japan-U.S. joint longline survey in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska. The darkened area illustrates the 101-1,000 m depth range except Regions II, III, and IV in the eastern Bering Sea where the depth ranges are 146-1,000 m.

hours, but it varied by section of the longline. For the first section of the longline hauled, the soaking time was about 3 hours, but for the last section hauled it was 7 to 9 hours. The catch in numbers was recorded by species or species group for each hachi. The fishing depth was recorded from a fish finder for each 5 hachi section of the longline while hauling. During the 1979 survey, tagged sablefish were not measured by depth caught, and thus the size composition data by depth in this year was incomplete. From 1980, all sablefish taken were measured by depth.

(2). Data analysis

Because age data is not yet available, size composition data, weighted by relative population numbers and relative population weights, were used to examine changes in population characteristics. The catch data were stratified by depth interval of 100 m, and thus there were a total of 9 depth strata in the 100 to 1,000 m depth range sampled for each survey area as shown in Fig. 32. For the analysis of size composition data, the first depth strata was 101-200 m, but at greater depths the strata intervals were 200 m.

Mean catch rates were calculated for each depth stratum. As stated earlier, the soaking time varied by section of the longline. Although there is a possibility that this variation in soaking time had an effect on the catch rates, no attempt was made to correct for this factor. The mean catch rate is an indicator of population density, but is not representative of total stock numbers. Therefore, mean catch rates for each stratum were weighted by the area of the stratum and this weighted value was defined as the relative population number (RPN). In addition, relative population numbers by size and mean body weight of fish by length class were used to derive relative population weights (RPW) for each stratum.

The size of the survey area was calculated on the basis of bottom contour charts printed in the United States (U.S. NAVAL OCEANOGRAPHIC OFFICE, 1973). The depth zone of 101-145 m in the eastern Bering Sea, except Region Ⅰ, was excluded from the analysis because of inadequate coverage and the extremely low density of sablefish in these areas at these depths. The area north of 59°N in the eastern Bering Sea, Bowers Bank in the Aleutian Region, and Cook Inlet, Prince William Sound, and the inland waters of the Southeastern Area in the Gulf of Alaska were also excluded in calculating the geographical size of the survey area.

Of the total survey area thus obtained, the Gulf of Alaska is the largest region, accounting for 64% of the total, followed by the Aleutian Region accounting for 23%, and the eastern Bering Sea accounting for 12%. The Kodiak Area of the Gulf of Alaska is the largest among all survey areas, accounting for 20% of the total survey area (Fig. 33). As for the total area of the 401-1,000 depth range, however, which constitutes the major fishing grounds for sablefish, the Aleutian Region is the largest, accounting for 42% of the total, followed by the Gulf of Alaska accounting for 36%, and the eastern Bering Sea accounting for 22%.

(3). Results

(i). Mean catch rate

The geographical distribution of mean catch rates per hachi, which is an index of relative

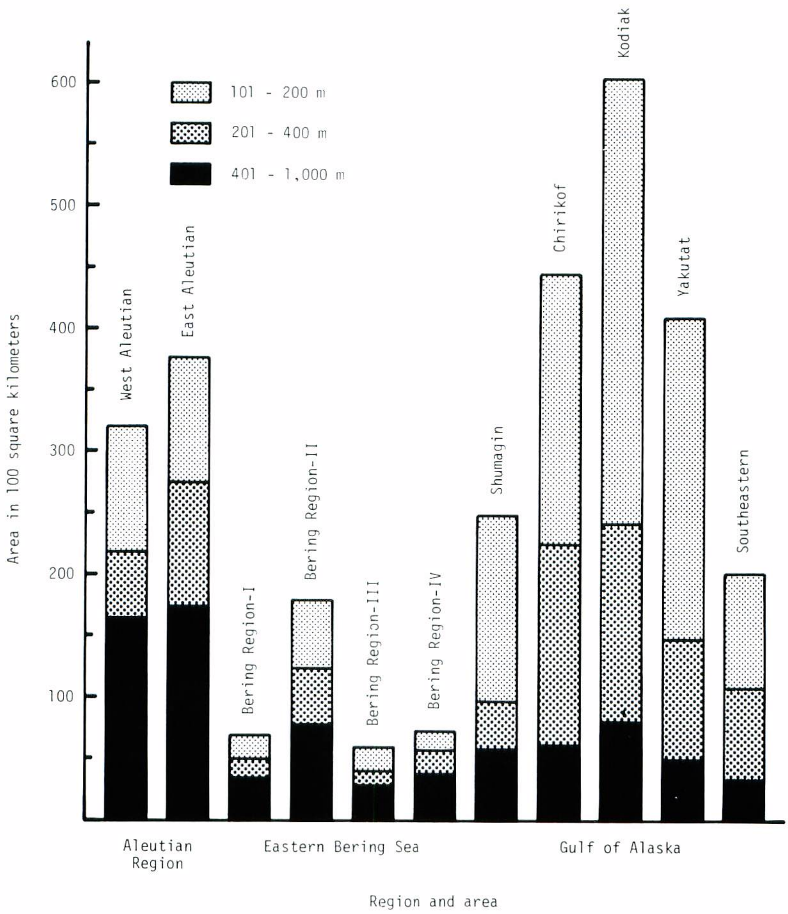

Fig. 33. Geographical sizes of depth zones by area within the 101-1,000 m depth range except Regions II, III, and IV in the eastern Bering Sea where the depth ranges are 146-1,000 m.

population density, showed generally that densities were highest in the eastern areas of the Gulf of Alaska, particularly the Southeastern Area, and lowest in the West Aleutian Area and Region VI of the eastern Bering Sea (Table 19, Fig. 34). The Shumagin and Chirikof Areas of the Gulf of Alaska showed high catch rates in the relatively shallow depth zone of 201-400 m (Table 19, Fig. 34). In other areas, catch rates were highest in the 401-600 or 601-800 m depth zone. Generally speaking, the catch rates were extremely low in the 101-200 m depth zone in the eastern Bering Sea except Region II, and the Aleutian Region.

After 1979, catch rates show a general increasing tendency in many of the areas (Table 19).

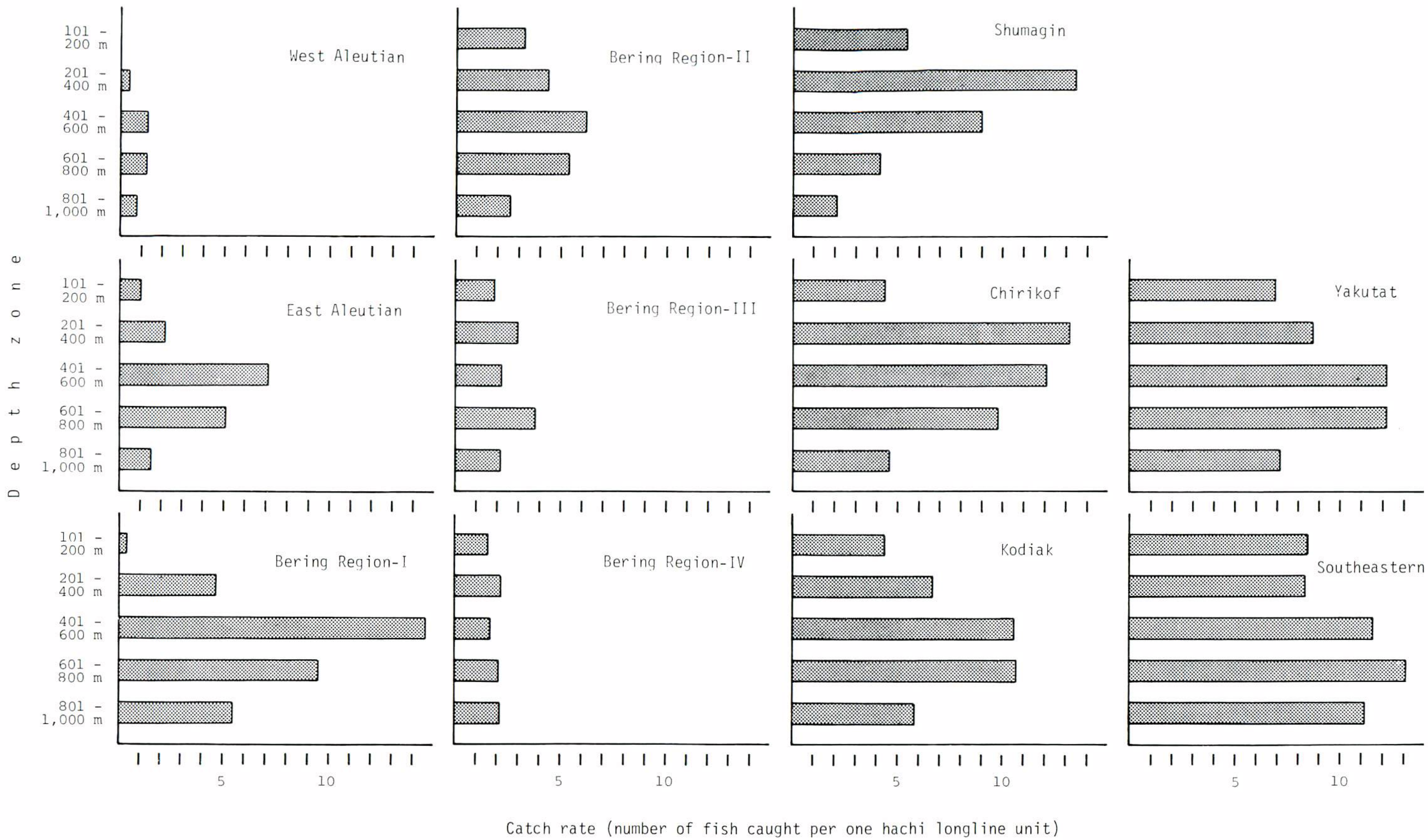

Fig. 34. Mean catch rate (number of fish per one hachi longline unit) of sablefish by area and depth in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summer of 1982.

Table 19. Areas of depth zones (A), mean catch rates (B), and relative population numbers (A・B) as an index of population size of sablefish by area and depth in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summers of 1979—1982.

Area	Depth (m)	(A)	1979[a]		1980[a]		1981[b]		1982[b]	
			(B)	(A・B)	(B)	(A・B)	(B)	(A・B)	(B)	(A・B)
Eastern Bering Sea	146— 200[c]	1,071		—		—		—		2,543
	201— 300	484		—		—		—		1,665
	301— 400	418		—		—		—		1,853
	401— 500	292		—		—		—		1,636
	501— 600	321		—		—		—		2,235
	601— 700	346		—		—		—		2,058
	701— 800	293		—		—		—		1,397
	801— 900	266		—		—		—		928
	901—1,000	212		—		—		—		535
	Total	3,703		—		—		—		14,850
Region-I	101— 200	180	0.10	18	0.01	2	0.02	4	0.34	61
	201— 300	77	0.81	62	0.15	12	0.84	65	3.58	276
	301— 400	73	0.71	52	0.23	17	3.52	257	5.96	435
	401— 500	66	0.61	40	1.19	79	6.47	427	11.41	753
	501— 600	61	0.40	24	3.19	195	9.67	590	16.73	1,021
	601— 700	56	1.18	66	3.42	192	8.50	476	12.40	694
	701— 800	60	5.08	305	2.03	122	4.84	290	6.67	400
	801— 900	61	2.58	157	1.98	121	3.12	190	5.76	351
	901—1,000	52	1.20	62	0.71	37	2.02	105	4.87	253
	Total	686		786		777		2,404		4,244
Region-II	146— 200	552	—	—	—	—	—	—	3.41	1,882
	201— 300	244	—	—	—	—	—	—	4.16	1,015
	301— 400	209	—	—	—	—	—	—	4.86	1,016
	401— 500	139	—	—	—	—	—	—	5.02	698
	501— 600	162	—	—	—	—	—	—	6.34	1,027
	601— 700	183	—	—	—	—	—	—	5.62	1,028
	701— 800	132	—	—	—	—	—	—	5.25	693
	801— 900	108	—	—	—	—	—	—	3.16	341
	901—1,000	62	—	—	—	—	—	—	1.74	108
	Total	1,791		—		—		—		7,808
Region-III	146— 200	184	—	—	—	—	—	—	1.88	346
	201— 300	60	—	—	—	—	—	—	2.93	176
	301— 400	52	—	—	—	—	—	—	3.14	163
	401— 500	38	—	—	—	—	—	—	1.83	70
	501— 600	51	—	—	—	—	—	—	2.58	132
	601— 700	63	—	—	—	—	—	—	3.99	251
	701— 800	53	—	—	—	—	—	—	3.64	193
	801— 900	47	—	—	—	—	—	—	2.58	121
	901—1,000	43	—	—	—	—	—	—	1.44	62
	Total	591		—		—		—		1,514
Region-IV	146— 200	155	—	—	—	—	—	—	1.64	254
	201— 300	103	—	—	—	—	—	—	1.92	198
	301— 400	84	—	—	—	—	—	—	2.84	239
	401— 500	49	—	—	—	—	—	—	2.35	115
	501— 600	47	—	—	—	—	—	—	1.17	55
	601— 700	44	—	—	—	—	—	—	1.93	85
	701— 800	48	—	—	—	—	—	—	2.32	111
	801— 900	50	—	—	—	—	—	—	2.29	115
	901—1,000	55	—	—	—	—	—	—	2.03	112
	Total	635		—		—		—		1,284

(ii). Relative population number (RPN)

Population numbers in the eastern Bering Sea and the Aleutian Region were each about 10% of that in the Gulf of Alaska, and numbers were larger in the 401-1,000 m depth range than in depths shallower than 400 m (Table 20). In contrast, in the Gulf of Alaska, 82% of the population was observed in the 101-400 m depth range. For this reason, differences in population num-

Table 19. Continued.

