YELLOWFIN SOLE

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2001 SAFE:

Changes to the input data

1) 2001 fishery age composition.
2) 2001 survey age composition.
3) 2002 trawl survey biomass point estimate and standard error.
4) Estimate of the discarded and retained portions of the 2001 catch.
5) Estimate of total catch and discard through 14 September 2002.

Assessment results

1) The projected age 2+ biomass for 2003 is 1,554,190 t.
2) The projected female spawning biomass for 2003 is 452,800 t.
3) The recommended 2003 ABC is 113,600 t based on an $F_{40\%}$ (0.115) harvest level.
4) The 2003 overfishing level is 134,800 t based on an $F_{35\%}$ (0.138) harvest level.

SUMMARY

	2002 Assessment Recommendations for 2003 harvest	2001 Assessment Recommendations For 2002 harvest
Total biomass	1,554,190 t	1,596,800 t
ABC	113,600 t	114,900 t
Overfishing yield	134,800 t	136,400 t
F_{ABC}	$F_{0.40} = 0.115$	$F_{0.40} = 0.11$
$F_{overfishing}$	$F_{0.35} = 0.138$	$F_{0.35} = 0.13$

SSC Comments

The SSC made a number of comments regarding Bering Sea flatfish in their December 2001 minutes. Two of the comments were applicable to yellowfin sole. The first comment encouraged the authors to "examine the assumption of static size-at-age common to flatfish assessments". Weight and size at age from survey age samples were examined for yellowfin sole and are reported in section *Length and weight at age and Maturity at age* in this assessment.

The second comment was as follows: "Many of the flatfish species have 30-40 years of stock recruitment data. Further, the stock recruitment plots are quite similar and indicate density dependent response at high biomass levels as well as strong recruitment response following the 1976-77 climatic change. The SSC recommends that for assessments with a lengthy stock recruitment time series, management under Tier 1 status be explored:"

The use of estimated recruitments and stock size to produce reliable estimates of F_{msy} and B_{msy} for subsequent management in Tier 1 is examined in the *Tier 1 Considerations* section of this document.

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. The resource inhabits the EBS shelf and is 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 2001, by quarter, are shown in the Appendix figures. The total catch (t) since implementation of the MFCMA in 1977 are shown in Table 3.1.

Yellowfin sole were overexploited by foreign fisheries in 1959-62 when catches averaged 404,000 t annually (Fig. 3.1). 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 which decreased to 101,201 t in 1998. The 2001 catch totaled 63,400 t and 55,400 t have been caught in 2002 through the middle of September. Thus far, the 2002 catch is 48% of the ABC and 64% of the TAC. The yellowfin sole harvest in 2002 has been constrained by two seasonal closures due to the attainment of halibut PSC limits: from May 11-May 21 and from June 15-June 30. In addition, zone 1 was closed on May 21 for the remainder of 2002 to prevent exceeding the 2002 bycatch allowance of red king crab specified for the yellowfin sole target fishery.

The catch information presented above also includes yellowfin sole which were discarded in DAP fisheries since their beginning in 1987. Discard estimates are calculated from weekly observer discard estimates, by target fishery, applied to the weekly 'blend' estimate of retained catch from the NMFS regional office summed over the fishing year.

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

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 3.2).

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 14 2002 (Table 3.1) and fishery catch-at-age (numbers) from 1964-2001 (Table 3.3, 1977-2001).

Survey Biomass Estimates and Population Age Composition Estimates

The survey estimates of population numbers-at-age from 1975 and 1979-2001 are used in the assessment model and are shown for 1982-2001 in Table 3.5. 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	135,300	1,719,900	1,855,200	1,600,300 - 2,110,000
2002			2,003,400	1,728,200 – 2,278,600

* 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 2002 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. Estimates of biomass since 1990 show 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 are 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. 3.2, 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 3.2). 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. 3.3) 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 and 2002. 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 3.4).

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

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	0.13
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. 3.5). 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 3.4). 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.

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

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 3.6). 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 3.5 presents the key equations used to model the yellowfin sole population dynamics in the Bering Sea and Table 3.7 provides a description of the variables used in Table 3.6.

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 3.5).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Survey catchability	Year class strength	Total
49	4	2	68	123

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 and the entry of another year class into the observed population.

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 using the population dynamics equations given in Table 3.6.

Selectivity

Fishery and survey selectivity was modeled in this assessment using the two parameter formulation of the logistic function, as shown in Table 3.6. 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

Last year's assessment (Wilderbuer and Nichol 2001) 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:

$$q = \alpha + \beta T$$

where q is catchability, T is the average annual bottom water temperature 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 3.6.

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. The approach was accepted by the SSC in the 2001 stock assessment.

MODEL RESULTS

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages is given in Table 3.8. The large 1997 catch corresponds to a full-selection F value of 0.16, which is higher than the 1977-2000 average full selection-F of 0.11 but only represents an exploitation fraction of 10%. Selectivities estimated by the model (Table 3.9, Figure 3.7) 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 1.35 for the period 1982-2002 which results in the model estimate of the 2002 total biomass at 1,551,700 t (Table 3.10). 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 3.10, Figure 3.7, bottom left panel). Sustained above average recruitment from 1967-76 combined with light exploitation resulted in a biomass increase to a peak of nearly 2.5 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 year class 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.

The female spawning biomass has also steadily declined since the peak in 1985, with a 2002 estimate of 478,500 t (30% decline). This level of spawning biomass is consistent with the estimates since 1999 and is about 125% of the $B_{40\%}$ level (Fig. 3.8). The model estimate of yellowfin sole population numbers at age for all years is shown in Table 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 3.7. Allowing q to be correlated with annual bottom temperature provides a close 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 3.7). Above average recruitment from the 1991 year-class 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 2003. Including the 2002 reported catch through 14 September (including discards), the model projects the total biomass for 2003 at **1,554,190 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 3.9 and Table 3.12). The 1981 year class was the strongest observed (and estimated) during the 46 year period analyzed and the 1983 year class is 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 year class was strong. With the exception of these three year classes, recruitment over the past 13 years has been below the 48 year average which has caused the population decline. The 1995 year-class, which will be better estimated in future years as they appear more often in survey and fishery catches, could be of average strength.

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. If we fit a stock-recruit relationship to these data, we can derive estimates of F_{MSY} and B_{MSY} which assume that the fit to the stock-recruitment data points represents the long-term productivity of the stock. However, 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 of flatfish larvae was 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. The presence of decadal shifts in production could be addressed in tier 3 by truncating the recruitment time series used to estimate the biological reference points.

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 Fig. 3.9 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 plan to perform 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.

Spawner-Recruit Relationship

The relationship between the model estimates of female spawning biomass and age 5 recruitment are shown in Figure 3.10. The forty-five data points were fit with a Ricker (1958) form of spawner-recruit curve. Estimation of recruitment using these data indicate that good year classes may result at high or low spawning stock size. However, estimation of MSY using these data is not recommended for management purposes since environmental processes which can determine the level of recruitment for a given stock size are not considered.

Historical Exploitation Rates

Based on results from the stock assessment model, annual exploitation rates of yellowfin sole ranged from 3 to 10% of the total biomass since 1977, and have averaged 6% (Table 3.8).

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 2003 is 1,554,190 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 1978-2001 from the stock assessment model to estimate **$B_{0.40}$ = 385,000 t**. The stock assessment projection model estimates the 2003 level of female spawning biomass at 444,700 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (453,700 > 392,200, Figure 3.8), yellowfin sole reference fishing mortality is defined in tier 3a. For the 2003 harvest: $F_{ABC} \leq F_{0.40} = 0.115$ (full selection F values).

Acceptable biological catch is estimated for 2003 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the 2002 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 2003 ABC of 113,600 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. The overfishing fishing mortality value, ABC fishing mortality value and their corresponding yields are given as follows:

Harvest level	F value	2003 Yield
$F_{OFL} = F_{0.35}$	0.138	134,800 t
$F_{ABC} = F_{0.40}$	0.115	113,600 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 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2002. 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 2003, 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 2003 recommended in the assessment to the *max* F_{ABC} for 2003. (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 1997-2001 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 2003 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

Scenario 7: In 2003 and 2004, 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 2015 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 3.13 and Figure 3.11 indicate that yellowfin are not currently overfished and are not approaching an overfished condition.

OTHER CONSIDERATIONS

Groundfish predators of yellowfin sole include Pacific cod, skates and Pacific halibut, mostly on fish ranging from 7 to 25 cm standard length. Yellowfin sole diet consists mainly of bivalves, polychaetes, amphipods and echiurids.

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Table 3.1- Catch of yellowfin sole 1977-2002. Catch for 2002 is the total through September 14, 2002.

		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			55,385	55,385

Table 3.2—Discard and retained catch, by target fishery, for yellowfin sole in 2001 and 2002.

2001

Target Fishery	Discard	Retained
Bottom pollock	106	328
Pacific cod	1,116	146
other flatfish	4	10
flathead sole	483	2,507
mid-water pollock	112	46
rock sole	842	3,098
Greenland turbot	3	2
arrowtooth flounder	1	10
yellowfin sole	5,954	48,611
no retained groundfish	13	0
Total	8,635	54,759

2002

Target Fishery	Discard	Retained
Bottom pollock	199	161
Pacific cod	1,368	453
other flatfish	1	5
rockfish	0	
flathead sole	312	1,531
mid-water pollock	138	268
rock sole	1,000	2,830
arrowtooth flounder	0	11
yellowfin sole	5,376	42,405
no retained groundfish	0	
Total	8,393	47,665

TABLE 3.3-YELLOWFIN SOLE FISHERY CATCH-AT-AGE IN NUMBERS (millions), 1977-2001.

