Chapter 4
YELLOWFIN SOLE

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Executive Summary

The following changes have been made to this assessment relative to the November 2005 SAFE:

Changes to the input data

1) 2005 fishery age composition.
2) 2005 survey age composition.
3) 2006 trawl survey biomass point estimate and standard error.
4) Estimate of the discarded and retained portions of the 2005 catch.
5) Estimate of total catch through 6 September 2006.

Assessment results

1) The projected age 2+ total biomass for 2007 is 1,996,000 t.
2) The projected female spawning biomass for 2007 is 585,100 t.
3) The Tier 3 2007 ABC is 135,600 t based on an $F_{40\%}$ (0.11) harvest level.
4) The Tier 3 2007 overfishing level is 160,300 t based on an $F_{35\%}$ (0.13) harvest level.

Summary

	2006 Assessment Values for the 2007 harvest	2005 Assessment values for the 2006 harvest
Total biomass	1,996,000 t	1,682,200 t
Tier 3ABC	135,600 t	121,400 t
Tier 3 Overfishing yield	160,300 t	144,000 t
Tier 3 F_{ABC}	$F_{0.40} = 0.11$	$F_{0.40} = 0.11$
Tier 3$F_{overfishing}$	$F_{0.35} = 0.13$	$F_{0.35} = 0.14$
$B_{40\%}$	459,700 t	412,000 t
$B_{35\%}$	402,200 t	360,000 t

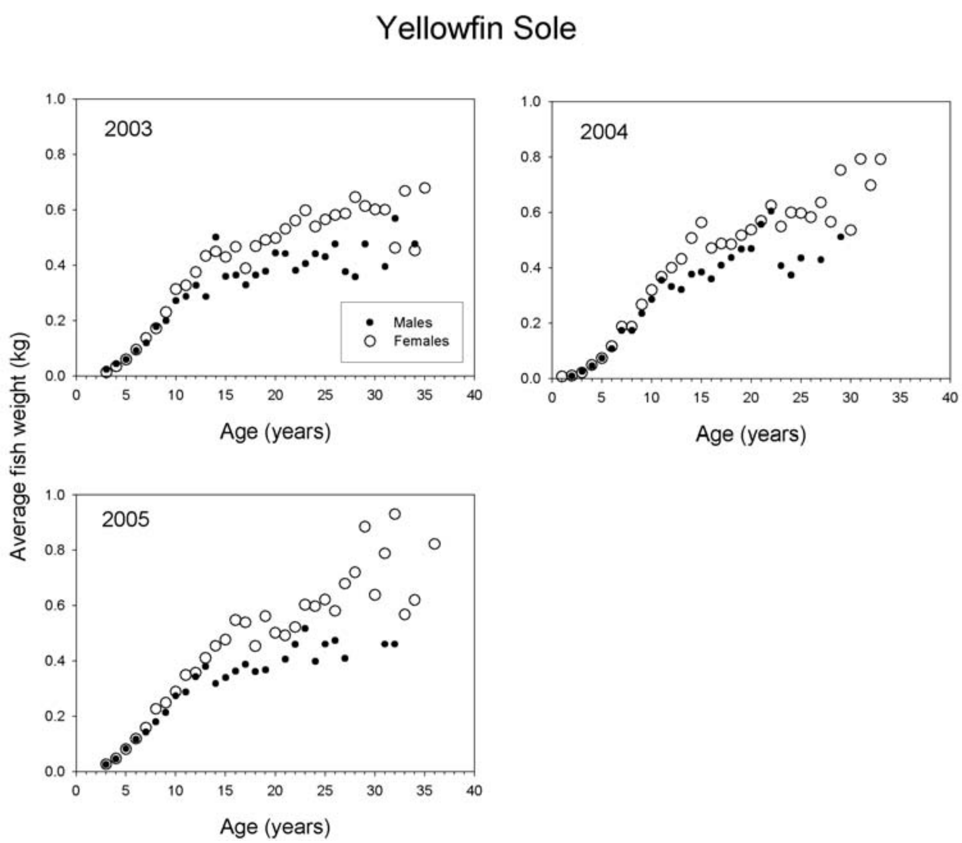
SSC Comments from December 2005

The SSC looks forward to results of the management strategy evaluation exercise that is exploring the consequences of a non-stationary spawner-recruit relationship.

See Tier 1 Considerations section

The SSC requests that the authors provide justification for their assumption that there are no gender-based differences in length-at-age or weight-at-length for yellowfin sole. If there is sexual dimorphism in growth, then size-based fisheries selection will generate temporal variations in sex ratios consequential to the stock's productivity.

The authors do not assume that there are not sexually explicit differences in growth for yellowfin sole. Instead of implementing a split sex stock assessment model, the weight at age for males and females combined is calculated as the average of their sex-specific weight for each age. Male and female yellowfin sole have the same weight-at-age from the juvenile stage until they become sexually mature (age of 50% maturity = 10 years, see figure below). After maturation, when the weights at age diverge, the average is appropriate to calculate population biomass because males and females are found in nearly equal numbers in the shelf trawl surveys (see table below). However, a split sex model is a consideration to improve modeling the population dynamics of males and females at ages older than the age at maturation.



Average weight at age of yellowfin sole, by sex, in the population from 2003-2005.

Proportion of male yellowfin sole in the population estimated from the past 10 shelf surveys.

year	Proportion male
1997	0.48
1998	0.46
1999	0.49
2000	0.46
2001	0.46
2002	0.48
2003	0.45
2004	0.46
2005	0.44
2006	0.46

Introduction

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

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

Catch History

Yellowfin sole have annually been caught with bottom trawls on the Bering Sea shelf since the fishery began in 1954 and were overexploited by foreign fisheries in 1959-62 when catches averaged 404,000 t annually (Fig. 4.1). As a result of reduced stock abundance, catches declined to an annual average of 117,800 t from 1963-71 and further declined to an annual average of 50,700 t from 1972-77. The lower yield in this latter period was partially due to the discontinuation of the U.S.S.R. fishery. In the early 1980s, after the stock condition had improved, catches again increased reaching a recent peak of over 227,000 t in 1985.

During the 1980s, there was also a major transition in the characteristics of the fishery. Yellowfin sole were traditionally taken exclusively by foreign fisheries and these fisheries continued to dominate through 1984. However, U.S. fisheries developed rapidly during the 1980s in the form of joint ventures, and during the last half of the decade began to dominate and then take all of the catch as the foreign fisheries were phased out of the EBS. Since 1990, only domestic harvesting and processing has occurred. The annual total catch (t) since implementation of the MFCMA in 1977 are shown in Table 4.1.

The 1997 catch of 181,389 t was the largest since the fishery became completely domestic but has since been at lower levels averaging 78,000 t from 1998-2005. As of 6 September, the 2006 catch totaled 96,931 t, the highest annual catch in the past 8 years. The fishery caught 2/3 of the annual total during March and April, almost evenly distributed from areas 509, 513, 514 and 521. The fishing season was finished on August 28, 2006 when the TAC was attained. The size composition of the 2006 catch for both males and females, from observer sampling, are shown in Figure 4.1 and the locations where yellowfin sole were caught in 2006, by month, are shown in the Appendix figures.

Harvesting events requiring regulatory actions in 2006 were as follows: The directed fishery was closed in the red king crab savings area on April 5 to prevent exceeding the red king crab bycatch allowance and also for the entire Bering Sea on April 20 and June 8 to prevent exceeding the second and third seasonal apportionments of halibut. Retention of yellowfin sole was prohibited on May 19 due to the attainment of the TAC. On 24 July 2006, 7,500 t of yellowfin sole TAC reserve was released to supplement the TAC which prolonged the fishery until 8 August 2006, at which time yellowfin sole were no longer allowed to be retained in BSAI fisheries.

The time-series of catch in Table 6.1 also includes yellowfin sole that were discarded in domestic fisheries during the period 1987 to the present. Annual discard estimates were calculated from at-sea sampling (Table 4.2). The rate of discard has ranged from a low of 10% of the total catch in 2005 to 30% in 1992. The trend has been toward fuller retention of the catch in recent years Discarding primarily occurs in the yellowfin sole directed fishery, with lesser amounts in the Pacific cod, rock sole, flathead sole, and other flatfish fisheries (Table 4.3).

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 6, 2006 (Table 4.1) and fishery catch-at-age (numbers) from 1964-2005 (Table 4.4, 1977-2005).

Survey Biomass Estimates and Population Age Composition Estimates

Biomass estimates for yellowfin sole from the annual bottom trawl survey on the eastern Bering Sea shelf are shown in Table 4.5. Estimates are given separately for unexploited ages (less than age 7) and exploited ages (ages 7 and older) except for 2006 where age data are not yet available. The data show a doubling of exploitable biomass between 1975 and 1979 with a further increase to over 3.3 million t in 1981. Total survey abundance estimates fluctuated erratically from 1983 to 1990 with biomass ranging from as high as 3.5 million t in 1983 to as low as 1.9 million t in 1986. Biomass estimates since 1990 indicate an even trend at high levels of abundance for yellowfin sole, with the exception of the results from the 1999 and 2000 summer surveys, which were at lower levels. Surveys from 2001-2005 estimated an increase each year but the 2006 estimate was lower at 2.1 million t.

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

Since 1981, the survey CPUEs have fluctuated widely. For example, they increased from 51 kg/ha in 1981 to 84 kg/ha in 1983 and then declined sharply to 39 kg/ha in 1986. They continued to fluctuate from 1986-90, although with less amplitude (Fig 4.2). From 1990-2006, the estimated CPUE was relatively stable but have declined the past year. Fluctuations of the magnitude shown between 1980 and 1990 and again between 1998 and 1999 are unreasonable considering the combined elements of slow growth and long life span of yellowfin sole and low exploitation rate, characteristics which should produce more gradual changes in abundance.

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

Over the past 15 years survey biomass estimates for yellowfin sole have shown a positive correlation with shelf bottom temperatures (Nichol, 1998); estimates have been low during cold years. The 1999 survey, which was conducted in exceptionally cold waters, indicated a decline in biomass that was unrealistic.

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 during the period 2001 – 2003, with the 2003 value the highest temperature and biomass observed over the 22 year time series. Given that both 1999 and 2000 surveys were conducted two weeks earlier than previous surveys, it is possible that the time difference may also have affected the availability of yellowfin sole to the survey. If, for example, the timing of peak yellowfin sole spawning in nearshore waters corresponded to the time of the survey, a greater proportion of the population would be unavailable to the standard survey area. This trend was observed again in 2006 where the temperature and the bottom trawl survey point estimate were lower.

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. In the case of 2006, a colder than average year in the Bering Sea, it is unclear from examining survey station catches along the survey border outside of Kuskowkim bay if a significant portion of the biomass lies outside this border (Fig 4.4).

Yellowfin sole population numbers-at-age estimated from the annual bottom trawl surveys are shown in Table 4.6.

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

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

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

Mean lengths and weights at age of yellowfin sole based on 12 years (1979-90) of data from AFSC surveys and the length (cm) – weight (g) relationship (W = 0.0097217 * L ** 3.0564) are shown in Table 4.7. Changes in length and weight at age over time has been documented for Bering Sea rock sole (Walters and Wilderbuer 2000) and Bering Sea and Gulf of Alaska Pacific halibut (Clark et al 1999). We examined our assumption of time invariant growth in length and weight of yellowfin sole by comparing the weight and length at age from fish collected during the 1987, 1994, 1999, 2000 and 2001 surveys (Fig. 4.5). Over the age range of 4 to 14 years (fish ageing > 14 years has more error and smaller sample sizes) there are only small differences in length and weight at age from 1987 to 2001. Largest annual differences in weight at age were found in 1999 (a cold year) which were not present in the same cohorts in 2001 (a warmer year). These differences seem to be more related to annual metabolic rate than a shift in population-wide growth. Based on these findings, we concluded that use of a single weight at age vector was justified for this assessment.

A review of the fishery and survey age composition data for this assessment revealed that the survey age composition data from 1982-1995 and the fishery age composition data from 1974-1992 were truncated at 17 years of age and allowed to accumulate as a 17+ group. This was left over from the stock assessment model used until the mid 1990s. Since then, the assessment has been structured to truncate the age compositions at age 20 and accumulate the older ages as a 20+ group. For this assessment, the 1974-1992 fishery age compositions and the 1982-95 survey age compositions have been structured in a manner consistent with the latter ages such that all the age compositions extend to age 20 and are allowed to accumulate as a 20+ plus group. This has had the effect of providing stability in the estimation of natural mortality, but has also had an influence on the estimate of survey catchability whereby the estimated value has been reduced from that in previous assessments.

Maturity information collected from yellowfin sole females during the 1992 and 1993 eastern Bering Sea trawl surveys is used in this assessment (Table 4.8). Nichol (1994) estimated the age of 50% maturity at 10.5 years based on the histological examination of 639 ovaries. In the case of most north Pacific flatfish species, including yellowfin sole, sexual maturity occurs well after the age of entry into the fishery. Yellowfin sole are 90% selected to the fishery by age 11 but females have been found to be only 50% mature at this age.

Analytic Approach

Model Structure

The abundance, mortality, recruitment and selectivity of yellowfin sole were assessed with a stock assessment model using the AD Model builder language (Ianelli and Fournier 1998). The conceptual model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information (Fournier and Archibald 1982). 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 given some distributional assumptions about the observed data.

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

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

The total log likelihood is the sum of the likelihoods for each data component (Table 4.9). The likelihood components may be weighted by an emphasis factor, however, equal emphasis was placed on fitting each likelihood component in the yellowfin sole assessment except for the catch. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library). Table 4.9 presents the key equations used to model the yellowfin sole population dynamics in the Bering Sea and Table 4.10 provides a description of the variables used in Table 4.9.

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 where 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 using data up to 1992 (Wilderbuer 1992). In addition, natural mortality is also allowed to be estimated as a free parameter in some of the stock assessment model runs which are evaluated in a latter section. A natural mortality value of 0.12 is used in the base model presented in this assessment.

Yellowfin sole maturity schedules were estimated from in situ observations as discussed in a previous section (Table 4.8).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Survey catchability	Year class strength	Spawner-recruit	Total
52	4	2	71	2	131

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 over time using the population dynamics equations given in Table 4.9.

Selectivity
Fishery and survey selectivity was modeled in this assessment using the two parameter formulation of the logistic function, as shown in Table 4.9. The model was run with an asymptotic selectivity curve for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years.

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

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

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

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

Spawner-Recruit Estimation

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

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

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

Model Evaluation

For this assessment 7 different configurations of the stock assessment model are considered, all of which differ in the estimation process of catchability and natural mortality. Model 1 is the base model which has been used in past assessments and operates by fixing M at 0.12 and then estimates q using the relationship between survey catchability and the annual average water temperature at the sea floor. Models 2 and 3 fix q at 1.16 (the value resulting from Model 1) but estimate M as a free parameter with different amounts of uncertainty in the parameter estimate ($sigma_M$ values of 0.2 and 0.5 for Models 2 and 3, respectively). Models 4 and 5 fix M at 0.12 but estimate q as a free parameter (without consideration of the relationship with annual bottom water temperature) with different amounts of uncertainty in the parameter estimate ($sigma_q$ values of 0.2 and 0.5 for Models 4 and 5, respectively). Models 6 and 7 estimate both M and q as free parameters, again with varying amounts of uncertainty ($sigma_M$ and $sigma_q$ values of 0.2 and 0.5 for Models 6 and 7, respectively).

Results from these runs indicate that fixing either M or q at values estimated from the base Model (Model 1) and then estimating the other parameter give similar estimates of 2007 female spawning biomass, total biomass, $F_{40\%}$ and 2007 tier 3 ABC (Models 2-5, Table 4.11). When M and q are both estimated as free parameters with no constraint on either, the best fit to the observable population characteristics occur at high values of q and low values of M (Models 6 and 7). These Models result in low estimates of female spawning biomass, total biomass and ABC, which are not credible.

Model runs 2-5 indicate that, even with a high level of uncertainty, M and q are fairly well estimated within a narrow range, as long as one of the parameters are constrained at the level present in Model 1. The values of M estimated in Models 6 and 7 (0.07 and 0.05) seem unrealistic given the maximum age of yellowfin sole observed from 42 years of data collection and age determination and the resulting low biomass estimates.

Modeling survey catchability as a nonlinear function of bottom water temperature at stations less than 100 m produces an estimate of survey catchability greater than 1. This value is consistent with supporting evidence from experiments examining the bridle efficiency of the Bering Sea survey trawl which 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) and also our hypothesis of the timing of the survey relative to the temperature dependent timing of the annual spawning migration to nearshore areas which are outside of the survey area. The herding experiments suggest that the survey trawl catchability is greater than 1.0. The likelihood profile of q from the model indicated a small variance with a narrow range of likely values with a low probability of q being equal to the value of 1.0 in a past assessment (Wilderbuer and Nichol 2003).

Thus, the model configuration which utilizes the relationship between annual seafloor temperature and survey catchability with M fixed at 0.12 (Model 1), will be used to base our assessment of the condition of the Bering Sea yellowfin sole resource for the 2007 fishing season.

Model Results

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages are given in Table 4.12. The full-selection F has averaged 0.08 over the period of 1978-2005 with a maximum of 0.16 in 1978 and a minimum in 2001 at 0.05. Selectivities estimated by the model (Table 4.13, Figure 4.7) indicate that yellowfin sole are 50% selected by the fishery at age 9 and nearly fully selected by age 13.

Abundance Trend

The model estimates q at an average value of 1.16 for the period 1982-2006 which results in the model estimate of the 2006 total biomass at 1,996,000 t (Table 4.14). Model results indicate 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 4.14, Figure 4.7, bottom left panel). Sustained above average recruitment from 1967-76 combined with light exploitation resulted in a biomass increase to a peak of 2.8 million t by 1985. The population biomass has since been in a slow decline as the strong 1981 and 1983 year-classes have passed through the population with only the 1991 and 1995 year classes at levels observed during the 1970s. Over the past twenty years stock biomass has declined 800,000 t since the peak biomass observed in 1985 (65% of the peak level), but has remained at a high and stable level for the past 9 years..

The female spawning biomass has also steadily declined since the peak in 1985, with a 2006 estimate of 599,000 t (25% decline). This level of spawning biomass is about 130% of the $B_{40\%}$ level (Fig. 4.8). The model estimate of yellowfin sole population numbers at age for all years is shown in Table 4.14 and the resulting fit to the observed fishery and survey age compositions input into the model are shown in the Appendix. The fit to the trawl survey biomass estimates are shown in Figure 4.7. Allowing q to be correlated with annual bottom temperature provides a better fit to the bottom trawl survey estimates.

Both the trawl survey and the stock assessment model indicate that the yellowfin sole resource slowly increased during the 1970s and early 1980s to a peak level during the mid-1980s after which the resource experienced a slow, consistent decline until about the past 9 years where the trend has been stable (Figure 4.7). Above average recruitment from the 1991 and 1995 year-classes is expected to maintain the abundance of yellowfin sole at a level above B_{40} in the near future. The stock assessment projection model (later section) indicates a slow increase 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.

Recruitment Trends

The primary reason for the sustained increase in abundance of yellowfin sole during the 1970s and early 1980s was the recruitment of a series of stronger than average year classes spawned in 1967-76 (Figure 4.9 and Table 4.16). The 1981 year class was the strongest observed (and estimated) during the 46 year period analyzed and the 1983 year class was also very strong. Survey age composition estimates and the assessment model also estimate that the 1987 and 1988 year classes were average and the 1991, 1995, 1999 and 2001 year classes are above average. With the exception of these 6 year classes, recruitment from 12 of the last 18 years estimated (since the strong 1983 year-class) has been below the 48 year average, which has caused the population to gradually decline. The 1995 year-class are at the maximum of their cohort biomass in 2005 and should contribute to the mature adult reservoir of spawners in future years. Recruitment in the near future may be indicated by the 1999 and 2001 year classes, which appear at average strength.

