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By

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ABSTRACT

Available sources of information on sablefish biology and the Gulf of Alaska sablefish fishery are reviewed and harvest recommendations are presented. A U.S. longline fishery for sablefish has existed in the Gulf of Alaska since the early 1900's. Gulf-wide catches escalated rapidly during the 1960's when the Japanese distant water fleet developed. Total Gulf of Alaska harvests peaked in 1972 at 36,199 metric tons and began to decline, with recent annual harvests at about 9,000 metric tons. The U.S. longline fishery traditionally fished only in the eastern Gulf of Alaska, but is currently expanding westward. Foreign sablefish harvests are currently restricted to the central and western Gulf of Alaska. Recent developments in sablefish aging techniques using "break and burn" methods describe very slow growth in adult sablefish. The slow growth rates imply that large sablefish are much older than previously calculated, with maximum ages frequently exceeding 40 years. A much lower natural mortality rate of 0.11 is estimated from the new growth information, substantially less than previous estimates of 0.2. Sablefish recruitment appears to be characterized by long periods of relatively low recruitment between very strong year classes. Because these periods of low recruitment may exceed 10 years, maintaining large number of older fish in the population may be critical to reproductive success. Electrophoretic studies of sablefish genetics indicate that there is some degree of spatial segregation of Gulf of Alaska sablefish stocks. However some tagging studies indicate substantial movements of fish, with small fish (< 66 cm) tending to move north and westward and larger fish moving south and eastward. Trends in sablefish abundance are derived from Japanese longline fishery statistics, a Gulf-wide U.S.-Japanese longline survey, pot indexing in Southeastern Alaska, and port sampling of the U.S. longline fleet in Southeastern Alaska. Sablefish stock biomass appears to be increasing in abundance throughout the Gulf, largely a result of the recruitment of the strong 1977 year class. Subsequent year classes have not been strong. A new stock production model which allows for increases in fishing power indicates that MSY is probably lower than calculated in previous models. Estimates of stock size are derived from stock production model parameters and from area-swept in a Bering Sea trawl survey, combined with comparative longline-trawl sampling in the Aleutian area. Yield-per-recruit analyses indicate that size limits will not increase the yield or landed value from the sablefish fishery. Population parameter estimates are used in an age and sex-structured simulation model to determine "equilibrium yields" (EY) which will maintain constant biomass from 1984-1991. However because of uncertainty in the parameter estimates, it is recommended that equilibrium yield (EY) calculated by other means be applied to the Gulf of Alaska. Optimum yield (OY) are recommended to remain at 75% of the EY, or 9,473 metric tons for the entire Gulf of Alaska. A new method of spatial allocation of the Gulf-wide OY is presented, based on the spatial distribution of biomass estimated in the U.S.-Japanese longline survey.

KEY WORDS: sablefish, stock status, age, growth, migration, Gulf of Alaska, longline fishery, equilibrium yield, mortality, maximum sustained yield, yield-per-recruit.

INTRODUCTION

The distribution of sablefish, *Anoplopoma fimbria*, in the northeastern Pacific Ocean ranges from northern Mexico to the Bering Sea with the largest concentrations occurring in the Gulf of Alaska. While U.S. fishermen have been harvesting sablefish since the early 1900's, the stocks were not heavily exploited until the Japanese distant water longline fishery developed in the early 1960's. Catches escalated through the 1960's until the maximum Gulf of Alaska harvest of 36,199 mt was reached in 1972. Catches have declined since that time because of reductions in population size and increasingly restrictive regulations.

Previous concepts of sablefish growth, stock structure, mortality rates, and equilibrium harvest levels are all being revised because of recent research findings. The purpose of this document is to review the literature on sablefish biology and to evaluate the current data pertaining to the status of the sablefish resource in the Gulf of Alaska.

THE GULF OF ALASKA SABLEFISH FISHERY

Sablefish in the Gulf of Alaska are harvested primarily by longline vessels of the U.S. and Japan. Small quantities of sablefish are also harvested by pot gear and incidentally by trawl and other fisheries. The U.S. longline fishery is concentrated in the eastern Gulf of Alaska, but has been expanding westward in recent years. Prior to 1979, the Japanese longline fishery targeted specifically on sablefish. Since that time, Japanese longliners have been allowed into waters shallower than 500 m where they harvest both sablefish and Pacific cod *(Gadus macrocephalus)*.

Catch and Fishing Effort

Sablefish catch by nation from 1958 through 1982 is presented in Table 1. U.S. landings have increased in recent years and catch by other nations has declined in the Gulf of Alaska.

U.S. Fishery:

The U.S. sablefish fishery is one of the oldest fisheries in Alaska. Landing documents exist as early as 1906 when the fishery was reported to be well established. Landings have fluctuated widely since that time, subject to current market conditions, with peak harvests during the early 1940's (Figure 1).

Most sablefish catch was incidental to the halibut longline fishery until 1913 when a directed fishery began, with harvests exceeding 200 metric tons by 1916. In 1916 the market name was changed from black cod to sablefish in an attempt to improve market demand.

The catch exceeded 600 metric tons during 1917 and 1918 and then dropped below 400 metric tons until 1923. Catches declined from 1924 to 1935 and then increased to the highest recorded levels during the 1940's. Peak catches of over 4,200 mt were reported in 1942 and again in 1946. The large catches during the war years

Table 1. Historical catches of sablefish in metric tons by area and nation in the Gulf of Alaska, 1958-1982[1].

	GULF OF ALASKA (SHUMAGIN-SOUTHEASTERN)					
Year	U.S.	Canada	Japan[2]	USSR	ROK[3]	Total
1958	698	94	--	--	--	--
1959	1,048	50	--	--	--	--
1960	1,925	206	--	--	--	--
1961	866	30	--	--	--	--
1962	684	45	--	--	--	--
1963	881	104	1,681	--	--	2,562
1964	1,172	226	1,041	--	--	2,213
1965	1,047	185	2,107	--	--	3,154
1966	1,067	319	3,514	--	--	4,581
1967	946	189	4,217	--	--	5,163
1968	161	123	13,886	--	--	14,047
1969	301	69	19,587	--	--	19,888
1970	527	67	21,397	--	--	21,924
1971	386	15	25,636	--	--	26,037
1972	1,081	16	34,259	535	308	36,199
1973	1,217	16	29,246	109	58	30,646
1974	1,114	10	23,300	38	2,431	26,893
1975	1,556	16	21,561	33	3,000	26,166
1976	1,145	23	22,947	41	3,700	27,856
1977	1,173	3	14,367	4	1,586	17,133
1978	1,777	0	6,458	4	665	8,904
1979	3,382	0	5,919	152	759	10,212[4]
1980	2,270	0	4,831	416	891	8,408
1981	1,801	0	6,910	--	1,062	9,777
1982	3,008	0	4,921	--	725	8,654

[1] Updated with U.S. catches revised from Balsiger and Alton 1981.

[2] Japanese catch is reported by fishing year through 1976; all other are reported by calendar year.

[3] Includes catches from other areas in the northeastern Pacific.

[4] Includes 55 mt by Mexico in 1979 and 4 mt by Poland in 1981.

SOURCE: U.S. data through 1973 from fishery statistics of the U.S., Statistical Digests 49-68; 1974-76 from PMFC data series, Groundfish section; 1977-80 from ADF&G extended jurisdiction section. Canadian data 1971-76 from PMFC data series, groundfish section; 1958-70 data not available. Japanese, USSR, ROK data from INPFC document 1883 and personal communication T. Sasaka, Far Seas Fishery Lab., Shimizu, Japan.

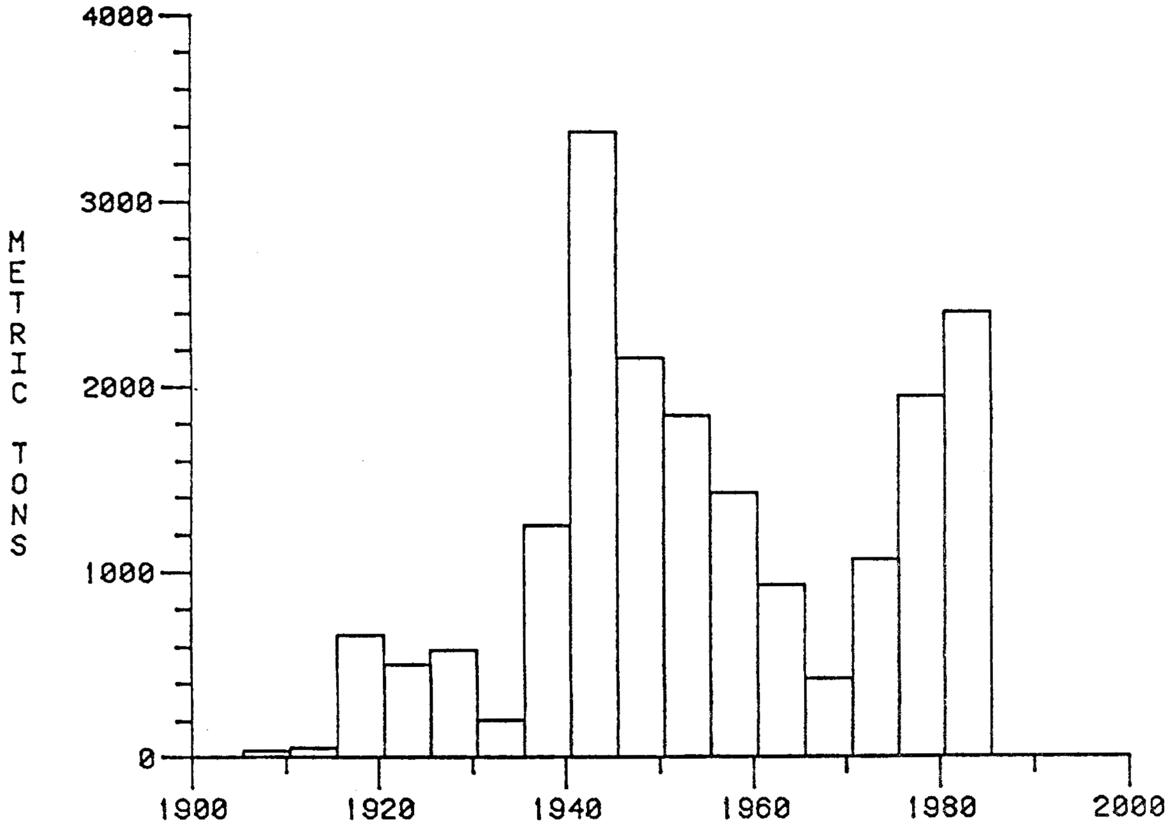


Figure 1. Five-year average domestic sablefish harvest in Alaskan waters, 1906-1982 (round weight).

were in response to a high demand for protein and for fish liver to manufacture vitamin A for overseas troops (Edson 1954). The harvest fluctuated widely after 1947 according to market demand which was closely related to current cold storage holdings. The pattern generally consisted of 1 or 2 years of high harvest which saturated the market, followed by a sharp decline until the fish on hand were sold. The long term trend however was one of decline from the late 1940's to the late 1960's with the 1966-1970 average annual harvest at the lowest level since the depression era slump of 1931-1935.

Landings began to increase again in 1972 with a renewed interest in smoked sablefish. It was not until 1978, however, that the catch increased substantially. That increase was in response to a resurgence of effort in the offshore areas of Southeastern Alaska after the Japanese fleet withdrew to the area west of 140 W longitude in June 1978. Largely a result of expansion into the offshore areas, the catch increased to 3,400 mt in 1979. The market price dropped sharply in 1980 and consequently landings declined in 1980 and 1981. In 1982 the U.S. landings once again exceeded 3,000 mt. The 1983 U.S. fishery harvest will exceed 3,500 mt.

Until the 1940's, most of the U.S. harvest came from the inside waters of Southeastern Alaska. By 1944, 32% of the catch was reported from offshore areas and from 1945 to 1953, 53% of the harvest was reported from offshore areas as far west as the Seward Gully. As the effort declined, a larger percentage of the catch again came from inside areas. Most of the catch was harvested from inside areas from 1960 until 1978 when the Japanese fleet withdrew. In 1982, 48% of the total U.S. harvest was reported from the offshore Southeastern areas, 26% from the Yakutat area, and only 26% from the inside areas of Southeastern Alaska.

The U.S. longline fishery has recently expanded westward into the central Gulf of Alaska. During the 1983 season, 296 metric tons of sablefish were landed from the Central Gulf by U.S. vessels in Kodiak, Homer, and Seward. However, gear conflicts and resulting gear loss because of the presence of the Japanese and Korean longline fleets are hampering further westward expansion of the U.S. fishery (Blackburn 1983).

Foreign Fisheries:

Foreign vessels have been harvesting sablefish in Alaska since the late 1920's. The foreign harvest was entirely by Canadian vessels until the mid 1960's when a major Japanese longline fishery began to develop. Recent foreign harvest allocations have been reduced as the U.S. fishery has expanded.

Canada. Longline vessels from Canada reported landings off Southeastern Alaska as early as the late 1920's. For the period between 1951 and 1953 the Canadian catch from Southeastern Alaskan waters averaged approximately 45% of the total annual Canadian landings (Ketchen and Forrester 1954) or about 600 mt per year.

Although Canadian effort was reported as far west as Middleton Island (147°W), most of the fishery occurred in the Southeastern area. In 1951 and 1952, International Pacific Halibut Commission (IPHC) Statistical Area 16 off Cape Ommaney yielded the largest catch of any area fished by Canada. The CPUE off Southeastern Alaska was also the highest in the Canadian fishery (Ketchen and Forrester 1954). The Canadian fishery in Alaska had declined by 1969 with the harvest averaging less than 25 mt between 1969 and 1978. By international agreement, no Canadian harvests were allowed in Alaskan waters after 1978. It is assumed that in the later years of the Canadian fishery in Alaska, most of the sablefish landings were incidental to the halibut fishery rather than directed effort. The Canadian catch from Alaskan waters from 1958 through 1978 is shown in Table 1.

Japan. The Japanese longline fishery began in the Gulf of Alaska in 1963 and peaked in 1972 at 34,259 mt. Because of declining sablefish abundance and the resulting restrictive regulations the harvest has declined in recent years, with only 4,921 mt harvested in 1982. Japanese fishermen withdrew from the area east of 140°W. longitude in 1978 and also withdrew from the western Yakutat area (140°W. long. to 147°W. long.) for a portion of the 1982 and 1983 seasons to accomodate the expanding U.S. fishery. All current Japanese effort is confined to the area west of 140°W. longitude.

Other Nations. The Republic of Korea (ROK), USSR, Mexico, and Poland have also fished for sablefish in the Gulf of Alaska. The ROK harvests are reported for the entire northeastern Pacific and averaged 1,380 mt between 1972 and 1982, with a peak harvest of 3,700 mt in 1976. The other nations harvested only relatively small amounts.

Fishery Management Regulations

The first regulations were imposed in the Alaska fishery in 1945 when the entire Southeastern Alaska area was closed for 2.5 months to curb the observed decline in catch per unit of effort (CPUE) in the fishery. Since that time the U.S. fishery in Southeastern Alaska has been continuously regulated by seasons and/or quotas which have become generally more restrictive in recent years. A review of regulations in the U.S. fishery is included in Bracken (1983b).

Waters of the Fishery Conservation Zone (FCZ) are managed by the National Marine Fisheries Service (NMFS) under a Fishery Management Plan developed by the North Pacific Fishery Management Council and approved by the Secretary of Commerce. Management of sablefish consists of setting optimum yield (OY) harvest levels by International North Pacific Fisheries Commission (INPFC) areas and monitoring both foreign and U.S. catches so as not to exceed the established levels. Since 1981, optimum yield levels west of 140°W. longitude have been set at 75% of an equilibrium yield (EY) derived from a general production model generated from Japanese catch data for 1967 to 1977. Japanese catch data has been used since 1977 to determine if adjustments to the originally established EY values were needed. Since the foreign longline fisheries were discontinued east of 140°W. longitude in 1978, that data source is no longer available for the eastern Yakutat and Southeastern Alaska areas.

The current OY for the area between 140°W. longitude and 137°W. longitude was derived using 75% of EY calculated using Japanese catch data through 1978 adjusted by observed trends in the U.S. fishery and NMFS pot indexing studies conducted in the adjacent Southeastern area. The Southeastern area OY is set using data from the U.S. fishery and results from the NMFS pot indexing survey. Both the eastern Yakutat and Southeastern OY levels are currently set as ranges. Sablefish OY levels recommended by the NPFMC for the INPFC areas of the Gulf of Alaska for 1983 and 1984 are presented in Table 2. The OY for the Gulf of Alaska for 1984 remains at 8,980 mt in order to promote rebuilding of sablefish stocks.

Table 2. Equilibrium yield (EY) and optimum yield (OY) values recommended for the Gulf of Alaska sablefish fishery in 1983 and 1984 (round weight in metric tons).