Area	Depth (m)	(A)	1979		1980		1981		1982	
			(B)	(A・B)	(B)	(A・B)	(B)	(A・B)	(B)	(A・B)
Aleutian Region	101— 200	2,036		—		2,021		374		60
	201— 300	786		—		1,584		846		649
	301— 400	758		—		1,104		1,565		1,798
	401— 500	699		—		1,599		2,376		2,390
	501— 600	647		—		2,225		2,225		3,161
	601— 700	597		—		1,556		1,818		2,199
	701— 800	529		—		1,318		1,193		1,619
	801— 900	496		—		981		730		711
	901—1,000	420		—		694		364		366
	Total	6,968		—		13,082		11,491		12,953
West Aleutian	101— 200	1,021		—		0		14		0
	201— 300	257		—		2		19		35
	301— 400	287		—		30		79		218
	401— 500	342		—		189		330		405
	501— 600	316		—		462		329		460
	601— 700	292		—		397		325		381
	701— 800	254		—		387		227		366
	801— 900	235		—		288		143		231
	901—1,000	199		—		49		164		93
	Total	3,203		—		1,804		1,630		2,189
NW Aleutian	101— 200	345	—	—	0.00	0	0.00	0	0.00	0
	201— 300	113	—	—	0.02	2	0.00	0	0.05	6
	301— 400	130	—	—	0.04	5	0.04	5	0.55	72
	401— 500	161	—	—	0.66	106	0.66	106	1.20	193
	501— 600	149	—	—	1.14	170	1.12	167	1.07	159
	601— 700	138	—	—	1.33	184	1.03	142	1.60	221
	701— 800	126	—	—	1.66	209	0.41	52	1.73	218
	801— 900	120	—	—	1.02	122	0.79	95	0.89	107
	901—1,000	101	—	—	0.26	26	0.83	84	0.25	25
	Total	1,383		—		824		651		1,001
SW Aleutian	101— 200	676	—	—	0.00	0	0.02	14	0.00	0
	201— 300	144	—	—	0.00	0	0.13	19	0.20	29
	301— 400	157	—	—	0.16	25	0.47	74	0.93	146
	401— 500	181	—	—	0.46	83	1.24	224	1.17	212
	501— 600	167	—	—	1.75	292	0.97	162	1.80	301
	601— 700	154	—	—	1.38	213	1.19	183	1.04	160
	701— 800	128	—	—	1.39	178	1.37	175	1.16	148
	801— 900	115	—	—	1.44	166	0.42	48	1.08	124
	901—1,000	98	—	—	0.23	23	0.82	80	0.69	68
	Total	1,820		—		980		979		1,188
East Aleutian	101— 200	1,015		120		2,021		360		60
	201— 300	529		325		1,582		827		614
	301— 400	471		539		1,074		1,486		1,580
	401— 500	357		742		1,410		2,046		1,985
	501— 600	331		849		1,763		1,896		2,701
	601— 700	305		805		1,159		1,493		1,818
	701— 800	275		465		931		966		1,253
	801— 900	261		354		693		587		480
	901—1,000	221		313		645		200		273
	Total	3,765		4,512		11,278		9,861		10,764
NE Aleutian	101— 200	516	0.03	15	0.31	160	0.06	31	0.00	0
	201— 300	226	0.85	192	2.20	497	0.94	212	0.61	138
	301— 400	220	1.09	240	1.52	334	2.01	442	2.00	440
	401— 500	208	2.02	420	3.36	699	4.68	973	3.42	711
	501— 600	193	2.67	515	6.87	1,326	5.39	1,040	7.62	1,471
	601— 700	178	3.06	545	4.90	872	6.70	1,193	5.95	1,059
	701— 800	165	2.04	337	4.40	726	4.93	813	5.49	906
	801— 900	159	1.68	267	3.01	479	2.80	445	1.63	259
	901—1,000	135	1.93	261	2.66	359	0.59	80	1.42	192
	Total	2,000		2,792		5,452		5,229		5,176
SE Aleutian	101— 200	499	0.21	105	3.73	1,861	0.66	329	0.12	60
	201— 300	303	0.44	133	3.58	1,085	2.03	615	1.57	476
	301— 400	251	1.19	299	2.95	740	4.16	1,044	4.54	1,140
	401— 500	149	2.16	322	4.77	711	7.20	1,073	8.55	1,274
	501— 600	138	2.42	334	3.17	437	6.20	856	8.91	1,230
	601— 700	127	2.05	260	2.26	287	2.36	300	5.98	759
	701— 800	110	1.16	128	1.86	205	1.39	153	3.15	347
	801— 900	102	0.85	87	2.10	214	(1.39)	(142)	2.17	221
	901—1,000	86	0.60	52	3.32	286	(1.39)	(120)	0.94	81
	Total	1,765		1,720		5,826		4,632		5,588

Table 19. Continued.

Area	Depth (m)	(A)	1979 (B)	1979 (A・B)	1980 (B)	1980 (A・B)	1981 (B)	1981 (A・B)	1982 (B)	1982 (A・B)
Gulf of Alaska	101— 200	10,853		34,092		54,125		48,375		60,215
	201— 300	3,118		21,638		23,350		23,879		30,568
	301— 400	2,255		14,887		14,244		16,279		21,811
	401— 500	580		4,124		2,858		5,143		5,872
	501— 600	492		2,796		2,682		4,635		5,750
	601— 700	405		2,085		2,061		2,818		4,223
	701— 800	475		2,489		2,177		2,280		4,077
	801— 900	508		1,954		2,061		1,787		3,156
	901—1,000	396		1,433		1,013		1,300		2,058
	Total	19,082		85,498		104,571		106,496		137,730
Shumagin	101— 200	1,506	1.43	2,154	3.18	4,789	5.18	7,801	5.37	8,087
	201— 300	209	3.53	738	5.91	1,235	7.78	1,626	14.37	3,003
	301— 400	178	3.16	562	3.28	584	6.35	1,130	12.70	2,261
	401— 500	117	5.14	601	3.26	381	7.96	931	9.42	1,102
	501— 600	108	5.08	549	3.26	352	6.48	700	8.62	931
	601— 700	100	2.80	280	2.37	237	3.63	363	5.69	569
	701— 800	94	2.08	196	1.69	159	1.97	185	2.45	230
	801— 900	91	2.02	184	2.46	224	0.92	84	2.01	183
	901—1,000	77	1.08	83	2.62	202	0.94	72	2.29	176
	Total	2,480		5,347		8,163		12,892		16,542
Chirikof	101— 200	2,189	6.23	13,637	4.84	10,595	3.06	6,698	4.43	9,697
	201— 300	974	9.84	9,584	9.24	9,000	9.20	8,961	13.42	13,071
	301— 400	670	7.07	4,737	6.36	4,261	6.98	4,677	12.94	8,670
	401— 500	81	9.87	799	4.15	336	10.22	828	12.42	1,006
	501— 600	81	5.02	407	4.39	356	7.64	619	11.76	953
	601— 700	80	5.42	434	3.37	270	4.87	390	10.28	822
	701— 800	135	4.99	674	3.19	431	2.26	305	9.27	1,251
	801— 900	162	1.88	305	3.57	578	(2.26)	(366)	5.44	881
	901—1,000	83	1.67	139	1.44	120	(2.26)	(188)	3.66	304
	Total	4,455		30,716		25,947		23,032		36,655
Kodiak	101— 200	3,629	2.49	9.036	4.23	15,351	2.59	9,399	4.61	16,730
	201— 300	938	6.72	6,303	6.41	6,013	6.23	5,844	7.10	6,660
	301— 400	681	6.66	4,535	6.49	4,420	4.90	3,337	6.02	4,100
	401— 500	181	6.81	1,233	4.63	838	7.87	1,424	8.75	1,584
	501— 600	146	5.27	769	4.83	705	8.32	1,215	12.35	1,803
	601— 700	111	4.40	488	5.02	557	6.57	729	11.44	1,270
	701— 800	119	4.87	580	5.07	603	4.74	564	9.57	1,139
	801— 900	123	5.37	661	2.52	310	3.28	403	6.89	847
	901—1,000	107	4.94	529	0.75	80	1.38	148	4.32	462
	Total	6,035		24,134		28,877		23,063		34,595
Yakutat	101— 200	2,619	2.69	7,045	7.02	18,385	6.58	17,233	6.86	17,966
	201— 300	561	5.62	2,951	7.95	4,460	6.46	3,624	8.30	4,656
	301— 400	413	5.52	2,280	3.90	1,611	7.78	3,213	8.99	3,713
	401— 500	126	5.58	703	4.87	614	9.47	1,193	10.80	1,361
	501— 600	98	5.71	560	7.24	710	12.90	1,264	13.61	1,334
	601— 700	70	5.97	418	7.10	497	10.24	717	13.93	975
	701— 800	72	5.47	394	5.33	384	7.51	541	10.53	758
	801— 900	72	5.57	401	4.86	350	4.38	315	7.83	564
	901—1,000	63	1.92	121	2.83	178	3.68	232	6.14	387
	Total	4,094		14,873		27,189		28,332		31,714
South-eastern	101— 200	910	2.44	2,220	5.50	5,005	(7.96)	(7,244)	8.50	7,735
	201— 300	436	4.73	2,062	6.06	2,642	8.77	3,824	7.29	3,178
	301— 400	313	8.86	2,773	10.76	3,368	12.53	3,922	9.80	3,067
	401— 500	75	10.51	788	9.19	689	10.22	767	10.92	819
	501— 600	59	8.66	511	9.47	559	14.19	837	12.36	729
	601— 700	44	10.56	465	11.37	500	14.06	619	13.35	587
	701— 800	55	11.73	645	10.90	600	12.46	685	12.70	699
	801— 900	60	6.71	403	9.99	599	10.31	619	11.35	681
	901—1,000	66	8.50	561	6.56	433	10.00	660	11.05	729
	Total	2,018		10,428		14,395		19,177		18,224

a Catch rates and relative population numbers are considerably underestimated, because some of the sablefish caught by the longline gear were eaten by killer whales in the course of hauling the longline gear.

b Catch rates and relative population numbers are underestimated to some extent due to the same reason as stated in footnote a.

c 101—200 m in Region-I.

Abbreviation A : Area of depth zone in 10 km².
B : Mean catch rate (number of fish per one hachi longline unit).
(A・B) : Relative population number (index of population size).

bers among regions in depths of 401-1,000 m, which is the major fishing ground for the Japanese sablefish longline fishery, was not so large. If population numbers in the 401-1,000 m depth range in the Gulf of Alaska were given a value of 100, the value in the eastern Bering Sea would be 35, and that in the Aleutian Region 42.

Population numbers among the areas in the Gulf of Alaska were largest for the 401-1,000 m depth zone in the Kodiak Area. This area accounted for 27% of the total population in this depth range on an average during the 4 year period of 1979-82 (Table 20). Numbers were next largest in the Southeastern and Yakutat Areas, which accounted for 22 % and 21% respectively of total population numbers in the Gulf of Alaska. The Chirikof Area accounted for 18%, or the 4th largest numbers of the population among the 5 areas. The Shumagin Area accounted for 13% of the total population numbers in the 401-1,000 m depth zone which was similar to the population in the 101-1,000 m depth range.

Annual change in population numbers in the eastern Bering Sea can only be made in Region I. Population numbers in this area increased 3.1 times between 1980 and 1981 (Table 20). Although this may represent an actual increase in the population, it is believed that the major factor is the loss of sablefish from the longline gear during the 1980 survey to killer whales. Longline fishing operations in the eastern Bering Sea are frequently hampered by killer whales which take sablefish from the longlines as they are being retrieved (SASAKI, 1980b). For this reason, population densities are underestimated and the degree of underestimation varies from year to year depending on the intensity of the attacks by killer whales. Losses were heavy in 1979 and 1980, but those in 1981 and 1982 were relatively light (SASAKI, 1982 ; 1983).

There were no data available for the Western Aleutian Area in 1979. Thus changes in population numbers can only be made for the Eastern Aleutian Area back to that year. However, because most of the population in this region is distributed in the eastern Aleutians, changes in the population size in the Eastern Aleutian Area can be considered as representative of changes in the overall Aleutian Region population. In the eastern Aleutians, population numbers increased 2.4 times from 1979 to 1982 (Table 20). By depth, the population size in the 101-400 m depth range decreased year after year, but it increased by 25% in the 401-1,000 m depth range from 1980 to 1982 (Table 20). In the Eastern Aleutian Area, population numbers in the 401-1,000 m depth range increased 2.4 times in the period from 1979 to 1982.

In the Gulf of Alaska, population numbers increased 1.6 times in the period from 1979 to 1982 (Table 20). Annual changes in population numbers in the 101-400 m depth range were generally similar to those in the 101-1,000 m depth range (Table 20). The population size in depths greater than 401 m was 1.7 times higher in 1982 than in 1979.

(iii). Relative population weight (RPW)

The distribution and annual changes in RPW, which is a relative value of biomass, among areas or regions were similar to that shown by the RPN values (Table 21). The results of the 1982 survey reveal that the biomass in the eastern Bering Sea and Aleutian Region were each about 10% of that in the Gulf of Alaska (Table 21, Fig. 35). However, regional differences in

Table 20. Relative population numbers (RPN) in the 101—400 m and 401—1,000 m depth ranges by area of the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summers of 1979—1982.

