Chapter 4 YELLOWFIN SOLE

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Executive Summary

The following changes have been made to this assessment relative to the November 2007 SAFE:

Changes to the input data

1) 2007 fishery age composition.
2) 2007 survey age composition.
3) 2008 trawl survey biomass point estimate and standard error.
4) Estimate of the discarded and retained portions of the 2007 catch.
5) Estimate of total catch through 13 September 2008.
6) Survey and fishery age composition time-series were recalculated for each sex instead of combining both sexes. Same for the weight-at-age.

Changes to the assessment model

Split-sex model was implemented.

Assessment results

1) The projected age 2+ total biomass estimate for 2009 is 1,868,500 t.
2) The projected female spawning biomass estimate for 2009 is 613,800 t.
3) The Tier 1 2009 ABC is 210,200 t based on an $F_{\text{har mean of FMSY}}$ (0.12) harvest level.
4) The Tier 1 2009 overfishing level is 223,900 t based on an F_{MSY} (0.13) harvest level.

Summary

Assessment Year	2007	2008	
Projections Year	2008	2009	2010
M	0.12	0.12	0.12
Tier	1a	1a	1a
B_{MSY} (t)	302,540 t	329,000 t	--
$B_{40\%}$ (t)	482,800 t	522,000 t	--
Female spawning biomass (t)	550,300	613,800	580,100
Total Biomass (t) (geometric mean 6+)	1,992,200	1,721,200	1,617,200
Tier 1 $F_{overfishing}$	0.13	0.13	0.13
Tier 1 F_{ABC} ($F_{\text{harmonic mean}}$)	0.12	0.12	0.12

Tier 1 ABC	247,500	210,200	197,500
Tier 1 overfishing	265,300	223,900	210,400

SSC Comments from December 2007

The SSC appreciates the author's efforts to continue an exploration of the robustness of Tier 1 management when changes in productivity occur and looks forward to reviewing results of these MSE analyses in the future.

The authors hope to make further progress on the MSE soon.

The SSC last year suggested the need for separating the dynamics of male and female yellowfin sole in the model and looks forward to results from a split-sex model that is slated to be developed next year.

The split-sex model is implemented in the yellowfin sole and northern rock sole assessments in this SAFE.

The SSC notes that selectivity is assumed to be constant over time and encourages the authors to evaluate the assumption of constant selectivity

We plan to estimate year-specific selectivity in the next assessment.

The ecosystem considerations table (p. 461) erroneously refers to rock sole instead of yellowfin sole

The table has been changed to refer to yellowfin sole.

Table 4.9: q should have a subscript for year (*qt*) and the terms for 'qlike' and 'mlike' should be labeled as priors rather than likelihood components.

The Table has been corrected with the right labels and subscripts.

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. Yellowfin sole are usually headed and gutted, frozen at sea, and then shipped to Asian countries for futher processing. 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 87,100 t from 1998-2008. As of 13 September, the 2008 catch totaled 111,464 t, the second highest annual catch in the past 11 years. The fishery caught 2/3 of the annual total from March through May, primarily from areas 509, 513, 514 and 521. As of late September 2008, the fishing season is ongoing. The size composition of the 2007 catch for both males and females, from observer sampling, are shown in Figure 4.2, the catch proportions by month and area are shown in Figure 4.3, and maps of the locations where yellowfin sole were caught in 2007, by month, are shown in the Appendix figures.

Harvesting events requiring regulatory actions in 2008 included two seasonal closures. The entire Bering Sea/Aleutian Islands were closed on May 19 to vessels participating in the Amendment 80 limited access fishery to prevent exceeding the first seasonal apportionments of Pacific halibut. On May 22 zone 1 was closed to prevent exceeding the red king crab bycatch limited, for these same vessels.

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 9% of the total catch in 2006 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 13, 2008 (Table 4.1) and fishery catch-at-age (numbers) from 1964-2007 (Table 4.4, 1977-2007).

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 2007 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 - 2008 estimates were similar at 2.13 and 2.15 and 2.1 million t, respectively.

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 4.4). 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. 4.5) 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, 2007 and 2008 when the temperatures and the bottom trawl survey point estimates 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 2008, 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 4.6).

Yellowfin sole population numbers-at-age estimated from the annual bottom trawl surveys are shown in Table 4.6 and their occurrence in trawl survey hauls and associated collections of lengths and age structures since 1982 are shown in Table 4.7.

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) have been used in past assessments. Changes in length and weight at age over time has been documented for Bering Sea northern rock sole (Walters and Wilderbuer 2000) and Bering Sea and Gulf of Alaska Pacific halibut (Clark et al 1999). In a past assessment the assumption of time invariant growth in length and weight of yellowfin sole was examined by comparing the weight and length at age from fish collected during the 1987, 1994, 1999, 2000 and 2001 surveys (Fig. 4.7). 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.

In the 2007 assessment, estimates of weight at age were reexamined to update the estimates to include age and weight data collected since 2001. All length-weight data collected during trawl surveys in the Bering Sea (n=6,365 fish) were fit using the usual power function, weight (g) = a Length(cm)^b, where a and b are parameters estimated to provide the best fit to the data (Fig. 4.8). These estimates of weight at length were applied to the annual trawl survey estimates of population length at age and were then averaged over all years, by sex, to calculate the weight at each age.

This method was selected to update the population weight at age because the weight at age in a population is a function of the length at age (Clark et al. 1999, Walters and Wilderbuer 2000) and this method uses the average population length at age in the calculation (Table 4.8). Results from the growth analysis indicate that male and female yellowfin sole exhibit similar growth until about the age of sexual maturity (50% mature and age 10.5) at which point females grow at a faster rate than males and reach a larger size (Table 4.8).

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 (1995) 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.

Since the sex-specific weight-at-age for yellowfin sole diverges after age of maturity (about age 10 for 50% of the stock) with females growing larger than males, it has been recommended by both the SSC and a panel of independent experts to develop a split-sex assessment model for this stock. In response to these suggestions, the current assessment model has been modified to accommodate the sex-specific aspects of the population dynamics of yellowfin sole. The model now allows for the input of sex-specific estimates of fishery and survey age composition and weight-at-age and provides sex-specific estimates of population numbers, fishing mortality, selectivity, fishery and survey age composition and allows for the estimation of sex-specific natural mortality and catchability. The model retains the utility to fit combined sex data inputs.

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 4.10). 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 4.10 presents the key equations used to model the yellowfin sole population dynamics in the Bering Sea and Table 4.11 provides a description of the variables used in Table 4.10.

