YELLOWFIN SOLE

Thomas K. Wilderbuer and Daniel Nichol

EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 1999 SAFE:

<u>Changes to the input data</u>

1) 1999 fishery age composition.
2) 1999 survey age composition.
3) 2000 trawl survey biomass point estimate and standard error.
4) Estimate of the discarded and retained portions of the 1999 catch.
5) Estimate of total catch and discard through 16 September 2000.

<u>Assessment results</u>

1) The projected age 2+ biomass for 2001 is 2,384,180 t.
2) The projected female spawning biomass for 2001 is 741,575 t.
3) The recommended 2001 ABC is 176,180 t based on an $F_{40\%}$ (0.11) harvest level.
4) The 2001 overfishing level is 208,890 t based on an $F_{35\%}$ (0.13) harvest level.

SUMMARY

	2000 Assessment Recommendations for 2001 harvest	1999 Assessment Recommendations For 2000 harvest
Total biomass	2,384,180 t	2,815,580 t
ABC	176,180 t	190,600 t
Overfishing yield	208,890 t	226,000 t
F_{ABC}	$F_{0.40} = 0.11$	$F_{0.40} = 0.11$
$F_{overfishing}$	$F_{0.35} = 0.13$	$F_{0.35} = 0.13$

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INTRODUCTION

The yellowfin sole (*Limanda aspera*) is 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^{o} N) to the Chukchi Sea (about lat. 70^{o} N) and south along the Asian coast to about lat. 35^{o} 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 1999, 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 past two years the catch has totaled 67,320 t in 1999 and 55,152 t through September 16, 2000. The 2000 catch represents only 29% of the ABC and 45% of the TAC. Through September 16, 2000 there have not been any fishery closures due to bycatch restrictions in year 2000.

The catch information presented above also includes large amounts of yellowfin sole discarded overboard in DAP fisheries since its 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

The rate of discard has ranged from 17% of the total catch in 1997 to 30% in 1992. Discarding occurs primarily in the yellowfin sole directed fishery, and in lesser amounts in the rock sole, flathead sole, and ‘other flatfish’ fisheries.

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 16, 2000 (Table 3.1) and fishery catch-at-age (numbers) from 1964-99 (Table 3.2, 1977-99).

Survey Biomass Estimates and Population Age Composition Estimates

The survey estimates of population numbers-at-age from 1975 and 1979-99 are used in the assessment model and are shown for 1982-99 in Table 3.3. 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:

Year	Age Groups 0-6	Age Groups 7 plus	Total	95% confidence Interval 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			1,581,900	1,382,000 - 1,781,800

* 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 2000 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 are 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 (Fig. 3.3). 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. 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 believe that in 1999 and 2000, a higher percentage of yellowfin sole resided in shallow waters unavailable to the standard survey. As in 1999, concentrations of yellowfin sole during the 2000 survey were on average greater along nearshore survey boundary in comparison to previous years (Fig.3.4), suggesting a distribution concentrated more inshore.

The addition of 20 exploratory nearshore stations during the 2000 survey confirmed greater concentrations of yellowfin sole outside the nearshore survey boundary, particularly near Togiak bay and Kuskokwim bay. We plan to continue sampling these stations during future eastern Bering Sea bottom trawl surveys in an effort to monitor the shifts of the population between “standard” and non-surveyed nearshore areas.

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) - weigh t(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

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.

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Length-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

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. 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	Distribution 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 3-5). 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 3-6 provides a description of the variables used in Table 3-5.

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 an M value of 0.12 (Bakkala and Wespestad 1984).

The natural mortality rate value of 0.12 was also evaluated using the synthesis model in an earlier assessment (Wilderbuer 1992). Values of natural mortality were varied from 0.09 to 0.18 to determine which level would fit the observable population characteristics best. Maximum log(likelihood) values occurred at M = 0.12 when the analysis was run using fishery catch-at-age data from 1977-91 and at M = 0.16 when data from 1964-91 were included. The natural mortality rate most likely falls within the range of 0.12 - 0.16.

The survey catchability coefficient (q) was set equal to 1.0. Yellowfin sole maturity schedules were estimated as discussed in section 3.3.3 (Table 3.4).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Total
47	4	66	117

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 3-5.

Selectivity

Fishery and survey selectivity was modeled in this assessment using the two parameter formulation of the double logistic function, as shown in Table 3-5. The model was run with the selectivity curve fixed asymptotically 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.

