Alaska Sablefish Assessment for 2000

by
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5.1 Executive Summary

5.1.1 Summary of major changes

Relative to the September preliminary assessment, we made the following substantive changes in the current assessment.

Input data: Relative abundance and length data from the 1999 longline survey and 1999 longline fishery and length data from the 1998 longline fishery were added to the assessment model.

Assessment results: Sablefish abundance increased during the mid-1960's due to strong year classes from the late 1950's and 1960's. Abundance subsequently dropped during the 1970's due to heavy fishing; catches peaked at 56,988 mt in 1972. The population recovered due to exceptional year classes from the late 1970's; spawning abundance peaked again in 1987. The population then decreased because these exceptional year classes are dying off.

The survey abundance index increased 10% in numbers and 5% in weight and the fishery abundance index increased 11% in weight from 1998 to 1999. These increases follow decreases from 1997 to 1998, so that relative abundance in 1999 is similar to 1997. Exploitable and spawning biomass are projected to increase 3 and 1%, respectively, from 1999 to 2000. **Alaska sablefish abundance now appears low and stable. This is a change from previous assessments where abundance appeared low and slowly decreasing.** Further years data are needed to confirm that abundance has stabilized.

ABC recommendation and decision analysis: A simple Bayesian analysis was completed by examining the effect of uncertainty in natural mortality and survey catchability on parameter estimation. A decision analysis was completed using the posterior probability from the Bayesian analysis to determine what catch levels likely will decrease abundance. The decision analysis indicates that a yield of about 17,000 mt most likely will keep spawning biomass the same and has only a 20% probability of reducing 2004 spawning biomass to less than 90% of 2000 spawning biomass. Based on this result, **we recommend a 2000 ABC of 17,000 mt for the combined stock**, a 7% increase from the 1999 ABC of 15,900 mt. The maximum permissible yield from an adjusted $F_{40\%}$ strategy is 17,200 mt.

Regional ABC recommendation:

A 5-year exponential weighting of the survey abundance index in weight (relative population weight or RPW) by region was used to apportion the combined ABC to regions, resulting in the following apportionments: Bering Sea 1,384 mt, Aleutian Islands 2,446 mt and Gulf of Alaska 13,170 mt, which is further apportioned Western 1,928 mt, Central 5,921 mt, West Yakutat 1,890 mt, and East Yakutat / Southeast 3,431 mt.

Members of the fishing industry have asked us to show how fishery and survey information could be combined to produce an alternate apportionment of ABC; see section 5.8.7.

5.1.2 Response to Council, SSC, and Plan Team comments

At their December 1998 meeting, the Council recommended that: (1) NMFS increase its efforts to incorporate observer data and logbook information on CPUE, length, sex, and age data into the sablefish stock assessment for 1999; and (2) NMFS develop and test new assessment techniques, such as port sampling and pre-recruit surveys to improve the accuracy of the sablefish assessment under the IFQ fishing regime. We added CPUE, length, and sex data from 1990 to 1999 to the current assessment. We expanded the sablefish logbook program in 1999 to include data from logbooks required for vessels over 60 feet, adding to the data already collected through the voluntary logbook program. Observers began collecting otoliths from the 1999 longline fishery and sampling levels will be increased in 2000. We will not add port sampling unless the expanded observer collections are unable to achieve reasonable sample sizes. NMFS began a pre-recruit survey for age-0 sablefish in 1995.

At their October 1999 meeting, the SSC recommended that more informative priors than the uniform priors on M and q be used. We examined the effect of using more informative priors; see section 5.8.4.

At their September 1999 meeting, the Plan Teams requested that we examine an alternate model which excludes fishery catch rate data and that we project yields based on recruitment estimates from the whole time series of 1957+, from 1977+, and from 1982+. We examined the effect of excluding fishery catch rates; see section 5.7.1. We projected yields using three time intervals for recruitment estimates; see section 5.8.3.

5.1.3 Sablefish longline survey - fishery interactions, 1995-1999

Sablefish longline survey - fishery interactions for 1995-1999 are described in appendix C.

5.2 Introduction

Distribution: Sablefish (*Anoplopoma fimbria*) inhabit the northeastern Pacific Ocean from northern Mexico to the Gulf of Alaska, westward to the Aleutian Islands, and into the Bering Sea (Wolotira et al 1993). Adult sablefish occur along the continental slope, shelf gulleys, and in deep fjords, generally at depths greater than 200 m. Sablefish observed from a manned submersible were found on or within 1 m of the bottom (Kreiger 1997).

Stock structure and management units: Sablefish appear to form two populations, a northern or Alaska population and a southern or west coast population, based on differences in growth rate, size at maturity, and tagging studies (McDevitt 1990, Saunders et al. 1996, Kimura et al. 1998). The Alaska population inhabits Alaska and northern British Columbia waters and the southern population inhabits southern British Columbia and Washington, Oregon and California waters, with mixing of the two populations occurring off southwest Vancouver Island and northwest Washington.

Alaska sablefish are highly migratory for at least part of their life and substantial movement between the Bering Sea-Aleutian Islands and the Gulf of Alaska has been documented (Heifitz and Fujioka, 1991; Maloney and Heifitz, 1997; Kimura et al. 1998) . Thus sablefish in Alaska waters are assessed as a single population. However, sablefish are managed by discrete regions to distribute exploitation throughout their wide geographical range. There are four management areas in the Gulf of Alaska: Western, Central, West Yakutat, and East Yakutat/Southeast Outside (SEO) and two management areas in the Bering Sea/Aleutian Islands (BSAI): the eastern Bering Sea (EBS) and the Aleutian Islands region.

Early life history: Spawning is pelagic at depths of 300-500 m near the edges of the continental slope (McFarlane and Nagata 1988), with eggs developing at depth and larvae developing near the surface as far offshore as 180 miles (Wing 1997). Near the end of the first summer, pelagic juveniles less than 20 cm drift inshore and spend the winter and following summer in inshore waters, reaching 30-40 cm by the end of their second summer (Rutecki and Varosi 1997). After their second summer, they begin moving offshore, typically reaching their adult habitat, the upper continental slope at 4 to 5 years.

Age and Size of Recruitment: Juvenile sablefish rear in nearshore and continental shelf waters, moving to the upper continental slope as adults. Fish first appear on the upper continental slope, where the longline survey and longline fishery primarily occur, at age 2 and length about 50-53 cm fork length, although only 10% are estimated to reach the slope at that young age. Fish are susceptible to trawl gear at an earlier age than to longline gear, probably because trawl fisheries more often occur on the continental shelf and shelf break inhabited by younger fish.

Growth and maturity: Sablefish grow rapidly in early life, reaching average maximum lengths and weights of 69 cm and 3.4 kg for males and 82 cm and 6.1 kg for females. Fifty percent of females mature at 65 cm, while 50 percent of males are mature at 57 cm (Sasaki 1985), corresponding to ages 6.5 years for females and about 5 years for males (Table 5.1).

Maximum age and natural mortality: Sablefish are long-lived; ages over 40 years are regularly recorded (Kimura et al. 1993). Reported maximum age for Alaska is 94 years (Kimura et al. 1998); the previous reported maximum was 62 (Sigler et al 1997). Canadian researchers report age determinations up to 55 years (McFarlane and Beamish, 1983). A natural mortality rate of M=0.10 has been assumed for previous sablefish assessments, compared to M=0.22 estimated by Low et al (1976) prior to the latest ageing techniques and M=0.112 assumed by Funk and

Bracken (1984). Johnson and Quinn (1988) used values of 0.10 and 0.20 in a catch-at-age analysis and found that estimated abundance trends agreed better with survey results when M=0.10 was used. In the current assessment, natural mortality is estimated rather than assumed to equal 0.10 as in previous assessments.

Prey and predators: Sablefish are opportunistic feeders. Fish constituted 3/4 of stomach content weight, with the remainder invertebrates, in a diet study of Gulf of Alaska sablefish (Yang 1993). Pollock were the most important fish; eulachon, capelin, Pacific herring, Pacific cod, Pacific sand lance, and some flatfish also were found. Squid were the most important invertebrate and euphasiids and jellyfish both also were found. Fish made up 76 percent of the diet in feeding studies conducted off Oregon and California (Laidig et al 1997). Euphausiids dominated the diet off the southwest coast of Vancouver Island; herring and other fish were increasingly important with sablefish size (Tanasichuk 1997).

Adult coho and chinook salmon feed on sablefish; they prey on young-of-the-year sablefish, which were the fourth most commonly reported species from the salmon troll logbook program from 1977 to 1984 (Wing 1985). Only one other fish species was reported as preying on juvenile or adult sablefish in a food habit study of fishes of the Gulf of Alaska, Pacific halibut, and sablefish comprised less than 1% of their stomach contents (M-S. Yang, Alaska Fisheries Science Center, 14 October 1999).

5.3 Fishery

5.3.1 Description of the directed fishery

Early U.S. fishery, 1976 and earlier

Sablefish have been exploited since the end of the 19th century by U.S. and Canadian fishermen. The North American fishery on sablefish developed as a secondary activity of the halibut fishery of the United States and Canada. Initial fishing grounds were off Washington and British Columbia and from there spread to Oregon, California, and Alaska during the 1920's. Since then, and up to 1957, the sablefish fishery was exclusively a U.S. and Canadian fishery, ranging from off northern California northward to Kodiak Island in the Gulf of Alaska; catches were relatively small, averaging 1,666 mt from 1930 to 1957, and generally limited to areas near fishing ports (Low et al 1976).

Foreign fisheries, 1958 to 1987

Japanese longliners began operations in the eastern Bering Sea in 1958. The fishery expanded rapidly in this area and catches peaked at 25,989 mt in 1962 (Table 5.2, Figure 5.1). As the fishing grounds in the eastern Bering were preempted by expanding Japanese trawl fisheries, the Japanese longline fleet expanded to the Aleutian Islands region and the Gulf of Alaska. In the Gulf of Alaska, sablefish catches increased rapidly as the Japanese longline fishery expanded, peaking at 36,776 mt overall in 1972. Catches in the Aleutian Islands region have historically remained at low levels with Japan harvesting the largest portion of the sablefish catch. Most sablefish harvests were taken from the eastern Being Sea until 1968, and then from the Gulf of Alaska until 1977. Heavy fishing by foreign vessels during the 1970's led to a substantial population decline and fishery regulations in Alaska which sharply reduced catches. Catch in the late 1970's was restricted to about one-fifth of the peak catch in 1972.

Japanese longliners had a directed fishery for sablefish. Sasaki (1985) described the gear used in the directed Japanese longline fishery. He found only minor differences in the structure of fishing gear and the fishing technique used by Japanese commercial longline vessels. There were small differences in the length of hachis (Japanese term for a longline skate) and in the number of hooks among vessels, but hook spacing remained about 1.6 m. The use of squid as bait by vessels also remained unchanged, except some limited number of vessels used Pacific saury as bait when squid was expensive. The standard number of hachis fished per day was 376 (Sasaki 1978) and the number of hooks per hachi was 43 until 1979, when the number was reduced to 40 (T. Sasaki, Japan Fisheries Agency, 4 January 1999).

Japanese trawlers also caught sablefish through directed effort toward sablefish, but mostly as bycatch in fisheries targeting other species. Sasaki (1973) reported two trawl fisheries catching sablefish in the Bering Sea through 1972, the North Pacific trawl fishery which caught sablefish as bycatch to the directed pollock fishery and the landbased dragnet fishery that sometimes targeted sablefish. The latter fishery mainly targeted rockfishes, Greenland turbot, and Pacific cod, and only a few vessels targeted sablefish (Sasaki 1985). The landbased fishery caught more sablefish, averaging 7,300 mt from 1964 to 1972, compared to the North Pacific trawl fishery, which averaged 4,600 mt. In the Gulf of Alaska, Sasaki (1973) reported that sablefish were caught as bycatch to the directed Pacific Ocean perch fishery until 1972, but some vessels started targeting sablefish in 1972. Most net-caught sablefish were caught by stern trawls, but significant amounts also were caught by side trawls and Danish seines the first few years of the Japanese trawl fishery.

Other foreign nations besides Japan also have caught sablefish. Substantial U.S.S.R. catches were reported from 1967-73 in the Bering Sea (McDevitt 1986). Substantial R.O.K. catches were reported from 1974-1983 scattered through Alaska. Other countries reporting minor sablefish catches were Republic of Poland, Taiwan, Mexico, Bulgaria, Federal Republic of Germany, and Portugal. The U.S.S.R. gear was factory-type stern trawl and the R.O.K. gear was longlines and traps (Low et al 1976).

Recent U.S. fishery, 1977 to present

The U.S. longline fishery began expanding in 1982 in the Gulf of Alaska and in 1988, harvested all sablefish taken in Alaska except minor joint venture catches. Following domestication of the fishery, the previously year-round season in the Gulf of Alaska began to shorten in 1984. By the late 1980's, the average season length decreased to one to two months. In some areas, this open-access fishery was as short as 10 days, warranting the label “derby” fishery.

Year	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Season length (months)	12	7.6	3.0	1.5	1.2	1.8	1.5	1.3	0.9	0.7	0.5	0.3	8

Season length continued to decrease until Individual Fishery Quotas (IFQ) were implemented for hook-and-line vessels in 1995 along with an 8-month season. The season runs from March 15-November 15, concurrent with the halibut IFQ fishery.

The expansion of the U.S. fishery was helped by exceptional recruitment during the late 1970's. This exceptional recruitment fueled an increase in abundance for the population which had been heavily fished during the 1970's. Increased abundance led to relaxation of fishing quotas and catches peaked again in 1988 at about 70% of the 1972 peak. Abundance has since fallen as the exceptional late 1970's year classes have died off. Catches also have fallen and in 1998, were about 37% of the 1988 peak.

The directed fishery primarily is a hook-and-line fishery. Sablefish also are caught as bycatch during directed trawl fisheries for other species groups such as rockfish and deepwater flatfish. Five state fisheries also land sablefish outside the IFQ program; the major fisheries Prince William Sound, Chatham Strait, and Clarence Strait and the minor fisheries northern Gulf of Alaska and Aleutian Islands. For Federal and State sablefish fisheries combined, the number of longline vessels targeting sablefish (Greig et al. 1998) and number of hooks deployed were:

Year	1993	1994	1995	1996	1997	1998
Vessels	871	1,078	613	578	504	na
Hooks (millions)	92.2	112.5	53.9	46.9	38.3	40.4

Longline gear in Alaska is fished on-bottom. In the 1996 directed fishery for sablefish, average set length was 9 km and average hook spacing was 1.2 m. The gear is baited by hand or by machine, with smaller boats generally baiting by hand and larger boats generally baiting by machine. Circle hooks usually are used, except for modified J-hooks on some boats with machine baiters. The gear usually is deployed from the vessel stern with the vessel traveling at 5-7 knots. Some vessels attach weights to the longline, especially on rough or steep bottom, so that the longline stays in place and lays on-bottom.

5.3.2 Catch

Annual catches in Alaska averaged about 1,700 mt from 1930 to 1957 and exploitation rates remained low until Japanese vessels began fishing for sablefish in the Bering Sea in 1959 and the Gulf of Alaska in 1963. Catches rapidly escalated during the mid-1960's. Annual catches in Alaska reached peaks in 1962, 1972, and 1988 (Table 5.2, Figure 5.1). The 1972 catch was the all-time high, at 53,080 mt, and the 1962 and 1988 catches were 50% and 72% of the 1972 catch.

Evidence of declining stock abundance led to significant fishery restrictions from 1978 to 1985, and total catches were reduced substantially. Catches averaged about 12,200 mt during this time. Exceptional recruitment fueled increased abundance and increased catches during the late 1980's. The domestic fishery also expanded during the 1980's, harvesting 100% of the catch in the Gulf of Alaska by 1985 and in the Bering Sea and Aleutians by 1988. Catches have declined during the 1990's. Catches peaked at 38,406 mt in 1988 and have fallen to about 14,000 mt currently.

5.3.3 Bycatch and discards

The percent of sablefish catch discarded during 1994 to 1997 averaged 2.1% in the directed Alaska-wide sablefish longline fishery, 32.2% in the Bering Sea/Aleutian Islands Greenland turbot longline fishery, and 33.6% in the Bering Sea/Aleutian Islands Pacific cod longline fishery. Sablefish discard averaged 16.1% in Alaska-wide rockfish trawl fisheries and 39.5% in flatfish trawl fisheries (Table 5.3). The average discard from 1994 to 1997 was 3% for all longline fisheries and 27% for all trawl fisheries.

5.3.4 Previous management actions

Quota allocation: Amendment 14 to the Gulf of Alaska Fishery Management Plan, allocated the sablefish quota by gear type: 80% to hook-and-line gear and 20% to trawl in the Western and Central Gulf of Alaska and 95% to hook-and-line gear and 5% to trawl in the Eastern Gulf of Alaska, effective 1985. Amendment 13 to the Bering Sea/Aleutian Islands Fishery Management Plan, allocated the sablefish quota by gear type, 50% to fixed gear and 50% to trawl in the eastern Bering Sea, and 75% to fixed gear and 25% to trawl gear in the Aleutians, effective January 1, 1990.