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

Table 3.4--Trawl survey estimates of yellowfin sole population numbers at age 1982-2001 (milions)

	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

Table 3.5--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	1.0
19	1.0
20	1.0

Table 3.6--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 3.7--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 3.8--Model estimates of yellowfin sole fishing mortality and exploitation rate (catch/total biomass)

Year	Full selection F	Exploitation Rate
1954	0.0104	0.0079
1955	0.0124	0.0090
1956	0.0214	0.0145
1957	0.0216	0.0137
1958	0.0407	0.0240
1959	0.1838	0.0978
1960	0.5660	0.2521
1961	1.0721	0.3809
1962	1.6066	0.4185
1963	0.4922	0.1233
1964	0.5896	0.1517
1965	0.2376	0.0731
1966	0.3645	0.1298
1967	0.5656	0.2080
1968	0.2981	0.1196
1969	0.6548	0.2331
1970	0.6410	0.2042
1971	1.0321	0.2485
1972	0.3572	0.0748
1973	0.5199	0.0996
1974	0.2207	0.0455
1975	0.2470	0.0571
1976	0.1577	0.0421
1977	0.1216	0.0374
1978	0.2306	0.0774
1979	0.1359	0.0515
1980	0.0983	0.0421
1981	0.0920	0.0439
1982	0.0781	0.0412
1983	0.0788	0.0449
1984	0.1084	0.0644
1985	0.1542	0.0916
1986	0.1473	0.0865
1987	0.1343	0.0772
1988	0.1757	0.0970
1989	0.1244	0.0699
1990	0.0630	0.0376
1991	0.0701	0.0440
1992	0.1147	0.0742
1993	0.0771	0.0518
1994	0.1074	0.0721
1995	0.0977	0.0650
1996	0.1062	0.0701
1997	0.1586	0.1022
1998	0.0958	0.0613
1999	0.0656	0.0419
2000	0.0827	0.0526
2001	0.0625	0.0405
2002		0.0357

Table 3.9--Model estimates of yellowfin sole age-specific selectivities for survey and fishery data.

Age	Fishery (1964-2001)	Survey (1982-2001)
1	0.000	0.002
2	0.001	0.007
3	0.002	0.032
4	0.006	0.130
5	0.016	0.403
6	0.043	0.753
7	0.110	0.933
8	0.255	0.984
9	0.486	0.996
10	0.724	0.999
11	0.879	1.000
12	0.953	1.000
13	0.982	1.000
14	0.982	1.000
15	0.982	1.000
16	0.982	1.000
17	0.982	1.000
18	0.982	1.000
19	0.982	1.000
20	0.982	1.000

Table 3.10-Model estimates of yellowfin sole 2+ biomass and begin-year female spawning biomass from the 2001 and 2002 stock assessments.

	2002 Assessment		2001 Assessment	
Year	Female Spawning Biomass	Age 2+ Total Biomass	Female Spawning Biomass	Age 2+ Total Biomass
1964	71,975	732,648	72,142	733,033
1965	74,509	735,777	74,707	736,123
1966	99,406	788,293	99,598	788,623
1967	116,434	779,899	116,608	780,210
1968	110,832	703,994	111,002	704,279
1969	121,354	717,128	121,507	717,376
1970	97,217	651,837	97,381	652,036
1971	79,500	645,348	79,664	645,541
1972	51,216	640,203	51,359	640,424
1973	58,617	785,769	58,730	785,977
1974	64,121	927,304	64,219	927,458
1975	88,568	1,133,200	88,649	1,133,220
1976	119,562	1,336,130	119,646	1,335,930
1977	165,511	1,561,680	165,601	1,561,190
1978	224,009	1,789,190	224,113	1,788,340
1979	269,069	1,921,810	269,215	1,920,570
1980	335,236	2,076,780	335,341	2,075,140
1981	413,845	2,218,580	413,837	2,216,570
1982	491,877	2,321,480	491,703	2,319,120
1983	569,993	2,411,280	569,620	2,408,550
1984	638,951	2,475,200	638,377	2,471,950
1985	676,426	2,480,370	675,679	2,476,320
1986	668,321	2,410,270	667,439	2,405,050
1987	647,567	2,349,050	646,543	2,342,180
1988	626,497	2,300,020	625,340	2,291,060
1989	582,216	2,190,980	580,946	2,179,820
1990	575,511	2,143,960	573,999	2,130,760
1991	607,345	2,159,720	605,350	2,144,850
1992	636,557	2,142,000	633,829	2,125,740
1993	633,416	2,049,380	629,727	2,032,500
1994	640,517	2,005,660	635,717	1,989,120
1995	616,620	1,918,910	610,719	1,903,910
1996	591,318	1,850,430	584,574	1,837,870
1997	560,805	1,775,610	553,640	1,765,470
1998	509,377	1,650,310	502,320	1,642,200
1999	491,235	1,606,790	484,524	1,600,920
2000	486,346	1,593,820	480,302	1,592,370
2001	477,860	1,564,820	473,070	1,571,180
2002	478,506	1,551,720		

Table 3.11--Model estimates of yellowfin sole population numbers (millions) from 1954-2002.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	2.87	4.06	2.23	0.92	0.44	0.38	0.36	0.35	0.34	0.33	0.33	0.33	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
1955	1.35	2.55	3.60	1.98	0.81	0.39	0.34	0.32	0.31	0.30	0.29	0.29	0.29	0.28	0.28	0.28	0.28	0.28	0.28	0.56
1956	0.87	1.20	2.26	3.19	1.76	0.72	0.35	0.30	0.28	0.27	0.27	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.74
1957	3.12	0.77	1.07	2.00	2.83	1.56	0.64	0.31	0.26	0.25	0.24	0.23	0.22	0.22	0.22	0.22	0.22	0.21	0.21	0.86
1958	2.31	2.77	0.68	0.95	1.78	2.51	1.38	0.57	0.27	0.23	0.22	0.21	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.93
1959	1.74	2.05	2.45	0.61	0.84	1.58	2.22	1.22	0.50	0.24	0.20	0.18	0.18	0.17	0.16	0.16	0.16	0.16	0.16	0.95
1960	1.84	1.55	1.82	2.18	0.54	0.74	1.39	1.93	1.03	0.40	0.18	0.15	0.14	0.13	0.13	0.12	0.12	0.12	0.12	0.82
1961	1.06	1.63	1.37	1.61	1.92	0.47	0.64	1.16	1.48	0.69	0.24	0.10	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.48
1962	1.83	0.94	1.44	1.21	1.42	1.68	0.40	0.51	0.78	0.78	0.28	0.08	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.17
1963	0.90	1.62	0.83	1.28	1.07	1.23	1.39	0.30	0.30	0.32	0.22	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.03
1964	0.85	0.80	1.44	0.74	1.13	0.94	1.06	1.17	0.23	0.21	0.20	0.12	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.02
1965	1.20	0.76	0.71	1.27	0.65	0.99	0.81	0.88	0.89	0.15	0.12	0.10	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.01
1966	1.43	1.06	0.67	0.63	1.13	0.58	0.87	0.70	0.74	0.70	0.12	0.09	0.07	0.04	0.01	0.00	0.00	0.00	0.00	0.01
1967	2.36	1.27	0.94	0.60	0.56	0.99	0.50	0.74	0.57	0.55	0.48	0.07	0.05	0.05	0.03	0.01	0.00	0.00	0.00	0.01
1968	2.56	2.10	1.13	0.84	0.53	0.49	0.86	0.42	0.57	0.38	0.32	0.26	0.04	0.03	0.02	0.01	0.00	0.00	0.00	0.00
1969	2.49	2.27	1.86	1.00	0.74	0.46	0.43	0.74	0.34	0.44	0.27	0.22	0.17	0.03	0.02	0.02	0.01	0.00	0.00	0.00
1970	3.43	2.21	2.01	1.65	0.88	0.65	0.40	0.35	0.55	0.22	0.24	0.14	0.10	0.08	0.01	0.01	0.01	0.00	0.00	0.00
1971	4.18	3.04	1.96	1.78	1.45	0.77	0.56	0.33	0.27	0.36	0.12	0.12	0.07	0.05	0.04	0.01	0.00	0.00	0.00	0.00
1972	4.04	3.70	2.70	1.73	1.57	1.27	0.66	0.44	0.23	0.14	0.15	0.04	0.04	0.02	0.02	0.01	0.00	0.00	0.00	0.00
1973	3.60	3.58	3.28	2.39	1.53	1.39	1.11	0.56	0.36	0.17	0.10	0.10	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00
1974	3.92	3.19	3.18	2.91	2.11	1.35	1.20	0.93	0.44	0.25	0.10	0.05	0.05	0.01	0.01	0.01	0.01	0.00	0.00	0.00
1975	4.69	3.48	2.83	2.82	2.58	1.87	1.18	1.04	0.78	0.35	0.19	0.07	0.04	0.04	0.01	0.01	0.01	0.00	0.00	0.00
1976	2.98	4.16	3.09	2.51	2.49	2.28	1.64	1.02	0.87	0.61	0.26	0.13	0.05	0.03	0.03	0.01	0.01	0.00	0.00	0.00
1977	3.46	2.64	3.69	2.74	2.22	2.21	2.01	1.43	0.87	0.71	0.48	0.20	0.10	0.04	0.02	0.02	0.01	0.01	0.00	0.00
1978	2.28	3.07	2.34	3.27	2.43	1.97	1.95	1.75	1.23	0.73	0.58	0.39	0.16	0.08	0.03	0.02	0.02	0.00	0.00	0.01
1979	1.51	2.03	2.72	2.08	2.90	2.14	1.73	1.68	1.47	0.97	0.55	0.42	0.27	0.11	0.06	0.02	0.01	0.01	0.00	0.01
1980	2.83	1.34	1.80	2.41	1.84	2.56	1.89	1.51	1.44	1.22	0.78	0.43	0.33	0.21	0.09	0.04	0.02	0.01	0.01	0.01
1981	2.03	2.51	1.19	1.59	2.14	1.63	2.27	1.66	1.30	1.22	1.01	0.64	0.35	0.26	0.17	0.07	0.04	0.01	0.01	0.01
1982	5.54	1.80	2.22	1.05	1.41	1.90	1.44	1.99	1.44	1.11	1.01	0.82	0.52	0.28	0.21	0.14	0.06	0.03	0.01	0.02
1983	0.93	4.91	1.59	1.97	0.93	1.25	1.68	1.27	1.73	1.23	0.93	0.84	0.68	0.42	0.23	0.18	0.11	0.05	0.02	0.02
1984	4.52	0.82	4.36	1.41	1.75	0.83	1.11	1.47	1.10	1.48	1.03	0.77	0.69	0.56	0.35	0.19	0.14	0.09	0.04	0.04
1985	1.40	4.01	0.73	3.86	1.25	1.55	0.73	0.97	1.27	0.93	1.21	0.83	0.61	0.55	0.44	0.28	0.15	0.11	0.07	0.06
1986	1.15	1.24	3.55	0.65	3.42	1.11	1.36	0.64	0.83	1.05	0.73	0.94	0.63	0.47	0.42	0.34	0.21	0.12	0.09	0.10
1987	1.61	1.02	1.10	3.15	0.57	3.03	0.98	1.19	0.54	0.68	0.83	0.57	0.72	0.49	0.36	0.32	0.26	0.16	0.09	0.15
1988	2.20	1.42	0.90	0.97	2.79	0.51	2.67	0.85	1.02	0.45	0.55	0.66	0.45	0.56	0.38	0.28	0.25	0.20	0.13	0.18
1989	2.17	1.95	1.26	0.80	0.86	2.47	0.45	2.32	0.72	0.83	0.35	0.42	0.49	0.33	0.42	0.28	0.21	0.19	0.15	0.23
1990	0.97	1.93	1.73	1.12	0.71	0.76	2.18	0.39	2.00	0.60	0.67	0.28	0.33	0.39	0.26	0.33	0.22	0.16	0.15	0.30
1991	1.00	0.86	1.71	1.53	0.99	0.63	0.68	1.92	0.34	1.72	0.51	0.56	0.23	0.27	0.32	0.22	0.27	0.18	0.14	0.37
1992	2.73	0.88	0.77	1.52	1.36	0.88	0.56	0.59	1.67	0.29	1.45	0.43	0.47	0.19	0.23	0.27	0.18	0.23	0.15	0.42
1993	1.54	2.42	0.78	0.68	1.34	1.20	0.78	0.49	0.51	1.40	0.24	1.16	0.34	0.37	0.15	0.18	0.21	0.14	0.18	0.45
1994	1.44	1.37	2.15	0.69	0.60	1.19	1.06	0.68	0.42	0.44	1.18	0.20	0.96	0.28	0.31	0.13	0.15	0.17	0.12	0.52
1995	1.11	1.28	1.22	1.90	0.62	0.53	1.05	0.93	0.59	0.36	0.36	0.95	0.16	0.76	0.22	0.24	0.10	0.12	0.14	0.51
1996	2.01	0.98	1.13	1.08	1.69	0.55	0.47	0.92	0.81	0.50	0.29	0.29	0.77	0.13	0.62	0.18	0.20	0.08	0.10	0.52
1997	1.20	1.78	0.87	1.01	0.96	1.49	0.48	0.41	0.80	0.68	0.41	0.24	0.23	0.61	0.10	0.49	0.14	0.16	0.06	0.49
1998	1.28	1.06	1.58	0.77	0.89	0.84	1.32	0.42	0.35	0.65	0.54	0.32	0.18	0.18	0.47	0.08	0.37	0.11	0.12	0.42
1999	1.18	1.14	0.94	1.40	0.69	0.79	0.75	1.16	0.36	0.30	0.54	0.44	0.26	0.15	0.14	0.38	0.06	0.30	0.09	0.44
2000	1.67	1.05	1.01	0.84	1.24	0.61	0.70	0.66	1.01	0.31	0.25	0.45	0.37	0.21	0.12	0.12	0.31	0.05	0.25	0.44
2001	1.88	1.48	0.93	0.90	0.74	1.10	0.54	0.61	0.57	0.86	0.26	0.21	0.37	0.30	0.17	0.10	0.10	0.26	0.04	0.56
2002	1.91	1.67	1.32	0.82	0.79	0.66	0.97	0.47	0.54	0.49	0.73	0.22	0.17	0.31	0.25	0.15	0.08	0.08	0.21	0.50