Historical Exploitation Rates

Based on results from the stock assessment model, annual exploitation rates of yellowfin sole ranged from 3 to 8% of the total biomass since 1977, and have averaged 5% (Table 4.11).

Tier 1 Considerations

The SSC has requested that flatfish assessments which have a lengthy time-series of stock and recruitment estimates explore management under a Tier 1 harvest policy. In the case of yellowfin sole, we have a lengthy time series of 45 years. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit data which we assume represents the equilibrium stock size-recruitment relationship and the model used to fit the data. In the stock assessment model, a Ricker form of the stock-recruit relationship was fit to these data and estimates of F_{MSY} and B_{MSY} were calculated, assuming that the fit to the stock-recruitment data points represent the long-term productivity of the stock.

However, very different estimates of F_{MSY} and B_{MSY} were obtained, depending on which years of stock-recruitment data points were included in the fitting procedure (Fig. 4.10) and also what form of the stock recruitment relationship is used to fit the data (Spencer 2004). When we fit the entire time-series from 1954-1999 (last year's assessment), we include large recruitments that occurred at a low spawning stock size in the 1960s and early 1970s which indicate a productive stock that is able to replace itself quite well at low stock sizes. Therefore, MSY and F_{MSY} are relatively high values (217,000 t and 0.37, respectively) and B_{MSY} is 208,800 t. If we limit the analysis to consider only recruitments which occurred after the well-documented regime shift in 1977, much lower values of MSY and F_{MSY} are obtained (150,100 t and 0.22, respectively) and B_{MSY} is 249,800 t.

There is a concern whether a single fit of stock recruitment time-series data is able to reliably capture any future changes in productivity or density-dependence of the yellowfin sole stock, especially since the Tier 1 harvest calculations do not explicitly allow for environmental change. A recent analysis of flatfish recruitment indicates that temporal trends in winter spawning flatfish production in the Eastern Bering Sea are consistent with the hypothesis that decadal scale climate variability influences marine survival during the early life history period (Wilderbuer et al. 2002). Periods of cross-shelf advection for winter spawning flatfish larvae were found to coincide with synchronous above-average recruitment (1980s) whereas periods of weak advection or advection to the west were associated with poor recruitment (1990s). These changes in stock productivity were found to coincide with a decadal scale shift in atmospheric forcing which warrant caution when trying to determine the long-term reproductive potential of this stock.

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

Given these concerns, a management strategy simulation study was performed to determine how robust the tier 1 harvest strategy calculations are when fitting the full time series of spawner recruit estimates for a fish stock experiencing temporal changes in reproductive potential due to changing ocean conditions. The simulation study was set up with an operating model which simulated 60 future years of stock and recruitment where a new productivity regime occurred every 15 years alternating between high and low productivity as described above and shown in Figure 4.10. A simulated survey value was produced for each year which incorporated the variability from the changing recruitment productivity schedule. Similarly, survey and fishery age composition "observations" were input into the model for each year. The stock assessment model was then run for each year inside the operating model simulation and re-estimated the spawner recruit time-series (adding a new point each year), fit the Ricker form of the stock recruitment curve to the entire time-series, and calculated MSY and the harmonic mean of F_{MSY} (tier 1 calculations) to set the harvest for the next year. One thousand replicates were made for each year and the results were averaged to compare the "known" population, biomass and recruitment values with those estimated by the stock assessment model.

Results indicate a consistent underestimate of the "true" recruitment and spawning biomass by the stock assessment model throughout the 60 year simulation, regardless of the productivity state (Figure 4.11). Thus the Tier 1 harvest control strategy, although it does not explicitly consider environmental change, appears to be robust to underlying changes in stock productivity.

Results from the previous Tier 1 calculations for yellowfin sole indicate that the harmonic mean of the F_{MSY} estimate is very close to the geometric mean value of the F_{MSY} estimate due to the low variability in the parameter estimates. This indicates that the previous analysis was performed with very little uncertainty. To better understand how uncertainty in certain parameter estimates affects the Tier 1 harvest policy calculations for yellowfin sole, the following analysis was undertaken. Selectivity, catchability and M were selected as important parameters whose uncertainty may directly affect the pdf of the estimate of F_{MSY}. Eleven different model configurations were chosen to illustrate the effect of a range of uncertainly in these parameter estimates (varying from small to large (0.03, 0.4 and 0.8)) and how they affect the estimate of the harmonic mean of F_{MSY}.

The analysis provided the following results (Table 4.17). The values of F_{MSY}, B_{MSY} and MSY are dependent on the years of stock size and recruitment selected to be fit by the model (Models 1-3). Using the full time-series (1955-2001, Model 1) to fit the spawner-recruit curve indicates that the yellowfin sole stock is most productive at a smaller stock size with the result that the F_{MSY} value is three times higher than $F_{40\%}$. (Recall that $F_{40\%} = 0.11$). When the 1978-2001 years are fit (Model 2), the F_{MSY} value is less than twice the $F_{40\%}$ value. Using the estimates of recruitment and stock size from 1978-2001 as the basis for the spawner-recruit relationship (Model 2), uncertainty was introduced for the estimates of selectivity (Models 4and 5), catchability (Models 6, 7 and 8) and natural mortality (Models 10 and 11). Adding uncertainty to selectivity resulted in the largest difference between the geometric mean and the harmonic mean of the estimate of F_{MSY} for these Model runs, but the introduced uncertainty only resulted in a 10% reduction. Similarly, the addition of uncertainty in estimating catchability and natural mortality resulted in a 7-8% reduction for the estimate of the harmonic mean (Models 8 and 11). Thus F_{MSY} appears to be well estimated by the model. The posterior distributions of F_{MSY} from the 11 model runs are shown in the Appendix.

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 2007 is 1,996,000 t.

The reference fishing mortality rate for yellowfin sole is determined by the amount of population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. The Alaska Fisheries Science Center policy is to use year classes spawned in 1977 or later to calculate the average equilibrium recruitment if no compelling reason exists to do otherwise. For this assessment we use the time-series of recruitment numbers estimated for 1978-2003 from the stock assessment model to estimate $\mathbf{B_{0.40} = 459{,}700}$ **t**. The stock assessment projection model estimates the 2007 level of female spawning biomass at 585,100 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (585,100 > 459,700, Figure 4.8), yellowfin sole reference fishing mortality is defined in tier 3a. For the 2007 harvest: $F_{ABC} = F_{0.40} = 0.11$ (full selection F values).

Acceptable biological catch is estimated for 2007 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2007 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 Tier 3 2007 ABC of 135,600 t**.

Alternatively, ABC can be calculated using Tier 1 methodology depending on whether the SSC determines that yellowfin sole are in Tier 1 or Tier 3. It is critical for the Tier 1 calculations to identify which subset of the stock recruitment data is used. Using the full time series to fit the spawner recruit curve estimates that the stock is most productive at a small stock size. Thus MSY and F_{MSY} are high values and B_{MSY} is a low value. If the stock was productive in the past at a small stock size because of non density dependent factors (environment), then reducing the stock size to low levels could be detrimental to the long-term sustainability of the stock if the environment, and thus productivity, had changed from the earlier period. Since observations of yellowfin sole recruitment at low stock sizes are not available from multiple time periods, it is uncertain if future recruitment events at low stock conditions would be as productive as during the late 1960s-early 1970s. Therefore a more conservative approach would be to select the 1978-2001 data set for the Tier 1 harvest recommendation (Model 2 in Table 4.17) where $F_{\text{harmonic mean}} = 0.199$ which gives a Tier 1 ABC harvest recommendation of **225,170** t and an OFL of 261,300 t for 2007.

Depending on which stock recruitment subset is used in the Tier 1 calculations, significantly different stock recruitment relationships are found. These results illustrate the non-stationarity of stock-recruitment relationships for Bering Sea yellowfin sole and bring into question whether a single stock recruit curve can adequately define the dynamics of the stock. Therefore, this assessment recommends retaining yellowfin sole in Tier 3.

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 sets the Tier 3a 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 values, ABC fishing mortality values and their corresponding yields are given as follows:

Harvest level	F value	2007 Yield
Tier 3 $F_{OFL} = F_{0.35}$	0.13	135,600 t
Tier 3 $F_{ABC} = F_{0.40}$	0.11	160,300 t
Tier 1 $F_{OFL} = F_{MSY}$	0.22	261,300 t
Tier 1 $F_{ABC} = F_{\text{harmonic mean}}$	0.20	225,170 t

Biomass Projections

Status Determination

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 2006 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2007 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2006. 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 2007, 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 2007 recommended in the assessment to the *max* F_{ABC} for 2007. (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 75% 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 2002-2006 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 2007 and above its MSY level in 2017 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2007 and 2008, 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 2019 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 4.18 and Figure 4.12 indicate that yellowfin are not currently overfished and are not approaching an overfished condition.

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2007, it does not provide the best estimate of OFL for 2008, because the mean 2007 catch under Scenario 6 is predicated on the 2007 catch being equal to the 2007 OFL, whereas the actual 2007 catch will likely be less than the 2007 ABC. Therefore, the projection model was re-run with the 2007 catch fixed equal to the 2006 catch and the 2008 fishing mortality rate fixed at F_{ABC}.

Tier 3a

Year	Catch	ABC	OFL
2007	96,930	**135,600**	**160,300**
2008	96,930	**134,200**	**158,000**

Tier 1

Year	Catch	ABC	OFL
2007	96,930	**225,170**	**239,700**
2008	96,930	**245,450**	**261,300**

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

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

2) Predator population trends

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

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

3) Changes in habitat quality

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

Fishery Effects on the ecosystem

1) The yellowfin sole target fishery contribution to the total bycatch of other non-prohibited species is shown for 1991-2005 in Table 4.19. The yellowfin sole target fishery contribution to the total bycatch of prohibited species is shown for 2003 and 2004 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2004 as follows:

Prohibited species	Yellowfin sole fishery % of total bycatch
Halibut mortality	14.0
Herring	7.0
Red King crab	41.7
C. bairdi	30.2
Other Tanner crab	71.4
Salmon	< 1

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

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

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

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

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

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

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

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.

Clark, W. G., Hare, S. R., Parms, A. M., Sullivan, P, J., Trumble, R. J. 1999. Decadal changes in growth and recruitment of Pacific halibut (*Hipplglossus stenolepis*). Can. J. fish. Aquat. Sci. 56, 242-252.

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.

Haflinger, K. 1981. A survey of benthic infaunal communities of the Southeastern Bering Sea shelf. *In* Hood and Calder (editors) The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 2. P. 1091-1104. Office Mar. Pol. Assess., NOAA. Univ. Wash. Press, Seattle, Wa 98105.

Ianelli, J. N. and D. A. Fournier. 1998. Alternative age-structured analyses of the NRC simulated stock assessment data. In Restrepo, V. R. [ed.] Analyses of simulated data sets in support of the NRC study on stock assessment methods. NOAA Tech. Memo. NMFS-F/SPO-30. 96 p.

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.

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.

Somerton, D.. A. and P. Munro. 2001. Bridle efficiency of a survey trawl for flatfish. Fish. Bull. 99:641-652 (2001).

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.

Walters, G. E. and T. K. Wilderbuer. 2000. Decreasing length at age in a rapidly expanding population of northern rock sole in the eastern Bering Sea and its effect on management advice. Journal of Sea Research 44(2000)17-26.

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. and D. Nichol. 2003. Yellowfin sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2004, chapter 4. 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.

Wilderbuer, T. K., A. B. Hollowed, W. J. Ingraham, Jr., P. D. Spencer, M. E. Conners, N. A. Bond, and G. E. Walters. Flatfish recruitment response to decadal climate variability and ocean conditions in the eastern Bering Sea. Progress Oceanography 55 (2002) 235-247.

Tables

Table 4.1. Catch (t) of yellowfin sole 1977-2006. Catch for 2006 is the total through September 6, 2006.

		Domestic		
Year	Foreign	JVP	DAP	Total
1977	58,373			58,373
1978	138,433			138,433
1979	99,019			99,019
1980	77,768	9,623		87,391
1981	81,255	16,046		97,301
1982	78,331	17,381		95,712
1983	85,874	22,511		108,385
1984	126,762	32,764		159,526
1985	100,706	126,401		227,107
1986	57,197	151,400		208,597
1987	1,811	179,613	4	181,428
1988		213,323	9,833	223,156
1989		151,501	1,664	153,165
1990		69,677	14,293	83,970
1991			115,842	115,842
1992			149,569	149,569
1993			106,101	106,101
1994			144,544	144,544
1995			124,740	124,740
1996			129,659	129,659
1997			181,389	181,389
1998			101,201	101,201
1999			67,320	67,320
2000			83,850	83,850
2001			63,395	63,395
2002			73,000	73,000
2003			74,418	74,418
2004			69,046	69,046
2005			94,383	94,383
2006			96,931	96,931

Table 4.2 Estimates of retained and discarded (t) yellowfin sole caught in Bering Sea fisheries.

Year	Retained	Discarded
1987	3	1
1988	7,559	2,274
1989	1,279	385
1990	10,093	4,200
1991	89,054	26,788
1992	103,989	45,580
1993	76,798	26,838
1994	107,629	36,948
1995	96,718	28,022
1996	101,324	28,334
1997	149,570	31,818
1998	80,365	20,836
1999	55,202	12,118
2000	69,788	14,062
2001	54,759	8,635
2002	62,050	10,950
2003	63,732	10,686
2004	57,378	11,668
2005	85,321	9,062

Table 4.3. Discarded and retained catch of yellowfin sole, by fishery, in 2004 and 2005.

2004

Target Fishery	Discard	Retained	Grand Total
Atka mackerel	5	2	7
Bottom pollock	32	125	157
Pacific cod	1,791	529	2,320
Mid-water pollock	365	250	615
Sablefish	0	0	0
Rockfish	0	0	0
Arrowtooth flounder	1	3	4
Flathead sole	337	1,889	2,226
Rock sole	1,918	1,646	3,564
Yellowfin sole	7,205	52,917	60,122
Greenland turbot	0	1	1
Other flatfish	8	15	23
Other species	7	2	9
2004 Total	11,668	57,378	69,046

2005

Target Fishery	Discard	Retained	Grand Total
Atka mackerel	4	22	26
Bottom pollock	42	4	46
Pacific cod	1,675	375	2,049
Mid-water pollock	11	6	17
Sablefish	0	0	0
Rockfish	0	0	0
Arrowtooth flounder	1	15	16
Flathead sole	470	1,729	2,199
Rock sole	1,300	6,280	7,580
Yellowfin sole	5,544	76,885	82,429
Greenland turbot	0	0	0
Other flatfish	15	6	21
Other species	0	0	0
			0
2005 Total	9,062	85,321	94,383

Table 4.4. Yellowfin sole fishery catch-at-age numbers (millions), 1977-2005.

YEAR/AGE	7	8	9	10	11	12	13	14	15	16	17+
1977	18.7	42.5	35.7	70.5	48.3	15.8	4.7	2.9	2.2	0.6	0.3
1978	66.8	131.7	113.8	97.8	104.3	38.9	21.6	12.3	4.5	2.7	0.7
1979	20.7	49.4	89.6	82.9	61.3	45.1	22.9	7.1	4.1	1.5	1.3
1980	33.1	19.7	41.3	64.1	60.8	47.7	42.4	23.2	7.4	10.1	4.2
1981	31.1	46.2	41.7	51.7	67.2	70.6	58.4	40.2	18.5	5.7	4.4
1982	27.7	58.9	45.1	42.2	71.5	75.0	39.6	20.1	10.4	2.7	0.5
1983	56.2	39.6	75.9	53.5	53.5	77.1	57.9	32.3	16.5	5.2	2.9
1984	13.2	26.3	34.0	70.5	72.2	94.1	107.8	102.1	56.5	23.6	11.3
1985	36.9	52.1	107.2	106.0	127.9	108.8	108.5	103.9	66.1	29.5	15.4
1986	49.3	40.7	67.6	111.6	82.5	74.7	64.3	40.2	56.5	51.8	28.8
1987	18.2	49.4	33.5	49.3	55.4	59.6	73.4	61.0	26.3	40.1	42.3
1988	29.0	57.5	140.5	40.8	71.7	89.4	53.6	104.1	82.1	34.8	176.9
1989	2.5	33.8	47.0	73.1	29.5	20.5	52.0	32.2	45.3	44.5	172.0
1990	8.8	7.0	52.4	29.2	49.4	20.0	18.4	16.9	17.4	23.2	72.2
1991	9.9	62.5	6.5	116.2	28.8	38.8	7.3	18.5	25.5	16.0	60.3
1992	5.9	24.2	83.8	22.5	123.3	29.9	25.0	13.3	15.2	12.7	71.8
1993	12.2	8.1	11.0	57.4	7.4	74.4	16.3	19.9	9.8	15.1	89.9
1994	21.3	33.7	26.8	26.9	127.5	3.2	90.8	9.7	33.9	13.7	85.6
1995	27.7	46.3	21.0	11.2	13.7	83.3	1.8	103.9	9.7	16.9	69.4
1996	13.1	41.1	43.8	19.4	15.5	25.9	74.2	14.3	75.4	10.6	73.6
1997	19.5	25.2	63.6	40.2	27.4	38.5	29.8	114.7	14.3	63.5	114.4
1998	12.2	13.2	15.7	33.2	28.6	20.0	15.8	16.8	28.2	15.3	100.3
1999	2.77	6.97	7.20	7.59	24.45	18.68	10.29	11.66	14.69	20.14	66.89
2000	1.28	7.72	24.69	10.50	11.66	29.30	25.37	19.02	8.89	20.06	21.35
2001	3.83	7.71	11.48	21.08	15.04	11.35	18.60	15.31	13.81	7.37	9.11
2002	2.88	9.67	12.35	16.72	31.51	14.74	10.74	18.97	13.15	7.62	74.66
2003	2.50	27.41	19.75	11.67	15.21	28.10	11.91	9.12	10.69	11.61	76.36
2004	4.51	6.04	39.73	13.11	9.78	8.89	17.09	6.80	4.72	13.32	78.81
2005	8.27	20.00	15.87	45.86	14.83	15.79	18.19	26.82	13.14	4.00	96.64

Table 4.5—Yellowfin sole biomass estimates (t) from the annual Bering Sea shelf bottom trawl survey and upper and lower 95% confidence intervals.