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 for both sexes 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 4.9).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Survey catchability	Year class strength	Spawner-recruit	Total
108	8	2	73	2	193

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 and the doubling of the number of fishing mortality and selectivity parameters due to sex-specific modeling.

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 4.10.

Selectivity

Fishery and survey selectivity was modeled separately for males and females using the two parameter formulation of the logistic function, as shown in Table 4.10. 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. A single selectivity curve was fit for all years of fishery data and a single curve for all years of survey data.

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 catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The model estimate of $\alpha = -0.128$ indicates that $q > 1$ suggesting that yellowfin sole are herded into the trawl path of the net which is consistent with the experimental results for other flatfish species. The second term, $e^{\beta T}$ is a time-varying (annual) q which relates to the metabolic aspect of herding or distribution (availability) which can vary annually with bottom water temperature. The result of the nonlinear fit to bottom temperature vs. estimated annual q is shown in Figure 4.9 (for the base model).

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.

Tier 1 Considerations

The SSC determined in December 2006 that yellowfin sole would be managed under the Tier 1 harvest guidelines, and therefore future harvest recommendations would be based on MSY and F_{MSY} values calculated from a spawner-recruit relationship. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit data which is assumed to represent the equilibrium stock size-recruitment relationship and the model used to fit the data. In the yellowfin sole 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 represents the long-term productivity of the stock.

For this assessment, 3 different stock-recruitment time-series were investigated: the full time-series 1955-2003, the pre-regime shift era of 1955-1977 and the post-regime shift era, 1978-2003 (Fig. 4.10) Very different estimates of the long-term sustainability of the stock (F_{MSY} and B_{MSY}) were obtained, depending on which years of stock-recruitment data were included in the fitting procedure (Table 4.12). When the entire time-series from 1955-2003 was fit, the large recruitments that occurred at low spawning stock sizes in the 1960s and early 1970s determined that the yellowfin sole stock was most productive at a smaller stock size with the result that F_{MSY} is 1.5 times higher than $F_{40\%}$ (recall that $F_{40\%} = 0.11$).

Therefore, F_{MSY} is a relatively high value (0.166) and B_{MSY} is 270,800 t. If we limit the analysis to consider only recruitments which occurred after the well-documented regime shift in 1977, a lower value of F_{MSY} is obtained (0.13) and B_{MSY} is 329,000 t.

Results from these Tier 1 calculations for yellowfin sole indicate that the harmonic mean of the F_{MSY} estimate is very close to the geometric mean value due to low variability in the parameter estimates. This result indicates that the estimates of F_{MSY} are obtained 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, natural mortality and recruitment variability σ_R were selected as important parameters whose uncertainty may directly affect the pdf of the estimate of F_{MSY}. Twelve different model configurations were chosen to illustrate the effect of a range of uncertainly in these individual parameter estimates (0.4 and 0.9 for M and 0.8, 1.0, 1.2 and 1.4 for σ_R) and how they affect the estimate of the harmonic mean of F_{MSY}.

When the 1978-2003 years are fit (Model 2), the F_{MSY} value is about 78% of the full time-series value (Model 1) and 73% of the pre-regime shift value (Model 3). Using the estimates of recruitment and stock size from 1978-2003 as the basis for the spawner-recruit relationship (Model 2), uncertainty was introduced for the estimates of recruitment variability (Models 4-7), selectivity (Models 8), catchability (Models 9 and 10) and natural mortality (Models 10 and 11). Adding uncertainty to recruitment variability resulted in the largest difference between the geometric mean and the harmonic mean of the estimate of F_{MSY} for these Model runs: a 32% reduction at the highest value considered. Placing more uncertainty on selectivity reduced the harmonic mean of F_{MSY} by 7%. Incorporating more uncertainty in the estimation of catchability and natural mortality resulted in a 6% reduction for the estimate of the harmonic mean (Models 9 and 12). Thus F_{MSY} appears to be well estimated by the model. [For the 2008 fishing season, the SSC chose an ABC and OFL based on the 1978-2002 data set, which is also considered here (except extended to 2003) as the base model for stock assessment model evaluation.]

Model Evaluation

Model evaluation for this assessment entails the use of a single structural model (Model 2 in Table 4.12) to consider the uncertainty in the key parameters M and catchability. Model 2 (from above) 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 (from survey stations at less than 100 m). Alternative Models 1 and 2 fix q at 1.14 (the value resulting from the base Model) but estimate male M (Alternative model 1) and female M (Alternative model 2) as free parameters with moderate amounts of uncertainty in the parameter estimate (σ_M = 0.5). Alternative Models 3 and 4 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 (σ_q values of 0.2 and 0.5 for Alternative Models 3 and 4, respectively). Alternative Models 5 and 6 estimate both male and female M and q (sexes combined) as free parameters, again with varying amounts of uncertainty (σ_M and σ_q values of 0.2 and 0.5 for Alternative Models 5 and 6, respectively).

Results from these runs indicate that fixing either M or q at values estimated from the base Model (Model 2) and then estimating the other parameter give similar estimates of 2009 female spawning biomass, total biomass, $F_{40\%}$ and 2009 tier 1 ABC (Alternative Models 1-4, Table 4.13). When male and female M and q are all estimated as free parameters with no constraints, the best fit to the observable population characteristics occur at high values of q and low values of M (Alternative Models 5 and 6). These Models result in low estimates of female spawning biomass, total biomass and ABC, which are not credible.

Alternative Model runs 1-4 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 the base model. In Alternative models 3 and 4 male M is consistently estimated at a slightly higher value than female M. The values of M estimated in Alternative Models 5 and 6 (0.07 and 0.05) seem unrealistic given the maximum age of yellowfin sole observed from 43 years of data collection and age determination (most collections have a maximum at age 30 although a single female was aged at 37 years old) and the resulting low biomass estimates.

Modeling survey catchability as a nonlinear function of bottom water temperature returns a mean value of 1.14. 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).

Allowing M to be estimated as a free parameter for males with females fixed at 0.12 provides a better fit to the sex ratio estimated from the annual trawl survey age compositions than does the base model (both sexes fixed at M = 0.12). However, since the population sex ratio annually observed at the time of the survey is a function of the timing of the annual spawning in adjacent inshore areas, it is questionable that providing the best fit to these observations is really fitting the population sex ratio better. Thus, the model configuration which utilizes the relationship between annual seafloor temperature and survey catchability with M fixed at 0.12 for both sexes (base model), will be used to base our assessment of the condition of the Bering Sea yellowfin sole resource for the 2009 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 4.14. The full-selection F has averaged 0.08 over the period of 1978-2007 with a maximum of 0.15 in 1978 and a minimum in 2001 at 0.04. Selectivities estimated by the model (Table 4.15, Figure 4.11) indicate that both sexes of 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 1.14 for the period 1982-2008 which results in the model estimate of the 2008 total biomass at 1,928,000 t (Table 4.16). 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 4.16, Figure 4.11, 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 1984. 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. Although the stock biomass has declined since the peak values in the mid-1980s, it has remained at high and stable levels in recent years and is currently estimated at 68% of the peak level.