AREA	Equilibrium Yield	1983 OY	1984 OY
Western Gulf	2,225	1,669	1,670
Central Gulf	4,075	3,056	3,060
Western Yakutat	2,240	1,680	1,680
Eastern Yakutat	1,135-1,510	851-1,133	1,135
Southeastern	1,290-2,580	968-1,935	1,435[1]
Total	10,965-12,630	8,224-9,473	8,980

[1] Does not include the 500 metric tons allocated to inside fisheries in Southeastern Alaska.

BIOLOGY OF SABLEFISH

Growth

Recent developments in aging techniques have substantially altered earlier concepts of growth of sablefish. The earliest sablefish growth studies (e.g., Bell and Gharret 1945; Pruter 1954) determined ages from scale patterns and obtained few ages greater than 10, even for fish up to 80 cm in length, Kennedy and Pletcher (1968) determined sablefish ages from both scales and otoliths and obtained similar results. Surprisingly, in that study scales were found to give older ages than otoliths, even though some of the otoliths had been cut, polished, and burned to accentuate the annual patterns. Sasaki et al. (1975) observed that the growth of young Bering Sea sablefish was markedly different than that of older fish. They found that two von Bertalanffy curves, one for fish younger than age 3.3 and one for fish older than age 3.3, described the data much better than a single curve.

Recently Beamish and Chilton (1982) reported a considerably different impression of the rate of sablefish growth using the "break-and-burn" otolith reading technique. They describe a species with very rapid initial growth, but very slow growth upon reaching maturity, with many members of the population surviving to very old ages. Funk and Bracken (1983) examined surface-aged otoliths from sablefish collected in Southeastern Alaskan waters and described even slower growth rates than those of Beamish and Chilton (1982) (Figure 2). However, after adjusting for suspected errors in the surface otoliths aging techniques based on following length frequency modes over several years, growth rates were very similar to those reported by Beamish and Chilton (Figure 3).

Thus the newer aging studies in both northern British Columbia and Southeastern Alaska depict sablefish growth in those areas as characterized by an initial period of fast growth, followed by slower asymptotic growth. The change in the rate of growth appears to be rather abrupt and coincides with the approximate age of sexual maturity. This relatively rapid transition from fast to slow growth is probably indicative of fundamental changes in physiology and behavior associated with the onset of sexual maturity. These newer, slower growth rates have a considerable impact on the estimates of the yield that can be obtained from sablefish stocks on a sustained basis. They also point to a radically different life history strategy from that described in earlier studies. However, more growth studies from westward areas of the Gulf of Alaska are needed in order to verify that the growth rates observed in the eastern Gulf are applicable to the central and western Gulf as well.

Stock and Recruitment

The sporadic high abundance of juvenile sablefish observed in shallow water areas and the periodic variability of fish size in the commercial catch over time suggest that sablefish recruitment is characterized by long periods of relatively low recruitment between very strong year classes. Recent observations suggest that these periods of low recruitment may exceed ten years. While the relationship between spawners and recruits is largely unexplored for sablefish, spawning success appears to be highly dependent upon favorable environmental conditions coincident

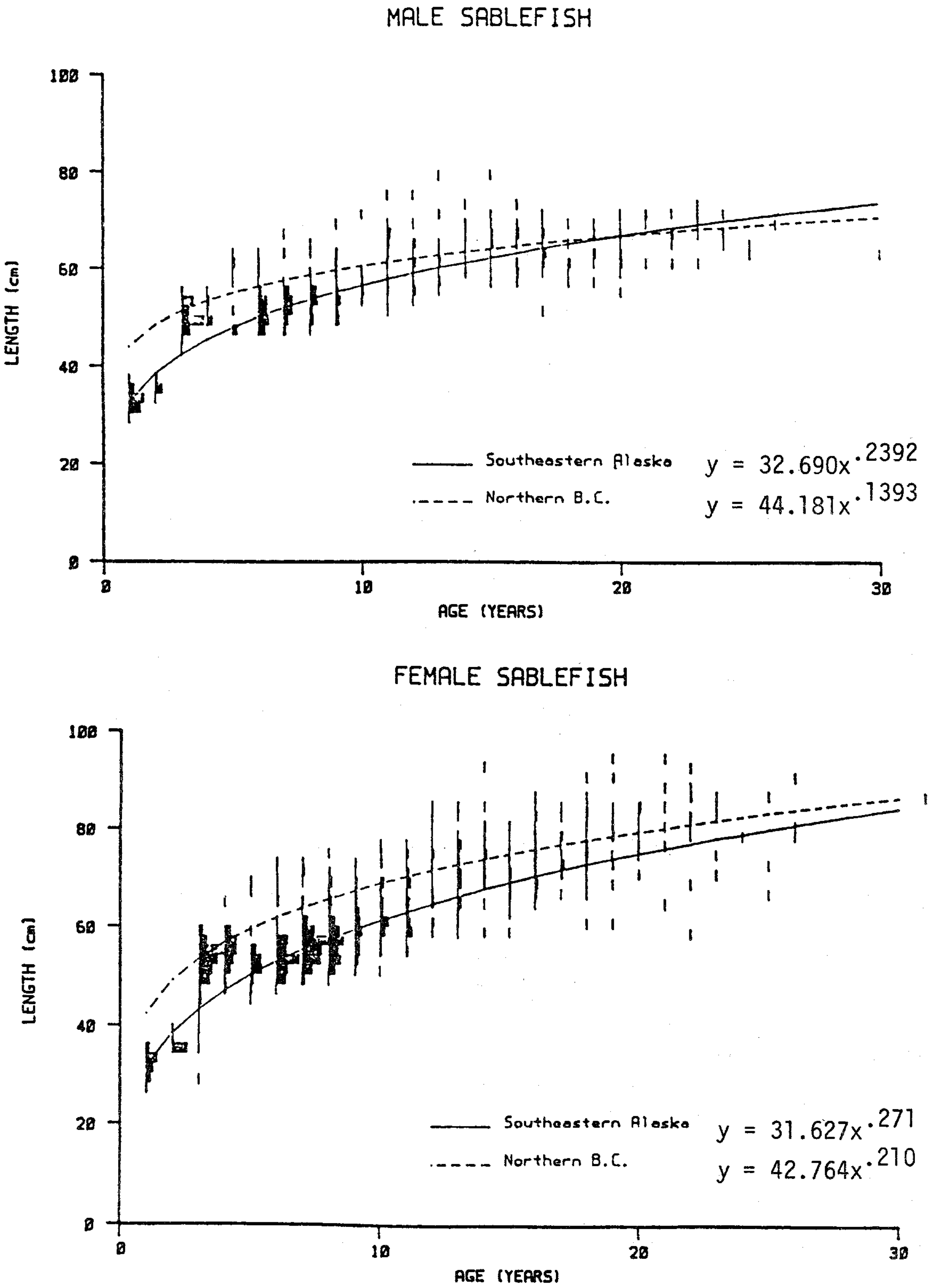
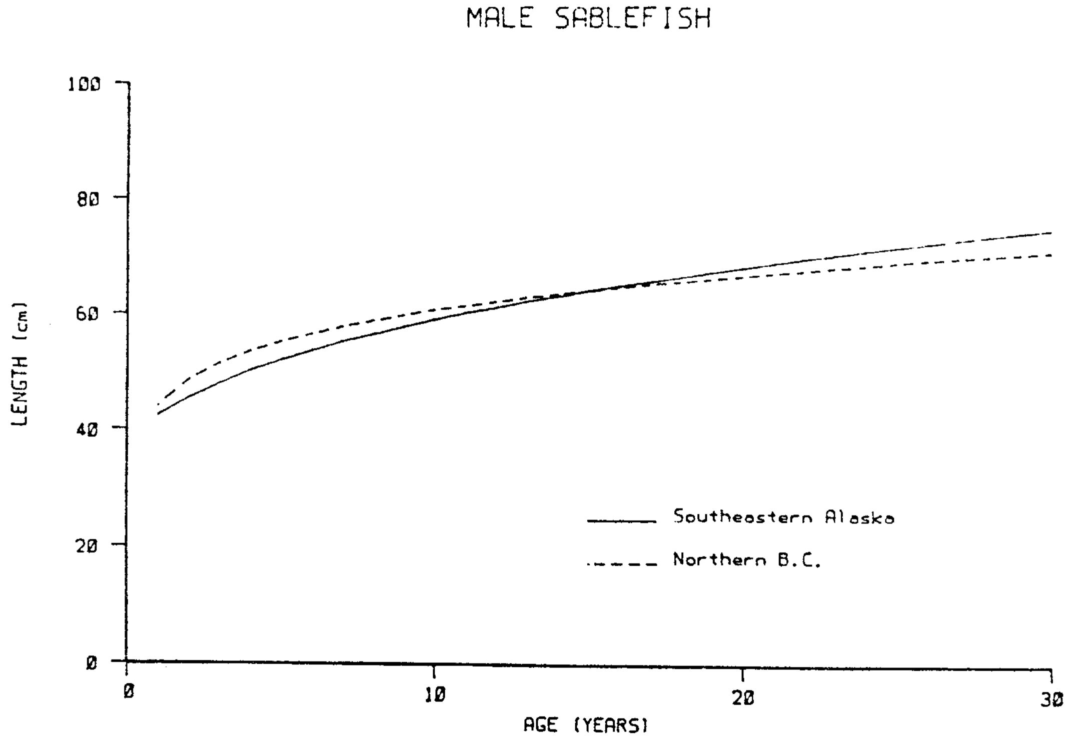


Figure 2. Comparison of length-at-age observations and fitted allometric models for northern British Columbia and Southeastern Alaska male and female sablefish.



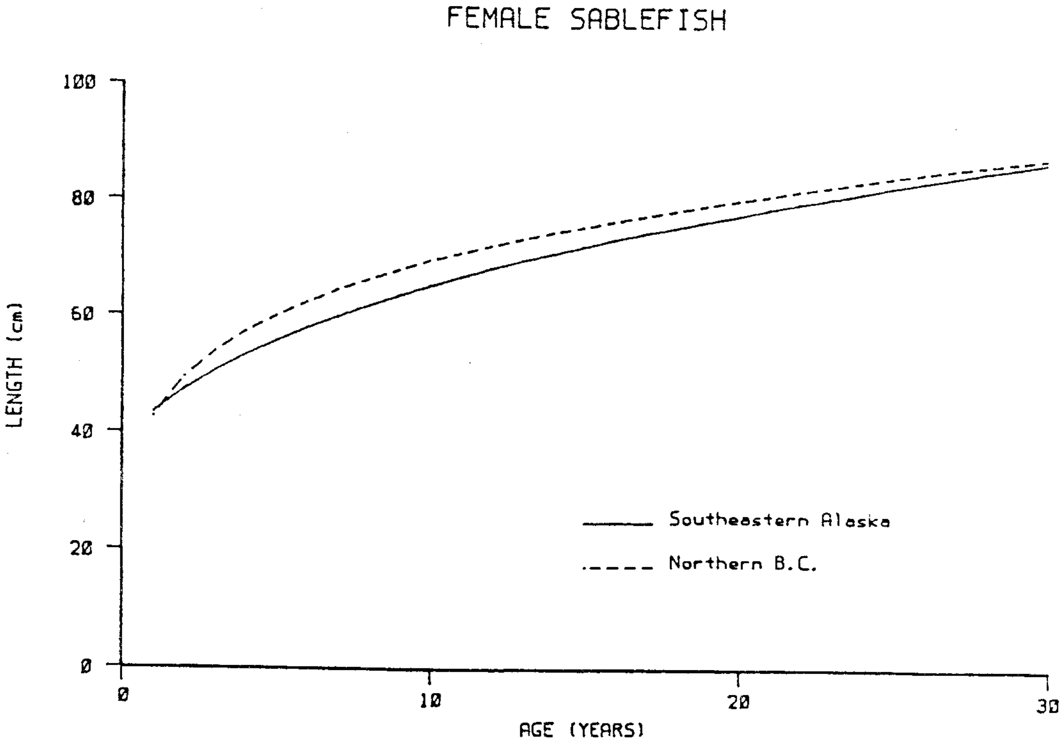


Figure 3. Comparison of fitted allometric models for male (A) and female (B) sablefish from northern British Columbia and Southeastern Alaska after adjusting for a two year aging error in the Alaskan data.

with the availability of a spawning population size above some, as yet undetermined, critical level. To sustain large yields, it is essential for egg production to remain above this critical level over long periods of time in order to take advantage of the relatively rare occurrences of favorable environmental conditions for larval survival. However, in the absence of information on the relationship between spawners and recruits, the critical level of egg production cannot be estimated. A conservative management strategy would be to maintain relatively high levels of annual egg production over the time spawn between strong year classes. In order to determine annual egg production, the age-fecundity relationship and spawning frequency of individual females must be determined and the age structure of the female population must be known.

Fecundity:

Little prior information on sablefish fecundity is available in the literature. Phillips and Imamura (1954) report a fecundity range of 100,000 to 1,000,000 eggs for a 53 cm and 102 cm fish, respectively. No mention was made of the method used or variability of their findings. Kodolov (1976) examined three fish from the Bering Sea and one each from the Gulf of Alaska and west coast of the U.S. and determined the following fecundities:

438,000 eggs at 73 cm (Bering Sea)
468,000 eggs at 74 cm (Bering Sea)
503,000 eggs at 83 cm (Bering Sea)
330,000 eggs at 70 cm (Gulf of Alaska)
400,000 eggs at 70 cm (West Coast)

As with the report by Phillips and Imamura (1954), no mention was made of the methods used to determine fecundity.

Mason et al. (1983) examined sablefish fecundity from samples collected in British Columbia waters in early February. They found a distinctly bimodal distribution of egg sizes with modes at 0.1 mm and 1.0-1.2 mm and concluded that only the larger eggs contributed to that year's spawning. Therefore, the smaller eggs were discounted when fecundity was determined. Volumetric techniques were used to estimate numbers of eggs in each ovary. The relationship between fecundity (F) and fork length in cm (FL) was described by the regression $F = 1.11987(FL)^{2.8244}$ with a correlation coefficient (r) of 0.78 (Figure 4). These fecundity values are considerably lower than those previously reported in the literature.

Bracken and Eastwood (1984) determined sablefish fecundity from Southeastern Alaska waters from gravid females collected in late January and early February. Subsamples of eggs were counted with a Klett bacterial colony counter and gravimetrically expanded to total ovary egg counts. Estimated fecundities ranged from 56,000 eggs for a 50 cm fish to 1.1 million eggs for a 95 cm fish. The relationship between fecundity (F) and fork length in cm (FL) was described by the regression $F = 0.02349*(FL)^{3.88}$ with a correlation coefficient (r) of 0.86 (Figure 4).