Year	Age 0-6	Age 7 +	Total	Lower CI		Upper CI
1975	169,500	803,000	972,500	812,300	–	1,132,700
1979	211,500	1,655,000	1,866,500	1,586,000	–	2,147,100
1980	235,900	1,606,500	1,842,400	1,553,200	–	2,131,700
1981	343,200	2,051,500	2,394,700	2,072,900	–	2,716,500
1982	685,700	2,692,100	3,377,800	2,571,000	–	4,184,600
1983	198,000	3,337,300	3,535,300	2,958,100	–	4,112,400
1984	172,800	2,968,400	3,141,200	2,636,800	–	3,645,600
1985	166,200	2,277,500	2,443,700	1,563,400	–	3,324,000
1986	80,200	1,829,700	1,909,900	1,480,700	–	2,339,000
1987	125,500	2,487,600	2,613,100	2,051,800	–	3,174,400
1988	45,600	2,356,800	2,402,400	1,808,400	–	2,996,300
1989	196,900	2,119,400	2,316,300	1,836,700	–	2,795,800
1990	69,600	2,114,200	2,183,800	1,886,200	–	2,479,400
1991	60,000	2,333,300	2,393,300	2,116,000	–	2,670,700
1992	145,900	2,027,000	2,172,900			
1993	188,200	2,277,200	2,465,400	2,151,500	–	2,779,300
1994	142,000	2,468,500	2,610,500	2,266,800	–	2,954,100
1995	213,000	1,796,700	2,009,700	1,724,800	–	2,294,600
1996	161,600	2,137,000	2,298,600	1,749,900	–	2,847,300
1997	239,330	1,924,070	2,163,400	1,907,900	–	2,418,900
1998	150,756	2,178,844	2,329,600	2,033,130	–	2,626,070
1999	57,700	1,246,770	1,306,470	1,118,800	–	1,494,150
2000	73,200	1,508,700	1,581,900	1,382,000	–	1,781,800
2001	135,900	1,727,800	1,863,700	1,605,000	–	2,122,300
2002	83,200	1,933,500	2,016,700	1,740,700	–	2,292,700
2003	2,900	2,236,700	2,239,600	1,822,700	–	2,656,600
2004	191,800	2,338,800	2,530,600	2,147,900	–	2,913,300
2005	158,865	2,664,635	2,823,500	2,035,800	–	3,499,800
2006			2,133,093	1,818,253		2,447,932

Table 4.6. Yellowfin sole population numbers-at-age (millions) estimated from the annual bottom trawl surveys, 1982-2005.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1982	123.9	363.4	742.8	2882.0	3155.6	2408.1	3193.9	1445.1	1556.8	1258.3	1140.6	863.7	531.6	163.8	73.6	90.3
1983	0.0	6.5	142.0	378.6	1659.5	3495.2	1836.1	2388.3	1786.5	1596.7	2079.7	1576.7	771.9	751.4	154.1	114.3
1984	0.0	115.7	494.3	577.0	957.6	1554.7	1765.8	1832.8	1982.2	1759.3	953.1	1018.8	723.4	580.1	310.5	251.4
1985	0.0	43.2	241.9	762.1	1040.2	619.0	1206.2	1353.3	787.5	904.7	846.5	568.1	519.4	448.5	295.5	177.8
1986	0.0	35.2	66.9	310.9	698.3	1297.7	535.4	888.1	787.9	693.1	482.5	507.6	302.1	450.0	212.2	496.4
1987	0.0	6.4	102.2	210.9	1554.7	932.7	1477.6	681.6	650.0	818.8	534.9	552.6	319.4	381.2	392.2	1199.0
1988	1.1	4.0	32.0	782.6	133.7	2997.0	1524.3	1271.8	319.0	500.8	446.7	464.6	821.5	547.6	290.8	1.8
1989	0.0	17.0	45.6	336.8	1848.0	504.1	3244.5	1350.7	979.0	255.0	280.1	503.4	351.8	540.7	267.2	1296.0
1990	0.0	29.1	116.5	220.9	637.7	1947.2	386.5	2400.2	726.2	746.3	141.6	137.6	174.9	102.4	286.1	1003.6
1991	0.0	12.9	229.3	594.0	256.3	718.7	1933.1	207.1	2423.2	535.7	764.6	142.8	196.5	137.6	164.9	1220.9
1992	0.0	12.7	281.7	670.1	854.0	386.5	436.9	1522.3	183.4	1526.2	232.2	467.1	128.0	133.9	203.9	1149.5
1993	0.0	52.8	180.6	610.3	1300.3	828.2	548.0	471.7	2418.5	147.8	1725.1	226.0	223.0	119.5	67.9	1059.6
1994	4.2	75.2	165.8	388.8	944.6	1857.4	1210.8	789.0	475.3	1992.2	25.7	1137.9	89.7	405.7	153.5	434.5
1995	0.0	18.9	321.7	408.2	451.4	1555.6	1192.1	368.7	314.5	99.9	1111.2	33.9	1163.4	153.2	104.5	929.9
1996	0.0	92.3	248.6	1649.8	536.7	513.3	877.8	879.0	555.1	295.4	299.6	1026.4	181.2	1115.8	179.6	1151.4
1997	0.0	37.7	541.6	927.9	1522.9	437.0	422.7	952.2	473.7	307.9	390.5	292.4	1014.1	122.7	578.4	948.9
1998	0.0	58.9	153.2	829.3	989.5	1732.4	418.8	429.9	574.2	685.3	715.0	320.6	333.6	452.9	179.9	1974.4
1999	0.0	8.8	169.1	343.9	402.9	430.5	1307.4	250.5	201.6	555.4	460.8	261.7	126.2	131.3	296.1	1974.4
2000	0.0	24.5	134.8	527.5	417.2	594.2	791.4	1020.8	268.9	384.0	320.1	344.4	278.8	264.3	233.1	1314.5
2001	0.0	1.3	146.4	376.7	1159.0	637.1	750.7	789.3	1174.6	493.1	281.5	406.5	216.7	227.6	302.5	1037.7
2002	0.0	70.4	201.7	326.9	590.9	1500.2	689.1	602.6	473.8	906.0	391.1	225.7	555.0	251.3	297.3	1268.7
2003	0.0	0.0	0.0	5.1	43.5	216.9	1784.3	387.0	773.8	256.2	1197.7	426.4	303.7	436.2	363.7	4524.7
2004	0.0	97.0	302.8	860.9	990.7	642.6	650.7	1830.1	508.4	326.0	417.6	515.0	189.3	58.0	373.7	1525.0
2005	0.0	101.6	333.3	380.8	1075.7	909.0	417.1	774.9	1806.2	318.9	285.6	312.5	456.5	239.5	146.0	1980.6

Table 4.7—Mean length and weight at age for yellowfin sole.

Length Weight				
Age	cm	in	g	lb
3	11.1	4.4	15.31	0.03
4	14.5	5.7	34.41	0.08
5	17.4	6.9	60.23	1.13
6	19.9	7.8	90.97	0.2
7	22.1	8.7	124.8	0.27
8	24	9.4	160.07	0.35
9	25.6	10.1	195.44	0.43
10	27	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	428.65	0.94
19	33.5	13.2	443.55	0.98
20	33.8	13.3	456.69	1.01
21	34	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

Table 4.8. Female yellowfin sole proportion mature at age from Nichol (1994).

Age	Proportion mature
1	0.00
2	0.00
3	.001
4	.004
5	*.008*
6	.020
7	.046
8	.104
9	.217
10	.397
11	.612
12	.790
13	.899
14	.955
15	.981
16	.992
17	.997
18	1.000
19	1.000
20	1.000

Table 4.9. Key equations used in the population dynamics model.

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

Table 4.10. Variables used in the population dynamics model.

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

Table 4.11. Models evaluated for the 2006 stock assessment of yellowfin sole. Sigma_M and Sigma_q are the level of uncertainty placed on the parameter estimates of natural mortality and catchability, respectively.

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
model	2005 model	2006 similar to 2005 model	M estimated with sigma_M = 0.2	M estimated with sigma_M = 0.5	q estimated with sigma_q = 0.2	q estimated with sigma_q = 0.5	M and q estimated with sigma = 0.2	M and q estimated with sigma = 0.5
ending FSB	538.031	598.748	655.172	656.397	625.663	626.363	453.061	393.011
ending total biomass	1705.11	1995.96	2085.32	2087.23	2063.09	2065.13	1406.47	1196.9
M	0.12	0.12	0.107	0.106	0.12	0.12	0.07	0.047
q	1.27	1.16	1.16	1.16	1.14	1.14	1.77	2.12
F40%	0.11	0.109	0.1	0.099	0.11	0.11	0.071	0.05
2007 ABC (tier 3)	121.425	135.463	136.034	135.964	141.546	141.702	70.419	45.586
survey, catch, age and recruit likelihood	1827.5	1272.36	1278.53	1278.53	1284.02	1284.02	1258.69	1253.4

Table 4.12. Model estimates of yellowfin sole fishing mortality and exploitation rate (catch/total biomass).

Year	Full selection F	Exploitation Rate
1964	0.48	0.15
1965	0.19	0.07
1966	0.31	0.13
1967	0.48	0.20
1968	0.26	0.12
1969	0.57	0.23
1970	0.54	0.19
1971	0.86	0.23
1972	0.29	0.06
1973	0.41	0.08
1974	0.17	0.04
1975	0.18	0.05
1976	0.11	0.04
1977	0.08	0.03
1978	0.16	0.07
1979	0.09	0.05
1980	0.07	0.04
1981	0.07	0.04
1982	0.06	0.04
1983	0.06	0.04
1984	0.09	0.06
1985	0.13	0.08
1986	0.12	0.08
1987	0.11	0.07
1988	0.14	0.08
1989	0.10	0.06
1990	0.05	0.03
1991	0.05	0.04
1992	0.09	0.06
1993	0.06	0.04
1994	0.08	0.06
1995	0.07	0.05
1996	0.08	0.06
1997	0.12	0.08
1998	0.07	0.05
1999	0.05	0.03
2000	0.06	0.04
2001	0.05	0.03
2002	0.05	0.04
2003	0.05	0.04
2004	0.05	0.03
2005	0.07	0.05
2006	0.07	0.05

Table 4.13. Model estimates of yellowfin sole age-specific selectivities for the survey and fishery.

Age	Fishery (1964-2005)	Survey (1982-2005)
1	0.00	0.00
2	0.00	0.01
3	0.00	0.03
4	0.01	0.13
5	0.02	0.42
6	0.06	0.78
7	0.15	0.95
8	0.33	0.99
9	0.57	1.00
10	0.78	1.00
11	0.91	1.00
12	0.96	1.00
13	0.99	1.00
14	0.99	1.00
15	0.99	1.00
16	0.99	1.00
17	0.99	1.00
18	0.99	1.00
19	0.99	1.00
20	0.99	1.00

Table 4.14. Model estimates of yellowfin sole age 2+ total biomass (t) and begin-year female spawning biomass (t) from the 2005 and 2006 stock assessments.

	2005 Assessment		2006 Assessment	
Year	Female Spawning Biomass	Age 2+ Total Biomass	Female Spawning Biomass	Age 2+ Total Biomass
1964	72,219	735,080	75,802	751,570
1965	75,031	739,271	80,474	754,941
1966	100,001	793,203	106,392	808,050
1967	117,105	786,580	124,093	799,107
1968	111,734	712,775	118,894	721,658
1969	122,532	728,388	129,491	738,735
1970	98,922	665,758	105,379	686,580
1971	81,746	662,584	87,490	706,195
1972	53,818	661,096	58,433	737,696
1973	61,836	812,389	65,835	929,017
1974	68,047	960,704	72,675	1,113,000
1975	93,595	1,174,670	101,108	1,353,500
1976	126,109	1,386,720	142,311	1,580,460
1977	174,138	1,622,290	205,787	1,820,570
1978	235,281	1,860,520	287,797	2,056,710
1979	283,520	2,004,200	357,796	2,196,480
1980	353,351	2,170,300	443,284	2,357,860
1981	436,048	2,323,140	532,240	2,506,810
1982	518,403	2,436,880	610,891	2,617,810
1983	600,970	2,538,280	683,757	2,717,900
1984	674,482	2,614,670	747,124	2,794,130
1985	716,457	2,633,580	782,118	2,813,890
1986	712,607	2,578,120	776,046	2,760,430
1987	695,686	2,531,850	759,970	2,716,430
1988	678,436	2,497,210	743,986	2,682,530
1989	638,154	2,400,990	705,115	2,586,800
1990	636,227	2,364,970	703,937	2,551,580
1991	673,684	2,389,490	741,134	2,576,460
1992	709,189	2,377,820	775,997	2,564,670
1993	712,390	2,288,670	779,120	2,476,360
1994	725,036	2,245,300	791,623	2,433,940
1995	705,083	2,154,950	771,891	2,344,140
1996	681,940	2,079,920	749,297	2,268,960
1997	652,056	1,999,830	720,089	2,188,600
1998	600,290	1,872,510	668,910	2,061,660
1999	581,091	1,827,720	650,042	2,020,170
2000	573,928	1,811,840	642,645	2,011,090
2001	562,268	1,778,980	630,890	1,990,910
2002	558,747	1,758,770	626,952	1,986,270
2003	553,118	1,736,940	621,447	1,983,570
2004	543,656	1,714,080	612,852	1,983,340
2005	538,031	1,705,110	609,868	1,998,940
2006			598,748	1,995,960

Table 4.15. Model estimates of yellowfin sole population number at age (billions) for 1954- 2006.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	3.33	4.25	2.04	0.80	0.40	0.34	0.33	0.32	0.32	0.31	0.31	0.32	0.32	0.32	0.32	0.32	0.33	0.33	0.33	0.33
1955	1.62	2.95	3.77	1.81	0.71	0.35	0.30	0.29	0.28	0.28	0.27	0.27	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.58
1956	1.01	1.44	2.62	3.34	1.61	0.63	0.31	0.27	0.25	0.25	0.24	0.24	0.24	0.24	0.25	0.25	0.25	0.25	0.25	0.76
1957	3.32	0.90	1.28	2.32	2.96	1.42	0.56	0.28	0.24	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.22	0.22	0.88
1958	2.37	2.94	0.79	1.13	2.06	2.63	1.26	0.49	0.24	0.21	0.19	0.19	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.95
1959	1.78	2.11	2.61	0.70	1.00	1.83	2.32	1.11	0.43	0.21	0.18	0.17	0.16	0.16	0.15	0.15	0.16	0.16	0.16	0.97
1960	1.84	1.58	1.87	2.31	0.62	0.89	1.60	2.00	0.93	0.34	0.16	0.13	0.12	0.12	0.12	0.11	0.11	0.12	0.12	0.84
1961	1.08	1.63	1.40	1.65	2.04	0.55	0.76	1.30	1.48	0.60	0.20	0.09	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.49
1962	1.85	0.96	1.44	1.24	1.45	1.77	0.45	0.58	0.83	0.74	0.24	0.07	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.18
1963	0.96	1.64	0.85	1.27	1.08	1.24	1.43	0.32	0.32	0.32	0.21	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.04
1964	0.88	0.85	1.46	0.75	1.13	0.95	1.07	1.19	0.25	0.22	0.20	0.13	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.03
1965	1.20	0.78	0.75	1.29	0.66	0.99	0.82	0.88	0.90	0.17	0.13	0.12	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.02
1966	1.25	1.06	0.69	0.67	1.14	0.59	0.86	0.70	0.73	0.71	0.13	0.10	0.09	0.05	0.01	0.00	0.00	0.00	0.00	0.01
1967	2.58	1.11	0.94	0.61	0.59	1.00	0.51	0.73	0.56	0.55	0.49	0.08	0.07	0.06	0.03	0.01	0.00	0.00	0.00	0.01
1968	3.96	2.29	0.98	0.83	0.54	0.52	0.86	0.42	0.55	0.38	0.33	0.28	0.05	0.04	0.03	0.02	0.00	0.00	0.00	0.01
1969	3.37	3.51	2.03	0.87	0.74	0.48	0.45	0.74	0.34	0.42	0.27	0.23	0.19	0.03	0.02	0.02	0.01	0.00	0.00	0.00
1970	4.42	2.99	3.11	1.79	0.77	0.64	0.41	0.37	0.54	0.22	0.24	0.14	0.12	0.10	0.02	0.01	0.01	0.01	0.00	0.00
1971	4.90	3.92	2.65	2.76	1.58	0.67	0.55	0.33	0.27	0.35	0.13	0.13	0.07	0.06	0.05	0.01	0.01	0.01	0.00	0.00
1972	3.97	4.34	3.47	2.34	2.42	1.37	0.56	0.43	0.22	0.15	0.16	0.05	0.05	0.03	0.02	0.02	0.00	0.00	0.00	0.00
1973	2.88	3.52	3.85	3.08	2.07	2.14	1.20	0.48	0.35	0.17	0.10	0.11	0.03	0.03	0.02	0.02	0.01	0.00	0.00	0.00
1974	3.98	2.55	3.12	3.41	2.72	1.82	1.85	1.00	0.37	0.24	0.11	0.06	0.06	0.02	0.02	0.01	0.01	0.01	0.00	0.00
1975	4.67	3.53	2.26	2.76	3.02	2.40	1.60	1.59	0.83	0.30	0.19	0.08	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.00
1976	3.31	4.14	3.13	2.00	2.45	2.67	2.11	1.38	1.33	0.67	0.23	0.14	0.06	0.04	0.04	0.01	0.01	0.01	0.00	0.01
1977	3.93	2.93	3.67	2.77	1.78	2.16	2.35	1.84	1.18	1.11	0.54	0.18	0.11	0.05	0.03	0.03	0.01	0.01	0.00	0.01
1978	2.61	3.48	2.60	3.26	2.46	1.57	1.91	2.06	1.58	0.99	0.92	0.45	0.15	0.09	0.04	0.02	0.02	0.01	0.01	0.01
1979	1.70	2.32	3.09	2.30	2.88	2.17	1.38	1.65	1.73	1.28	0.78	0.71	0.34	0.11	0.07	0.03	0.02	0.02	0.01	0.01
1980	3.25	1.51	2.05	2.74	2.04	2.55	1.91	1.21	1.42	1.45	1.06	0.63	0.57	0.27	0.09	0.06	0.02	0.01	0.01	0.02
1981	2.29	2.88	1.34	1.82	2.43	1.81	2.25	1.68	1.05	1.21	1.22	0.88	0.52	0.47	0.23	0.08	0.05	0.02	0.01	0.02
1982	6.27	2.03	2.56	1.19	1.61	2.15	1.60	1.98	1.46	0.89	1.02	1.01	0.73	0.43	0.39	0.19	0.06	0.04	0.02	0.03
1983	1.08	5.56	1.80	2.27	1.05	1.43	1.90	1.40	1.72	1.25	0.75	0.85	0.85	0.61	0.36	0.33	0.16	0.05	0.03	0.04
1984	5.17	0.96	4.93	1.60	2.01	0.93	1.26	1.67	1.22	1.47	1.05	0.63	0.71	0.71	0.51	0.30	0.27	0.13	0.04	0.06
1985	1.70	4.59	0.85	4.37	1.42	1.78	0.82	1.10	1.44	1.03	1.21	0.86	0.51	0.58	0.57	0.41	0.24	0.22	0.11	0.08
1986	1.41	1.51	4.07	0.75	3.87	1.25	1.56	0.72	0.94	1.18	0.82	0.96	0.67	0.40	0.45	0.45	0.32	0.19	0.17	0.15
1987	1.91	1.25	1.34	3.61	0.67	3.42	1.10	1.36	0.61	0.78	0.95	0.65	0.75	0.53	0.31	0.35	0.35	0.25	0.15	0.25
1988	2.58	1.69	1.11	1.19	3.19	0.59	3.02	0.96	1.17	0.51	0.63	0.76	0.52	0.60	0.42	0.25	0.28	0.28	0.20	0.32
1989	2.53	2.29	1.50	0.98	1.05	2.82	0.52	2.62	0.81	0.95	0.40	0.49	0.59	0.40	0.46	0.32	0.19	0.22	0.22	0.40
1990	1.09	2.24	2.03	1.33	0.87	0.93	2.49	0.45	2.25	0.68	0.78	0.33	0.40	0.48	0.32	0.37	0.26	0.15	0.17	0.49
1991	1.25	0.97	1.99	1.80	1.18	0.77	0.82	2.19	0.40	1.94	0.58	0.66	0.28	0.34	0.40	0.27	0.31	0.22	0.13	0.57
1992	2.94	1.11	0.86	1.76	1.59	1.05	0.68	0.72	1.91	0.34	1.65	0.49	0.56	0.23	0.28	0.34	0.23	0.26	0.18	0.58
1993	1.60	2.61	0.98	0.76	1.56	1.41	0.92	0.59	0.62	1.61	0.28	1.34	0.40	0.45	0.19	0.23	0.27	0.19	0.21	0.62
1994	1.39	1.42	2.31	0.87	0.68	1.38	1.25	0.81	0.52	0.53	1.36	0.24	1.12	0.33	0.38	0.16	0.19	0.23	0.16	0.70
1995	1.31	1.23	1.26	2.05	0.77	0.60	1.22	1.09	0.70	0.44	0.44	1.12	0.19	0.92	0.27	0.31	0.13	0.16	0.19	0.70
1996	3.47	1.16	1.09	1.12	1.82	0.69	0.53	1.07	0.94	0.59	0.37	0.37	0.92	0.16	0.75	0.22	0.25	0.11	0.13	0.73
1997	1.25	3.08	1.03	0.97	0.99	1.61	0.60	0.46	0.92	0.80	0.49	0.30	0.30	0.75	0.13	0.62	0.18	0.21	0.09	0.70
1998	1.30	1.11	2.73	0.91	0.86	0.88	1.42	0.53	0.39	0.77	0.65	0.39	0.24	0.24	0.59	0.10	0.49	0.14	0.16	0.62
1999	1.80	1.15	0.98	2.42	0.81	0.76	0.77	1.24	0.46	0.34	0.64	0.54	0.33	0.20	0.20	0.49	0.08	0.40	0.12	0.65
2000	2.50	1.60	1.02	0.87	2.14	0.72	0.67	0.68	1.08	0.39	0.29	0.55	0.45	0.28	0.17	0.17	0.42	0.07	0.34	0.65
2001	1.83	2.22	1.42	0.91	0.77	1.90	0.63	0.59	0.59	0.93	0.33	0.24	0.46	0.38	0.23	0.14	0.14	0.35	0.06	0.83
2002	2.87	1.62	1.97	1.25	0.80	0.68	1.68	0.56	0.52	0.51	0.79	0.28	0.20	0.39	0.32	0.19	0.12	0.12	0.29	0.75
2003	2.58	2.55	1.44	1.75	1.11	0.71	0.61	1.48	0.49	0.44	0.44	0.67	0.24	0.17	0.32	0.27	0.16	0.10	0.10	0.88
2004	1.96	2.29	2.26	1.28	1.55	0.99	0.63	0.53	1.29	0.42	0.38	0.37	0.56	0.20	0.14	0.27	0.23	0.14	0.08	0.82
2005	2.14	1.74	2.03	2.00	1.13	1.37	0.87	0.55	0.46	1.11	0.36	0.32	0.31	0.48	0.17	0.12	0.23	0.19	0.12	0.76
2006	2.16	1.90	1.54	1.80	1.78	1.00	1.21	0.76	0.48	0.40	0.93	0.30	0.26	0.26	0.39	0.14	0.10	0.19	0.16	0.73

Table 4.16. Model estimates of yellowfin sole age 5 recruitment (millions) from the 2005 and 2006 stock assessments.