The female spawning biomass has also declined since the peak in 1985, with a 2008 estimate of 637,800 t (22% decline). The spawning biomass has been in a gradual decline for the past 7 years and is about 139% of the $B_{40\%}$ level and 193% of the B_{MSY} level (Fig. 4.17). The model estimate of yellowfin sole population numbers at age for all years is shown in Table 4.17 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 4.13. 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 increased during the 1970s and early 1980s to a peak level during the mid-1980s. The twelve years since the mid 1990s have seen the yellowfin sole population biomass slowly decrease as the majority of year-classes since then have been below average strength. Above average recruitment from the 1995 and 1999 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 decline in female spawning biomass in the near future if the fishing mortality rate continues at the same level as the average of the past 5 years.

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 4.14 and Table 4.18). 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 and 1999 year classes are above average. With the exception of these 5 year classes, recruitment from 13 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 were at the maximum of their cohort biomass in 2005 and but should contribute to the mature adult reservoir of spawners in future years. The recruitment contribution to the stock biomass in the near future may be indicated by the 1999 year class, which is estimated at above 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 4.14).

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 2009 is 1,868,550 t.

The SSC has determined that yellowfin sole qualify as a Tier 1 stock and therefore the 2009 ABC is calculated using Tier 1 methodology. 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 relatively high values and B_{MSY} is a lower 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. In 2006 the SSC used a conservative approach and selected the 1978-2001 data set for the Tier 1 harvest recommendation. Using this approach again for the 2008 harvest (1978-2003) recommendation (Model 2 in Table 4.12), the $F_{ABC} = F_{harmonic\ mean} = 0.12$.

The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{MSY} and the geometric mean of the 2009 biomass estimate, as follows:

$B_{gm} = e^{\ln \hat{B} - \frac{cv^2}{2}}$, where B_{gm} is the geometric mean of the 2009 biomass estimate, $\hat{B}$ is the point estimate of the 2009 biomass from the stock assessment model and cv^2 is the coefficient of variation of the point estimate;

and

$\bar{F}_{har} = e^{\ln \hat{F}_{msy} - \frac{\ln sd^2}{2}}$, where $\bar{F}_{har}$ is the harmonic mean, $\hat{F}_{msy}$ is the peak mode of the F_{MSY} distribution and sd^2 is the square of the standard deviation of the F_{MSY} distribution. This calculation gives a Tier 1 ABC harvest recommendation of **210,200 t** and an OFL of 223,900 t for 2009.

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 1 harvest limit at the F_{MSY} fishing mortality value. The overfishing fishing mortality values, ABC fishing mortality values and their corresponding yields are given as follows (Tier 3a values are also included:

Harvest level	F value	2009 Yield
Tier 3 F_{OFL} = $F_{0.35}$	0.125	158,400 t
Tier 3 F_{ABC} = $F_{0.40}$	0.105	134,000 t
Tier 1 F_{OFL} = F_{MSY}	**0.12**	**223,900 t**
Tier 1 F_{ABC} = $F_{harmonic\ mean}$	**0.13**	**210,200 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 2008 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2009 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2008. 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 2009, are as follows ("*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 2009 recommended in the assessment to the *max* F_{ABC} for 2009. (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 2004-2008 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 its MSY level in 2009 and above its MSY level in 2021 under this scenario, then the stock is not overfished.)

Scenario 7: In 2009 and 2010, 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 2021 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 4.19 and Figure 4.15 indicate that yellowfin sole 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. The 2008 numbers at age from the stock assessment model are projected to 2009 given the 2008 catch and then the 2008 OFL harvest rate is applied to the projected 2009 population biomass to obtain the 2010 OFL.

Tier 1 Projection

Year	Catch	SSB	Geometric mean 6+ total biomass	ABC	OFL
2009	120,000	616,300	1,721,200	210,200	223,900
2010	140,000	580,100	1,617,200	197,500	210,400

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-five 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 1992-2007 in Table 4.20. The yellowfin sole target fishery contribution to the total bycatch of prohibited species is shown for 2005 and 2006 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2006 as follows:

Prohibited species	Yellowfin sole fishery % of total bycatch
Halibut mortality	12.7
Herring	7.1
Red King crab	31.6
C. bairdi	25.9
Other Tanner crab	57.3
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 its history of light exploitation (6%) over the past 30 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 yellowfin sole mortality	
Changes in habitat quality			
Temperature regime	Cold years yellowfin sole catchability and herding may decrease, timing of migration may be prolonged	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Yellowfin sole* effects on ecosystem**

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

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Tables

Table 4.1--Catch (t) of yellowfin sole 1977-2008. Catch for 2008 is the total through September 13, 2008.

		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			99,068	99,068
2007			121,029	121,029
2008			111,464	111,464

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
2006	90,570	8,498
2007	109,084	11,945

Table 4.3. Discarded and retained catch of yellowfin sole, by fishery, in 2006 and 2007.

2006			
Target Fishery			
	Discard	**Retained**	**Grand Total**
Atka mackerel	1	1	1.9
Bottom pollock	52	56	108
Pacific cod	1,109	795	1,904
Mid-water pollock	126	22	148
Sablefish	0	0	0
Rockfish	0	0	0
Arrowtooth flounder	38	32	70
Flathead sole	358	2,244	2,602
Rock sole	1,007	8,886	9,893
Yellowfin sole	5,743	78,436	84,178
Greenland turbot	0	0	0
Other flatfish	63	93	156
Other species	1	5	6
	0	0	1
Total	8,498	90,570	99,068

2007			
Target Fishery			
	Discard	**Retained**	**Grand Total**
Atka mackerel	1	0	1.3
Bottom pollock	0	64	64
Pacific cod	784	335	1,120
Mid-water pollock	3	18	21
Sablefish	0	0	0
Rockfish	0	0	0
Arrowtooth flounder	2	5	7
Flathead sole	1,106	1,414	2,520
Rock sole	588	8,328	8,916
Yellowfin sole	9,437	98,817	108,254
Alaska plaice	0	0	0
Greenland turbot	0	35	35
Other flatfish	22	67	89
Other species	1	1	2
Total	11,945	109,084	121,029