Area	Year	Total		101—400 m		401—1,000 m	
		RPN	Annual change (%)	RPN	Annual change (%)	RPN	Annual change (%)
Eastern Bering Sea							
Region-I	1979[a]	786	− 1	132	− 77	654	+ 14
	1980[a]	777	+209	31	+952	746	+179
	1981[b]	2,404	+ 77	326	+137	2,078	+ 67
	1982[b]	4,244		772		3,472	
Region-II	1982[b]	7,808		3,913		3,895	
Region-III	1982	1,514		685		839	
Region-IV	1982	1,284		691		593	
Total	1982	14,850		6,061		8,789	
Aleutian Region							
West Aleutian	1980	1,804	− 10	32	+250	1,772	− 15
	1981	1,630	+ 34	112	+126	1,508	+ 28
	1982	2,189		253		1,936	
East Aleutian	1979	4,512	+150	984	+375	3,528	+ 87
	1980	11,278	− 13	4,677	− 43	6,601	+ 9
	1981	9,861	+ 9	2,673	− 16	7,188	+ 18
	1982	10,764		2,254		8,510	
Total	1980	13,082	− 12	4,709	− 41	8,373	+ 4
	1981	11,491	+ 13	2,785	− 10	8,706	+ 20
	1982	12,953		2,507		10,446	
Gulf of Alaska							
Shumagin	1979	5,347	+ 53	3,454	+ 91	1,893	− 18
	1980	8,163	+ 58	6,608	+ 60	1,555	+ 50
	1981	12,892	+ 28	10,557	+ 26	2,335	+ 37
	1982	16,542		13,351		3,191	
Chirikof	1979	30,716	− 16	27,958	− 15	2,758	− 24
	1980	25,947	− 11	23,856	− 15	2,091	+ 29
	1981	23,032	+ 59	20,336	+ 55	2,696	+ 94
	1982	36,655		31,438		5,217	
Kodiak	1979	24,134	+ 20	19,874	+ 30	4,260	− 27
	1980	28,877	− 20	25,784	− 28	3,093	+ 45
	1981	23,063	+ 50	18,580	+ 48	4,483	+ 58
	1982	34,595		27,490		7,105	
Yakutat	1979	14,873	+ 83	12,276	+ 99	2,597	+ 5
	1980	27,189	+ 4	24,456	− 2	2,733	+ 56
	1981	28,332	+ 12	24,070	+ 9	4,262	+ 26
	1982	31,714		26,335		5,379	
Southeastern	1979	10,428	+ 38	7,055	+ 56	3,373	± 0
	1980	14,395	+ 33	11,015	+ 36	3,380	+ 24
	1981	19,177	− 5	14,990	− 7	4,187	+ 1
	1982	18,224		13,980		4,244	
Total	1979	85,498	+ 22	70,617	+ 30	14,881	− 14
	1980	104,571	+ 2	91,719	− 3	12,852	+ 40
	1981	106,496	+ 29	88,533	+ 27	17,963	+ 40
	1982	137,730		112,594		25,136	

a RPN is considerably underestimated, because many of the sablefish caught by the longline gear were removed by killer whales in the course of hauling the gear.

b RPN is slightly underestimated because of predation of sablefish by killer whales.

Table 21. Relative population weight (RPW) as an index of biomass in the 101—400 m and 401—1,000 m depth ranges by area of the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summers of 1979—1982.

Area	Year	Total		101—400 m		401—1,000 m	
		RPW	Annual change (%)	RPW	Annual change (%)	RPW	Annual change (%)
Eastern Bering Sea							
Region-I	1980[a]	1,579		37		1,542	
	1981[b]	5,779	+266	835	+2,157	4,944	+221
	1982[b]	10,628	+ 84	1,762	+ 111	8,866	+ 79
Region-II	1982[b]	16,206		8,406		7,800	
Region-III	1982	3,721		1,664		2,057	
Region-IV	1982	2,983		1,546		1,437	
Total	1982	33,538		13,378		20,160	
Aleutian Region							
West Aleutian	1980	6,473		42		6,431	
	1981	6,014	− 7	337	+ 702	5,677	− 12
	1982	7,740	+ 29	587	+ 74	7,153	+ 26
East Aleutian	1979	12,545		c		c	
	1980	21,768	+ 74	6,476		15,292	
	1981	21,486	− 1	4,739	− 27	16,747	+ 10
	1982	23,244	+ 8	4,629	− 2	18,615	+ 11
Total	1980	28,241		6,518		21,723	
	1981	27,500	− 3	5,076	− 22	22,424	+ 3
	1982	30,834	+ 13	5,216	+ 3	25,768	+ 15
Gulf of Alaska							
Shumagin	1979	11,580		c		c	
	1980	17,819	+ 54	12,739		5,080	
	1981	27,851	+ 56	20,888	+ 64	6,963	+ 37
	1982	41,309	+ 48	31,353	+ 50	9,956	+ 43
Chirikof	1979	61,237		c		c	
	1980	57,951	− 5	51,319		6,632	
	1981	52,437	− 10	45,183	− 12	7,254	+ 9
	1982	87,115	+ 66	72,125	+ 60	14,990	+107
Kodiak	1979	55,413		c		c	
	1980	57,945	+ 5	48,955		8,990	
	1981	51,640	− 11	39,030	− 20	12,610	+ 40
	1982	79,715	+ 54	60,026	+ 54	19,689	+ 56
Yakutat	1979	35,148		c		c	
	1980	52,437	+ 49	44,994		7,443	
	1981	66,712	+ 27	55,991	+ 24	10,721	+ 44
	1982	67,076	+ 1	51,872	− 7	15,204	+ 42
Southeastern	1979	25,324		c		c	
	1980	27,982	+ 10	18,658		9,324	
	1981	51,123	+ 83	38,510	+ 106	12,613	+ 35
	1982	44,752	− 12	31,453	− 18	13,299	+ 5
Total	1979	188,702		c		c	
	1980	214,134	+ 13	176,665		37,469	
	1981	249,763	+ 17	199,602	+ 13	50,161	+ 34
	1982	319,967	+ 28	246,829	+ 24	73,138	+ 46

a RPW is considerably underestimated because many of the sablefish caught by the longline gear were removed by killer whales in the course of hauling the gear.

b RPW is slightly underestimated because of predation of sablefish by killer whales.

c Not available because of incomplete size composition by depth.

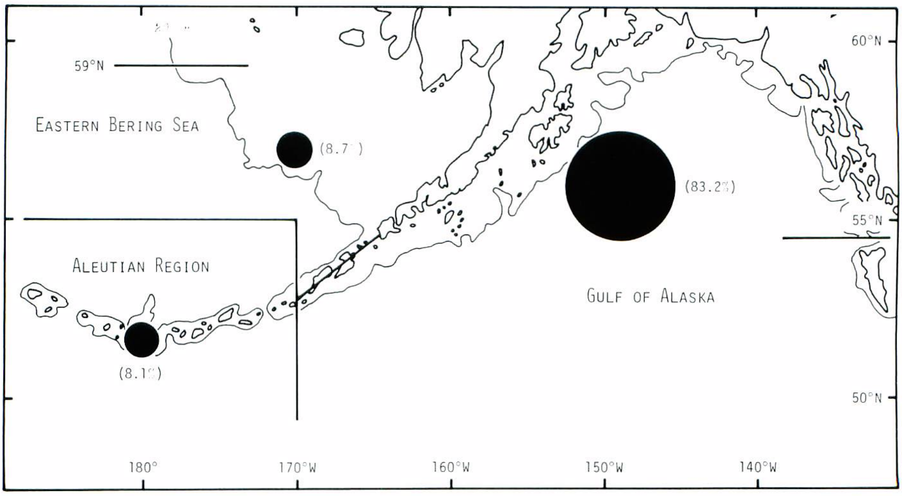

Fig. 35. Comparison of relative regional biomasses in the 101-1,000 m depth range of the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summer of 1982.

biomass were less in the 401-1,000 m depth range. If the relative biomass in the Gulf of Alaska is assigned a value of 100, the value in the eastern Bering Sea would be 28 and that in the Aleutian Region 35 (Table 21, Fig. 36). Nevertheless, these values show larger regional differences than did population numbers. This means that the proportion of medium and large fish in the Gulf of

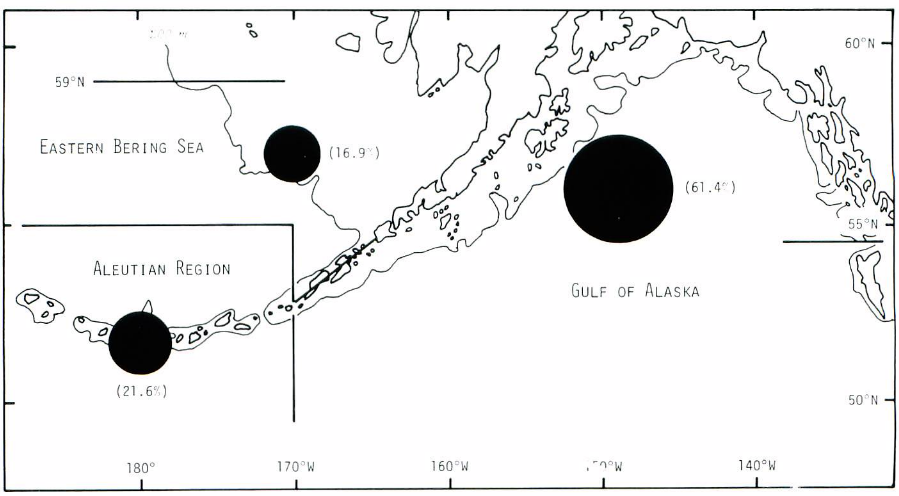

Fig. 36. Comparison of relative regional biomasses in the 401-1,000 m depth range of the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summer of 1982.

Alaska at depths of 401-1,000 m is larger than that in the eastern Bering Sea or the Aleutian Region.

Relative biomass estimates in the entire 101-1,000 m depth range among areas in the Gulf of Alaska were high in the Chirikof, Kodiak, and Yakutat Areas of the Gulf of Alaska (Table 21, Fig. 37). However, from a comparison of 3 year average estimates in the 401-1,000 m depth range, which is the major fishing ground for sablefish, the Kodiak, Southeastern, and Yakutat Areas show relatively large values (Table 21, Fig. 38), similar to that for population numbers. The biomass in the Chirikof Area is the 4th highest and that in the Shumagin Area the smallest.

Annual changes in biomass were also similar to those shown by population numbers, indicating a rising trend in both the Aleutian Region and Gulf of Alaska. However, the degree of change was a little different than that shown by population numbers (Table 21). Using the 1979 value as a base, the biomass in 1982 increased 1.9 times in the Eastern Aleutian Area and 1.7 times in the Gulf of Alaska. Annual changes in relative biomass in the eastern Bering Sea can only be made for Region I, and biomass in this area increased 3.7 times from 1980 to 1981 (Table 21). As mentioned before, it is believed that this degree of increase is overestimated because of the attacks by killer whales in 1980.

(iv). Size structure of the population

In the eastern Bering Sea, the size structure of the stock in 1982 in the 101-1,000 m depth range showed a nearly normal distribution with a modal peak at 58.5 cm (Table 22, Fig. 39). Compared with sablefish in the Aleutian Region and Gulf of Alaska, the proportion of fish in the eastern Bering Sea greater than 70.0 cm was extremely small, accounting for only 2% of the total population. The major part of the eastern Bering Sea population is believed to consist of the strong 1977 year class judging from the growth curve for this species, and the size structures and their annual changes observed in other regions. UMEDA *et al.* (1983) also reported that the 1982 population in the continental slope area in the eastern Bering Sea was probably predominated (approximately 90%) by age 5 fish of the 1977 year class.

In the Aleutian Region, the extremely abundant 1977 year class recruited to the population at depths greater than 100 m in 1980 (Table 22, Fig. 39). As a result of the recruitment of the 1977 year class, the population numbers in the size range from 50.0 to 65.9 cm increased rapidly. The population numbers for sizes exceeding 66.0 cm remained almost unchanged.

In the Gulf of Alaska, the abundant 1977 year class partially recruited to the population at depths greater than 100 m in 1979 (Table 23, Fig. 39). The abundance of this year class at these depths increased further in 1980, since then population numbers in the size range from 50.0 to 65.9 cm increased rapidly as in the Aleutian Region. As a result, the size structure changed from a near trapezoid pattern in 1979 to a normal unimodal pattern in 1982 with a modal peak at 56.0-57.9 cm. There was no significant change in population numbers for fish 66.0 cm or larger.