IFQ management: Amendment 20 to the Gulf of Alaska Fishery Management Plan and 15 to the Bering Sea/Aleutian Islands Fishery Management Plan established IFQ management for sablefish beginning in 1995. These amendments also allocated 20% of the fixed gear allocation of sablefish to a CDQ reserve for the Bering Sea and Aleutian Islands.

Maximum retainable bycatch: Maximum retainable bycatch percentages for sablefish were revised in the Gulf of Alaska by a Regulatory Amendment, effective 4/10/97. The percentage depends on the basis species: pollock 1%, Pacific cod 1%, deep flatfish 7%, rex sole 7%, flathead sole 7%, shallow flatfish 1%, arrowtooth flounder 0%, Pacific ocean perch 7%, shortraker and rougheye rockfish 7%, other rockfish 7%, northern rockfish 7%, pelagic rockfish 7%, demersal shelf rockfish in the Southeast Outside district 7%, thornyhead 7%, Atka mackerel 1%, other species 1%, and aggregated amount of non-groundfish species 1%.

Allowable gear: Amendment 12 to the Gulf of Alaska Fishery Management Plan banned the use of pots for fishing for sablefish in the Gulf of Alaska and Bering Sea, effective 1982. The prohibition on sablefish longline pot gear use was removed for the Bering Sea, except from June 1 to 30 to prevent gear conflicts with trawlers during that month, effective 9/12/96. Sablefish longline pot gear are allowed in the Aleutian Islands.

Management areas: Amendment 8 to the Gulf of Alaska Fishery Management Plan established the West and East Yakutat management areas for sablefish, effective 1980.

5.4 Data

Source	Data	Dates
Fisheries	Catch	1960-1999
Japanese longline fishery	Effort	1964-1981
	Length	1963-1980
Japanese trawl fishery	Length	1964-1971
U.S. longline fishery	Effort, length, discards	1990-1999
U.S. trawl fisheries	Length	1990, 1991, 1994, 1995, 1996
	Discards	1990-1999
Japan-U.S. cooperative longline survey	Catch, effort, length	1979-1994
	Age	1983, 1987, 1989, 1991, 1993
Domestic longline survey	Catch, effort, length	1990-1999
	Age	1996-1998

5.4.1 Fishery

Catch, effort, and length data are collected from sablefish fisheries. The catch data covers several decades. Length and effort data were collected from the Japanese and U.S. longline fisheries (Table 5.4). Length data were collected from the Japanese and U.S. trawl fisheries. The Japanese data were collected by fishermen trained by Japanese scientists (L-L. Low, Alaska Fisheries Science Center, 25 August 1999). The U.S. fishery data were collected by at-sea and plant observers. No age data were systematically collected from the fisheries until 1999 because of the difficulty of obtaining representative samples from the fishery and because a limited number of sablefish can be aged each year. The equations used to compile the fishery and survey data used in the assessment are shown in Appendix A.

Some catches probably were not reported during the late 1980's (Kinoshita et al 1995). Unreported catches could account for the Japan-U.S. cooperative longline survey index's sharp drop from 1989-90 (Figures 5.2 and 5.3, Table 5.5). We tried to estimate the amount of unreported catches by comparing reported catch to another measure of sablefish catch, sablefish imports to Japan, the primary buyer of sablefish. However the trends of reported catch and imports were similar, so we decided to change our approach for catch reporting in this year's assessment. We assumed that non-reporting is due to at-sea discards and apply discard estimates from 1994 to 1997 to inflate U.S. reported catches before 1994 (2.9% for hook-and-line and 26.6% for trawl).

One problem with the fishery data is that the length sample sizes for the trawl fishery have been completely inadequate since 1996. A small number of lengths are collected each year, but the resultant length frequencies are ragged and can not be used in the assessment model. For example in the Central Gulf of Alaska, the number of sampled lengths decreased from 288 in 1998 to 119 in 1999. The problem is that sablefish often are caught with other species like rockfish and deepwater flatfish, but are not the predominant species. The observer sampling protocol calls for sampling the predominant species, so sablefish are poorly sampled. We have communicated this problem to the observer program. They are considering multispecies sampling which would alleviate this problem.

5.4.2 Longline surveys

Catch, effort, age, length, weight, and maturity data are collected during sablefish longline surveys. Japan and the United States conducted a cooperative longline survey for sablefish in the Gulf of Alaska annually from 1978 to 1994 (Sasaki 1985, Sigler and Fujioka 1988). The survey was expanded to include the Aleutian Islands region in 1980 and the Eastern Bering Sea in 1982. Since 1987, the Alaska Fisheries Science Center has conducted annual longline surveys of the upper continental slope, referred to as domestic longline surveys, designed to continue the time series of the Japan-U.S. cooperative survey (Sigler and Zenger 1989). The domestic longline survey began annual sampling of the Gulf of Alaska in 1987, biennial sampling of the Aleutian Islands in 1996, and biennial sampling of the eastern Bering Sea in 1997 (Rutecki et al 1997). The domestic survey also samples major gullies of the Gulf of Alaska in addition to sampling the upper continental slope. Longline survey catches are tabled in appendix D.

Length data were collected all survey years and sablefish otoliths were collected most survey years. Only a subset of these otoliths were aged until 1996, when annual ageing of samples began. Otolith collections were length-stratified from 1979-94 and random thereafter.

The order areas are surveyed was changed in 1998 to avoid surveying areas during times when short, intense fisheries were occurring. The survey order has been Aleutians and/or Bering Sea, Western, Central, Eastern, but in 1998 the Eastern area was surveyed before the Central area. Starting in 1998, the Eastern area was surveyed about one month earlier and the Central area about one month later compared to 1979-97.

Kimura and Zenger (1997) compared the performance of the two surveys from 1988 to 1994 in detail, including experiments comparing hook and gangion types used in the two surveys. The abundance index for both longline surveys decreased from 1988 to 1989, but the cooperative survey decreased from 1989 to 1990, while the domestic survey increased (Table 5.5). It is not clear why the two surveys showed divergent trends from 1989 to 1990; Kimura and Zenger (1997) attributed the difference to the domestic longline survey not being standardized until

1990.

Killer whale depredation of the survey's sablefish catches has been a problem in the Bering Sea since the beginning of the survey (Sasaki, 1987). The problem occurred mainly east of 170^{o} W in the eastern Bering Sea and to a lesser extent in the northeast Aleutians between 170^{o} W and 175^{o} W. The 1983 (Sasaki 1984), 1986 and 1987 (T. Sasaki, Far Seas Fisheries Research Laboratory) and 1988 Bering Sea abundance indices likely were underestimated, although sablefish catches were lower at all stations in 1987 compared to 1986 , regardless of whether killer whales were present. Killer whale depredation has been fairly consistent since 1988. An analysis is planned for next year's assessment to exclude killer whale affected stations from abundance calculations with the cooperative longline survey data. Portions of the gear affected by killer whale depredation during domestic longline surveys already are excluded from the analysis of the survey data.

5.4.3 Trawl surveys

Trawl surveys of the upper continental slope that adult sablefish inhabit have been conducted approximately triennially since 1979 in the Bering Sea, 1980 in the Aleutians, and 1984 in the Gulf of Alaska. Trawl surveys of the Eastern Bering Sea shelf are conducted annually, but sablefish have never occurred on the shelf in large numbers except for juveniles of the 1977 year class which showed up in large numbers in 1978. The slope trawl surveys are not considered good indicators of the sablefish relative abundance over time because of differences in net types used each year, depths sampled, and high sampling variation and so are not used in the sablefish assessment. Trawl survey catches are tabled in appendix D.

5.4.4 Recruitment data

Juvenile sablefish are pelagic and at least part of the population inhabits shallow near-shore areas for their first one to two years of life (Rutecki and Varosi 1997). Most years juveniles are found only in a few places such as Saint John Baptist Bay near Sitka, Alaska. The appearance of large numbers of juveniles widespread in inside waters of southeastern Alaska likely indicates a strong year class. Juvenile sablefish were common during the summers of about 1960 (J. Fujioka, Auke Bay Laboratory, 15 August 1999), 1978 and 1979, 1981, 1985, and 1999, corresponding to strong year classes in about 1959, 1977 and possibly 1978, 1980, 1984, and 1998. Juvenile sablefish also were common in Prince William Sound in 1998 (W. Bechtol, Alaska Department of Fish and Game, 22 September 1999; M. Miller, Alaska Department of Fish and Game, 19 October 1999) and 1999 (M. Miller, Alaska Department of Fish and Game, 19 October 1999) and around Kodiak Island in 1999 (D. Jackson, Alaska Department of Fish and Game, 7 October 1999), but not around Dutch Harbor in 1999 (R. Gish, Alaska Department of Fish and Game, 1 September 1999).

Catch, effort, age, length, and diet data for young-of-the-year and age-1+ sablefish are collected from surface gillnet surveys of the Aleutian Islands, Bering Sea, and Gulf of Alaska. Surface gillnet surveys have been conducted annually since 1995 generally near the edge of the continental shelf. Catch rates of young-of-the-year sablefish from gillnet surveys were above average in 1995 and below average in 1999, implying that the 1995 year class may be above average within this 5-year period.

5.4.5 Relative abundance data summary

Relative abundance has cycled through three valleys and two peaks with peaks in about 1970 and 1985 (Table 5.5, Figure 5.2). The post-1970 decrease likely is due to heavy fishing. The 1985 peak likely is due to the exceptional late 1970's year classes. Since 1988, relative abundance has decreased substantially. Regionally, abundance has decreased faster in the Eastern Bering Sea and Aleutian Islands and more slowly in the Gulf of Alaska. These latter areas may be the outer edges of sablefish distribution and less favored habitat than the apparent center of sablefish abundance, the Gulf of Alaska.

5.5 Analytic approach

5.5.1 Model

Model structure

The analysis generally follows the approach described by Kimura (1990) for age-structured population analysis. This approach also was tested for sablefish by Sigler (1999). The analysis was completed using AD model builder software, a C++ based software for development and fitting of general nonlinear statistical models (Otter Research 1996). Details of the model structure are shown in Appendix B.

The sablefish population in Alaska is represented with an age-structured model. Numbers at age for ages 2 to 30, pooled age 31, and years 1960 to 1999 were estimated with the age-structured model.

Sablefish are difficult to age, especially those older than eight years (Kimura and Lyons 1991, Table 6) and sablefish often are misaged. An ageing error matrix based on known-age otoliths was used to account for ageing error (Heifetz et al. 1999). An age-length transition matrix was used to translate age into length.

Selectivity is represented using a function and is separately estimated for longline surveys, longline fisheries, and trawl fisheries. Selectivity for longline surveys and longline fisheries is restricted to be asymptotic. Selectivity for trawl fisheries is allowed to be dome-shaped. The age of 50% availability for longline fisheries is allowed to vary with season length. Fishermen may choose where they fish in the IFQ fishery, compared to the crowded fishing grounds during the pre-1995 “derby” fishery, when fishermen reportedly often fished in less productive depths due to crowding. In choosing their ground, they presumably target bigger, older fish.

Catchability is separately estimated for the Japanese longline fishery, the cooperative longline survey, the domestic longline survey, and the U.S. longline fishery. Information is available to link these estimates of catchability. Kimura and Zenger (1997) analyzed the relationship between the cooperative and domestic longline surveys. We used their results to create a prior distribution which linked catchability estimates for the two surveys. Sasaki and Sigler conducted hook spacing experiments. The fishery and survey data differ in their hook spacing but otherwise are similar. We used the hook spacing data to create prior distributions which linked the catchability estimates for the surveys and fisheries.

A natural mortality rate of M=0.10 was assumed for previous sablefish assessments. In this year's assessment, natural mortality is estimated in the assessment model.

Some information used in the assessment model was estimated independently of the assessment model. The parameters and equations describing growth and maturity were estimated independently of the assessment modeling, then were incorporated into the assessment model as fixed values.

Annual tag releases from 1978 to 1994 during the Japan-U.S. cooperative longline survey and tag recoveries from 1979 to 1997 were included in preliminary model analyses. This analysis is not finished and so will not be used in this year's assessment.

Sablefish-specific population projections

A set of population projections were completed that are specific to the Alaska sablefish population. These sablefish-specific projections are used in the Bayesian and decision analyses which are described in a later section of the assessment. The method of projecting the population is similar to the standard set of projections described in the next section, except that a different harvest policy is tested in the sablefish-specific projections.

The modeled population was projected forward 5 years. Future recruitment was sampled with replacement from the estimated recruitments for the 1982-1995 year classes. Each stochastic projection was repeated 250 times. Earlier year classes were not included because estimated recruitments for the 1977-1981 year classes were higher and may not recur in the next five years. The 1996 and 1997 year classes also were not included because these year classes have been observed only one or two times and are only partially recruited (estimated less than 20% selected).

Sixteen harvest levels were tested, 10,000, 11,000, ... , 25,000 mt in the projections. For example, the modeled population was projected forward 5 years with a catch of 10,000 mt each year. The purpose of testing several harvest levels was to determine the harvest level which kept future abundance the same.

Standard set of population projections

This year, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 1999 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2000 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 1999. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2000, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2000 recommended in the assessment to the *max* F_{ABC} for 2000. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
>
> *Scenario 3*: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 4*: In all future years, F is set equal to the 1994-1998 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC

may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2000 and above its MSY level in 2010 under this scenario, then the stock is not overfished.)

Scenario 7: In 2000 and 2001, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2012 under this scenario, then the stock is not approaching an overfished condition.)

Bayesian analysis

Previous sablefish assessments assumed that the value of natural mortality was known exactly. This assessment incorporates uncertainty in the value of natural mortality as well as survey catchability using the same approach as the Pacific cod assessments. Other population parameters are uncertain, but uncertainty in only these two parameters was examined because they are the most important parameters determining the value of abundance.

The likelihood surface was mapped over a grid of M and q-values. Equally spaced M and q-values were examined. The natural mortality values and survey catchability values were paired to create a grid of M - q pairs. The remaining population parameters were estimated with the population model given each M - q pair. The resulting likelihood values are an estimate of the likelihood surface given M and q. Each M - q pair was assumed to have equal prior probability, so the posterior probabilities were computed by normalizing the likelihoods so their sum was 1.0. One concern with mapping the likelihood is that the choice of the grid boundaries can have an impact on the results. However we made sure that the boundaries of the grid extended past nearly all of the probability of the normalized likelihood, so that the choice of the grid boundaries can not affect the shape of the posterior.

Decision analysis

The general approach of recommending recent sablefish ABC's has been to consider current abundance and trend relative to historical cycles. Current abundance is estimated as low and stable, so the ABC should not decrease abundance because abundance is low. Thus a reasonable criteria for choosing ABC is a catch level that does not decrease abundance. Five-year projected abundance was compared to next year's projected abundance. The posterior probability from the Bayesian analysis was used to compute the probability of decreasing abundance, that 2004 abundance will be less than 2000 abundance, for several values of catch. Five years was chosen for the projection time frame because, compared to longer time frame projections, projected abundance is only slightly influenced by the assumed value of future stock productivity.

5.6 Model evaluation

5.6.1 Data fits

The model fit the observed abundance indices, survey and fishery length data, and survey age data (Figures 5.2, 5.3, and 5.4 [the length fits are not shown for brevity]).

5.7 Results

5.7.1 Model

Annual estimated recruitment varies widely, with strong year classes estimated for 1959, 1963, 1967, 1974, 1977, 1980, 1981, 1984, 1988, 1990, 1994, 1995, and 1997 (Figure 5.5). Intervening year classes are relatively weak. Two recent strong year classes are the 1994 and 1995 year classes, whereas last year's model identified only the 1995 year class as strong. The change occurred with the addition of the 1998 longline survey age data. However estimates of the strength of recent year classes strength are uncertain because these year classes have been observed only a few times and are only partially recruited. More reliable estimates of the strength of the 1994 and 1995 year class will be available with 1-2 more years of survey data.