Table 4.4. Yellowfin sole fishery catch-at-age numbers (millions), 1977-2007.

year/age	7	8	9	10	11	12	13	14	15	16	17+
1977	32.31	52.53	56.03	58.43	32.32	11.96	7.57	3.18	1.87	2.01	12.09
1978	47.23	109.08	134.86	110.12	97.01	49.56	17.77	11.12	4.64	2.73	15.77
1979	19.77	51.76	90.95	85.78	58.93	47.84	23.65	8.38	5.21	2.17	28.63
1980	20.58	27.71	55.68	75.40	60.26	38.29	30.12	14.72	5.19	3.23	29.42
1981	24.41	37.73	39.07	60.69	69.80	51.67	31.83	24.75	12.04	4.24	54.81
1982	14.49	40.52	48.23	38.64	51.00	54.33	39.00	23.75	18.39	8.93	222.61
1983	19.00	28.28	60.94	56.15	38.25	46.78	48.33	34.29	20.80	16.08	477.88
1984	17.43	49.91	57.04	94.89	74.22	46.82	55.52	56.70	40.06	24.26	422.70
1985	15.92	46.31	101.08	88.55	124.49	89.98	54.98	64.43	65.51	46.21	190.68
1986	28.94	27.82	61.48	102.41	75.54	97.94	68.51	41.35	48.24	48.97	20.73
1987	19.04	48.05	35.17	59.41	83.42	56.78	71.27	49.25	29.59	34.47	15.62
1988	69.62	44.77	85.82	47.95	68.29	88.47	58.29	72.28	49.73	29.83	4.48
1989	8.85	88.20	43.16	63.17	29.72	39.01	48.92	31.84	39.30	26.99	5.62
1990	19.60	8.21	62.93	23.75	29.47	12.83	16.32	20.22	13.10	16.15	6.48
1991	7.54	40.84	13.20	78.54	25.25	29.05	12.26	15.43	19.04	12.32	3.22
1992	9.47	22.92	95.42	23.84	120.51	35.89	40.05	16.71	20.93	25.79	10.17
1993	8.63	11.77	21.89	70.32	14.90	69.69	20.12	22.18	9.22	11.53	10.69
1994	16.31	22.29	23.36	33.59	91.67	17.99	81.60	23.28	25.57	10.61	12.13
1995	14.27	27.09	28.43	22.98	28.02	70.74	13.46	60.32	17.14	18.79	2.94
1996	7.32	28.40	41.41	33.53	23.00	25.96	63.54	11.95	53.32	15.13	7.46
1997	11.41	19.77	58.65	65.72	45.05	28.57	31.25	75.60	14.15	63.07	3.51
1998	15.25	12.56	16.66	37.97	35.96	22.77	13.99	15.12	36.41	6.81	4.10
1999	5.96	19.44	12.35	12.69	24.59	21.58	13.25	8.05	8.66	20.82	2.94
2000	6.26	13.91	35.05	17.28	15.11	27.16	23.13	14.04	8.49	9.12	2.37
2001	4.60	8.90	15.29	29.88	12.53	10.16	17.72	14.92	9.02	5.44	6.39
2002	14.42	10.02	14.98	19.98	33.27	12.95	10.19	17.56	14.72	8.88	4.27
2003	6.10	27.50	14.76	17.11	19.43	30.00	11.33	8.81	15.12	12.66	3.98
2004	4.80	10.56	36.77	15.31	15.12	15.92	23.84	8.90	6.89	11.81	5.89
2005	9.67	12.35	20.93	56.48	20.02	18.32	18.72	27.72	10.30	7.97	7.51
2006	15.75	19.25	18.91	24.77	56.78	18.64	16.54	16.70	24.63	9.14	14.36
2007	9.77	36.82	34.52	26.16	29.05	61.63	19.62	17.20	17.29	25.46	35.48

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	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	141,053	1,992,017	2,133,070	1,818,253	2,447,932
2007	173,185	1,979,553	2,152,738	1,775,191	2,530,285
2008			2,099,521	1,599,100	2,600,000

Table 4.6. Yellowfin sole population numbers-at-age (millions) estimated from the annual bottom trawl surveys, 1982-2007.

Females

year/age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1979	21	113	150	442	616	386	555	801	626	528	219	274	59	35	29	15
1980	1	92	342	518	800	1055	413	661	880	651	765	285	113	33	23	23
1981	0	20	195	839	692	1321	1155	261	477	744	527	311	168	55	23	45
1982	38	183	349	1211	1485	1424	1619	843	829	832	704	409	246	159	51	84
1983	0	5	59	154	751	1413	843	1065	936	753	1155	866	295	160	60	54
1984	0	53	278	264	427	745	841	1111	1080	941	541	583	480	239	174	133
1985	0	3	105	442	587	406	632	915	441	518	545	384	298	321	205	127
1986	0	8	24	219	349	666	279	574	519	377	284	318	196	250	136	259
1987	0	0	70	120	803	458	843	259	376	599	356	449	243	270	247	688
1988	0	0	7	370	71	1495	560	557	184	239	351	208	360	273	219	886
1989	0	0	14	98	718	234	1337	593	446	74	179	308	234	238	183	565
1990	0	0	70	102	325	1066	192	1257	408	482	101	72	107	78	231	605
1991	0	10	127	248	123	405	896	151	1263	213	525	63	128	87	123	807
1992	0	19	247	485	520	213	286	938	94	825	75	309	129	137	170	715
1993	0	24	100	357	634	434	269	224	1314	78	866	157	165	69	68	674
1994	0	54	95	223	518	905	555	482	284	1170	516	44	274	142	42	588
1995	0	19	153	288	181	889	627	274	135	25	634	21	561	104	80	512
1996	0	16	154	809	288	279	434	517	206	146	151	602	116	637	47	619
1997	0	18	324	502	725	256	239	506	228	114	176	184	500	44	314	533
1998	0	10	83	479	420	900	260	203	370	413	369	170	176	265	67	1167
1999	0	3	65	198	175	185	727	104	107	245	190	186	72	102	175	425
2000	0	11	54	248	208	304	444	537	189	198	237	219	65	117	145	572
2001	0	1	71	239	522	248	403	415	654	374	83	191	154	127	189	617
2002	0	16	123	170	255	778	346	290	229	457	221	91	307	116	152	805
2003	0	15	115	241	251	287	1143	225	279	286	251	103	115	170	168	943
2004	10	33	192	430	560	441	217	966	221	212	218	219	106	20	167	1020
2005	0	53	167	194	602	433	213	487	834	196	144	191	324	170	53	1332
2006	0	67	302	376	276	634	470	176	325	738	133	133	71	156	175	514
2007	0	37	515	348	376	277	504	308	124	227	504	119	137	127	105	724