There were no differences in the size structure of sablefish by depth in the eastern Bering Sea (Table 24, Fig. 40). In the Aleutian Region, the recruitment of the 1977 year class was observed in 1980 in the depth zone of 101-200 m, but they had practically disappeared from this

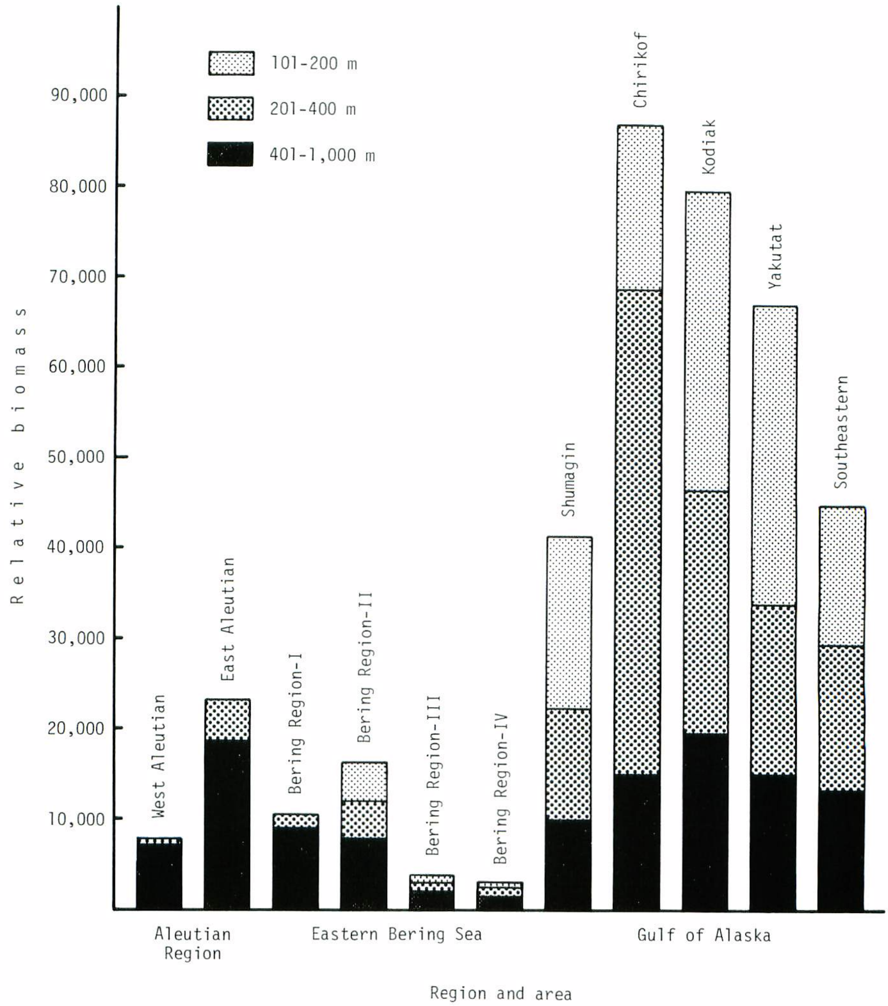

Fig. 37. Relative population weight as an index of biomass by area and depth in the 101-1,000 depth range of the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summer of 1982.

depth zone by 1981 (Table 24, Fig. 41). In the 201-400 m and 401-600 m depth zones, the 1977 year class increased in abundance year after year. Even in the 601-800 m depth zone there was some evidence of the 1977 year class. In the Gulf of Alaska more of the population inhabits depths less than 400 m than in the eastern Bering Sea and Aleutian Region (Table 25, Fig. 42). The size structure observed in the 101-200 m depth zone reflects the partial recruitment of the extremely strong 1977 year class which recruited partially to this depth zone in 1979 as mentioned before. The 1977 year class was observed in only low abundance during the 1978

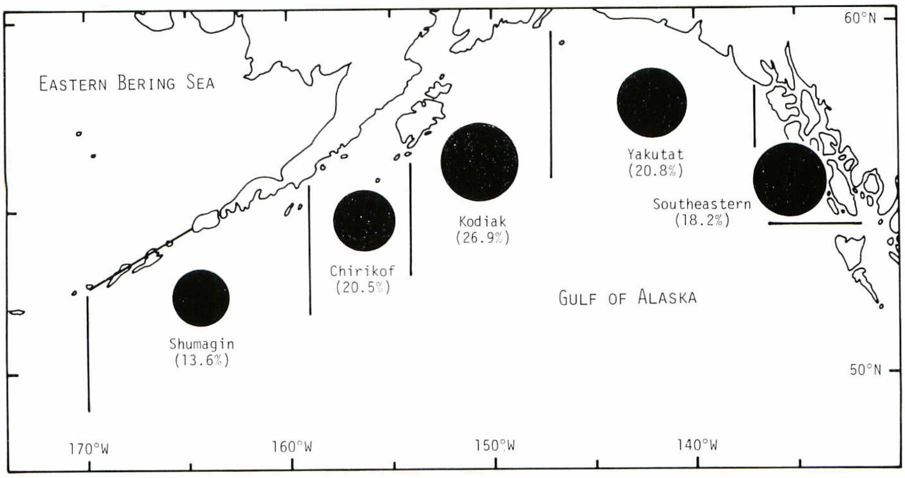

Fig. 38. Comparison of relative biomasses in the 401-1,000 m depth range by INPFC area of the Gulf of Alaska based on three years average values from 1980 to 1982 summer longline surveys.

survey (SASAKI, 1978b). At that time, the overall abundance of sablefish distributed in the 101-200 m depth zone was extremely low. Even at depths greater than 201 m since 1979, the increase in abundance of this year class was remarkable.

The relative biomass of middle and large-sized fish larger than 58.0 cm in fork length (with average body weight of 2.00 kg) which have high commercial value increased in 1982 than that of 1979 by 1.3 times for the Eastern Aleutian Area, and by 1.7 times for the Gulf of Alaska (Table 26).

1-2. Longline survey by *Aomori maru* in 1969

The *Aomori maru*, a fishery training vessel of the fishery high school of Aomori Prefecture, was commissioned in 1969 by the Fisheries Agency of Japan to conduct a groundfish survey in the Gulf of Alaska using bottom longline gear. This survey was chiefly to provide training for students in actual fishing operations, and secondarily to obtain data on the resources.

Fishing operations were mainly conducted in the 400-800 m depth range of the Kodiak and Yakutat Areas (Fig. 43) during 19 days with a total effort of 3,454 hachis and a total catch 33,444 sablefish (Table 27). A hachi used aboard the *Aomori maru* consisted of a 100 m groundline with 55 hooks, and ring-cut squid were used as bait. The mean catch rate for the combined Kodiak-Yakutat Region was 9.68 fish or 30.2 kg per hachi.

1-3. Japan-U.S. joint trawl survey

Since 1979, large-scale trawl surveys have been carried out jointly by Japan and the United States in the eastern Bering Sea and the Aleutian Region including continental slope

Table 22. Length frequency distributions of sablefish weighted by relative population numbers by area of the eastern Bering Sea and Aleutian Region in the summers of 1979—1982.

Fork length (cm)	Eastern Bering Sea							Aleutian Region										
	Region-I			Region-II	Region-III	Region-IV	Total	West Aleutian			East Aleutian				Total		
	1980	1981	1982	1982	1982	1982	1982	1980	1981	1982	1979	1980	1981	1982	1980	1981	1982
20~	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
36	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
38	—	—	—	—	—	—	—	—	—	—	10	—	—	—	—	—	—
40	—	—	—	—	1	—	1	—	—	—	30	—	4	2	—	4	2
42	—	—	4	—	—	—	4	2	—	—	22	16	6	3	18	6	3
44	7	7	1	10	—	—	11	16	—	—	40	232	35	9	248	35	9
46	51	20	7	43	2	—	52	79	—	—	115	1,018	178	110	1,097	178	110
48	84	63	45	131	7	5	188	155	8	8	92	1,914	578	349	2,069	586	357
50	110	122	131	390	21	24	566	194	27	11	90	1,928	1,205	863	2,122	1,232	874
52	80	233	228	837	62	60	1,187	123	43	36	146	1,227	1,503	1,336	1,350	1,546	1,372
54	68	209	322	1,158	118	140	1,738	84	33	63	140	692	1,394	1,605	776	1,427	1,668
56	78	206	465	1,435	177	178	2,255	103	46	110	302	567	1,059	1,522	670	1,105	1,632
58	70	262	494	1,254	202	216	2,166	110	40	131	459	440	763	1,217	550	803	1,348
60	42	280	564	1,012	258	218	2,052	133	81	180	531	465	641	1,010	598	722	1,190
62	21	289	545	712	234	199	1,690	127	155	244	530	476	490	842	603	645	1,086
64	38	255	478	456	204	126	1,264	137	156	215	427	449	399	616	586	555	831
66	47	183	432	205	128	79	844	137	231	195	447	458	392	426	595	623	621
68	26	107	272	108	72	22	474	105	160	214	385	362	336	318	467	496	532
70	26	70	144	34	26	6	210	92	127	175	232	342	214	174	434	341	349
72	26	33	55	19	5	6	85	62	136	142	164	214	178	120	276	314	262
74	6	24	24	1	1	4	30	42	90	147	172	152	152	94	194	242	241
76	—	10	17	1	2	2	22	33	82	70	75	104	107	50	137	189	120
78	—	13	6	1	1	—	8	18	61	59	45	53	74	42	71	135	101
80	—	11	6	—	1	1	8	11	34	47	36	28	64	18	39	98	65
82	—	1	3	—	—	—	3	11	33	45	22	37	26	7	48	59	52
84	—	1	—	—	—	—	—	11	19	21	8	36	31	13	47	50	34
86	—	1	—	—	—	—	—	4	13	23	—	11	17	5	15	30	28
88	—	1	—	—	—	—	—	7	9	23	8	23	9	3	30	18	26
90	—	—	—	—	—	—	—	1	9	11	—	6	4	1	7	13	12
92	—	1	1	—	—	—	1	4	9	7	—	12	4	1	16	13	8
94	—	—	—	—	—	—	—	1	8	9	—	8	—	7	9	8	16
96	—	—	—	—	—	—	—	—	2	2	—	3	4	—	3	6	2
98	—	—	—	—	—	—	—	2	10	5	—	6	2	—	8	12	5
100	—	—	—	—	—	—	—	1	2	2	—	1	—	—	2	2	2
102	—	—	—	—	—	—	—	—	2	—	—	—	2	—	—	4	—
104	—	—	—	—	—	—	—	1	—	—	—	3	—	—	4	—	—
106	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	780	2,402	4,244	7,807	1,522	1,286	14,859	1,806	1,626	2,195	4,528	11,283	9,871	10,763	13,089	11,497	12,958

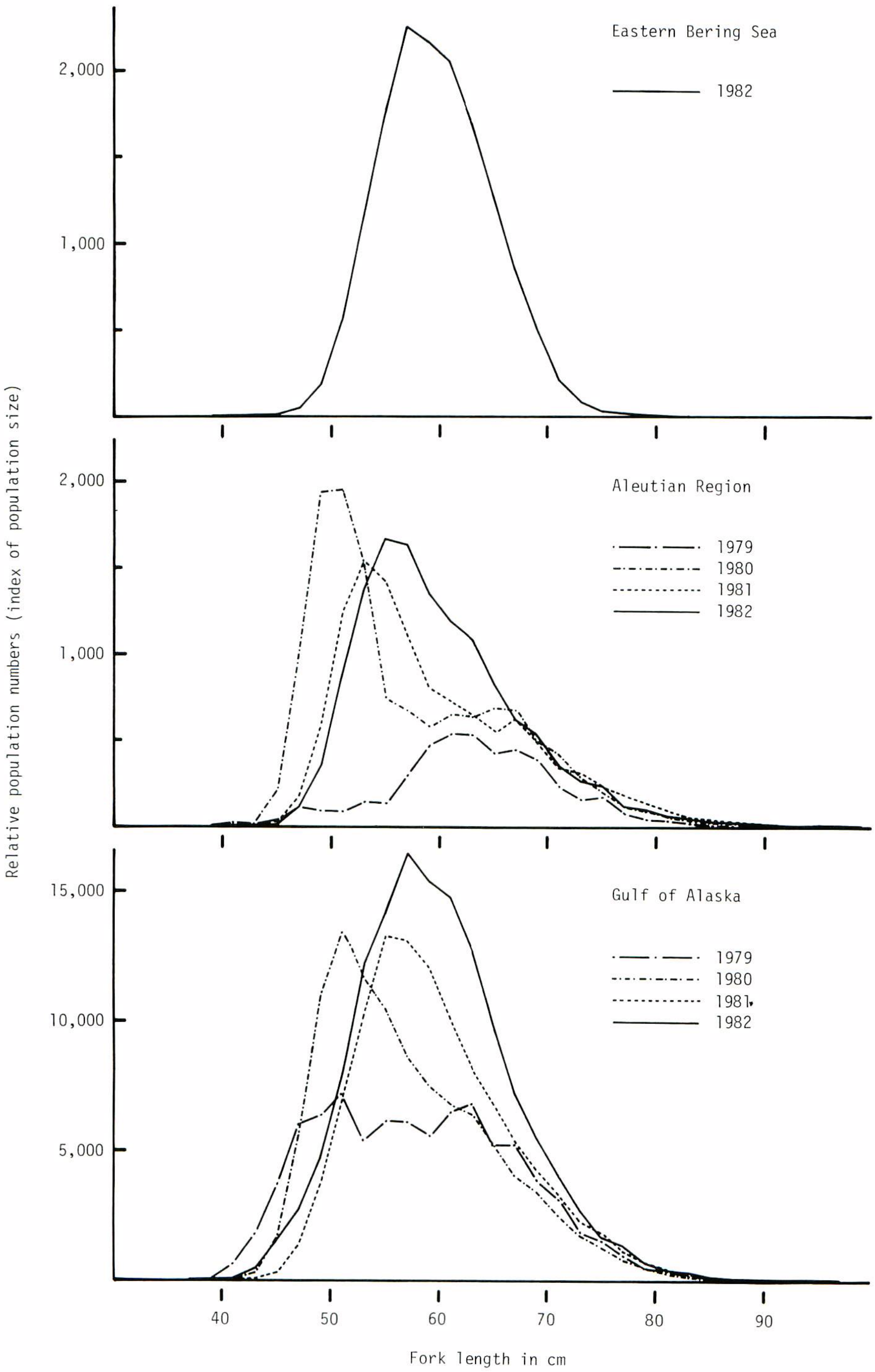

Fig. 39. Size structure of sablefish populations weighted by relative population numbers in the 101-1,000 m depth range of the eastern Bering Sea, Aleutian Region, and Gulf of Alaska from 1979 to 1982. The size structure for the Aleutian Region in 1979 is from only the eastern part of Aleutian Region.

Table 23. Length frequency distributions of sablefish weighted by relative population numbers by area of the Gulf of Alaska in the summers of 1979—1982.