The length-weight relationship observed for mature females by Bracken and Eastwood (1984) was applied to the lengths presented by Kodolov (1976) and Mason et al. (1983) to determine eggs per gram of body weight. The relationship of fecundity to body size varies among the different studies and ranges from 100 eggs per gram of body weight in Kodolov's (1976) report and 97 eggs per gram in the ADF&G study

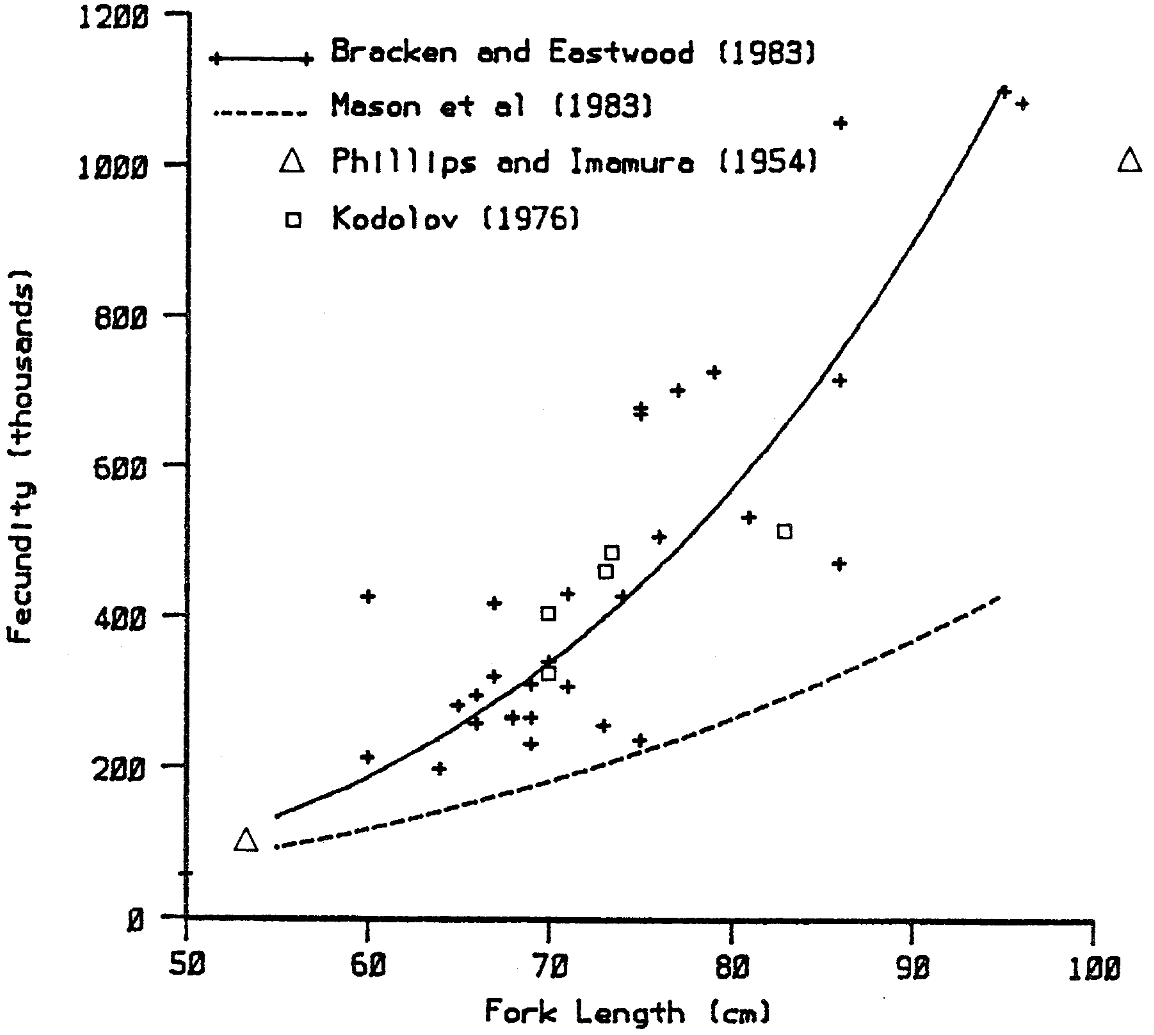


Figure 4. Fecundity at length from sablefish studies in the northeastern Pacific. Only the fitted equation of Mason et al. (1983) is shown.

to less than 50 eggs per gram in the Canadian studies of Mason et al. (1983). The biomdal distribution of egg size indicated in the Canadian study was not observed in Southeastern Alaska samples and so all eggs were counted resulting in higher fecundity values.

Spawning Frequency:

Fecundity studies conducted in British Columbia show a bimodal distribution of egg sizes in mature sablefish ovaries (Mason et al. 1983). However, the relatively short duration of ripe females in the samples suggests a single annual spawning.

Sampling conducted in the inshore waters of Southeastern Alaska from January to March has failed to locate sablefish in spawning condition. However ripening fish have been observed in the same areas from September to December during earlier research cruises and in the commercial fisheries. This suggests a possible movement of ripening fish into the offshore areas for spawning. This is consistent with the observations of Beamish et al. (1983) that nearly all eggs were found at stations over or adjacent to the continental slope and there was no indication of major spawning in inshore waters. There is no evidence which suggests multiple spawning for sablefish.

Stock Structure

There is currently a considerable amount of controversy over the population structure of Gulf of Alaska sablefish stocks. Wespestad et al. (1978, 1983) consider sablefish to be generally non-migratory and to consist of localized, discrete populations. Sasaki (1979) and Bracken (1982; 1983a) feel that sablefish are highly migratory and that the Gulf of Alaska population should be considered essentially a single stock. Two types of information are currently available for investigating the discreteness of sablefish stocks. A limited amount of genetic investigation has been performed and tagging programs have been instigated by several governmental agencies.

Genetic Studies:

Early work on sablefish population structure by Phillips et al. (1954) utilized meristics counts. They found statistically different counts of morphometric characters for each of 11 sample areas ranging from Southeastern Alaska to California. Phillips et al. (1954) concluded that Alaskan stocks are separate from southern British Columbia stocks and northern Washington stocks and stated that their "data would seem to indicate that all the sablefish along the coast do not intermingle freely, and that there is more than one stock or race of fish." They also found that "the most northern and the most southern areas were responsible for the greatest discordance ..." indicating that interchange was somewhat less towards the extremes of the range. However, comparisons of meristic counts from different areas should be interpreted with caution since environmental conditions can exert substantial influence upon phenotypes, particularly during early development. Environmental conditions vary considerably over the broad latitudinal range Phillips et al. (1954) examined and could be the cause of the difference in meristic counts.

Gharret et al. (1982; 1983) have more directly examined sablefish genotypes over a wide latitudinal range by using electrophoretic techniques to study regional variation in allelic frequencies of polymorphic sablefish enzymes. They found an extraordinary amount of polymorphism in sablefish enzyme systems which complicated the interpretation of their results. Gharret et al. (1982) reported a relatively large amount of heterogeneity among comparative samples from different regions which indicated a large degree of interchange. They conclude that the "heterogeneity is consistent with the idea that the collections represent mixtures of populations which are genetcially distinct, but mobile at the time of sampling." As in Phillips et al.'s (1954) meristic study, less heterogeneity was observed towards the end of the range, supporting this hypothesis.

Gharret et al. (1983) re-examined the electrophoretic data using more objective criteria for pooling samples and reported considerably different results. Groups of homogenous collections were found off California, in the inside waters of Southeastern Alaska and in the Bering Sea-Aleutian area. These groups were not homogenous with each other or with adjacent single collections except for a single seamount collection from the eastern Gulf of Alaska which was homogenous with part of the Southeastern Alaska collection and part of the Bering Sea-Aleutian collection. Gharret et al. (1983) conclude that "there is some genetic/stock structure for sablefish that can be defined as geographic terms". The specimens examined by Gharret et al. (1982; 1983) were not collected from spawning populations so that the samples could represent mixtures of individuals from several genetically distinct populations.

Tagging Studies:

Sablefish tagging studies have been carried out by a number of agencies: the U.S. National Marine Fisheries Service (NMFS), Canadian Department of Fisheries and Oceans, Alaska Department of Fish and Game (ADF&G), California Department of Fish and Game, Oregon Department of Fish and Wildlife, and the Japanese Far Seas Fisheries Research Laboratory. The results of the early tag experiments are difficult to interpret, due to very low return rates. However there are examples of extremely long range movements in these early studies.

Edson (1954) tagged 6,322 fish in the eastern Gulf of Alaska. Of the 21 recaptures, one had traveled to Cape Flattery, Washington, a distance of 1,979 km. Pruter (1959) tagged 1,108 sablefish in Holmes Harbor, Washington, in 1955. Of the 89 recoveries by 1959, one had moved northward to Middleton Island in the Gulf of Alaska. Five additional recaptures were later recorded, all in the Bering Sea (Pasqualle 1962, Pattie 1970).

The NMFS coordinated a tagging program in the northeastern Pacific from 1971 to 1976 in which 34,679 sablefish were tagged by vessels from NMFS, the California Department of Fish and Game, the Oregon Department of Fish and Wildlife, the Republic of Korea, and the U.S.S.R. Recaptures of these tagged fish are summarized by Wespestad et al. (1978; 1983). They found that the average distance traveled for recovered tags was only 117 km and concluded that "sablefish" are primarily non-migratory and that most movement is limited to relatively short distances." A significant, but slight, correlation between distance traveled and days at large was found. No differences were found in distance traveled by size or in direction of movement by area. Direction of movement was not examined by size groups. On the basis of the tagging experiments, Wespestad et al. (1978; 1983) recommend that Gulf of Alaska sablefish be managed as discrete stock units and suggest the current INPFC boundaries may be sufficient to delineate stocks for management purposes. It should be noted that Wespestad et al.'s (1978; 1983) summarized analysis was not separated by geographic area and included results from all tagging coastwide experiments. No attempts were made to correct for return rate or population size in different areas.

Other recent tagging investigations have reached considerably different conclusions. Japanese tagging observations are summarized by Sasaki (1979). The Japanese tagging experiments involved releases of 7,456 sablefish in the Bering Sea and Gulf of Alaska from 1962 to 1972. By 1978, 121 tags had been recovered in the fisheries of the U.S., Canada, U.S.S.R., Japan, and Korea. Sasaki (1979) reports that 60% of the returned tags were recovered in a different INPFC area than they were released. Many fish tagged in the Bering Sea were recovered in the Gulf of Alaska. Sasaki (1980) reports additional recoveries of tags released in 1978 and 1979. A total of 48 of the 79 recaptures from 1979 releases moved at least 48 km, with most of those migrating much further (Sasaki 1980) Sasaki (1979) concludes that the sablefish stocks are considerably mixed and that there are no grounds for delineating separate stocks.

Canadian tagging studies are summarized by Beamish and McFarlane (1983). They found that juvenile sablefish tended to move offshore and northward and that a large proportion of the offspring from sablefish which spawned in Canadian waters moved northward into the Gulf of Alaska as juveniles. Beamish and McFarlane (1983) found little evidence of any movement of mature adult sablefish tagged in British Columbia waters.

Bracken (1982; 1983a) tagged sablefish in Southeastern Alaska inshore areas and found that an unexpectedly large number of recaptures occurred in offshore waters, some as far away as the Bering Sea. The direction of movement of the fish that moved offshore was clearly related to fish size. Fish less than 60 cm tended to move north and west once offshore waters were reached, while fish 60 cm and greater moved southeastward into British Columbia waters. Bracken (1982) then reanalyzed Japanese and NMFS tag recovery data and found similar trends in direction of movement by size. Recaptures of Japanese tagged fish had traveled an average of 589 km and 46% of the recaptures examined had crossed at least one INPFC boundary. Recaptured fish tagged by NMFS in the Gulf of Alaska which were at large less than 1,000 days had traveled somewhat less distance, averaging 188 km with only 20% of the recoveries occurring in a different INPFC area from that in which they were tagged. Dark (1983) reexamined the NMFS tag recovery data from the NMFS sablefish pot indexing survey releases which were first reported by Wespestad et al. (1978; 1983). After allowing for time at large and direction of movement by size he found similar patterns to Bracken (1982). The pattern of direction traveled by size group for fish which were recovered at least 160 km is very similar for the Japanese, ADF&G, and NMFS tag recoveries (Figure 5).

Bracken (1983a) adjusted the results of the ADF&G tag recoveries for return rate, size of harvest, and relative population size. He estimated that 57% of the tagged population had left the Southeastern Alaska INPFC area of tagging within 3 years (Table 3).

Conceptual Model of Sablefish Movements:

Bracken (1982) proffered a conceptual model of sablefish movement to explain the observed patterns of sablefish tag recoveries. He postulates that the major sable-

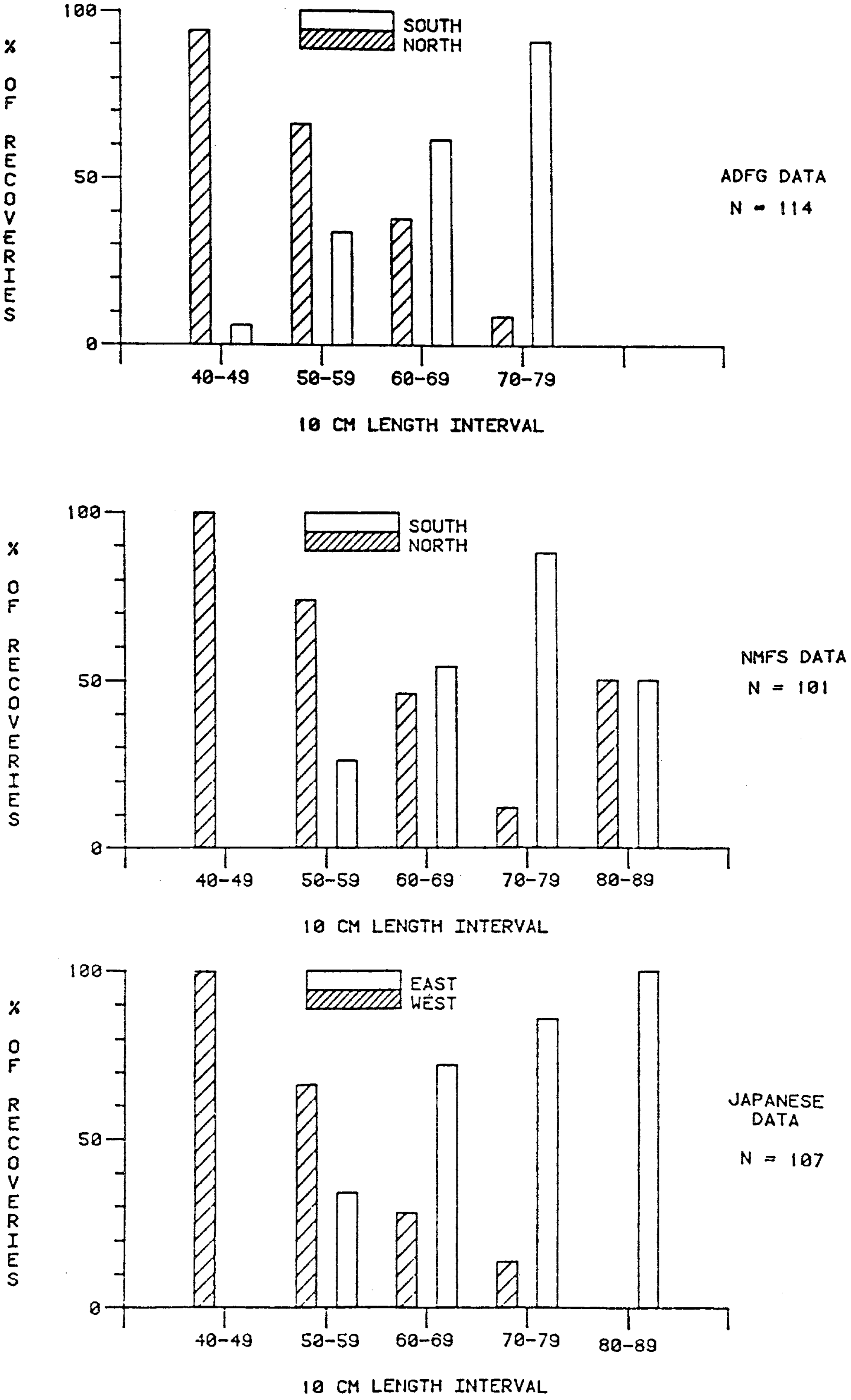


Figure 5. Direction of travel by size group and sablefish tagged in the Gulf of Alaska.

Table 3. Distribution of recoveries from ADF&G sablefish tagging experiments in the Ketchikan area of Southeastern Alaska, 1978-1982.

INPFC area recovered	Raw Recovery No.	Raw Recovery %	Adjusted for return rate[1] No.	Adjusted for return rate[1] %	Adjusted for return & harvest[2] %	Adjusted for return harvest, and estimated relative population[3] %
Vancouver	6	1.8	7	1.2	1.1	1.3
Charlotte	90	27.0	100	18.6	6.5	18.9
S.E. Inside	168	50.5	197	36.8	68.5	37.4
S.E. Outside	22	6.6	36	6.7	4.8	5.9
Yakutat	22	6.6	110	20.5	8.3	17.4
Kodiak	13	3.9	45	8.4	4.9	11.1
Chirikof	2	0.6	7	1.3	0.9	2.0
Shumagin	5	1.5	17	3.2	2.1	1.6
Aleutian	2	0.6	7	1.3	2.2	2.4
Bering Sea	3	0.9	10	1.9	0.8	2.0

[1] Estimated percent of recaptured tags returned to the tagging agency.

[2] Average of the 1981 and 1982 harvest by INPFC area.

[3] Relative population was based on relative population numbers (RPN) calculated by Sasaki (1981) for the Gulf of Alaska and Aleution Region and by using fisheries performance as an indicator of relative abundance in the Canadian and Bering Sea areas.

fish spawning grounds are in the eastern Gulf of Alaska. Juvenile sablefish rear in shallow nearshore bays and coastal fjords until they are about 3 years old or about 45 cm. At this time, they move into adjacent deeper waters and begin to move north and westward along the continental slope, either actively swimming or passively transported in the fast-moving coastal currents. Upon nearing the size of sexual maturity, the direction of movement reverses as the maturing fish begin to head for the principal spawning grounds off Southeastern Alaska and northern British Columbia. Thus the eastern Gulf of Alaska serves as a pooling area for large mature fish, and little additional movement is observed once the fish return to that area. With this pattern of movement it is essential to consider the Gulf of Alaska sablefish as one stock for management purposes.