Table 4.6.(continued)

Males

year/age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1979	21	115	143	390	381	303	583	847	604	406	349	247	54	76	29	36
1980	20	78	306	632	853	1221	457	558	616	568	444	370	147	18	8	8
1981	0	50	200	1047	640	1280	858	394	372	546	534	266	66	83	55	12
1982	89	193	428	1780	1781	1059	1673	644	774	463	471	482	302	8	24	8
1983	0	1	65	183	724	1729	808	1049	676	699	722	566	425	550	77	51
1984	0	68	246	323	497	734	830	612	788	718	358	379	201	316	122	106
1985	0	41	172	419	559	263	652	527	401	451	360	224	260	157	112	65
1986	0	13	47	108	373	652	262	327	284	335	211	205	115	210	82	252
1987	0	5	41	106	838	467	673	445	328	277	210	147	106	142	185	600
1988	0	2	10	435	49	1163	553	443	85	187	28	177	336	189	28	599
1989	0	2	23	181	788	177	1306	513	357	135	50	103	54	204	35	478
1990	0	11	47	121	316	888	195	1144	318	263	40	65	67	24	55	389
1991	0	0	103	354	139	275	1046	68	1137	328	244	74	64	60	53	420
1992	0	0	146	445	566	262	226	812	114	907	193	213	12	12	61	607
1993	0	20	52	233	646	393	279	247	1096	69	842	53	53	50	0	341
1994	4	22	71	166	427	953	656	308	191	822	26	622	46	132	11	303
1995	0	0	169	120	270	667	565	94	179	75	478	13	603	49	24	418
1996	0	76	95	837	244	227	425	344	331	141	139	399	61	449	125	495
1997	0	10	214	425	798	181	184	446	245	194	214	108	514	79	264	416
1998	0	48	70	351	569	832	159	226	204	272	346	140	157	191	113	814
1999	0	5	100	142	225	243	575	146	94	309	269	75	53	28	119	425
2000	0	0	36	219	259	143	509	583	78	215	133	77	92	78	66	547
2001	0	0	87	141	652	341	375	357	562	208	87	158	65	73	140	432
2002	0	58	72	158	309	758	318	333	262	442	194	120	220	161	133	507
2003	0	24	95	178	258	251	1074	238	363	53	284	173	10	71	57	682
2004	4	63	114	469	447	199	395	993	263	81	195	223	103	47	249	456
2005	0	49	166	187	474	476	204	288	972	123	142	121	133	69	93	726
2006	0	101	173	348	332	505	393	288	298	384	116	155	89	39	11	590
2007	0	58	481	352	405	284	545	209	166	252	338	101	133	72	59	620

Table 4.7-Occurance of yellowfin sole in the Bering Sea trawl survey and collections of length and age structures and the number of otoliths aged from each survey.

Year	Total Hauls	Hauls w/length	Number lengths	Hauls w/otolith	Number otoliths	Number ages
1982	334	246	37,023	35	744	744
1983	353	256	33,924	37	709	709
1984	355	271	33,894	56	821	796
1985	358	262	33,831	44	810	802
1986	354	249	30,470	34	739	739
1987	360	224	31,241	16	798	798
1988	373	254	27,138	14	543	543
1989	373	235	29,518	24	740	740
1990	371	251	30,257	28	792	792
1991	372	249	27,988	26	742	742
1992	356	229	23,628	16	606	606
1993	375	242	26,651	20	549	549
1994	376	270	24,451	14	526	522
1995	376	254	22,116	20	654	647
1996	375	247	27,505	16	729	721
1997	376	262	26,034	11	470	466
1998	375	310	34,509	15	575	570
1999	373	276	28,431	31	777	770
2000	372	255	24,880	20	517	511
2001	375	251	26,558	25	604	593
2002	375	246	26,309	32	738	723
2003	376	241	27,135	37	699	695
2004	375	251	26,103	26	725	712
2005	373	251	24,658	34	644	635
2006	376	246	28,470	39	440	426
2007	376	247	24,790	66	779	772
2008	375	238	25,848	65	858	

Table 4.8—Mean length and weight at age for yellowfin sole.

	mean length at age (cm)		**mean weight at age (g)**	
	males	females	males	females
1	7.4		4	6
2	10.7	9.8	14	8
3	11.8	12.6	18	20
4	14.3	14.6	32	31
5	16.9	17.4	54	55
6	19.6	19.8	85	84
7	22.0	22.4	120	124
8	24.0	24.5	156	165
9	25.7	26.7	193	217
10	27.0	28.5	225	266
11	28.0	29.6	253	301
12	28.9	30.8	280	341
13	29.7	31.7	303	374
14	30.3	32.5	324	407
15	30.5	33.0	330	428
16	31.0	33.4	344	443
17	31.3	34.2	355	480
18	31.6	34.3	366	483
19	32.2	33.2	390	499
20	32.1	33.8	423	588

Table 4.9. 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 4.10. Key equations used in the population dynamics model.

Equation	Description
$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}, \quad \tau_t \sim N(0,\delta^2{}_R)$	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*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}, \quad \varepsilon^F{}_t \sim N(o,\sigma^{2_F})$	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

$$qprior = \lambda \frac{0.5(\ln q_{est,t} - \ln q_{prior})^2}{\sigma_q^2}$$ survey catchability prior (when estimated)

$$mprior = \lambda \frac{0.5(\ln m_{est} - \ln m_{prior})^2}{\sigma_m^2}$$ natural mortality prior (when estimated)

$$reclike = \lambda (\sum_{i=1965}^{endyear} \bar{R} - R_i)^2 + \sum_{a=1}^{20} (\bar{R}_{init} - R_{init,a})^2 + \frac{1}{2((\sum_{i=1965}^{endyear} \bar{R} - R_i)\frac{1}{n+1})})$$ recruitment likelihood

$$catchlike = \lambda \sum_{i=startyear}^{endyear} (\ln C_{obs,i} - \ln C_{est,i})^2$$ catch likelihood

$$surveylike = \lambda \frac{(\ln B - \ln \hat{B})^2}{2\sigma^2}$$ survey likelihood

$$SurvAgelike = \sum_{i,t} m_t P_{t,a} \ln \frac{\hat{P}_{t,a}}{P_{t,a}}$$ survey age composition likelihood

$$FishAgelike = \sum_{i,t} m_t P_{t,a} \ln \frac{\hat{P}_{t,a}}{P_{t,a}}$$ fishery age composition likelihood

Table 4.11. 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 4.12- 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. Models 4-12 include the same years in the spawner-recruit fit as model 2. S/R = spawner-recruit, R = recruitment, q = catchability and M = natural mortality.