MODEL RESULTS

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages is given in Table 3.7. The large 1997 catch corresponds to an F value of 0.113, which is higher than the 1977-99 average full selection F of 0.091 but only represents an exploitation fraction of 7%. Selectivities estimated by the model (Table 3.8, Fig. 3.5) indicate that yellowfin sole are 50% selected by the fishery at age 9 and nearly fully selected by age 13.

Abundance Trend

Model results indicates that yellowfin sole total biomass (age 2+) was at low levels during most of the 1960s and early 1970s (700,000-800,000 t) after a period of high exploitation (Table 3.9, Fig 3.5, bottom left panel). Sustained above average recruitment from 1967-76 combined with light exploitation resulted in a biomass increase to over 2.9 million t by 1985. The population biomass has remained at this high level since then, primarily due to the influence of the strong 1981 and 1983 year-classes. Over the past fifteen years stock biomass has remained stable with annual estimates of total biomass consistently over 2.5 million through 1996. The model estimates the 2000 total biomass at over 2.3 million t and is projected to increase further as the very strong 1991 year class begins to maximize its cohort biomass. The female spawning biomass is also at a high level. 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 3.5. The model does not provide a good fit the one million t decline in estimated survey biomass from 1998 to 1999 or the slightly higher 2000 estimate. However, the past 2 year’s lower survey biomass estimates have had the effect of lowering the model estimates of total biomass and female spawning biomass and recruitment numbers relative to the previous assessment (Table 3.9).

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 remained abundant and stable since then (Figure 3.5). The biomass time-series is indicative of a slow-growing species with a low natural mortality rate which is known to have been lightly exploited (Figure 3.5 top right panel) during a period of average to strong recruitment. Model estimates indicate a declining trend in recent years due to the influence of the past two years lower survey biomass estimates. Average to above average recruitment from the 1991 and 1993 year-classes are expected to maintain the abundance of yellowfin sole at a high level in the near future. The stock assessment projection model (later section) indicates a stock biomass increase in the near future due to the present age composition of the yellowfin sole stock.

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 2001. Including the 2000 reported catch through 16 September (including discards), the model projects the total biomass for 2001 at **2,384,200 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 (Fig. 3.6 and Table 3.11). Many of these year classes still provide a portion of the exploitable population. The 1981 year class is the strongest observed (and estimated) during the 46 year period analyzed and the 1983 year class is also very strong. In addition, survey age composition estimates and the assessment model also estimate that the 1987 and 1988 year classes are above average and the 1991 year class is strong. The future contribution from these year-classes should keep the population at its current high and stable level in the near future under current exploitation levels.

Spawner-Recruit Relationship

The relationship between the model estimates of female spawning biomass and age 5 recruitment are shown in Figure 3.7. 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. The fitted curve to this data is not recommended for use in predicting recruitment for stock management purposes.

Historical Exploitation Rates

Based on results of stock synthesis modeling, annual exploitation rates of yellowfin sole ranged from 3 to 8% of the total biomass since 1977, and have averaged 5%.

ACCEPTABLE BIOLOGICAL CATCH

After increasing during the 1970s and early 1980s, estimates of total biomass from the stock assessment model have been relatively stable at over 2.5 million t since 1982 while estimates from bottom trawl surveys have fluctuated around these estimates. The model's year 2001 estimate of total biomass is 2,384,200 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. For the 2000 assessment, the Alaska Fisheries Science Center policy is to use only year classes spawned in 1977 or later to calculate the average equilibrium recruitment. Using the time-series of recruitment numbers from 1978-98 from the stock assessment model results in an estimate of **$B_{0.40}$ = 502,200 t**. The stock assessment model estimates the 2001 level of female spawning biomass at 741,500 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (741,500 > 502,200), yellowfin sole reference fishing mortality is defined in tier 3a. For the 2000 harvest: $F_{ABC} \leq F_{0.40} = 0.11$ (full selection F values).

Acceptable biological catch is estimated for 2001 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the 2001 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{max}} \bar{w}_a n_a \left(\frac{F s_a}{M + F s_a} \right) \left(1 - e^{-M - F s_a}\right)$$

where S_a is the selectivity at age, M in natural mortality, W_a is the mean weight at age, and n_a is the beginning of the year numbers at age. **This calculation results in a 2001 ABC of 176,180 t**.

