Chapter 4

YELLOWFIN SOLE

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2003 SAFE:

Changes to the input data

1) 2003fishery age composition.
2) 2003 survey age composition.
3) 2004 trawl survey biomass point estimate and standard error.
4) Estimate of the discarded and retained portions of the 2003 catch.
5) Estimate of total catch through 4 September 2004.

Assessment results

1) The projected age 2+ total biomass for 2004 is 1,557,900 t.
2) The projected female spawning biomass for 2005 is 494,400 t.
3) The recommended 2005 ABC is 124,300 t based on an $F_{40\%}$ (0.114) harvest level.
4) The 2005 overfishing level is 147,500 t based on an $F_{35\%}$ (0.137) harvest level.

SUMMARY

	2004 Assessment Recommendations for 2005 harvest	2003 Assessment Recommendations For 2004 harvest
Total biomass	1,557,900 t	1,557,200 t
ABC	124,300 t	113,500 t
Overfishing yield	147,500 t	134,700 t
F_{ABC}	$F_{0.40} = 0.114$	$F_{0.40} = 0.115$
$F_{overfishing}$	$F_{0.35} = 0.137$	$F_{0.35} = 0.138$

INTRODUCTION

The yellowfin sole (Limanda aspera) is one of the most abundant flatfish species in the eastern Bering Sea (EBS) and is the target of the largest flatfish fishery in the United States. They inhabit the EBS shelf and are considered one stock. Abundance in the Aleutian Islands region is negligible.

Yellowfin sole are distributed in North American waters from off British Columbia, Canada, (approx. lat. 49° N) to the Chukchi Sea (about lat. 70° N) and south along the Asian coast to about lat. 35° N off the South Korean coast in the Sea of Japan. Adults exhibit a benthic lifestyle and occupy separate winter, spawning and summertime feeding distributions on the eastern Bering Sea shelf. From over-winter grounds near the shelf margins, adults begin a migration onto the inner shelf in April or early May each year for spawning and feeding. The directed fishery typically occurs from spring through December.

CATCH HISTORY

Yellowfin sole have annually been caught with bottom trawls on the Bering Sea shelf since the fishery began in 1954. The catch locations of vessels targeting on yellowfin sole in 2003, by quarter, are shown in the Appendix figures. The total catch (t) since implementation of the MFCMA in 1977 are shown in Table 4.1.

Yellowfin sole were overexploited by foreign fisheries in 1959-62 when catches averaged 404,000 t annually (Fig. 4.1). As a result of reduced stock abundance, catches declined to an annual average of 117,800 t from 1963-71 and further declined to an annual average of 50,700 t from 1972-77. The lower yield in this latter period was partially due to the discontinuation of the U.S.S.R. fishery. In the early 1980s, after the stock condition had improved, catches again increased reaching a recent peak of over 227,000 t in 1985.

During the 1980s, there was also a major transition in the characteristics of the fishery. Yellowfin sole were traditionally taken exclusively by foreign fisheries and these fisheries continued to dominate through 1984. However, U.S. fisheries developed rapidly during the 1980s in the form of joint ventures, and during the last half of the decade began to dominate and then take all of the catch as the foreign fisheries were phased out of the EBS. Since 1990, only domestic harvesting and processing has occurred.

The 1997 catch of 181,389 t was the largest since the fishery became completely domestic and then declined to 101,201 t in 1998. The 2003 catch totaled 74,418 t and 68,543 t have been caught in 2004 through 4 September. Thus far, the 2004 catch is 60% of the ABC and 86% of the TAC. The yellowfin sole directed harvest in 2004 was closed on June 4 to prevent the attainment of the 2004 TAC of 86,075. The size composition of the 2003 catch for both males and females, from observer sampling, are shown in Figure 4.1.

The catch information presented above also includes yellowfin sole which were discarded in domestic fisheries since their beginning in 1987. Annual discard estimates are calculated from at-sea sampling for 1987-2003 as follows:

Year	Retained	Discards

1987	3	1
1988	7,559	2,274
1989	1,279	385
1990	10,093	4,200
1991	89,054	26,788
1992	103,989	45,580
1993	76,798	26,838
1994	107,629	36,948
1995	96,718	28,022
1996	101,324	28,334
1997	149,570	31,818
1998	80,365	20,836
1999	55,202	12,118
2000	69,788	14,062
2001	54,759	8,635
2002	62,050	10,950
2003	63,732	10,686

The rate of discard has ranged from a low of 14% of the total catch in 2001 to 30% in 1992. The trend has been toward fuller retention of the catch in recent years Discarding primarily occurs in the yellowfin sole directed fishery, with lesser amounts in the Pacific cod, rock sole, flathead sole, and 'other flatfish' fisheries (Table 4.2).

DATA

The data used in this assessment include estimates of total catch, bottom trawl survey biomass estimates and their attendant 95% confidence intervals, catch-at-age from the fishery and population age composition estimates from the bottom trawl survey. Weight-at-age and proportion mature-at-age are also available from studies conducted during the bottom trawl surveys.

Fishery Catch and Catch-at-Age

This assessment uses fishery catch data from 1955- September 4 2004 (Table 4.1) and fishery catch-at-age (numbers) from 1964-2003 (Table 4.3, 1977-2003).

Survey Biomass Estimates and Population Age Composition Estimates

The survey estimates of population numbers-at-age from 1975 and 1979-2003 are used in the assessment model and are shown for 1982-2003 in Table 4.4. Biomass (t) estimates from AFSC surveys conducted in a standardized area of the EBS encompassing waters from 20 to 200 m and from the Alaska Peninsula north to a latitude of St. Matthew and Nunivak Islands are given below:

	Age Groups			95% confidence Interval
Year	0-6	7 plus	Total	of Total
1975	169,500	803,000	972,500	812,300 - 1,132,700
1979	211,500	1,655,000	1,866,500	1,586,000 - 2,147,100
1980	235,900	1,606,500	1,842,400	1,553,200 - 2,131,700
1981	343,200	2,051,500	2,394,700	2,072,900 - 2,716,500
1982	685,700	2,692,100	3,377,800	2,571,000 - 4,184,600
1983	198,000	3,337,300	3,535,300	2,958,100 - 4,112,400
1984	172,800	2,968,400	3,141,200	2,636,800 - 3,645,600
1985	166,200	2,277,500	2,443,700	1,563,400 - 3,324,000
1986	80,200	1,829,700	1,909,900	1,480,700 - 2,339,000
1987	125,500	2,487,600	2,613,100	2,051,800 - 3,174,400
1988	45,600	2,356,800	2,402,400	1,808,400 - 2,996,300
1989	196,900	2,119,400	2,316,300	1,836,700 - 2,795,800
1990	69,600	2,114,200	2,183,800	1,886,200 - 2,479,400
1991	60,000	2,333,300	2,393,300	2,116,000 - 2,670,700
1992	145,900	2,027,000	2,172,900	*
1993	188,200	2,277,200	2,465,400	2,151,500 - 2,779,300
1994	142,000	2,468,500	2,610,500	2,266,800 - 2,954,100
1995	213,000	1,796,700	2,009,700	1,724,800 - 2,294,600
1996	161,600	2,137,000	2,298,600	1,749,900 - 2,847,300
1997	239,330	1,924,070	2,163,400	1,907,900 - 2,418,900
1998	150,756	2,178,844	2,329,600	2,033,130 - 2,626,070
1999	57,700	1,246,770	1,306,470	1,118,800 - 1,494,150
2000	73,200	1,508,700	1,581,900	1,382,000 - 1,781,800
2001	135,900	1,727,800	1,863,700	1,605,000 - 2,122,300
2002	83,200	1,933,500	2,016,700	1,740,700 – 2,292,700
2003	2,900	2,236,700	2,239,600	1,822,700 – 2,656,600
2004			2,530,600	2,147,900 – 2,913,300

* 95% confidence intervals cannot be calculated for 1992 since the total estimate includes an unsampled area for which a 3 year average was used as a proxy.

Estimates are given separately for unexploited ages (less than age 7) and exploited ages (ages 7 and older) except for 2004 where age data are not yet available. The data show a doubling of biomass between 1975 and 1979 with a further increase to over 2.3 million t in 1981 for the exploitable portion of the population. Survey abundance estimates fluctuated erratically from 1981 to 1990 with biomass ranging from as high as 3.5 million t in 1983 to as low as 1.9 million t in 1986. Biomass estimates since 1990 indicate an even trend at high levels of abundance for yellowfin sole, with the exception of the results from the 1999 and 2000 summer surveys, which were at lower levels.

Indices of relative abundance available from AFSC surveys have also shown a major increase in the abundance of yellowfin sole during the late 1970s increasing from 21 kg/ha in 1975 to 51 kg/ha in 1981 (Fig. 4.2, Bakkala and Wilderbuer 1990). These increases have also been documented through Japanese commercial pair trawl data and catch-at-age modeling in past assessments (Bakkala and Wilderbuer 1990).

Since 1981, the survey CPUEs have fluctuated widely. For example, they increased from 51 kg/ha in 1981 to 84 kg/ha in 1983 and then declined sharply to 49 kg/ha in 1985. They continued to fluctuate from 1986-90, although with less amplitude (Fig 4.2). From 1990-1998, the estimated CPUE was relatively stable but have declined the past two years. Fluctuations of the magnitude shown between 1980 and 1990 and again between 1998 and 1999 are unreasonable considering the combined elements of slow growth and long life span of yellowfin sole and low exploitation rate, characteristics which should produce more gradual changes in abundance.

Variability of yellowfin sole survey abundance estimates (Fig. 4.3) is in part due to the availability of yellowfin sole to the survey area (Nichol, 1998). Yellowfin sole are known to undergo annual migrations from wintering areas off the shelf-slope break to nearshore waters where they spawn throughout the spring and summer months (Nichol, 1995; Wakabayashi, 1989; Wilderbuer et al., 1992). Exploratory survey sampling in coastal waters of the eastern Bering Sea indicate that yellowfin sole concentrations can be greater in these shallower areas not covered by the standard AFSC survey. Commercial bottom trawlers have commonly found high concentrations of yellowfin sole in areas such as near Togiak Bay (Low and Narita, 1990) and in more recent years from Kuskokwim Bay to just south of Nunivak Island. The coastline areas are sufficiently large enough to offer a substantial refuge for yellowfin sole from the current survey.

Over the past 15 years survey biomass estimates for yellowfin sole have shown a positive correlation with shelf bottom temperatures (Nichol, 1998); estimates have been low during cold years. The 1999 survey, which was conducted in exceptionally cold waters, indicated a biomass estimate that was unrealistically low. The bottom temperatures during the 2000 survey were much warmer than in 1999, and the biomass increased, but still did not approach estimates from earlier years. Average bottom temperature and biomass both increased again in 2001 – 2003, with the 2003 value the highest observed over the 22 year time series. Given that both 1999 and 2000 surveys were conducted two weeks earlier than previous surveys, it is possible that the time difference may also have affected the availability of yellowfin sole to the survey. If, for example, the timing of peak yellowfin sole spawning in nearshore waters corresponded to the time of the survey, a greater proportion of the population would be unavailable to the standard survey area.

We propose two possible reasons why survey biomass estimates are lower during years when bottom temperatures are low. First, catchability may be lower because yellowfin sole may be less active when temperatures are low. Less active fish may be less susceptible to herding, and escapement under the footrope of survey gear may increase if fish are less active. Secondly, bottom temperatures may influence the timing of the inshore spawning migrations of yellowfin sole and therefore affect their availability to the survey area. Because yellowfin sole spawning grounds include nearshore areas outside the survey area, availability of fish within the survey area can vary with the timing of this migration and the timing of the survey. As was the case in 2000, greater than average catches along the survey border outside of Kuskowkim bay may indicate that a significant portion of the biomass lies outside this border (Fig 4.4).

Length and Weight-at-Age and Maturity-at-Age

Parameters of the von Bertalanffy growth curve for yellowfin sole from 12 years of combined data have been estimated as follows:

age range	L_{inf} (cm)	K	t_0
3-26	35.8	0.147	0.47

Mean lengths and weights at age of yellowfin sole based on 12 years (1979-90) of data from AFSC surveys and the length (cm) – weight (g) relationship (W = 0.0097217 * L ** 3.0564) are as follows:

	Length		Weight	
Age	cm	in	g	lb
3	11.1	4.4	15.31	0.03
4	14.5	5.7	34.41	0.08
5	17.4	6.9	60.23	1.13
6	19.9	7.8	90.97	0.20
7	22.1	8.7	124.80	0.27
8	24.0	9.4	160.07	0.35
9	25.6	10.1	195.44	0.43
10	27.0	10.6	229.92	0.51
11	28.2	11.1	262.79	0.58
12	29.2	11.5	293.59	0.65
13	30.1	11.9	322.06	0.71
14	30.9	12.2	348.09	0.77
15	31.6	12.4	371.67	0.82
16	32.1	12.6	392.87	0.87
17	32.6	12.8	411.81	0.91
18	33.1	13.0	428.65	0.94
19	33.5	13.2	443.55	0.98
20	33.8	13.3	456.69	1.01
21	34.0	13.4	468.25	1.03
22	34.3	13.5	478.38	1.05
23	34.5	13.6	487.24	1.07
24	34.7	13.7	494.99	1.09
25	34.8	13.7	501.74	1.11
26	34.9	13.7	507.61	1.12

Changes in length and weight at age over time has been documented for Bering Sea rock sole (Walters and Wilderbuer 2000) and Bering Sea and Gulf of Alaska Pacific halibut (Clark et al 1999). We examined our assumption of time invariant growth in length and weight of yellowfin sole by comparing the weight and length at age from fish collected during the 1987, 1994, 1999, 2000 and 2001 surveys (Fig. 4.5). Over the age range of 4 to 14 years (fish ageing > 14 years has more error and smaller sample sizes) there are only small differences in length and weight at age from 1987 to 2001. Largest annual differences in weight at age were found in 1999 (a cold year) which were not present in the same cohorts in 2001 (a warmer year). These differences seem to be more related to annual metabolic rate than a shift in population-wide growth. Based on these findings, we concluded that use of a single weight at age vector was justified for this assessment.

Maturity information collected from yellowfin sole females during the 1992 and 1993 eastern Bering Sea trawl surveys is used in this assessment (Table 4.5). Nichol (1994) estimated the age of 50% maturity at 10.5 years based on the histological examination of 639 ovaries. In the case of most north Pacific flatfish species, including yellowfin sole, sexual maturity occurs well after the age of entry into the fishery. Yellowfin sole are 90% selected to the fishery by age 11 but females have been found to be only 50% mature at this age.

ANALYTIC APPROACH

Model Structure

The abundance, mortality, recruitment and selectivity of yellowfin sole were assessed with a stock assessment model using the AD Model builder language (Ianelli and Fournier 1998). The conceptual model is similar to that implemented in the stock synthesis program (Methot 1990, Fournier and Archibald 1982). The model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information. The assessment model simulates the dynamics of the population and compares the expected values of the population characteristics to the characteristics observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics is optimized by maximizing a log(likelihood) function.

The suite of parameters estimated by the model are classified by three likelihood components:

Data component	**Distributional assumption**
Trawl fishery catch-at-age	Multinomial
Trawl survey population age composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component (Table 4.6). The likelihood components may be weighted by an emphasis factor, however, equal emphasis was placed on fitting each likelihood component in the yellowfin sole assessment except for the catch. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library). Table 4.6 presents the key equations used to model the yellowfin sole population dynamics in the Bering Sea and Table 4.7 provides a description of the variables used in Table 4.6.

Sharp increases in trawl survey abundance estimates for most species of Bering Sea flatfish between 1981 and 1982 indicate that the 83-112 trawl was more efficient for capturing these species than the 400-mesh eastern trawl used in 1975, and 1979-81. Allowing the model to tune to these early survey estimates would most likely underestimate the true pre-1982 biomass, thus exaggerating the degree to which biomass increased during that period. Although this underestimate would have little effect on the estimate of current yellowfin sole biomass, it would affect the spawner and recruitment estimates for the time-series. Hence, the pre-1982 survey biomass estimates were omitted from the analysis.