Fork length (cm)	Gulf of Alaska																							
	Shumagin				Chirikof				Kodiak				Yakutat				Southeastern				Total			
	1979	1980	1981	1982	1979	1980	1981	1982	1979	1980	1981	1982	1979	1980	1981	1982	1979	1980	1981	1982	1979	1980	1981	1982
20～	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—	—	—	—	37	—	—	—	—	—	—	—	37	—	—
28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	—	—	—	—	—	—	—	—	—	—	—	—	—	37	—	—	—	—	—	—	—	37	—	—
32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—	—	—	—	—	—	92	—	—	—	—	—	—	—	92	—	—
36	—	—	—	—	—	—	—	—	—	—	—	10	—	92	—	—	—	—	—	12	—	92	—	22
38	5	—	—	—	—	—	—	—	31	—	—	10	21	—	—	4	8	—	—	12	65	—	—	26
40	47	7	5	—	234	1	—	—	187	1	1	6	119	2	—	9	71	17	2	31	658	28	8	46
42	122	9	2	9	578	5	4	10	426	39	15	12	313	135	31	333	355	177	13	137	1,794	365	65	501
44	201	52	50	5	1,280	101	21	101	770	263	46	199	625	323	111	942	818	932	66	324	3,694	1,671	294	1,571
46	381	419	118	52	2,285	676	151	332	1,317	1,063	346	463	1,132	1,495	479	1,254	875	2,142	269	602	5,990	5,795	1,363	2,703
48	421	821	410	231	2,406	1,828	428	924	1,634	3,069	1,193	976	1,249	2,794	1,043	1,823	667	2,431	592	799	6,377	10,943	3,666	4,753
50	537	963	1,060	605	2,866	2,646	1,174	2,029	1,805	4,707	1,944	1,921	1,354	3,397	1,726	2,205	630	1,669	1,093	1,204	7,192	13,382	6,997	7,964
52	444	897	1,705	1,149	2,268	2,559	2,127	3,163	1,406	4,142	2,519	3,180	919	3,131	2,465	3,216	348	995	1,439	1,476	5,385	11,724	10,255	12,184
54	442	776	2,030	1,504	2,717	2,731	3,093	3,446	1,686	3,006	2,911	3,685	959	3,569	3,480	4,025	368	485	1,702	1,592	6,172	10,567	13,216	14,252
56	395	671	1,744	1,694	2,702	2,019	3,117	4,125	1,847	2,263	2,942	4,659	823	3,323	3,480	4,333	365	411	1,755	1,644	6,132	8,687	13,098	16,455
58	324	552	1,459	2,042	2,333	2,406	3,182	4,537	1,808	1,824	2,589	4,199	536	2,322	3,146	3,095	441	444	1,678	1,556	5,442	7,548	12,054	15,429
60	363	505	1,217	2,093	2,843	2,365	2,535	4,599	1,841	1,734	1,893	3,818	728	1,581	2,808	2,673	706	641	1,630	1,608	6,481	6,826	10,083	14,791
62	323	464	856	1,975	2,774	2,309	2,069	3,572	2,044	1,506	1,547	3,607	891	1,407	2,205	2,113	819	732	1,588	1,477	6,851	6,418	8,265	12,744
64	275	411	580	1,653	1,875	1,701	1,677	3,005	1,607	1,472	1,215	2,375	839	851	1,889	1,453	742	839	1,508	1,304	5,338	5,274	6,869	9,790
66	238	408	494	1,215	1,520	1,466	1,212	2,146	1,778	968	1,047	1,611	951	551	1,362	1,110	775	648	1,320	1,146	5,262	4,041	5,435	7,228
68	207	366	355	835	1,021	1,099	904	1,696	1,197	872	766	1,273	839	573	1,156	859	657	503	1,081	821	3,921	3,413	4,262	5,484
70	188	250	246	602	622	758	542	1,158	1,004	653	733	996	831	481	959	624	497	379	872	664	3,142	2,521	3,352	4,044
72	136	216	194	341	131	444	302	780	639	492	519	588	582	359	604	561	422	298	682	477	1,910	1,809	2,301	2,747
74	108	129	136	205	144	374	183	385	511	318	339	390	476	241	599	360	309	242	602	389	1,548	1,304	1,859	1,729
76	98	100	81	121	44	202	94	345	292	229	200	301	303	190	330	275	252	152	453	319	989	873	1,158	1,361
78	39	61	66	75	24	137	51	132	135	125	147	137	190	116	185	167	94	87	333	226	482	526	782	737
80	29	37	27	58	38	59	67	61	109	75	82	89	103	63	133	124	72	66	212	139	351	300	521	471
82	11	18	31	27	11	28	18	69	22	30	45	38	46	35	70	75	46	46	151	106	136	157	315	315
84	13	10	14	19	8	4	13	15	8	9	16	26	22	15	28	30	24	22	68	68	75	60	139	158
86	—	7	10	9	5	7	5	13	1	8	5	21	24	4	26	21	11	6	24	39	41	32	70	103
88	—	2	2	9	2	6	1	5	6	6	1	4	3	10	11	12	25	5	23	28	36	29	38	58
90	—	—	—	4	5	—	—	3	2	2	1	3	1	2	—	8	5	—	8	9	13	4	9	27
92	—	1	1	—	7	—	—	—	—	—	—	—	2	—	—	—	17	—	10	3	26	1	11	3
94	—	—	—	5	—	—	—	1	—	—	1	—	—	—	—	—	—	—	1	3	—	—	2	9
96	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	2	—	—	3	2	—	—	4	5
98	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	1	1	1
100	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	2
102	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	1	1
104	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
106	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	5,347	8,152	12,894	16,539	30,743	25,932	23,030	36,652	24,113	28,876	23,063	34,597	14,881	27,228	28,327	31,706	10,419	14,369	19,179	18,220	85,503	104,557	106,493	137,714

Table 24. Length frequency distributions of sablefish weighted by relative population numbers by depth of the eastern Bering Sea and Aleutian Region in the summers of 1980—1982.

Fork length (cm)	Eastern Bering Sea						Aleutian Region																		
	101-200m	201-400m	401-600m	601-800m	801-1,000m	Total	101-200 m			201-400 m			401-600 m			601-800 m			801-1,000 m			Total		
	1982	1982	1982	1982	1982	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982
20~	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
36	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
38	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40	—	1	—	—	—	1	—	—	—	—	2	2	—	2	—	—	—	—	—	—	—	—	4	2
42	—	1	2	1	—	4	—	2	—	9	—	—	5	—	1	4	2	2	—	2	—	18	6	3
44	—	4	4	2	1	11	95	—	—	72	16	2	56	12	4	22	2	—	3	5	3	248	35	9
46	3	19	12	10	8	52	373	4	—	339	56	9	239	67	47	126	44	48	20	7	8	1,097	178	110
48	14	51	52	55	16	188	576	18	—	683	183	19	586	244	156	170	125	159	54	16	23	2,069	586	357
50	44	124	194	153	51	566	478	38	—	639	399	146	731	546	368	224	231	327	50	18	33	2,122	1,232	874
52	134	274	346	336	97	1,187	276	65	6	410	459	215	539	701	624	96	303	476	29	18	51	1,350	1,546	1,372
54	255	469	480	395	139	1,738	134	79	13	217	414	408	294	649	745	97	254	454	34	31	48	776	1,427	1,668
56	416	594	506	551	188	2,255	58	83	11	143	344	448	209	418	750	136	217	383	124	43	40	670	1,105	1,632
58	468	579	431	493	195	2,166	4	48	13	46	173	425	196	322	572	98	201	293	206	59	45	550	803	1,348
60	475	499	430	453	195	2,052	2	20	13	37	116	317	172	265	510	193	212	267	194	109	83	598	722	1,190
62	351	384	396	375	184	1,690	28	9	2	34	63	210	123	239	468	235	194	296	183	140	110	603	645	1,086
64	225	253	346	296	144	1,264	—	2	2	16	41	132	152	189	387	232	210	182	186	113	128	586	555	831
66	108	149	314	173	100	844	—	—	—	12	37	57	109	214	261	314	241	208	160	131	95	595	623	621
68	41	71	205	97	60	474	—	4	—	7	35	26	112	161	212	244	184	183	104	112	111	467	496	532
70	8	31	101	38	32	210	—	—	—	13	15	14	91	133	152	231	144	121	99	49	62	434	341	349
72	2	8	29	22	24	85	—	—	—	2	24	11	80	120	91	140	111	122	54	59	38	276	314	262
74	—	3	13	2	12	30	—	—	—	3	8	4	51	85	59	81	88	96	59	61	82	194	242	241
76	—	1	9	3	9	22	—	—	—	—	10	3	29	63	39	82	78	45	26	38	33	137	189	120
78	—	—	1	2	5	8	—	—	—	—	11	—	23	49	31	39	53	40	9	22	30	71	135	101
80	—	1	4	—	3	8	—	—	—	3	—	—	9	37	16	27	39	37	—	22	12	39	98	65
82	—	1	2	—	—	3	—	—	—	—	2	—	10	33	19	18	19	23	20	5	10	48	59	52
84	—	—	—	—	—	—	—	—	—	—	2	—	3	17	8	18	22	16	26	9	10	47	50	34
86	—	—	—	—	—	—	—	—	—	—	—	—	2	13	9	4	10	11	9	7	8	15	30	28
88	—	—	—	—	—	—	—	—	—	—	—	—	—	6	4	14	12	17	16	—	5	30	18	26
90	—	—	—	—	—	—	—	—	—	—	—	—	—	6	3	4	2	9	3	5	—	7	13	12
92	—	—	—	1	—	1	—	—	—	—	—	—	2	6	3	14	2	3	—	5	2	16	13	8
94	—	—	—	—	—	—	—	—	—	—	—	—	2	2	4	4	6	5	3	—	7	9	8	16
96	—	—	—	—	—	—	—	—	—	—	2	—	—	2	2	—	2	—	3	—	—	3	6	2
98	—	—	—	—	—	—	—	—	—	—	2	—	2	2	2	6	3	3	—	5	—	8	12	5
100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	2	—	—	—	—	2	2	2
102	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	2	—	—	—	—	—	4	—
104	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	4	—	—
106	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	2,544	3,517	3,877	3,458	1,463	14,859	2,024	372	60	2,685	2,414	2,448	3,827	4,605	5,549	2,879	3,015	3,824	1,674	1,091	1,077	13,089	11,497	12,958

Table 25. Length frequency distributions of sablefish weighted by relative population numbers by depth of the Gulf of Alaska in the summers of 1980—1982.

Fork length (cm)	Gulf of Alaska																	
	101-200 m			201-400 m			401-600 m			601-800 m			801-1,000 m			Total		
	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982
20~	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	37	—	—	—	—	—	—	—	—	—	—	—	—	—	—	37	—	—
28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	37	—	—	—	—	—	—	—	—	—	—	—	—	—	—	37	—	—
32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
34	92	—	—	—	—	—	—	—	—	—	—	—	—	—	—	92	—	—
36	92	—	22	—	—	—	—	—	—	—	—	—	—	—	—	92	—	22
38	—	—	22	—	—	4	—	—	—	—	—	—	—	—	—	—	—	26
40	15	5	23	6	2	18	3	—	4	4	1	1	—	—	—	28	8	46
42	242	23	370	66	21	110	37	8	9	17	12	10	3	1	2	365	65	501
44	972	109	1,148	460	66	335	142	54	32	75	59	50	22	6	6	1,671	294	1,571
46	3,968	442	1,763	1,411	432	700	280	260	109	118	206	115	18	23	16	5,795	1,363	2,703
48	7,575	1,586	2,903	2,851	1,212	1,314	364	524	257	127	306	249	26	38	30	10,943	3,666	4,753
50	9,646	3,579	4,764	3,267	2,383	2,362	320	697	420	127	292	357	22	46	61	13,382	6,997	7,964
52	8,371	6,212	7,344	2,945	3,055	3,638	262	713	706	97	242	414	49	33	82	11,724	10,255	12,184
54	7,500	8,514	8,129	2,660	3,737	4,695	215	718	880	120	192	419	72	55	129	10,567	13,216	14,252
56	5,407	8,176	9,144	2,661	3,899	5,559	281	714	1,084	182	211	452	156	98	216	8,687	13,098	16,455
58	3,682	6,791	7,530	3,027	4,060	5,840	343	767	1,145	249	260	593	247	176	321	7,548	12,054	15,429
60	2,325	4,599	6,319	3,432	4,025	6,157	422	821	1,257	342	371	660	305	267	398	6,826	10,083	14,791
62	1,701	2,999	4,712	3,460	3,698	5,599	507	839	1,223	418	424	711	332	305	499	6,418	8,265	12,744
64	880	1,940	2,630	3,194	3,381	4,781	449	803	1,077	416	429	749	335	316	553	5,274	6,869	9,790
66	496	1,267	1,588	2,427	2,717	3,433	410	695	902	405	422	757	303	334	548	4,041	5,435	7,228
68	548	814	924	1,830	2,197	2,671	393	590	749	354	389	659	288	272	481	3,413	4,262	5,484
70	296	589	372	1,401	1,656	2,000	311	472	577	298	365	621	215	270	474	2,521	3,352	4,044
72	90	258	278	987	1,171	1,224	266	377	412	263	287	459	203	208	374	1,809	2,301	2,747
74	77	298	119	683	916	712	193	264	282	198	210	312	153	171	304	1,304	1,859	1,729
76	71	88	66	385	573	567	134	183	195	171	151	277	112	163	256	873	1,158	1,361
78	20	32	18	237	410	280	101	136	107	99	103	183	69	101	149	526	782	737
80	5	44	—	107	256	139	58	63	88	72	68	105	58	90	139	300	521	471
82	5	9	13	53	168	136	25	36	40	35	42	61	39	60	65	157	315	315
84	—	5	5	14	61	50	12	17	27	17	27	35	17	29	41	60	139	158
86	—	—	—	—	29	26	7	15	19	14	15	27	11	11	31	32	70	103
88	—	—	—	6	20	23	6	8	9	6	5	10	11	5	16	29	38	58
90	—	—	—	—	7	6	2	1	2	2	1	8	—	—	11	4	9	27
92	—	—	—	—	7	—	—	2	—	1	1	2	—	1	1	1	11	3
94	—	—	—	—	—	—	—	1	3	—	1	1	—	—	5	—	2	9
96	—	—	—	—	—	2	—	1	—	—	—	1	—	3	2	—	4	5
98	—	—	—	—	—	—	—	—	—	1	—	—	—	1	1	1	1	1
100	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	—	—	2
102	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	1	1
104	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
106	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	54,150	48,379	60,206	37,570	40,159	52,381	5,543	9,779	11,615	4,228	5,092	8,299	3,066	3,084	5,213	104,557	106,493	137,714

Table 26. Relative population weight (RPW) of small (<58 cm in FL), middle and large (58 cm ≦ in FL) sizes, and total sablefish in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in the summers of 1979—1982.