Table 3.12--Estimated age 5 recruitment (millions)
from the 2001 and 2002 assessments.

Year class	2002 Assessment	2001 Assessment
1959	1,129	1,129
1960	651	651
1961	1,128	1,129
1962	556	556
1963	526	527
1964	740	740
1965	883	882
1966	1,455	1,454
1967	1,572	1,573
1968	1,533	1,534
1969	2,112	2,113
1970	2,576	2,575
1971	2,495	2,491
1972	2,221	2,217
1973	2,425	2,422
1974	2,898	2,894
1975	1,840	1,837
1976	2,140	2,138
1977	1,412	1,411
1978	933	932
1979	1,748	1,746
1980	1,252	1,250
1981	3,424	3,417
1982	573	545
1983	2,792	2,777
1984	863	836
1985	709	679
1986	993	968
1987	1,360	1,375
1988	1,343	1,352
1989	602	595
1990	616	575
1991	1,688	1,776
1992	955	984
1993	891	922
1994	686	688
1995	1,241	1,150
1996	741	799

Table 3.13--Projections of yellowfin sole female spawing 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
2002	450.669	65.004	0.06
2003	444.709	113.597	0.12
2004	421.803	107.747	0.12
2005	400.140	102.395	0.12
2006	381.082	96.528	0.11
2007	364.915	88.733	0.11
2008	352.898	83.928	0.11
2009	346.032	82.082	0.10
2010	345.477	83.089	0.10
2011	350.218	86.133	0.10
2012	356.170	89.379	0.11
2013	362.381	92.222	0.11
2014	367.872	94.288	0.11
2015	372.941	95.985	0.11

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2002	450.669	65.003	0.06
2003	452.761	58.237	0.06
2004	452.202	57.983	0.06
2005	450.294	57.609	0.06
2006	448.216	57.125	0.06
2007	445.548	56.732	0.06
2008	442.993	56.782	0.06
2009	442.442	57.386	0.06
2010	446.655	58.572	0.06
2011	456.205	60.144	0.06
2012	466.917	61.626	0.06
2013	478.354	63.026	0.06
2014	489.292	64.291	0.06
2015	500.120	65.511	0.06

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2002	450.669	65.005	0.06
2003	447.791	92.612	0.09
2004	433.248	89.494	0.09
2005	418.715	86.508	0.09
2006	405.458	83.668	0.09
2007	393.137	81.305	0.09
2008	382.549	79.957	0.09
2009	375.504	79.757	0.09
2010	374.149	80.621	0.09
2011	378.357	82.139	0.09
2012	384.300	83.625	0.09
2013	391.213	85.044	0.09
2014	397.951	86.319	0.09
2015	404.663	87.544	0.09

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2002	450.669	0	0
2003	460.960	0	0
2004	484.879	0	0
2005	507.113	0	0
2006	528.389	0	0
2007	547.812	0	0
2008	565.526	0	0
2009	583.115	0	0
2010	604.145	0	0
2011	630.406	0	0
2012	656.697	0	0
2013	683.240	0	0
2014	708.575	0	0
2015	733.698	0	0

Table 3.13—continued.

Scenario 6

Determination of whether yellowfin sole are currently overfish

B35=336.913 t

Year	Female spawning biomass	catch	F
2002	450.669	65.004	0.06
2003	441.555	**134.804**	0.14
2004	410.333	125.437	0.14
2005	382.037	116.247	0.14
2006	358.783	102.520	0.13
2007	341.087	93.009	0.12
2008	328.481	87.381	0.12
2009	321.610	85.333	0.11
2010	321.213	86.524	0.11
2011	325.958	89.907	0.12
2012	331.839	93.560	0.12
2013	337.762	96.952	0.12
2014	342.725	99.585	0.12
2015	346.978	101.717	0.12

Scenario 7

Determination of whether the stock is approaching an overfished condition

B35=336.913 t

Year	Female Spawning biomass	catch	F
2002	450.669	65.002	0.06
2003	444.710	113.597	0.12
2004	421.803	107.747	0.12
2005	397.305	121.515	0.14
2006	371.207	109.506	0.13
2007	350.326	97.878	0.12
2008	335.230	90.780	0.12
2009	326.417	87.701	0.12
2010	324.533	88.187	0.12
2011	328.146	91.101	0.12
2012	333.175	94.342	0.12
2013	338.486	97.328	0.12
2014	343.087	99.734	0.12
2015	347.188	101.768	0.12

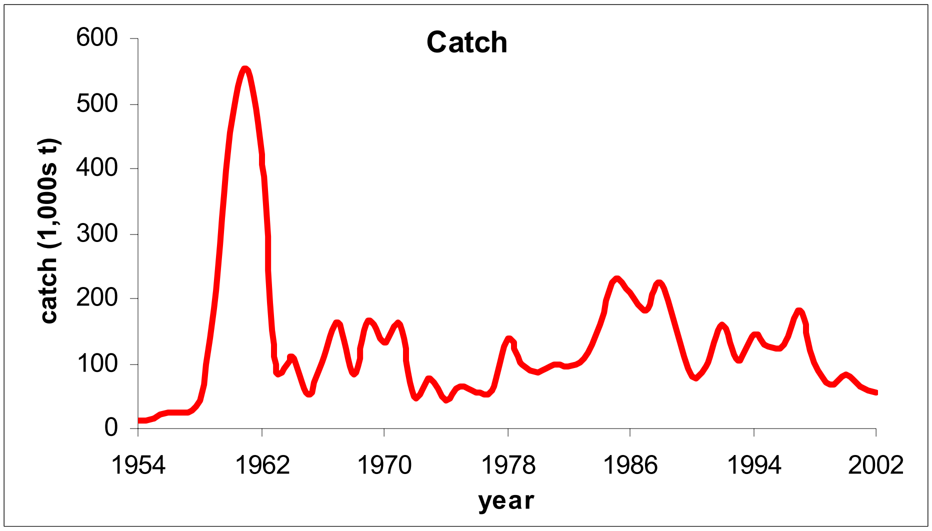


Figure 3.1--Catch of yellowfin sole (1,000s t) 1954-September 14, 2002.