TRENDS IN SABLEFISH STOCK ABUNDANCE

Japanese fisheries performance data has been used extensively to determine stock abundance trends in the Gulf of Alaska. With the withdrawal of the Japanese fleet from the eastern Gulf of Alaska in 1978, a consistent Gulf-wide catch data base was no longer available. Other methods for determining abundance have become necessary. Beginning in 1978 a U.S.-Japanese cooperative longline survey has been conducted in the Gulf of Alaska. Also in 1978, the NMFS initiated a pot indexing survey off Southeastern Alaska. A port sampling and skipper interview program has been conducted by the ADF&G in the eastern Gulf of Alaska since 1979. ADF&G sampling effort is currently being expanded westward into the Central Gulf.

U.S. - Japanese Cooperative Longline Survey

The U.S. and Japan have jointly conducted longline surveys using Japanese longline vessels in the Gulf of Alaska since 1978. These surveys collect detailed catch information by length, sex, and depth intervals for each INPFC area in the Gulf of Alaska. The initial survey in 1978 was of a limited, preliminary nature. The results of the surveys from 1979 to 1982 are summarized in Sasaki (1983). Sasaki (1981) describes the computation of "relative population numbers" (RPN) and "relative population weights" (RPW), by depth and area based on longline survey catch information. These numbers are derived by multiplying the bottom area of each depth zone in each INPFC area by the average catch per hachi in numbers (for RPN) or kilograms (for RPW) in each length interval for each INPFC area and depth zone. RPN summed over all depths and INPFC areas in the Gulf of Alaska for all length intervals combined has shown a 57% increase since 1979 (Figure 6a). RPW has increased 70% over the same period. Much of these increases are due to the effect of the strong 1977 year class. The length distribution of RPN for 1979 to 1982 depicts the entry of this year class into the fishable population (Figure 6b). The 1977 year class was first detected in the longline survey in 1980 as a strong mode at 51 cm. The effect of this year class is visible as strong modes at 55 and 57 cm in the 1981 and 1982 surveys, respectively.

However, the apparent increase in total RPN and RPW is not due merely to the effect of the 1977 year class. The survey estimates of the RPN of older, larger fish has increased as well. Fish 67 to 74 cm in particular show marked increases in RPN in 1980 and again in 1982. Three factors could account for the observed increase in the abundance indicator for these older, fully recruited fish:

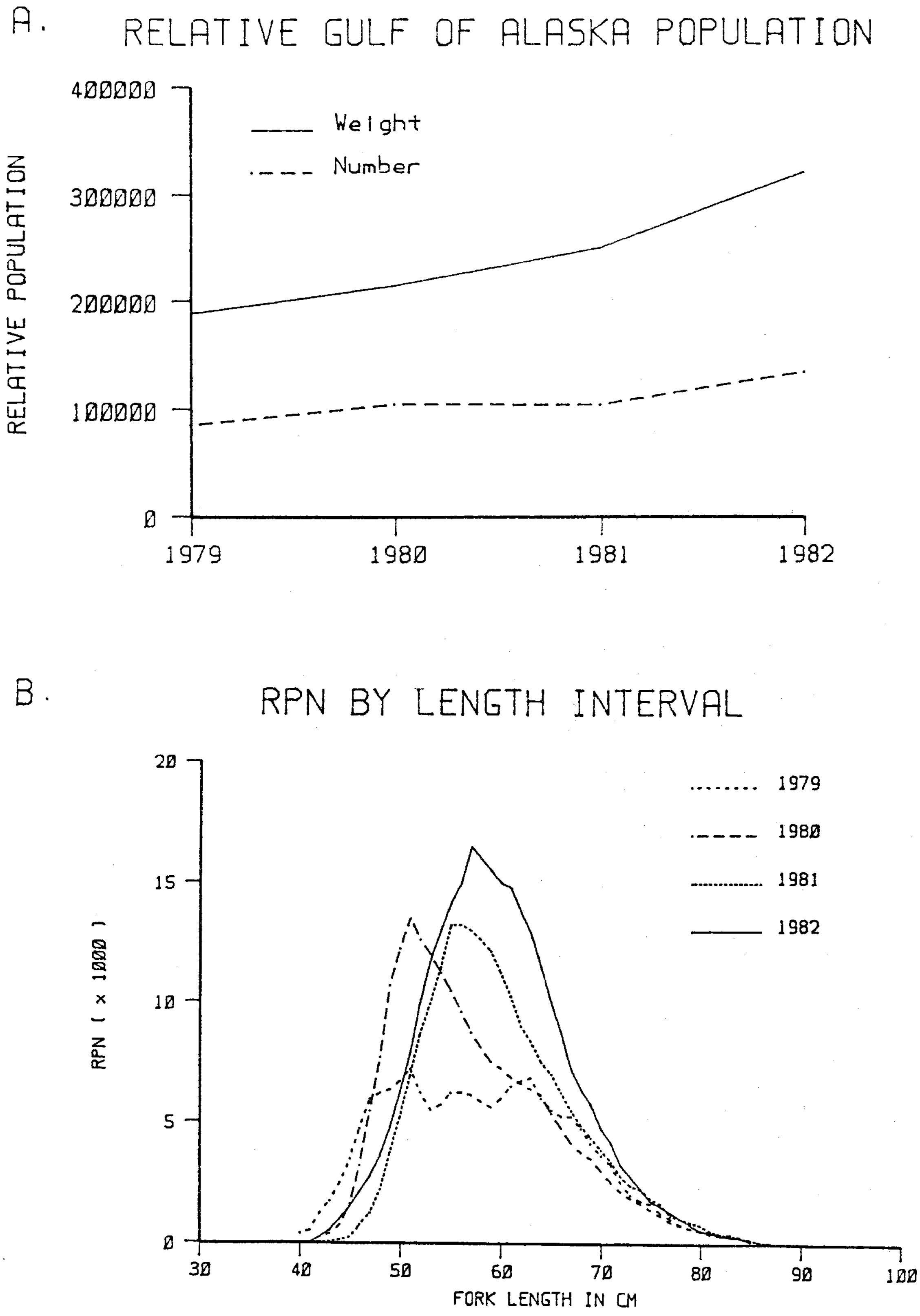


Figure 6. A. Relative Gulf of Alaska population weights (RPW) and numbers (RPN) from the U.S. - Japanese longline survey (from Sasaki 1983) and B. length-frequency distribution of RPN from the U.S. - Japanese longline survey, 1979 to 1982.

1) Movement of large fish into the Gulf of Alaska from adjacent zones,

2) A change in catchability or availability to the longline gear, and

3) Random fluctuations because of the variance of the abundance indicator.

Movement of a large number of older fish into the Gulf of Alaska is unlikely to explain the magnitude of the observed increase in RPN. Changes in catchability or availability are difficult to determine but could easily occur for several reasons. Change in bait quality, fishing efficiency, or survey timing could affect the index. Also the behavior of sablefish could be changing as a response to changes in oceanographic conditions. The variance of the components of RPN has not yet been reported. Abundance indices based on CPUE often have very high variability, so that the observed increases in RPN of the larger age classes could be attributed to random fluctuations. Until estimates of the variance of RPN are made available, the observed increases in the abundance of older fish cannot be meaningfully interpreted.

Estimates of RPN by length interval for the Eastern, Central, and Western Gulf of Alaska for 1979 to 1981 are shown in Figure 7. In 1979 in the Eastern Gulf large fish (> 66 cm) were more abundant than in the other areas. A small mode representing the 1977 year class is evident only in the Eastern Gulf in 1979. In 1980 the 1977 year class dominated the length frequency distributions in all areas, but the effect is most noticeable in the Eastern Gulf. In 1981 this year class continued to dominate the size distributions in the Central and Western Gulf, but declined in importance in the Eastern Gulf. Large fish (> 66 cm) were again more abundant in the Eastern Gulf than in the westward areas in 1981.

Japanese Longline Fishery CPUE

A continuous time series of catch per unit effort (CPUE) statistics from the Japanese longline fishery in the Gulf of Alaska is available from 1964 to 1977. In 1978 the Japanese longliners were allowed to fish in depths shallower than 500 m for Pacific cod. Further regulatory changes caused a large shift in Japanese fishing effort into these shallower regions. Statistics provided by the Japanese do not allow allocation of fishing effort between sablefish and Pacific cod in these areas so that CPUE statistics after 1978 must be treated separately from those prior to 1977. However, Okada et al. (1982) present CPUE data to form a continous time series from 1967 to 1981 (Table 4), although Stauffer (1983) notes that it is not clear how effort directed specifically at sablefish was calculated.

Stauffer (1983) presents CPUE data from U.S. observers aboard Japanese vessels targeting on sablefish in waters deeper than 500 m. The Gulf-wide average observer CPUE for all sized fish declined from 1977 to 1979 and increased considerably from 1980 to 1982 (Table 4). Most of the increases have been due to small fish from the 1977 year class, as the CPUE of large fish (> 67 cm) has not shown marked improvements.

The arithmetic mean of the annual changes in RPW, Japanese reported longline CPUE and observer reported CPUE is also shown for 1978 to 1982. All abundance indicators point to dramatic increases in stock abundance as a result of the 1977 year class.

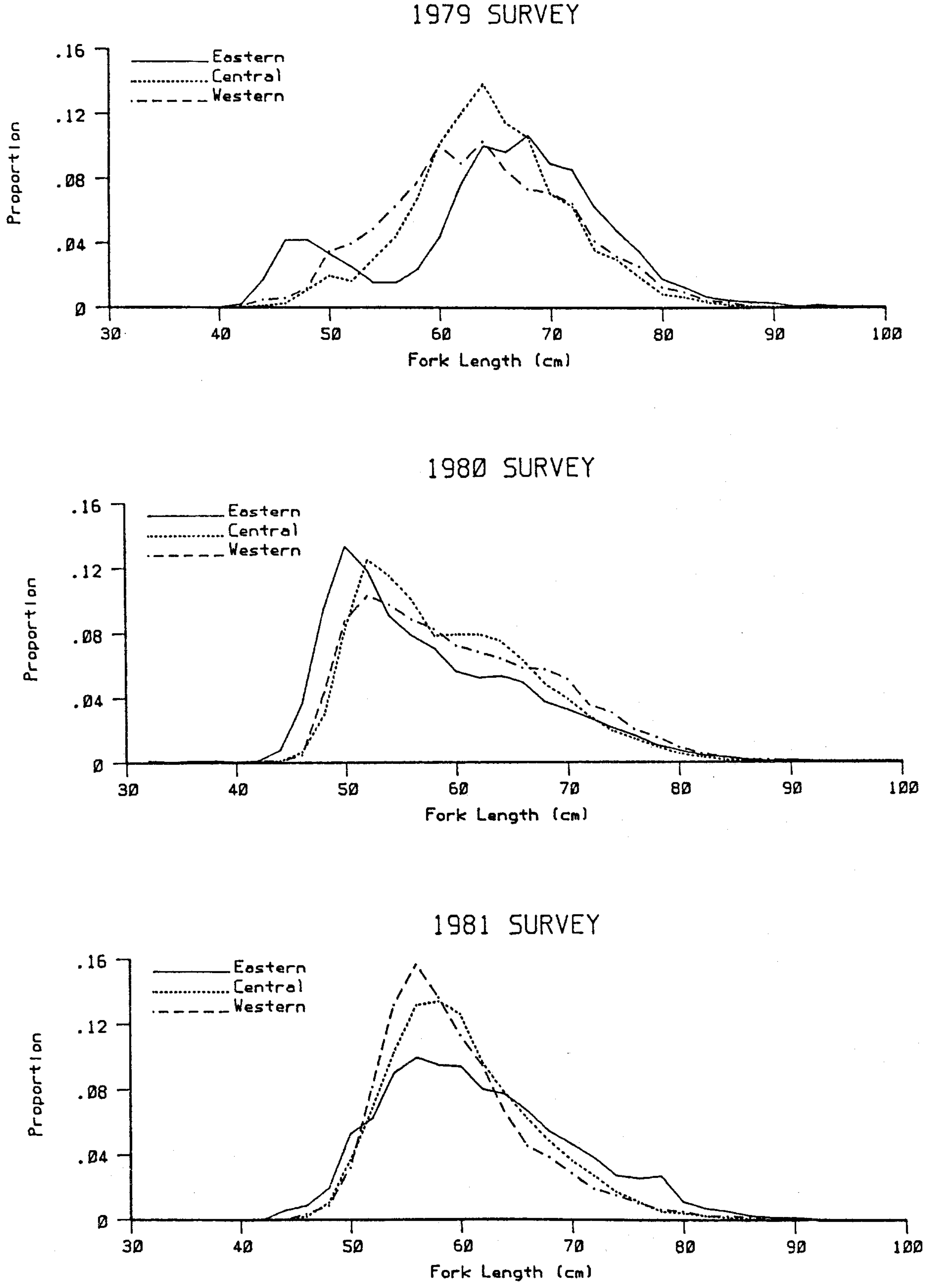


Figure 7. Length distribution of RPN in the eastern, central, and western Gulf of Alaska from 1979 to 1981 from the U.S. - Japanese longline survey.

Table 4. Gulf-wide summary of abundance indicators for the Gulf of Alaska from 1967 to 1982. Percent change in each abundance indicator is indicated in parentheses. The last column gives the average annual change in all abundance indicators.

Year	U.S.-Jap. Survey[1] (RPW)	Jap. Longline CPUE[2] (Kg/10 hachi)	Observer CPUE[3] (Kg/10 hachi)	Average Change
1967		212		
1968		263		
1969		235		
1970		235		
1971		207		
1972		208		
1973		209		
1974		190		
1975		177		
1976		186		
1977		139	132	
1978		135 (- 2.9%)	104 (-21.2%)	-12.0%
1979	188,702	109 (-19.3%)	97 (- 6.7%)	-13.0%
1980	214,134 (13.5%)	122 (11.9%)	134 (38.1%)	21.2%
1981	249,763 (16.6%)	151 (23.8%)	150 (11.9%)	17.4%
1982	319,967 (28.1%)		235 (56.7%)	42.4%

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[1] Relative population weights (RPW) from the U.S. Japanese longline survey from Sasaki (1983).

[2] Japanese longline CPUE as reported in Stauffer (1983). The 1980 and 1981 CPUE was originally reported by Okada et al. (1982).

[3] Observer CPUE from observed hauls > 500 m in depth as reported by Stauffer (1983).

U.S. Fishery Port Sampling

The Alaska Department of Fish and Game began dockside sampling of sablefish longline vessels in 1979 in Southeastern Alaska to determine in-season and annual changes in CPUE and length-weight composition of the catch. These data are used for setting the annual harvest level within the guideline harvest ranges in the inside waters of Southeastern Alaska. Results are also used in conjunction with other methods for determining changes in stock status in the outside waters of Southeastern Alaska and the Yakutat area. Port sampling has been conducted for landings from the inside areas since 1979 and for the landings from outside areas since 1981. In 1983 a port sampling program for sablefish was also initiated in Kodiak.

A port sample consists of a systematically selected subsample of approximately 100 sablefish from each longline vessel sampled. Fish are measured to the nearest centimeter and weighed to the nearest 0.1 kilogram. Conversions have been established to convert dressed length and weight to round length and weight for both the eastern cut and western cut methods of dressing. In conjunction with the length-weight sample, an interview is conducted with the vessel operator to determine the area of fishing, type and number of hooks set, and the total number of fish landed. That information is combined with fish ticket information to determine the number of fish per hook and number of pounds per hook. These data are then summarized by area to furnish an indication of stock status based on fisheries performance.

Until 1983, sampling of the U.S. fishery in the outside areas of the Eastern Gulf of Alaska was not as consistent or intense as inside fishery sampling. In 1983 the sampling program was expanded so that landings from outside areas were sampled throughout most of the fishing season, with a season average sampling fraction of 29% of the catch by weight. Only two openings, each of one week duration, were allowed in northern inside waters in 1983. The sampling fraction for these openings was over 70%. In Kodiak in 1983, 11 landings were sampled for a sampling fraction of 31% of the catch.

Port sampling estimates of average pounds per hook show an increasing trend in the northern inside area (Table 5). The same trend appears to be occurring in outside waters, although sampling was only conducted in 1981 and 1983. Average fish size and CPUE has been higher in the northern inside fishery than in the outside fishery. Pounds per hook from the Kodiak landings are considerably lower than those from the Eastern Gulf of Alaska in 1983.

One drawback of port sampling as an indicator of stock condition is that the current market demands fish of over 3 pounds dressed weight. Smaller fish are captured by the longline gear and are discarded at sea. On-board observers are needed to obtain unbiased samples from these small fish. Such a sampling program would be particularly useful as an early indicator of the presence of unusually strong or weak year classes.

NMFS Pot Indexing Survey

The NMFS began sablefish abundance indexing in Alaska during 1978, using standardized fishing procedures and sablefish trap gear. Annual change in relative abundance and size composition of sablefish are monitored at specific sites along the outer coast of Southeastern Alaska. Three sites were fished in 1978 and four sites

Table 5. Average pounds per hook from ADF&G port sampling in the northern Southeastern inside and outside areas and from the Kodiak area from 1980 to 1983.