Year class	2005 Assessment	2006 Assessment
1959	1,134	1,126
1960	666	664
1961	1,144	1,141
1962	578	591
1963	544	540
1964	759	736
1965	905	767
1966	1,490	1,583
1967	1,618	2,425
1968	1,581	2,072
1969	2,178	2,719
1970	2,661	3,019
1971	2,582	2,447
1972	2,298	1,776
1973	2,515	2,458
1974	3,017	2,885
1975	1,928	2,043
1976	2,255	2,428
1977	1,502	1,615
1978	1,005	1,053
1979	1,879	2,010
1980	1,358	1,417
1981	3,717	3,872
1982	639	667
1983	3,080	3,194
1984	993	1,051
1985	796	868
1986	1,089	1,181
1987	1,454	1,595
1988	1,453	1,562
1989	641	676
1990	691	774
1991	1,725	1,818
1992	889	991
1993	832	857
1994	772	811
1995	1,884	2,144
1996	637	773
1997	568	805
1998	752	1,112
1999	1,108	1,547
2000	1,185	1,132

Table 4.17- Models used to evaluate the effect of uncertainty on the estimate of the harmonic mean of F_{MSY}. The highlighted values are those which change between models.

	Years used in S/R fit	Selectivity CV	q sigma	M sigma	F_{MSY}	Harmonic mean of F_{MSY}
Model 1	1955-2001	0.03	q not estimated	M not estimated	0.330	0.327
Model 2	1978-2001	0.03	q not estimated	M not estimated	0.216	0.199
Model 3	1955-1978	0.03	q not estimated	M not estimated	0.387	0.382
Model 4	1978-2001	0.4	q not estimated	M not estimated	0.216	0.1977
Model 5	1978-2001	0.8	q not estimated	M not estimated	0.216	0.1936
Model 6	1978-2001	0.03	0.03	M not estimated	0.216	0.1992
Model 7	1978-2001	0.03	0.4	M not estimated	0.213	0.1965
Model 8	1978-2001	0.03	0.8	M not estimated	0.213	0.1964
Model 9	1978-2001	0.03	q not estimated	0.03	0.213	0.199
Model 10	1978-2001	0.03	q not estimated	0.4	0.213	0.199
Model 11	1978-2001	0.03	q not estimated	0.8	0.213	0.199

Table 4.18. Projections of yellowfin sole female spawning biomass (1,000s t), catch (1,000s t) and full selection fishing mortality rate for seven future harvest scenarios. 2007 ABC is highlighted.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2006	561.732	96.61	0.08
2007	543.162	135.48	0.11
2008	515.51	130.63	0.11
2009	494.125	127.60	0.11
2010	480.972	126.29	0.11
2011	474.991	125.75	0.11
2012	471.547	124.64	0.11
2013	468.413	123.18	0.11
2014	464.14	121.88	0.11
2015	460.347	121.08	0.11
2016	456.43	119.81	0.11
2017	454.588	119.15	0.11
2018	454.141	119.26	0.11
2019	455.685	119.85	0.11

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2006	561.732	96.61	0.08
2007	552.849	67.73	0.05
2008	555.252	45.32	0.04
2009	567.14	46.83	0.04
2010	584.751	48.68	0.04
2011	607.752	50.63	0.04
2012	631.119	52.19	0.04
2013	652.874	53.44	0.04
2014	670.823	54.56	0.04
2015	687.434	55.74	0.04
2016	700.455	56.75	0.04
2017	713.397	57.74	0.04
2018	726.442	58.68	0.04
2019	739.091	59.54	0.04

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2006	561.732	96.61	0.08
2007	551.069	80.33	0.06
2008	546.881	68.39	0.05
2009	549.541	69.64	0.05
2010	558.178	71.46	0.05
2011	572.345	73.46	0.05
2012	587.195	74.92	0.05
2013	600.808	75.98	0.05
2014	611.23	76.91	0.05
2015	620.833	78.00	0.05
2016	627.855	78.92	0.05
2017	635.365	79.87	0.05
2018	643.403	80.79	0.05
2019	651.414	81.62	0.05

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2006	561.732	96.61	0.08
2007	562.244	0	0
2008	589.403	0	0
2009	619.641	0	0
2010	655.679	0	0
2011	697.384	0	0
2012	739.257	0	0
2013	779.257	0	0
2014	814.684	0	0
2015	848.264	0	0
2016	876.336	0	0
2017	903.413	0	0
2018	929.92	0	0
2019	955.413	0	0

Table 4.18—continued.

Scenario 6
Determination of whether yellowfin sole are currently overfished **B35=402.195**

Year	Female spawning biomass	catch	F
2006	561.732	96.61	0.08
2007	539.529	160.33	0.13
2008	502.296	151.90	0.13
2009	473.016	146.13	0.13
2010	453.53	140.87	0.13
2011	443.052	135.74	0.13
2012	436.941	131.97	0.12
2013	432.528	128.81	0.12
2014	428.079	126.22	0.12
2015	425.223	125.06	0.12
2016	423.028	124.42	0.12
2017	422.85	124.63	0.12
2018	424.013	125.17	0.12
2019	425.679	125.76	0.12

Scenario 7
Determination of whether the stock is approaching an overfished condition **B35=402.195**

Year	Female spawning biomass	catch	F
2006	561.732	96.61	0.08
2007	543.16	135.48	0.11
2008	515.505	130.63	0.11
2009	490.859	151.04	0.13
2010	468.875	146.96	0.13
2011	455.286	142.78	0.13
2012	445.895	136.95	0.13
2013	438.867	132.22	0.12
2014	432.415	128.50	0.12
2015	428.11	126.54	0.12
2016	424.858	125.34	0.12
2017	423.961	125.16	0.12
2018	424.654	125.46	0.12
2019	426.019	125.91	0.12

Table 4-19. Yellowfin catch and bycatch from 1992-2004 estimated from a combination of regional office reported catch and observer sampling of the catch.

Species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Pollock	13,100	15,253	33,200	27,041	22,254	24,100	15,335	8,701	13,425	16,502	14,489	11,396	10,382	10,312
Arrowtooth Flounder	366	1,017	1,595	346	820	386	2,382	1,627	1,998	1,845	998	1,125	279	645
Pacific Cod	8,700	8,723	16,415	13,181	8,684	12,825	10,224	4,380	5,192	6,531	6,259	4,621	3,606	3,767
Groundfish, General	7,990	3,847	3,983	2,904	2,565	4,755	3,580	2,524	3,541	3,936	2,678	3,133	1,612	2,134
Rock Sole	14,646	7,301	8,097	7,486	12,903	16,693	9,825	10,773	7,345	5,810	10,665	8,419	10,068	10,086
Flathead Sole		1,198	2,491	3,929	3,166	3,896	5,328	2,303	2,644	3,231	2,190	2,899	1,102	1,246
Sablefish	0	0		0	0	0	0	4	0	0				1
Atka Mackerel	1	0			0	0	1	33	0	0	0	17		110
Pacific ocean Perch	0	5		0		0	1	12	1	1	1	11		15
Rex Sole			1	1		0	20	36	1	2	0			
Flounder, General	16,826	6,615	7,080	11,092	10,372	10,743	6,362	8,812	7,913	4,854	378	214	434	654
Squid	0		5	0	11	0	2	1	0	0	0	1		
Dover Sole			35											
Thornyhead					0		1							
Shortraker/Rougheye	0				1	0	1	15		1				
Butter Sole			0			3	3		2		7			
Eulachon smelt								0						
Starry Flounder		227	106	16	37	124	35	48	71	82	133			
Northern Rockfish						1	0	0			1			3
Dusky Rockfish								0			0			
Yellowfin Sole	136,804	91,931	126,163	108,493	112,818	169,661	90,062	62,941	71,479	54,722	66,178	68,954	65,604	82,420
English Sole		1									1			
Unsp.demersal rockfish						12	0							
Greenland Turbot	1	5	5	67	8	4	103	70	24	32	2		1	7
Alaska Plaice		1,579	2,709	1,130	553	6,351	2,758	2,530	2,299	1,905	10,396	365	5,891	8,707
Sculpin, General								215	97	12	1,226			
Skate, General								26	4	21	1,042			
Sharpchin Rockfish								1						
Bocaccio	0													
Rockfish, General	0		0	3	23	0	1	3	4	1		1	3	1
Octopus								0						
Smelt, general								0	0	0				
Chilipepper		1												
Eels								1	1	0	0			
Lingcod										2				
Jellyfish (unspecified)									127	173	161			
Snails								12	4	0	4			
Sea cucumber								0	56		0			
Korean horsehair crab								0	0	0				
Greenling, General									0					
Shrimp, general								0	0	0	0			

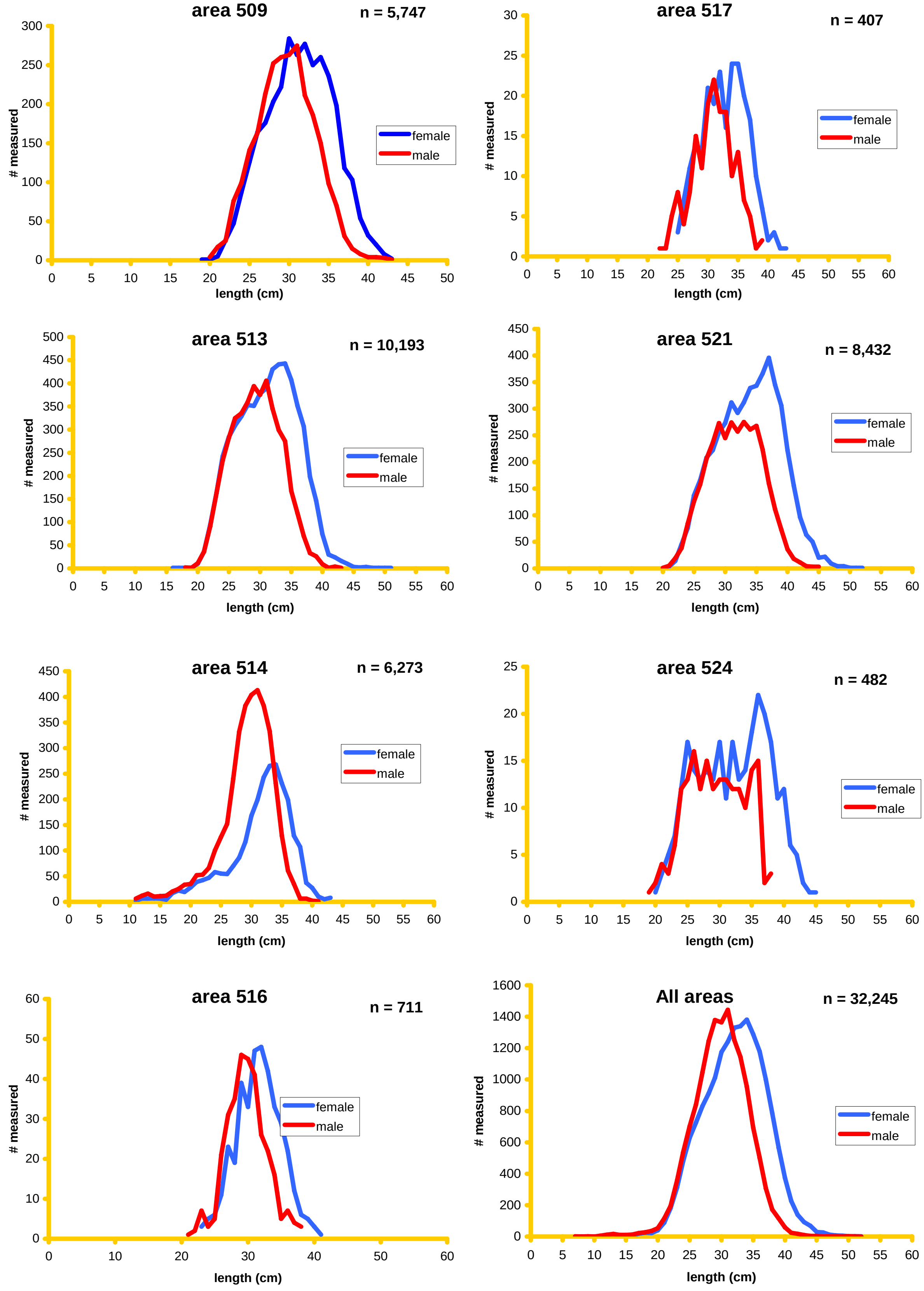


Figure 4.1—Size composition of the yellowfin sole catch in 2006, by subarea and total.

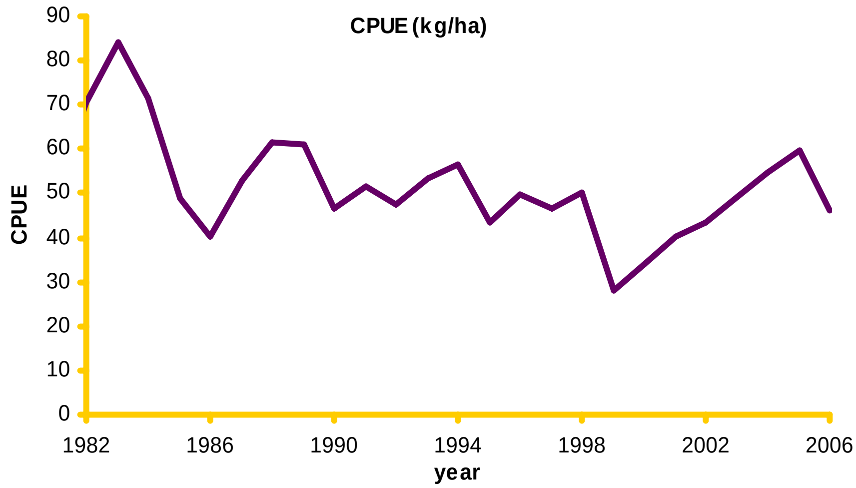


Figure 4.2. Yellowfn sole CPUE (catch per unit effort in kg/ha) from the annual Bering Sea shelf trawl surveys, 1982-2006.

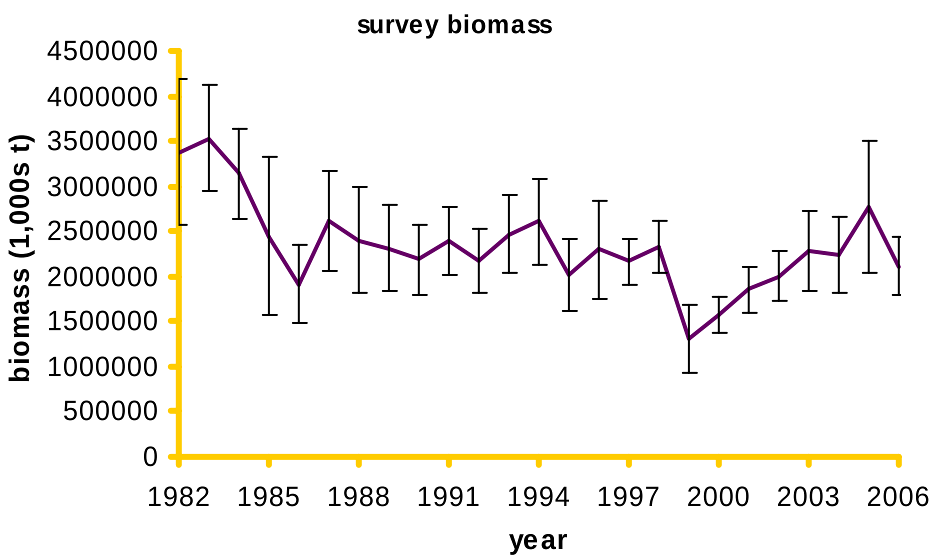


Figure 4.3. Annual bottom trawl survey biomass point-estimates and 95% confidence intervals for yellowfin sole.