Overfishing

The stock assessment analysis must also consider harvest limits, usually described as "overfishing" fishing mortality levels with corresponding yield amounts. Previous stock assessments used $F_{0.30}$ or the fishing mortality rate which would reduce the spawning biomass per recruit to 30% of its unfished level as the harvest limit. Amendment 56 to the BS/AI FMP now sets the harvest limit at the $F_{0.35}$ fishing mortality value. The overfishing fishing mortality value, ABC fishing mortality value and their corresponding yields are given as follows:

Harvest level	F value	2000 Yield
$F_{OFL} = F_{0.35}$	0.13	208,890 t
$F_{ABC} = F_{0.40}$	0.11	176,180 t

BIOMASS PROJECTIONS

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

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

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

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

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

> *Scenario 6*: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2000 and above its MSY level in 2010 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2000 and 2001, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching

an overfished condition. If the stock is expected to be above its MSY level in 2012 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 3.12 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.

REFERENCES

Bakkala, R. G. and V. Wespestad. 1984. Yellowfin sole. In R. G. Bakkala and L. resources of the eastern Bering Sea and Aleutian Islands region in 1983, p. 37-60. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-53.

Bakkala, R. G., V. Wespestad, and L. Low. 1982. The yellowfin sole (Limanda aspera) resource of the eastern Bering Sea--its current and future potential for commercial fisheries. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-33, 43p.

Bakkala, R. G., and T. K. Wilderbuer. 1990. Yellowfin sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1990, p. 60-78. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Fournier, D. A. and C.P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can. J. Fish Aquat. Sci. 39:1195-1207.

Greiwank, A. and G. F. Corliss (eds) 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. And Applied Mathematics, Philadelphia.

Low, L. and R.E. Narita. 1990. Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-178, 224 p.

Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. INPFC Bull.50:259-277. Symposium on application of stock assessment techniques to Gadoids.

Methot, R. D. 1998. Application of Stock Synthesis to NRC Text Data Sets. In Analysis of Simulated Data Sets in Support of the NRC Study on Stock Assessment Methods, V. R. Restrepo (editor), Chap. 6. NOAA Tech. Mem. NMFS-F/SPO-30. U.S. Dep.Commer. NOAA, Nat. Mar. Fish. Serv.

Nichol, D. R . 1995. Spawning and maturation of female yellowfin sole in the eastern Bering Sea. In Proceedings of the international flatfish symposium, October 1994, Anchorage, Alaska, p. 35-50. Univ. Alaska, Alaska Sea Grant Rep. 95-04.

Nichol, D.R. 1998. Annual and between sex variability of yellowfin sole, *Pleuronectes asper*, spring-summer distributions in the eastern Bering Sea. Fish. Bull., U.S. 96: 547-561.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Bd. Can., (119) 300 p.

Wakabayashi, K. 1989. Studies on the fishery biology of yellowfin sole in the eastern Bering Sea. [In Jpn., Engl. Summ.] Bull. Far Seas Fish. Res. Lab. 26:21-152.

Wakabayashi, K., R. Bakkala, and L. Low. 1977. Status of the yellowfin sole resource in the eastern Bering Sea through 1976. Unpubl. manuscr., 45p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Bin C 15700, Seattle, Wa 98115.

Wilderbuer, T. K. 1992. Yellowfin sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1993, chapter 3. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Wilderbuer, T. K. 1993. Yellowfin sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1994, chapter 3. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Wilderbuer, T.K., G.E. Walters, and R.G. Bakkala 1992. Yellowfin sole, *Pleuronectes asper*, of the eastern Bering Sea: biological characteristics, history of exploitation, and management. Mar Fish. Rev. 54(4):1-18.

Appendix

1) 1999 fishery locations by quarter where yellowfin sole comprised 20% or more of the catch.

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, 1977-98.

Table 3.4--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 3.1- Catch of yellowfin sole 1977-2000. Catch for 2000 is the total through September 16, 2000.

		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			55,152	55,152

Table 3-5.–Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1945-64
$N_{t,1} = R_t = R_\gamma e^{\tau_t}, \; \tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1965-96
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}} \left(1 - e^{-Z_{t,a}}\right) N_{t,a}$	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
$L = \sum_{t,a} m_t p_{t,a} \ln \frac{\hat{p}_{t,a}}{p_{t,a}} + (-0.5) \sum_t \left[\left(\ln \frac{surB_t}{\widehat{surB}_t} \, 1/\sigma_t \right)^2 - \ln \sigma_t \right]$	Total log likelihood

Table 3-6.–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, 1945-64
R_γ	Geometric mean value of age 1 recruitment, 1965-96
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*