	Northern SE Inside	Southern SE Outside	Kodiak
1980	.29	--	
1981	--	.29	
1982	.57	--	
1983	.81	.43	.36

were fished from 1979 through 1983. Sampling procedures and results from 1978 to 1981 are reviewed by Zenger (1981).

Between 1979 and 1980 the abundance index for marketable or 'large' sablefish (> 57 cm) declined at the northern Cape Cross and Cape Ommaney sites, while increases of 70% and 1% were noted at the Cape Addington and Cape Muzon sites, respectively. The increase in abundance for all four sites combined totaled only 3% between 1979 and 1980, leading Zenger and Hughes (1981) to conclude that the allowable biological catch (ABC) for the period June 1980 to May 1981 should not exceed the June 1979 through May 1980 harvest of 2,580 mt.

Abundance indexing showed a further decline in large fish (> 57 cm) for all sites in 1981 with an overall decline of 51% between 1979 and 1981. Catch rate of "prerecuit" size fish, (< 57 cm) was increasing, however, as the strong 1977 year class became available to the pot survey gear. A 53% increase in small fish was observed between 1979 and 1981.

Results from the 1982 pot indexing survey are inconclusive because of problems with weather and bait. Abundance indices computed from the 1982 data showed moderate increases at all sites except Cape Muzon, which showed a 43% decline. Catch rates of marketable size fish were substantially lower than in 1981 only at the Cape Muzon site.

Preliminary results of the 1983 survey show that catch rates of marketable-sized sablefish increased at all four sample sites, reversing the downward trend in abundance the past few years (NMFS Cruise Report, JC-83-02). Catch rates were highest at Cape Muzon and decreased northward to Cape Ommaney and Cape Cross, where the U.S. fishery is concentrated. Abundance of pre-recruits continued to increase at Cape Muzon and Cape Addington, but remained at nearly the same level as previous years at the northern two sites. Detailed analysis of the 1983 survey data is not yet complete.

POPULATION DYNAMICS

Stock Production Models

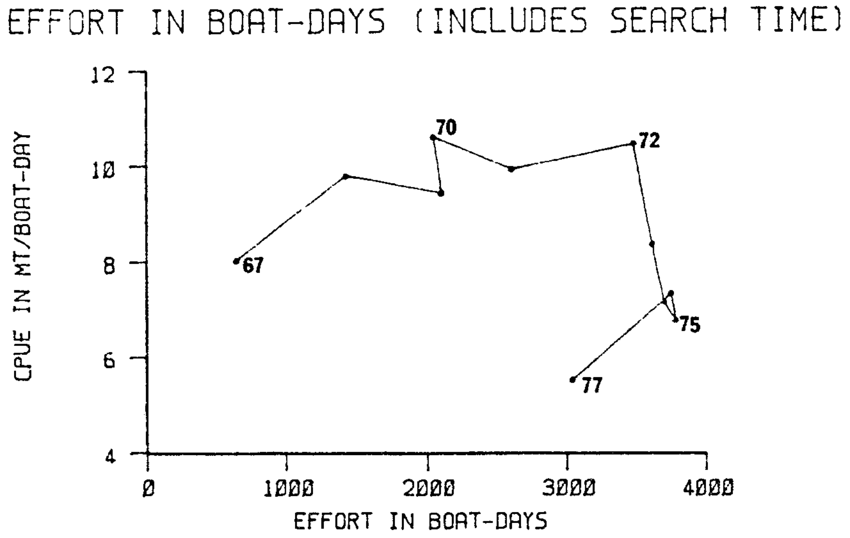
Several attempts have been made to determine maximum sustained yields (MSY's) for Gulf of Alaska sablefish using various forms of stock production models. The stock production models of Schaefer (1954; 1957); Pella and Tomlinson (1969); Fox (1971); and Fletcher (1978a, b) all result from the simple assumption that a stock of fishes, when subjected to fishing mortality, will attempt to restore their former level of abundance at a rate proportional to the amount that the stock has been displaced from its level of abundance prior to fishing. This simplistic class of models ignores the explicit treatment of the underlying processes of individual growth, mortality, and recruitment. When fit to populations that are not at equilibrium (almost always the case), the time lag between a given stock size and the resulting recruitment is not allowed for. Stochastic variation in recruitment can have disastrous effects on populations which are managed according to stock production model recommendations (Larkin 1977). For these reasons "equilibrium yields" or "maximum sustained yields" resulting from stock production models should be regarded with caution.

Moreover, the parameters of stock production models are customarily estimated from a time series of catch and effort data of at least 10 years. One of the most important attributes of contemporary fishing fleets is a continuous increase in fishing power. Therefore, unadjusted time series of catch and effort data will almost always be misleading. For example, Brown et al. (1976) estimated that the fishing power of a number of different fishing fleets in the North Atlantic increased an average of 5% per year over the period 1962-1972. Over a 10-year period this would amount to an effective increase in fishing power of 1.65. With such increases in fishing power, stock production model parameters estimated with unadjusted time series of catch and effort data are almost certainly in error.

Stock production model parameters for sablefish in the north Pacific have all been estimated from time series of catch and effort data from the Japanese longline fishery. In the Japanese longline fishery, fishing power would have been expected to increase over the period 1964 to 1977 for several reasons. First, searching efficiency would have increasee because higher resolution and more economical electronic equipment became available during this period. Improved acoustical gear would have allowed easier location of productive fishing areas. Improvements in position finding equipment (LORAN, satellite navigation, radar) would have allowed greater precision in returning to fishing areas that were productive in the past. Secondly, local knowledge of the Gulf of Alaska fishing grounds was continually being accumulated by the Japanese longline skippers during that period. Thirdly, longline setting and retrieval methods, baiting techniques, and processing methodology were undoubtedly being modernized and streamlined during that period.

Low et al. (1976) fit Fox's (1970) exponential surplus production model to Japanese longline CPUE for 1963-1973 using Gulland's (1969) technique of relating CPUE to the prior average fishing effort over the number of years that a year class contributes to a fishery. An attempt was made to remove some of the effects of fishing power increases by using boat-days instead of units of gear as a measure of fishing effort. Sablefish from the Bering Sea to California were assumed to be one stock unit. MSY estimates for the adjusted data were 42,568 mt if a year class was assumed to contribute significantly to the fishery for 4 years, and 46,536 metric tons if a year class contributed for 3 years. However, under the newer growth curves of Beamish and Chilton (1982) and Funk and Bracken (1983), sablefish contribute to the fishery for much longer than 4 years. Thus the estimate of MSY using Low's procedure is probably too high.

Sasaki (1978) further adjusted Japanese longline effort measured in boat days to remove non-fishing time (travel time, weather time, etc.). Both methods of computing effort describe similar overall relationships between CPUE and effort in the Gulf of Alaska over the period 1967 to 1977 (Figure 8). Both CPUE and effort were low at the start of the Gulf of Alaska data series in 1967 with CPUE reaching a peak at intermediate effort levels in 1970. Effort tended to increase until 1976, while CPUE declined to 66% of the initial levels by 1977. The most obvious effect of measuring effort in boat days is depicted by the reduction in CPUE for 1973 compared to measuring effort in 100 hachi units in 1973. By this time stock abundance may have been reduced so that significant amounts of time were being spent searching for concentrations of fish. Effort measured in boat days would include this search time and cause CPUE to be reduced compared to effort measured in 100 hachi units.



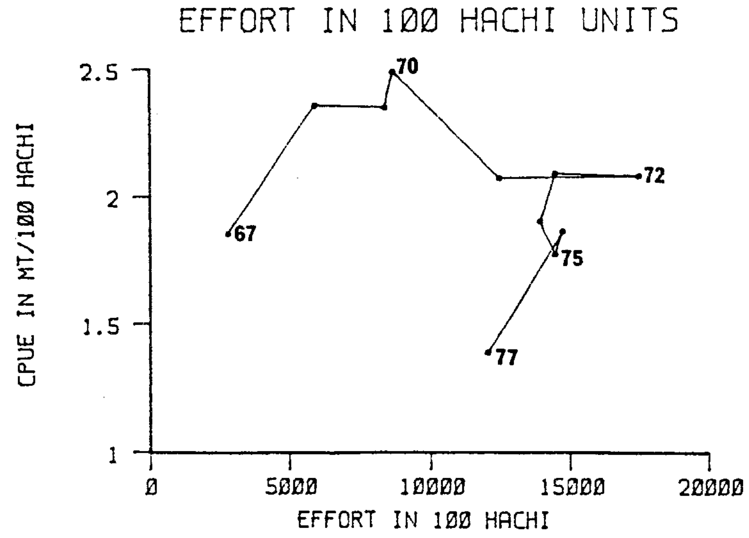


Figure 8. Catch per unit effort (CPUE) and effort for two methods of computing effort in the Japanese longline fishery in the Gulf of Alaska, 1967-1977. Catch in metric tons from Low (1978). Effort in 100 hachi units from Low (1978).

Sasaki (1978) used Gulland's (1969) technique on the adjusted data and assumed that a sablefish year class contributes significantly to the fishery for 4 or 5 years. His estimates of MSY are much higher, ranging from 69,600 to 87,200 mt for the entire North Pacific. Gulf of Alaska MSY's were estimated at 31,200 to 32,400 mt.

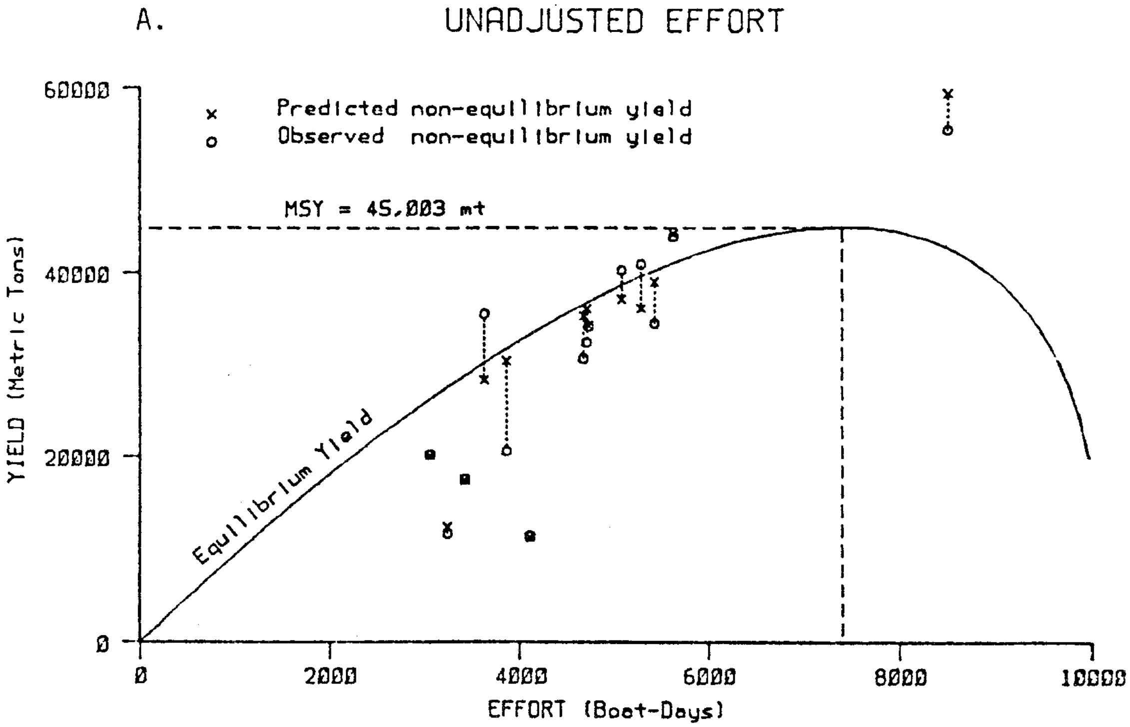
Low and Wespestad (1979) fit several types of stock production models to the 1964 through 1977 Japanese longline CPUE, using both unadjusted catch per hachi and CPUE adjusted for non-fishing time from Sasaki (1978). They used both the GSPFIT procedure to estimate parameters of Fox's (1970) exponential model and the PARFIT technique of Rivard and Bledsoe (1978) to estimate parameters of the restructured Pella-Tomlinson model of Fletcher (1978b). Their estimates of MSY for the entire North Pacific averaged 50,300 mt over all data sets and models. For the Bering Sea-Aleutian-Gulf of Alaska region MSY was estimated at 40,800 mt over all data sets and models. For the Gulf of Alaska data, MSY averaged 26,500 mt, although parameter estimates for several of the data sets did not converge to meaningful values. An MSY of 25,100 mt was assigned to the Gulf of Alaska region, based on the results of the stock production models for the larger regions and the historical patterns of catch.

In order to investigate the effects of changes in fishing power on MSY estimates from stock production models, we re-estimated stock production model parameters under the assumption that fishing power gradually increased over the time period from 1964 to 1977. The PARFIT parameter estimation technique of Rivard and Beldsoe (1978) was applied to the restructured Pella-Tomlinson model of Fletcher (1978b). The model was first verified by fitting it to unadjusted data for the Bering Sea-Aleutian-Gulf of Alaska area from Sasaki (1978), with effort measured in boat days. The PARFIT technique was able to describe this data series reasonably well, although a few of the residuals are large (Figure 9a). MSY was estimated at 45,003 mt for the entire area. The parameter estimates are similar to those reported by Low and Wespestad (1979) for the same data. The minor differences are probably due to differences in data weighting techniques. Additive proportional errors were assumed for these estimates. Parameters were then re-estimated after adjusting fishing effort to allow for a 1.5% annual increase in fishing power from 1964 to 1977. MSY was then estimated at 40,702 mt (Figure 9b), a 9.6% reduction from the unadjusted data. Using the allocation technique of Low and Wespestad (1979), the Gulf of Alaska MSY would be 23,956 mt. Attempts were made to estimate parameters for annual fishing power increases greater than 1.5%. In all cases, the estimation technique failed to converge to reasonable parameter values. However, if MSY were related in a linear fashion to the annual rate of increase in fishing power over this 10-year span, projections can be made for annual fishing power increases greater than 1.5%. Using this method, if fishing power had increased at an annual rate of 5%, MSY would be reduced 32% to 30,603 mt for the Bering Sea-Aleutian-Gulf of Alaska region. Using the allocation methods of Low and Wespestad (1979), MSY for the Gulf of Alaska would then be 18,012 mt.

Population Parameter Estimates

Parameter estimation for Gulf of Alaska sablefish is hampered by a lack of consistent area-wide time series of data. Because of gaps and uncertainties in the data, we feel that the most appropriate approach is to average parameter estimates from as many sources as possible, attempting to average the results of techniques that will tend to overestimate and to underestimate parameters where possible.

A.



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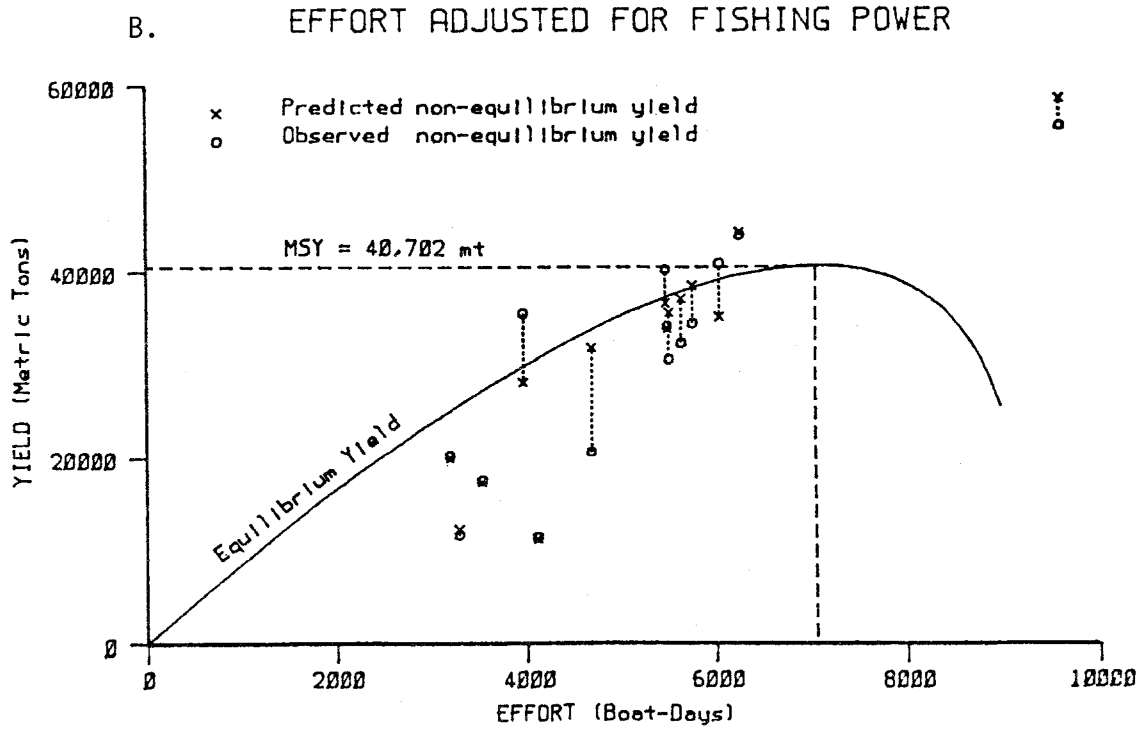

Figure 9. Restructured Pella-Tomlinson stock production model of Fletcher (1978b) fit to A) unadjusted catch and effort data from the Japanese longline fishery in the Bering Sea-Aleutian-Gulf of Alaska area and B) catch and effort data adjusted for a 1.5% annual increase in fishing power over the period 1967-1977. Parameters were estimated with the PARFIT technique of Rivard and Bledsoe (1978).