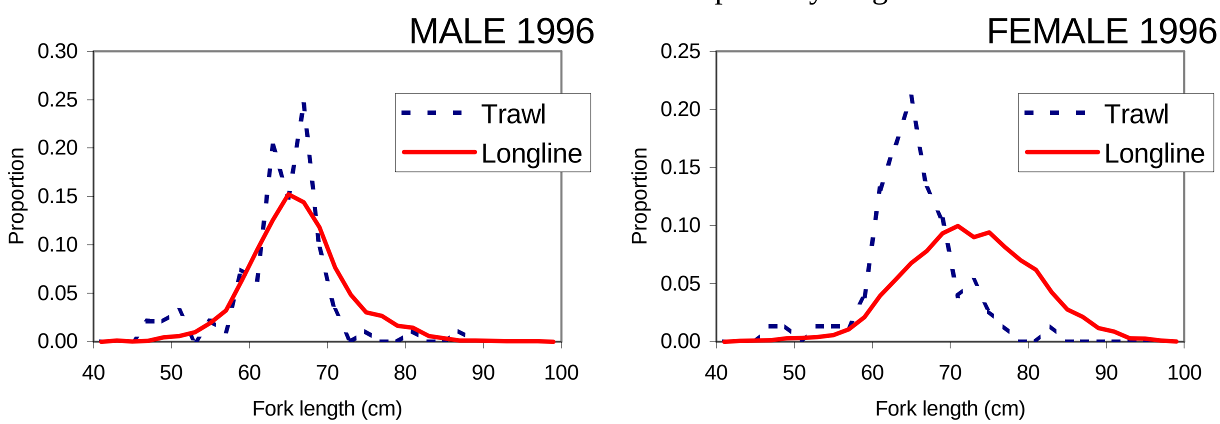
Sablefish abundance increased during the mid-1960's (Table 5.6, Figure 5.6) due to strong year classes from the late 1950's and 1960's. Abundance subsequently dropped during the 1970's due to heavy fishing; catches peaked at 56,988 mt in 1972. The population recovered due to strong year classes from the late 1970's; spawning abundance peaked again in 1987. The population then decreased because these strong year classes are dying off.

Estimated exploitable biomass for Aleutian Islands, eastern Bering Sea, Gulf of Alaska combined decreased 1.2% and spawning biomass increased 0.9% from 1998 to 1999. Projected 2000 exploitable biomass is about 175,000 mt, spawning biomass 175,000 mt, increases of 2.8 and 0.6% from the estimated values for 1999. **Alaska sablefish abundance now appears low but stable. This is a change from previous assessments where abundance appeared low and slowly decreasing.** Further years data are needed to confirm that abundance has stabilized.

The 1977, 1980 and 1981 strong year classes appear to be exceptional year classes associated with the regime shift of 1976-1977. Subsequent year classes are weaker, but may be "normal" for the changed oceanographic state following the regime shift. A major change in the productivity of the stock appears to have occurred following these exceptional year classes.

Estimates of recruitment strength during the 1960's are uncertain because they depend on length rather than age data and because the abundance index is the fishery catch rate, which may be a biased measure of abundance. Late 1970's abundance may be overestimated; predicted mean weight is greater than observed mean weight, implying that predictions of how many fish survived the heavy fishing during the 1970's is overestimated. The observed population during the late 1970's appears to consist of more young fish than was predicted.

The age of 50% selection by the longline survey is about 4 years (Figure 5.7). The age of 50% selection is about 1.5 years later for the IFQ longline fishery, about the same for short open-access seasons ("derby" fishery), and about 1.5 years earlier for the trawl fishery. Selectivity is asymptotic for the longline survey and fishery and dome-shaped for the trawl fishery. Selection of younger fish during short open-access seasons likely was due to crowding of the fishing grounds, so that some fishermen were pushed to fish shallower water that young fish inhabit. Young fish are more vulnerable and older fish are less vulnerable to the trawl fishery (see following figure [only 1996 data shown for brevity]) because trawling often occurs on the continental shelf and < 300 m water of the continental slope that young sablefish inhabit.



Catchability was separately estimated for the "derby" and IFQ fisheries. On average fishery catchability was 38% less during the "derby" fishery. Like the selectivity effect, this likely occurred due to crowding of the fishing grounds, so that fishermen were pushed to fish areas where sablefish densities were less. Fishermen also fished the same area repeatedly, with associated decrease in catch rate due to "fishing down" the area.

A value of 0.102 was estimated for natural mortality in this year's assessment, similar to the assumed value of 0.10 used in previous assessments.

Fishery catch rates often are biased estimates of relative abundance (e.g. Crecco and Overholtz 1990). The assessment results shown in this section used both survey and fishery catch rates as measures of sablefish relative abundance. Because of the potential bias of sablefish fishery catch rates, we tested the effect of the sablefish fishery catch rates. We found that fishery catch rates have little effect on spawning biomass estimates. Their inclusion in the assessment model increased spawning biomass estimates by no more than 1% for any year.

5.7.2 Comparison to last year's model

The scale and the trend of the spawning and exploitable biomass estimates are similar between the November 1998 and 1999 assessments, except for minor differences (Figure 5.8). The 1999 assessment shows a lower peak in the mid-1980's and a slower decreasing trend during the 1990's. The scale of estimated biomass increased slightly in the 1999 assessment; the estimate of 1998 spawning biomass is 5% higher in the 1999 assessment compared to the 1998 assessment. The estimated recruitment values are more distinct from one another in the November 1999 assessment: strong year classes appear stronger and weak year classes appear weaker. The ageing error matrix based on known-age otoliths caused this change and estimated year-class strengths more accurately.

5.8 Projections and harvest alternatives

5.8.1 Reference fishing mortality rates

Reference point values, $B_{40\%}$, $F_{40\%}$, $F_{35\%}$, and adjusted $F_{40\%}$ and $F_{35\%}$ based on projected 2000 spawning biomass estimate, are shown in Table 5.7. Reference biomass values were computed for recruitment equal to average recruitment from the 1977-95 year classes. Projected 2000 spawning biomass is 32% of unfished spawning biomass and 81% of $B_{40\%}$. A downward adjustment to the reference fishing mortality rates is required to set the maximum Acceptable Biological Catch under Tier 3b.

5.8.2 Maximum sustainable yield

A spawner-recruit relationship has not been determined for sablefish, thus estimates of maximum sustainable yield are unavailable.

5.8.3 Population projections

Projected 2000 exploitable biomass is about 175,000 mt for Aleutian Islands, eastern Bering Sea, Gulf of Alaska combined, spawning (male and female) biomass 175,000 mt. Abundance is projected to increase in 2001, regardless of future average recruitment or fishing mortality (less than or equal to maximum permissible) (Figure 5.9). What happens next depends on future average recruitment and fishing mortality. If catch is about 17,000 mt, then abundance is projected to decrease in 2002, then stay the same if future average recruitment equals 1982-1995 average recruitment or increase if future average recruitment equals 1977-1995 average recruitment. The latter recruitment scenario is more optimistic because it includes the exceptional 1977-1981 year classes. Projected abundances for maximum permissible fishing mortality and 5-year average fishing mortality are similar to projected abundances for catch of 17,000 mt. Abundance will increase in 2000 and later if fishing mortality is half maximum permissible or zero.

At their September meeting, the Plan Teams requested that we project yields based on recruitment estimates from the whole time series of 1957+, from 1977+, and from 1982+. Abundance and yield projections are described in the previous paragraph for 1977+ and 1982+; abundance and yield projections for 1957+ are similar to 1977+ because average recruitment for both time intervals is similar, about 21 million 2-year old sablefish per year, compared to 13.7 million for 1982+, and so are not displayed for brevity.

Spawning biomass, fishing mortality, and yield also are tabulated for the seven standard projection scenarios (Table 5.8).

Status determination

Alaska sablefish are not overfished nor are they approaching an overfished condition (Table 5.8).

5.8.4 Bayesian analysis

The parameters natural mortality and survey catchability are well-defined by the available data. Most of the probability lies between M of 0.07 and 0.15 and q of 5.2 and 12.2 (Figure 5.10). The probability changes smoothly and is well-mapped by the chosen values for the q-M grid. We plan to test an algorithm such as MCMC to integrate the posterior probability over all possible combinations of q and M for next year's assessment.

At their October 1999 meeting, the SSC recommended that more informative priors than the uniform priors on M and q be used. Adding more informative priors should narrow the posterior. We tested a more informative prior for natural mortality and as expected, the posterior was narrower. The amount of narrowing depended on the variance assumed for the prior.

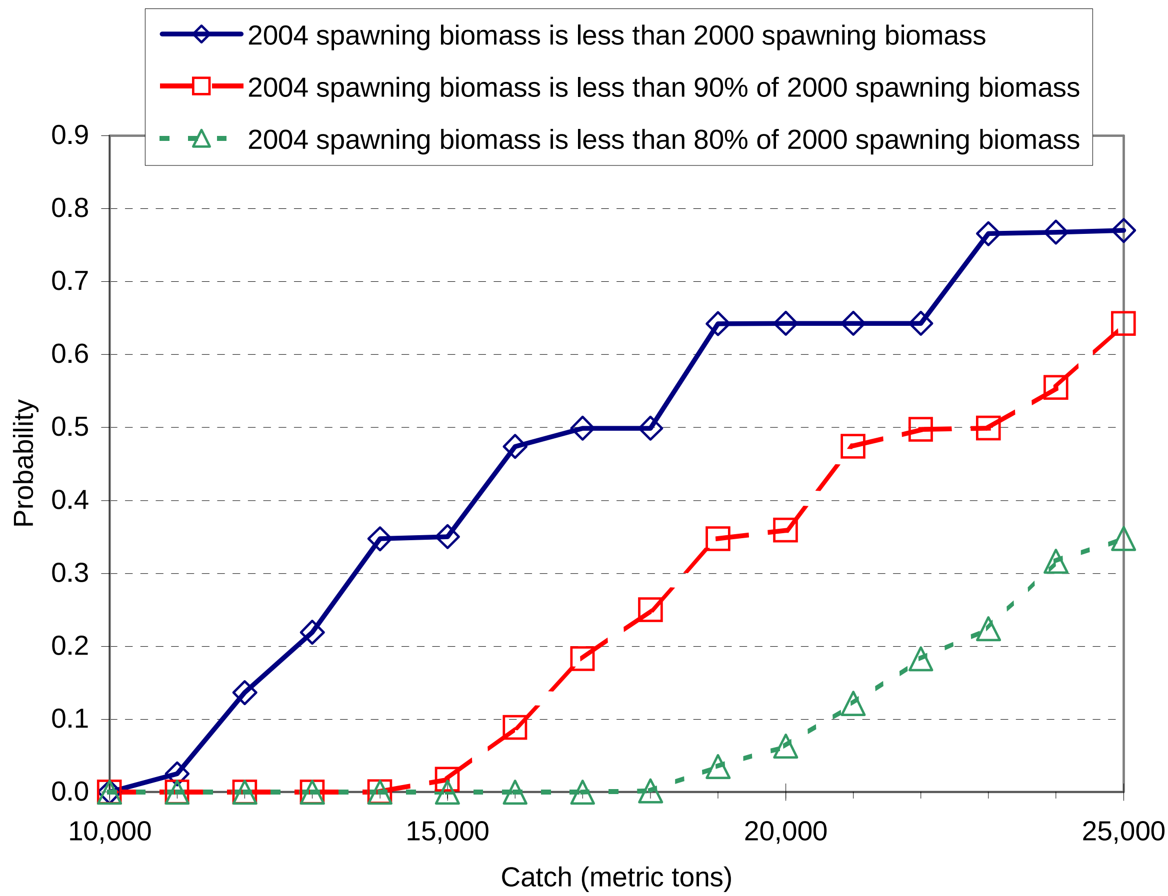
Adding more informative priors also should reduce the estimates of the probability that spawning biomass will decrease in the future. This probability forms the basis of the decision analysis used to recommend the 2000 ABC and described in the next section. Therefore if the prior is "too" informative, the probability estimates of what catch level will decrease sablefish abundance will be underestimated, e.g. the probability that 2004 abundance will be less than 90% of 2000 abundance will be 0.1 rather than 0.2.

One basis for adding a more informative prior is sablefish biologists' opinion of the value of natural mortality. However our opinion primarily is based on age-structured modeling. Adding a an opinion-based prior to the age-structured model essentially is double-counting the information used to estimate natural mortality. Therefore we did not add more informative priors based on our opinion of natural mortality.

Another approach for adding more informative priors which does not depend on sablefish data alone is a meta-analysis based on the value of natural mortality for other species, if the analysis includes long-lived species of the Scorpaeniformes (which includes sablefish and rockfish) or a meta-analysis that uses other life history relationships such as natural mortality and the growth parameter *k*. During development of the Bayes and decision analyses we considered using meta-analysis priors for natural mortality as well as stock-recruitment relationship "steepness" and may add these priors to future sablefish assessments.

5.8.5 Decision analysis

The decision analysis asks the question: What is the probability that spawning biomass will decrease in the future? The years 2000 and 2004 were compared. The probability that spawning biomass will be higher in 2004 is 0.5 and equals the probability that spawning biomass will be lower. The spawning biomass most likely will be the same in 2000 and 2004 for catch of 17,000 mt each year (based on the expected value of the spawning biomass comparison). The probability that this catch will reduce 2004 spawning biomass to less than 90% of 2000 spawning biomass is about one in five and to less than 80% of 2000 spawning biomass is near zero.



5.8.6 Acceptable biological catch

Biomass estimates have changed between assessments in some previous assessments and may not result in a consistent series of ABC's when an $F_{40\%}$ strategy is applied. Given the low abundance of sablefish, we feel that prior ABC's and the abundance trend should be considered to recommend ABC. The approach we used to recommend the 1997, 1998, and 1999 acceptable biological catches (ABC) consisted of two steps, compute the short-term equilibrium yield, then recommend a linear reduction one third of the way from the current ABC to the respective short-term equilibrium yield. For example, the 1997 combined ABC was 17,200 mt, the short-term equilibrium yield projected in the 1998 assessment was 16,000 mt, so the 1998 ABC recommendation was 16,800 mt for the combined stock. The short-term equilibrium yield was used to recommend ABC because the yield from an adjusted $F_{40\%}$ strategy in the 1997 and 1998 assessments represented an increase over recent ABC's. Increasing ABC was inconsistent with declining stock trend. Rather than increasing ABC then reducing thereafter toward the predicted short-term equilibrium yield, in the 1997 and 1998 assessments we recommended an incremental adjustment of ABC toward the short-term equilibrium yield. An incremental adjustment was used to recommend ABC to spread out the change from current ABC to short-term equilibrium yield over 3 years and because estimates of short-term equilibrium yield may change as new data become available and we use new methods of estimating short-term equilibrium yield.

We recommend choosing the 2000 ABC based on the same concerns for abundance trend and low abundance. The decision analysis presented in the previous section addresses this concern using more sophisticated methods of estimating the risk of decreasing abundance. The decision analysis indicates that a yield of about 17,000 mt most likely will keep spawning biomass the same and has only a 20% probability of reducing 2004 spawning biomass to less than 90% of 2000 spawning biomass. Based on this result, **we recommend a 2000 ABC of 17,000 mt for the combined stock**, a 7% increase from the 1999 ABC of 15,900 mt.

An increased 2000 ABC is consistent with other measures of sablefish abundance trend. Exploitable and spawning biomass are projected to increase 3 and 1%, respectively, from 1999 to 2000. The survey abundance index increased 5% in weight and 10% in number and the fishery abundance index increased 11% from 1998 to 1999. These increases follow decreases from 1997 to 1998, so that relative abundance in 1999 is similar to 1997 (Table 5.5). The 1999 combined ABC was 15,900 mt. The 2000 yield of 17,200 mt from an adjusted $F_{40\%}$ strategy is consistent with the decision analysis based recommendation of 17,000 mt.

The current approach of considering the risk of decreasing abundance for recommending ABC is appropriate for a population which is decreasing or stable and at low abundance. If abundance increases substantially, well away from the current low abundance, the opportunity will arise to consider other objectives and concerns. If abundance were to increase, then increased emphasis on yield maximization will be appropriate. Another concern which is more a TAC concern, is considering that abundance may increase, then subsequently decrease as has occurred twice in the last forty years. A TAC strategy for increasing abundance might consider how best to manage through this cycle, including bringing in market and economic considerations such as expansion and subsequent contraction of the supply of sablefish over a 10- to 20-year period.