	Years used in S/R fit	**Selectivity CV**	σ_R	σ_q	σ_M	F_{MSY}	**Harmonic mean of F_{MSY} (% of F_{msy})**
Model 1	1955-2003	0.4	0.6	q not estimated	M not estimated	0.166	0.165 (99%)
Model 2	1978-2003	0.4	0.6	q not estimated	M not estimated	0.130	0.122 (94%)
Model 3	1955-1978	0.4	0.6	q not estimated	M not estimated	0.178	0.176 (99%)
Model 4	1978-2002	0.4	0.8	q not estimated	M not estimated	0.133	0.119 (90%)
Model 5	1978-2002	0.4	1.0	q not estimated	M not estimated	0.137	0.116 (84%)
Model 6	1978-2002	0.4	1.2	q not estimated	M not estimated	0.142	0.111 (78%)
Model 7	1978-2002	0.4	1.5	q not estimated	M not estimated	0.152	0.104 (68%)
Model 8	1978-2002	0.9	0.6	q not estimated	M not estimated	0.131	0.122 (94%)
Model 9	1978-2002	0.4	0.6	0.9	M not estimated	0.13	0.122 (94%)
Model 10	1978-2002	0.4	0.6	0.4	M not estimated	0.13	0.122 (94%)
Model 11	1978-2002	0.4	0.6	q not estimated	0.9 males only	0.127	0.119 (94%)
Model 12	1978-2002	0.4	0.6	q not estimated	0.4 males only	0.127	0.119 (94%)

Table 4.13. Models evaluated for the 2008 stock assessment of yellowfin sole. σ_M and σ_q are the level of uncertainty placed on the parameter estimates of natural mortality and catchability, respectively. Biomass is in 1,000s t.

		Model 2	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6
model	Combined sex 2007 model	Split-sex BASE model	Male M estimated with σ_M = 0.5	Male and female M estimated with σ_M = 0.5	q estimated with σ_q = 0.2	q estimated with σ_q = 0.5	Male and female M and q estimated with σ = 0.2	Male and female M and q estimated with σ = 0.5
ending FSB	602.431	637.811	680.07	758.87	629.096	630.45	482.18	411.924
ending total biomass	2155.67	1928.09	1862.49	1951.67	1887.73	1891.19	1212.15	1013.58
M	0.12	fixed at 0.12	female 0.12 male 0.136	female 0.105 male 0.122	fixed at 0.12	fixed at 0.12	female 0.059 male 0.076	female 0.03 male 0.47
q	1.17	1.14	fixed at 1.14	fixed at 1.14	1.14	1.14	1.9	2.34
F40%	0.109	0.104	0.105	0.94	0.104	0.105	0.06	0.04
Fharmonic	0.124	0.122	0.119	0.126	0.122	0.121	0.151	0.167
Tier 1 ABC	247.500	210.197	196.901	221.016	204.861	205.24	166.731	155.984
survey, catch, age and recruit likelihood	1337.0	1602.04	1562.31	1550.33	1618.179	1618.17	1521.44	1513.34

Table 4.14. Model estimates of yellowfin sole fishing mortality and exploitation rate (catch/total biomass).

Year	Full selection F	Exploitation Rate
1964	0.43	0.14
1965	0.17	0.07
1966	0.28	0.12
1967	0.45	0.19
1968	0.24	0.11
1969	0.54	0.21
1970	0.52	0.18
1971	0.83	0.22
1972	0.28	0.06
1973	0.41	0.09
1974	0.17	0.04
1975	0.18	0.05
1976	0.11	0.04
1977	0.08	0.03
1978	0.15	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	0.11	0.08
1998	0.07	0.05
1999	0.05	0.03
2000	0.06	0.04
2001	0.04	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
2007	0.09	0.06
2008	0.08	0.06

Table 4.15-Model estimates of yellowfin sole age-specific selectivities for the survey and fishery.

Age	Fishery (1975-2008)		Survey (1982-2008)	
	females	males	females	males
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.01	0.01
3	0.00	0.00	0.04	0.04
4	0.01	0.01	0.15	0.14
5	0.03	0.02	0.43	0.41
6	0.07	0.07	0.77	0.75
7	0.17	0.18	0.94	0.93
8	0.36	0.40	0.99	0.98
9	0.60	0.66	1.00	1.00
10	0.80	0.86	1.00	1.00
11	0.91	0.95	1.00	1.00
12	0.97	0.98	1.00	1.00
13	0.99	0.99	1.00	1.00
14	0.99	1.00	1.00	1.00
15	1.00	1.00	1.00	1.00
16	1.00	1.00	1.00	1.00
17	1.00	1.00	1.00	1.00
18	1.00	1.00	1.00	1.00
19	1.00	1.00	1.00	1.00
20	1.00	1.00	1.00	1.00

Table 4.16. Model estimates of yellowfin sole age 2+ total biomass (t) and begin-year female spawning biomass (t) from the 2007 and 2008 stock assessments.