Stock Size:

Preliminary estimates of stock biomass for Gulf of Alaska sablefish are available from stock production models and from methods based on calculations of area swept in trawl surveys. Sablefish stock production models provide estimates of biomass only for the entire Bering Sea-Aleutian-Gulf of Alaska area, since fits to Japanese catch and effort data for the Gulf of Alaska alone were not sufficient to allow meaningful parameter estimation. These estimates of total biomass can be allocated to the Bering Sea, Aleutian, and Gulf of Alaska areas based on the relative population weights (RPW) for these areas determined from the U.S.-Japanese Cooperative Longline Survey. The longline survey covered all three areas only in 1982. However, the longline survey does not cover the inside waters of Southeastern Alaska. RPW for the inside waters is estimated at 8.0% of the Gulf of Alaska total RPW, based on fisheries performance (see Table 13). Therefore, the spatial allocation of biomass based on 1982 RPW is:

	RPW	%
Bering Sea	33,538	8.2
Aleutians	30,984	7.6
Gulf of Alaska	319,967	78.0
Southeastern Inside	25,597	6.2
Total	410,086	100.0%

The total Gulf of Alaska allocation, including inside waters, is 84.2%. The stock production model estimates of stock biomass (in metric tons) for the Bering Sea-Aleutian-Gulf of Alaska area in 1977 is 149,380 mt without adjusting for fishing power increases. If fishing power had increased by 1.5% per year, the 1977 stock biomass estimate from the stock production model is 120,380 mt. The allocations to the Gulf of Alaska are then 125,778 mt for the unadjusted data and 101,360 mt for the effort adjusted data. Because of uncertainties in the estimates, the average of these two values of 113,569 will be used as the 1977 stock production estimate of the Gulf of Alaska biomass. Table 6 depicts the biomass projections for 1978 to 1982 based on this estimate of the 1977 stock biomass and the average annual change in abundance indicators from Table 4.

Recently Japanese scientists have derived stock size estimates from comparative trawl and longline sampling. The NMFS performed a trawl survey in the Aleutian region in 1980 and estimated sablefish biomass in the 100-900 m depth range at 19,464 tons. The 1980 U.S. - Japanese longline survey relative population biomass in this depth zone was 23,602. From this comparative sampling, Japanese scientists estimates that absolute biomass = 0.8247 * relative biomass (Sasaki 1983). The estimates of sablefish biomass based on this relationship are also shown in Table 6.

These RPN based estimates must be considered to be very preliminary in nature. The expanded estimates are all based on compared trawl and longline samples from only one year and only in the Aleutian area. The bathymetry of the Aleutian area is extremely diverse. Since the trawl and longline surveys were not coordinated, very different habitats could have been sampled in the two surveys. The technique holds promise but should be based on an adequately designed comparison for the entire Gulf of Alaska.

Table 6. Biomass estimates for Gulf of Alaska sablefish based on the stock production model estimate for 1977 projected out to 1982 based on average change in abundance indices, and the biomass estimates of Sasaki (1983) based on comparative trawl and longline CPUE in the Aleutian region.

Year	Average change[1] in abundance indices	Biomass Estimate[2] Derived from Stock Production Model (metric tons)	RPN-Trawl Based Biomass Estimate (Sasaki 1983) (metric tons)
1977		113,569	
1978	-12.0%	99,941	
1979	-13.0%	86,948	155,618
1980	+21.2%	105,381	176,591
1981	+17.4%	123,717	205,973
1982	+42.4%	176,173	263,869

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[1] Average of the percent change in Japanese fishery CPUE, observer CPUE from observed hauls in greater than 500 m depths and RPW over all depths and sizes.

[2] Average of the unadjusted fishing effort estimate and the estimated adjusted for 1.5% annual increase in fishing effort.

Mortality:

Low et al. (1976) initially estimated sablefish natural mortality by the Alverson-Carney procedure (Alverson and Carney 1975). This procedure estimates the instantaneous rate of natural mortality (M) from the von Bertalanffy growth coefficient (K) and the time at which a cohort is expected to achieve maximum biomass (T_{mb}):

$$T_{mb} = (1/K) * \ln[(M + 3K)/M]$$

Low et al. (1976) approximate the age of maximum biomass as 1/4 of the maximum observed age in the unfished population, as suggested by Alverson and Carney (1975) for preliminary approximation. Estimating this age at 30 years, they derived an instantaneous natural mortality estimate of 0.22.

The newer, slower growth rates require a re-evaluation of these natural mortality estimates. The Alverson-Carney procedure was used to estimate natural mortality for a range of maximum ages, using the von Bertalanffy growth coefficients of Funk and Bracken (1983) for northern British Columbia. A range of maximum ages was used, approximating the age of maximum biomass as 1/4 of the maximum observed age in unfished populations. The average estimated natural mortality for male and female sablefish ranged from 0.080, if the maximum age was 40 years, to 0.024 at a maximum age of 65 years (Table 7). Beamish and Chilton (1982) report a maximum age in the commercially fished population in British Columbia at approximately 45 years. Alverson and Carney (1975) express caution concerning the preliminary estimation of T_{mb} as 1/4 of the maximum observed age in unfished populations. They note that values of T_{mb} reported in the literature are closer to 1/3 of the maximum observed age in unfished populations, which reduces the natural mortality estimates. At the older maximum ages, the natural mortality estimate is not as sensitive to changes in T_{mb} as at younger maximum ages. A maximum age of 55 years is assumed for unfished populations, which gives an Alverson-Carney instantaneous natural mortality estimate of 0.036.

The strong 1977 year class provides an opportunity to use some simple length-frequency modal separation techniques for estimating instantaneous fishing and natural mortality. Modal separation techniques are difficult to apply to adult sablefish because with their slow growth; the length frequency distributions of individual cohorts overlap considerably. Therefore, modal separation techniques are only useful when sablefish are first recruited to the fishery, which occurred in 1980 for the 1977 year class.

Two simple modal separation techniques are applied to the sablefish data. The first technique estimates survival directly from the length distribution of RPN. The survival of all cohorts present in the population in 1979 is computed for one year, from 1979 to 1980. The 1977 year class is assumed to be unavailable to longline gear in 1979. The 1977 year class is separated from the population remaining in 1980 by assuming that the first mode in the length distribution of RPN for 1980 (Figure 6) is entirely due to the 1977 year class. The unknown form of the descending right limb of length distribution of the 1977 year class in 1980 is assumed to be symmetrical with the ascending left limb. This technique overestimates the abundance of the 1977 year class since portions of other year classes will be included in the estimate. To some extent, the inclusion of partially

Table 7. Natural mortality estimates for male and female sablefish from the Alverson-Carney procedure for a range of estimates of maximum age in unfished populations. The age of maximum biomass (T_{mb}) is computed as 1/4 of the maximum age in unfished populations. The von Bertalanffy growth coefficient, K, was estimated by Funk and Bracken (1983) for northern British Columbia samples.

Maximum Unfished Observed Age:	40	45	50	55	60	65
Age of Maximum Biomass (Tmb):	10	11.25	12.5	13.75	15	16.25
Natural Mortality Rate (Females): (K = 0.147)	.132	.104	.084	.067	.055	.045
Natural Mortality Rate (Males): (K = 0.377)	.027	.017	.010	.006	.004	.002
Average of Male and Female:	.080	.061	.047	.036	.030	.024

recruited year classes in 1979 will tend to compensate for this effect. Using this method, the 1977 year class accounts for 47.2% of the 1980 Gulf-wide RPN shown in Figure 6. Total population sizes in numbers of fish were estimated for 1979 and 1980 using both of the biomass estimates of Table 6 along with the length distribution of RPN and a length-weight relationship derived from sampling in Southeastern Alaska (Table 8). The contribution of the 1977 year class was then subtracted from the total 1980 population estimate to determine the survivors of all previous year classes that were present in 1979. Catch in numbers was estimated from the harvest weights given in Table 1. The length frequency distribution in the commercial catch was assumed to be similar to that of RPN. The simple form of the catch equation and an exponential survival model can then be used to estimate instantaneous fishing mortality (F) and instantaneous natural mortality (M) from the catch (C) and population sizes (N_1 and N_0):

$$N_1 = N_0 * \exp(-Z)$$

$$C = N_0\ (1 - \exp[-(Z)]\ ) * F/(Z)$$

where Z = F+M. Natural mortality estimates are .238 for the stock production model based biomass estimate and .364 for the RPN-trawl based biomass estimate.

The second natural mortality estimation technique based on length frequencies first converts lengths to ages and then examines survival from the resulting age frequency distributions. This technique tends to underestimate the abundance of the 1977 year class. Conversions from length distributions to age distributions, in general, are subject to bias (Kimura 1977; Westrheim and Ricker 1978; Clark 1981; Bartoo and Parker 1983). However, results can be cautiously considered in comparison to the previous method, which overestimated the contribution of the 1977 year class. More detailed age data are required in order to apply more sophisticated techniques of estimating age distribution for the Gulf of Alaska sablefish fishery.

Estimates of total population biomass were first converted to numbers at length using the length distribution of RPN for the Gulf of Alaska from 1979 to 1980 from Sasaki (1983) (Figure 6b), and a length-weight function derived from ADF&G sampling in Southeastern Alaska. These length distributions were then separated by sex, using the length-specific sex ratios for 1981 given in Sasaki et al. (1982). The sex-specific length distributions were then converted to age distributions using the lengths at age from the "northern British Columbia" growth curve of Funk and Bracken (1983). Fish 7 years and older were pooled into a single "7+" age category because of excessive overlap in the length distribution at older ages. The resulting age frequency distributions are given in Table 9 for 1979 and 1980. The 1977 year class was aged 2 in 1979 and becomes particularly noticeable at age 3 in 1980. Gulf of Alaska sablefish yields in metric tons for 1979-1982 from Table 1 were converted to numbers of fish caught at age using the same procedure. This assumes that the age distribution of the total Gulf of Alaska catch is the same as that of the U.S. Japanese Longline Survey in the corresponding year. Mortality rates are estimated from the survival of the population aged 3 and older in 1979 to the population aged 4 and over in 1980. Mortality rates are estimated using the same equations as in the previous method. The instantaneous rate of natural

Table 8. Estimation of natural mortality from the survival from 1979 to 1980 of the population which was recruited to the fishery in 1979. The estimated size of the 1977 year class is subtracted from the 1980 population estimate. Biomass estimate in metric tons are from Table 6. Population sizes are estimated from biomass using the length distribution of RPN and a length-weight regression derived from ADF&G sampling in Southeastern Alaska.

	Stock Production Estimate	RPN-Trawl Estimate
1979 Biomass (t):	86,948	155,618
1979 Population:	41,263,556	73,853,000
1980 Biomass (t):	105,381	176,591
1980 Population:	53,447,762	89,564,300
1980 Population less the 47.2% contribution of the 1977 year class:	28,220,418	47,333,168
1979 Catch (numbers):	4,846,500	4,846,500
Estimated Instantaneous rates		
Z (Total mortality):	0.379	0.445
F (Fishing mortality):	0.141	0.081
M (Natural mortality):	0.238	0.364

Table 9. Estimation of natural mortality from the survival from 1979 to 1980 of the population which was aged 3 and older in 1979, based on conversion of length distributions to age distributions.

	Stock Production Estimate		RPN-Trawl Estimate	
Age	1979	1980	1979	1980
2	7,208,083	7,029,421	12,900,937	11,779,449
3	9,536,151	17,301,355	17,067,685	28,992,491
4	6,060,698	9,928,739	10,847,362	16,637,938
5	4,254,240	5,434,639	7,614,185	9,107,017
6	3,227,737	3,503,837	5,776,963	5,871,504
7+	10,976,648	10,249,770	19,645,868	17,175,901
3 and older:	34,055,473		60,952,063	
4 and older:		29,116,986		48,792,360

Instantaneous Mortality Estimates

	Stock Production Estimate	RPN-Trawl Estimate
Z (Total Mortality):	0.157	0.223
F (Fishing Mortality):	0.145	0.083
M (Natural Mortality):	0.012	0.139

mortality was estimated at 0.012 for the stock production based biomass estimate, and at 0.139 for the RPN-trawl based biomass estimate.

Lacking better data for estimating mortality, the average of the length-frequency method, which tends to overestimate natural mortality rates and the age-frequency method, which to underestimate natural mortality rates will be used to represent rates derived from length and age methods:

	Stock production biomass estimate	RPN trawl biomass estimate
Length-frequency method	.238	.364
Age-frequency method	.012	.139
Average	.125	.252
	(.188)	

The average of the length and age methods is 0.188. This estimate and the estimate from the Alverson-Carney procedure of 0.036 were averaged to obtain the estimate of the instantaneous natural mortality rate for Gulf of Alaska sablefish of 0.112.

Equilibrium Yield Per Recruit

Low et al. (1976) published results of a Beverton-Holt yield-per-recruit model based on the older faster growth rates and relatively high rates of natural mortality. They felt that the natural mortality rate was approximately 0.22. With relatively fast growth, the optimum age of exploitation was about 5, with instantaneous fishing mortality rates of about 1.0. The newer, slower growth rates and lower natural mortality rates depict a quite different situation.

A revised Beverton-Holt yield-per-recruit model was constructed to reflect the current parameter estimates of the Gulf of Alaska sablefish population and the sablefish longline fishery. The yield-per-recruit model includes the effects of hooking mortality on fish that are either below a hypothetical size limit or are discarded. Currently there is little or no market for small (< 3 lb) sablefish so they are frequently discarded at sea.

The rate of accumulation of yield (dY) from a cohort at age t is defined as:

$$dY = F * N(t) * W(t)\,dt$$

where F is the instantaneous rate of fishing mortality, N(t) is a survival model describing numbers surviving at age t, and W(t) is a model describing average weight at age t. The yield over the lifespan of the cohort from the age of first retention in the catch (t_c) to theoldest age t_λ is given by:

$$Y = F * \int_{t_c}^{t_\lambda} N(t) * W(t)\,dt$$

The survival model $N(t)$ has two components. The first component describes survival from the age of first vulnerability to the fishing gear (t_r) to the age first retained in the catch t_c):

$$N(t_c) = N(t_r) * \exp - [H(F)+M]*(t_c-t_r)$$

where N_0 is the number of fish at age t_r, $H(F)$ is a function describing the instantaneous rate of hooking mortality on discarded fish as a function of the instantaneous rate of fishing mortality on large fish (F), and M is the instantaneous natural mortality rate.

The second component of the survival model describes survival to age t, beyond the age of first retention in the catch (t_c):

$$N(t) = N(t_c) \exp - (F+M)(t-t_c)$$

The allometric growth function for "northern British Columbia" from Funk and Bracken (1983) is used to describe weight at age [$W(t)$]. Male and female growth is tracked separately in the model, assuming equal numbers of recruits in the initial population. The instantaneous rate of natural mortality is assumed to be 0.112.

The current economic structure of the U.S. sablefish fishery values large fish (> 5 lbs dressed weight) at over twice that of small fish. In order to reflect current market conditions, the landed value per recruit was also computed as:

$$V = F * \int_{t_c}^{t_\lambda} N(t) * W(t) * V(W)\, dt$$

where $V(W)$ describes the ex-vessel price per pound of a fish of weight W.

The usual interpretation of yield-per-recruit models is to assume constant recruitment and constant fishing and natural mortality for a period of at least $t_\lambda - t_c$ years so that the yield from a cohort over its lifespan is the same as the yield during a single year from all cohorts in the population. Optimum age of first retention in the catch (t_c) for a given level of fishing mortality (F) is then determined. Other information should be used to choose the appropriate level of fishing mortality since yield-per-recruit models do not include the potential impact of overfishing on recruitment.