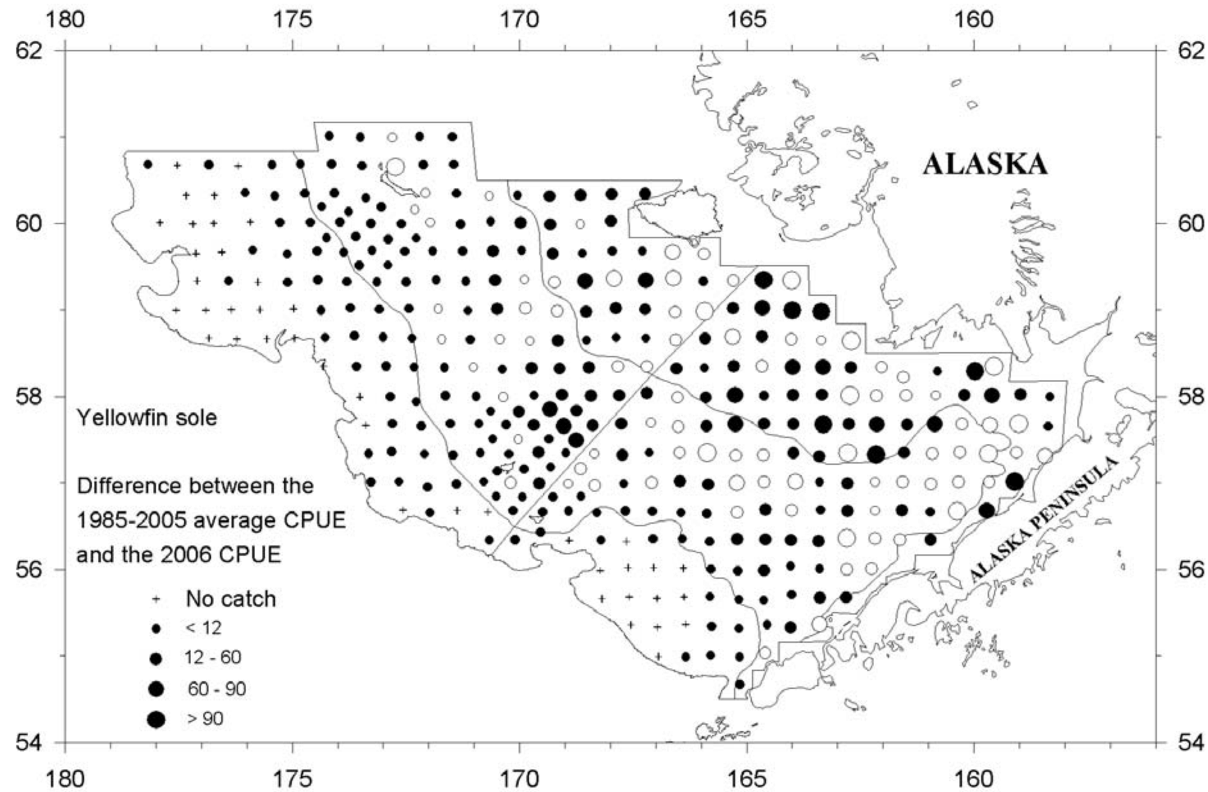


Figure 4.4. Difference between the 1985-2005 average trawl survey CPUE for yellowfin sole and the 2006 survey CPUE. Open circles indicate that the magnitude of the catch was greater in 2006 than the long-term average, closed circles indicate the catch was greater in the long-term average than in 2006.

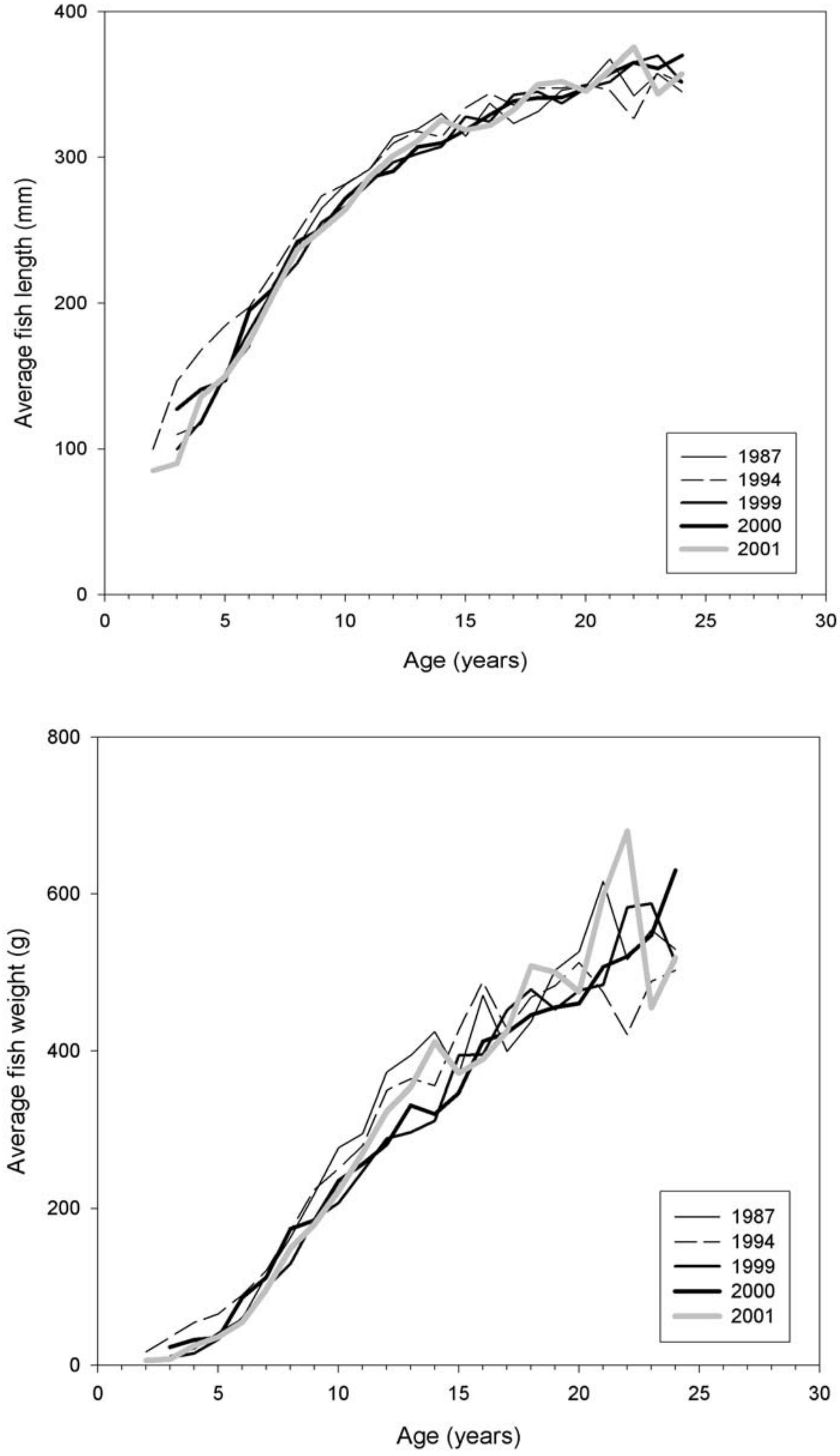


Figure 4.5. Comparison of yellowfin sole length at age (top panel) and weight at age (bottom panel) from biological samples collected in 1987, 1994, 1999, 2000 and 2001.

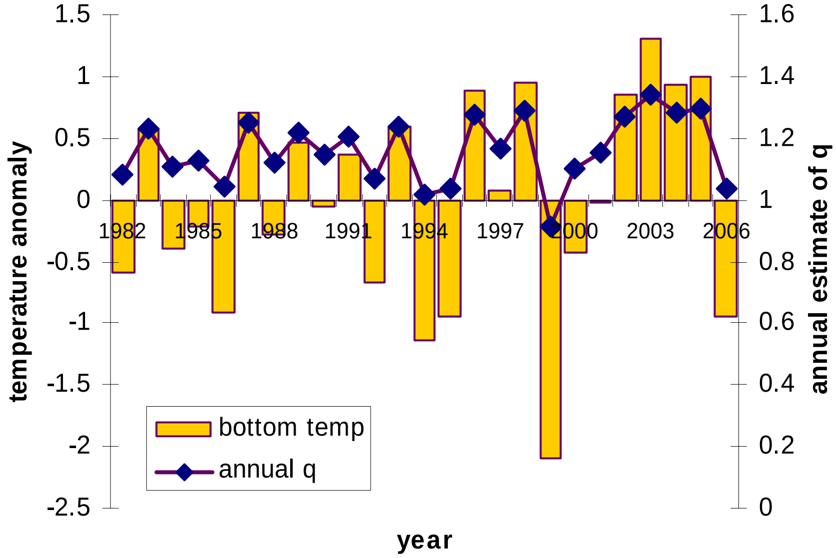


Figure 4.6. Average bottom water temperature from stations less than or equal to 100 m in the Bering Sea trawl survey and the stock assessment model estimate of q for each year 1982-2006.

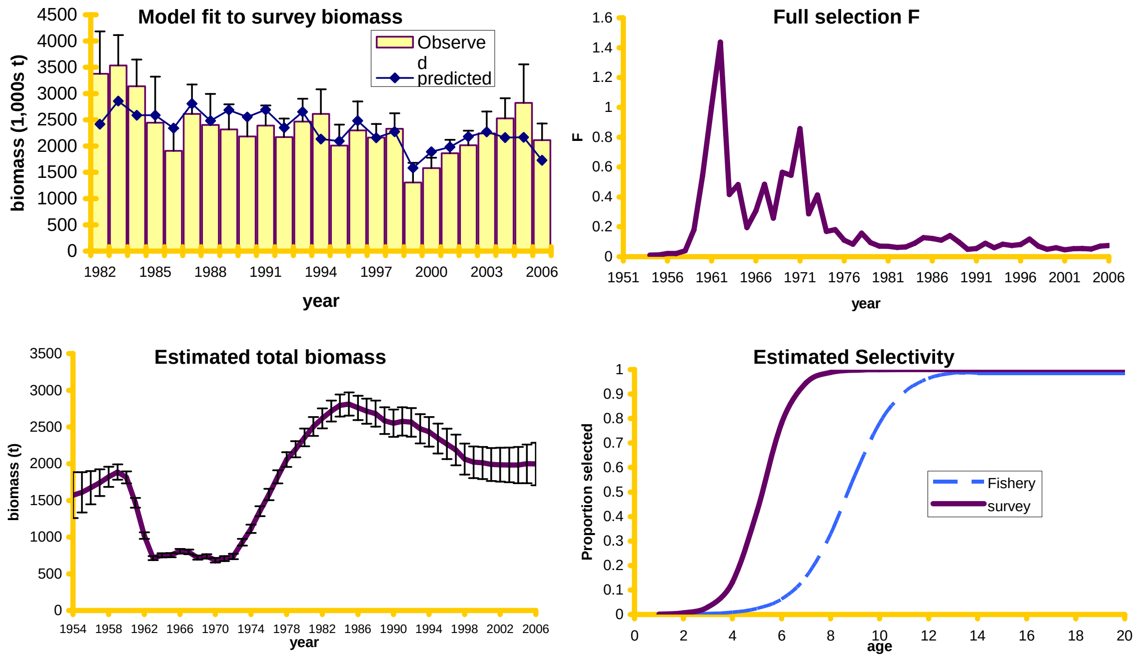


Figure 4.7. Model fit to the survey biomass estimates (top left panel), model estimate of the full selection fishing mortality rate throughout the time-series (top right panel), model estimate of total biomass (bottom left panel) and the model estimate of fishery and survey selectivity (bottom right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

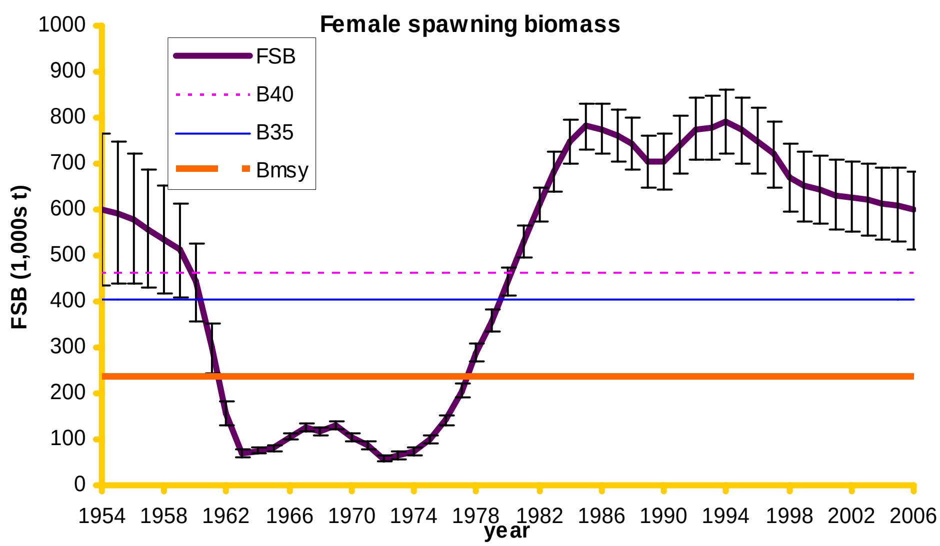


Figure 4.8. Model estimate of yellowfin sole female spawning biomass from 1955-2006 with B40, B35 and Bmsy levels indicated.

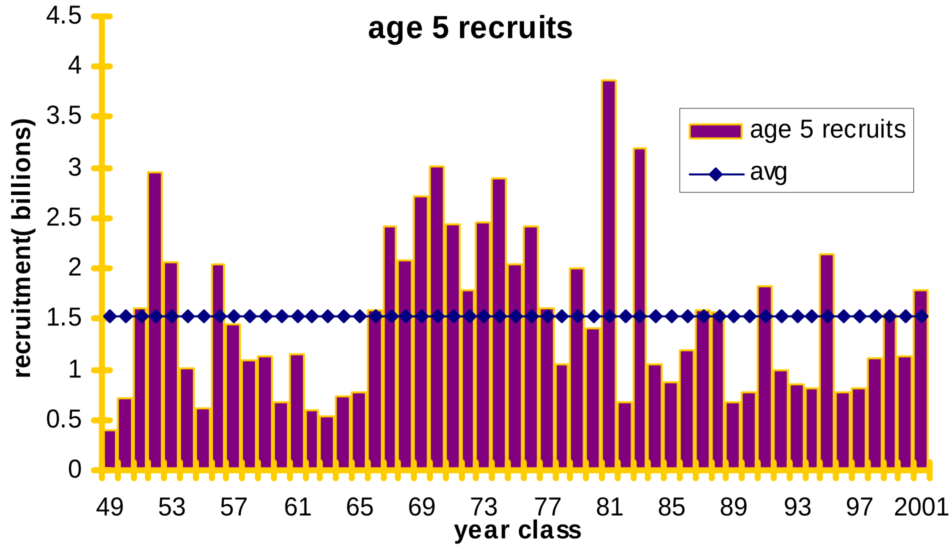


Figure 4.9 Year class strength of age 5 yellowfin sole estimated by the stock assessment model. The dotted line is the average of the estimates from 49 years of recruitment.

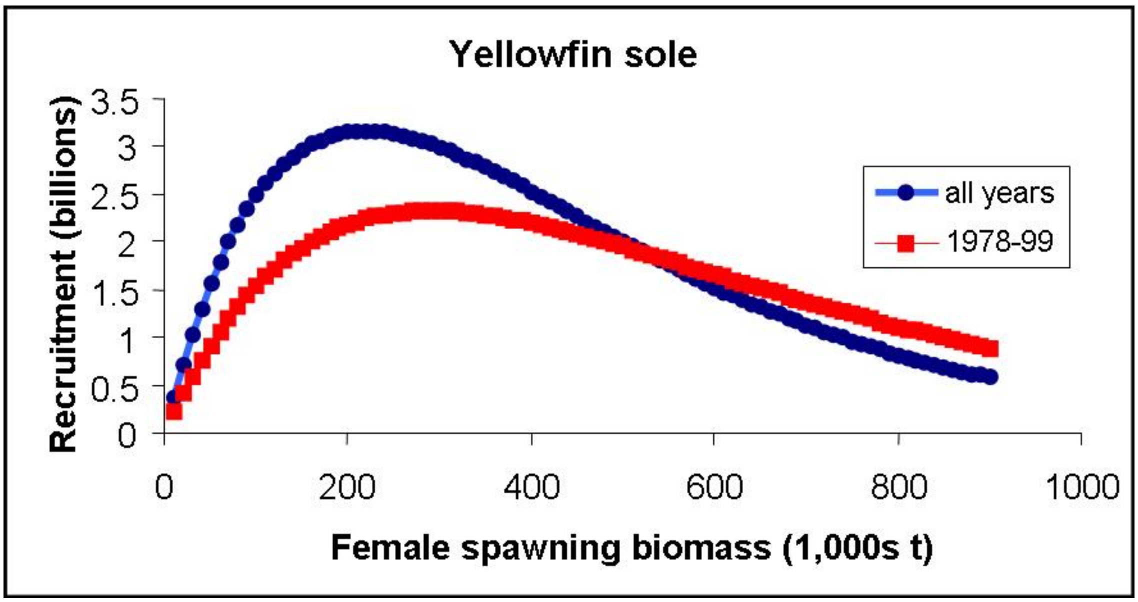


Figure 4.10. Ricker curve fit to yellowfin sole female spawning biomass-age 2 recruitment numbers for two productivity regimes: 1954-99 (all years) and 1978-99. These estimates provided the foundation for initial simulation trials for underlying “true” operational model.

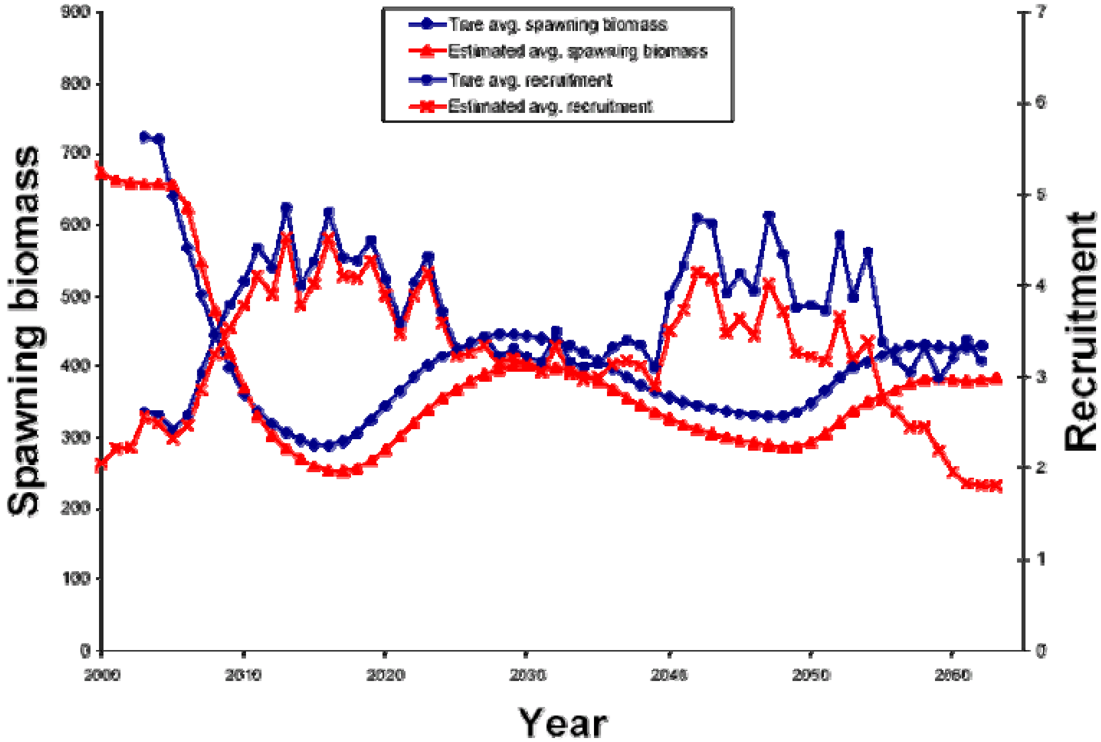


Figure 4.11. Results of the MSE analysis used to evaluate the Tier 1 harvest policy using Bering Sea yellowfin sole population dynamics from two productivity regimes alternative every 15 over a 60 year time horizon.