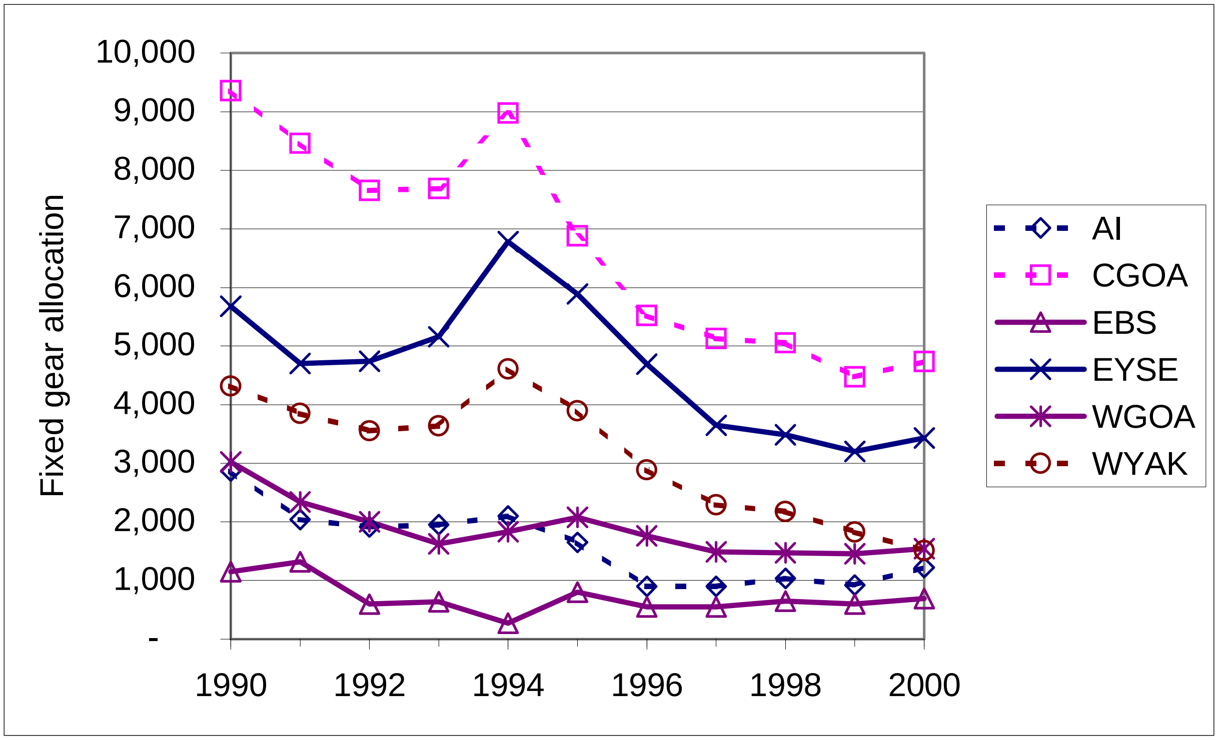
5.8.7 Regional and area apportionment

The combined ABC has been apportioned to regions using weighted moving average methods since 1993; these methods reduce the magnitude of interannual changes in the allocation. Weighted moving average methods are robust to uncertainties about movement rates and measurement error of biomass distribution, while adapting to current information about biomass distribution. However mixing rates for sablefish are sufficiently high and fishing rates sufficiently low that moderate variations of the biomass based apportionment would not significantly change overall sablefish yield unless there are strong areal differences in recruitment, growth, and survival (Heifetz et al 1997). The 1993 TAC was apportioned using a 5 year running average with emphasis doubled for the current year survey abundance index in weight (relative population weight or RPW). Since 1995, the ABC was allocated using an exponential weighting of regional RPW's. This method of determining weighting values depends on the assumed ratio between measurement (survey variance) to process error (recruitment, natural mortality, and migration variability). If survey variability is 1/N-th of total variability, the weighting factor is reduced 1/N-th each previous year. The sablefish longline surveys are assumed fairly accurate relative to many other surveys and probably survey variability is no more than ½ of total variability. A $(1/2)^x$ weighting scheme reduced annual fluctuations in ABC, while keeping regional fishing rates from exceeding overfishing levels in a stochastic migratory model, where *x* is the year index (J. Heifetz, Auke Bay Lab, pers. comm.). The weights are year index 5: weight 0.0625; 4: 0.0625; 3: 0.1250; 2: 0.2500; 1: 0.5000.

	Survey-based ABC apportionment					
	1999 ABC Apportionment	**1999 Survey RPW**	**2000 ABC Apportionment**	**1999 ABC**	**2000 ABC**	**Percent change**
Total				15,900	17,000	6.9%
Bering	8.43%	7.83%	8.14%	1,340	1,384	3.3%
Aleutians	11.70%	16.42%	14.39%	1,860	2,446	31.5%
GOA	79.87%	75.75%	77.47%	12,700	13,170	3.7%
Western	14.33%	14.58%	14.64%	1,820	1,928	5.9%
Central	44.02%	46.15%	44.96%	5,590	5,921	5.9%
W Yak	15.12%	13.89%	14.35%	1,920	1,890	-1.6%
Eyak/SE	26.54%	25.38%	26.05%	3,370	3,431	1.8%

Age 4+ biomass was estimated by year and region by applying the same survey-based weights used to allocate the ABC (Table 5.9).

The next figure shows the fixed gear allocation from 1990 to 1999 and the survey-based fixed gear allocation for 2000 ABC of 17,000 mt.



Alternate ABC apportionment which includes fishery information

Members of the fishing industry have asked us to show how fishery and survey information could be combined to produce an alternate apportionment based of ABC (Figure 5.11 compares fishery and survey catch rates). In previous years, the ABC has been apportioned using survey estimates of relative abundance by area. Relative population weights based on fishery catch rates are another measure of relative abundance by area.

The fishery and survey information were combined to allocate ABC using the following method. The RPW based on the fishery data were weighted with the same exponential weights used to weight the survey data (year index 5: weight 0.0625; 4: 0.0625; 3: 0.1250; 2: 0.2500; 1: 0.5000). The fishery and survey data were combined by computing a weighted average of the survey and fishery estimates, with the weight inversely proportional to the variability of each data source. The variance for the fishery data is about twice that for the survey data, so the survey data was weighted twice as much as the fishery data.

This method of combining the fishery and survey data appears reasonable, but using equal exponential weights for the fishery and survey data is not consistent with the theory used to determine the exponential weights. Weighting the survey data twice as much as the fishery data when combining the data, as described above, fits the theory. However using the same exponential weights for the fishery and survey data does not. More study is needed to resolve this inconsistency.

	Fishery and survey-based ABC apportionment						
	1999 ABC Apportion ment	**1999 Fishery RPW**	**1999 Survey RPW**	**2000 ABC Apportion ment**	**1999 ABC**	**2000 ABC**	**change**
Total					15,900	17,000	6.92%
Bering	8.43%	6.25%	7.83%	8.90%	1,340	1,513	12.90%
Aleutians	11.70%	14.40%	16.42%	14.07%	1,860	2,392	28.61%
GOA	79.87%	79.34%	75.75%	77.03%	12,700	13,095	3.11%
Western	14.33%	12.64%	14.58%	13.77%	1,820	1,803	-0.91%
Central	44.02%	38.65%	46.15%	42.96%	5,590	5,626	0.65%
W Yak	15.12%	17.31%	13.89%	15.17%	1,920	1,986	3.44%
Eyak/SE	26.54%	31.40%	25.38%	28.10%	3,370	3,679	9.18%

The fishery indicates proportionately more fish are in West Yakutat and East Yakutat/Southeast, so combining the fishery and survey data increases the proportion of the ABC allocated to these two areas and decreases the proportion of the ABC allocated to Western and Central.

Alternate ABC apportionment based on (IFQ) Quota Share Pool

The two ABC apportionment methods described above use a moving average of estimated relative abundance to apportion the ABC. The advantage of moving-average methods is that the ABC follows estimated changes in regional abundance. An alternative to moving-average methods is a fixed-average method, where the ABC allocation percentages do not change from year to year. The advantage of fixed-average methods is that each area ABC rises and falls together with the combined Alaska-wide ABC. For example if the combined ABC increases 5%, then each area ABC increases 5%. Tying area ABC changes to combined ABC changes makes changes in area ABC more predictable because it's much easier to predict changes in Alaska-wide sablefish abundance and ABC than to predict area abundance and ABC based on moving-average methods. More predictable area ABC make it easier to for IFQ share holders to decide whether to buy, sell, or hold IFQ shares by reducing the unpredictability of the value of their shares.

Because sablefish are considered one population in Alaska and have high movement rates, fixed-average methods are satisfactory for allocating ABC as long as the allocation percentages used do not allow substantially higher fishing mortalities in one or more areas in some years. Yield and the risk of reducing spawning biomass to less than 30% of the unfished level were examined in a migratory age-structured model of Alaska sablefish (Heifetz et al. 1997). Yield and risk are similar for moving-average and fixed-average methods of allocating ABC for the migration and fishing mortality rates estimated for sablefish.

To use a fixed-average method, a basis for the fixed-average percentages must be found. One basis is the Quota Share Pool units issued by the Restricted Access Management Division. The Quota Share Pool units are based on the IFQ-qualified vessels reports of their five best annual catches from 1985 to 1990. The Quota Share Pool percentages closely match total reported longline catch by area from 1985 to 1990.

				Quota share, fixed-average ABC apportionment		
	1999 ABC Apportionment	**Quota share pool**	**2000 ABC Apportion ment**	**1999 ABC**	**2000 ABC**	**change**
Total				15,900	17,000	6.9%
Bering	8.43%	5.88%	5.88%	1,340	1,000	-25.4%
Aleutians	11.70%	9.98%	9.98%	1,860	1,696	-8.8%
GOA	79.87%	84.14%	84.14%	12,700	14,304	12.6%
Western	14.33%	13.53%	13.53%	1,820	1,936	6.4%
Central	44.02%	41.70%	41.70%	5,590	5,965	6.7%
W Yak	15.12%	19.99%	19.99%	1,920	2,860	49.0%
Eyak/SE	26.54%	24.77%	24.77%	3,370	3,543	5.1%

The biggest change is the West Yakutat allocation. The reason for this change is that the percentage of the ABC allocated to the West Yakutat area has dropped substantially since 1995, the first year of IFQ management. The Quota Share Pool percentage is 19.99%, the percent of the total reported longline catch from 1985 to 1990 was 20.67%, and the 1995 survey-based allocation was 19%, whereas the 1999 survey-based allocation was 15.12%. The allocation to West Yakutat has decreased from 1995 to 1999 because longline surveys indicate that the proportion of sablefish in West Yakutat is about one-fifth less in 1999 compared to 1995.

Possible scientific concerns with apportionment method

The only possible scientific concern with changes in the apportionment method we foresee is a method which allows substantially higher fishing rates in one or more areas. However differences in fishing mortality between areas for the survey-based, the survey and fishery-based, and the quota share pool-based apportionment methods should not affect yield or risk of overfishing based on a previous analysis of moving-average and fixed-average apportionment methods for sablefish (Heifetz et al. 1997); see the following table.

Effect of ABC apportionment method. Yield and CPUE are expressed relative to the maximum. Risk is defined as the percentage of the time that spawning biomass in an area was less than 30% of the unfished level. The exploitation rate was set at 0.10, which approximates the current level of exploitation. From Heifetz et al. 1997, Table 5.

Area	Policy	Average yield	CV yield	CPUE	Risk
Eastern Gulf of Alaska	Moving average	0.41	0.18	0.94	0.10
Eastern Gulf of Alaska	Fixed average	0.41	0.19	0.94	0.10
Central Gulf of Alaska	Moving average	0.25	0.20	0.60	0.05
Central Gulf of Alaska	Fixed average	0.26	0.19	0.60	0.05
Western Gulf of Alaska	Moving average	0.15	0.21	0.68	0.04
Western Gulf of Alaska	Fixed average	0.15	0.19	0.68	0.04
Eastern Bering Sea	Moving average	0.05	0.27	0.08	0.02
Eastern Bering Sea	Fixed average	0.05	0.19	0.08	0.03
Aleutian Islands	Moving average	0.13	0.24	0.11	0.02
Aleutian Islands	Fixed average	0.13	0.19	0.11	0.03
All areas combined	Moving average	1.00	0.10	0.67	0.05
All areas combined	Fixed average	1.00	0.10	0.66	0.06

Yield, CV yield, CPUE, and risk are similar for both apportionment methods. The only notable difference is an increase in risk in the Bering Sea and Aleutian Islands areas from 0.02 for the moving average method to 0.03 for the fixed average method. The tradeoff is decreased yield variability for the fixed average method. The overfishing level (the B_{msy} proxy) was 30% of unfished in this analysis, whereas the current standard is 35%. Presumably risk would increase similarly for both allocation methods; further simulations could be completed to test this presumption.

Since sablefish are considered to be one population in Alaska, this analysis implies that it does not matter in what area they're harvested, as long as fishing mortality rates do not greatly differ between areas. Thus as assessment authors, we have no recommendation on which of these three apportionment methods should be used.

5.8.8 Overfishing level

Applying an adjusted $F_{35\%}$ as prescribed for Over Fishing Level (OFL) in Tier 3b results in a value of 21,400 mt for the combined stock. The OFL is apportioned by region, Bering Sea (1,739 mt), Aleutian Islands (3,073 mt), and Gulf of Alaska (16,546 mt), by the same method as the survey-based ABC apportionment.

5.9 Acknowledgements Milo Adkison provided advice for the Bayes and decision analyses.

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Table 5.1.--Sablefish fork length (cm), weight (kg), and proportion mature by age and sex. Maturity at age was computed using logistic equations fit to the length/maturity relationships shown in Sasaki (1985, Figure 23). A value of 0.4 is used for the slope parameter for maturity at length (cm) of 50 percent maturity.

	Fork length (cm)		Weight (kg)		Fraction mature	
Age	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
2	50	52	1.2	1.4	0.059	0.006
3	53	56	1.5	1.7	0.165	0.024
4	55	59	1.7	2.1	0.343	0.077
5	57	62	1.9	2.4	0.543	0.198
6	59	64	2.1	2.7	0.704	0.394
7	61	66	2.3	3.0	0.811	0.604
8	62	68	2.4	3.3	0.876	0.765
9	63	70	2.6	3.6	0.915	0.865
10	64	71	2.7	3.9	0.939	0.921
11	65	72	2.8	4.1	0.954	0.952
12	65	74	2.9	4.3	0.964	0.969
13	66	75	3.0	4.5	0.971	0.979
14	66	76	3.1	4.7	0.976	0.986
15	67	76	3.1	4.9	0.979	0.990
16	67	77	3.2	5.1	0.982	0.992
17	67	78	3.2	5.2	0.984	0.994
18	67	78	3.2	5.3	0.985	0.995
19	68	79	3.3	5.4	0.986	0.996
20	68	79	3.3	5.5	0.987	0.997
21	68	80	3.3	5.6	0.988	0.997
22	68	80	3.3	5.7	0.988	0.998
23	68	80	3.4	5.8	0.989	0.998
24	68	81	3.4	5.9	0.989	0.998
25	68	81	3.4	5.9	0.989	0.998
26	68	81	3.4	6.0	0.990	0.998
27	68	81	3.4	6.0	0.990	0.999
28	69	81	3.4	6.1	0.990	0.999
29	69	82	3.4	6.1	0.990	0.999
30	69	82	3.4	6.1	0.990	0.999

Table 5.2--Alaska sablefish catch, 1956-1998. The values include landed catch and discard estimates. For years where discard estimates were not available from observer data (before 1993), discards were estimated for U.S. fisheries by multiplying reported catch by 2.9% for fixed gear and 26.9% for trawl gear. The grand total sometimes includes an additional amount where the area was unknown.

		AREA							GEAR	
Year	GRAND TOTAL	Bering Sea	Aleutians	Western	Central	Eastern	West Yakutat	E. Yakutat/ Southeast	Fixed	Trawl
1956	773	0	0	0	0	773			773	0
1957	2,059	0	0	0	0	2,059			2,059	0
1958	477	6	0	0	0	471			477	0
1959	910	289	0	0	0	621			910	0
1960	3,054	1,861	0	0	0	1,193			3,054	0
1961	16,078	15,627	0	0	0	451			16,078	0
1962	26,379	25,989	0	0	0	390			26,379	0
1963	16,901	13,706	664	266	1,324	941			10,557	6,344
1964	7,273	3,545	1,541	92	955	1,140			3,316	3,957
1965	8,733	4,838	1,249	764	1,449	433			925	7,808
1966	15,583	9,505	1,341	1,093	2,632	1,012			3,760	11,823
1967	19,196	11,698	1,652	523	1,955	3,368			3,852	15,344
1968	30,940	14,374	1,673	297	1,658	12,938			11,182	19,758
1969	36,831	16,009	1,673	836	4,214	14,099			15,439	21,392
1970	37,858	11,737	1,248	1,566	6,703	16,604			22,729	15,129
1971	43,468	15,106	2,936	2,047	6,996	16,382			22,905	20,563
1972	53,080	12,758	3,531	3,857	11,599	21,320			28,538	24,542
1973	36,926	5,957	2,902	3,962	9,629	14,439			23,211	13,715
1974	34,545	4,258	2,477	4,207	7,590	16,006			25,466	9,079
1975	29,979	2,766	1,747	4,240	6,566	14,659			23,333	6,646
1976	31,684	2,923	1,659	4,837	6,479	15,782			25,397	6,287
1977	21,404	2,718	1,897	2,968	4,270	9,543			18,859	2,545
1978	10,394	1,193	821	1,419	3,090	3,870			9,158	1,236
1979	11,814	1,376	782	999	3,189	5,391			10,350	1,463
1980	10,444	2,205	275	1,450	3,027	3,461			8,396	2,048
1981	12,604	2,605	533	1,595	3,425	4,425			10,994	1,610
1982	12,048	3,238	964	1,489	2,885	3,457			10,204	1,844
1983	11,715	2,712	684	1,496	2,970	3,818			10,155	1,560
1984	14,109	3,336	1,061	1,326	3,463	4,618			10,292	3,817
1985	14,465	2,454	1,551	2,152	4,209	4,098			13,007	1,457
1986	28,817	4,184	3,285	4,067	9,105	8,175			21,500	7,316
1987	35,161	4,904	4,112	4,141	11,505	10,500			27,593	7,568
1988	38,388	4,006	3,616	3,789	14,505	12,473			29,264	9,124
1989	34,829	1,516	3,704	4,533	13,224	11,852			27,509	7,320
1990	32,086	2,606	2,412	2,251	13,786	11,030			26,568	5,518
1991	26,985	1,318	2,168	1,821	11,662	10,014			23,039	3,946
1992	22,251	586	1,497	2,401	11,135	6,632			18,939	3,312
1993	25,433	668	2,080	739	11,971	9,975	4,619	5,356	22,912	2,521
1994	23,760	694	1,726	555	9,495	11,290	4,497	6,793	20,797	2,963
1995	20,954	990	1,333	1,747	7,673	9,211	3,866	5,345	18,342	2,612
1996	17,577	697	905	1,648	6,772	7,555	2,899	4,656	15,390	2,187
1997	14,922	728	929	1,374	6,237	5,653	1,928	3,725	13,287	1,635
1998	14,108	614	734	1,435	5,877	5,448	1,899	3,479	12,644	1,464

Table 5.3--Discarded catches of sablefish (amount [mt] and percent of total catch) by target fishery, gear (H&L=hook & line, TWL=trawl), and management area for 1994 to 1998.