	2007 Assessment		2008 Assessment	
Year	Female spawning biomass	Total biomass	Female spawning biomass	Total biomass
1964	65,407	711,918	87,137	779,806
1965	74,806	717,847	97,798	782,860
1966	95,853	776,175	122,030	841,433
1967	105,745	770,668	131,987	835,689
1968	107,887	695,412	132,391	764,032
1969	107,128	713,163	129,495	783,357
1970	87,790	661,973	104,955	724,283
1971	66,661	669,499	78,801	732,692
1972	52,430	691,397	60,692	743,707
1973	57,059	877,659	64,222	910,397
1974	67,401	1,058,160	72,738	1,078,420
1975	95,251	1,300,760	98,427	1,323,880
1976	139,084	1,557,710	139,698	1,562,440
1977	202,170	1,813,790	203,739	1,814,060
1978	277,358	2,056,540	282,953	2,056,470
1979	353,146	2,209,920	365,406	2,197,770
1980	442,917	2,386,040	463,623	2,364,110
1981	530,673	2,541,310	563,293	2,519,110
1982	604,824	2,646,370	651,750	2,654,900
1983	672,456	2,739,390	731,409	2,759,030
1984	721,476	2,811,830	793,196	2,834,670
1985	736,855	2,781,790	818,291	2,833,620
1986	723,475	2,698,870	812,568	2,761,470
1987	708,248	2,630,040	797,895	2,700,320
1988	682,446	2,590,450	772,214	2,679,690
1989	651,743	2,491,030	740,709	2,597,740
1990	659,078	2,470,660	752,713	2,582,690
1991	694,005	2,505,500	794,528	2,610,620
1992	718,947	2,499,170	824,059	2,608,850
1993	730,248	2,415,630	844,138	2,535,700
1994	735,074	2,376,670	855,155	2,490,730
1995	719,222	2,288,120	840,166	2,399,380
1996	694,757	2,205,540	816,825	2,332,990
1997	662,308	2,130,310	776,677	2,257,750
1998	618,422	2,003,580	735,500	2,125,930
1999	603,433	1,948,750	717,476	2,076,640
2000	590,615	1,934,200	711,179	2,086,100
2001	587,255	1,935,110	706,434	2,077,920
2002	578,963	1,943,390	698,773	2,076,580
2003	579,664	1,964,560	696,636	2,074,290
2004	576,871	1,997,590	689,725	2,066,830
2005	574,888	2,059,450	685,289	2,059,970
2006	568,079	2,098,380	673,815	2,022,160
2007	562,879	2,155,670	658,395	1,985,740
2008			637,811	1,928,090

Table 4.17—Model estimates of yellowfin sole population numbers at age (billions) for 1954-2008.

Females

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	1.91	2.4	0.86	0.33	0.21	0.19	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
1955	0.88	1.69	2.13	0.76	0.29	0.18	0.17	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.29
1956	0.52	0.78	1.5	1.89	0.68	0.26	0.16	0.15	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.39
1957	1.69	0.46	0.69	1.33	1.68	0.6	0.23	0.14	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.45
1958	1.18	1.5	0.41	0.61	1.18	1.49	0.53	0.2	0.13	0.11	0.11	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.49
1959	0.88	1.04	1.33	0.36	0.54	1.05	1.31	0.47	0.18	0.11	0.1	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.5
1960	0.85	0.78	0.93	1.18	0.32	0.48	0.92	1.13	0.39	0.14	0.09	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.44
1961	0.49	0.76	0.69	0.82	1.04	0.28	0.41	0.74	0.83	0.25	0.08	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.26
1962	0.92	0.44	0.67	0.61	0.72	0.9	0.23	0.31	0.47	0.42	0.11	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.1
1963	0.46	0.82	0.39	0.59	0.53	0.61	0.72	0.17	0.17	0.19	0.13	0.03	0.01	0	0	0	0	0	0	0.03
1964	0.42	0.41	0.73	0.34	0.52	0.47	0.53	0.6	0.13	0.12	0.13	0.08	0.02	0	0	0	0	0	0	0.02
1965	0.58	0.37	0.36	0.64	0.3	0.46	0.4	0.44	0.46	0.09	0.08	0.08	0.05	0.01	0	0	0	0	0	0.01
1966	0.59	0.52	0.33	0.32	0.57	0.27	0.4	0.35	0.36	0.37	0.07	0.06	0.06	0.04	0.01	0	0	0	0	0.01
1967	1.15	0.52	0.46	0.29	0.28	0.5	0.23	0.34	0.28	0.27	0.26	0.05	0.04	0.04	0.02	0.01	0	0	0	0.01
1968	1.73	1.02	0.46	0.41	0.26	0.25	0.43	0.19	0.26	0.19	0.17	0.15	0.03	0.02	0.02	0.01	0	0	0	0
1969	1.72	1.54	0.9	0.41	0.36	0.23	0.22	0.37	0.15	0.2	0.14	0.12	0.11	0.02	0.02	0.02	0.01	0	0	0
1970	2.22	1.52	1.36	0.8	0.36	0.31	0.19	0.18	0.27	0.1	0.11	0.07	0.06	0.06	0.01	0.01	0.01	0.01	0	0
1971	2.51	1.97	1.35	1.21	0.71	0.32	0.27	0.16	0.13	0.17	0.06	0.06	0.04	0.03	0.03	0.01	0	0	0	0
1972	1.99	2.22	1.75	1.19	1.06	0.61	0.26	0.21	0.1	0.07	0.08	0.02	0.02	0.02	0.01	0.01	0	0	0	0
1973	1.4	1.77	1.97	1.55	1.05	0.93	0.53	0.22	0.16	0.08	0.05	0.05	0.02	0.02	0.01	0.01	0.01	0	0	0
1974	1.92	1.24	1.57	1.75	1.37	0.92	0.8	0.44	0.17	0.11	0.05	0.03	0.03	0.01	0.01	0.01	0.01	0	0	0
1975	2.31	1.7	1.1	1.39	1.54	1.21	0.81	0.69	0.37	0.14	0.09	0.04	0.02	0.02	0.01	0.01	0	0	0	0
1976	1.54	2.05	1.51	0.97	1.23	1.36	1.06	0.7	0.58	0.29	0.11	0.07	0.03	0.02	0.02	0.01	0.01	0	0	0
1977	1.93	1.36	1.82	1.34	0.86	1.09	1.2	0.92	0.59	0.48	0.24	0.08	0.05	0.02	0.01	0.01	0	0	0	0.01
1978	1.25	1.71	1.21	1.61	1.19	0.76	0.96	1.05	0.79	0.5	0.4	0.2	0.07	0.04	0.02	0.01	0.01	0	0	0.01
1979	0.79	1.11	1.51	1.07	1.42	1.05	0.67	0.83	0.88	0.64	0.39	0.31	0.15	0.05	0.03	0.01	0.01	0.01	0	0.01
1980	1.52	0.7	0.98	1.34	0.95	1.26	0.92	0.58	0.71	0.74	0.53	0.32	0.25	0.12	0.04	0.03	0.01	0.01	0.01	0.01

Table 4.17—Model estimates of yellowfin sole population numbers at age (billions) for 1954-2008 (continued).