The model of yellowfin sole population dynamics was evaluated with respect to the observations of the time-series of survey and fishery age compositions and the survey biomass trend since 1982.

Parameters Estimated Independently

Natural mortality (M) was initially estimated by a least squares analysis. Catch-at-age data were fitted to Japanese pair trawl effort data while varying the catchability coefficient (q) and M simultaneously. The best fit to the data (the point where the residual variance was minimized) produced a M value of 0.12 (Bakkala and Wespestad 1984). This was also the value which provided the best fit to the observable population characteristics when M was profiled over a range of values in the stock assessment model (Wilderbuer 1992). Thus, a natural mortality value of 0.12 is used in this assessment.

Yellowfin sole maturity schedules were estimated from in situ observations as discussed in a previous section (Table 4.5).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Survey catchability	Year class strength	Spawner recruit	Total
51	4	2	70	2	129

The increase in the number of parameters estimated in this assessment compared to last year can be accounted for by the input of another year of fishery data, the entry of another year class into the observed population and fitting a spawner-recruit model.

Year class strengths

The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it moves through the population over time using the population dynamics equations given in Table 4.6.

Selectivity

Fishery and survey selectivity was modeled in this assessment using the two parameter formulation of the logistic function, as shown in Table 4.6. The model was run with an asymptotic selectivity curve for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years.

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis was placed on the catch likelihood component.

Survey Catchability

A past assessment (Wilderbuer and Nichol 2001) first examined the relationship between estimates of survey biomass and bottom water temperature. To better understand how water temperature may affect the catchability of yellowfin sole to the survey trawl, catchability was estimated for each year in the stock assessment model as:

$$q = e^{\alpha+\beta T}$$

where q is catchability, T is the average annual bottom water temperature anomaly at survey stations less than 100 m, and -α and β are parameters estimated by the model. The result of the linear fit to bottom temperature vs. estimated q is shown in Figure 4.6.

Spawner-Recruit Estimation

Annual recruitment estimates were constrained to fit a Ricker (1958) form of the stock recruitment relationship as follows:

$$R = \alpha S e^{-\beta S}$$

where R is age 1 recruitment, S is female spawning biomass (t) the previous year, and α and β are parameters estimated by the model. The spawner-recruit fitting is estimated in a later phase after initial estimates of survival, numbers-at-age and selectivity are obtained.

Model Evaluation

Three models were evaluated in last year's assessment: 1) survey catchability = 1.0; 2) a single value of survey catchability was estimated for the entire time series; and 3) survey catchability modeled as a linear function of average bottom water temperature at stations less than or equal to 100 m depth. The likelihood profile of q from the 3rd model indicated a small variance with a narrow range of likely values. The probability of q being as low or lower than the value of 1.0

assumed in the first model, given the data, appears to be very low. In addition, supporting evidence from experiments examining the bridle efficiency of the Bering Sea survey trawl indicate that yellowfin sole are herded into the trawl path from an area between the wing tips of the net and the point where the bridles contact the seafloor (Somerton and Munro 2001) indicating that the survey trawl catchability is greater than 1.0. Thus the model of choice for this assessment, as last year, is the model which estimates an annual q by considering average bottom water temperature because it provides a significantly better fit to the data overall, and because the value of 1.0 for q no longer appears realistic.

MODEL RESULTS

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages are given in Table 4.8. The full-selection F has averaged 0.1 over the period of 1977-2003 with a maximum of 0.14 in 1997 and a minimum in 2001 at 0.05. Selectivities estimated by the model (Table 4.9, Figure 4.7) indicate that yellowfin sole are 50% selected by the fishery at age 9 and nearly fully selected by age 13.

Abundance Trend

The model estimates q at an average value of 1.27 for the period 1982-2004 which results in the model estimate of the 2004 total biomass at 1,601,460 t (Table 4.10). Model results indicate that yellowfin sole total biomass (age 2+) was at low levels during most of the 1960s and early 1970s (600,000-800,000 t) after a period of high exploitation (Table 4.10, Figure 4.7, bottom left panel). Sustained above average recruitment from 1967-76 combined with light exploitation resulted in a biomass increase to a peak of 2.6 million t by 1985. The population biomass has since been in a slow decline as the strong 1981 and 1983 year-classes have passed through the population with only the 1991 and 1995 year classes at levels observed during the 1970s. Over the past fifteen years stock biomass has declined nearly 1 million t since the peak biomass observed in 1985 (61% of the peak level).

The female spawning biomass has also steadily declined since the peak in 1985, with a 2004 estimate of 540,650 t (24% decline). This level of spawning biomass is consistent with the estimates since 1999 and is about 140% of the $B_{40\%}$ level (Fig. 4.8). The model estimate of yellowfin sole population numbers at age for all years is shown in Table 4.11 and the resulting fit to all the observed fishery and survey age compositions input into the model are shown in the Appendix. The fit to the trawl survey biomass estimates are shown in Figure 4.7. Allowing q to be correlated with annual bottom temperature provides a better fit to the bottom trawl survey estimates.

Both the trawl survey and the stock assessment model indicate that the yellowfin sole resource slowly increased during the 1970s and early 1980s to a peak level during the mid-1980s and that the resource has been in a slow, consistent decline since then (Figure 4.7). Above average recruitment from the 1991 and 1995 year-classes is expected to maintain the abundance of yellowfin sole at a level above B_{40} in the near future. The stock assessment projection model (later section) indicates a continued slow decline in female spawning biomass in the near future if the fishing mortality rate continues at the same level as the average of the past 5 years.

Total Biomass

The stock assessment model estimate of total biomass (begin year population numbers multiplied by mid-year weight at age) is used to recommend the ABC for 2005. Including the 2004 reported catch through 4 September (including discards), the model projects the total biomass for 2005 at **1,557,900 t**.

Recruitment Trends

The primary reason for the sustained increase in abundance of yellowfin sole during the 1970s and early 1980s was the recruitment of a series of stronger than average year classes spawned in 1967-76 (Figure 4.9 and Table 4.12). The 1981 year class was the strongest observed (and estimated) during the 46 year period analyzed and the 1983 year class was also very strong. Survey age composition estimates and the assessment model also estimate that the 1987 and 1988 year classes were average and the 1991 and 1995 year classes are strong. With the exception of these 4 year classes, recruitment from 12 of the last 16 years estimated (since the strong 1983 year-class) has been below the 48 year average, which has caused the population decline. The 1995 year-class will be at the maximum of their cohort biomass in 2005 and should contribute to the mature adult reservoir of spawners in future years.

Tier 1 Considerations

The SSC has requested that flatfish assessments which have a lengthy time-series of stock and recruitment estimates explore management under a Tier 1 harvest policy. In the case of yellowfin sole, we have a lengthy time series of 45 years. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit data which we assume represents the equilibrium stock size-recruitment relationship and the model used to fit the data. In the stock assessment model used here, a Ricker form of the stock-recruit relationship was fit to these data and estimates of F_{MSY} and B_{MSY} were calculated, assuming that the fit to the stock-recruitment data points represent the long-term productivity of the stock. However, very different estimates of F_{MSY} and B_{MSY} were obtained, depending on which years of stock-recruitment data points were included in the fitting procedure (Fig. 4.10). When we fit the entire time-series from 1954-1999, we include large recruitments that occurred at a low spawning stock size in the 1960s and early 1970s which indicate a productive stock that is able to replace itself quite well at low stock sizes. Therefore, MSY and F_{MSY} are relatively high values (217,000 t and 0.37, respectively) and B_{MSY} is 208,800 t. If we limit the data to consider only recruitments which occurred after the well-documented regime shift in 1977, much lower values of MSY and F_{MSY} are obtained (150,100 t and 0.22, respectively) and B_{MSY} is 249,800 t.

This calls into concern whether a single fit of stock recruitment time-series data is able to reliably capture the long-term reproductive potential of the yellowfin sole stock. A recent analysis of flatfish recruitment indicates that temporal trends in winter spawning flatfish production in the Eastern Bering Sea are consistent with the hypothesis that decadal scale climate variability influences marine survival during the early life history period (Wilderbuer et al. 2002). Periods of cross-shelf advection for winter spawning flatfish larvae were found to coincide with synchronous above-average recruitment (1980s) whereas periods of weak advection or advection to the west were associated with poor recruitment (1990s). These changes in stock productivity were found to coincide with a decadal scale shift in atmospheric forcing which warrant caution when trying to determine the long-term reproductive potential of this stock.

The aforementioned analysis was performed for rock sole, arrowtooth flounder and flathead sole, species which spawn in the winter in offshore areas and are seemingly reliant upon advection to nursery areas 3-4 months later. In contrast, yellowfin sole are known to spawn in shallow near shore areas of northern Bristol Bay, primarily in May and June, where it would seem that advection would play a diminished role in juvenile survival resulting in less variable recruitment. However, it is evident from Figure 4.9 that the time series of year class strength for yellowfin sole has shifts in production (1956-66, 1967-77, 1984-97). These shifts may be a cause of concern if we assume that the long term productivity is closely related to spawning stock size while ignoring mechanisms governing the variability in production which may correspond to decadal (or longer) shifts in environmental conditions.

Given these concerns, the authors are currently performing a simulation study to determine the appropriateness of applying a harvest strategy from fitting the full time series for a fish stock experiencing temporal changes in reproductive potential due to changing oceanic conditions. For this assessment then, we recommend a continued Tier 3 harvest strategy. Under this harvest strategy, the fishing mortality limit ($F_{0.35} = 0.137$) is much more conservative than they would be under a Tier 1 harvest strategy ($F_{MSY} = 0.37$ using all data or $F_{MSY} = 0.22$ using 1977-2000 data).

Historical Exploitation Rates

Based on results from the stock assessment model, annual exploitation rates of yellowfin sole ranged from 3 to 9% of the total biomass since 1977, and have averaged 6% (Table 4.8).

ACCEPTABLE BIOLOGICAL CATCH

After increasing during the 1970s and early 1980s, estimates from the stock assessment model indicate the total biomass has been at a slow decline from high levels of stock biomass since the peak in 1985. The estimate of total biomass for 2005 is 1,557,900 t.

The reference fishing mortality rate for yellowfin sole is determined by the amount of population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. The Alaska Fisheries Science Center policy is to use year classes spawned in 1977 or later to calculate the average equilibrium recruitment if no compelling reason exists to do otherwise. For this assessment we use the time-series of recruitment numbers estimated for 1978-2003 from the stock assessment model to estimate $\mathbf{B_{0.40} = 387{,}600}$ **t**. The stock assessment projection model estimates the 2005 level of female spawning biomass at 449,400 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B > B_{0.40}$ (449,400 > 387,600, Figure 4.8), yellowfin sole reference fishing mortality is defined in tier 3a. For the 2005 harvest: $F_{ABC} \leq F_{0.40} = 0.114$ (full selection F values).

Acceptable biological catch is estimated for 2005 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2005 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{nages}} \overline{w}_a n_a \left(1 - e^{-M - Fs_a}\right) \frac{Fs_a}{M + Fs_a}$$

where S_a is the selectivity at age, M in natural mortality, W_a is the mean weight at age, a_r is the age at recruitment to the fishery and n_a is the beginning of the year numbers at age. **This calculation results in a 2005 ABC of 124,300 t**.

Overfishing

The stock assessment analysis must also consider harvest limits, usually described as "overfishing" fishing mortality levels with corresponding yield amounts. Amendment 56 to the BSAI FMP now sets the harvest limit at the $F_{0.35}$ fishing mortality value or the fishing mortality rate which would reduce the spawning biomass per recruit to 35% of its unfished level (for tier 3a). The overfishing fishing mortality value, ABC fishing mortality value and their corresponding yields are given as follows:

Harvest level	F value	2005 Yield
$F_{OFL} = F_{0.35}$	0.137	147,500 t
$F_{ABC} = F_{0.40}$	0.114	124,300 t

BIOMASS PROJECTIONS

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 Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. 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 2005, 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 2005 recommended in the assessment to the *max* F_{ABC} for 2005. (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 2000-2004 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 2005 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2005 and 2006, 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 2017 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 4.13 and Figure 4.11 indicate that yellowfin are not currently overfished and are not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Yellowfin sole diet by life stage varies as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes bivalves, polychaetes, amphipods, mollusks, euphausids, shrimps, brittle stars, sculpins and miscellaneous crustaceans. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not been re-sampled since. The large populations of flatfish which have occupied the middle shelf of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the yellowfin sole resource.

2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea yellowfn sole due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they have been found in stomachs of Pacific cod and Pacific halibut; mostly on small yellowfin sole ranging from 7 to 25 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume and also from Annual reports compiled by the International Pacific Halibut Commission. Encounters between yellowfin sole and their predators may be limited since their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect yellowfin sole distribution patterns, recruitment success, migration timing and patterns and are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the ecosystem

1) The yellowfin sole target fishery contribution to the total bycatch of other non-prohibited species is shown for 1991-2003 in Table 4.14. The yellowfin sole target fishery contribution to the total bycatch of prohibited species is shown for 2002 and 2003 in Table 14 of the Economic SAFE (Appendix C) and is summarized for 2003 as follows:

Prohibited species	Yellowfin sole fishery % of total bycatch
Halibut mortality	19.0
Herring	3.0
Red King crab	26.0
C. bairdi	21.9
Other Tanner crab	44.0
Salmon	< 1

2) Relative to the predator needs in space and time, the yellowfin sole target fishery has a low selectivity for fish between 7-25 cm and therefore has minimal overlap with removals from predation.

3) The target fishery is not perceived to have an effect on the amount of large size target fish in the population due to it's history of light exploitation (6%) over the past 27 years.

4) Yellowfin sole fishery discards are presented in the Catch History section.

5) It is unknown what effect the fishery has had on yellowfin sole maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from the yellowfin sole fishery is available in the Preliminary draft of the Essential Fish Habitat environmental Impact Statement.

Ecosystem effects on yellowfin sole			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pacific cod, halibut, skates)	Stable	Possible increases to rock sole mortality	
Changes in habitat quality			
Temperature regime	Cold years yellowfin sole catchability and herding may decrease, timing of migration may be prolonged	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Yellowfin sole* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Low exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	unknown	NA	Possible concern

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Table 4.1- Catch (t) of yellowfin sole 1977-2004. Catch for 2004 is the total through September 4, 2004.

		Domestic		
Year	Foreign	JVP	DAP	Total
1977	58,373			58,373
1978	138,433			138,433
1979	99,019			99,019
1980	77,768	9,623		87,391
1981	81,255	16,046		97,301
1982	78,331	17,381		95,712
1983	85,874	22,511		108,385
1984	126,762	32,764		159,526
1985	100,706	126,401		227,107
1986	57,197	151,400		208,597
1987	1,811	179,613	4	181,428
1988		213,323	9,833	223,156
1989		151,501	1,664	153,165
1990		69,677	14,293	83,970
1991			115,842	115,842
1992			149,569	149,569
1993			106,101	106,101
1994			144,544	144,544
1995			124,740	124,740
1996			129,659	129,659
1997			181,389	181,389
1998			101,201	101,201
1999			67,320	67,320
2000			83,850	83,850
2001			63,395	63,395
2002			73,000	73,000
2003			74,418	74,418
2004			68,543	68,543

Table 4.2—Discard and retained catch, by target fishery, for yellowfin sole in 2002 and 2003.