Results of a yield-per-recruit model are customarily presented as a response surface showing the yield-per-recruit at particular combinations of fishing mortality and size of entry into the fishery. With no hooking mortality the yield-per-recruit response surface for sablefish is relatively broad and flat (Figure 10). Optimum retention size for a given level of fishing mortality is shown by the location of the "eumetric fishing curve". Yield remains approximately the same over a wide range of size limits or discard sizes so that little yield is lost when the harvest conditions are varied off of the eumetric fishing line. However, a model of a longline fishery without hooking mortality is simply not realistic.

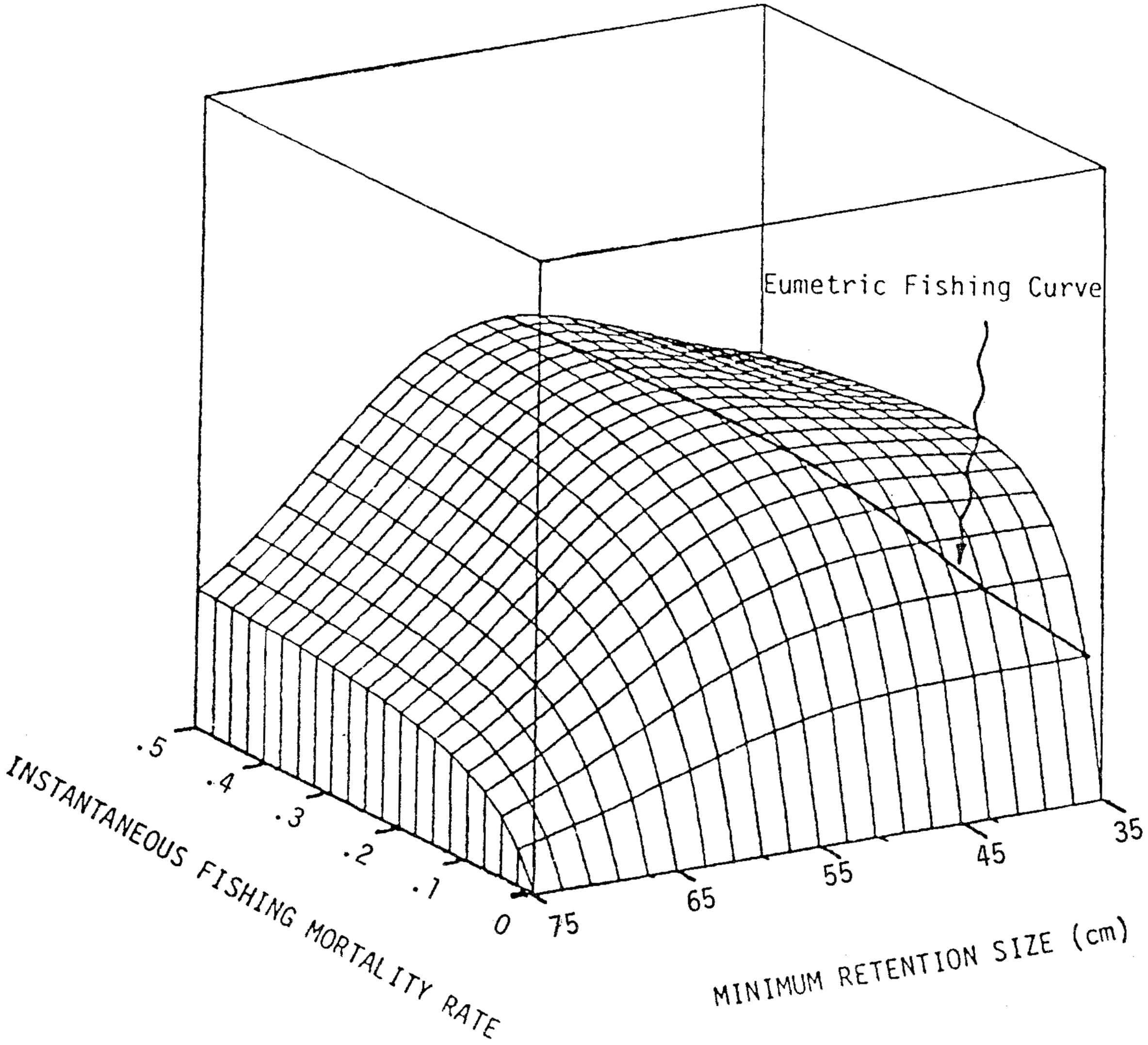

Figure 10. Sablefish yield-per-recruit response surface with no hooking mortality.

Although hooking mortality has not been quantified, estimates of 25% to 75% have been received from U.S. longline skippers (B.B. pers. obs.).

When 35% hooking mortality is incorporated into the model, delayed harvest reduces the potential yield considerably, particularly at higher fishing mortalities (Figure 11). While optimum yields are obtained at very small minimum retention sizes (< 41 cm), there is very little decrease in potential yields unless minimum retention sizes are larger than about 50 cm.

If hooking mortality is increased to 50%, optimum yields are obtained at even smaller minimum retention sizes (Figure 12). Minimum retention sizes larger than 47 cm cause significant loss of potential yield. Optimum size limits indicated by the eumetric fishing curve are very small, less than 37 cm.

Current sablefish ex-vessel prices vary considerably with fish size. In 1983 western cut sablefish prices in the eastern Gulf of Alaska were approximately $0.32/lb for 3-5 lb fish and $0.65/lb for 5 lbs and over fish. Incorporating this price structure into the model with 35% hooking mortality, the resulting landed value-per-recruit surface is shown in Figure 13. The landed value response surface is relatively flat over a wide range of minimum retention sizes, as was yield-per-recruit response surface. A slight ridge occurs in the surface at a minimum retention size of 58 cm, because of the increase in price which occurs at this size. Optimum minimum retention sizes are slightly larger than for the yield-per-recruit surface. However, the landed value per recruit is within 6.5% of the optimum for minimum retention sizes between 40 and 58 cm at a fishing mortality rate of .06. At an instantaneous fishing mortality rate of 0.14, landed value per recruit is within 2.9% of the optimum for minimum retention sizes between 40 and 58 cm.

Neither sablefish yield nor landed value per recruit are improved by the addition of size limits or market conditions which favor the retention of only large fish. By the time sablefish recruit to the fishery, their period of rapid growth is over, hence there are few advantages to be gained by delayed harvest. Although the natural mortality rate is low, apparently it is approximately equal to the rate of production due to growth by the population until sablefish reach 45 to 50 cm. At this size mortality begins to exceed growth so further delaying harvest only reduces yield and landed value. Altering minimum retention sizes below 45 cm will have little noticeable effect on either yield or landed value.

Non-Equilibrium Yield Projections ("EY")

In order to specify "EY" for sablefish for the Gulf of Alaska, current population parameter estimates were incorporated into an age structured simulation model. The model begins with an initial population at the beginning of 1983 and simulates recruitment, growth, natural mortality, and fishing mortality out to 1991. "EY" is determined here as the annual yield which causes no change in population biomass from the biomass present at the end of 1983. Since the age distribution does not stabilize within the time frame of the simulation, the population is not at equilibrium and "EY" varies from year to year.

The results of the 1982 U.S.-Japanese longline survey are used to establish an initial age structure ranging from age 3 to age 25 (Table 10). The length-frequency distribution observed in the longline survey was converted to an age-

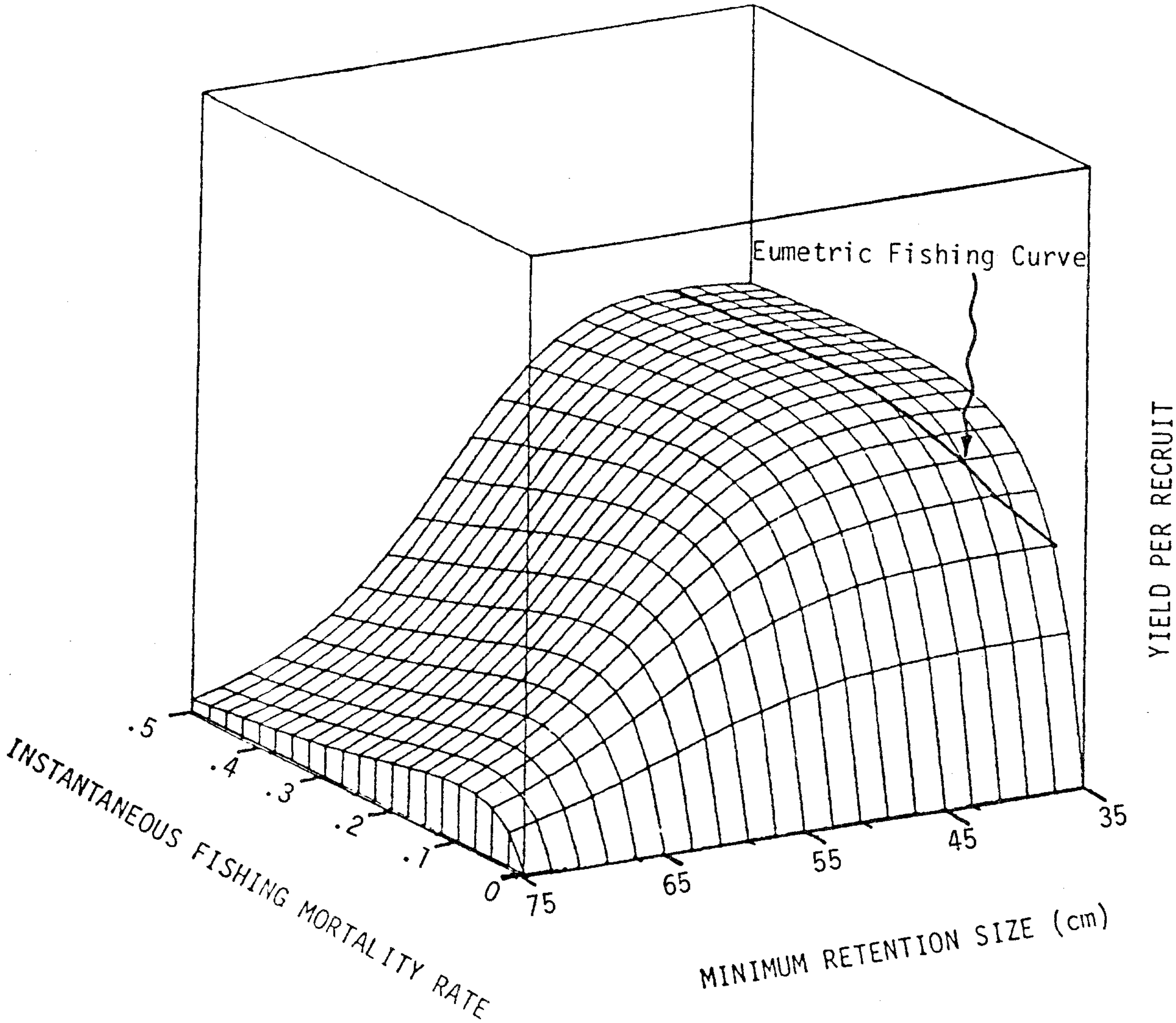

Figure 11. Sablefish yield-per-recruit response surface with 35% hooking mortality on fish below the minimum retention size.

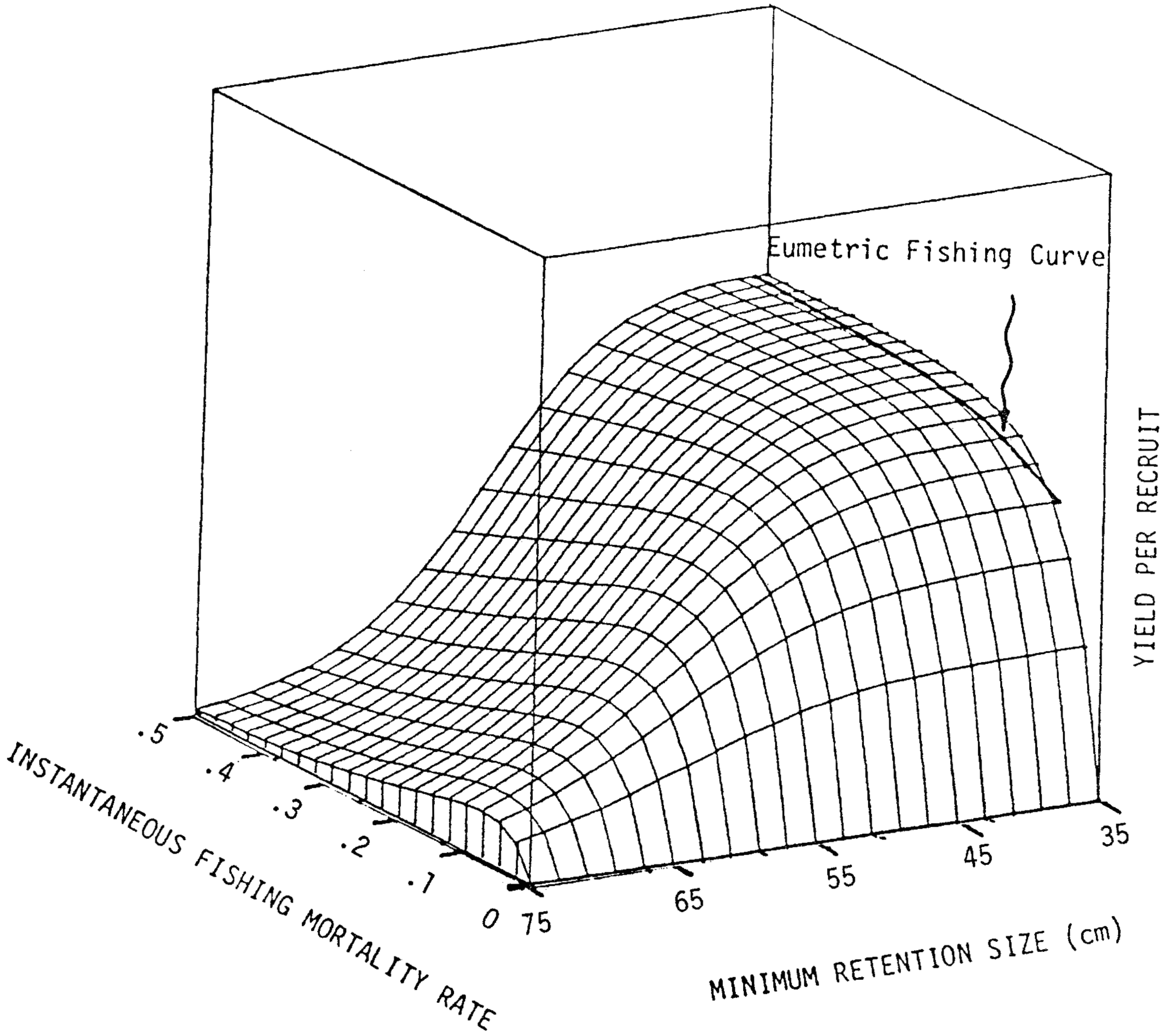

Figure 12. Sablefish yield-per-recruit response surface with 50% hooking mortality on fish below the minimum retention size.