		Eastern Bering Sea		**Aleutian Islands**		**Western**		**Central**		**West Yakutat**		**East Yakutat/ SEO**	
Target fishery	Year	Amt.	Pct.	Amt.	Pct.	Amt.	Pct.	Amt.	Pct.	Amt.	Pct.	Amt.	Pct.
Sablefish (H&L)	1994	7	4	16	1	11	2	75	1	39	1	66	1
	1995	5	1	8	1	40	2	111	2	71	2	132	2
	1996	7	2	9	1	33	2	137	3	56	2	79	2
	1997	8	4	19	3	41	3	116	2	88	5	123	3
	1998	6	4	5	1	91	6	210	5	46	2	184	5
Greenland	1994	1	1	2	3	0	-	0	-	0	-	0	-
turbot (H&L)	1995	82	48	40	53	0	-	0	-	0	-	0	-
	1996	75	41	5	17	0	-	0	-	0	-	0	-
	1997	92	40	1	11	0	-	0	-	0	-	0	-
	1998	85	31	7	5	0	-	0	-	0	-	0	-
Pacific cod (H&L)	1994	7	15	1	2	1	23	0	-	0	-	0	-
	1995	15	37	2	18	2	96	4	11	0	-	0	-
	1996	15	64	13	19	0	-	0	-	0	-	0	-
	1997	15	71	5	16	8	75	114	89	0	-	0	-
	1998	9	63	4	31	0	-	5	46	0	2	0	-
All other (H&L)	1994	0	0	0	0	0	-	0	-	4	72	0	-
	1995	0	0	3	83	0	-	0	-	0	-	0	7
	1996	0	57	0	6	0	-	0	-	0	-	0	-
	1997	1	39	0	-	0	-	0	-	0	-	0	-
	1998	2	90	0	-	0	-	3	36	0	5	6	48
Total H&L	1994	14	5	19	1	11	3	75	1	44	1	66	1
	1995	102	16	52	5	42	3	115	2	71	2	132	2
	1996	98	19	27	4	33	2	137	3	56	2	79	2
	1997	117	24	25	3	49	4	230	5	88	5	123	3
	1998	101	22	16	3	91	6	218	5	46	2	190	5

Table 5.3 cont.		Eastern Bering Sea		Aleutian Islands		Western		Central		West Yakutat		East Yakutat/ SEO	
Target fishery	Year	Amt.	Pct.	Amt.	Pct.	Amt.	Pct.	Amt.	Pct.	Amt.	Pct.	Amt.	Pct.
Sablefish (TWL)	1994	13	28	0	-	0	-	10	15	0	-	0	-
	1995	0	-	1	10	0	-	62	61	0	-	0	-
	1996	0	1	0	-	0	-	1	2	2	3	0	-
	1997	0	-	0	-	0	-	0	-	0	-	0	-
	1998	0	-	0	-	0	-	0	-	0	-	0	-
Rockfish (TWL)	1994	1	-	9	12	1	1	54	8	28	13	0	-
	1995	0	-	1	4	2	4	167	21	57	25	0	-
	1996	0	5	0	2	0	-	208	19	28	13	0	-
	1997	0	-	1	5	0	5	159	19	5	13	0	-
	1998	0	-	0	1	0	-	67	9	0	-	0	-
Arrowtooth (TWL)	1994	0	-	0	-	0	-	20	42	0	-	0	-
	1995	0	-	0	-	0	-	286	75	0	-	0	-
	1996	0	-	0	-	1	36	133	76	0	-	0	-
	1997	0	-	0	-	0	-	24	47	0	-	0	-
	1998	5	21	0	-	13	62	62	96	0	-	0	-
Deepwater	1994	0	-	0	-	0	-	180	40	12	26	47	73
flatfish (TWL)	1995	0	-	0	-	0	-	76	41	7	22	0	-
	1996	0	-	0	-	0	-	66	39	6	23	0	-
	1997	0	-	0	-	0	-	117	47	3	49	93	59
	1998	0	-	0	-	0	-	71	35	1	29	0	-
Shallow water	1994	0	-	0	-	0	-	9	8	0	-	0	-
flatfish (TWL)	1995	0	-	0	-	0	-	18	33	0	-	0	-
	1996	0	-	0	-	0	-	7	23	0	-	0	-
	1997	0	-	0	-	0	-	11	32	0	-	0	-
	1998	0	-	0	-	0	-	32	84	0	-	0	-
Rex sole (TWL)	1994	0	-	0	-	0	-	137	30	0	-	0	-
	1995	0	-	0	-	0	-	36	16	6	94	0	-
	1996	0	-	0	-	0	-	32	24	42	-	0	-
	1997	0	-	0	-	0	3	5	13	16	77	0	-
	1998	0	-	0	-	3	34	6	11	0	-	0	-
Greenland	1994	35	12	10	18	0	-	0	-	0	-	0	-
turbot (TWL)	1995	7	3	16	22	0	-	0	-	0	-	0	-
	1996	3	6	0	-	0	-	0	-	0	-	0	-
	1997	0	1	0	-	0	-	0	-	0	-	0	-
	1998	1	1	0	-	0	-	0	-	0	-	0	-
All other (TWL)	1994	17	48	0	4	3	54	35	25	0	-	0	-
	1995	13	61	3	49	8	70	18	20	0	-	0	-
	1996	16	26	10	77	2	13	1	13	0	-	0	-
	1997	11	37	0	23	1	15	44	48	0	-	0	-
	1998	7	11	4	43	4	62	56	54	1	39	0	-
Total TWL	1994	66	17	18	12	4	4	445	23	40	15	47	63
	1995	20	7	20	19	10	13	663	36	70	26	0	-
	1996	19	14	10	41	3	11	448	27	77	22	0	-
	1997	11	20	1	6	2	8	360	28	23	35	93	55
	1998	12	9	4	21	20	44	294	24	2	3	0	-
Grand total	1994	80	12	38	2	15	3	520	6	83	2	112	2
	1995	122	13	72	7	53	3	777	10	141	4	132	2
	1996	117	18	36	5	35	2	585	9	133	5	79	2
	1997	128	23	26	3	51	4	589	9	111	6	216	6
	1998	114	19	20	3	111	8	512	9	48	2	190	5

Table 5.4.--Sample sizes for age and length data collected from Alaska sablefish. Japanese fishery data from Sasaki (1985), U.S. fishery data from observer databases, and longline survey data from longline survey databases. All fish were sexed before measurement, except for the Japanese fishery data. Survey sample sizes are approximate; exact values will be tabulated for the next year's assessment.

	LENGTH						AGE	
	Japanese fishery		U.S. fishery		Cooperative longline survey	Domestic longline survey	Cooperative longline survey	Domestic longline survey
Year	Trawl	Longline	Trawl	Longline				
1963		30,562						
1964	3,337	11,377						
1965	6,267	9,631						
1966	27,459	13,802						
1967	31,868	12,700						
1968	17,727							
1969	3,843							
1970	3,456							
1971	5,848	19,653						
1972	1,560	8,217						
1973	1,678	16,332						
1974		3,330						
1975								
1976		7,704						
1977		1,079						
1978		9,985						
1979		1,292			100,000			
1980		1,944			100,000			
1981					100,000			
1982					100,000			
1983					100,000		1,200	
1984					100,000			
1985					100,000			
1986					100,000			
1987					100,000		1,200	
1988					100,000			
1989					100,000		1,200	
1990			1,229	33,822	100,000	60,000		
1991			721	29,615	100,000	60,000	1,200	
1992			0	21,000	100,000	60,000		
1993			468	23,884	100,000	60,000	1,200	
1994			89	13,614	100,000	60,000		
1995			87	18,174		60,000		
1996			239	15,213		60,000		1,200
1997			0	20,311		60,000		1,200
1998			35	8,900		60,000		1,200
1999			269	17,863		60,000		

Table 5.5.--Sablefish abundance index values (1,000's) for Alaska (200-1,000 m) including deep gully

habitat, from the Japan-U.S. Cooperative Longline Survey, Domestic Longline Survey, and Japanese and U.S. longline fisheries. One or two indices of population abundance were computed: catch per effort in numbers weighted by respective strata areas to produce a relative population number (RPN) and catch per effort measured in weight multiplied by strata areas, to produce a relative population weight (RPW). Indices were extrapolated for unsampled survey areas: Aleutian Islands 1979, 1995, 1997, 1999; Bering Sea 1979-1981, 1995, 1996, 1998.

	RPN		**RPW**			
Year	**Cooperative longline survey**	**Domestic longline survey**	**Japanese longline fishery**	**Cooperative longline survey**	**Domestic longline survey**	**U.S. fishery**
1964			1,452			
1965			1,806			
1966			2,462			
1967			2,855			
1968			2,336			
1969			2,443			
1970			2,912			
1971			2,401			
1972			2,247			
1973			2,318			
1974			2,295			
1975			1,953			
1976			1,780			
1977			1,511			
1978			942			
1979	413		809	1,075		
1980	388		1,040	968		
1981	460		1,343	1,153		
1982	613			1,572		
1983	621			1,632		
1984	685			1,822		
1985	903			2,569		
1986	838			2,456		
1987	667			2,068		
1988	707			2,088		
1989	661			2,178		
1990	450	649		1,454	2,141	1,201
1991	386	593		1,321	2,071	1,066
1992	402	511		1,390	1,758	908
1993	395	563		1,318	1,894	904
1994	366	489		1,288	1,882	822
1995		501			1,803	1,243
1996		520			2,017	1,201
1997		491			1,764	1,341
1998		466			1,662	1,130
1999		511			1,740	1,258

Table 5.6.--Sablefish age 4+ biomass, exploitable biomass, spawning biomass, and catch

(thousands mt) by year. Projected values assume catch of 17,000 mt from 2000-2004, the authors' recommended ABC for 2000, and recruitment based on average for 1982-1995 year classes.

Year	Age 4+ biomass	Exploitable biomass	Spawning biomass	Catch	Catch / Age 4+ biomass
1960	263	219	227	3	0.012
1961	254	217	225	16	0.063
1962	231	203	217	26	0.114
1963	358	178	214	17	0.047
1964	385	178	246	7	0.019
1965	383	229	293	9	0.023
1966	371	302	329	16	0.042
1967	485	318	337	19	0.040
1968	470	315	357	31	0.066
1969	432	325	363	37	0.085
1970	409	341	356	38	0.093
1971	466	309	329	44	0.093
1972	426	289	328	53	0.124
1973	366	280	308	37	0.101
1974	316	283	285	35	0.110
1975	260	248	238	30	0.115
1976	217	211	204	32	0.146
1977	173	168	167	21	0.124
1978	211	139	150	10	0.049
1979	198	125	149	12	0.060
1980	186	134	162	10	0.056
1981	281	154	181	13	0.045
1982	308	155	202	12	0.039
1983	329	185	242	12	0.036
1984	401	278	280	14	0.035
1985	443	361	310	15	0.033
1986	425	402	335	29	0.068
1987	400	387	340	35	0.088
1988	387	354	318	38	0.099
1989	347	323	285	35	0.100
1990	308	295	263	32	0.104
1991	262	261	237	27	0.103
1992	265	236	212	22	0.084
1993	237	230	201	25	0.107
1994	253	222	192	24	0.094
1995	239	185	188	21	0.087
1996	223	186	182	18	0.079
1997	208	182	178	15	0.072
1998	220	174	173	14	0.064
1999	234	171	175	14	0.061
2000	220	175	175	17	0.077
2001	228	181	179	17	0.075
2002	223	175	174	17	0.076
2003	222	175	174	17	0.076
2004	221	175	174	17	0.077

Table 5.7--Alaska sablefish harvest information by recruitment scenario.

		1982-1995 mean recruitment projection	1977-1995 mean recruitment projection
Natural mortality	0.102		
Age at 50% selection for survey	4.2		
Age at 50% selection for "derby" fishery	4.2		
Age at 50% selection for IFQ fishery	5.5		
Equilibrium unfished exploitable biomass	551		
Equilibrium unfished spawning biomass	542		
Reference point spawning biomass, $B_{40\%}$	217		
Reference point spawning biomass, $B_{35\%}$	190		
2000 exploitable biomass		175	175
2000 spawning biomass		175	175
Ratio 2000 : unfished spawning biomass		0.32	0.32
HARVEST ALTERNATIVES			
Maximum permissible fishing level			
$F_{40\%}$	0.136		
2000 $F_{40\%}$ adjusted		0.108	0.109
2000 $F_{40\%}$ adjusted yield		17.2	17.2
Overfishing level			
$F_{35\%}$	0.170		
2000 $F_{35\%}$ adjusted		0.136	0.136
2000 $F_{35\%}$ adjusted yield		21.4	21.4
Authors' recommendation			
2000 F	0.107		
2000 ABC	17.0		

Table 5.8--Alaska sablefish spawning biomass, fishing mortality, and yield for seven harvest scenarios. The reference spawning biomass used to determine if the population is overfished, $B_{35\%}$, is 190 thousand mt, which sablefish are projected to reach by 2007, so Alaska sablefish are not classified as overfished. Projections are based on the 1977 to 1995 year classes.

Year	Maximum permissible F	Fraction maximum F	Half maximum F	5-year average F	No fishing	Overfished?	Approaching overfished?
Spawning biomass							
1999	175	175	175	175	175	175	175
2000	176	176	176	176	176	176	176
2001	180	180	187	180	196	176	180
2002	176	177	191	178	208	170	178
2003	181	182	201	183	227	173	180
2004	190	190	215	192	249	179	185
2005	196	197	225	199	269	184	188
2006	201	202	235	206	288	188	192
2007	206	207	244	212	306	191	195
2008	211	213	255	219	326	196	199
2009	215	216	262	225	344	198	200
2010	218	219	269	229	360	200	202
2011	220	221	274	232	373	201	202
2012	221	223	280	235	389	202	202
Fishing mortality							
1999	0.091	0.091	0.091	0.091	0.091	0.091	0.091
2000	0.109	0.107	0.054	0.104	0.000	0.136	0.109
2001	0.111	0.109	0.058	0.104	0.000	0.136	0.111
2002	0.109	0.107	0.059	0.104	0.000	0.132	0.137
2003	0.111	0.109	0.061	0.104	0.000	0.133	0.135
2004	0.113	0.111	0.063	0.104	0.000	0.135	0.136
2005	0.113	0.111	0.063	0.104	0.000	0.135	0.136
2006	0.114	0.112	0.063	0.104	0.000	0.136	0.137
2007	0.114	0.113	0.063	0.104	0.000	0.136	0.138
2008	0.116	0.114	0.064	0.104	0.000	0.138	0.140
2009	0.117	0.115	0.064	0.104	0.000	0.140	0.140
2010	0.118	0.116	0.065	0.104	0.000	0.140	0.141
2011	0.118	0.116	0.065	0.104	0.000	0.141	0.141
2012	0.119	0.117	0.065	0.104	0.000	0.141	0.141
Yield							
1999	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2000	17.3	17.0	8.9	16.7	0.0	21.5	17.3
2001	18.2	18.0	10.2	17.2	0.0	21.6	18.2
2002	17.3	17.1	10.4	16.7	0.0	19.8	21.7
2003	18.1	17.9	11.4	17.1	0.0	20.3	22.0
2004	19.5	19.3	12.5	18.0	0.0	21.8	23.1
2005	20.5	20.3	13.3	18.8	0.0	22.9	23.7
2006	21.4	21.2	14.0	19.5	0.0	23.8	24.4
2007	22.1	21.9	14.7	20.1	0.0	24.4	25.1
2008	23.0	22.8	15.4	20.8	0.0	25.3	25.9
2009	23.7	23.5	16.0	21.4	0.0	25.9	26.4
2010	24.2	24.0	16.5	21.8	0.0	26.4	26.7
2011	24.5	24.3	16.9	22.2	0.0	26.6	26.7
2012	24.8	24.6	17.3	22.5	0.0	26.8	26.7

Table 5.9.--Regional estimates of sablefish age-4+ biomass.