2002

Target Fishery	Discard	Retained
Atka mackerel	0	0
Pacific cod	1583	429
Pollock	346	459
Sablefish	0	0
Rockfish	0	1
Arrowtooth flounder	0	18
Flathead sole	395	1,682
Rock sole	1333	6,138
Yellowfin sole	7386	53,192
Greenland turbot	0	0
Other flatfish	1	36
	0	0
Total	11,044	61,955

2003

Target Fishery	Discard	Retained
Atka mackerel	0	1
Bottom pollock	0	56
Pacific cod	1,348	296
Mid-water pollock	95	44
Sablefish	0	0
Rockfish	0	0
Arrowtooth flounder	0	0
Flathead sole	338	1,981
Rock sole	1,535	4,556
Yellowfin sole	7,370	56,787
Greenland turbot	0	1
Other flatfish	0	0
Other species	0	11
Total	10,686	63,732

Table 4.3—Yellowfin sole fishery catch-at-age numbers (millions), 1977-2003.

YEAR/AGE	7	8	9	10	11	12	13	14	15	16	17+
1977	18.7	42.5	35.7	70.5	48.3	15.8	4.7	2.9	2.2	0.6	0.3
1978	66.8	131.7	113.8	97.8	104.3	38.9	21.6	12.3	4.5	2.7	0.7
1979	20.7	49.4	89.6	82.9	61.3	45.1	22.9	7.1	4.1	1.5	1.3
1980	33.1	19.7	41.3	64.1	60.8	47.7	42.4	23.2	7.4	10.1	4.2
1981	31.1	46.2	41.7	51.7	67.2	70.6	58.4	40.2	18.5	5.7	4.4
1982	27.7	58.9	45.1	42.2	71.5	75.0	39.6	20.1	10.4	2.7	0.5
1983	56.2	39.6	75.9	53.5	53.5	77.1	57.9	32.3	16.5	5.2	2.9
1984	13.2	26.3	34.0	70.5	72.2	94.1	107.8	102.1	56.5	23.6	11.3
1985	36.9	52.1	107.2	106.0	127.9	108.8	108.5	103.9	66.1	29.5	15.4
1986	49.3	40.7	67.6	111.6	82.5	74.7	64.3	40.2	56.5	51.8	28.8
1987	18.2	49.4	33.5	49.3	55.4	59.6	73.4	61.0	26.3	40.1	42.3
1988	29.0	57.5	140.5	40.8	71.7	89.4	53.6	104.1	82.1	34.8	176.9
1989	2.5	33.8	47.0	73.1	29.5	20.5	52.0	32.2	45.3	44.5	172.0
1990	8.8	7.0	52.4	29.2	49.4	20.0	18.4	16.9	17.4	23.2	72.2
1991	9.9	62.5	6.5	116.2	28.8	38.8	7.3	18.5	25.5	16.0	60.3
1992	5.9	24.2	83.8	22.5	123.3	29.9	25.0	13.3	15.2	12.7	71.8
1993	12.2	8.1	11.0	57.4	7.4	74.4	16.3	19.9	9.8	15.1	89.9
1994	21.3	33.7	26.8	26.9	127.5	3.2	90.8	9.7	33.9	13.7	85.6
1995	27.7	46.3	21.0	11.2	13.7	83.3	1.8	103.9	9.7	16.9	69.4
1996	13.1	41.1	43.8	19.4	15.5	25.9	74.2	14.3	75.4	10.6	73.6
1997	19.5	25.2	63.6	40.2	27.4	38.5	29.8	114.7	14.3	63.5	114.4
1998	12.2	13.2	15.7	33.2	28.6	20.0	15.8	16.8	28.2	15.3	100.3
1999	2.77	6.97	7.20	7.59	24.45	18.68	10.29	11.66	14.69	20.14	66.89
2000	1.28	7.72	24.69	10.50	11.66	29.30	25.37	19.02	8.89	20.06	21.35
2001	3.83	7.71	11.48	21.08	15.04	11.35	18.60	15.31	13.81	7.37	9.11
2002	2.88	9.67	12.35	16.72	31.51	14.74	10.74	18.97	13.15	7.62	74.66
2003	2.50	27.41	19.75	11.67	15.21	28.10	11.91	9.12	10.69	11.61	76.36

Table 4.4—Yellowfin sole population numbers-at-age estimated from the annual bottom trawl surveys, 1982-2003.

YEAR/AGE	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1982	123.92	363.40	742.81	2882.02	3155.60	2408.06	3193.93	1445.10	1556.82	1258.34	1140.63	863.75	531.61	163.76	73.56	90.30
1983	0.00	6.51	142.01	378.56	1659.47	3495.21	1836.08	2388.32	1786.45	1596.73	2079.66	1576.73	771.86	751.40	154.05	114.31
1984	0.00	115.73	494.28	577.04	957.63	1554.66	1765.76	1832.76	1982.22	1759.32	953.15	1018.81	723.36	580.14	310.55	251.42
1985	0.00	43.18	241.90	762.09	1040.18	618.98	1206.24	1353.31	787.50	904.66	846.54	568.07	519.45	448.47	295.50	177.82
1986	0.00	35.15	66.88	310.90	698.31	1297.69	535.40	888.12	787.86	693.12	482.52	507.65	302.11	449.96	212.17	496.40
1987	0.00	6.42	102.16	210.91	1554.66	932.70	1477.58	681.56	649.96	818.80	534.89	552.59	319.38	381.16	392.15	1198.97
1988	1.05	4.01	32.02	782.57	133.73	2997.03	1524.25	1271.78	318.99	500.79	446.73	464.61	821.54	547.60	290.81	1.76
1989	0.00	17.04	45.57	336.77	1847.96	504.12	3244.51	1350.68	978.98	255.00	280.08	503.42	351.80	540.72	267.24	1295.95
1990	0.00	29.10	116.55	220.85	637.65	1947.17	386.52	2400.18	726.23	746.35	141.64	137.63	174.89	102.42	286.12	1003.59
1991	0.00	12.92	229.34	594.04	256.28	718.66	1933.06	207.09	2423.15	535.68	764.55	142.83	196.50	137.61	164.88	1220.88
1992	0.00	12.71	281.70	670.10	854.01	386.54	436.94	1522.33	183.38	1526.22	232.18	467.06	128.03	133.92	203.93	1149.53
1993	0.00	52.78	180.61	610.32	1300.31	828.16	548.03	471.74	2418.53	147.79	1725.10	225.96	222.99	119.53	67.92	1059.59
1994	4.24	75.20	165.77	388.84	944.64	1857.40	1210.83	789.04	475.32	1992.18	25.72	1137.87	89.67	405.69	153.48	434.45
1995	0.00	18.90	321.67	408.22	451.40	1555.61	1192.14	368.72	314.47	99.90	1111.24	33.90	1163.38	153.19	104.54	929.92
1996	0.00	92.33	248.64	1649.80	536.75	513.25	877.81	878.98	555.07	295.42	299.57	1026.43	181.20	1115.82	179.63	1151.40
1997	0.00	37.69	541.59	927.90	1522.86	436.97	422.70	952.22	473.65	307.94	390.50	292.35	1014.11	122.74	578.36	948.94
1998	0.00	58.92	153.23	829.25	989.47	1732.39	418.81	429.94	574.20	685.32	715.00	320.56	333.60	452.87	179.95	1974.36
1999	0.00	8.82	169.07	343.88	402.87	430.49	1307.45	250.52	201.63	555.35	460.84	261.72	126.15	131.30	296.15	1974.36
2000	0.00	24.50	134.75	527.47	417.21	594.20	791.41	1020.82	268.87	383.99	320.12	344.41	278.76	264.25	233.10	1314.46
2001	0.00	1.34	146.40	376.67	1159.04	637.07	750.71	789.33	1174.59	493.06	281.54	406.50	216.70	227.60	302.49	1037.69
2002	0.00	70.43	201.71	326.86	590.91	1500.17	689.08	602.62	473.79	905.97	391.06	225.67	554.98	251.28	297.31	1268.74
2003	0.00	0.00	0.00	5.05	43.53	216.85	1784.33	386.99	773.78	256.24	1197.74	426.43	303.65	436.21	363.67	4524.67

Table 4.5--Female yellowfin sole proportion mature at age from Nichol (1994).

Age	Proportion mature
1	0
2	0
3	.001
4	.004
5	.008
6	.020
7	.046
8	.104
9	.217
10	.397
11	.612
12	.790
13	.899
14	.955
15	.981
16	.992
17	.997
18	1.000
19	1.000
20	1.000

Table 4.6--Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}$, $\tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}$, $\tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1976-96
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right) N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a} e^{-z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1} e^{-z_{t,A-1}} + N_{t,A} e^{-z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a} W_{t,a} \phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}$, $\varepsilon^F{}_t \sim N(o,\sigma^2{}_F)$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha + \beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {C_{t,a}}/{C_t}$	Proportion at age in catch
$SurB_t = q \sum N_{t,a} W_{t,a} v_a$	Survey biomass
$L = \sum_{t,a} m_t p_{t,a} \ln \frac{\hat{p}_{t,a}}{p_{t,a}} + (-0.5) \sum_t \left[\left(\ln \frac{surB_t}{\hat{surB}_t} \, {1}/{\sigma_t} \right)^2 - \ln \sigma_t \right]$	Total log likelihood

Table 4.7--Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
ϕ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

Table 4.8--Model estimates of yellowfin sole fishing mortality and exploitation rate (catch/total biomass).

Year	Full selection F	Exploitation Rate
1954	0.01	0.01
1955	0.01	0.01
1956	0.02	0.01
1957	0.02	0.01
1958	0.04	0.02
1959	0.18	0.10
1960	0.56	0.25
1961	1.06	0.38
1962	1.59	0.42
1963	0.49	0.12
1964	0.58	0.15
1965	0.23	0.07
1966	0.36	0.13
1967	0.56	0.21
1968	0.29	0.12
1969	0.64	0.23
1970	0.62	0.20
1971	0.99	0.24
1972	0.34	0.07
1973	0.49	0.10
1974	0.21	0.04
1975	0.23	0.06
1976	0.15	0.04
1977	0.12	0.04
1978	0.22	0.08
1979	0.13	0.05
1980	0.09	0.04
1981	0.09	0.04
1982	0.07	0.04
1983	0.07	0.04
1984	0.10	0.06
1985	0.15	0.09
1986	0.14	0.08
1987	0.13	0.07
1988	0.16	0.09
1989	0.11	0.06
1990	0.06	0.03
1991	0.06	0.04
1992	0.10	0.07
1993	0.07	0.05
1994	0.10	0.07
1995	0.09	0.06
1996	0.09	0.06
1997	0.14	0.09
1998	0.08	0.05
1999	0.06	0.04
2000	0.07	0.05

2001	0.05	0.04
2002	0.06	0.04
2003	0.06	0.04

Table 4.9—Model estimates of yellowfin sole age-specific selectivities for survey and fishery data.---

Age	Fishery (1964-2003)	Survey (1982-2003)
1	0.00	0.00
2	0.00	0.01
3	0.00	0.03
4	0.01	0.13
5	0.02	0.40
6	0.04	0.75
7	0.11	0.93
8	0.26	0.98
9	0.50	1.00
10	0.74	1.00
11	0.89	1.00
12	0.96	1.00
13	0.98	1.00
14	0.98	1.00
15	0.98	1.00
16	0.98	1.00
17	0.98	1.00
18	0.98	1.00
19	0.98	1.00
20	0.98	1.00

Table 4.10—Model estimates of yellowfin sole age 2+ total biomass (t) and begin-year female spawning biomass (t) from the 2003 and 2004 stock assessments.

Year	2004 Assessment Female Spawning Biomass	Age 2+ Total Biomass	2003 Assessment Female Spawning Biomass	Age 2+ Total Biomass
1964	71,918	733,966	71,453	732,312
1965	74,665	738,122	74,133	736,371
1966	99,616	791,942	99,059	789,963
1967	116,714	785,181	116,139	782,875
1968	111,323	711,206	110,701	708,399
1969	122,109	726,487	121,446	722,815
1970	98,452	663,428	97,689	658,497
1971	81,233	659,551	80,364	652,687
1972	53,290	657,118	52,325	647,531
1973	61,251	807,119	60,102	793,780
1974	67,337	953,848	65,854	935,733
1975	92,683	1,165,990	90,663	1,142,160
1976	124,867	1,376,060	121,983	1,345,530
1977	172,432	1,609,570	168,300	1,571,590
1978	232,970	1,845,720	227,147	1,799,720
1979	280,426	1,987,380	272,360	1,933,070
1980	349,428	2,151,620	338,735	2,089,190
1981	431,244	2,302,750	417,544	2,232,510
1982	512,714	2,414,930	495,766	2,337,300
1983	594,443	2,514,760	574,099	2,429,430
1984	667,189	2,589,550	643,398	2,496,160
1985	708,486	2,606,750	681,397	2,504,590
1986	704,057	2,549,530	674,048	2,438,100
1987	686,691	2,501,510	654,221	2,380,580
1988	669,033	2,465,220	634,249	2,335,200
1989	628,304	2,367,550	591,257	2,229,570
1990	625,821	2,330,280	585,851	2,185,250
1991	662,642	2,353,930	619,086	2,203,180
1992	697,421	2,342,050	649,794	2,187,250
1993	699,873	2,253,670	648,140	2,095,960
1994	711,919	2,212,350	656,543	2,052,570
1995	691,574	2,125,540	633,694	1,964,910
1996	668,278	2,055,270	609,042	1,894,580
1997	638,485	1,979,650	578,813	1,817,600
1998	587,145	1,855,270	527,485	1,690,210
1999	568,876	1,811,370	509,300	1,643,890
2000	563,328	1,792,830	503,990	1,628,580
2001	553,904	1,749,830	494,597	1,599,070
2002	552,885	1,709,920	493,675	1,586,250
2003	549,349	1,658,780	489,761	1,571,580
2004	540,650	1,601,460		