Area	Year	Total		Small sized		Middle-large sized	
		RPW	Annual change (%)	RPW	Annual change (%)	RPW	Annual change (%)
Eastern Bering Sea							
Region-I	1980[a]	1,579		688		891	
	1981[b]	5,779	+266	1,363	+ 98	4,416	+396
	1982[b]	10,628	+ 84	2,018	+ 48	8,610	+ 95
Region-II	1982[b]	16,206		6,695		9,511	
Region-III	1982	3,721		669		3,052	
Region-IV	1982	2,983		706		2,277	
Total	1982	33,538		10,088		23,450	
Aleutian Region							
West Aleutian	1980	6,473		262		6,211	
	1981	6,014	− 7	254	− 3	5,760	− 7
	1982	7,740	+ 29	395	+ 56	7,345	+ 28
East Aleutian	1979	12,545		1,459		11,086	
	1980	21,768	+ 74	10,474	+618	11,294	+ 2
	1981	21,486	− 1	9,169	− 12	12,317	+ 9
	1982	23,244	+ 8	9,335	+ 2	13,909	+ 13
Total	1980	28,241		10,736		17,505	
	1981	27,500	− 3	9,423	− 12	18,077	+ 3
	1982	30,984	+ 13	9,730	+ 3	21,254	+ 18
Gulf of Alaska							
Shumagin	1979	11,580		4,087		7,493	
	1980	17,819	+ 54	6,698	+ 64	11,121	+ 48
	1981	27,851	+ 56	11,420	+ 70	16,431	+ 48
	1982	41,309	+ 48	8,667	− 24	32,642	+ 99
Chirikof	1979	61,237		23,953		37,284	
	1980	57,951	− 5	18,831	− 21	39,120	+ 5
	1981	52,437	− 10	16,775	− 11	35,662	− 9
	1982	87,115	+ 66	22,734	+ 36	64,381	+ 81
Kodiak	1979	55,413		15,360		40,053	
	1980	57,945	+ 5	26,939	+ 75	31,006	− 23
	1981	51,640	− 11	18,772	− 30	32,868	+ 6
	1982	79,715	+ 54	24,338	+ 30	55,377	+ 68
Yakutat	1979	35,148		9,924		25,224	
	1980	52,437	+ 49	26,992	+172	25,445	+ 1
	1981	66,712	+ 27	20,420	− 24	46,292	+ 82
	1982	67,076	+ 1	27,445	+ 34	39,631	− 14
Southeastern	1979	25,324		5,433		19,891	
	1980	27,982	+ 10	11,389	+110	16,593	− 17
	1981	51,123	+ 83	10,916	− 4	40,207	+142
	1982	44,752	− 12	11,664	+ 7	33,088	− 18
Total	1979	188,702		58,757		129,945	
	1980	214,134	+ 13	90,849	+ 55	123,285	− 5
	1981	249,763	+ 17	78,303	− 14	171,460	+ 39
	1982	319,967	+ 28	94,848	+ 21	225,119	+ 31

a RPW is considerably underestimated because many of sablefish caught by the longline gear were removed by killer whales in the course of hauling the gear.

b RPW is slightly underestimated because of removals of sablefish by killer whales.

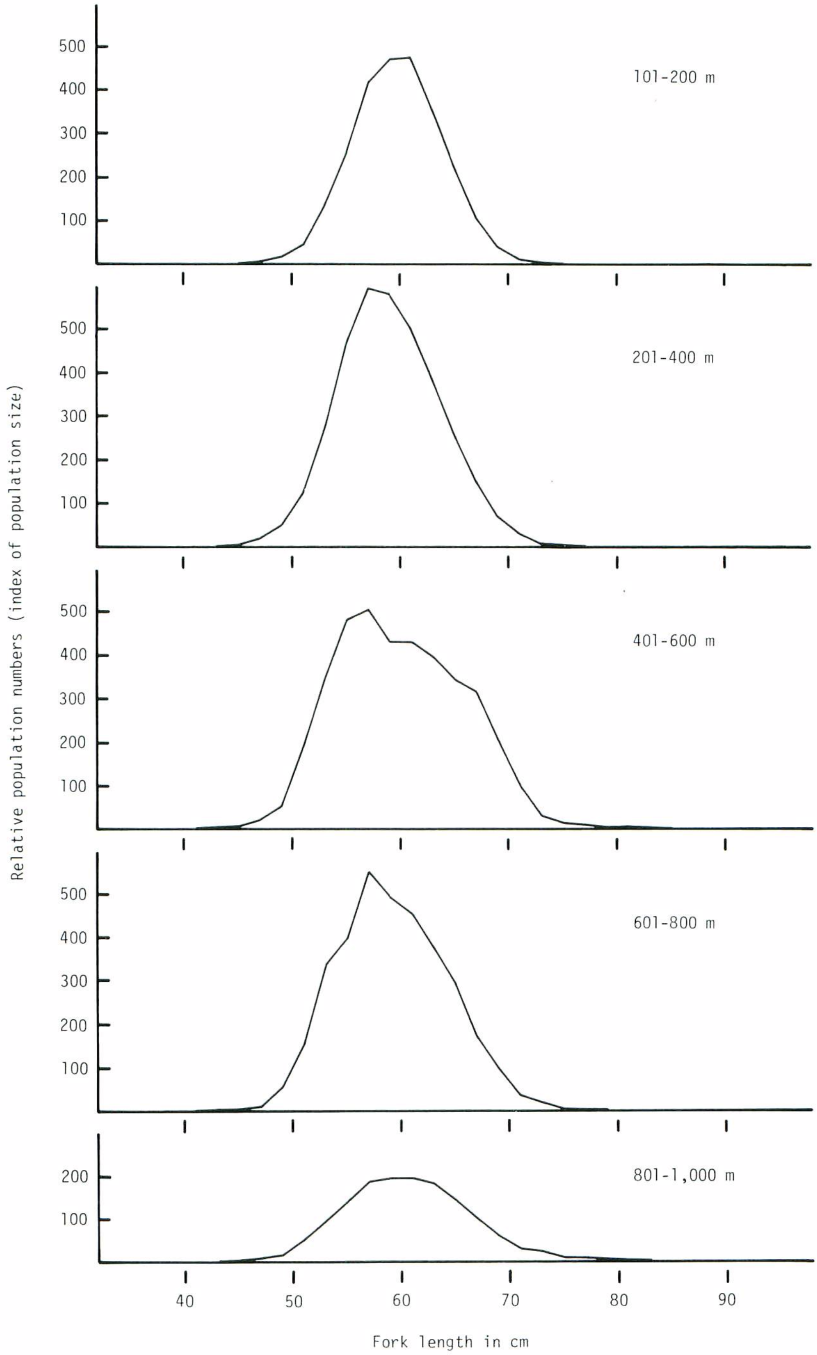

Fig. 40. Size structure of sablefish populations, weighted by relative population numbers, by depth of the eastern Bering Sea in the summer of 1982.

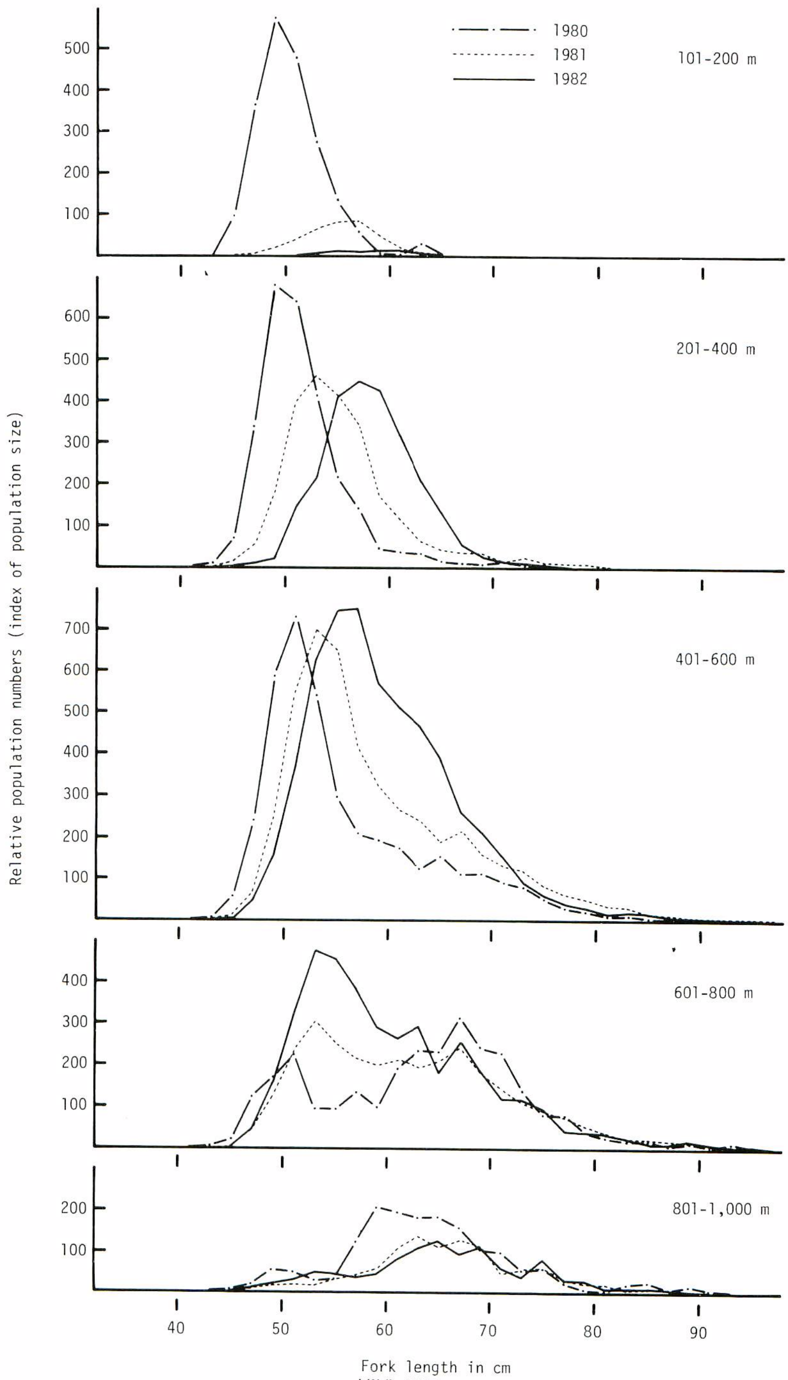

Fig. 41. Size structure of sablefish populations, weighted by relative population numbers, by depth of the Aleutian Region in the summers of 1980-1982.