Year	Bering Sea	Aleutian Islands	Gulf of Alaska	Alaska
1979	35	38	124	198
1980	33	36	117	186
1981	47	67	167	281
1982	53	70	186	308
1983	56	66	206	329
1984	71	82	248	401
1985	81	96	265	443
1986	82	90	253	425
1987	79	80	241	400
1988	57	82	249	387
1989	43	65	239	347
1990	42	60	206	308
1991	35	44	184	262
1992	25	40	200	265
1993	20	33	184	237
1994	14	34	204	253
1995	17	32	190	239
1996	17	30	175	223
1997	18	24	166	208
1998	19	23	178	220
1999	20	31	182	234
2000	18	33	169	220

Appendix A.--The equations listed below were used to compile the fishery and survey data used in the assessment. Some notes about the data are: The strata for U.S. fisheries data are Bering, Aleutians, Western, Central, West Yakutat, East Yakutat / Southeast, but are coarser for the Japanese fisheries: Bering Sea and Aleutians combined and Western, Central, West Yakutat, East Yakutat / Southeast combined, i.e. Gulf of Alaska.

Fishery data

For all years, let

w_k = weight at length k,

A_m = Areal size of strata.

For each year, let

Y_m = catch in weight for strata m,

Y_{mn} = catch in weight for strata m and set n,

E_{mn} = effort in number of hooks for strata m and set n,

f_{km} = proportion for length k and strata m,

then

$U_m \equiv \frac{\sum_n Y_{mn}/E_{mn}}{N}$ = Catch per hook for strata m,

$RPW_m \equiv U_m A_m$ = Relative population weight for strata m,

$\overline{w}_m \equiv \sum_k f_{km} w_k$ = mean weight

$c_m \equiv y_m / \overline{w}_m$ = catch in number

$f_k \equiv \sum_m f_{km} c_m / \sum_m c_m$ = proportion at length for Alaska

Length frequencies by statistical area were used to “randomize” the earlier age collections and compute an age frequency representative of the area’s surveyed population (Kimura 1977). The age frequencies by area were weighted by the area RPN, then summed across area to obtain an RPN weighted age frequency for Alaska.

Appendix B.--The equations listed below were used to represent the sablefish population in Alaska.

Let i = 1, . . . y be the year index, and j = 1, . . . a be the age index. Let

c_i = the observed catch in numbers,
μ_i = the exploitation rate for fully vulnerable ages (i.e., ages for which s_j = 1),
s_j = the selectivity for age j fish such that the assumption of "separability" holds, i.e.,
$\mu_{ij} = \mu_i s_j$ = the exploitation fraction of age j fish during year i,
N_{ij} = the total number at age,

$N^f_{ij} = s_j N_{ij}$ = the fishable number at age, and

$N^f_i = \sum_{j=1}^{a} N^f_{ij}$ = the fishable number.

$U_{ij} = F_{ij} / (M + F_{ij})\ (1 - \exp(-M - F_{ij}))$ is the exploitation rate on age *j* fish in year *i*, assuming an instantaneous natural mortality rate of *M*. It follows that

$$N_{i+1,j+1} = N_{ij}\, e^{-M-F_{ij}}$$

and predicted catch would be $\hat{c}_{ij} = U_{ij} N_{ij}$.

A function which can describe either asymptotic or dome-shaped selectivity is the "exponential-logistic" function (Thompson 1994):

$$s_j = \left(\frac{1}{1-\gamma}\right)\left(\frac{1-\gamma}{\gamma}\right)^{\gamma}\left(\frac{e^{\beta\gamma(A_{50}-j)}}{1+e^{\beta(A_{50}-j)}}\right)$$

This function's advantages are that it automatically scales maximum vulnerability to 1.0, reduces to an asymptotic function of age as γ approaches zero, and A_{50} and β have biological meaning when $\gamma = 0$: A_{50} is the age where 50% of the population is vulnerable and β is the slope of the function at A_{50}.

We allowed A_{50} to vary with season length,

$$A^s_{50} = A_{50}\,\frac{1}{1+e^{-\beta(s-m_{50})}}$$

where *s* is season length in months, and A_{50}, β, and m_{50} are estimated.

A predicted abundance index in numbers is

$$\hat{S}_i = \hat{q}\hat{N}^f_i$$

where *q* is survey catchability and quantities predicted with the model are denoted with "hats." A predicted abundance index in weight is computed by multiplying the predicted abundance index in numbers by the predicted mean weight of the available population.

An ageing error matrix based on known-age otoliths (Heifetz et al 1999) was used to account for ageing error. Known-age otoliths were obtained in the following manner. Age-1+ sablefish have been tagged and released in nearshore waters of southeast Alaska annually since 1985. Otoliths sometimes were collectd with recoveries. These known-age fish were read in a blind test, where the age reader did not know the true age. The assigned ages were used to compute how often the true age was assigned, and if they differed, by how much. For example, of true age 3 fish, 0.15 were assigned age 2, 0.61 age 3, 0.23 age 4, and 0.01 age 5. The resultant matrix was used in the population model to convert predicted true age to predicted reader age. The known-age ageing error matrix was not available for last year's assessment and instead, age data were aggregated over several ages {2, 3, 4, 5, 6, 7, 8, 9-10, 11-15, 16+}, as suggested by Deriso et al. (1989) if errors are present in age compositions.

An age-length transition matrix also was calculated from the survey results, where l_{jk} = the probability that a fish sampled of age class *j* will be of length class *k*. The predicted length distributions are

$$\hat{f}_{ik} = \sum_{j} \hat{p}_{ij} l_{jk}$$

The length data were aggregated into 2-cm length classes by sex: {40-41, 42-43, . . . 98-99 cm fork length}.

Parameters can be estimated by assuming the probability distributions of the sampled abundnace indices, age, and length data are known. Fournier and Archibald (1982) suggested multinomial errors for age data and log-normal errors for catch data. Log-normal errors were assumed for the abundance indices and multinomial errors for the age and length data. The log-likelihood incorporating the sablefish data is (not all data is shown for brevity)

$$L = \sum_{ij} m_i p_{ij} \log \frac{\hat{p}_{ij}}{p_{ij}} + \sum_{ik} n_i f_{ik} \log \frac{\hat{f}_{ik}}{f_{ik}} - \frac{1}{2\sigma^2} \sum_{i} (\log(S_i) - \log(\hat{q}\hat{N}_i^f))^2$$

where m_i and n_i are the number of ages and lengths sampled in year *i* and σ^2 is the variance of the observed abundance index. Maximum likelihood estimates for the parameters can be found by maximizing *L*. As noted by Kimura (1989, 1990), reliability in the estimation process is improved if the log-parameters rather than parameters on the original scale are estimated. This makes the parameters more similar in magnitude, and probably reduces parameter-effects non-linearity (Ratkowsky 1983).

Data weighting

The variances of the age data and the survey index were estimated independently of the population modeling (Kimura 1977, Sigler and Fujioka 1988) and were used to weight the likelihood components of the population model. The estimated c.v. for the survey index is 0.05 and for the age data is 0.6. The effective sample size assuming a multinomial distribution was computed from the variance of the age data. Variances of the age and length data were assumed equal.

Appendix C.--Sablefish longline survey - fishery interactions, 1995-1999

NMFS has requested the assistance of the fishing fleet to avoid the annual sablefish longline survey since the inception of sablefish IFQ management in 1995. We requested that fishermen stay at least five nautical miles away from each survey station for 7 days before and 3 days after the planned sampling date (3 days allowed for survey delays). Beginning in 1999, we also revised the longline survey schedule to avoid the July 1 rockfish trawl fishery opening as well as other short, but less intense fisheries.

History of interactions

Publicity, the revised longline survey schedule, and fishermen cooperation have been effective at reducing trawl fishery interactions until 1999, when their number increased. The number of interactions fell in 1997, was zero in 1998, but increased in 1999. The increase was due to one trawler during a reopening of the rockfish fishery and 5 trawlers during the new pollock “C” season.

Distribution of the survey schedule to all IFQ permit holders, radio announcements from the survey vessel, and the threat of a regulatory rolling closure finally was effective at reducing the annual number of longline fishery interactions in 1999. The number of fishing vessels has been about 10 from 1995 to 1998, but decreased to 3 in 1999. Two of the vessels were captained by hired skippers, implying that future publicity should target these captains.

	Longline		Trawl		Total	
Year	Stations	Vessels	Stations	Vessels	Stations	Vessels
1995	8	7	9	15	17	22
1996	12	18	16	17	28	35
1997	8	8	8	7	16	15
1998	10	9	0	0	10	9
1999	3	3	2	6	5	9

Recommendation

We have followed several practical measures to alleviate fishery interactions with the survey. Trawl and longline fishery interactions generally have decreased, although trawl interactions increased in 1999. We will continue to work with association representatives and individual fishermen from the longline and trawl fleets to reduce fishery interactions and ensure accurate estimates of sablefish abundance.

Michael Sigler Alaska Fisheries Science Center 15 October 1999

Appendix D.--Research survey catches (kg) by survey type, 1977-1999.

Year	Echo integration trawl	Trawl	Japan US longline survey	Domestic longline survey	Total
1977		3,126			3,126
1978	23	14,302			14,325
1979		27,274	103,839		131,113
1980		69,738	114,055		183,793
1981	813	87,268	150,372		238,452
1982		107,898	239,696		347,595
1983	44	45,780	235,983		281,807
1984		127,432	284,431		411,864
1985		185,692	390,202		575,894
1986	80	123,419	395,851		519,350
1987		116,821	349,424		466,245
1988		14,570	389,382	302,670	706,622
1989		3,711	392,624	367,156	763,491
1990	94	25,835	272,274	366,236	664,439
1991		3,307	255,057	386,212	644,576
1992	168	10	281,380	392,607	674,165
1993	34	39,275	280,939	407,839	728,088
1994	65	852	270,793	395,443	667,153
1995				386,169	386,169
1996	0	12,686		426,479	439,165
1997	0	1,080		396,266	397,347
1998	5	25,528		310,564	336,096
1999		na		295,459	295,459

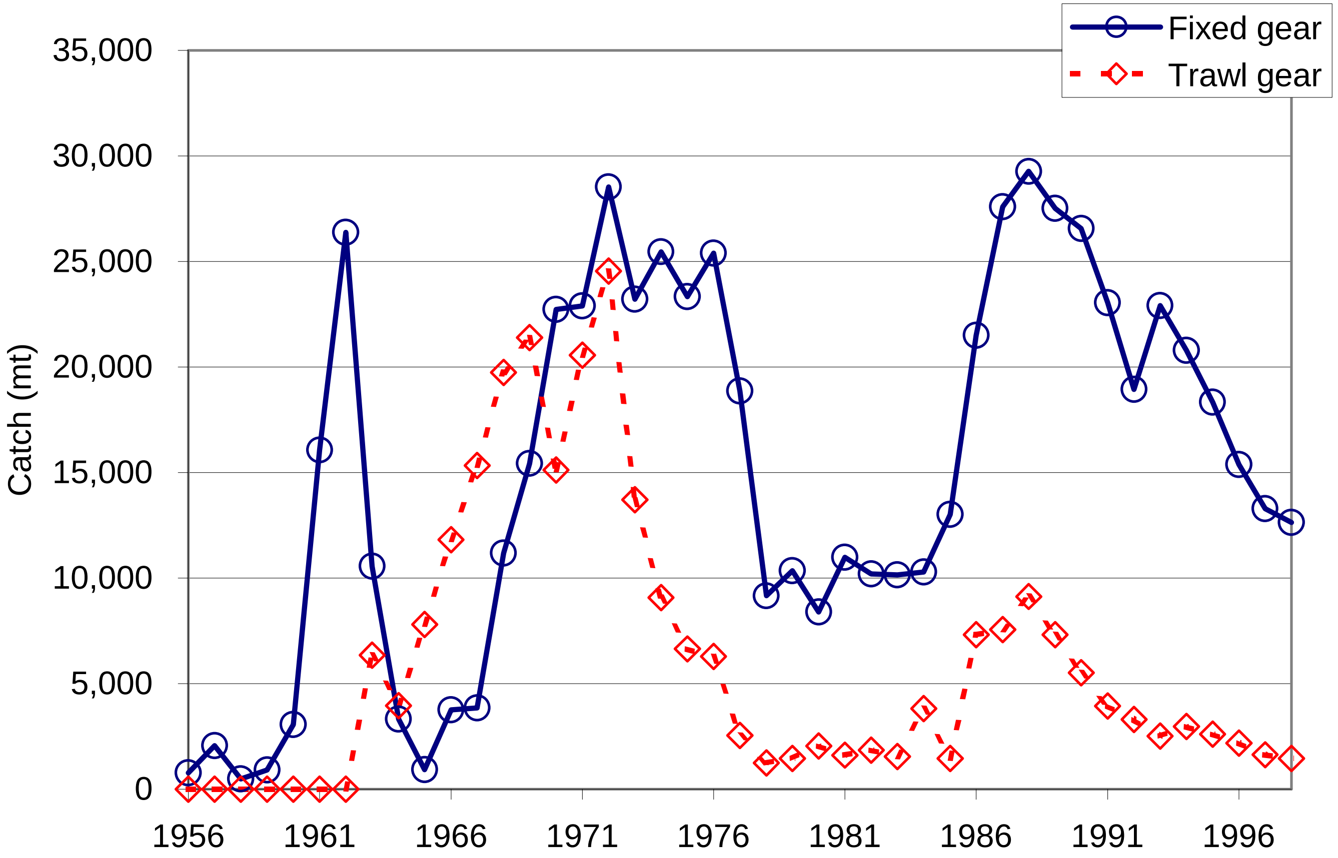

Figure 5.1--Sablefish fishery total reported catch (mt) by gear type and year.

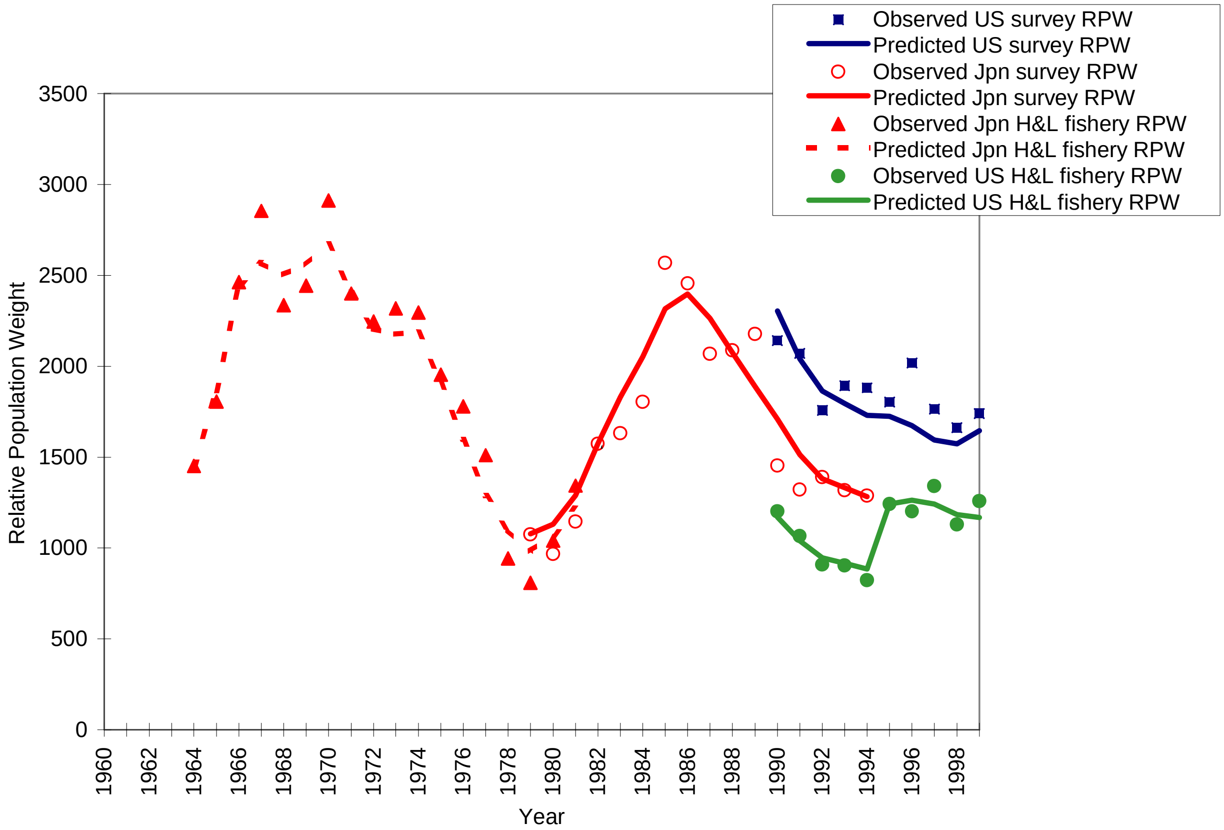

Figure 5.2.--Observed and predicted sablefish relative population weight versus year.