Table 4.11—Model estimates of yellowfin sole population number at age (billions) for 1954- 2004.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	2.915	4.045	2.148	0.873	0.433	0.374	0.354	0.346	0.336	0.325	0.326	0.329	0.330	0.330	0.331	0.331	0.331	0.330	0.334	0.334
1955	1.382	2.585	3.588	1.905	0.774	0.384	0.332	0.313	0.306	0.296	0.286	0.287	0.289	0.289	0.290	0.290	0.291	0.291	0.290	0.587
1956	0.893	1.226	2.293	3.182	1.690	0.686	0.340	0.294	0.277	0.270	0.260	0.251	0.252	0.253	0.254	0.254	0.254	0.255	0.255	0.768
1957	3.110	0.792	1.087	2.033	2.822	1.498	0.608	0.301	0.259	0.243	0.236	0.227	0.218	0.219	0.220	0.220	0.221	0.221	0.222	0.889
1958	2.305	2.759	0.703	0.964	1.803	2.502	1.328	0.538	0.266	0.227	0.212	0.205	0.197	0.189	0.190	0.191	0.191	0.192	0.192	0.965
1959	1.750	2.045	2.447	0.623	0.855	1.598	2.215	1.172	0.472	0.231	0.196	0.182	0.175	0.168	0.161	0.162	0.163	0.163	0.164	0.986
1960	1.844	1.552	1.813	2.169	0.552	0.756	1.406	1.925	0.991	0.383	0.179	0.148	0.136	0.130	0.125	0.120	0.120	0.121	0.121	0.854
1961	1.081	1.635	1.376	1.606	1.918	0.485	0.654	1.171	1.474	0.665	0.225	0.097	0.077	0.069	0.067	0.064	0.061	0.062	0.062	0.499
1962	1.850	0.959	1.449	1.218	1.416	1.672	0.411	0.515	0.786	0.770	0.270	0.078	0.031	0.024	0.022	0.021	0.020	0.019	0.019	0.175
1963	0.934	1.640	0.849	1.281	1.070	1.224	1.384	0.305	0.301	0.315	0.212	0.059	0.015	0.006	0.004	0.004	0.004	0.004	0.004	0.036
1964	0.880	0.828	1.454	0.753	1.133	0.942	1.063	1.162	0.238	0.209	0.196	0.122	0.033	0.008	0.003	0.002	0.002	0.002	0.002	0.022
1965	1.227	0.780	0.734	1.288	0.665	0.996	0.815	0.883	0.885	0.158	0.121	0.104	0.062	0.016	0.004	0.002	0.001	0.001	0.001	0.012
1966	1.464	1.088	0.692	0.651	1.141	0.588	0.874	0.704	0.737	0.699	0.118	0.088	0.074	0.044	0.012	0.003	0.001	0.001	0.001	0.009
1967	2.408	1.298	0.965	0.613	0.576	1.006	0.513	0.745	0.568	0.547	0.476	0.076	0.055	0.046	0.027	0.007	0.002	0.001	0.001	0.006
1968	2.616	2.135	1.151	0.854	0.542	0.506	0.871	0.427	0.571	0.382	0.322	0.258	0.040	0.028	0.024	0.014	0.004	0.001	0.000	0.003
1969	2.548	2.320	1.893	1.020	0.757	0.479	0.443	0.747	0.351	0.437	0.273	0.220	0.173	0.026	0.019	0.016	0.009	0.002	0.001	0.003
1970	3.512	2.259	2.057	1.677	0.901	0.664	0.413	0.366	0.560	0.226	0.242	0.137	0.106	0.082	0.012	0.009	0.007	0.004	0.001	0.001
1971	4.281	3.114	2.003	1.822	1.482	0.791	0.573	0.341	0.275	0.364	0.127	0.123	0.067	0.051	0.039	0.006	0.004	0.004	0.002	0.001
1972	4.149	3.796	2.760	1.773	1.606	1.294	0.672	0.454	0.233	0.149	0.155	0.047	0.042	0.022	0.017	0.013	0.002	0.001	0.001	0.001
1973	3.693	3.679	3.366	2.446	1.569	1.417	1.130	0.574	0.369	0.174	0.103	0.102	0.030	0.027	0.014	0.011	0.008	0.001	0.001	0.001
1974	4.044	3.275	3.262	2.982	2.164	1.381	1.230	0.948	0.447	0.256	0.108	0.059	0.057	0.016	0.015	0.008	0.006	0.005	0.001	0.001
1975	4.852	3.586	2.904	2.892	2.642	1.913	1.214	1.066	0.796	0.358	0.195	0.080	0.043	0.041	0.012	0.011	0.006	0.004	0.003	0.001
1976	3.097	4.303	3.180	2.575	2.562	2.334	1.679	1.048	0.889	0.629	0.267	0.140	0.056	0.030	0.029	0.008	0.007	0.004	0.003	0.003
1977	3.618	2.747	3.816	2.820	2.282	2.266	2.057	1.464	0.894	0.732	0.500	0.208	0.108	0.043	0.023	0.022	0.006	0.006	0.003	0.005
1978	2.408	3.209	2.436	3.384	2.499	2.020	2.000	1.801	1.260	0.749	0.596	0.400	0.165	0.086	0.034	0.018	0.017	0.005	0.005	0.006
1979	1.610	2.136	2.846	2.160	2.997	2.209	1.774	1.731	1.508	1.002	0.565	0.436	0.288	0.118	0.061	0.024	0.013	0.012	0.004	0.008
1980	3.006	1.428	1.894	2.523	1.914	2.653	1.948	1.551	1.484	1.254	0.808	0.447	0.341	0.225	0.092	0.048	0.019	0.010	0.010	0.009
1981	2.171	2.666	1.266	1.679	2.237	1.695	2.343	1.710	1.342	1.256	1.038	0.660	0.363	0.276	0.182	0.075	0.039	0.015	0.008	0.015
1982	5.943	1.926	2.364	1.123	1.489	1.981	1.498	2.058	1.482	1.140	1.045	0.852	0.538	0.295	0.225	0.148	0.061	0.031	0.013	0.019
1983	1.020	5.271	1.708	2.097	0.996	1.319	1.751	1.317	1.790	1.266	0.957	0.867	0.704	0.444	0.243	0.185	0.122	0.050	0.026	0.026
1984	4.916	0.904	4.675	1.515	1.859	0.882	1.166	1.540	1.146	1.529	1.063	0.794	0.716	0.580	0.366	0.200	0.153	0.101	0.041	0.043
1985	1.582	4.360	0.802	4.145	1.342	1.646	0.779	1.022	1.330	0.965	1.257	0.861	0.638	0.574	0.465	0.293	0.161	0.122	0.081	0.067
1986	1.267	1.403	3.867	0.711	3.673	1.188	1.451	0.679	0.872	1.096	0.769	0.980	0.664	0.490	0.441	0.357	0.225	0.123	0.094	0.114

1987	1.736	1.124	1.245	3.429	0.630	3.251	1.047	1.266	0.581	0.722	0.878	0.603	0.761	0.514	0.379	0.341	0.276	0.174	0.096	0.161
1988	2.324	1.539	0.997	1.104	3.039	0.558	2.867	0.916	1.087	0.484	0.584	0.697	0.474	0.596	0.402	0.297	0.267	0.217	0.136	0.201
1989	2.327	2.061	1.365	0.884	0.978	2.688	0.491	2.497	0.778	0.889	0.381	0.448	0.529	0.358	0.451	0.304	0.225	0.202	0.164	0.255
1990	1.061	2.064	1.828	1.211	0.783	0.866	2.372	0.430	2.149	0.652	0.725	0.305	0.356	0.419	0.284	0.357	0.241	0.178	0.160	0.332
1991	1.134	0.941	1.830	1.621	1.073	0.694	0.766	2.090	0.376	1.852	0.554	0.611	0.256	0.299	0.351	0.238	0.299	0.202	0.149	0.412
1992	2.886	1.006	0.835	1.623	1.437	0.951	0.614	0.674	1.823	0.323	1.567	0.465	0.510	0.213	0.249	0.293	0.198	0.249	0.168	0.468
1993	1.499	2.560	0.892	0.740	1.439	1.273	0.840	0.538	0.582	1.535	0.265	1.268	0.373	0.408	0.171	0.199	0.234	0.159	0.200	0.509
1994	1.446	1.329	2.270	0.791	0.656	1.275	1.125	0.739	0.469	0.499	1.294	0.221	1.053	0.309	0.338	0.142	0.165	0.194	0.132	0.588
1995	1.278	1.282	1.179	2.013	0.701	0.581	1.126	0.987	0.639	0.396	0.412	1.054	0.179	0.850	0.250	0.273	0.114	0.133	0.157	0.581
1996	2.764	1.134	1.137	1.045	1.785	0.621	0.513	0.989	0.856	0.543	0.330	0.339	0.861	0.146	0.692	0.203	0.222	0.093	0.109	0.601
1997	0.988	2.452	1.005	1.008	0.927	1.581	0.548	0.451	0.856	0.725	0.450	0.269	0.275	0.697	0.118	0.560	0.165	0.180	0.075	0.574
1998	0.789	0.876	2.174	0.891	0.894	0.820	1.393	0.479	0.385	0.708	0.581	0.353	0.209	0.213	0.540	0.091	0.434	0.127	0.139	0.503
1999	0.712	0.700	0.777	1.928	0.790	0.791	0.725	1.224	0.416	0.328	0.591	0.479	0.289	0.171	0.174	0.441	0.075	0.355	0.104	0.525
2000	0.718	0.631	0.621	0.689	1.710	0.700	0.700	0.639	1.070	0.358	0.279	0.499	0.402	0.243	0.144	0.146	0.370	0.063	0.298	0.528
2001	1.214	0.637	0.560	0.551	0.611	1.515	0.619	0.616	0.556	0.916	0.302	0.232	0.413	0.333	0.201	0.119	0.121	0.306	0.052	0.683
2002	1.681	1.076	0.565	0.497	0.488	0.541	1.340	0.546	0.539	0.480	0.781	0.255	0.196	0.348	0.280	0.169	0.100	0.102	0.258	0.618
2003	1.863	1.490	0.955	0.501	0.440	0.433	0.479	1.180	0.476	0.463	0.407	0.655	0.213	0.163	0.290	0.234	0.141	0.083	0.085	0.731
2004	1.894	1.652	1.322	0.847	0.444	0.390	0.383	0.422	1.029	0.409	0.392	0.341	0.546	0.177	0.136	0.241	0.194	0.117	0.069	0.679

Table 4.12—Model estimates of yellowfin sole age 5 recruitment (millions) from the 2003 and 2004 stock assessments.

Year Class	2004 Assessment	2003 Assessment
1959	1,133	1,132
1960	665	664
1961	1,141	1,137
1962	576	572
1963	542	538
1964	757	750
1965	901	891
1966	1,482	1,462
1967	1,606	1,579
1968	1,569	1,539
1969	2,164	2,117
1970	2,642	2,580
1971	2,562	2,499
1972	2,282	2,223
1973	2,499	2,431
1974	2,997	2,908
1975	1,914	1,853
1976	2,237	2,159
1977	1,489	1,433
1978	996	955
1979	1,859	1,776
1980	1,342	1,277
1981	3,673	3,479
1982	630	594
1983	3,039	2,834
1984	978	899
1985	783	733
1986	1,073	1,012
1987	1,437	1,363
1988	1,439	1,375
1989	656	618
1990	701	649
1991	1,785	1,662
1992	927	915
1993	894	857
1994	790	730
1995	1,710	1,282
1996	611	699
1997	488	714
1998	440	950
1999	444	

Table 4.13—Projections of yellowfin sole female spawning biomass (1,000s t), catch (1,000s t) and full selection fishing mortality rate for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2004	509.719	68.546	0.06
2005	494.445	124.338	0.11
2006	461.967	114.389	0.11
2007	426.827	104.123	0.11
2008	390.268	95.030	0.11
2009	357.949	81.022	0.10
2010	336.842	73.891	0.10
2011	328.289	72.457	0.10
2012	328.634	74.313	0.10
2013	335.361	78.332	0.10
2014	344.653	83.123	0.10
2015	354.782	87.782	0.10
2016	362.885	91.037	0.10
2017	369.867	93.534	0.11

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2004	509.719	68.546	0.06
2005	503.417	63.761	0.06
2006	495.700	61.703	0.06
2007	481.967	58.957	0.06
2008	462.547	56.254	0.06
2009	441.714	54.249	0.06
2010	426.105	53.579	0.06
2011	420.212	54.217	0.06
2012	421.946	55.478	0.06
2013	430.506	57.117	0.06
2014	442.706	58.852	0.06
2015	457.400	60.663	0.06
2016	470.527	62.200	0.06
2017	483.150	63.626	0.06

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2004	509.718	68.547	0.06
2005	506.920	39.559	0.04
2006	509.372	39.038	0.04
2007	505.145	38.012	0.04
2008	494.042	36.907	0.04
2009	480.017	36.123	0.04
2010	469.920	36.088	0.04
2011	468.803	36.824	0.04
2012	474.701	37.909	0.04
2013	487.317	39.218	0.04
2014	503.552	40.578	0.04
2015	522.520	41.994	0.04
2016	539.481	43.207	0.04
2017	555.847	44.346	0.04

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2004	509.718	0	0
2005	512.553	0	0
2006	531.954	0	0
2007	544.469	0	0
2008	548.914	0	0
2009	548.509	0	0
2010	550.256	0	0
2011	560.004	0	0
2012	575.819	0	0
2013	598.241	0	0
2014	624.289	0	0
2015	653.611	0	0
2016	680.055	0	0
2017	705.759	0	0

Table 4.13—continued.

Scenario 6

Determination of whether yellowfin sole are currently overfished **B35=341.600**

Year	Female spawning biomass	catch	F
2004	509.719	68.546	0.06
2005	490.939	147.472	0.14
2006	449.272	132.991	0.14
2007	406.840	118.775	0.14
2008	366.057	100.006	0.13
2009	333.113	84.100	0.12
2010	312.361	76.347	0.11
2011	304.418	75.010	0.11
2012	305.395	77.338	0.11
2013	312.469	81.962	0.11
2014	321.778	87.351	0.11
2015	331.500	92.686	0.12
2016	338.990	96.586	0.12
2017	345.060	99.570	0.12

Scenario 7

Determination of whether the stock is approaching an overfished condition **B35=341.600**

Year	Female spawning biomass	catch	F
2004	509.719	68.546	0.06
2005	494.445	124.338	0.11
2006	461.967	114.389	0.11
2007	423.768	123.478	0.14
2008	379.911	107.580	0.13
2009	343.3	89.147	0.12
2010	319.87	79.864	0.11
2011	309.944	77.584	0.11
2012	309.415	79.315	0.11
2013	315.366	83.590	0.11
2014	323.856	88.636	0.11
2015	332.965	93.529	0.12
2016	340.027	97.112	0.12
2017	345.838	99.850	0.12

Table 4-14—Yellowfin catch and bycatch from 1992-2003 estimated from a blend of regional office reported catch and observer sampling of the catch.

Species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Grand Total
Walleye Pollock	13,100	15,253	33,200	27,041	22,254	24,100	15,335	8,701	13,425	16,502	14,489	11,396	214,798
Arrowtooth Flounder	366	1,017	1,595	346	820	386	2,382	1,627	1,998	1,845	998	1,125	14,506
Pacific Cod	8,700	8,723	16,415	13,181	8,684	12,825	10,224	4,380	5,192	6,531	6,259	4,621	105,736
Groundfish, General	7,990	3,847	3,983	2,904	2,565	4,755	3,580	2,524	3,541	3,936	2,678	3,133	45,435
Rock Sole	14,646	7,301	8,097	7,486	12,903	16,693	9,825	10,773	7,345	5,810	10,665	8,419	119,963
Flathead Sole		1,198	2,491	3,929	3,166	3,896	5,328	2,303	2,644	3,231	2,190	2,899	33,276
Sablefish	0	0		0	0	0	0	4	0	0			5
Atka Mackerel	1	0			0	0	1	33	0	0	0	17	53
Pacific Ocean Perch	0	5		0		0	1	12	1	1	1	11	33
Rex Sole			1	1		0	20	36	1	2	0		61
Flounder, General	16,826	6,615	7,080	11,092	10,372	10,743	6,362	8,812	7,913	4,854	378	214	91,263
Squid	0		5	0	11	0	2	1	0	0	0	1	19
Dover Sole			35										35
Thornyhead					0		1						1
Shortraker/Rougheye	0				1	0	1	15		1			18
Butter Sole			0			3	3		2		7		15
Eulachon smelt								0					0
Starry Flounder		227	106	16	37	124	35	48	71	82	133		880
Northern Rockfish						1	0	0			1		1
Dusky Rockfish								0			0		0

Yellowfin Sole	136,804	91,931	126,163	108,493	112,818	169,661	90,062	62,941	71,479	54,722	66,178	68,954	1,160,205
English Sole		1									1		1
Unsp. demersal rockfish						12	0						12
Greenland Turbot	1	5	5	67	8	4	103	70	24	32	2		321
Alaska Plaice		1,579	2,709	1,130	553	6,351	2,758	2,530	2,299	1,905	10,396	365	32,574
Sculpin, General								215	97	12	1,226		1,549
Skate, General								26	4	21	1,042		1,093
Sharpchin Rockfish								1					1
Bocaccio	0												0
Rockfish, General	0		0	3	23	0	1	3	4	1		1	36
Octopus								0					0
Smelt, general								0	0	0			0
Chilipepper		1											1
Eels								1	1	0	0		2
Lingcod										2			2
Jellyfish (unspecified)									127	173	161		462
Snails								12	4	0	4		20
Sea cucumber								0	56		0		57
Korean horsehair crab								0	0	0			0
Greenling, General									0				0
Shrimp, general								0	0	0	0		0
Grand Total	198,435	137,704	201,884	175,690	174,214	249,557	146,024	105,069	116,226	99,664	116,810	109,458	1,830,738