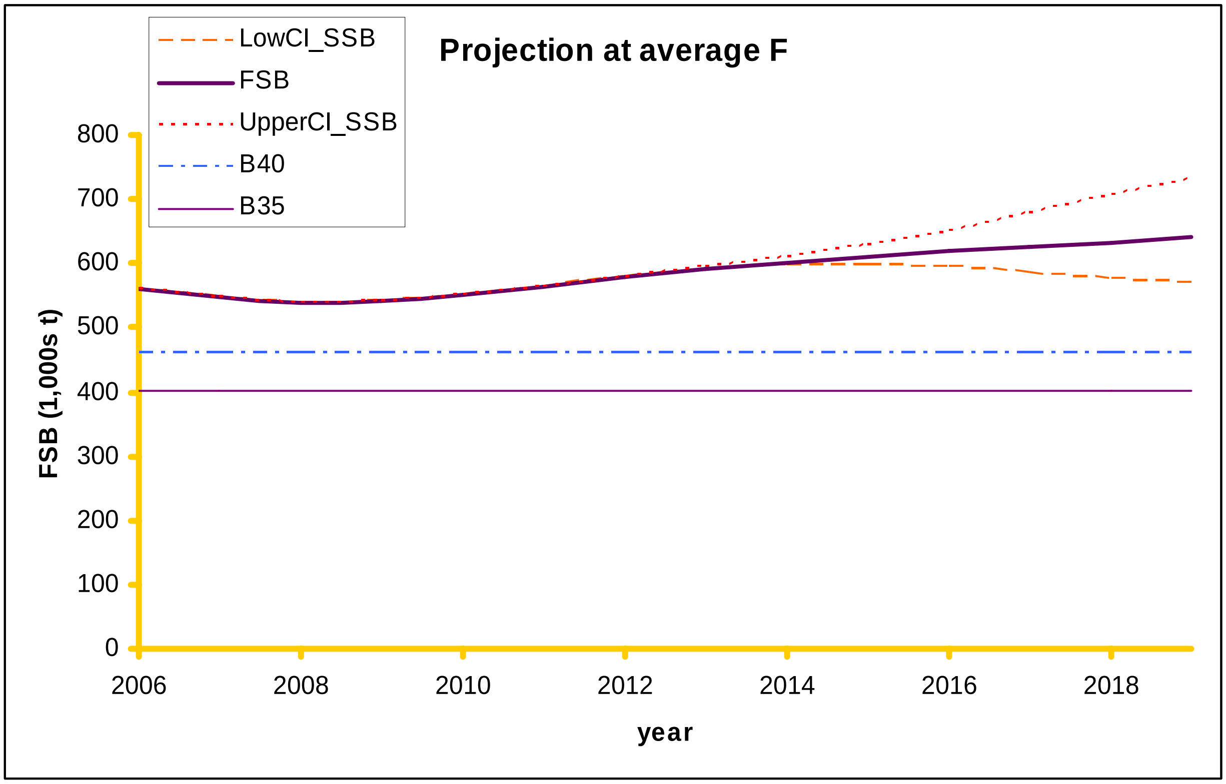
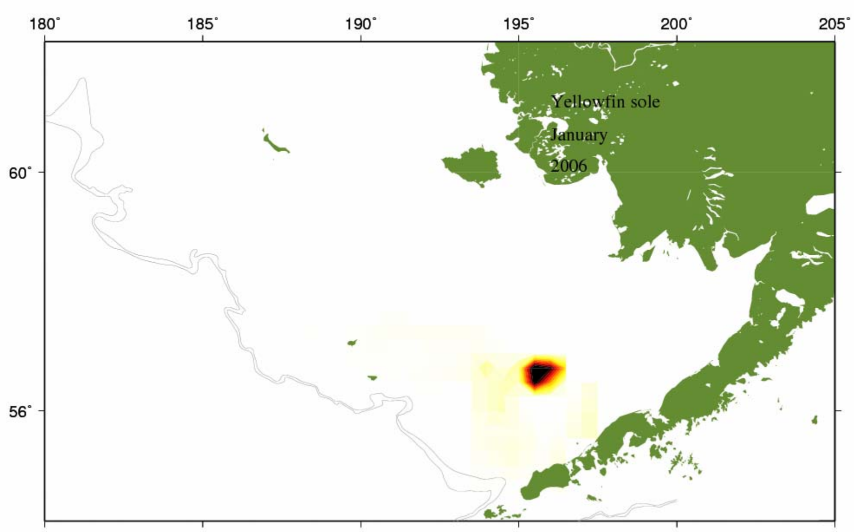
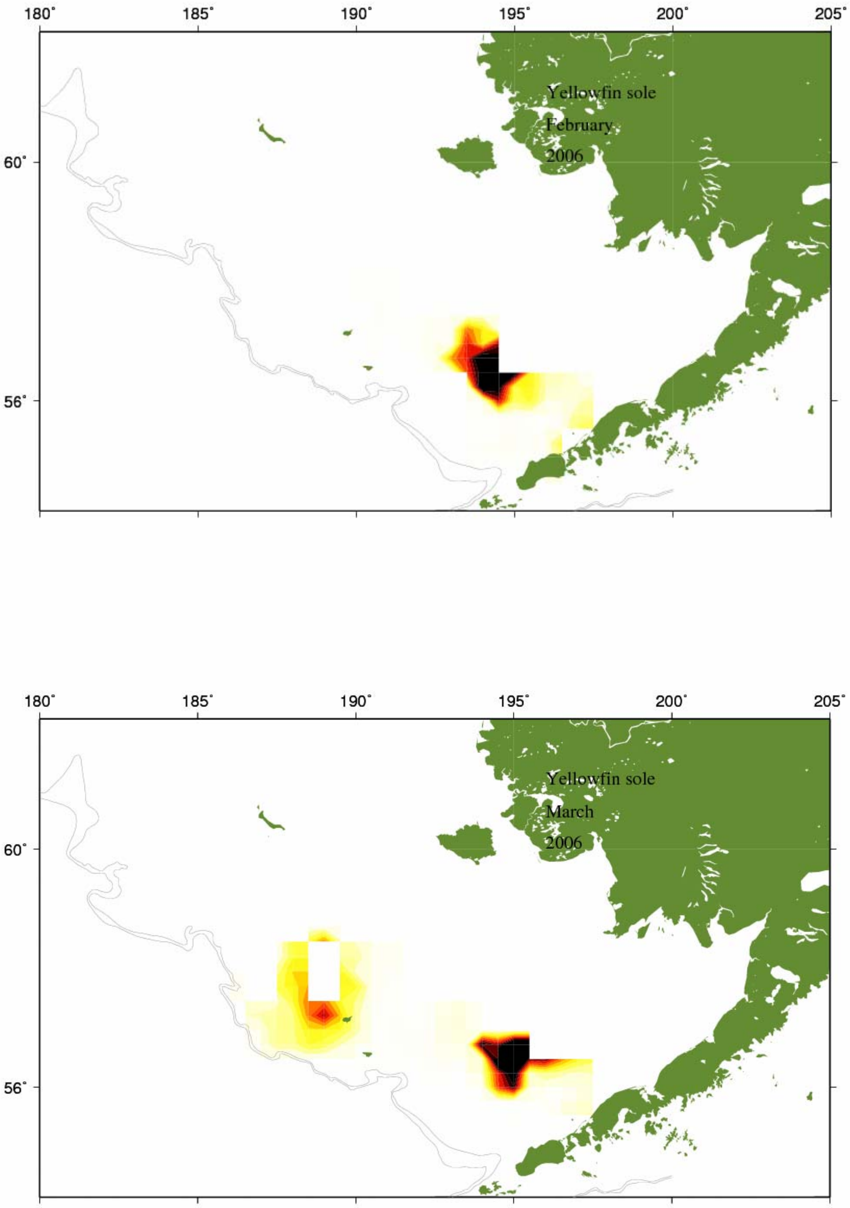


Figure 4.12. Projection of yellowfin sole female spawning biomass (1,000s t) at the average F from the past 5 years (0.055) through 2019 with $B_{40\%}$ and $B_{35\%}$ levels indicated.

Appendix

List of figures and tables

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Yellowfin sole
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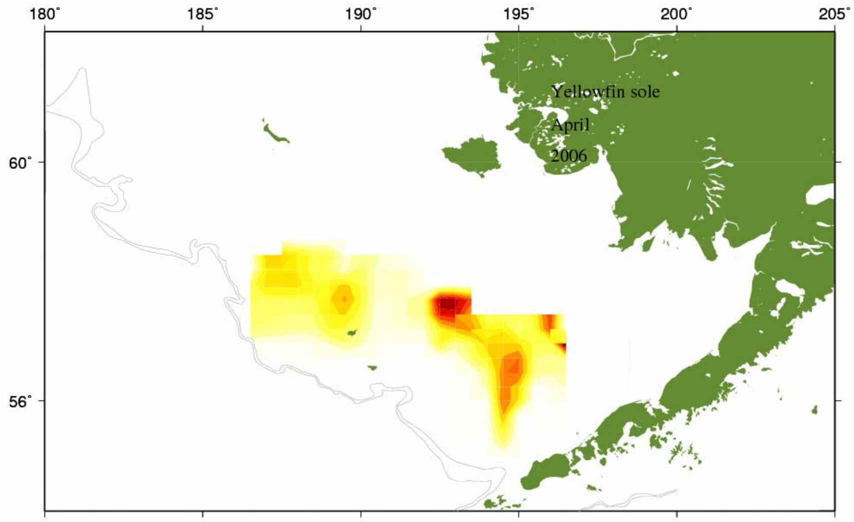
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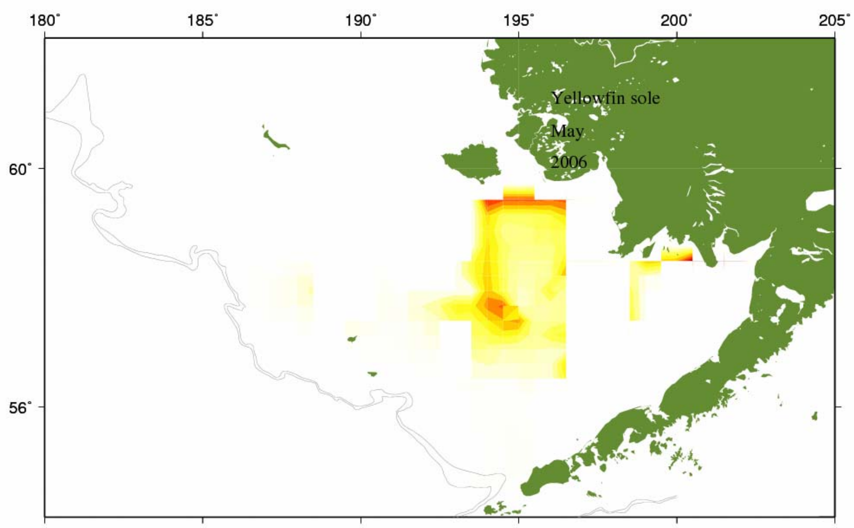
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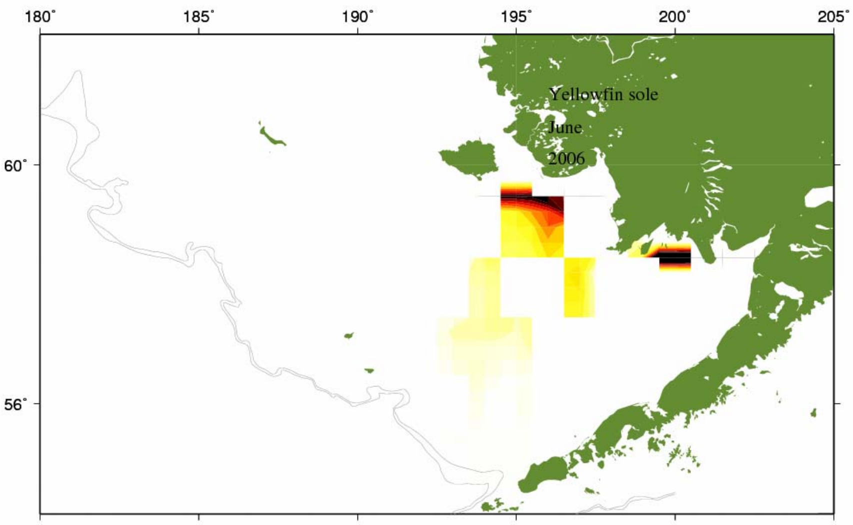
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Yellowfin sole
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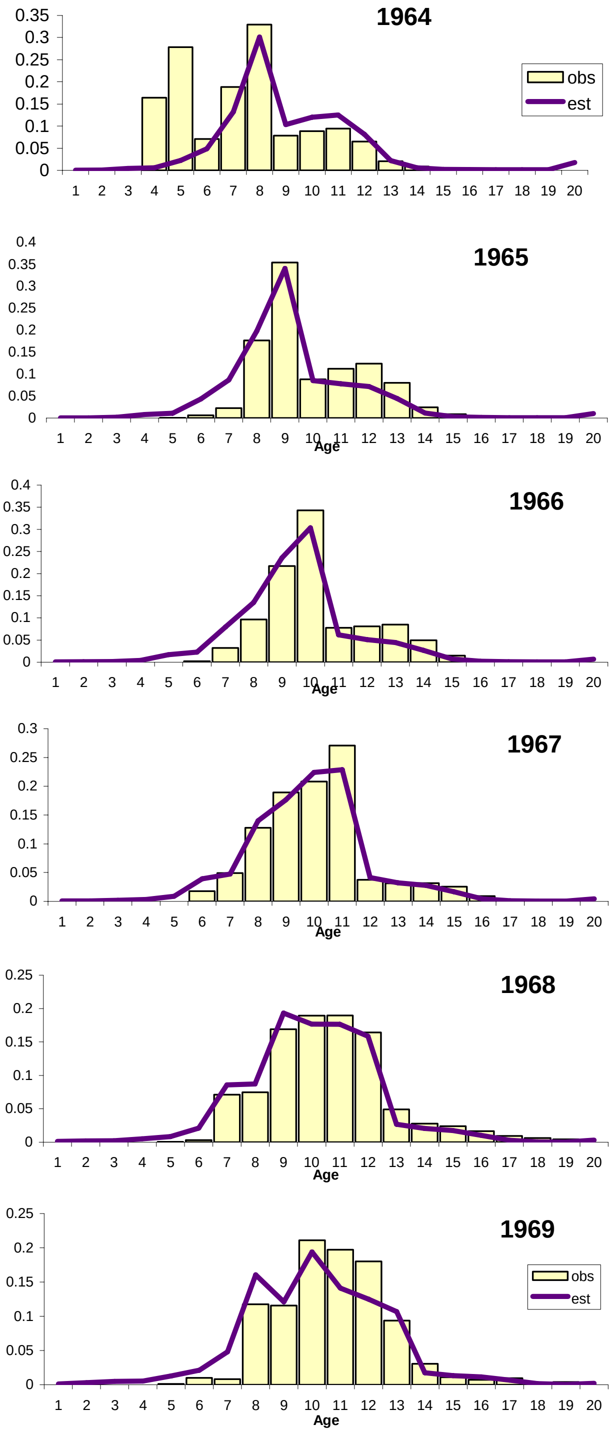

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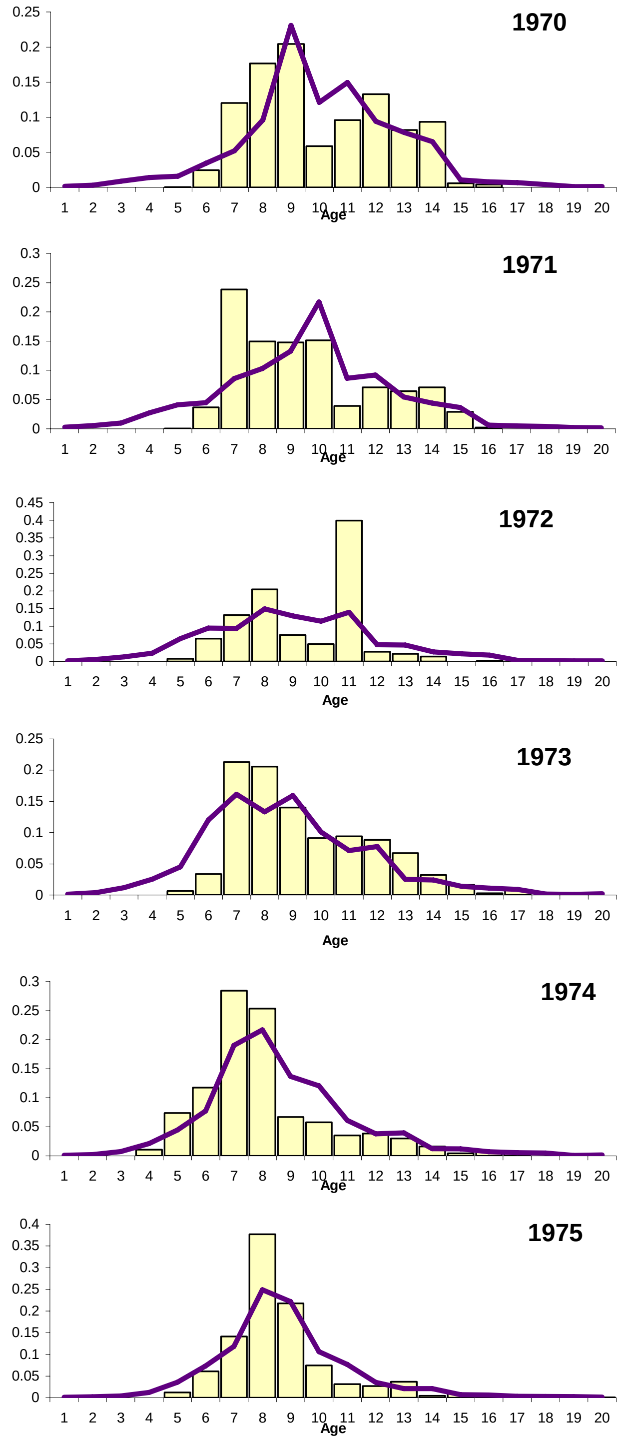