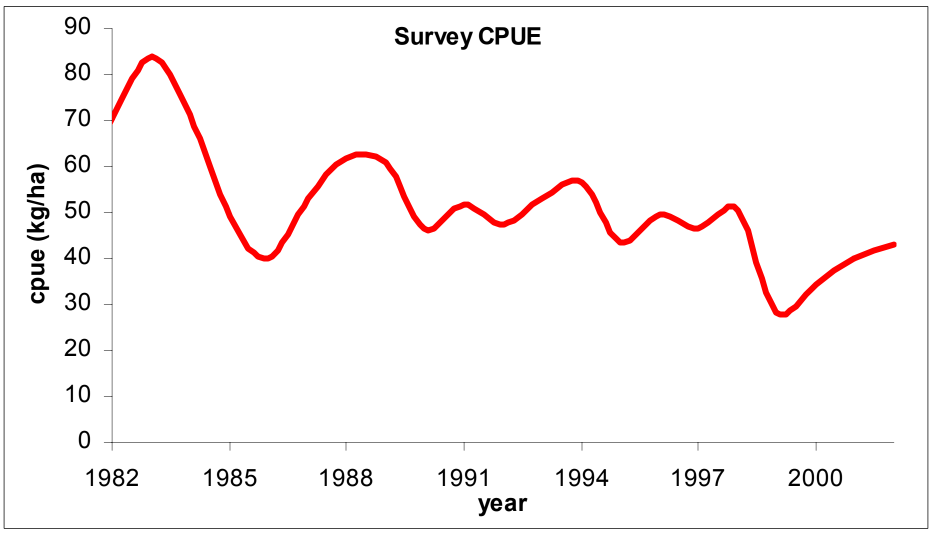


Figure 3.2--Yellowfin sole CPUE (catch per unit effort in kg/ha) from the annual Bering Sea shelf trawl surveys, 1982-2002.

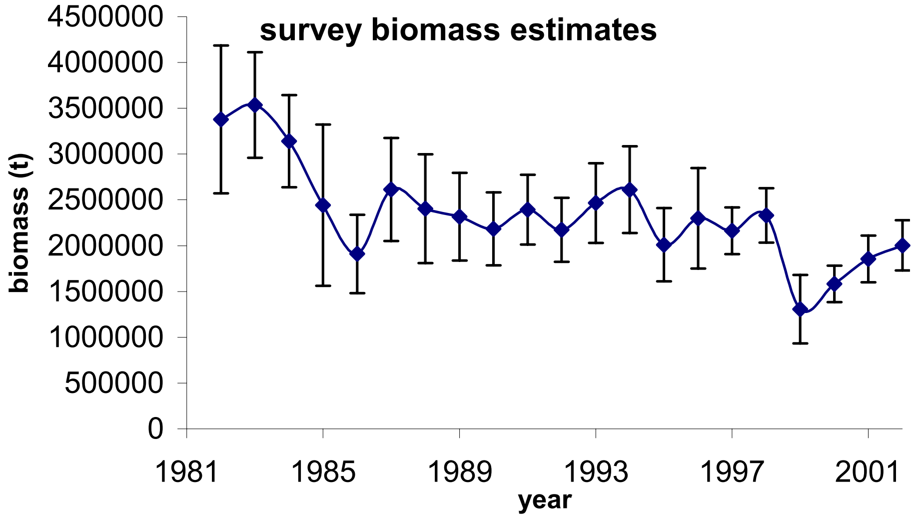


Figure 3.3--Annual bottom trawl survey biomass point-estimates and 95% confidence intervals for yellowfin sole.

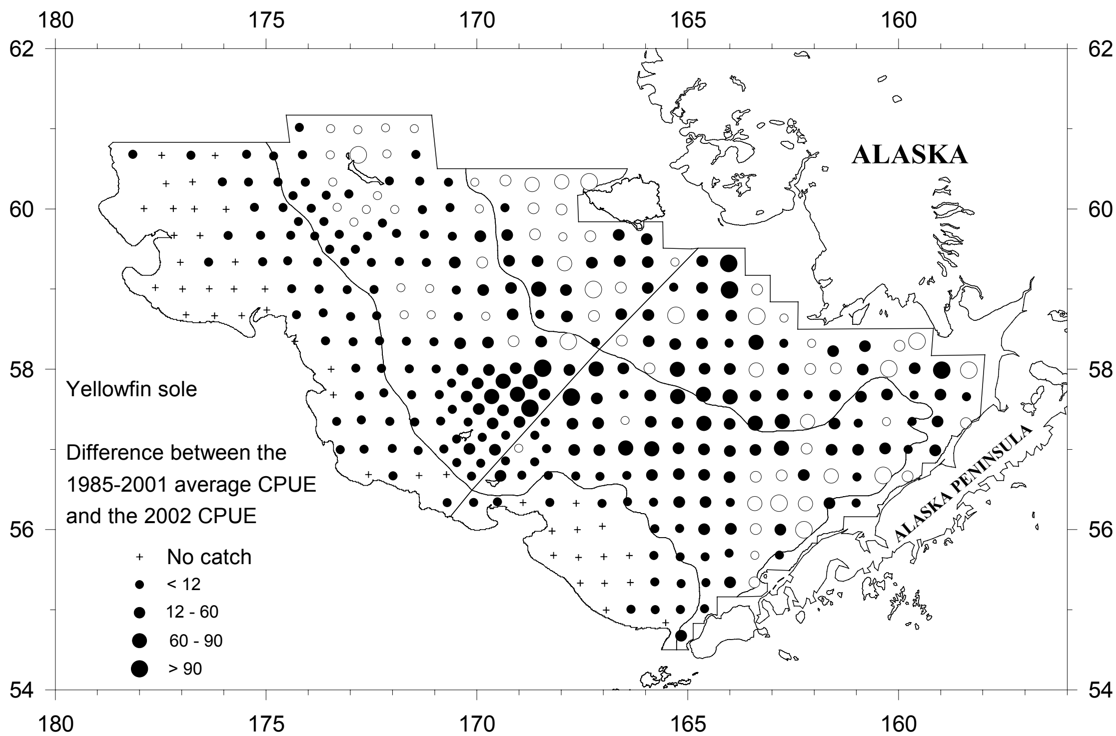


Figure 3.4—Difference between the 1985-2000 average trawl survey CPUE for yellowfin sole and the 2002 survey CPUE. Open circles indicate that the magnitude of the catch was greater in 2002 than the long-term average.