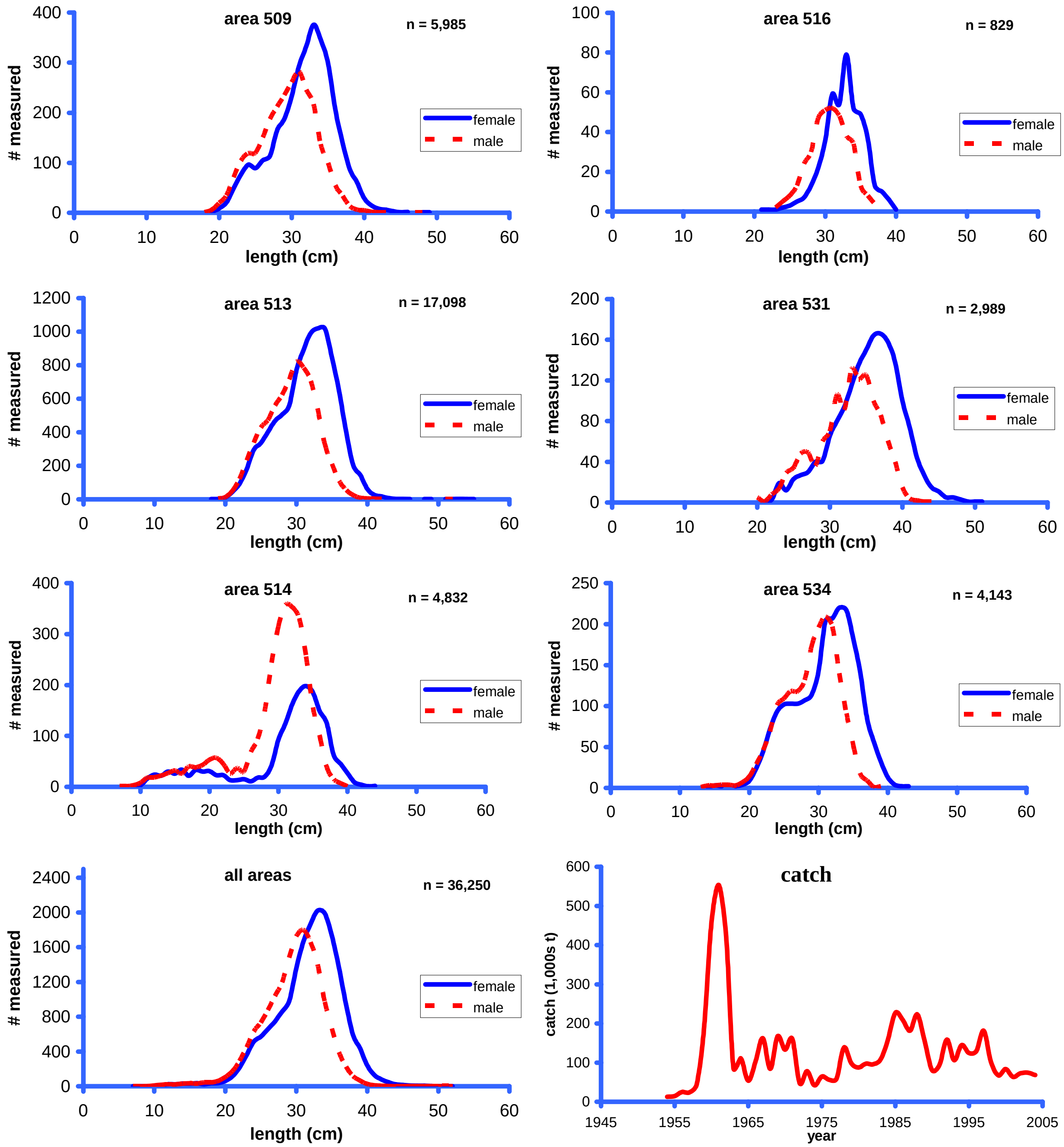


Figure 4.1—Size composition of the yellowfin sole catch in 2003, by subarea and total. The total catch (t) of yellowfin sole 1954-September 4, 2004 is in the lower right panel..

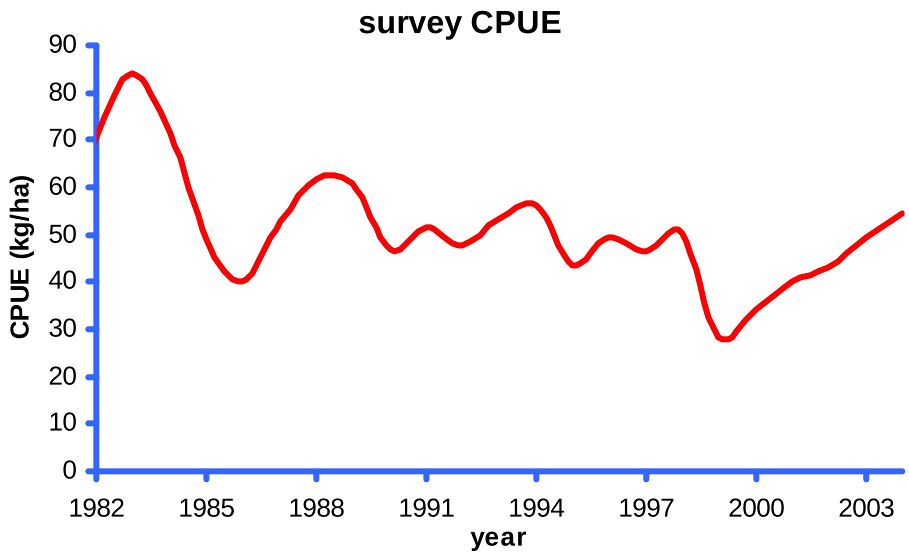


Figure 4.2—Yellowfn sole CPUE (catch per unit effort in kg/ha) from the annual Bering Sea shelf trawl surveys, 1982-2004.

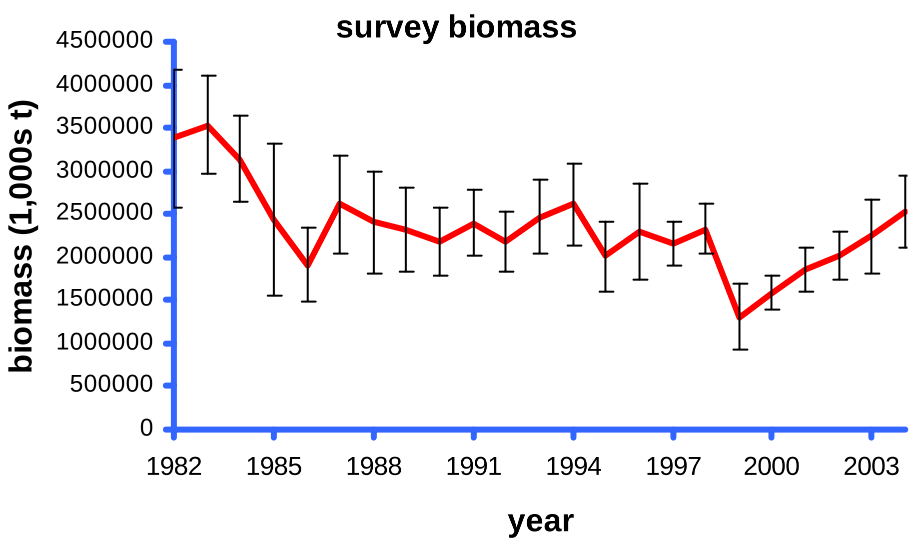


Figure 4.3--Annual bottom trawl survey biomass point-estimates and 95% confidence intervals for yellowfin sole.

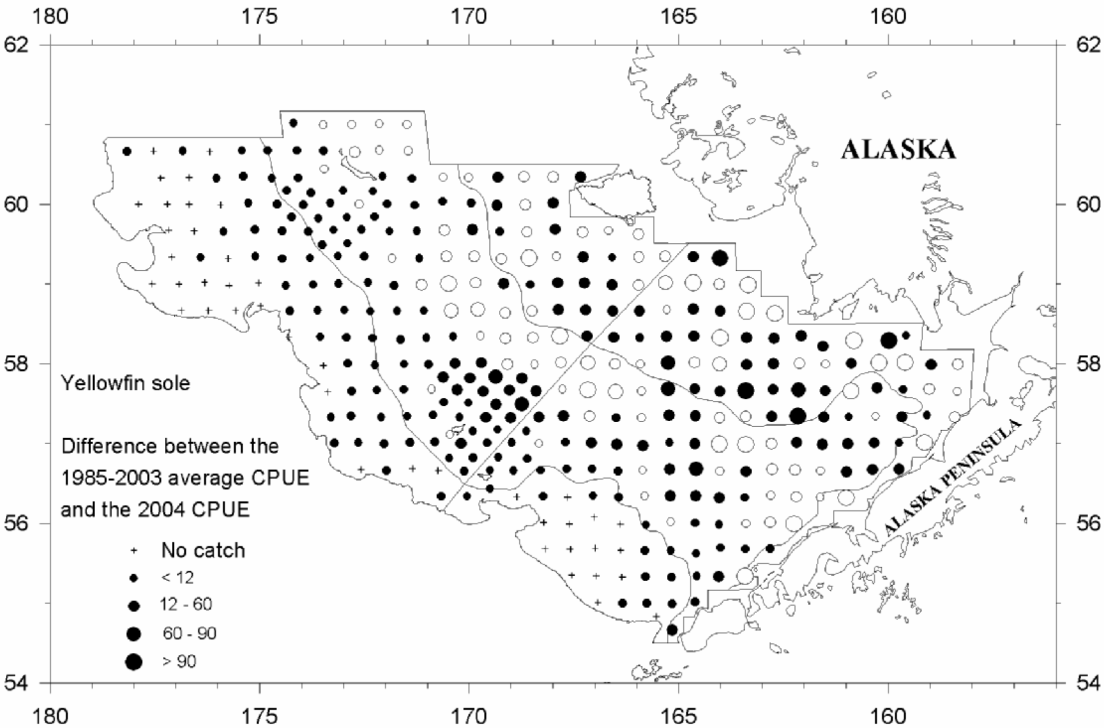


Figure 4.4—Difference between the 1985-2003 average trawl survey CPUE for yellowfin sole and the 2004 survey CPUE. Open circles indicate that the magnitude of the catch was greater in 2004 than the long-term average, closed circles indicate the catch was greater in the long-term average than in 2004.

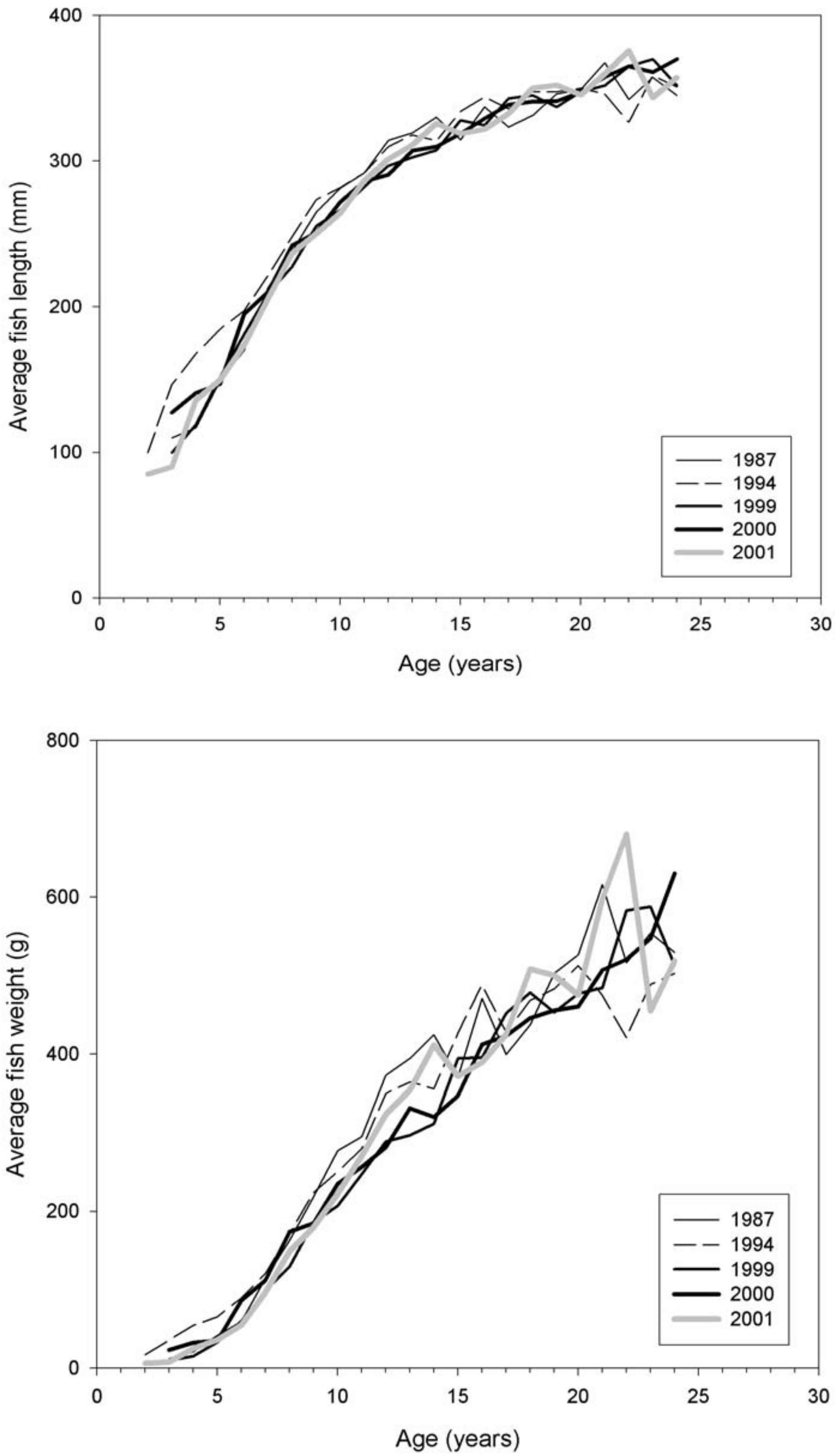


Figure 4.5 -Comparison of yellowfin sole length at age (top panel) and weight at age (bottom panel) from biological samples collected in 1987, 1994, 1999, 2000 and 2001.

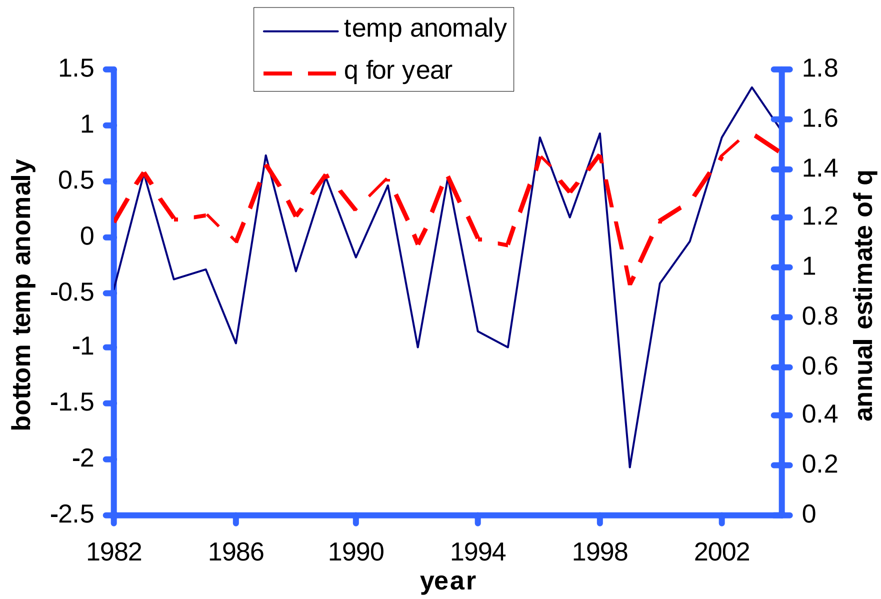


Figure 4.6--Average bottom water temperature from stations less than or equal to 100 m in the Bering Sea trawl survey and the stock assessment model estimate of q for each year 1982-2003.