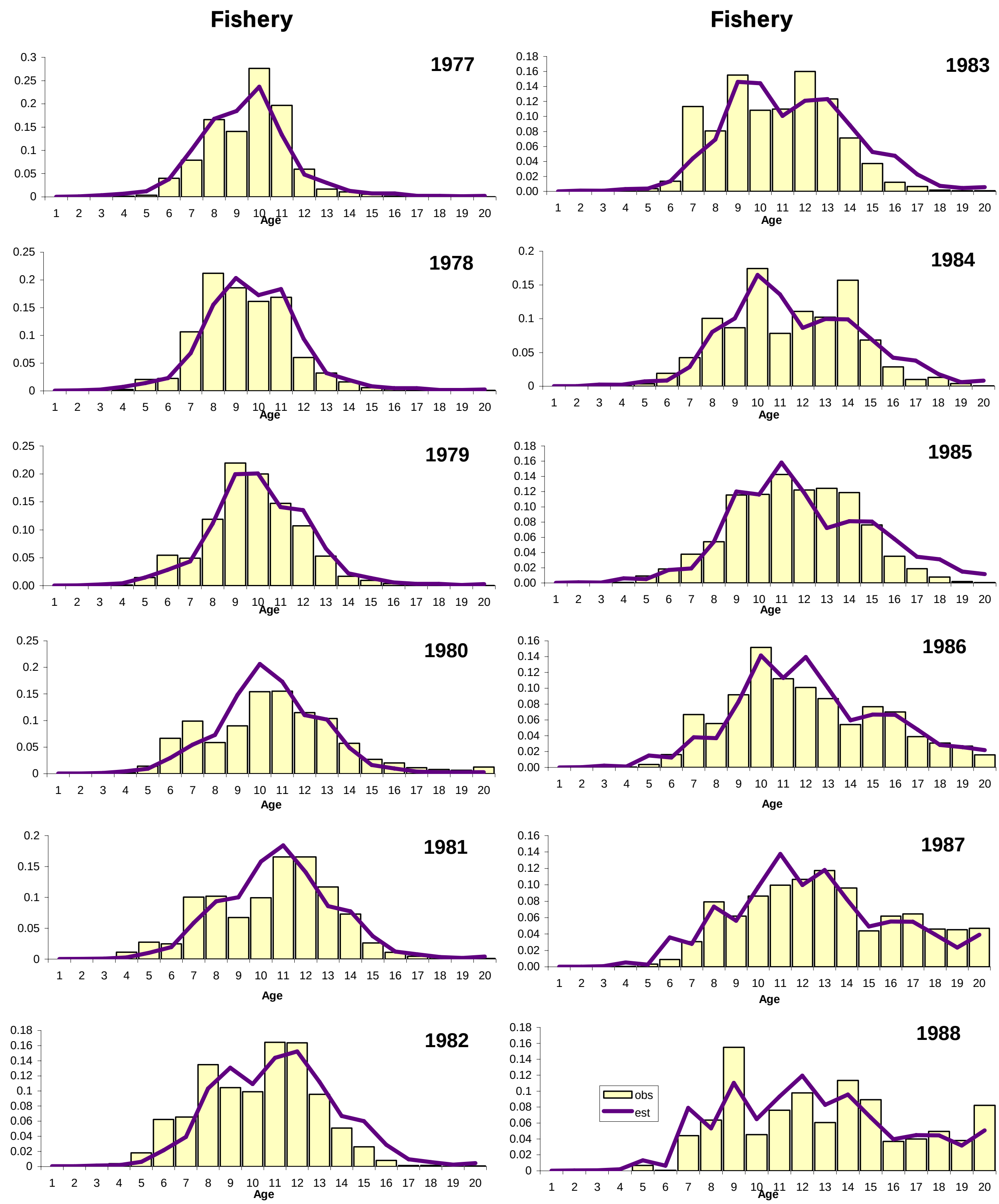

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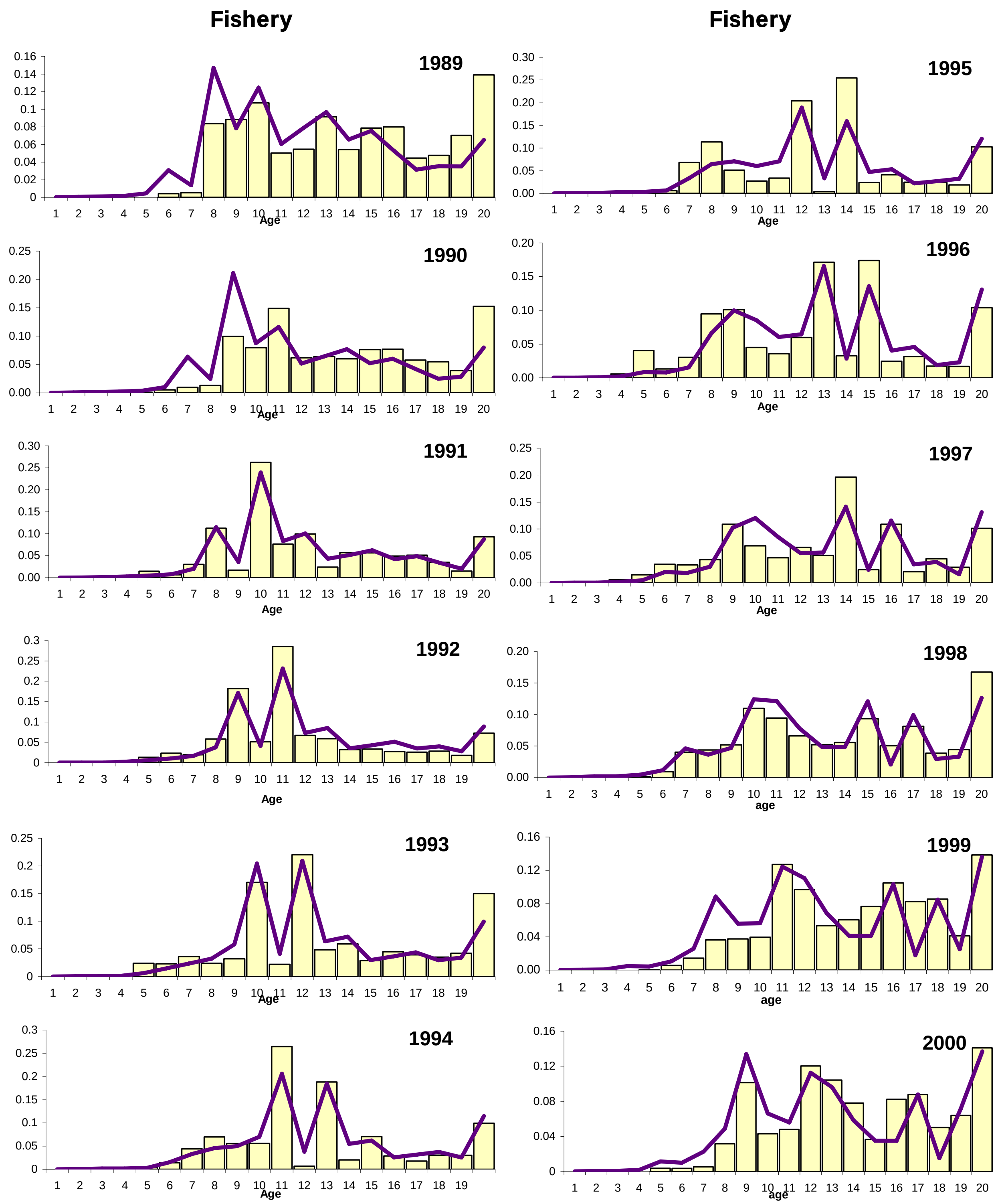
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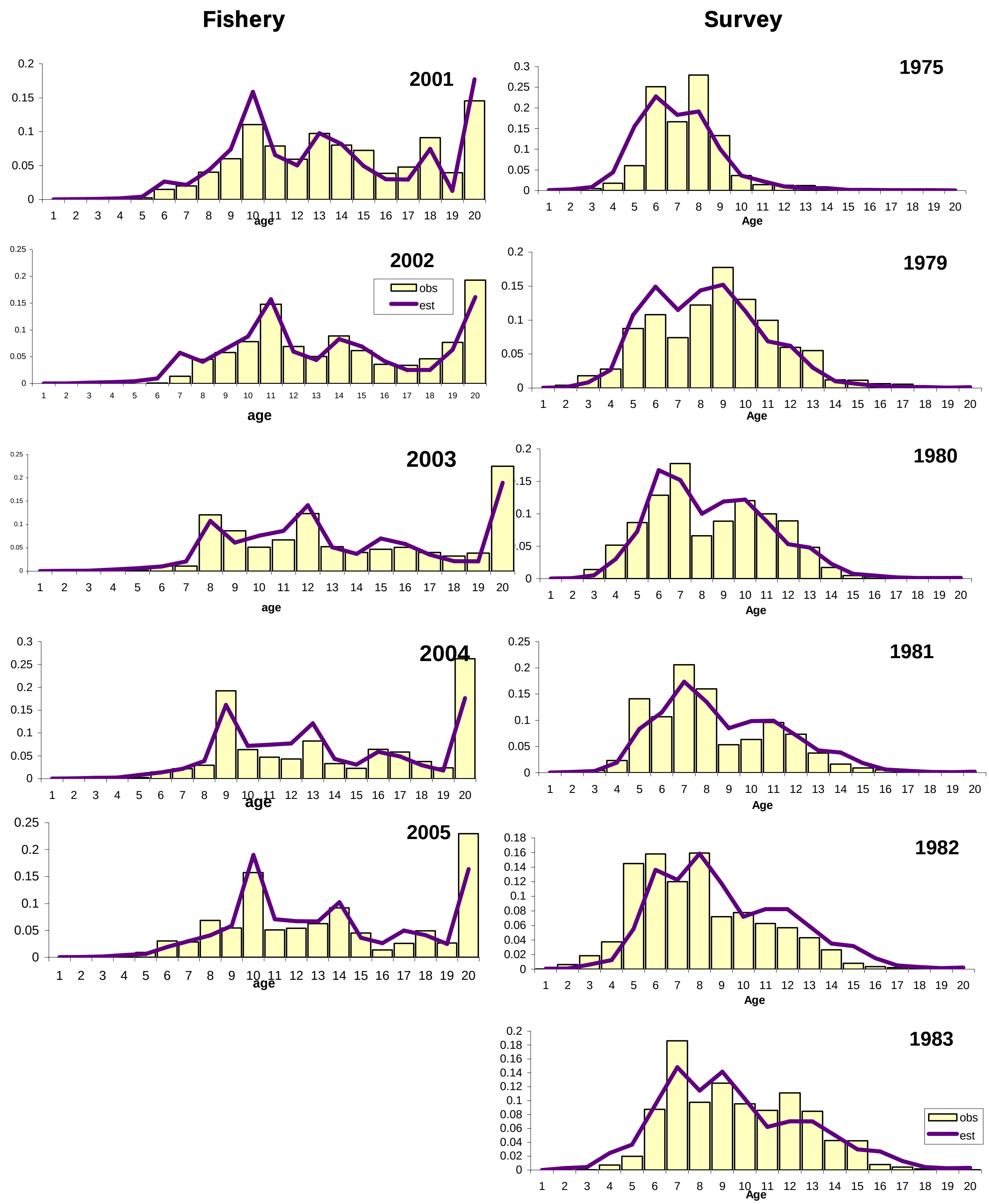
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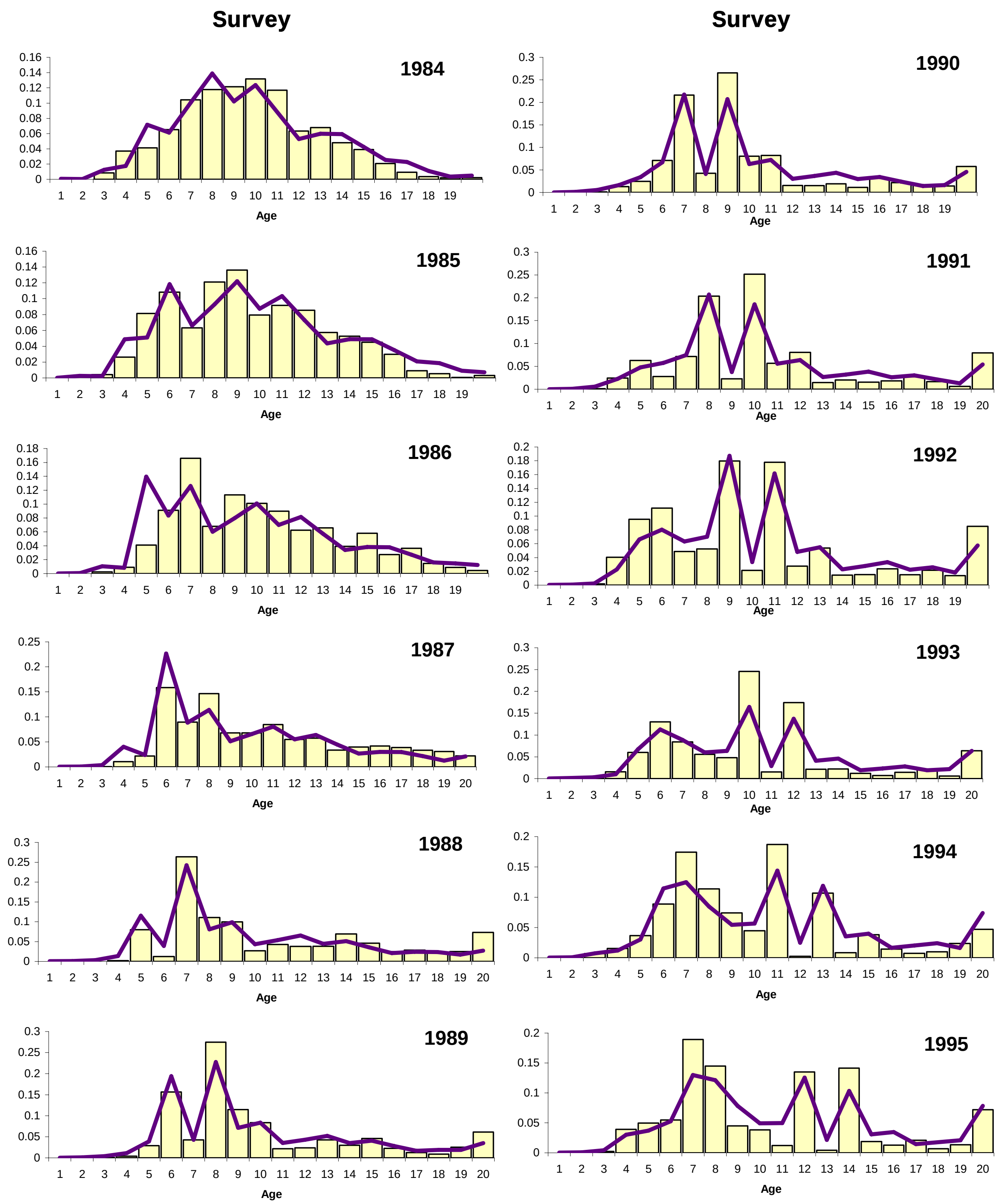
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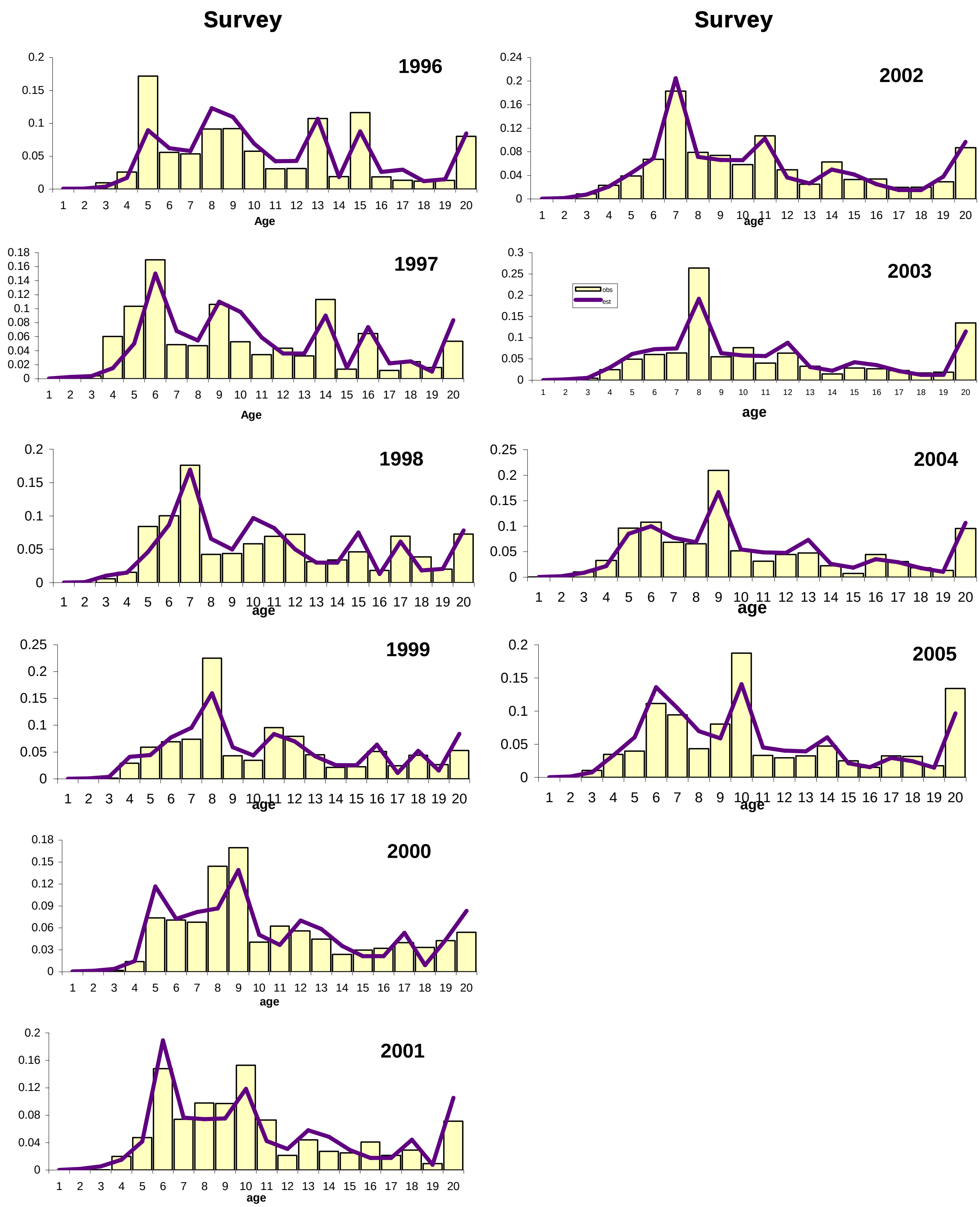
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Total catch of yellowfin sole in Alaska Fisheries Science Center surveys in the Bering Sea.

Year	Research catch (t)
1977	60
1978	71
1979	147
1980	92
1981	74
1982	158
1983	254
1984	218
1985	105
1986	68
1987	92
1988	138
1989	148
1990	129
1991	118
1992	60
1993	95
1994	91
1995	95
1996	72
1997	76
1998	79
1999	61
2000	72
2001	75
2002	76
2003	78
2004	114
2005	94
2006	74