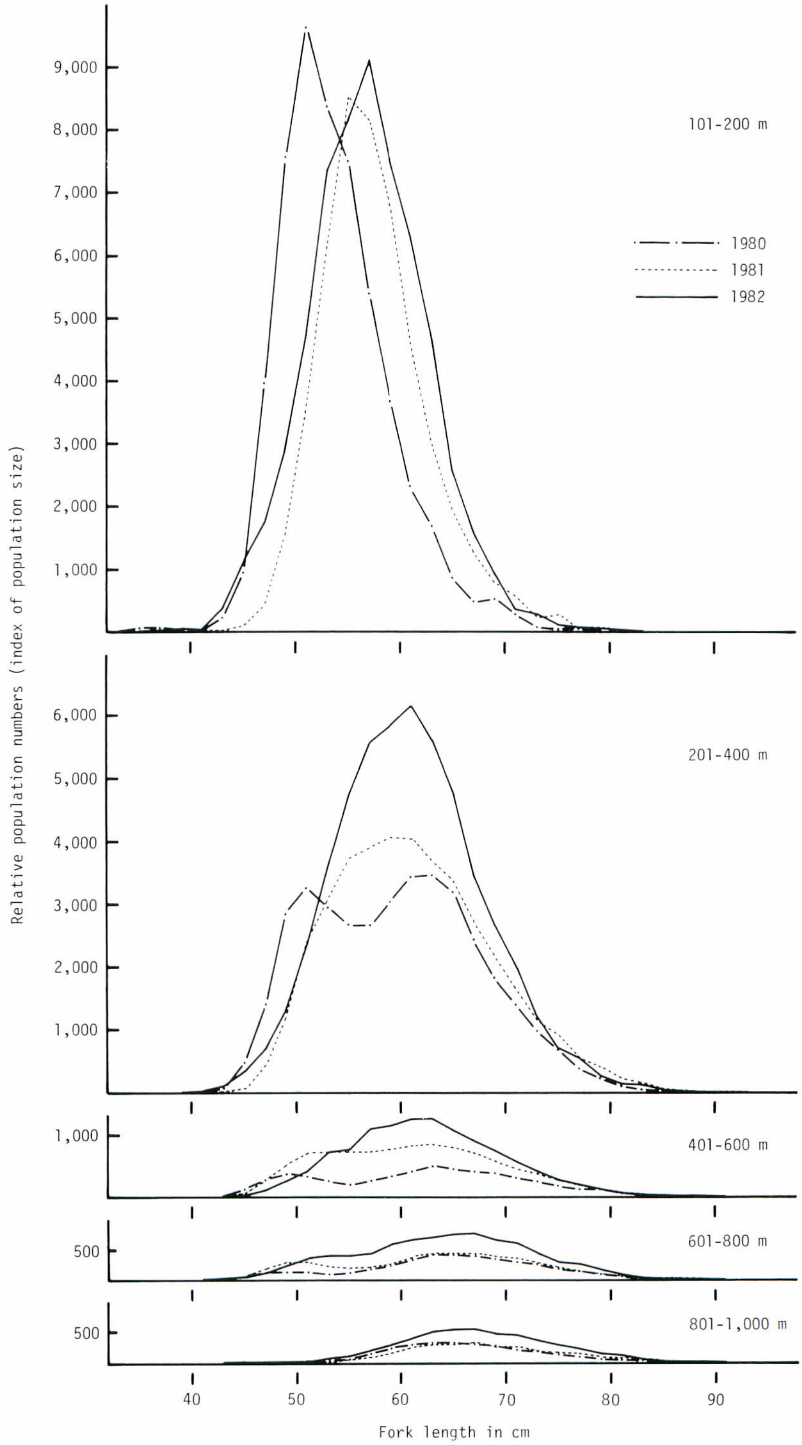

Fig. 42. Size structure of sablefish populations, weighted by relative population numbers, by depth of the Gulf of Alaska in the summers of 1980-1982.

Table 27. Operational records of the *Aomori maru* during the longline survey in the Gulf of Alaska in the summer of 1969.

Area	Operation number	Date	Depth (m)	Number of hachi fished	Nmuber of hooks fished	Bait	Soaking time	Number of sablefish caught	Catch rates[a]	Average catch rates[b]
Kodiak	L- 1	June 11	450-730	120	6,600	Squid	8^{h}-40^{m}	1,226	10.22	
	L- 2	12	450-830	160	8,800	〃	9 -35	1,111	6.94	
	L- 3	13	410-630	180	9,900	〃	10 -07	2,053	11.41	
	L- 4	14	500-550	200	11,000	〃	10 -16	2,347	11.74	
	L- 5	15	580-700	230	12,650	〃	13 -30	2,219	9.65	
	L- 6	16	510-600	240	13,200	〃	16 -20	2,121	8.84	
	L- 7	18	760-800	150	8,250	〃	11 -34	940	6.27	
	L- 8	19	480-610	215	11,825	〃	15 -35	1,921	8.93	
	L- 9	20	500-750	220	12,100	〃	14 -00	1,249	5.68	
	L-10	21	500-700	249	13,695	〃	14 -14	1,977	7.94	
	L-11	22	500-700	160	8,800	〃	11 -13	855	5.34	
	Total			2,124	116,820			18,019	8.45	7.10
Yakutat	L-12	June 24	550-600	170	9,350	Squid	10 -00	1,968	11.58	
	L-13	25	500-750	180	9,900	〃	11 -45	2,774	15.41	
	L-14	26	550-700	180	9,900	〃	12 -50	2,315	12.86	
	L-15	27	550-750	170	9,350	〃	11 -30	1,314	7.73	
	L-16	28	500-680	180	9,900	〃	11 -05	2,333	12.96	
	L-17	29	500-800	190	10,450	〃	10 -50	2,226	11.72	
	L-18	30	550-800	190	10,450	〃	15 -00	1,675	8.82	
	L-19	July 1	600-650	70	3,850	〃	8 -03	820	11.71	
	Total			1,330	73,150			15,425	11.60	9.74
South-eastern	L-20	July 2	500-780	80	4,400	Squid	7 -52	1,097	13.71	
	L-21	3	600-800	50	2,750	〃	8 -10	806	16.12	
	Total			130	7,150			1,903	14.92	12.53
Charlotte	L-22	July 4	740-870	50	2,750	Squid	6 -00	652	13.04	
	L-23	5	500-650	60	3,300	〃	7 -10	643	10.72	
	L-24	6	720-880	60	3,300	〃	4 -00	864	14.40	
	Total			170	9,350			2,159	12.72	10.68
Vancouver	L-25	July 7	640-1,450	45	2,475	Squdi	6 -35	383	8.51	7.15

a Original catch rates (number of fish per hachi with 55 hooks).

b Converted catch rates (number of fish per hachi with 45 hooks).

waters. Trawl and longline surveys were both conducted in 1980 in the Aleutian Region and in 1982 in the eastern Bering Sea. The results of the 1982 trawl survey have not yet been reported. One of the purposes of the trawl survey is to estimate the biomass of all demersal species in the depth range from about 10 to 600 fathoms using the area-swept method.

Based on a 1979 trawl survey the sablefish biomass in the eastern Bering Sea was estimated to be 45,400 tons (BAKKALA *et al.*, 1982). Preliminary data indicated that the estimated biomass during the 1981 trawl survey was 47,000 tons, 3.5% larger than in 1979 (data exchange between NWAFC and FSFRL). According to the 1979 survey report, 97% (44,200 tons) of the

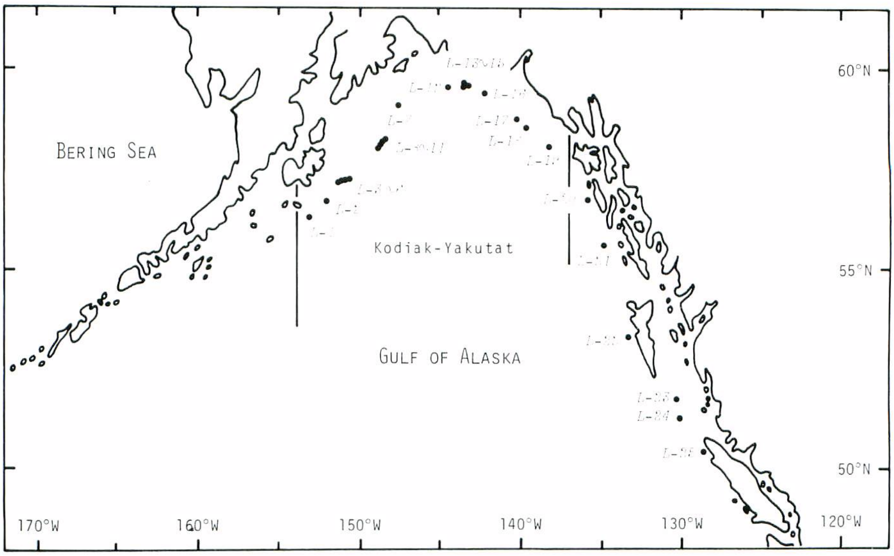

Fig. 43. Survey area and fishing positions during the longline survey by *Aomori maru* in the Gulf of Alaska in the summer of 1969.

sablefish biomass was distributed in waters southeast of the Pribilof Islands. However, the 1981 survey revealed that 40% (18,800 tons) of the biomass was distributed in the area northwest of the Pribilof Islands. A major part of the eastern Bering Sea population was composed of the extremely abundant 1977 year class (BAKKALA *et al.*, 1982). In the Aleutian Region, a preliminary report of results from the 1980 trawl survey indicate that the biomass of sablefish in the 101-900 m depth range (excluding Bowers Bank) was 19,464 tons (data exchange between the NWAFC and FSFRL).

1-4. Estimates of regional biomass in recent years

In 1980, both a trawl survey as well as the longline survey were conducted in the Aleutian Region, which made it possible to relate relative biomass (RPW) from the longline survey to biomass estimates from the trawl survey in the 101-900 m depth range. By using this relationship and the 1982 RPW values to estimate biomass in other regions, the 1982 estimates were 32,788 tons in the eastern Bering Sea, 25,552 tons in the Aleutian Region, and 263,869 tons in the Gulf of Alaska (Table 28). Using this same method, the biomass in the Gulf of Alaska in 1979 was estimated to be 155,618 tons. This shows that the biomass in 1982 increased by 108,251 tons from the level of 1979.

The 1982 longline survey in the eastern Bering Sea did not extend north of 59°N unlike the trawl surveys in this region. The biomass in the area not surveyed was estimated using results from the 1981 trawl survey. Additionally, the biomass estimated from the 1981 trawl survey in the eastern Bering Sea was revised to 55,000 tons for the whole area using the result of the 1982 longline survey for the area not surveyed by trawl.

Table 28. Biomass estimates of sablefish in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska in recent years, based on results of trawl and longline surveys.

Year	Eastern Bering Sea		Aleutian Region		Gulf of Alaska
	Trawl[a]	Longline[b]	Trawl[a]	Longline[b]	Longline[b]
1979	45,400	—	—	—	155,618
1980	—	—	19,464	—	176,591
1981	55,000	—	—	22,679	205,973
1982	c	32,788	—	25,552	263,869

a Estimated from U.S.-Japan trawl survey data in the depth range of < 100—900m.

b Estimated from the relationship between a biomass estimate from a trawl survey and a relative biomass value from a longline survey in the Aleutian Region in 1980. The depth range for the estimates are 101-1,000 m.

c Unavailable.

2. Present stock condition based on results of the longline surveys

In order to compare results between the Japan-U.S. joint longline surveys since 1979 with those from the 1969 survey by the *Aomori maru*, mean catches per hachi in number and weight for the 401-800 m depth range of the Kodiak-Yakutat Region were calculated from the 1979-82 joint longline survey data. During the Japan-U.S. joint longline surveys, the longline gear had 45 hooks per hachi, while the longline gear used aboard the *Aomori maru* had 55 hooks per hachi. The length of groundline was the same. Thus the catch rate from the *Aomori maru* survey was converted to 45 hooks per hachi on the basis of the ralationship between hook spacing and catch rates (SASAKI, 1979b). The results are shown in Table 29.

Table 29. Changes in relative abundance of sablefish as indices of population size in the 401-800 m depth range of the Kodiak-Yakutat Region in the Gulf of Alaska, based on results of 1969 and 1979-1982 longline surveys.

Index	1969	1979	1980	1981	1982
Number of fish per hachi	8.22	5.58	5.60	8.71	11.48
Weight in kg per hachi	25.4	16.7	15.6	22.3	30.2

The exploitation of sablefish in the Gulf of Alaska had remained at a low level and was limited to traditional localized fishing grounds until 1968. Therefore, the 1969 stock level was considered to be only slightly exploited. Based on a comparison of catch rates from the *Aomori maru* survey and the Japan-U.S. joint surveys, the population in 1979 and 1980 was 61-66% by weight of that in 1969. However, in 1982 the population was 1.2 times higher by weight over the level in 1969. Size composition data shows that this increase was caused by a large influx of the extremely strong 1977 year class into the 401-800 m depth zone since 1981 (Fig. 44). The size composition shows that the abundance of sablefish in the mid-portion of the mode was reduced in 1979 and 1980 from that in 1969. However, the range in lengths and the modal peak of the size compositions remained practically unchanged.

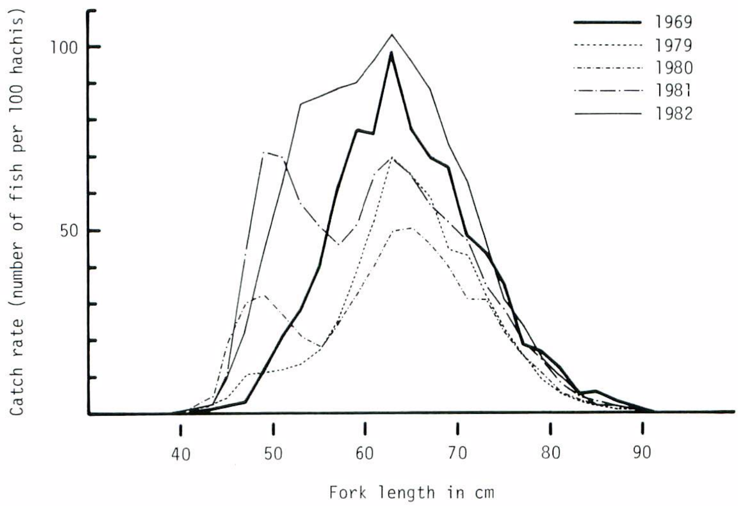

Fig. 44. Size compositions of sablefish weighted by catch rates in the 401-800 m depth range of the Kodiak-Yakutat Region in the Gulf of Alaska from 1969 and 1979-1982 longline surveys.

Because the above discussion was based on survey data from the 401-800 m depth range in the Kodiak-Yakutat Region, they do not apply to the overall population in the Gulf of Alaska. However, after 1969 sablefish in the Gulf of Alaska have chiefly been exploited by Japanese longline vessels in the 401-800 m depth range. It should also be noted that the biomass in the 401-800 m depth range of the Kodiak-Yakutat Region accounts for about half of the total biomass in this depth range over the entire Gulf of Alaska. Therefore, it seems unlikely that a serious mistake would be made by extending the results of this study to the entire Gulf of Alaska.