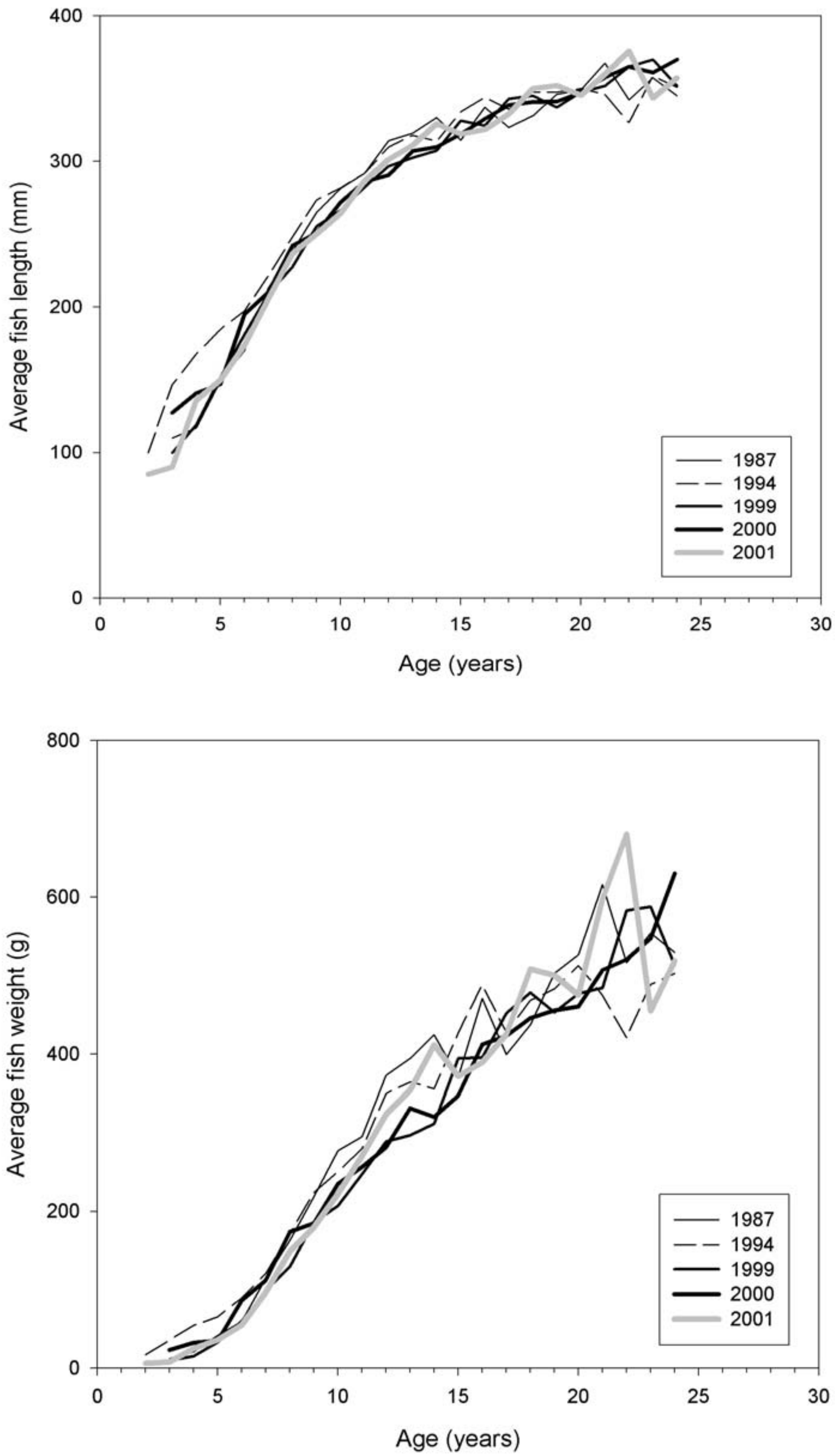


Figure 3.5 -Comparison of yellowfin sole length at age (top panel) and weight at age (bottom panel) from biological samples collected in 1987, 1994, 1999, 2000 and 2001.

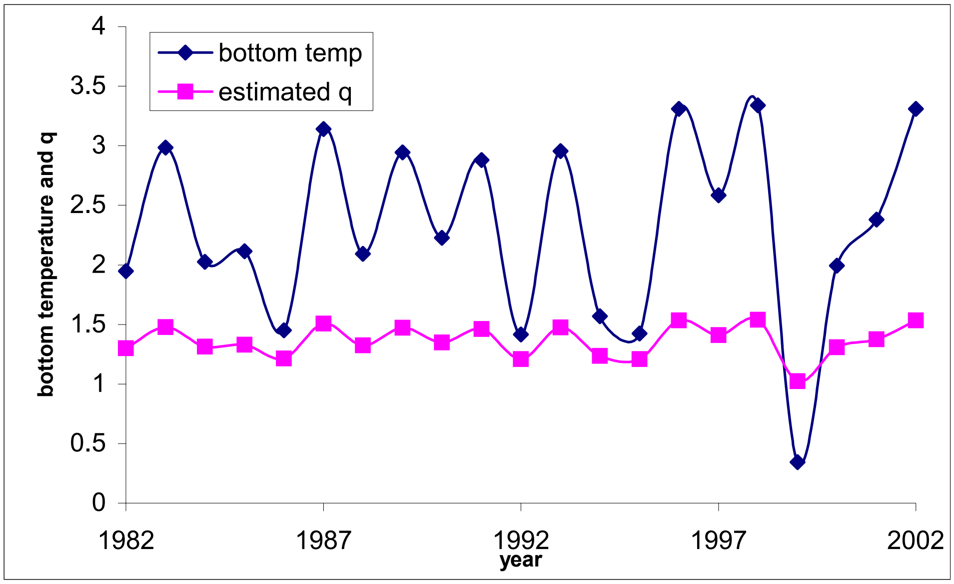


Figure 3.6--Average bottom water temperature from stations less than or equal to 100 m in the Bering Sea trawl survey and the stock assessment model estimate of q for each year 1982-2002.

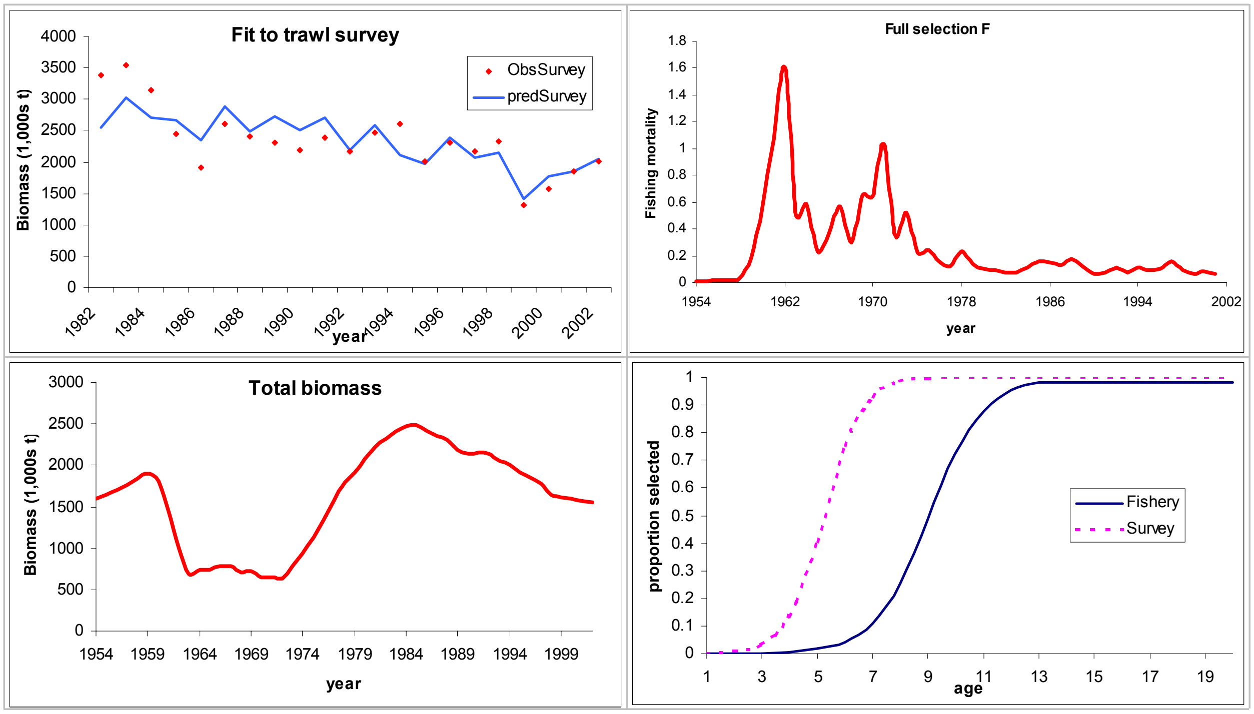


Figure 3.7--Model fit to the survey biomass estimates (top left panel), model estimate of the full selection fishing mortality rate throughout the time-series (top right panel), model estimate of total biomass (bottom left panel) and the model estimate of fishery and survey selectivity (bottom right panel).

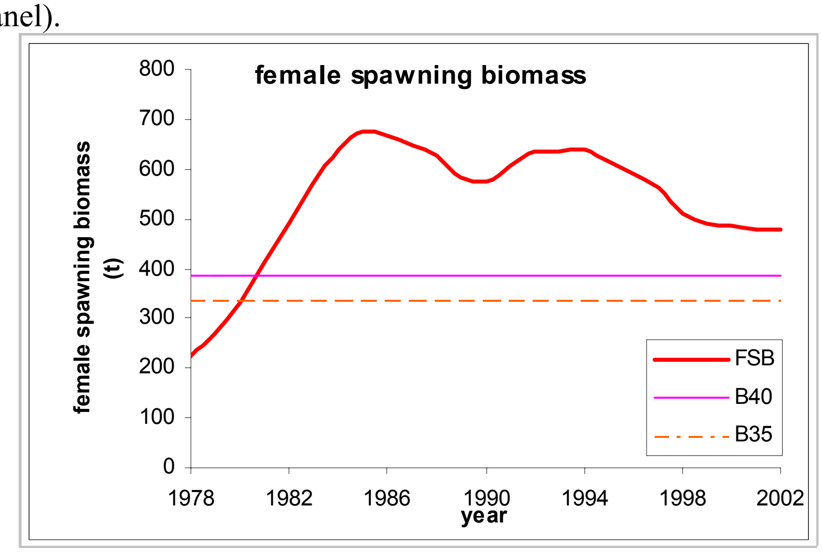


Figure 3.8--Model estimate of yellowfin sole female spawning biomass from 1978-2002 with B40 and B35 levels indicated.

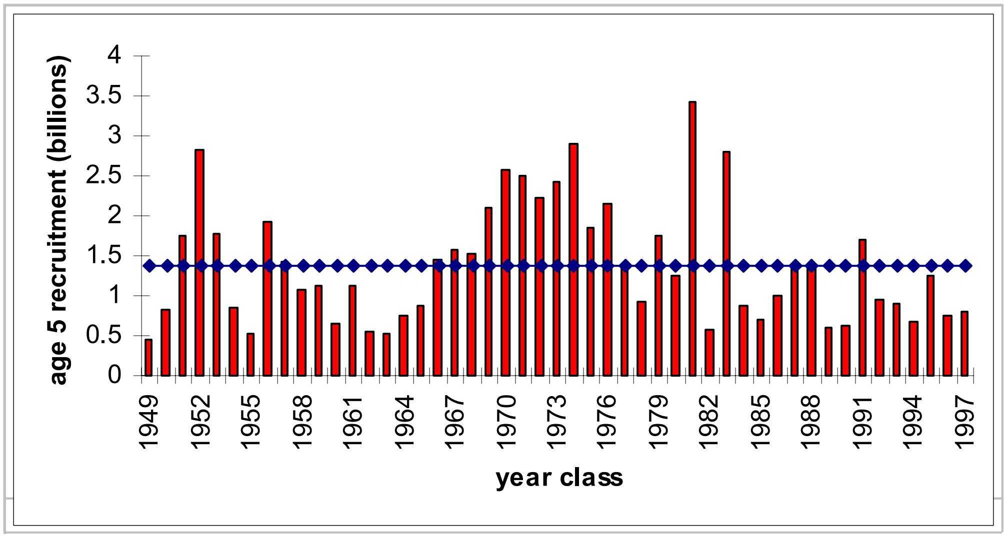


Figure 3.9--Year class strength of age 5 yellowfin sole estimated by the stock assessment model. The dotted line is the average of the estimates from 49 years of recruitment.