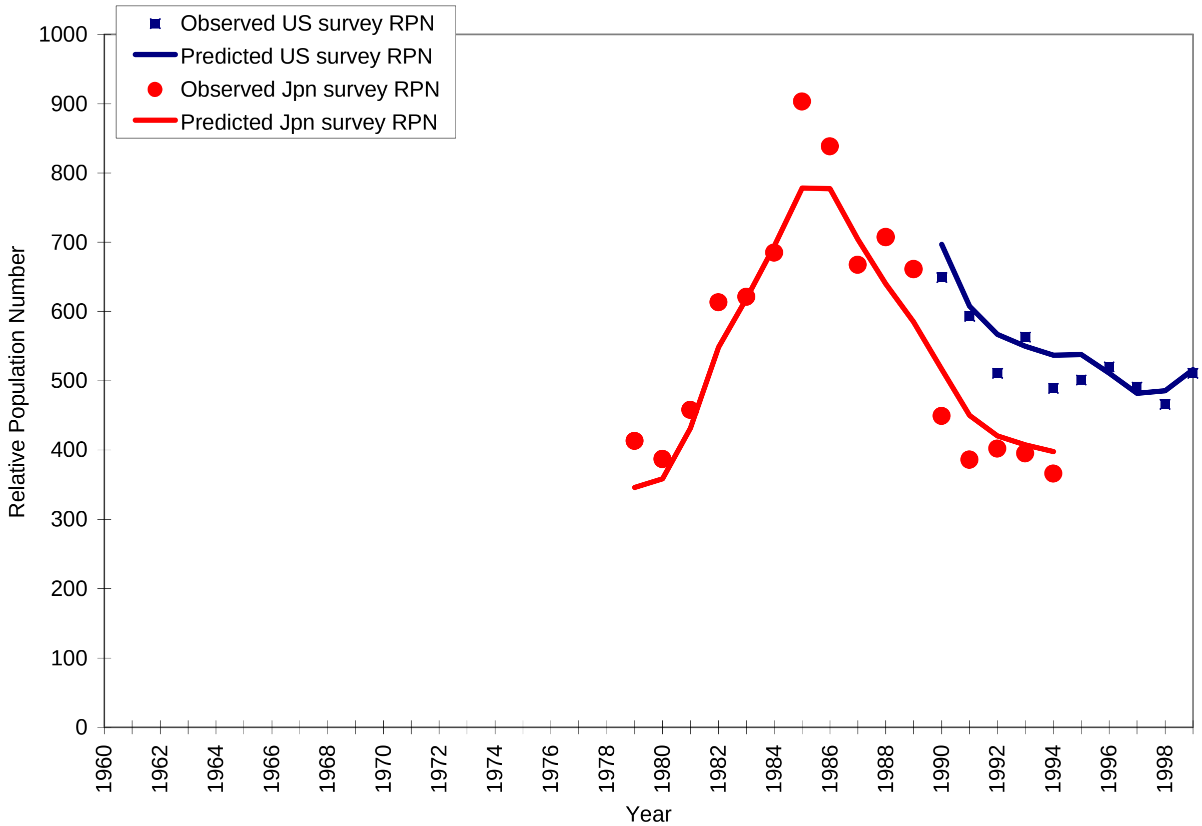

Figure 5.3.--Observed and predicted sablefish relative population number versus year.

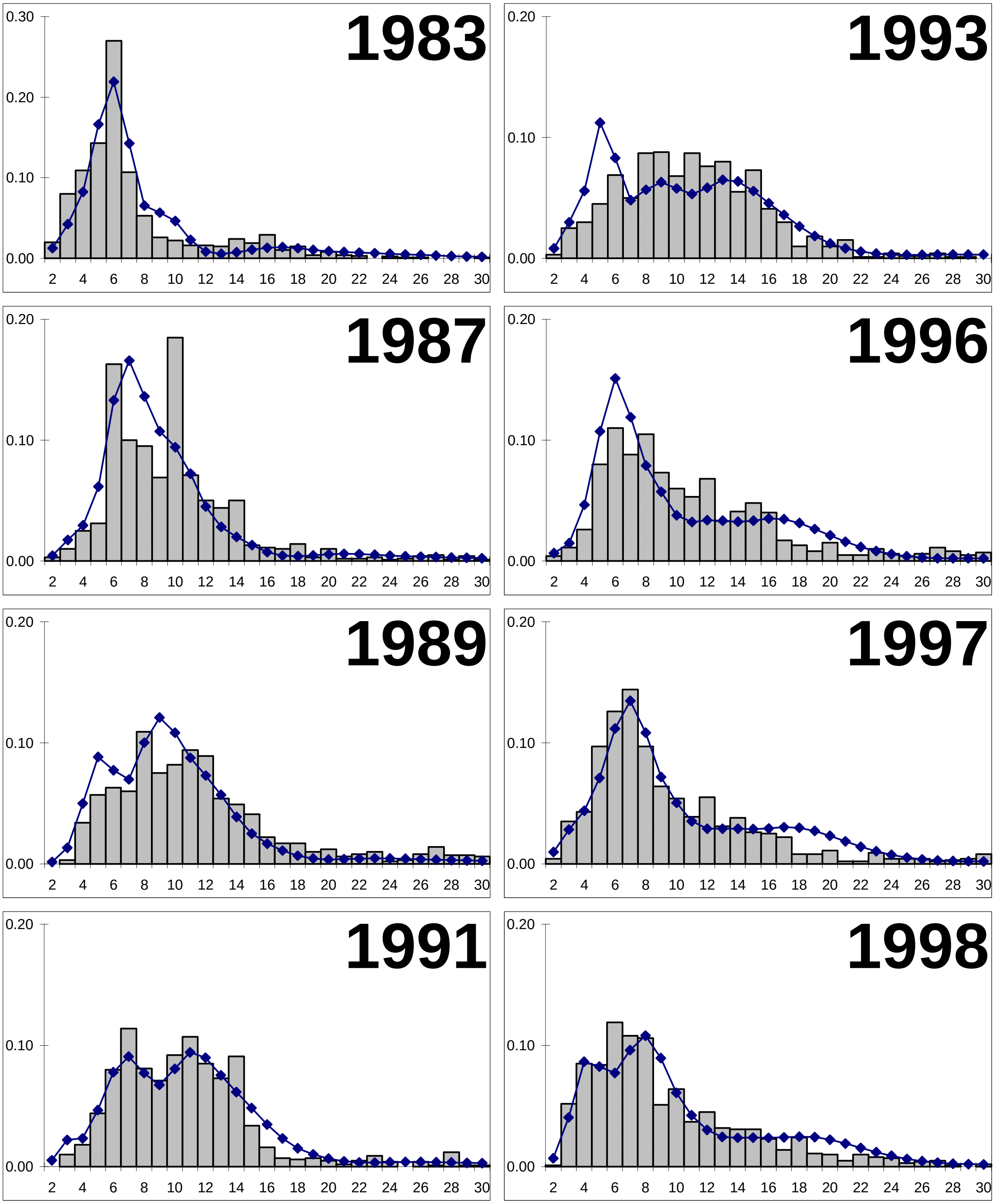

Figure 5.4 Observed (bar) and predicted (line) sablefish survey age frequency by age group and year.

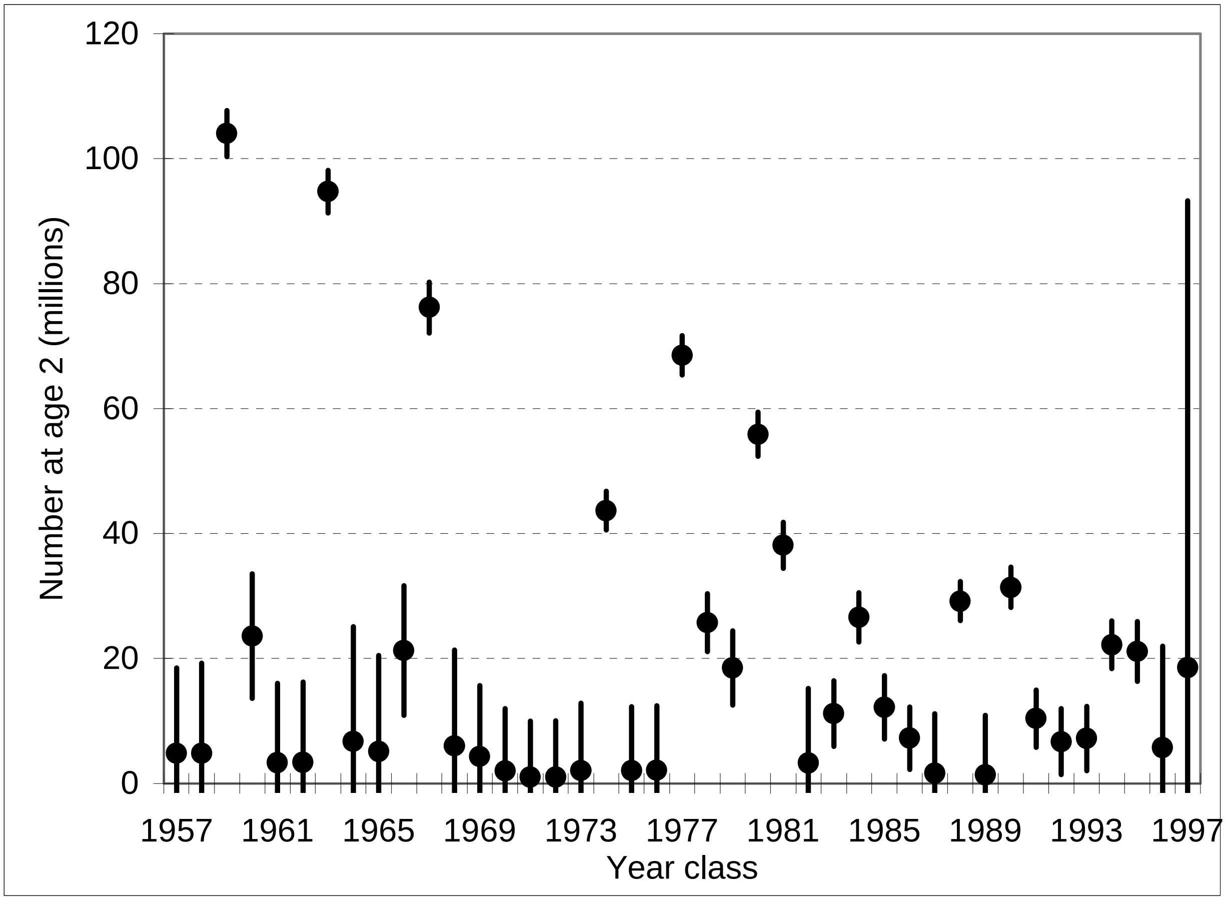

Figure 5.5 Model estimates of the number of age-2 sablefish (millions) +/- 2 standard errors by year class. Standard error estimates based on covariance matrix from age-structured model output. The variability estimates do not include variability of the independently estimated parameters, so the variability probably is underestimated.

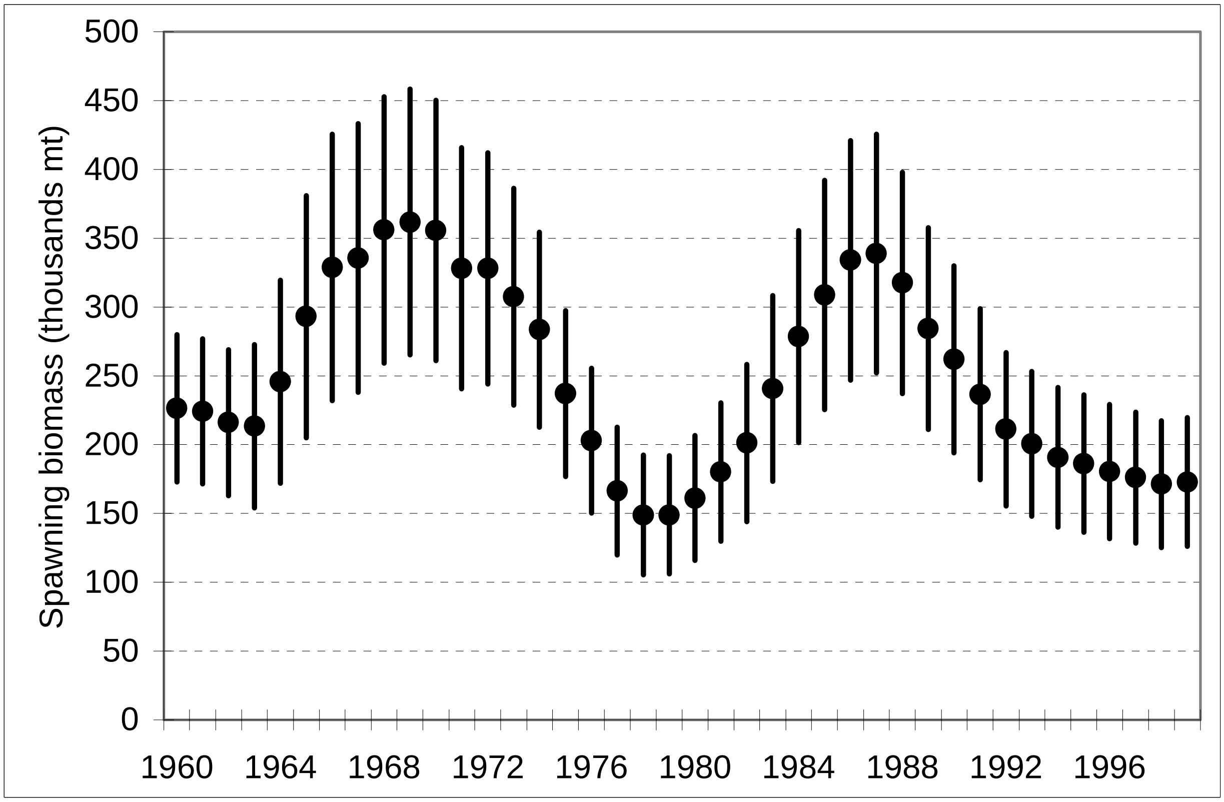

Figure 5.6 Model estimates of exploitable and male and female spawning biomass (thousands mt) +/- 2 standard errors by year. Standard error estimates based on covariance matrix from age-structured model output. The variability estimates do not include variability of the independently estimated parameters, so the variability probably is underestimated..

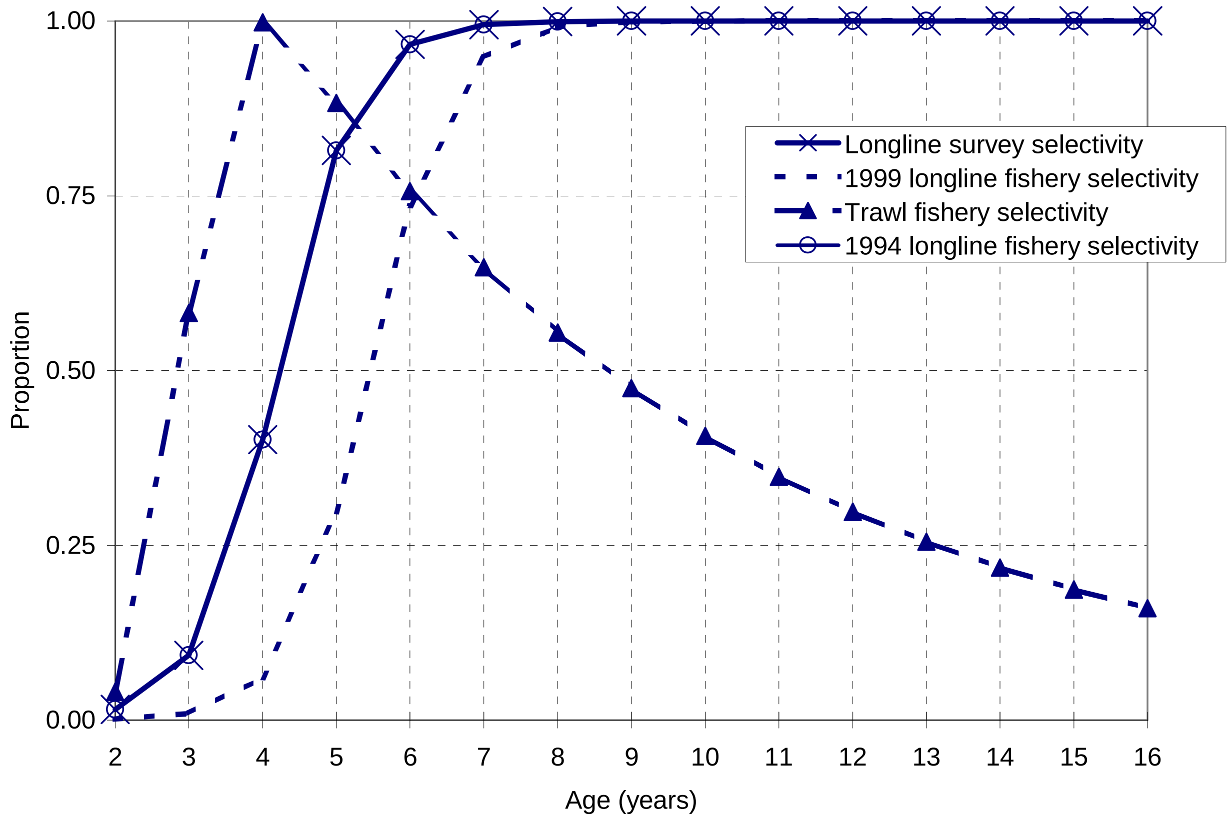

Figure 5.7 Sablefish survey, longline fishery, and trawl fishery selectivity functions. We chose to display the 1994 and 1999 longline selectivity functions because they are representative of the selectivity functions for the short open-access seasons ("derby" fishery) and IFQ seasons respectively.