3. Discussion

Since there was no precedent for a large-scale systematic groundfish survey using bottom longline gear, it was necessary to plan the survey carefully. The most important consideration was whether the abundance of the sablefish stock could be accurately estimated by longline gear. The advantages of a longline survey are that there are less limitations in operations due to bottom contours and water depth, the size of the research vessel or the horsepower of the engine will not affect the efficiency of the fishing gear, and the fishing gear is so simple that fishing techniques will not be altered by changes in fishing personnel making it possible to conduct the surveys under similar conditions each year. On the other hand, disadvantages are that stock abundance can only be estimated in terms of relative values, catch rates may be underestimated when fishing operations are hampered by predators removing fish from the longlines while retrieving the gear such as the case of killer whales in this study, and longlines are only effective for limited kinds of species of fish as will be mentioned below.

Because the longline gear is stationary, it is impossible to cover many survey stations in a limited period of time as is the case during trawl surveys. For this reason, longline surveys are not suitable for accurately estimating abundance of species of fish that tend to move in schools and change their patterns of distribution. It was found from results of the 1978 survey that, although the density distribution of sablefish varies greatly by area and water depth, differences in variances of the density estimates between survey stations within a depth stratum were relatively small. This shows that sablefish are relatively evenly distributed and based on this finding it was determined that this species was suited for longline surveys.

With regard to the joint longline surveys conducted thus far, survey effort has not been adequate in the 101-200 m depth zone in the Gulf of Alaska. Therefore, the accuracy of the estimated relative population size in this depth zone is questionable. It should also be noted that there is a difference in soaking time of at least 5 or 6 hours between the time hauling starts and the time the haul is completed, that the area of the deeper fishing zones is underestimated, and that there is some difference between the recorded and actual fishing depths. These are unsolved problems and should be confirmed through future experiments. However, as the survey method remained unchanged in all years and at all survey stations, it is believed that the relative values of population size within a depth zone will not basically differ from the results of the analysis in this report even if adjustments were made for variations in soaking time, and any inaccuracies in the size of the survey area and in the fishing depths. Therefore, the population sizes and their annual changes by area or region are adequately reflected by the data herein reported. The changes in biomass shown were principally caused by recruitment of an extremely strong year class, which coincided with the period of the surveys.

A remaining problem other than those described above is to develop methods of estimating absolute abundance from the longline survey data. EGGERS *et al.* (1982) studied methods of estimating biomass from longline and trap gear data. Their method was to estimate the area fished by baited hooks and traps by experimentally changing the spacing along the groundline. With regard to sablefish the area fished per hook was estimated to be 4.9 m^2 by them based on data of SASAKI (1979b). This data was from the 401-600 m depth zone in the Yakutat Area of the Gulf of Alaska, and the mean catch rate was 0.1256 sablefish per hook with an average body weight of 3.5 kg and the size of the fishing area was 2,240 km^2. Therefore, we can calculate that population numbers in this depth zone are 57.4 million fish and the biomass 200,000 tons using the value of the area fished per hook estimated by EGGERS *et al.* (1982). The total biomass in the Gulf of Alaska was estimated to be 13.6 million tons using the relationship between relative and absolute estimates of biomass. This value is 85 times larger than the biomass of 160,000 tons estimated for the Gulf of Alaska from 1979 longline survey as shown in Table 21. Although the biomass of 160,000 tons may be underestimated, the estimate from the method of EGGERS *et al.* (1982) appears to be much too high. It is necessary to conduct more detailed experiments to make this method practical.

Although 1969 longline survey by *Aomori maru* was conducted only once, the information obtained on the abundance of sablefish by this non-commercial vessel is very valuable considering that it came from a period immediately after the Japanese longline fishery began operations over a large expanse of the northeastern Pacific Ocean. The CPUE from the Japanese commercial longline vessels was 23.5 kg per hachi in 1969 (Table 16). Because the quality of fisheries statistics after 1977 may have changed as discussed earlier, the CPUE in 1969 is compared with the 1976 value which was 18.6 kg per hachi or 21% less than in 1969. This decrease is of the same magnitude as the 34% decrease shown by the 1969 and 1979 research vessel survey data. This evidence supports the reliability of the survey data.

In general, changes in depths are very abrupt, and bottom contours are rough on the continental slope of the survey area, which make systematic trawling operations extremely difficult. The difficulty increases with depth. In addition, biomass estimates are made assuming that vulnerability of fish to the trawl gear is 1.00. Taking these factors into consideration, it is believed that biomass is considerably underestimated by trawl surveys in slope waters.

To summarize the above observations, the population size in the Gulf of Alaska decreased 34% in 1979 from the level in 1969 when the population was almost at an unexploited level. The condition of the population in 1979 was still favorable in both abundance and size composition and it retained the reproductive capacity to produce a strong year class. The condition of the population in 1982 was at a high level because of the recruitment of the extremely strong 1977 year class and the abundance of the medium and large sized fish of 58.0 cm in fork length and larger increased 1.3 times over 1979.

VII. Acceptable biological catch (ABC) and fisheries management

Since 1977, fisheries resources within the U.S. 200-mile fishing zone has been managed by the United States exclusively. The United States introduced the concept of acceptable biological catch (ABC) for the management of fisheries. ABC is defined as the differences between the MSY level and the present stock condition (IKEDA, 1980 ; LEAMAN, 1979). If the stock level is below the MSY level, ABC will be set below EY to allow the stock to recover. For an unexploited stock, ABC will be set above EY to reduce the stock to a MSY level. Furthermore, in using the concept of ABC, factors such as the reliability of the basic data and assumptions about the parameters are considered. If different ABC estimates are obtained for a given stock, the more conservative estimate is always used. Methods used for estimating ABC are different by species depending on an extent of available information. Since size and age data from commercial catches are limited, production model which does not require biological parameters has been used for sablefish. ABC has been driven from MSY estimated by appling the general production model to fishery statistics and trend of CPUE (U.S. DEPARTMENT of COMMERCE, 1978). However, it is not reliable because the assumptions and methods used in the estimation are not correct as previously noted in Chapter V.

It was clarified that the stock is in good condition from the examination of statistics of Japanese commercial longline vessels in this study, but it was also noted that the statistics cannot use to analyze the trend of stock condition of sablefish after 1977, and that the accuracy of estimated MSY is questionable because the range of basic numerical values used in the model in this study are very narrow. Furthermore, as discussed in Chapters III and VI, because it is believed that recruitment is not stable, that the life-span of sablefish is much longer than previously thought, and thus the stock consists of many year classes, it can be concluded that stock assessment using the production model, which is based on catch and effort data obtained from a relatively short time period, will not provide reasonable results. If the recruitment of sablefish fluctuates widely, it will be possible to estimate MSY from maximum yield from the yield per recruit and annual recruitment. However, reasonably reliable values of the biological parameters required by this model are not yet available. In this chapter, taking the above discussion into account ABC and fishery management was examined by using results of groundfish survey data described in Chapter VI.

It is necessary to maintain a certain level of adult stock to take advantage of opportunities to produce strong year classes. The level of adult stock required for this purpose is not clear at this point in time. Since it is believed that the level of the adult stock in 1979 was not much different than the level in 1977 which produced an extremely strong year class, the level of the adult stock in 1979 can be used as a measure of the stock size needed to produce strong year class.

As earlier mentioned, the biomass in the Gulf of Alaska in 1979 was 66% of that in 1969 when the stock condition was almost in an unexploited stage (Table 29). In the period from 1969 to 1978 the accumulated catch of sablefish by all nations fishing in the Gulf of Alaska was 242,300 tons, with an annual average of 24,230 tons. There seems to be no direct relationship between the size of the adult stock and the recruitment of sablefish, and there is no guarantee that recruitment will increase if the biomass is increased over the level of 1979. Since the biomass in 1982 is 1.2 times higher over the level in 1969, if consideration should be given to maintaining the biomass at a level no lower than that in 1979, an annual catch of 24,000 tons over the next 10 years, which is the average of the 10 years from 1969 to 1978, will not reduce the population in the Gulf of Alaska below the 1979 level. An annual catch of 24,000 tons represents 9% of the estimated biomass of 263,869 tons in the Gulf of Alaska in 1982 (Table 28). Since the biomass was considerably underestimated, the exploitation rate from a catch of 24,000 tons will actually be far lower than 9%.

Following the same reasoning used for the Gulf of Alaska to determine ABC, an exploitation rate of 9% applied to the 1982 biomass estimates in the eastern Bering Sea and Aleutian Region produces values of 3,000–5,000 tons and 2,300 tons for these respective Regions. The ABC in the eastern Bering Sea was given a range because there were large difference between the biomass estimates in 1981 and 1982 obtained from the different procedures. Like in the Gulf of Alaska the actual exploitation rates based on these catch levels will be considerably lower than 9%.

Based on the current high population level in the Gulf of Alaska as shown by data presented in this study, it is clearly possible to sustain the recommended allowable catches of 24,000 tons annually. However, these estimates are based on the assumption that the natural fluctuations of the population in the future will not differ substantially from those observed in the period 1969 to 1978. It will therefore be necessary to continue extensive surveys to carefully monitor changes in the sablefish stock and to improve the accuracy of biological parameters needed for the variety of stock models so that more precise stock analyses can be made in the future. It will be also necessary to observe the occurrence of Ekman current in the northeastern Pacific Ocean which is supposed by Canadian scientists to be a factor in the producing of strong year class of sablefish (INPFC, 1981). ABC values estimated in this paper were not based on specific theoretical models. They were rather obtained empirically giving careful consideration to the uncertainty of various factors. The estimates appear to be the most conservative of the values thus far obtained. The estimates should be improved as more biological information is accumulated in the future.

The sablefish population in the Gulf of Alaska are managed by three districts. Since the movement and inter-mixting of sablefish among areas in the Gulf of Alaska is more pronounced than previously thought, there is no strong basis for managing the population by district. However, if it is considered necessary to manage the population by district for other than biological reasons, management should be based on allocating the allowable catch in proportion to the geographical distribution of biomass. The results of the 1982 longline survey (Table 21) revealed that the proportion of the biomass in these districts was 13% in the Western District (Shumagin Area), 52% in the Central District (Chirikof and Kodiak Areas), and 35% in the Eastern District (Yakutat and Southeastern Areas). On the basis of this proportion the ABC values would be 3,100 tons in the Western District, 12,500 tons in the Central District, and 8,400 tons in the Eastern District.

As noted in Chapter II, the populations in the eastern Bering Sea and Aleutian Region are believed to be maintained by fish that migrate mainly from the northeastern Pacific Ocean. It has been shown by tagging experiments that sablefish from the eastern Bering Sea and Aleutian Region and those from the northeastern Pacific Ocean mix with each other. As earlier mentioned, however, it is believed that not all of the sablefish from the former two regions return to the northeastern Pacific Ocean, but rather that many remain in these more northern waters. The eastern Bering Sea and Aleutian populations can be considered as emigrant populations that do not contribute to the reproduction of the overall stock in the North Pacific Ocean, and it may not be necessary to be particularly concerned about maintaining the abundance of these populations. To test the validity of this view, it will be necessary to clarify the degree and frequency of inter-mixing of populations among these regions.

In addition, BRACKEN (1982) concluded on the basis of tagging experiments that sablefish in the Gulf of Alaska actively migrate. He further believed that young fish originate in southeastern Alaska, migrate west where they grow, and then return to the southeastern Alaska for spawning. BRACKEN (1982), therefore, concluded that if exploitation in the western part of the Gull of Alaska is reduced to relatively low levels, the stock abundance in the eastern part would be expected to rise. It was noted earlier, however, that the validity of these hypotheses needs to be verified by further studies.

In order to promote optimum fisheries management of the sablefish resource, it will be necessary to clarify the age structure of the populations, the frequency and degree of geographic intermixting, and the mechanisms that result in strong year classes, as well as to improve the accuracy of biomass estimates and biological parameters. At the same time, it will also be important to continue to monitor the stock condition over a broad area of its range and to promote an active exchange of information among the countries concerned with the resource.

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北太平洋のギンダラ資源の研究

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摘　　要

ギンダラ（*Anoplopoma fimbria*（PALLAS））は，北太平洋とベーリング海に広く分布する重要な底魚資源の一つである。資源の開発は，北米西海岸の漁民により19世紀の終り頃から行なわれている。北洋水域における日本のギンダラ漁業は，1958年にベーリング海北部で開始され，順調に発展してきたが，1972年を頂点として漁獲量は減少し始めた。沿岸国である米国とカナダが200海里体制を制度化した1977年以後漁獲量は急激に減少し，日本のギンダラ漁業は極めて厳しい状態に置かれることとなった。漁獲量の急激な減少は，米国とカナダによるギンダラの資源管理が強化されたことによるものであったが，その背景には社会経済的要因の他に，資源状態に対する日米間の見解の相違があった。

本研究では，ギンダラの生物学的特徴を分布，回遊，資源の構造，年齢と成長，性成熟，性比，食性，及び加入の実態などの諸項目について明らかにした。また，日本のはえなわ漁業の漁獲統計資料から資源の動向を分析し，はえなわ調査の結果から近年の資源状態を評価するとともに，はえなわ調査とトロール調査の結果を併用して資源量を推定した。最後に，1969年から1979年までの漁業の経過と資源水準の変化及び1979年以後の資源量の変化を分析し，さらに1977年に顕著な卓越年級群が発生したことなどを考慮に入れて，東部ベーリング海，アリューシャン水域，及びアラスカ湾における1983年以後の生物学的許容漁獲量を推定した。

ギンダラ資源について適正な資源管理を進めるには，ギンダラ個体群の年齢組成，水域間における地理的混合の速度と規模，及び卓越年級群の発生機構などを明らかにするとともに，資源量推定値や生物学的パラメーターの精度の向上が必要である。同時に，広い水域における資源のモニタリング調査の継続と，関係国間における情報交換をより活発にすることも重要であろう。