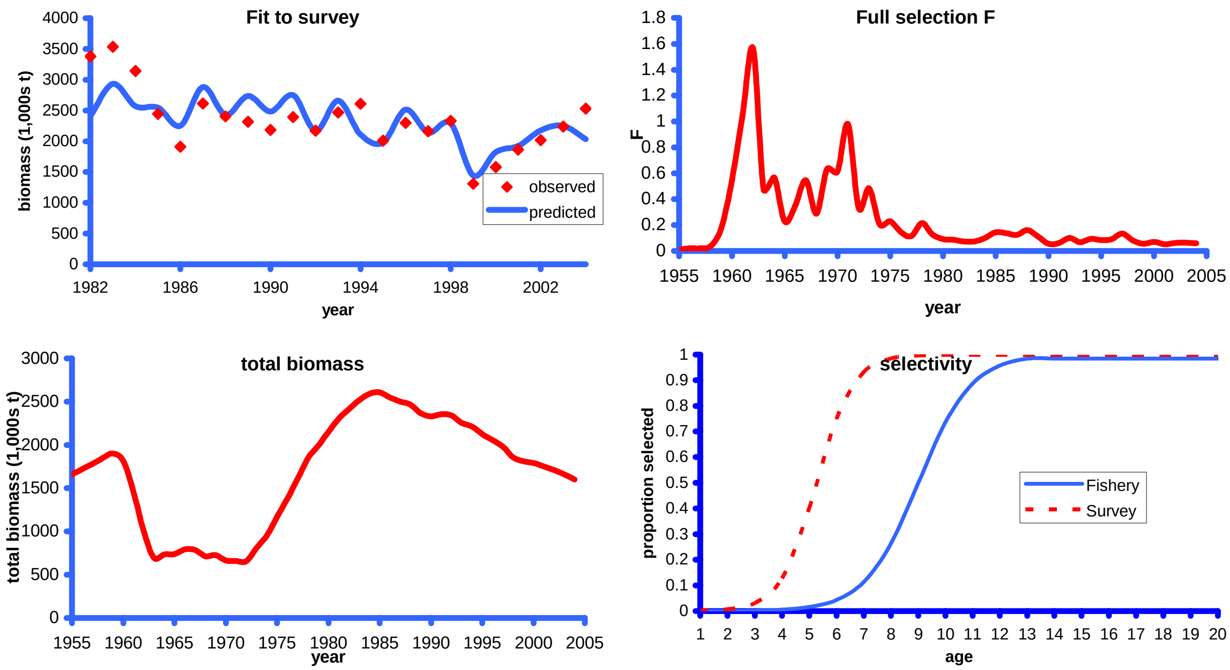


Figure 4.7--Model fit to the survey biomass estimates (top left panel), model estimate of the full selection fishing mortality rate throughout the time-series (top right panel), model estimate of total biomass (bottom left panel) and the model estimate of fishery and survey selectivity (bottom right panel).

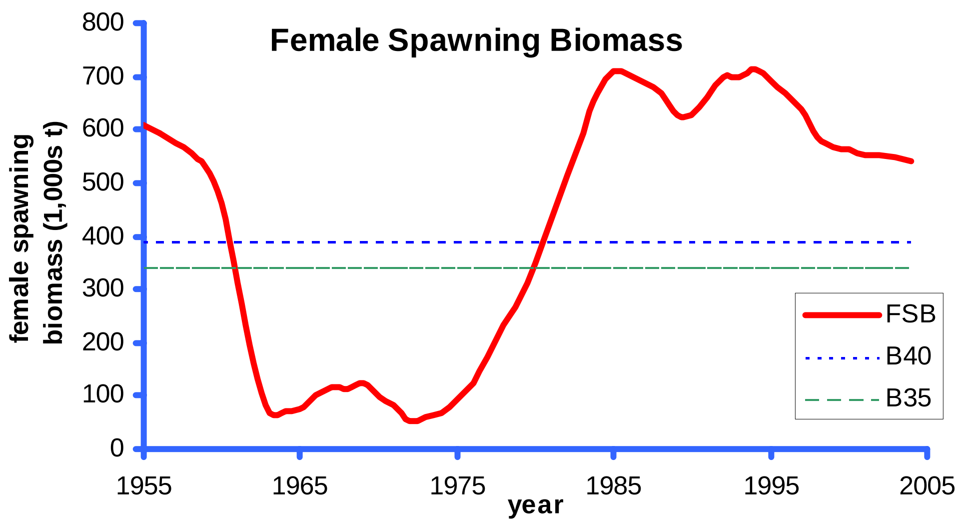


Figure 4.8--Model estimate of yellowfin sole female spawning biomass from 1978-2002 with B40 and B35 levels indicated.

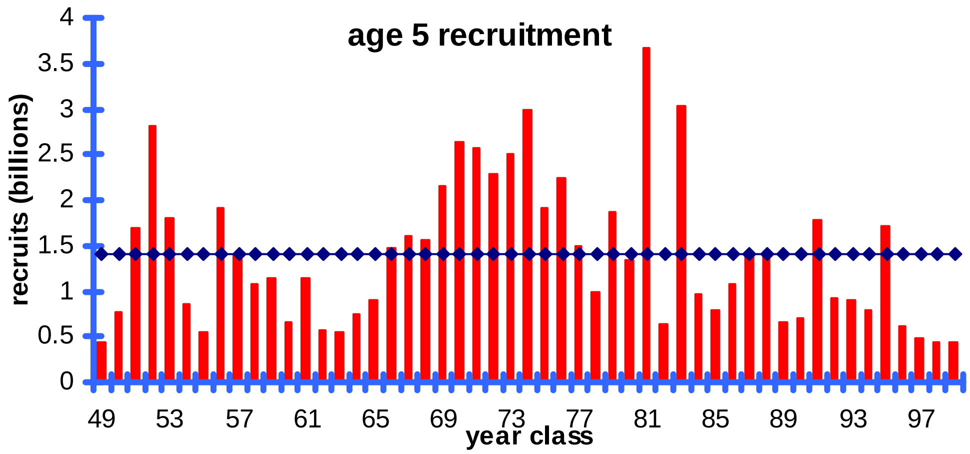


Figure 4.9--Year class strength of age 5 yellowfin sole estimated by the stock assessment model. The dotted line is the average of the estimates from 49 years of recruitment.

All years

Fmsy=0.37

MSY=217,000 t

Bmsy=208,800 t

1978-99

Fmsy=0.22

MSY=150,100

Bmsy=249,800

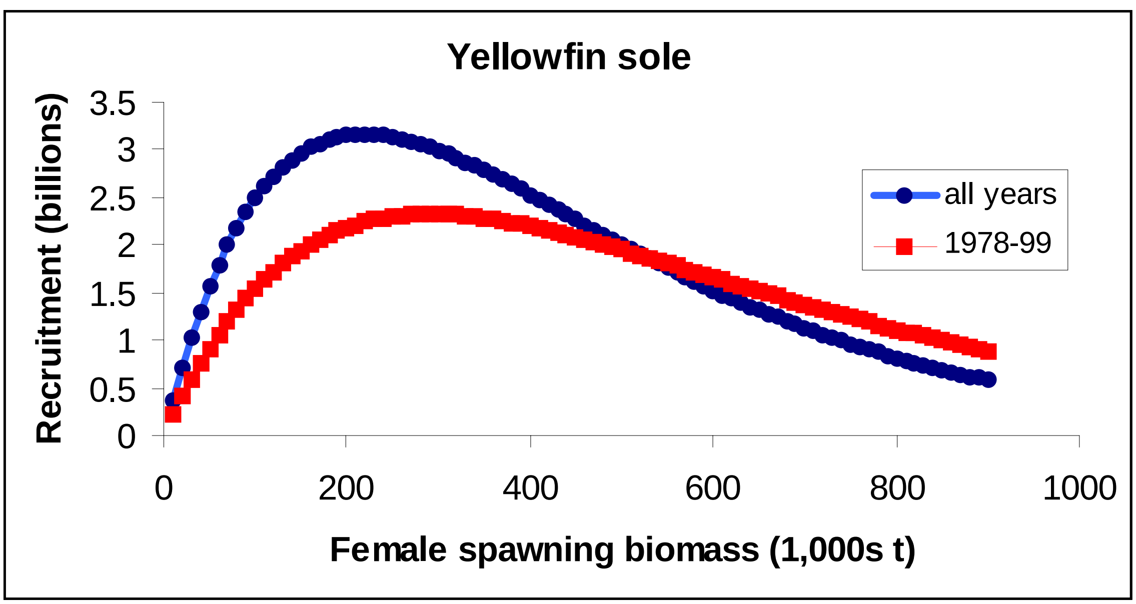


Figure 4.10--Ricker curve fit to yellowfin sole female spawning biomass-age 2 recruitment numbers for two data sets: 1954-99 (all years) and 1978-99.

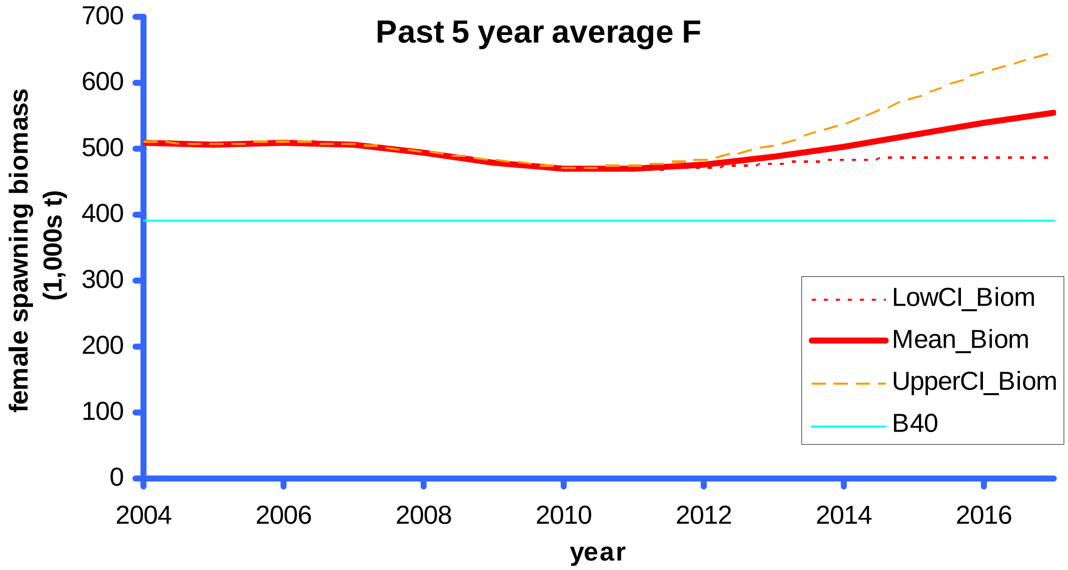


Figure 4.11--Projection of yellowfin sole female spawning biomass (1,000s t) at the average 2000-2004 F level through 2017 with $B_{0.40}$ level indicated.

Appendix

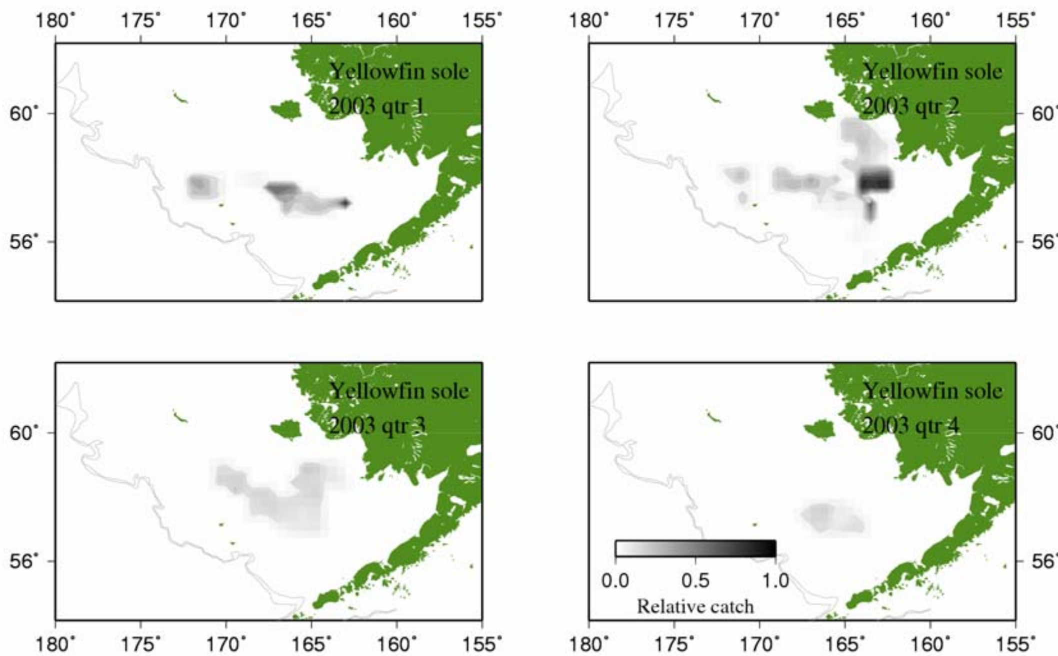
1) 2003 fishery locations by quarter.

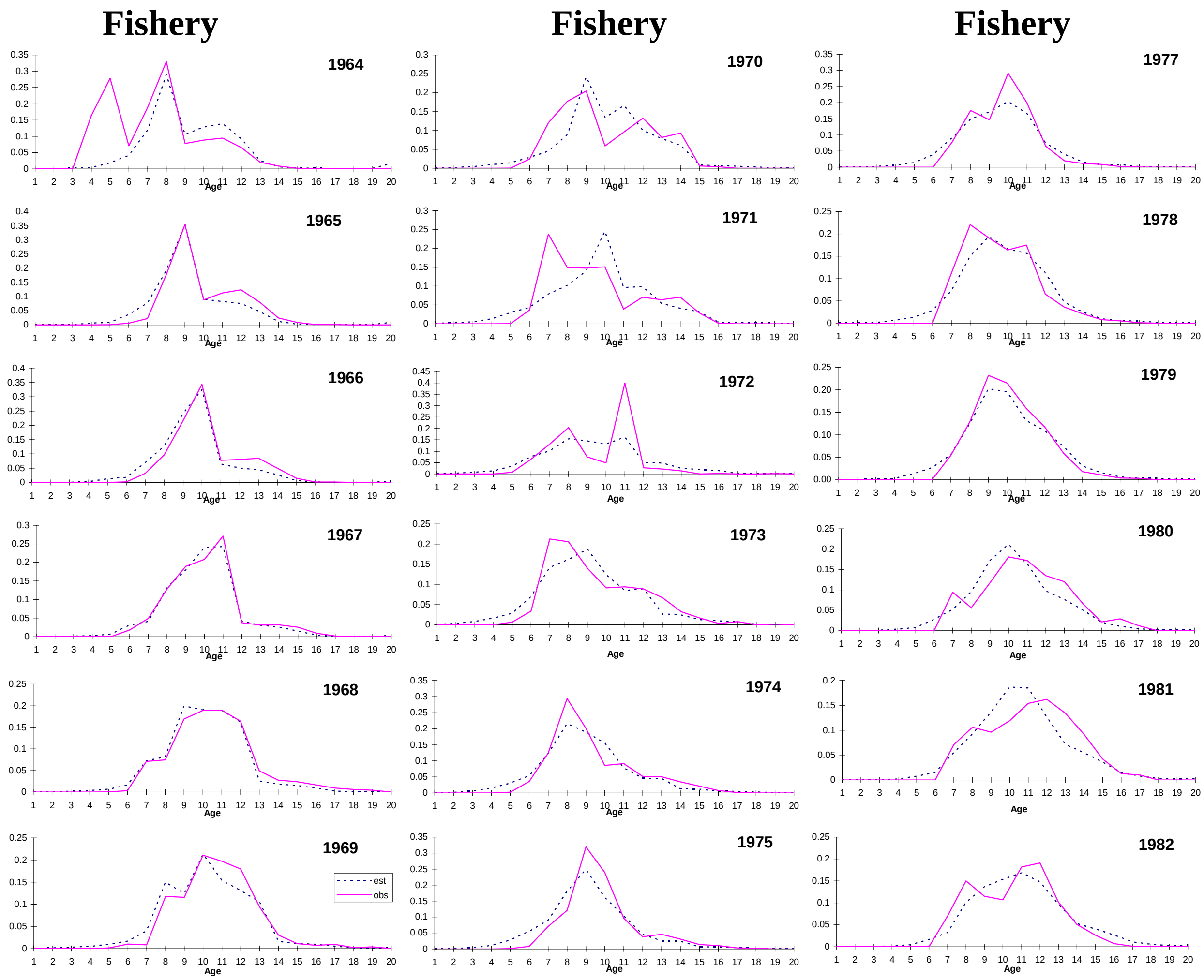
2) Figures showing the fit of the stock assessment model to the time-series of fishery and trawl survey age compositions (survey and fishery observations are the solid lines).