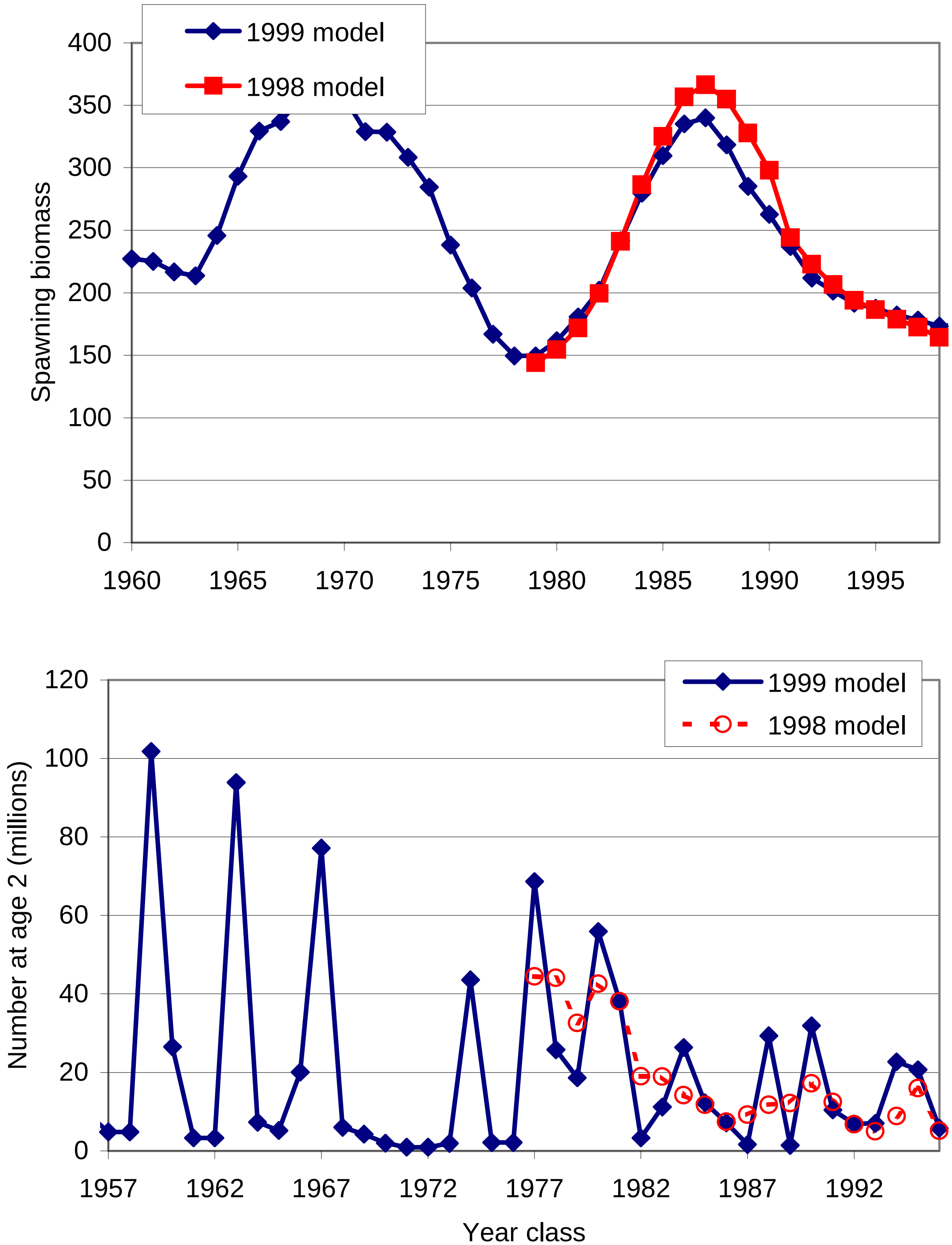

Figure 5.8 Estimated and projected sablefish spawning biomass (thousands mt) versus year and estimated recruitment (number at age 2, millions) for the 1998 and 1999 assessments.

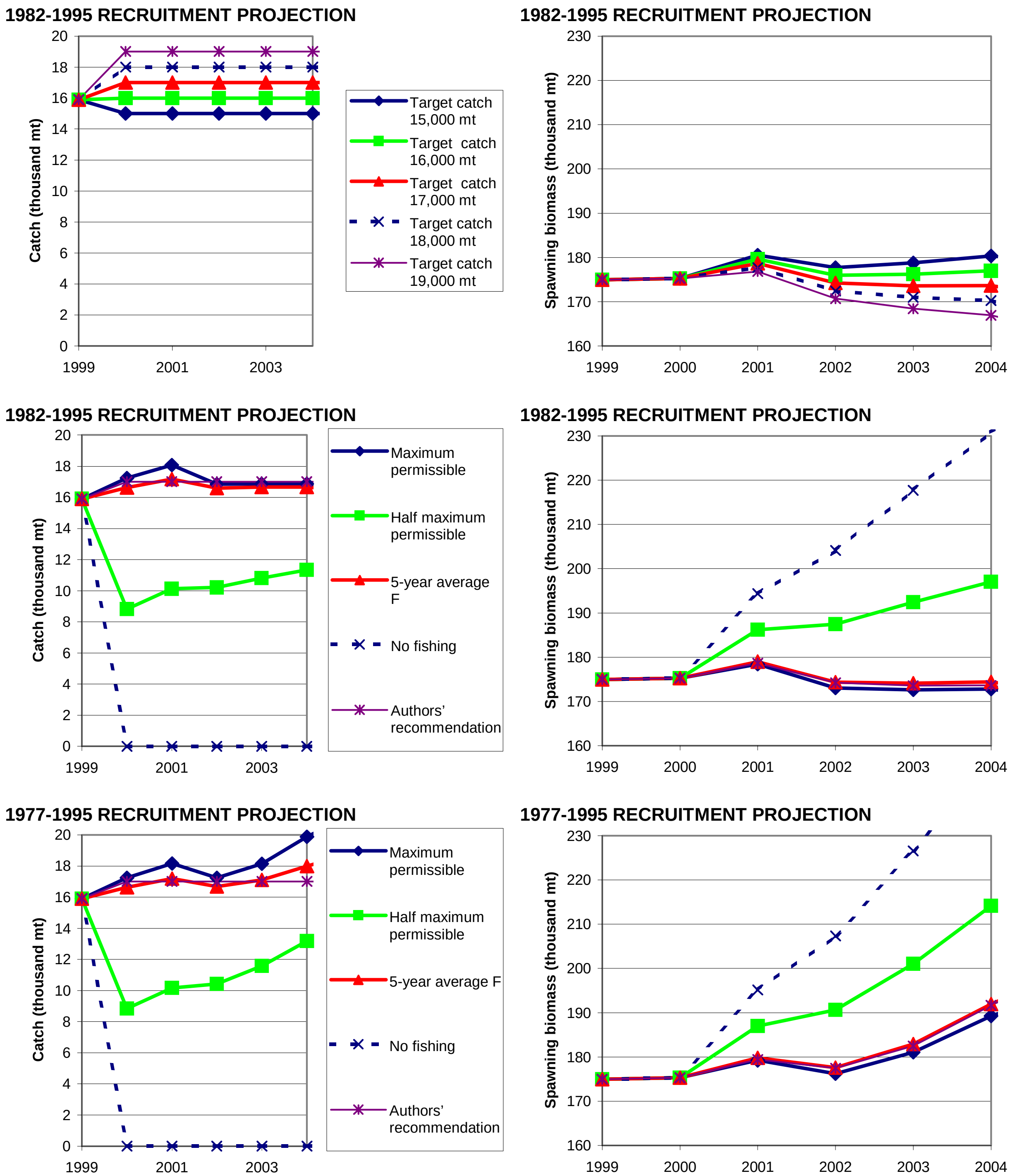

Figure 5.9--Sablefish spawning biomass and catch (thousands mt) for two recruitment scenarios and several harvest alternatives. Recruitment is projected using average recruitment for the 1982-1995 year classes or for the 1977-1995 year classes, which includes the exceptional 1977-1981 year classes. The harvest alternatives are described in section 5.1, *Sablefish-specific population projections* and *Standard set of population projections*. The authors' recommended ABC is 17,000 mt.

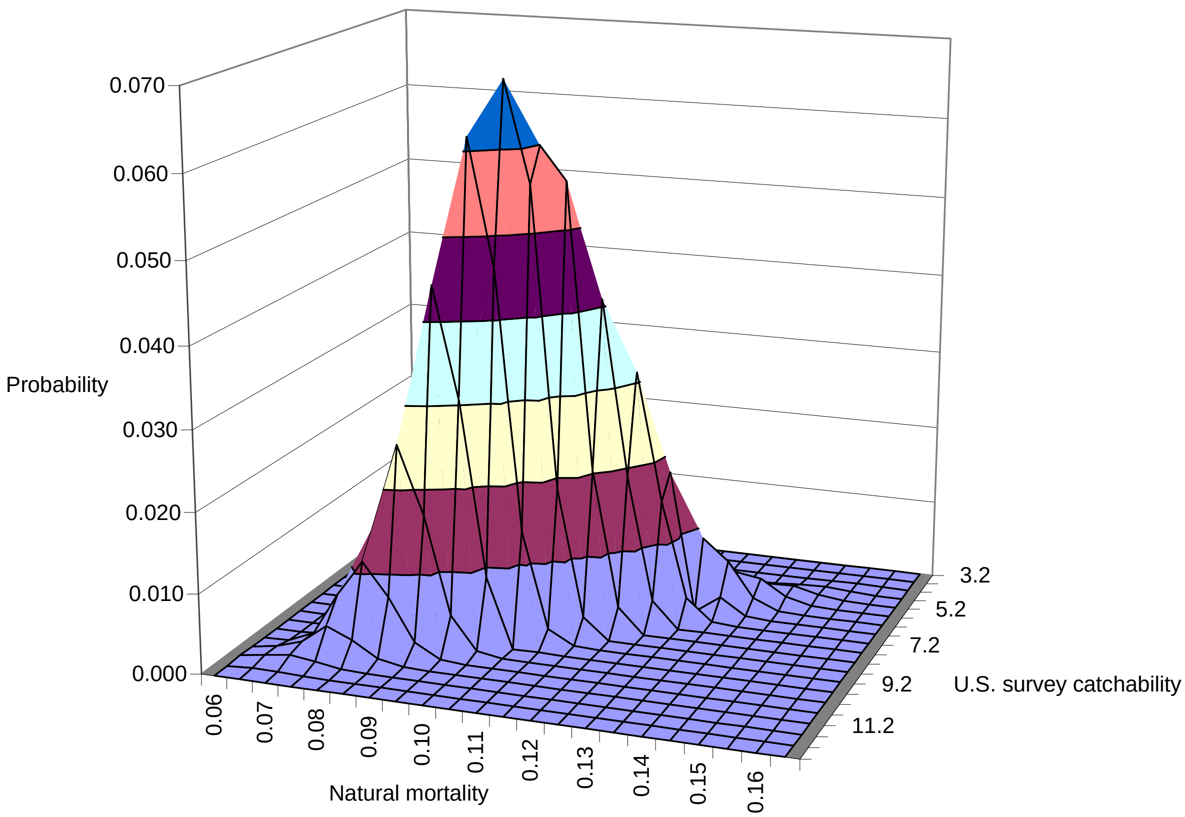

Figure 5.10.--Posterior probability versus catchability and natural mortality.

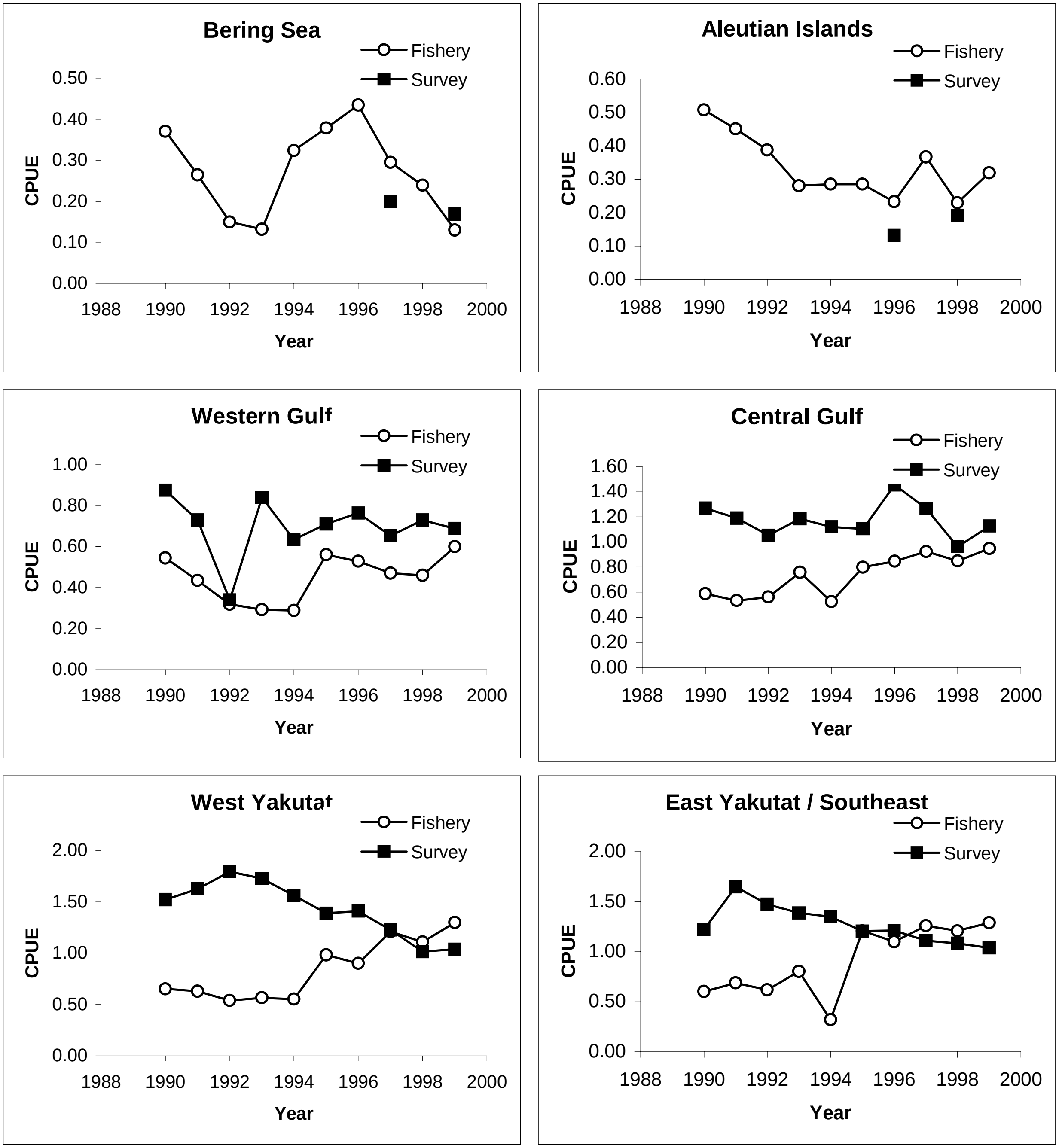

Figure 5.11.--Fishery and survey catch (round pounds) per hook. Both catch rates are standardized to 1-m spacing, the most common spacing used during directed longline fishing for sablefish.