Model estimates of yellowfin sole female spawners (millions) from 1954-2006.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	0.4	1.3	1.6	1.4	1.7	2.0	7.5	16.7	34.2	61.1	95.6	125.1	143.5	153.3	158.3	161.1	162.6	163.3	165.0	165.6
1955	0.2	0.9	3.0	3.2	3.0	2.1	7.0	15.0	30.7	55.1	82.9	108.5	125.0	133.9	138.3	140.6	142.2	143.2	143.4	290.3
1956	0.1	0.4	2.1	5.8	6.7	3.8	7.2	13.9	27.6	49.6	74.7	93.9	108.2	116.4	120.5	122.5	123.8	125.0	125.5	380.1
1957	0.4	0.3	1.0	4.1	12.4	8.5	12.9	14.4	25.6	44.2	66.7	83.9	92.9	99.8	103.8	105.8	107.0	107.9	108.6	439.1
1958	0.3	0.9	0.6	2.0	8.7	15.8	29.2	25.6	26.4	41.0	59.5	74.9	83.0	85.6	89.1	91.2	92.4	93.2	93.7	475.6
1959	0.2	0.6	2.1	1.2	4.2	11.0	53.8	57.7	46.7	41.9	54.4	65.6	72.7	75.1	75.0	76.7	78.1	78.9	79.4	485.1
1960	0.2	0.5	1.5	4.0	2.6	5.3	37.0	104.1	100.6	68.3	49.7	52.8	55.6	57.2	57.2	56.2	57.2	58.0	58.5	418.4
1961	0.1	0.5	1.1	2.9	8.6	3.3	17.6	67.8	160.6	119.2	60.7	34.5	31.3	30.4	30.2	29.7	29.0	29.5	29.9	245.3
1962	0.2	0.3	1.1	2.2	6.1	10.6	10.5	29.9	89.6	145.9	73.5	27.6	13.0	10.8	10.1	9.9	9.7	9.4	9.6	89.2
1963	0.1	0.5	0.7	2.2	4.5	7.5	33.1	16.7	34.3	63.5	63.9	22.4	6.8	2.9	2.3	2.2	2.1	2.0	2.0	20.8
1964	0.1	0.3	1.2	1.3	4.7	5.7	24.9	61.7	26.9	43.8	62.4	49.9	15.1	4.2	1.8	1.4	1.3	1.2	1.2	13.3
1965	0.2	0.2	0.6	2.3	2.8	5.9	18.9	45.9	97.2	33.1	40.8	45.9	31.4	8.8	2.4	1.0	0.8	0.7	0.7	8.0
1966	0.2	0.3	0.5	1.2	4.8	3.5	20.0	36.5	79.6	141.0	38.8	39.1	38.3	24.4	6.6	1.8	0.7	0.6	0.5	6.3
1967	0.3	0.3	0.7	1.1	2.5	6.0	11.8	38.0	61.0	108.2	151.2	33.5	29.2	26.5	16.3	4.3	1.2	0.5	0.4	4.4
1968	0.5	0.7	0.8	1.5	2.3	3.1	20.0	21.8	59.8	74.8	100.9	111.0	21.1	17.0	14.9	9.0	2.4	0.6	0.3	2.6
1969	0.4	1.1	1.6	1.5	3.1	2.9	10.5	38.3	37.0	83.7	83.5	91.2	87.1	15.3	12.0	10.3	6.2	1.6	0.4	2.0
1970	0.6	0.9	2.5	3.1	3.2	3.9	9.4	19.1	58.6	43.4	73.1	56.9	53.0	46.6	7.9	6.1	5.2	3.1	0.8	1.2
1971	0.6	1.2	2.1	4.8	6.6	4.0	12.8	17.2	29.4	69.5	38.5	50.8	33.7	29.0	24.6	4.1	3.1	2.7	1.6	1.0
1972	0.5	1.3	2.8	4.1	10.2	8.2	13.0	22.3	24.0	29.1	48.2	20.1	22.2	13.5	11.2	9.4	1.6	1.2	1.0	1.0
1973	0.4	1.1	3.1	5.4	8.7	12.8	27.7	24.8	37.4	33.0	31.7	42.4	15.3	15.7	9.2	7.5	6.3	1.0	0.8	1.3
1974	0.5	0.8	2.5	6.0	11.4	10.9	42.7	51.7	40.0	47.9	32.5	24.8	28.6	9.5	9.5	5.5	4.4	3.7	0.6	1.3
1975	0.6	1.1	1.8	4.8	12.7	14.4	37.0	82.8	90.5	59.0	57.3	31.9	21.3	22.7	7.3	7.2	4.1	3.3	2.8	1.4
1976	0.4	1.2	2.5	3.5	10.3	16.0	48.7	71.5	144.3	132.4	69.9	55.6	27.0	16.7	17.3	5.5	5.3	3.1	2.5	3.1
1977	0.5	0.9	2.9	4.9	7.5	13.0	54.4	95.4	127.5	219.8	166.0	72.4	50.4	22.8	13.7	13.9	4.4	4.2	2.4	4.4
1978	0.3	1.0	2.1	5.7	10.3	9.4	44.2	106.8	171.6	197.3	281.4	176.0	67.3	43.7	19.1	11.3	11.4	3.6	3.5	5.6
1979	0.2	0.7	2.5	4.0	12.1	13.0	31.9	85.9	187.5	254.5	238.4	279.0	152.4	54.2	34.0	14.6	8.6	8.7	2.7	6.9
1980	0.4	0.5	1.6	4.8	8.6	15.3	44.3	62.7	153.9	288.4	323.2	250.5	257.0	130.8	45.0	27.8	11.9	7.0	7.0	7.7
1981	0.3	0.9	1.1	3.2	10.2	10.9	52.2	87.2	113.2	239.9	373.0	346.8	236.0	225.6	111.0	37.6	23.1	9.9	5.7	12.2
1982	0.8	0.6	2.0	2.1	6.8	12.9	37.0	102.7	157.7	176.6	310.7	400.7	327.2	207.4	191.8	92.9	31.3	19.2	8.2	14.8
1983	0.1	1.7	1.4	4.0	4.4	8.6	44.0	72.9	186.2	247.1	230.1	336.2	381.0	289.9	177.7	161.8	77.9	26.2	16.0	19.2
1984	0.7	0.3	3.9	2.8	8.4	5.6	29.2	86.6	132.0	291.3	321.3	248.5	318.9	336.7	247.8	149.5	135.3	65.0	21.8	29.2
1985	0.2	1.4	0.7	7.6	6.0	10.7	19.0	57.4	155.5	203.5	371.2	338.9	229.8	274.7	280.5	203.2	121.9	110.0	52.7	41.4
1986	0.2	0.5	3.2	1.3	16.3	7.5	36.2	37.1	101.8	234.6	251.6	378.1	302.0	190.6	220.3	221.5	159.4	95.4	85.9	73.5
1987	0.2	0.4	1.1	6.3	2.8	20.5	25.5	70.8	66.0	154.1	291.5	257.7	339.1	252.1	153.9	175.0	174.9	125.6	75.0	125.2
1988	0.3	0.5	0.9	2.1	13.4	3.5	69.8	50.0	126.2	100.6	193.3	302.0	233.9	286.4	205.9	123.7	139.9	139.5	99.9	159.2
1989	0.3	0.7	1.2	1.7	4.4	16.9	12.0	136.0	88.2	189.1	123.2	194.6	265.9	191.6	226.9	160.6	95.9	108.2	107.6	199.9
1990	0.1	0.7	1.6	2.3	3.6	5.6	57.6	23.5	243.5	135.4	239.4	129.0	178.7	227.4	158.4	184.7	129.9	77.4	87.1	247.4
1991	0.2	0.3	1.6	3.1	5.0	4.6	19.0	113.8	42.9	384.3	178.2	262.1	124.1	160.3	197.2	135.3	156.8	110.0	65.4	282.5
1992	0.4	0.3	0.7	3.1	6.7	6.3	15.7	37.6	206.7	67.4	503.3	194.0	250.8	110.7	138.3	167.5	114.1	132.0	92.4	292.1
1993	0.2	0.8	0.8	1.3	6.6	8.5	21.3	30.9	67.5	318.6	85.9	530.7	179.4	216.0	92.2	113.3	136.4	92.8	107.0	311.7
1994	0.2	0.4	1.8	1.5	2.8	8.3	28.9	42.1	56.0	105.8	415.5	93.0	505.1	159.1	185.3	77.9	95.1	114.3	77.5	349.7
1995	0.2	0.4	1.0	3.6	3.3	3.6	28.2	56.7	75.7	86.7	135.5	440.7	86.6	437.8	133.4	152.9	63.9	77.9	93.3	348.6
1996	0.5	0.3	0.9	2.0	7.6	4.1	12.2	55.6	102.3	117.8	111.7	144.8	413.6	75.7	370.2	111.0	126.5	52.7	64.1	363.7
1997	0.2	0.9	0.8	1.7	4.2	9.7	14.0	24.0	100.1	158.7	151.2	118.9	135.2	359.7	63.7	306.5	91.3	103.8	43.2	350.2
1998	0.2	0.3	2.2	1.6	3.6	5.3	32.8	27.4	42.8	151.8	197.7	155.4	106.9	113.2	291.3	50.8	242.8	72.2	81.9	310.1
1999	0.2	0.3	0.8	4.2	3.4	4.6	17.9	64.6	49.4	66.7	196.5	212.3	146.5	94.0	96.2	243.6	42.2	201.4	59.7	324.2
2000	0.3	0.5	0.8	1.5	9.0	4.3	15.5	35.4	117.5	78.1	87.8	215.3	204.5	131.6	81.6	82.2	207.0	35.8	170.3	324.6
2001	0.2	0.7	1.1	1.6	3.2	11.4	14.7	30.6	64.2	184.3	101.8	95.2	205.0	181.4	112.9	68.9	69.0	173.4	29.9	413.4
2002	0.4	0.5	1.6	2.2	3.4	4.1	38.9	29.0	55.8	101.5	243.1	111.8	91.9	184.5	157.9	96.7	58.7	58.7	146.9	375.5
2003	0.3	0.8	1.1	3.1	4.7	4.3	14.0	76.7	52.8	87.9	133.1	265.1	107.1	82.1	159.3	134.3	81.7	49.5	49.3	439.3
2004	0.3	0.7	1.8	2.2	6.5	5.9	14.6	27.7	139.4	83.0	115.1	144.9	253.7	95.5	70.8	135.3	113.3	68.8	41.6	410.3
2005	0.3	0.5	1.6	3.5	4.8	8.2	20.2	28.8	50.3	219.8	109.0	125.7	139.2	227.1	82.7	60.3	114.6	95.8	58.0	380.8
2006	0.3	0.6	1.2	3.1	7.5	6.0	28.0	39.7	52.0	78.4	284.2	117.0	118.5	122.2	192.8	69.1	50.1	95.0	79.1	362.6

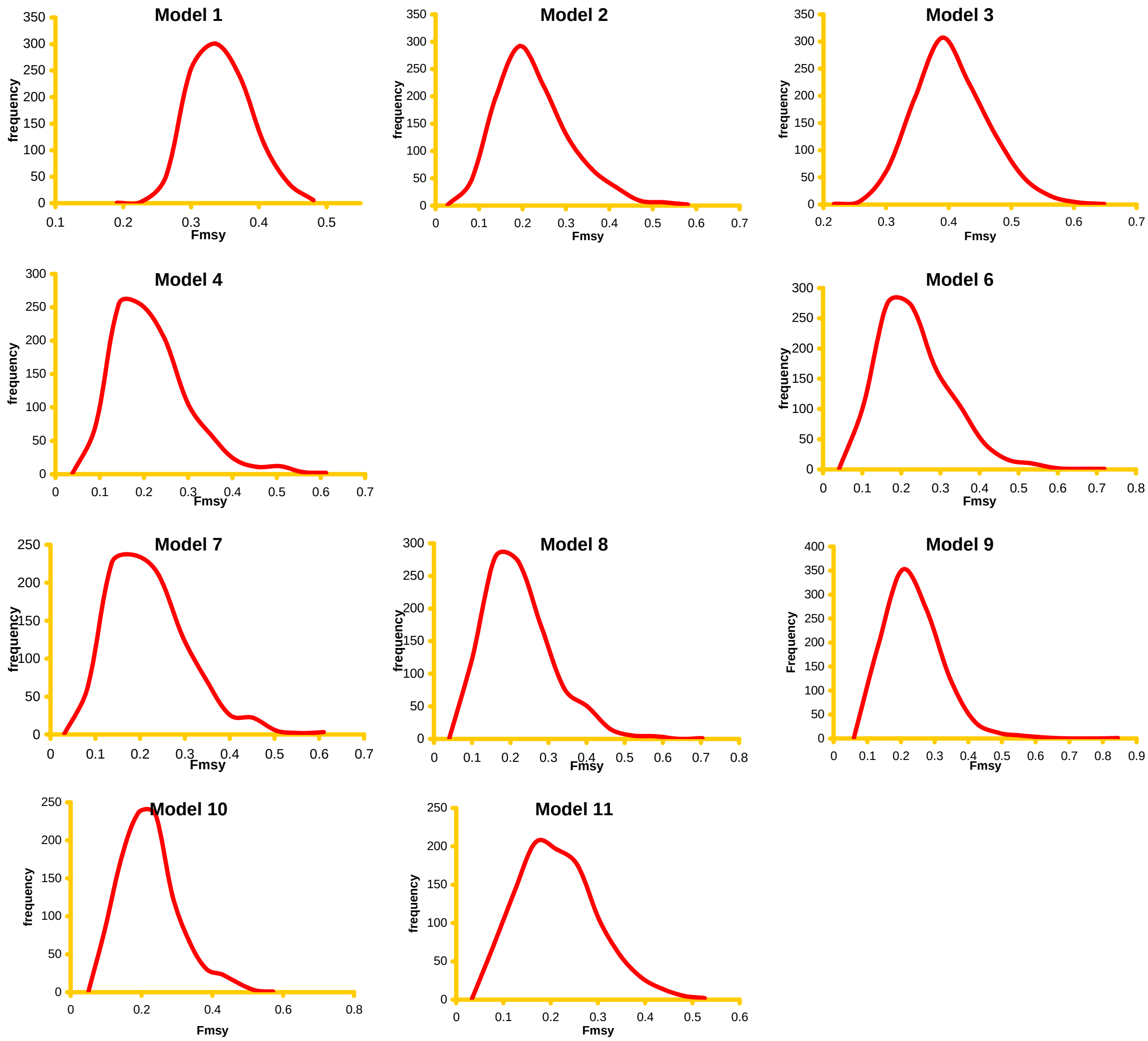
Selected parameter estimates and their standard deviation from the stock assessment model.

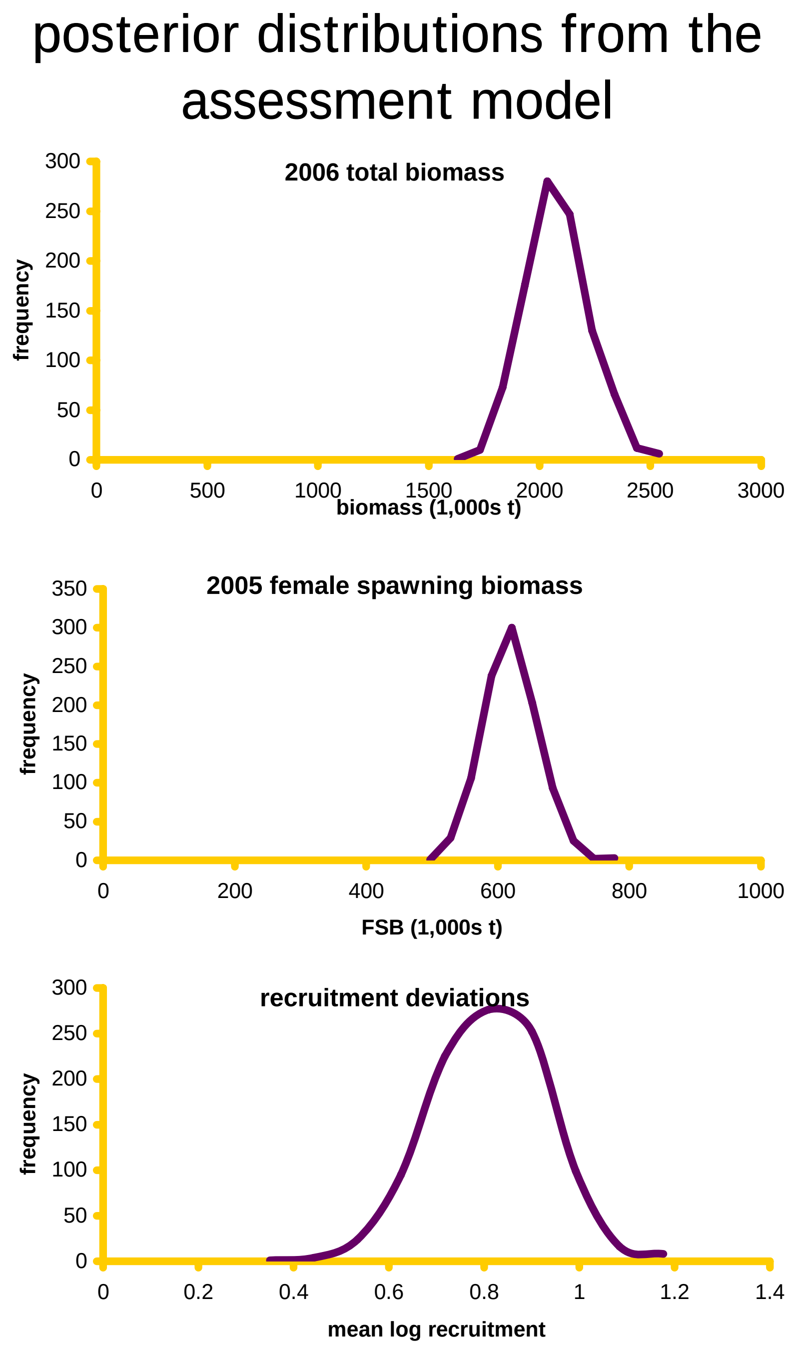
	Parameter	value	std dev		Parameter	value	std dev
	alpha (q estimation)	-0.14	0.05	1972	Total biomass	737.70	19.82
	beta (q estimation)	0.11	0.02	1973	Total biomass	929.02	24.31
	mean_log_rec	0.77	0.10	1974	Total biomass	1113.00	29.30
	sel_slope_fsh	0.99	0.02	1975	Total biomass	1353.50	34.72
	sel_slope_srv	1.58	0.07	1976	Total biomass	1580.50	40.18
	sel50_fsh	8.72	0.07	1977	Total biomass	1820.60	45.58
	sel50_srv	5.20	0.06	1978	Total biomass	2056.70	50.81
	F40	0.11	0.00	1979	Total biomass	2196.50	55.50
	F35	0.13	0.00	1980	Total biomass	2357.90	59.97
	F30	0.16	0.00	1981	Total biomass	2506.80	64.01
	Ricker SR logalpha	-3.33	0.17	1982	Total biomass	2617.80	67.50
	Ricker SR logbeta	-5.58	0.09	1983	Total biomass	2717.90	70.76
	Fmsy	0.32	0.04	1984	Total biomass	2794.10	73.86
	logFmsy	-1.13	0.13	1985	Total biomass	2813.90	76.83
	msy	235.18	28.24	1986	Total biomass	2760.40	79.53
	Bmsy	249.96	18.80	1987	Total biomass	2716.40	82.32
1954	Total biomass	1572.10	150.34	1988	Total biomass	2682.50	84.95
1955	Total biomass	1610.10	131.69	1989	Total biomass	2586.80	87.05
1956	Total biomass	1672.80	110.18	1990	Total biomass	2551.60	89.29
1957	Total biomass	1741.60	88.12	1991	Total biomass	2576.50	91.46
1958	Total biomass	1821.50	67.89	1992	Total biomass	2564.70	93.12
1959	Total biomass	1888.00	51.79	1993	Total biomass	2476.40	94.37
1960	Total biomass	1814.80	41.36	1994	Total biomass	2433.90	95.76
1961	Total biomass	1467.30	32.69	1995	Total biomass	2344.10	96.81
1962	Total biomass	1021.50	21.97	1996	Total biomass	2269.00	97.90
1963	Total biomass	713.53	13.58	1997	Total biomass	2188.60	99.07
1964	Total biomass	751.57	14.18	1998	Total biomass	2061.70	100.21
1965	Total biomass	754.94	14.42	1999	Total biomass	2020.20	102.08
1966	Total biomass	808.05	15.24	2000	Total biomass	2011.10	104.07
1967	Total biomass	799.11	15.56	2001	Total biomass	1990.90	106.46
1968	Total biomass	721.66	14.96	2002	Total biomass	1986.30	108.64
1969	Total biomass	738.73	15.78	2003	Total biomass	1983.60	111.68
1970	Total biomass	686.58	15.86	2004	Total biomass	1983.30	115.57
1971	Total biomass	706.20	17.51	2005	Total biomass	1998.90	122.02
				2006	Total biomass	1996.00	132.65

Yellowfin sole TAC and ABC levels, 1980-2006

Year	TAC	ABC
1980	117,000	169,000
1981	117,000	214,500
1982	117,000	214,500
1983	117,000	214,500
1984	230,000	310,000
1985	229,900	310,000
1986	209,500	230,000
1987	187,000	187,000
1988	254,000	254,000
1989	182,675	241,000
1990	207,650	278,900
1991	135,000	250,600
1992	235,000	372,000
1993	220,000	238,000
1994	150,325	230,000
1995	190,000	277,000
1996	200,000	278,000
1997	230,000	233,000
1998	220,000	220,000
1999	207,980	212,000
2000	123,262	191,000
2001	113,000	176,000
2002	86,000	115,000
2003	83,750	114,000
2004	86,075	114,000
2005	90,686	124,000
2006	95,701	121,000

Posterior Distributions of F_{msy} from the Tier 1 Analysis




posterior distributions from the assessment model
2006 total biomass
frequency
0
50
100
150
200
250
300
0
500
1000
1500
2000
2500
3000
biomass (1,000s t)
2005 female spawning biomass
frequency
0
50
100
150
200
250
300
350
0
200
400
600
800
1000
FSB (1,000s t)
recruitment deviations
frequency
0
50
100
150
200
250
300
0
0.2
0.4
0.6
0.8
1
1.2
1.4
mean log recruitment