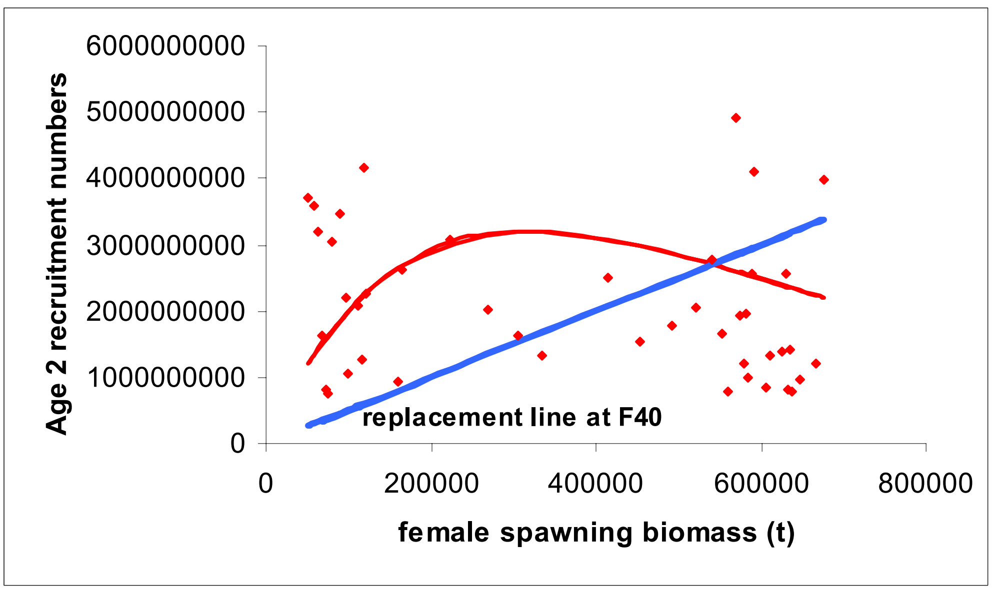


Figure 3.10--Ricker curve fit to yellowfin sole female spawning biomass-age 2 recruitment numbers.

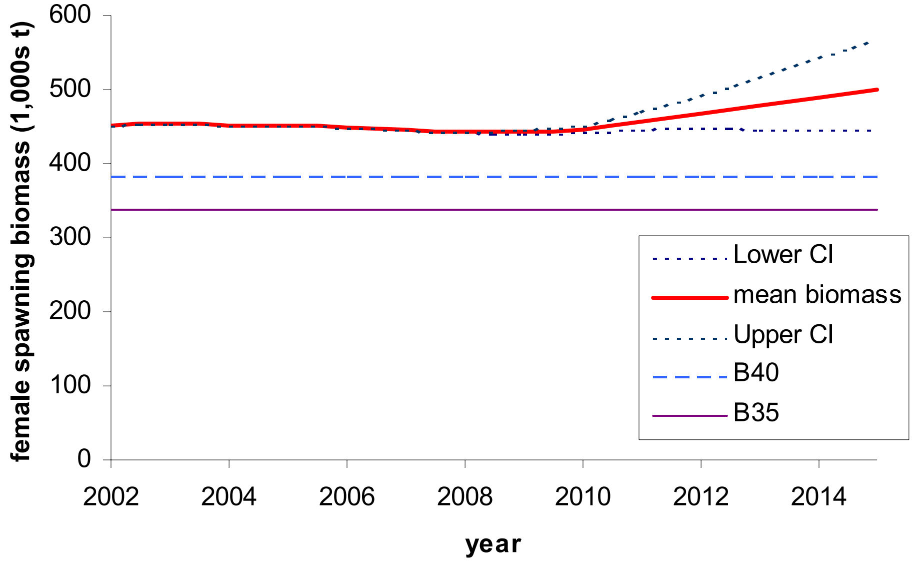


Figure 3.11--Projection of yellowfin sole female spawning biomass (1,000s t) at one half of the maximum ABC through 2014 with B40 and B35 levels indicated.

Appendix

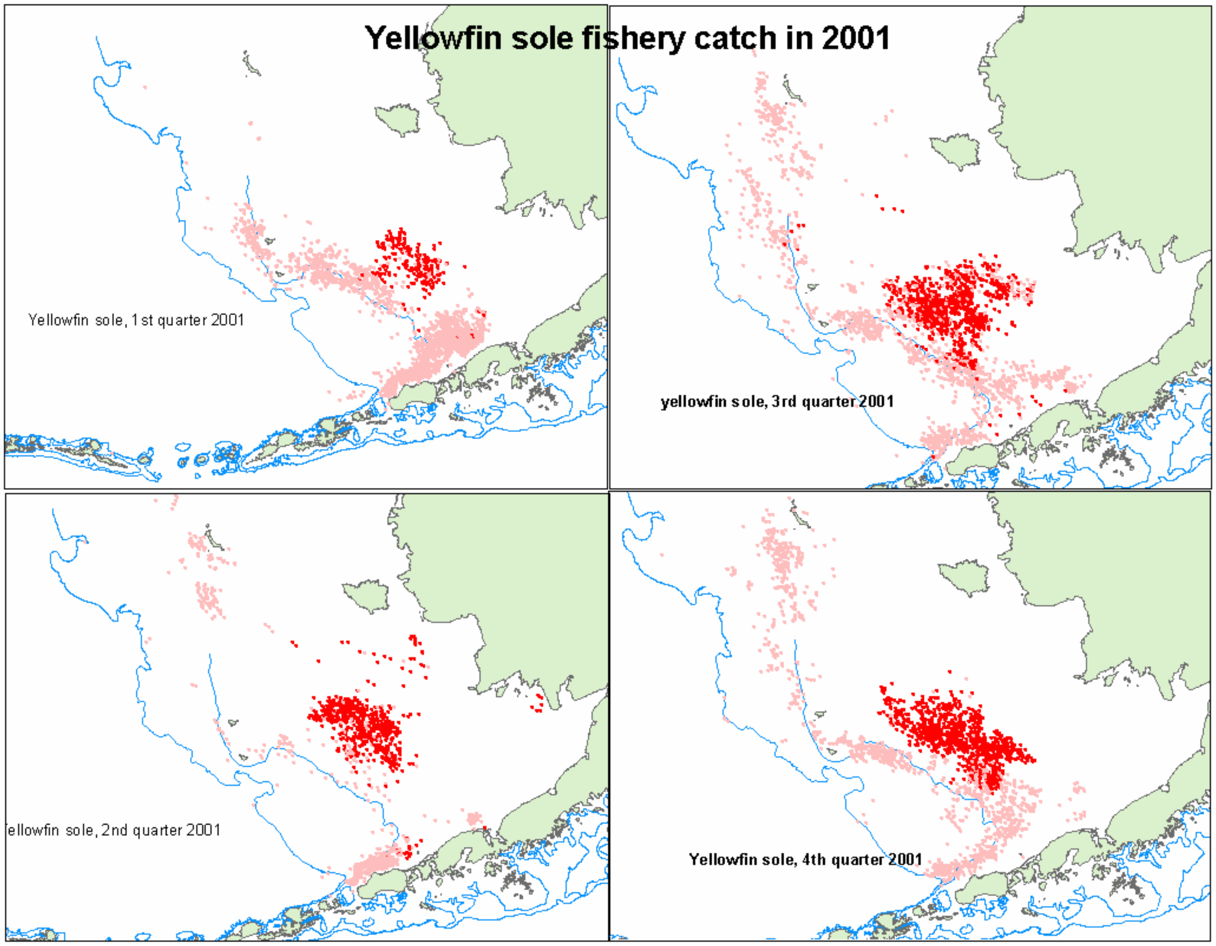
1) 2001 fishery locations by quarter. Catches where yellowfin sole comprised 20% or more of the catch are indicated as darker circles.