3) Table of yellowfin sole catch from surveys conducted in the eastern Bering Sea and Aleutian Islands area, 1977-2004.

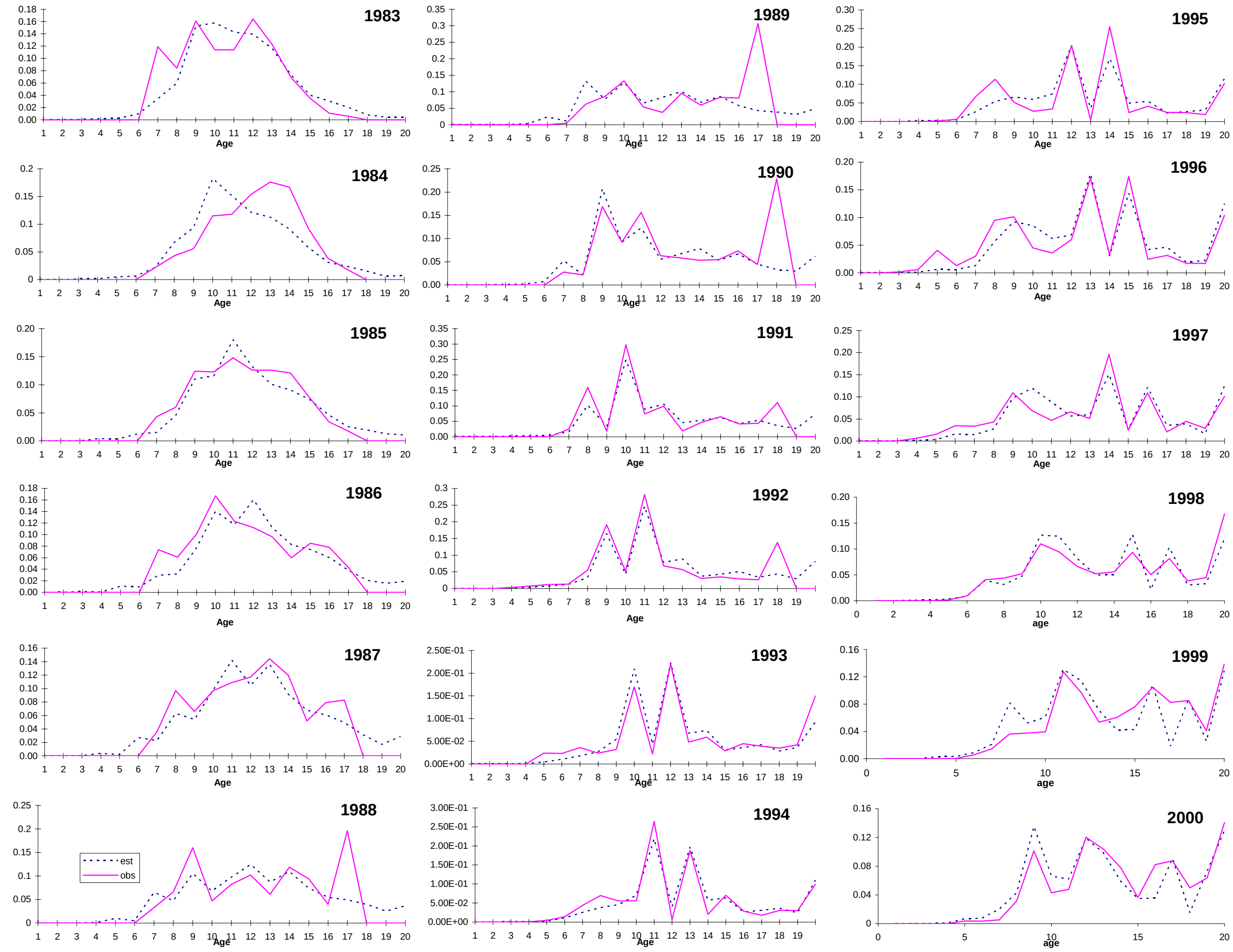
4) Table of number of female spawners (millions) estimated by the stock assessment model for each year.

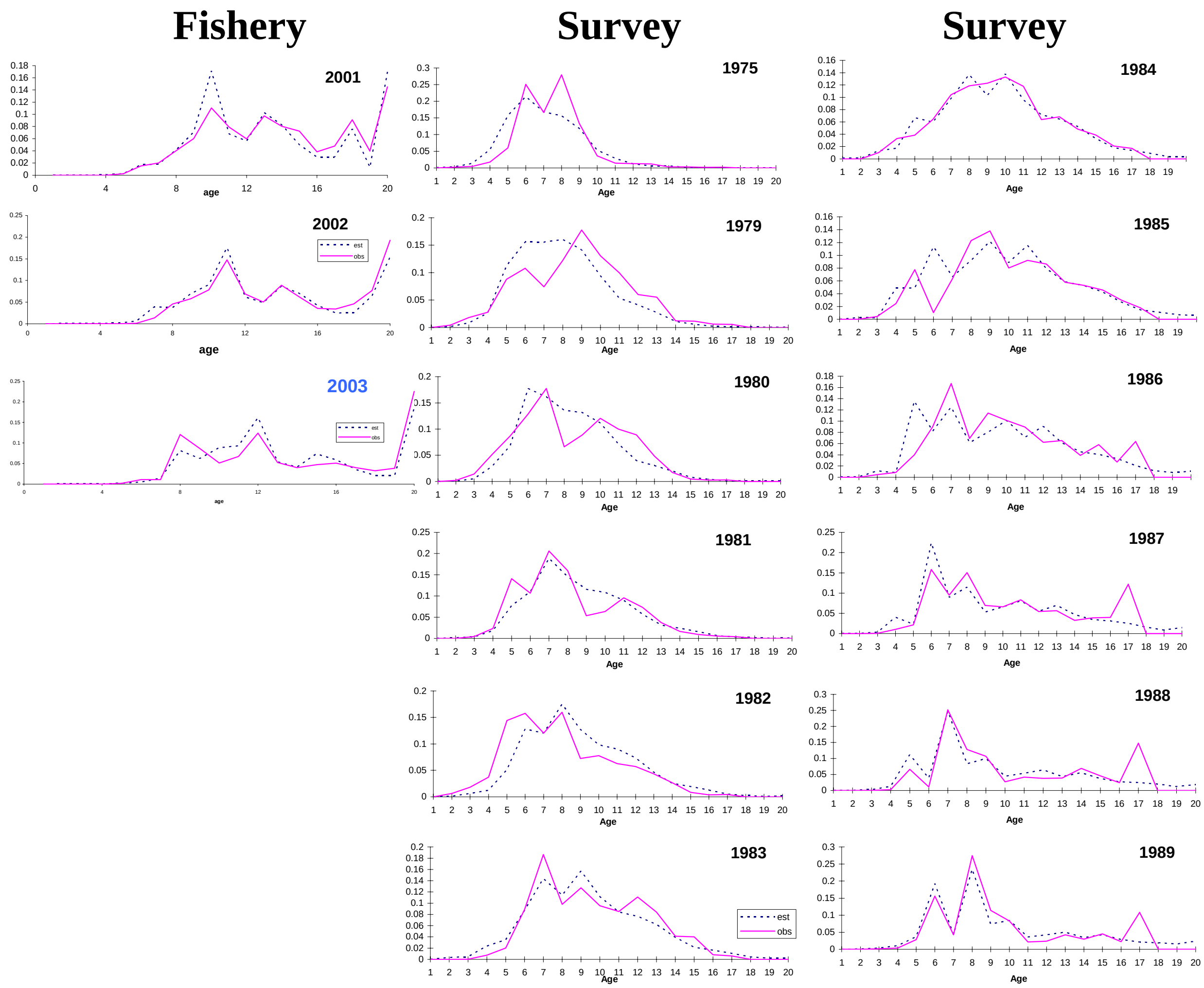
5) Selected parameter estimates and their standard deviation from the stock assessment model.


Yellowfin sole
2003 qtr 1
Yellowfin sole
2003 qtr 2
Yellowfin sole
2003 qtr 3
Yellowfin sole
2003 qtr 4
180˚ 175˚ 170˚ 165˚ 160˚ 155˚
60˚
56˚
0.0 0.5 1.0
Relative catch


Fishery
Fishery
Fishery
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1977
1978
1979
1980
1981
1982
est
obs
Age

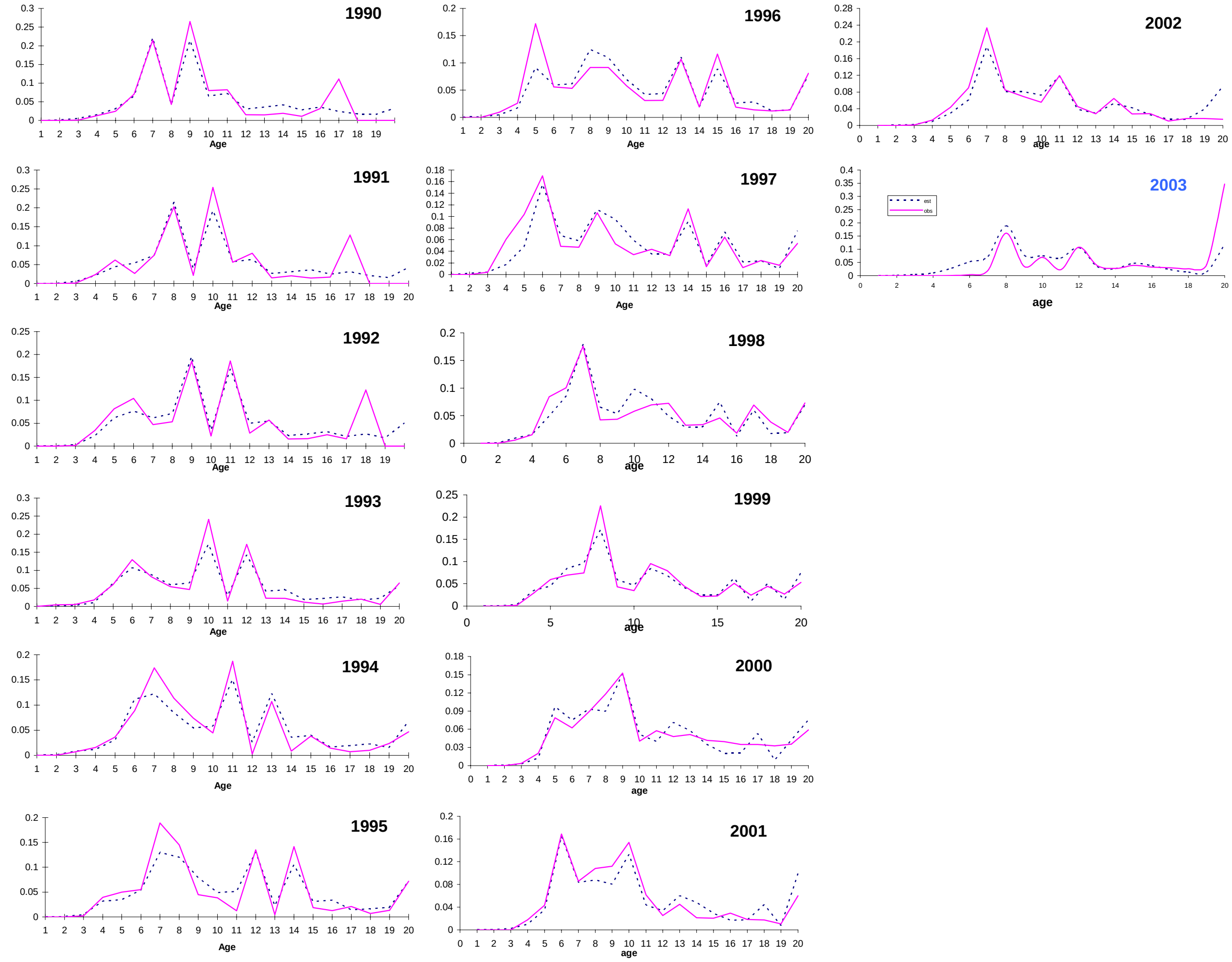
Fishery Fishery Fishery





Fishery
Survey
Survey
2001
2002
2003
1975
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
age
Age
est
obs

Survey Survey Survey



Total catch of yellowfin sole in Alaska
Fisheries Science Center surveys in the Bering Sea.