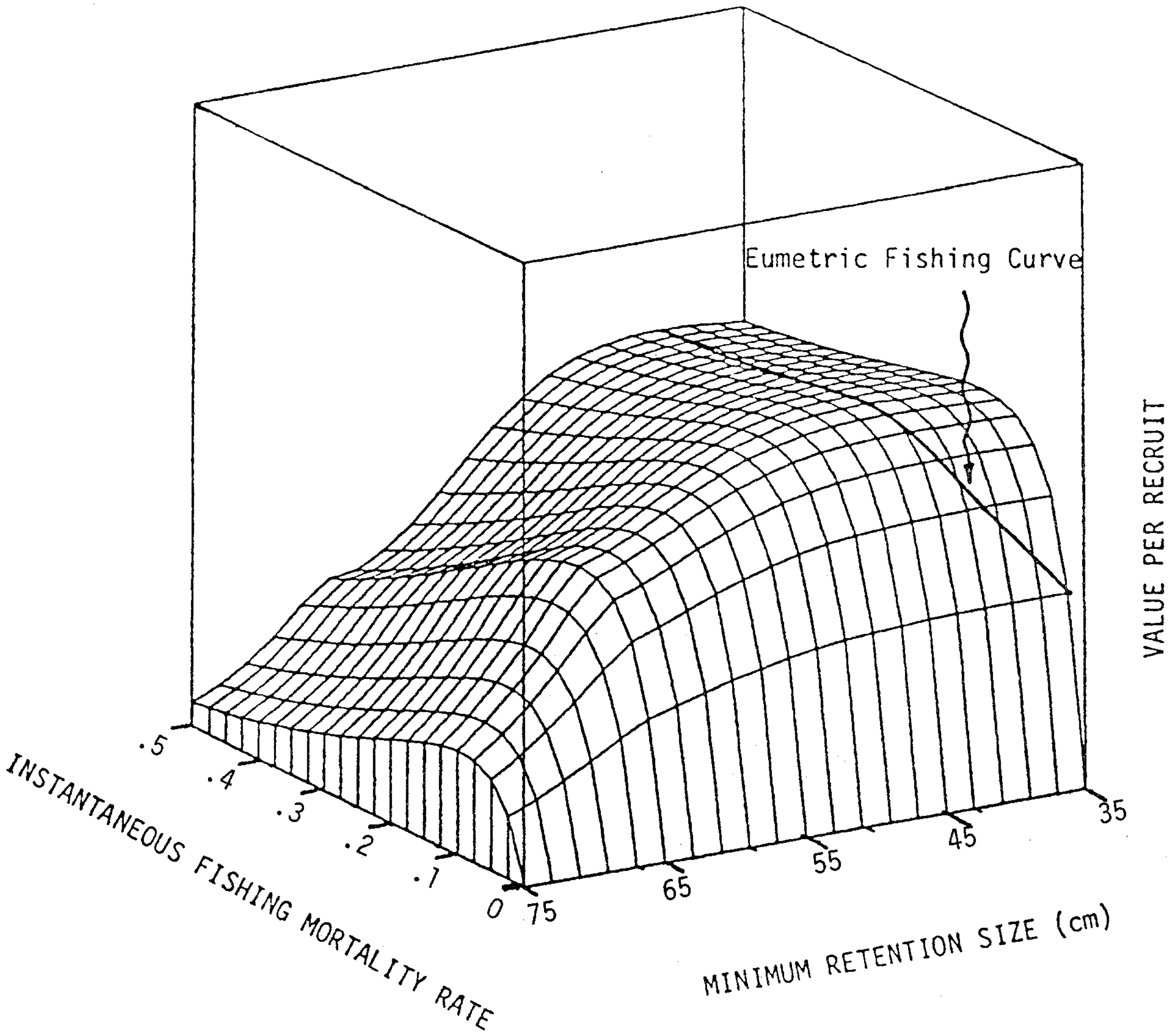

Figure 13. Sablefish landed value per recruit with 35% hooking mortality on fish below the minimum retention size and a price of \$.32/lb per fish less than 5 lb dressed and a price of \$.65/lb for fish larger than 5 lb.

Table 10. Initial 1983 relative age distribution derived from U.S. - Japanese longline survey, used as input to non-equilibrium yield simulation model.

Age	Male	Female
3	10.83%	8.41%
4	9.75%	7.48%
5	8.40%	6.38%
6	10.57%	7.99%
7	5.20%	3.88%
8	2.74%	2.69%
9	1.75%	1.96%
10	1.45%	1.34%
11	1.23%	0.97%
12	0.88%	0.94%
13	0.57%	0.80%
14	0.38%	0.65%
15	0.25%	0.48%
16	0.17%	0.37%
17	0.11%	0.30%
18	0.08%	0.23%
19	0.05%	0.17%
20	0.04%	0.13%
21	0.03%	0.10%
22	0.02%	0.07%
23	0.01%	0.06%
24	0.01%	0.05%
25	0.00%	0.04%

frequency distribution using the allometric growth function of Funk and Bracken (1983) for northern British Columbia sablefish. This technique of converting lengths to age tends to underestimate the size of the 1977 year class and to overestimate the size of the adjacent 1976 and 1978 year classes. The two 1982 stock size estimates of Table 6 are used to set total initial biomass. The model starts with this initial population, and simulates population size, population biomass, age structure and yields out to 1992. Age 3 recruits enter the population each year as the average number of the age 3 recruits of the 1976, 1978, and 1979 year classes determined from the U.S. - Japanese longline survey in 1979, 1981, and 1982. The 1983 harvest is specified at the midpoint of the OY range of 8,849 mt round weight. Fishing is assumed to occur continuously, year round. The instantaneous rate of natural mortality is assumed to be 0.112. Growth is assumed to occur according to the northern British Columbia growth curve of Funk and Bracken (1983).

"EY" depends upon the initial biomass estimate used for the simulation. "EY" for initial biomass estimates based on the stock production model ranges from 17,700 mt to 19,200 mt round weight (Table 11). The initial 1982 biomass estimates based on the stock production model of 176,173 mt for all ages recruited to longline fishing gear corresponds to a biomass of 171,240 mt for the population aged 3 and at the end of 1982. A fixed harvest at the midpoint of the OY range of 8,849 mt (round weight) is removed from the population in 1983. At the end of 1983, the age 3+ biomass is 180,800 mt. The 1984 harvest which maintains the population at this level (the "EY" harvest) is 19,200 mt dressed weight. The "EY" harvest slowly declines to 17,700 mt by 1991.

The initial biomass estimate based on Bering Sea trawl area-swept and comparative longline-trawl sampling in the Aleutians was 263,289 mt for 1982 (Sasaki 1983). This corresponds to a biomass of 256,481 mt for fish aged 3 and older at the end of 1982. Assuming a fixed harvest of 8,849 mt (round weight) in 1983, the age 3 and older biomass at the end of 1983 is 274,400 mt. With average recruitment as previously described, the "EY" harvest which maintain this biomass range from 28,600 mt in 1984 to 26,100 mt in 1991 (Table 12).

A large amount of uncertainty surrounds many of the parameter estimates used in the model, particularly the initial biomass and "average recruitment" estimates. Current initial biomass estimates are extremely tentative. The stock production biomass is based on a very simplistic model and uses relatively old data, not indicative of the current status of the fishery. The longline-trawl biomass estimate is based on a single trawl survey in the Aleutian area. Abundance estimation based on trawl surveys in the Aleutian area should be treated with caution due to the extremely rough topography. "Average" recruitment is probably overestimated in the model, because of the length-to-age conversion techniques used in specifying the initial age distribution and in measuring the relative strengths of recruitment from the 1976 through 1979 year classes. "EY" would decline more rapidly in the model after 1984 if average recruitment had not been overestimated. Actual sablefish recruitment is highly variable from year to year. Incorporation of stochastic terms into the recruitment process would probably decrease the long term "EY", particularly if a spawner-recruit mechanism was incorporated into the model.

Previously, "EY" for the Gulf of Alaska sablefish fishery was determined by modifying results of Low and Wespestad's stock production model by trends in abundance

Table 11. Results of yield production for "EY" approximation, assuming an initial 1983 biomass derived from stock-production model parameters of 176,173 mt, corresponding to an initial biomass of 171,240 mt for ages 3 and older. A 1983 harvest at the midpoint of the OY range of 8,849 mt (round weight) is assumed. "EY" harvests in subsequent years are specified so as to maintain the biomass present at the end of 1983.

Year	F	Biomass at End of Year (Age 3+ in mt)	"EY" (round wt. in mt)
1982	-	171,240	-
1983	.052	180,800	8,849
1984	.110	180,800	19,200
1985	.107	180,800	18,600
1986	.105	180,800	18,300
1987	.104	180,800	18,100
1988	.103	180,800	17,900
1989	.103	180,800	17,800
1990	.102	180,800	17,700
1991	.102	180,800	17,700
		1984-1991 average:	18,171

Table 12. Results of yield projection for "EY" approximation, assuming an initial 1983 biomass derived from trawl area-swept estimates and comparative trawl-longline sampling of 263,289 mt (Sasaki 1983), corresponding to an initial biomass of 256,481 mt for ages 3 and older. A 1983 harvest at the midpoint of the OY range of 8,849 mt (round weight) is assumed. "EY" harvests in subsequent years are specified so as to maintain the biomass present at the end of 1983.

Year	F	Biomass at End of Year (Age 3+ in mt)	"EY" (round wt. in mt)
1982	-	256,481	-
1983	.035	274,400	8,849
1984	.108	274,400	28,600
1985	.105	274,400	27,700
1986	.103	274,400	27,100
1987	.101	274,400	26,700
1988	.101	274,400	26,500
1989	.100	274,400	26,300
1990	.100	274,400	26,200
1991	.099	274,400	26,100
		1984-1991 average:	26,900

indicators throughout the Gulf of Alaska. Because of the large amount of uncertainty in the parameter estimates of the simulation model, we recommend the conservative approach of maintaining the 1983 "EY" values for the 1984 fishing season. These values range from 10,965 to 12,630 mt round weight for the entire Gulf of Alaska (Table 2).

Optimum Yield (OY)

Optimum yield is defined as the yield which provides the greatest overall benefit to the nation. Amendment 11 to the Gulf of Alaska Fishery Management Plan more stringently specifies OY for Gulf of Alaska sablefish at 75% of the EY level.

Gulf-wide Harvest:

Because movements of sablefish in the Gulf of Alaska are significant (Bracken 1982, 1983a; Sasaki 1979, 1980; Dark 1983) it is appropriate to treat the Gulf of Alaska as one stock when establishing harvest levels. Regardless of the initial biomass level assumed, Gulf-wide "EY" shows a slightly declining trend from 1984 to 1991. This decline is due to the senescence of the strong 1977 year class. This decline would be more severe than indicated in the model if the "average recruitment" were not overestimated. The growth rate of the 1977 year class has now slowed to the point where it no longer causes "EY" to increase. Subsequent year classes have not been strong and in the absence of further strong year classes, EY will continue to decline after 1983. Since the increase in abundance and EY in recent years is attributable to that one year class, it is unwise to increase the harvest substantially until further evidence of additional strong year classes are observed. Therefore OY should remain at 75% of the EY to promote continued rebuilding of the Gulf of Alaska sablefish population. The recommended OY is 75% of the upper range of the 1983 Gulf-wide EY or 9,473 mt round weight.

Spatial Allocation of Gulf-wide Harvest:

While the Gulf of Alaska sablefish resource should be considered as a single stock for establishing overall harvest levels, until the migration process is better understood, it is appropriate to allocate harvest to specific regions to prevent concentrations of fishing effort and the potential for localized depletion. The Gulf-wide harvest should be allocated to a given area based on the proportion of the population in that area. The Japanese estimates of RPW by area (Sasaki 1983) provide the only current standardized Gulf-wide source of estimates of the spatial distribution of biomass. Previously used methods of allocation depended on the historical patterns of catch in the Gulf of Alaska. Because of the changes in the nature of the fishery in the last decade, the strong influence of the 1977 year class, and the large amount of movement now known to occur among areas, the previous methods are not a valid means of spatial allocation of the harvest. The current harvest allocation is out of proportion with the estimates of relative population weight, particularly in the Shumagin INPFC area.

RPW for the Gulf of Alaska for 1981 to 1982 from Sasaki (1983) are shown by INPFC area in Table 13. The recommended harvest allocation to areas is based on the average of the 1981 and 1982 RPW. Since RPW is not available for the inside waters of Southeastern Alaska, the catch allocation is based on the average ratio of inside to outside harvest for the 1978-1982 base period. The recommended harvest allocations based on an OY of 9,473 mt are shown in the last column of Table 13.

Table 13. Recommended spatial allocation of the Gulf of Alaska sablefish harvest, based on the average of the 1981-1982 Relative Population Weights (RPW) by INPFC area (from Sasaki 1983), and the recommended 1984 OY (round weight in metric tons).

AREA	RPW		AVERAGE RPW	RECOMMENDED HARVEST ALLOCATION	RECOMMENDED 1984 OY
	1981	1982			
SE - Inside	*	*	(24794)[1]	8.0%	759
SE - Outside	51123	44752	47938	15.5%	1,466
Yakutat	66712	67076	66894	21.6%	2,046
Kodiak	51640	79715	65678	21.2%	2,009
Chirikof	52437	87115	69776	22.5%	2,135
Shumagin	27851	41309	34580	11.2%	1,058
Total:				100.0%	9,473

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[1] RPW is not available for Southeastern Alaskan inside waters. The recommended Southeastern Alaskan inside waters harvest allocation is based on the average ratio of inside to outside harvests between 1978-1982.

DISCUSSION

The review of available sablefish information highlighted many sources of conflicting information and revealed extensive gaps in the available data. Some of the shortcomings of the data result from discontinuities in sampling caused by the withdrawal of the foreign fleets and their replacement by domestic fishermen. Others results from the fact that only limited samples have been utilized with recently discovered techniques for analyzing biological data. In the near future, major effort should be devoted to resolving the problems in the sources of data on sablefish catch and effort, growth, stock structure, and stock abundance.

Catch and Effort

There is no consistent time series of catch and effort data from the commercial sablefish fisheries. Current management is based on a combination of U.S. and Japanese catch statistics. As the foreign fishery is displaced, it will be necessary to establish and maintain a sampling program to replace foreign observer data. On-board observers will be needed to determine discard rate and incidental species catch. Since sablefish are headed and gutted prior to delivery, on-board observers will also be needed to obtain information on age, sex, and maturity. Dockside sampling and logbook programs will be needed to obtain information on precise location and amount of fishing effort. With these data, catch-per-unit effort from the domestic fishery can be used as an abundance indicator. Particular emphasis should be placed on obtaining representative age samples from the commercial fishery so that cohort analysis techniques can be accurately applied to sablefish populations.

Growth

Recent aging techniques describe substantially different growth rates than depicted in the earlier literature. Standardized procedures for utilizing the new techniques need to be agreed upon by all agencies participating in the management of Gulf of Alaska sablefish stocks. Current sablefish aging data have been all collected from the eastern Gulf of Alaska. Age structures need to be obtained from other areas of the Gulf to investigate regional variation in growth rate.

Stock Structure

The results of the electrophoretic studies are inconclusive largely because they depended on opportunistic sampling rather than sampling from spawning populations. If spawning migrations of discrete stocks do exist for sablefish and if these stocks are mixed at other times of the year, samples taken during non-spawning periods will yield confusing results. Samples of adult sablefish for future genetic studies should be collected at the time of spawning.

Extensive large scale tagging projects have been conducted in recent years by a number of different agencies. Analyses of the tag return data from these studies have produced conflicting results primarily due to differences in the level of stratification on the analyses. Some tagging studies have detected significant movements by size, direction of movement, and area of recovery, that were not evident in less finely stratified analyses. Sablefish tag recovery data should first be analyzed with very fine stratifications. In addition, a data base of all available sablefish tagging information from all agencies should be established so that standardized analyses can be applied to all sources of data.

Stock Abundance

Specially designed stock abundance surveys were initiated to provide Gulf-wide sampling coverage after the withdrawal of the Japanese longline fleet from the eastern Gulf began in 1978. However, the statistical reliability of the abundance surveys has not been reviewed. Pot indexing in the eastern Gulf utilizes repetitive sampling so that the precision of the abundance indicator could be easily calculated. The design of the U.S.-Japanese longline survey does not include repetitive sampling, so that it is difficult to evaluate the significance of inter-annual and inter-regional trends in the abundance indicators. Thorough reviews of these surveys are needed to determine if improvements can be made in sampling design.

Long-term sablefish harvest strategy depends on the frequency of occurrence of strong year classes. Existing shallow water crab, shrimp, and groundfish trawl surveys can be used to provide early prediction of the recruitment of strong year classes. The causes of the variation in sablefish recruitment are currently unknown, but are probably related to the occurrence and timing of oceanographic phenomena. Surveys of oceanographic conditions during early sablefish life history should be used to determine some of the causes of the variation and may enable even earlier prediction of strong year classes.

Optimum Yield Levels

The reduced harvests of the past few years, coupled with the effects of the strong 1977 year class, have promoted rebuilding of the sablefish stocks in the Gulf of Alaska. However, the rebuilding is just now beginning to provide fish of the 5 lb average size required for the U.S. fishery. The 5 lb size is also approximately coincident with the size of sexual maturity for female sablefish. The shift in the age distribution towards older ages will also ensure sufficient levels of annual egg production to capitalize on the relatively rare occurrences of environmental conditions favorable for larval survival. Further conservative management of the Gulf of Alaska sablefish population will be necessary to ensure that the age distribution favors harvest of fish of the size required for the U.S. fishery, sustains the production of large numbers of eggs and promotes continued rebuilding of the stocks to MSY levels.

CONCLUSIONS

1. Sablefish growth is substantially slower than previously thought. As a result, natural mortality rates are lower than used in earlier modeling exercises.

2. Sablefish recruitment is extremely variable and this variability must be taken into account when establishing harvest levels.

3. Recent tagging studies show that sablefish movement is much greater than previously thought, particularly for young fish in the Gulf of Alaska. There are important directional components to this movement that become particularly evident when tagging data are stratified by fish size.

4. Allocation of harvest by area based on historical catch data is inappropriate and should be adjusted periodically based on indexing results.

5. There does not appear to be any advantage to either setting a minimum size limit or delaying the harvest. The yield-per-recruit models used to investigate size limits address only the problems of growth overfishing. The problems of recruitment overfishing cannot be addressed with yield-per-recruit models. The assumptions used in the yield-per-recruit model apply to a longline-only fishery.

6. The Gulf of Alaska sablefish population appears to be improving, but most of that improvement is due to the strong recruitment of the 1977 year class.

7. Gulf-wide sampling programs to estimate the age distribution of the catch need to be implemented in order to improve the precision of sablefish population parameter estimates.

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