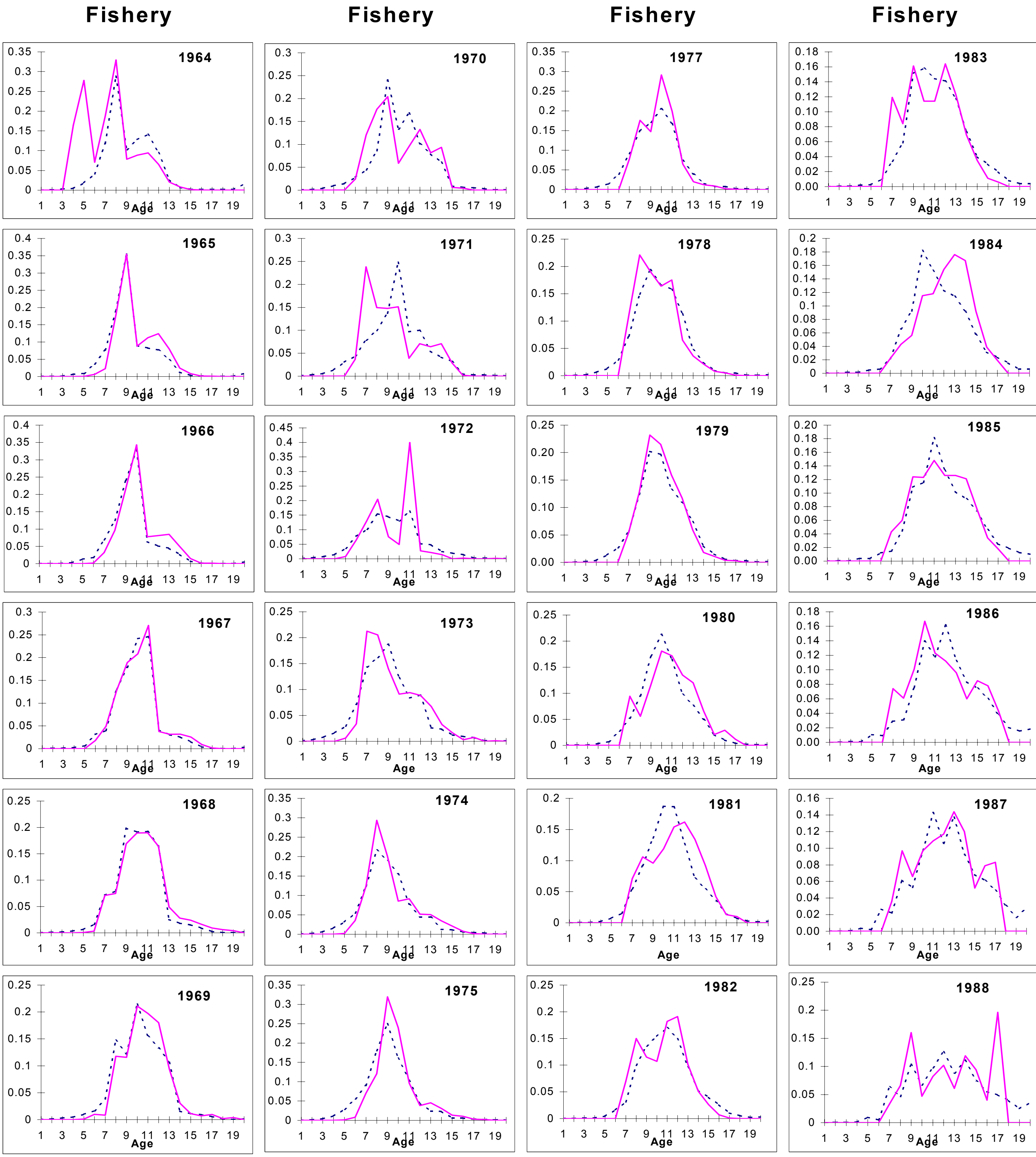
2) Figures showing the fit of the stock assessment model to the time-series of fishery and trawl survey age compositions (survey and fishery observations are the solid lines).

3) Table of yellowfin sole catch from surveys conducted in the eastern Bering Sea and Aleutian Islands area, 1977-2002.

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 fishery catch in 2001
Yellowfin sole, 1st quarter 2001
yellowfin sole, 3rd quarter 2001
ellowfin sole, 2nd quarter 2001
Yellowfin sole, 4th quarter 2001


Fishery
Fishery
Fishery
Fishery
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Age


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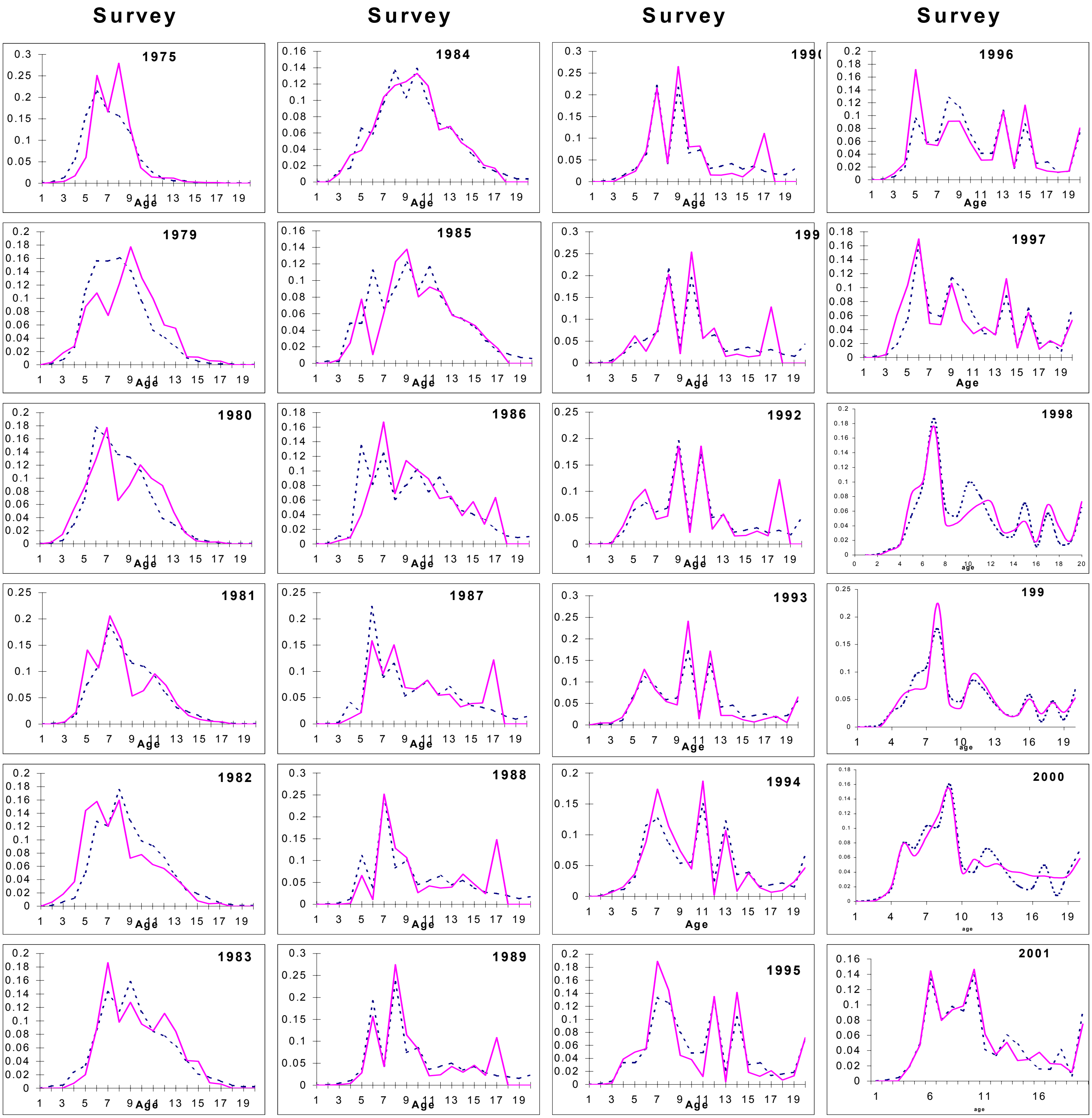
Survey
Survey
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1983
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1995
2001
Age