Year	Research catch (t)
1977	60
1978	71
1979	147
1980	92
1981	74
1982	158
1983	254
1984	218
1985	105
1986	68
1987	92
1988	138
1989	148
1990	129
1991	118
1992	60
1993	95
1994	91
1995	95
1996	72
1997	76
1998	79
1999	61
2000	72
2001	75
2002	76
2003	78
2004	114

Model estimates of yellowfin sole female spawners (millions) from 1954-2004.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	0.38	1.21	1.71	1.53	1.82	2.24	8.19	17.97	36.38	64.37	99.87	129.76	148.17	157.75	162.15	164.29	165.09	165.12	166.75	167.22
1955	0.18	0.78	2.85	3.33	3.25	2.30	7.68	16.28	33.16	58.77	87.39	113.34	129.72	138.22	142.30	143.98	144.99	145.41	144.99	293.27
1956	0.12	0.37	1.82	5.57	7.10	4.12	7.88	15.26	30.02	53.51	79.68	99.01	113.10	120.78	124.44	126.12	126.83	127.46	127.45	384.13
1957	0.40	0.24	0.86	3.56	11.85	8.99	14.08	15.64	28.07	48.24	72.08	89.57	97.97	104.39	107.80	109.34	110.14	110.54	110.75	444.51
1958	0.30	0.83	0.56	1.69	7.57	15.01	30.73	27.96	28.78	45.10	64.97	81.01	88.61	90.41	93.15	94.69	95.46	95.96	96.02	482.34
1959	0.23	0.61	1.95	1.09	3.59	9.59	51.28	60.89	51.17	45.80	59.90	71.81	78.71	80.26	79.19	80.32	81.15	81.65	81.83	493.18
1960	0.24	0.47	1.44	3.80	2.32	4.54	32.56	100.00	107.41	75.91	54.83	58.43	60.97	62.06	61.20	59.44	59.92	60.42	60.60	426.81
1961	0.14	0.49	1.09	2.81	8.05	2.91	15.15	60.83	159.71	131.92	68.81	38.26	34.56	33.14	32.62	31.67	30.57	30.75	30.92	249.41
1962	0.24	0.29	1.15	2.13	5.95	10.03	9.51	26.75	85.14	152.65	82.62	30.76	14.00	11.46	10.63	10.30	9.94	9.57	9.60	87.51
1963	0.12	0.49	0.68	2.24	4.50	7.35	32.04	15.82	32.59	62.56	64.88	23.16	6.80	2.76	2.19	2.00	1.92	1.85	1.78	18.06
1964	0.11	0.25	1.16	1.32	4.76	5.65	24.61	60.36	25.76	41.54	59.87	48.33	14.70	3.98	1.56	-1.22	1.11	1.06	1.02	10.92
1965	0.16	0.23	0.58	2.25	2.79	5.97	18.86	45.88	95.90	31.33	37.10	41.04	28.05	7.83	2.05	0.79	0.61	0.56	0.53	5.99
1966	0.19	0.33	0.55	1.14	4.79	3.53	20.23	36.56	79.82	138.61	36.10	34.56	33.16	21.01	5.68	1.46	0.56	0.43	0.39	4.60
1967	0.31	0.39	0.77	1.07	2.42	6.04	11.88	38.68	61.55	108.41	145.70	30.11	24.78	21.97	13.46	3.58	0.92	0.35	0.27	3.11
1968	0.34	0.64	0.91	1.50	2.28	3.04	20.17	22.21	61.83	75.74	98.53	101.98	17.87	13.52	11.59	6.99	1.85	0.47	0.18	1.74
1969	0.33	0.70	1.51	1.79	3.18	2.87	10.26	38.83	38.04	86.74	83.52	87.04	77.81	12.62	9.23	7.79	4.67	1.23	0.31	1.28
1970	0.46	0.68	1.63	2.93	3.79	3.98	9.55	19.00	60.68	44.83	73.98	54.15	47.57	38.99	6.12	4.40	3.70	2.21	0.58	0.75
1971	0.56	0.93	1.59	3.19	6.22	4.75	13.27	17.72	29.83	72.15	38.74	48.73	30.10	24.26	19.23	2.97	2.13	1.78	1.06	0.64
1972	0.54	1.14	2.19	3.10	6.75	7.76	15.56	23.60	25.24	29.48	47.47	18.38	19.01	10.66	8.31	6.48	1.00	0.71	0.59	0.57
1973	0.48	1.10	2.68	4.28	6.59	8.50	26.17	29.81	39.94	34.60	31.42	40.25	13.42	12.83	6.96	5.34	4.14	0.63	0.45	0.74
1974	0.53	0.98	2.59	5.22	9.09	8.28	28.48	49.27	48.46	50.75	32.97	23.28	25.40	7.80	7.21	3.85	2.94	2.27	0.35	0.65
1975	0.63	1.08	2.31	5.06	11.10	11.48	28.10	55.36	86.30	70.92	59.56	31.40	19.26	19.51	5.79	5.27	2.80	2.13	1.64	0.72
1976	0.40	1.29	2.53	4.51	10.76	14.01	38.87	54.46	96.32	124.71	81.70	55.46	25.36	14.43	14.13	4.13	3.73	1.98	1.50	1.67
1977	0.47	0.82	3.03	4.93	9.58	13.60	47.62	76.07	96.87	145.16	152.84	81.96	48.54	20.63	11.35	10.94	3.18	2.87	1.51	2.42
1978	0.31	0.96	1.94	5.92	10.50	12.12	46.30	93.54	136.51	148.48	182.39	158.01	74.10	40.83	16.78	9.09	8.71	2.52	2.27	3.12
1979	0.21	0.64	2.26	3.78	12.59	13.25	41.08	89.90	163.36	198.70	172.87	172.01	129.37	56.28	29.99	12.13	6.53	6.24	1.80	3.85
1980	0.39	0.43	1.51	4.42	8.04	15.92	45.10	80.57	160.76	248.71	247.19	176.58	153.50	107.37	45.17	23.69	9.53	5.12	4.88	4.42
1981	0.28	0.80	1.01	2.94	9.39	10.17	54.25	88.82	145.44	249.13	317.61	260.58	163.03	131.94	89.24	36.96	19.27	7.73	4.14	7.52
1982	0.77	0.58	1.88	1.97	6.25	11.89	34.67	106.91	160.57	226.06	319.55	336.59	241.96	140.95	110.30	73.45	30.23	15.73	6.29	9.49
1983	0.13	1.58	1.36	3.67	4.18	7.91	40.54	68.43	193.94	251.21	292.75	342.59	316.46	211.90	119.36	91.95	60.85	25.00	12.97	13.01
1984	0.64	0.27	3.72	2.65	7.81	5.29	26.99	80.01	124.12	303.33	325.16	313.68	321.90	276.97	179.33	99.44	76.14	50.29	20.59	21.40
1985	0.21	1.31	0.64	7.25	5.64	9.88	18.03	53.10	144.06	191.42	384.61	339.86	286.94	274.06	228.02	145.33	80.10	61.21	40.30	33.66
1986	0.16	0.42	3.07	1.24	15.43	7.13	33.58	35.29	94.52	217.45	235.13	386.93	298.33	234.15	216.26	177.12	112.20	61.71	47.02	56.81

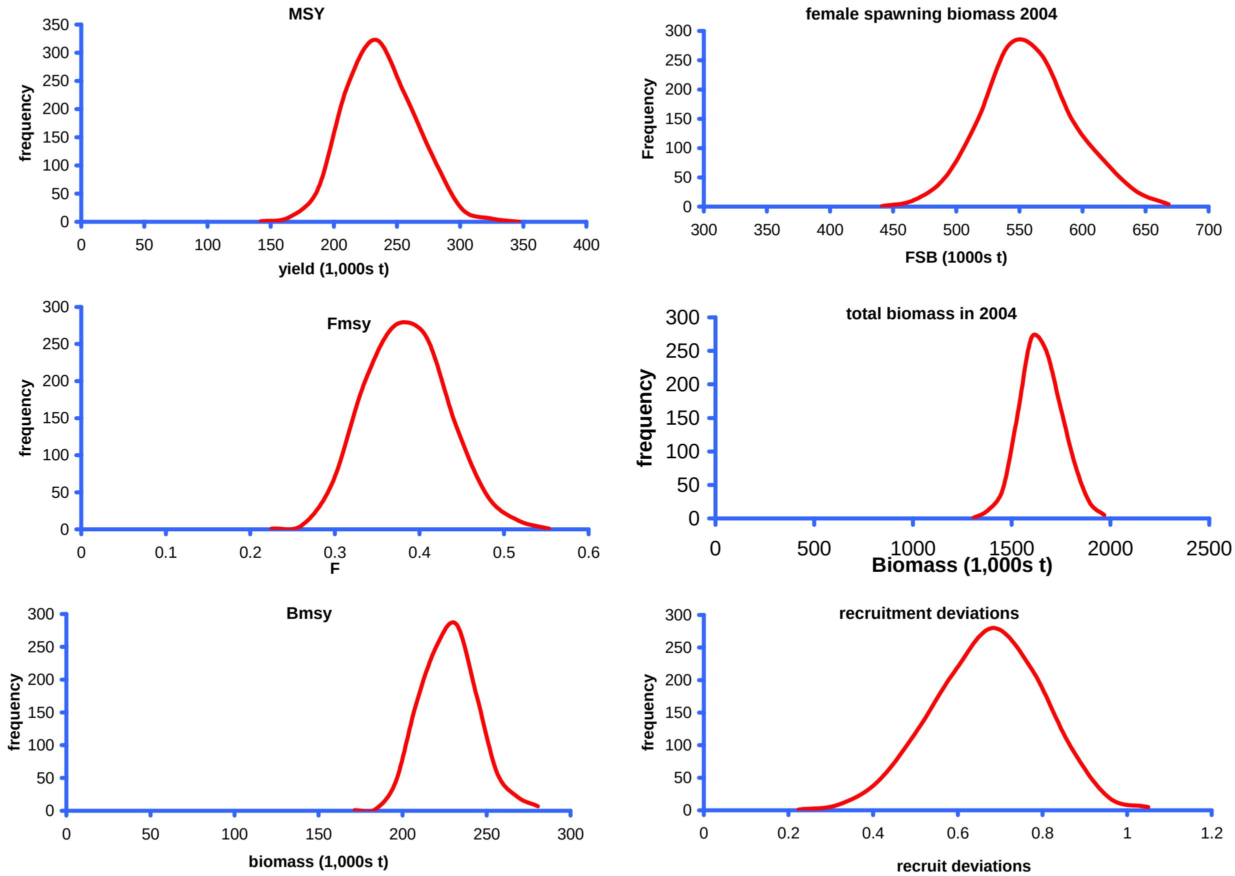
1987	0.23	0.34	0.99	6.00	2.65	19.50	24.24	65.79	62.94	143.20	268.55	238.09	342.04	245.21	186.10	169.20	137.74	87.08	47.75	80.34
1988	0.30	0.46	0.79	1.93	12.76	3.35	66.38	47.57	117.75	95.98	178.56	275.11	213.12	284.78	197.42	147.50	133.28	108.28	68.25	100.39
1989	0.30	0.62	1.09	1.55	4.11	16.13	11.37	129.71	84.31	176.26	116.46	177.00	237.67	171.08	221.06	150.86	112.02	101.02	81.82	127.43
1990	0.14	0.62	1.45	2.12	3.29	5.19	54.92	22.34	232.84	129.30	221.66	120.52	160.19	200.13	139.30	177.19	120.18	89.06	80.08	165.87
1991	0.15	0.28	1.45	2.84	4.51	4.16	17.73	108.59	40.71	367.35	169.54	241.21	115.15	142.63	172.30	118.07	149.26	101.04	74.65	206.14
1992	0.38	0.30	0.66	2.84	6.04	5.71	14.21	35.04	197.54	64.02	479.44	183.48	229.09	101.90	122.04	145.14	98.85	124.71	84.16	233.90
1993	0.19	0.77	0.71	1.30	6.04	7.64	19.44	27.95	63.07	304.55	81.13	500.80	167.72	194.91	83.83	98.84	116.83	79.40	99.88	254.74
1994	0.19	0.40	1.80	1.38	2.76	7.65	26.05	38.38	50.77	98.92	395.88	87.38	473.14	147.62	165.88	70.23	82.30	97.09	65.79	293.81
1995	0.17	0.38	0.94	3.52	2.94	3.49	26.06	51.29	69.24	78.58	126.10	416.44	80.48	405.70	122.40	135.40	56.98	66.63	78.37	290.26
1996	0.36	0.34	0.90	1.83	7.50	3.73	11.89	51.36	92.75	107.67	100.87	133.76	387.06	69.65	339.52	100.83	110.86	46.56	54.29	300.31
1997	0.13	0.74	0.80	1.76	3.89	9.48	12.70	23.41	92.71	143.75	137.51	106.35	123.50	332.71	57.90	277.82	82.01	89.98	37.67	286.94
1998	0.10	0.26	1.73	1.56	3.75	4.92	32.26	24.88	41.77	140.52	177.65	139.36	94.10	101.61	264.69	45.34	216.24	63.70	69.69	251.40
1999	0.09	0.21	0.62	3.37	3.32	4.75	16.78	63.61	45.04	65.08	180.88	189.08	130.00	81.74	85.35	218.87	37.27	177.36	52.09	262.57
2000	0.09	0.19	0.49	1.21	7.18	4.20	16.21	33.18	115.93	71.10	85.39	197.03	180.85	115.87	70.45	72.42	184.57	31.36	148.82	264.02
2001	0.16	0.19	0.45	0.96	2.57	9.09	14.33	32.01	60.24	181.67	92.30	91.82	185.84	158.90	98.45	58.93	60.20	153.12	25.94	341.46
2002	0.22	0.32	0.45	0.87	2.05	3.25	31.02	28.35	58.37	95.21	238.85	100.77	88.04	166.06	137.30	83.74	49.82	50.79	128.81	309.06
2003	0.24	0.45	0.76	0.88	1.85	2.60	11.09	61.31	51.59	91.87	124.39	258.81	95.83	78.02	142.30	115.82	70.21	41.68	42.37	365.25
2004	0.25	0.50	1.05	1.48	1.87	2.34	8.86	21.91	111.51	81.12	119.85	134.53	245.64	84.75	66.71	119.78	96.90	58.62	34.70	339.32

Selected parameter estimates and their standard deviation from the stock assessment model.

	Parameter	**value**	**std dev**		**Parameter**	**value**	**std dev**
	alpha (q estimation)	-0.235	0.046	1970	total biomass	663.430	14.330
	beta (q estimation)	0.149	0.026	1971	total biomass	659.550	15.320
	mean_log_rec	0.639	0.107	1972	total biomass	657.120	16.567
	sel_slope_fsh	1.029	0.024	1973	total biomass	807.120	19.934
	sel_slope_srv	1.509	0.072	1974	total biomass	953.850	23.700
	sel50_fsh	9.003	0.073	1975	total biomass	1166.000	28.069
	sel50_srv	5.273	0.066	1976	total biomass	1376.100	32.696
	F40	0.114	0.001	1977	total biomass	1609.600	37.492
	F35	0.137	0.002	1978	total biomass	1845.700	42.283
	F30	0.165	0.002	1979	total biomass	1987.400	46.627
	Ricker S/R logalpha	-3.252	0.171	1980	total biomass	2151.600	50.860
	Ricker S/R logbeta	-5.441	0.089	1981	total biomass	2302.700	54.721
	Fmsy	0.368	0.048	1982	total biomass	2414.900	58.061
	logFmsy	-0.999	0.131	1983	total biomass	2514.800	61.163
	msy	224.920	27.214	1984	total biomass	2589.500	64.084
	Bmsy	219.200	15.819	1985	total biomass	2606.700	66.837
1954	total biomass	1621.600	138.610	1986	total biomass	2549.500	69.272
1955	total biomass	1660.400	121.080	1987	total biomass	2501.500	71.813
1956	total biomass	1719.400	101.190	1988	total biomass	2465.200	74.332
1957	total biomass	1780.100	81.127	1989	total biomass	2367.500	76.315
1958	total biomass	1848.100	63.086	1990	total biomass	2330.300	78.589
1959	total biomass	1900.200	49.087	1991	total biomass	2353.900	80.901
1960	total biomass	1813.000	40.170	1992	total biomass	2342.000	82.766
1961	total biomass	1456.000	32.155	1993	total biomass	2253.700	84.210
1962	total biomass	1005.700	21.503	1994	total biomass	2212.400	85.900
1963	total biomass	696.670	12.850	1995	total biomass	2125.500	87.332
1964	total biomass	733.970	13.419	1996	total biomass	2055.300	88.912
1965	total biomass	738.120	13.608	1997	total biomass	1979.600	90.581
1966	total biomass	791.940	14.402	1998	total biomass	1855.300	92.137
1967	total biomass	785.180	14.672	1999	total biomass	1811.400	94.244
1968	total biomass	711.210	13.950	2000	total biomass	1792.800	96.126
1969	total biomass	726.490	14.644	2001	total biomass	1749.800	97.784
				2002	total biomass	1709.900	98.617
				2003	total biomass	1658.800	99.804
				2004	total biomass	1601.500	102.070

Yellowfin sole		
year	TAC	ABC
1980	117,000	169,000
1981	117,000	214,500
1982	117,000	214,500
1983	117,000	214,500
1984	230,000	310,000
1985	229,900	310,000
1986	209,500	230,000
1987	187,000	187,000
1988	254,000	254,000
1989	182,675	241,000
1990	207,650	278,900
1991	135,000	250,600
1992	235,000	372,000
1993	220,000	238,000
1994	150,325	230,000
1995	190,000	277,000
1996	200,000	278,000
1997	230,000	233,000
1998	220,000	220,000
1999	207,980	212,000
2000	123,262	191,000
2001	113,000	176,000
2002	86,000	115,000
2003	83,750	114,000
2004	86,075	114,000

posterior distributions



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