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

Model estimates of yellowfin sole female spawners (thousands) from 1954-2002.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	0.37	1.22	1.77	1.60	1.87	2.29	8.33	18.31	37.08	65.21	100.09	128.71	145.78	153.96	157.55	159.06	159.69	160.04	159.97	159.92
1955	0.18	0.76	2.86	3.46	3.41	2.36	7.82	16.55	33.78	59.90	88.53	113.57	128.64	135.95	138.84	139.86	140.34	140.62	140.50	280.82
1956	0.11	0.36	1.80	5.59	7.37	4.32	8.09	15.54	30.52	54.51	81.20	100.28	113.30	119.73	122.37	123.01	123.17	123.34	123.21	369.17
1957	0.41	0.23	0.85	3.51	11.90	9.34	14.79	16.06	28.60	49.04	73.42	91.26	99.18	104.53	106.82	107.47	107.38	107.29	107.12	427.63
1958	0.30	0.83	0.54	1.65	7.47	15.07	31.92	29.36	29.54	45.94	66.04	82.50	90.25	91.49	93.24	93.80	93.79	93.52	93.17	464.34
1959	0.23	0.61	1.95	1.06	3.52	9.45	51.48	63.25	53.75	47.03	61.02	72.97	80.11	81.69	80.08	80.34	80.33	80.16	79.69	475.08
1960	0.24	0.46	1.44	3.81	2.25	4.45	32.10	100.41	111.65	79.80	56.31	59.45	61.83	63.00	62.13	59.96	59.79	59.66	59.35	410.74
1961	0.14	0.49	1.09	2.81	8.08	2.83	14.85	60.03	160.77	137.66	72.47	39.22	35.00	33.41	32.92	31.96	30.65	30.50	30.35	239.13
1962	0.24	0.28	1.15	2.12	5.95	10.06	9.24	26.27	84.48	154.96	86.66	32.35	14.26	11.50	10.62	10.30	9.94	9.51	9.44	83.37
1963	0.12	0.49	0.66	2.23	4.48	7.35	32.15	15.42	32.26	62.79	66.26	24.19	7.07	2.77	2.16	1.97	1.89	1.82	1.74	16.99
1964	0.11	0.24	1.14	1.29	4.74	5.63	24.64	60.60	25.15	41.23	60.15	49.24	15.28	4.11	1.56	1.20	1.08	1.04	1.00	10.24
1965	0.16	0.23	0.56	2.23	2.74	5.95	18.79	45.95	96.46	30.66	36.81	41.03	28.35	8.07	2.10	0.78	0.60	0.54	0.52	5.59
1966	0.19	0.32	0.53	1.10	4.74	3.45	20.16	36.43	80.00	139.52	35.31	34.21	33.02	21.15	5.82	1.49	0.55	0.42	0.38	4.29
1967	0.31	0.38	0.75	1.04	2.33	5.97	11.63	38.54	61.40	108.79	146.58	29.35	24.40	21.75	13.47	3.65	0.93	0.34	0.26	2.89
1968	0.33	0.63	0.90	1.46	2.21	2.93	19.93	21.76	61.72	75.72	98.82	102.12	17.29	13.19	11.37	6.93	1.87	0.47	0.17	1.60
1969	0.32	0.68	1.48	1.75	3.11	2.79	9.90	38.39	37.30	86.69	83.48	87.09	77.60	12.15	8.97	7.61	4.61	1.24	0.31	1.18
1970	0.45	0.66	1.60	2.88	3.71	3.90	9.28	18.34	60.09	44.05	73.82	53.77	47.11	38.43	5.82	4.23	3.56	2.16	0.58	0.69
1971	0.54	0.91	1.56	3.12	6.11	4.65	12.98	17.20	28.80	71.44	37.88	48.12	29.47	23.65	18.65	2.78	2.01	1.69	1.02	0.60
1972	0.53	1.11	2.14	3.03	6.60	7.61	15.22	23.05	24.46	28.31	46.29	17.51	18.17	10.07	7.82	6.07	0.90	0.65	0.54	0.52
1973	0.47	1.08	2.61	4.18	6.44	8.32	25.66	29.13	38.93	33.38	29.90	38.73	12.58	12.06	6.46	4.94	3.81	0.56	0.40	0.66
1974	0.51	0.96	2.53	5.09	8.87	8.09	27.85	48.23	47.19	49.09	31.34	21.68	23.83	7.11	6.59	3.48	2.64	2.03	0.30	0.57
1975	0.61	1.04	2.25	4.93	10.82	11.20	27.42	54.09	84.34	68.82	57.23	29.56	17.74	18.07	5.22	4.76	2.50	1.89	1.45	0.62
1976	0.39	1.25	2.45	4.39	10.48	13.66	37.93	53.11	93.95	121.43	78.73	52.75	23.58	13.11	12.92	3.67	3.33	1.74	1.32	1.44
1977	0.45	0.79	2.93	4.79	9.33	13.24	46.42	74.19	94.37	141.28	148.19	78.49	45.82	19.03	10.23	9.92	2.80	2.54	1.32	2.10
1978	0.30	0.92	1.86	5.73	10.19	11.80	45.08	91.16	133.04	144.43	176.97	152.50	70.56	38.31	15.39	8.14	7.85	2.21	2.00	2.69
1979	0.20	0.61	2.16	3.63	12.17	12.86	39.97	87.48	159.00	193.09	167.19	165.48	123.58	53.01	27.83	11.00	5.79	5.57	1.56	3.31
1980	0.37	0.40	1.43	4.23	7.73	15.39	43.75	78.38	156.30	241.65	239.38	169.91	146.76	101.89	42.26	21.84	8.58	4.51	4.32	3.79
1981	0.26	0.75	0.94	2.79	8.99	9.77	52.44	86.14	141.40	241.93	307.84	251.44	156.18	125.55	84.28	34.41	17.68	6.93	3.63	6.53
1982	0.72	0.54	1.77	1.84	5.93	11.37	33.32	103.32	155.64	219.53	309.62	325.15	232.52	134.44	104.50	69.06	28.03	14.37	5.62	8.23
1983	0.12	1.47	1.27	3.45	3.92	7.51	38.79	65.74	187.36	243.28	283.77	331.02	304.67	202.89	113.43	86.80	57.01	23.09	11.80	11.37
1984	0.59	0.25	3.46	2.47	7.34	4.96	25.60	76.53	119.19	292.75	314.31	303.20	309.96	265.66	171.07	94.15	71.61	46.94	18.95	19.02
1985	0.18	1.20	0.58	6.76	5.26	9.29	16.89	50.35	137.71	183.58	370.22	327.21	276.02	262.53	217.58	137.92	75.45	57.27	37.42	30.28
1986	0.15	0.37	2.82	1.13	14.38	6.65	31.57	33.05	89.54	207.43	224.59	370.21	285.17	223.50	205.56	167.71	105.66	57.68	43.65	51.61
1987	0.21	0.31	0.87	5.51	2.41	18.18	22.60	61.83	58.88	135.33	255.04	225.96	324.78	232.49	176.20	159.53	129.36	81.34	44.27	73.11
1988	0.29	0.43	0.72	1.70	11.73	3.04	61.85	44.32	110.52	89.55	167.96	259.54	200.69	268.18	185.63	138.49	124.63	100.85	63.22	91.23
1989	0.28	0.59	1.00	1.40	3.62	14.82	10.34	120.75	78.40	164.75	107.86	164.82	221.61	159.12	205.60	140.10	103.89	93.29	75.27	115.28
1990	0.13	0.58	1.38	1.96	2.98	4.58	50.43	20.29	216.39	119.81	205.94	110.72	147.78	184.78	128.29	163.18	110.51	81.78	73.22	149.56
1991	0.13	0.26	1.36	2.69	4.17	3.77	15.63	99.68	36.94	340.73	156.58	223.12	105.25	130.88	158.24	108.15	136.73	92.41	68.18	185.73
1992	0.35	0.26	0.61	2.65	5.71	5.28	12.86	30.88	181.13	57.96	442.99	168.58	210.66	92.56	111.30	132.47	89.99	113.53	76.50	210.20
1993	0.20	0.73	0.62	1.19	5.64	7.23	17.98	25.28	55.47	278.12	72.96	458.62	152.55	177.33	75.34	89.18	105.50	71.52	89.96	227.18
1994	0.19	0.41	1.71	1.22	2.53	7.14	24.65	35.48	45.84	86.74	359.77	78.07	430.15	133.24	149.77	62.64	73.69	87.00	58.80	260.76
1995	0.14	0.38	0.97	3.33	2.59	3.20	24.32	48.47	63.85	70.65	109.77	374.86	71.14	364.69	109.23	120.87	50.25	58.99	69.43	255.04
1996	0.26	0.30	0.90	1.89	7.09	3.27	10.90	47.89	87.46	98.86	90.04	115.36	344.78	60.90	301.86	89.01	97.89	40.61	47.54	261.46
1997	0.16	0.53	0.69	1.76	4.01	8.97	11.14	21.45	86.22	134.86	125.23	93.92	105.25	292.67	49.99	243.92	71.48	78.45	32.45	246.91
1998	0.17	0.32	1.25	1.35	3.74	5.07	30.47	21.79	38.10	129.59	164.46	124.74	81.51	84.86	228.18	38.36	186.06	54.42	59.55	212.03
1999	0.15	0.34	0.75	2.45	2.88	4.73	17.28	60.01	39.34	59.04	165.39	173.13	114.94	69.90	70.37	186.27	31.13	150.65	43.93	219.24
2000	0.22	0.31	0.80	1.46	5.21	3.65	16.15	34.14	109.17	61.87	77.02	178.78	164.17	101.53	59.71	59.17	155.68	25.96	125.28	218.84
2001	0.24	0.45	0.74	1.57	3.11	6.59	12.43	31.85	61.84	170.26	79.71	82.01	166.80	142.61	85.29	49.37	48.63	127.69	21.23	281.40
2002	0.25	0.50	1.05	1.44	3.33	3.94	22.50	24.58	57.99	97.39	222.59	86.40	78.00	147.79	122.19	71.94	41.39	40.69	106.50	252.43

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

Parameter	value	std dev	Parameter	value	std dev
alpha (q estimation)	0.964	0.093	1976 total biomass	1336.1	31.466
beta (q estimation)	0.172	0.037	1977 total biomass	1561.7	36.123
mean_log_rec	0.649	0.109	1978 total biomass	1789.2	40.786
fishery selectivity -slope	1.018	0.024	1979 total biomass	1921.8	45.002
survey selectivity -slope	1.510	0.075	1980 total biomass	2076.8	49.134
age at 50% fishery selectivity	9.054	0.076	1981 total biomass	2218.6	52.916
age at 50% survey selectivity	5.261	0.069	1982 total biomass	2321.5	56.199
1954 total biomass	1595.1	161.28	1983 total biomass	2411.3	59.261
1955 total biomass	1639.2	140.13	1984 total biomass	2475.2	62.157
1956 total biomass	1703.2	116.16	1985 total biomass	2480.4	64.878
1957 total biomass	1768.2	91.953	1986 total biomass	2410.3	67.235
1958 total biomass	1839.6	70.025	1987 total biomass	2349	69.692
1959 total biomass	1894.4	52.674	1988 total biomass	2300	72.128
1960 total biomass	1809	41.401	1989 total biomass	2191	73.997
1961 total biomass	1453.8	32.335	1990 total biomass	2144	76.217
1962 total biomass	1005.3	21.482	1991 total biomass	2159.7	78.529
1963 total biomass	696.05	12.806	1992 total biomass	2142	80.408
1964 total biomass	732.65	13.355	1993 total biomass	2049.4	81.84
1965 total biomass	735.78	13.52	1994 total biomass	2005.7	83.577
1966 total biomass	788.29	14.291	1995 total biomass	1918.9	85.091
1967 total biomass	779.9	14.528	1996 total biomass	1850.4	86.812
1968 total biomass	703.99	13.748	1997 total biomass	1775.6	88.553
1969 total biomass	717.13	14.382	1998 total biomass	1650.3	90.111
1970 total biomass	651.84	13.957	1999 total biomass	1606.8	92.424
1971 total biomass	645.35	14.821	2000 total biomass	1593.8	95.025
1972 total biomass	640.2	15.91	2001 total biomass	1564.8	98.511
1973 total biomass	785.77	19.148	2002 total biomass	1551.7	103.28
1974 total biomass	927.3	22.76			
1975 total biomass	1133.2	26.986			