Females

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1981	1.11	1.35	0.63	0.87	1.19	0.84	1.11	0.81	0.51	0.61	0.62	0.44	0.27	0.21	0.1	0.04	0.02	0.01	0.01	0.01
1982	3.16	0.98	1.2	0.55	0.77	1.05	0.74	0.98	0.7	0.43	0.51	0.52	0.37	0.22	0.17	0.08	0.03	0.02	0.01	0.02
1983	0.58	2.8	0.87	1.06	0.49	0.68	0.93	0.65	0.85	0.6	0.37	0.43	0.44	0.31	0.19	0.14	0.07	0.02	0.02	0.02
1984	2.58	0.52	2.49	0.77	0.94	0.43	0.6	0.82	0.56	0.72	0.51	0.31	0.36	0.36	0.26	0.16	0.12	0.06	0.02	0.03
1985	0.89	2.29	0.46	2.21	0.68	0.83	0.38	0.53	0.7	0.48	0.6	0.41	0.25	0.29	0.3	0.21	0.13	0.1	0.05	0.04
1986	0.68	0.79	2.03	0.41	1.95	0.61	0.73	0.33	0.45	0.58	0.38	0.47	0.33	0.2	0.23	0.23	0.16	0.1	0.08	0.07
1987	0.93	0.6	0.7	1.8	0.36	1.73	0.53	0.64	0.28	0.37	0.47	0.3	0.37	0.26	0.15	0.18	0.18	0.13	0.08	0.11
1988	1.27	0.83	0.54	0.62	1.59	0.32	1.52	0.46	0.54	0.24	0.3	0.37	0.24	0.3	0.2	0.12	0.14	0.14	0.1	0.15
1989	1.24	1.12	0.73	0.48	0.55	1.41	0.28	1.32	0.39	0.44	0.19	0.23	0.29	0.19	0.23	0.16	0.09	0.11	0.11	0.2
1990	0.59	1.1	1	0.65	0.42	0.48	1.24	0.24	1.13	0.33	0.36	0.15	0.19	0.23	0.15	0.19	0.13	0.08	0.09	0.25
1991	0.64	0.53	0.98	0.88	0.58	0.37	0.43	1.09	0.21	0.97	0.28	0.31	0.13	0.16	0.2	0.13	0.16	0.11	0.06	0.29
1992	1.43	0.56	0.47	0.87	0.78	0.51	0.33	0.38	0.95	0.18	0.83	0.24	0.26	0.11	0.14	0.17	0.11	0.13	0.09	0.29
1993	0.81	1.27	0.5	0.41	0.77	0.69	0.45	0.29	0.32	0.8	0.15	0.68	0.19	0.21	0.09	0.11	0.14	0.09	0.11	0.31
1994	0.68	0.72	1.12	0.44	0.37	0.68	0.61	0.39	0.25	0.28	0.68	0.13	0.57	0.16	0.18	0.07	0.09	0.11	0.07	0.35
1995	0.66	0.61	0.64	1	0.39	0.32	0.6	0.54	0.34	0.21	0.23	0.56	0.1	0.46	0.13	0.14	0.06	0.08	0.09	0.35
1996	1.78	0.59	0.54	0.57	0.88	0.35	0.29	0.52	0.46	0.29	0.18	0.19	0.46	0.09	0.38	0.11	0.12	0.05	0.06	0.36
1997	0.74	1.58	0.52	0.48	0.5	0.78	0.31	0.25	0.45	0.39	0.24	0.15	0.16	0.38	0.07	0.32	0.09	0.1	0.04	0.35
1998	0.63	0.66	1.4	0.46	0.42	0.45	0.69	0.27	0.21	0.38	0.32	0.19	0.12	0.12	0.3	0.06	0.25	0.07	0.08	0.31
1999	0.92	0.56	0.58	1.24	0.41	0.37	0.39	0.6	0.23	0.18	0.32	0.27	0.16	0.1	0.1	0.25	0.05	0.21	0.06	0.32
2000	1.4	0.82	0.5	0.52	1.1	0.36	0.33	0.35	0.53	0.2	0.16	0.27	0.22	0.14	0.08	0.09	0.21	0.04	0.18	0.32
2001	0.69	1.25	0.72	0.44	0.46	0.97	0.32	0.29	0.3	0.45	0.17	0.13	0.23	0.19	0.11	0.07	0.07	0.18	0.03	0.42
2002	0.92	0.61	1.1	0.64	0.39	0.4	0.86	0.28	0.25	0.26	0.39	0.14	0.11	0.19	0.16	0.1	0.06	0.06	0.15	0.38
2003	0.81	0.82	0.55	0.98	0.57	0.34	0.36	0.76	0.25	0.22	0.22	0.33	0.12	0.09	0.16	0.14	0.08	0.05	0.05	0.45
2004	0.67	0.72	0.72	0.48	0.87	0.5	0.3	0.31	0.66	0.21	0.19	0.19	0.28	0.1	0.08	0.14	0.11	0.07	0.04	0.42
2005	0.68	0.59	0.64	0.64	0.43	0.77	0.45	0.27	0.27	0.57	0.18	0.16	0.16	0.23	0.09	0.07	0.12	0.1	0.06	0.39
2006	0.94	0.6	0.52	0.56	0.57	0.38	0.68	0.39	0.23	0.23	0.48	0.15	0.13	0.13	0.19	0.07	0.06	0.1	0.08	0.37
2007	1.03	0.83	0.53	0.46	0.5	0.5	0.33	0.59	0.34	0.2	0.2	0.4	0.12	0.11	0.11	0.16	0.06	0.05	0.08	0.38
2008	1.04	0.91	0.74	0.47	0.41	0.44	0.44	0.29	0.51	0.28	0.16	0.16	0.32	0.1	0.09	0.09	0.13	0.05	0.04	0.37

Table 4.17—Model estimates of yellowfin sole population numbers at age (billions) for 1954-2008 (continued).

Males

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	1.91	1.55	0.76	0.32	0.21	0.19	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
1955	0.88	1.69	1.37	0.68	0.28	0.18	0.17	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.29
1956	0.52	0.78	1.5	1.22	0.6	0.25	0.16	0.15	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.39
1957	1.69	0.46	0.69	1.33	1.08	0.53	0.22	0.14	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.45
1958	1.18	1.5	0.41	0.61	1.18	0.96	0.47	0.2	0.13	0.11	0.11	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.49
1959	0.88	1.04	1.33	0.36	0.54	1.05	0.85	0.41	0.17	0.11	0.1	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.5
1960	0.85	0.78	0.93	1.18	0.32	0.48	0.92	0.73	0.34	0.14	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.44
1961	0.49	0.76	0.69	0.82	1.04	0.28	0.41	0.74	0.53	0.22	0.08	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.26
1962	0.92	0.44	0.67	0.61	0.72	0.9	0.23	0.31	0.45	0.25	0.09	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.1
1963	0.46	0.82	0.39	0.59	0.54	0.62	0.73	0.16	0.16	0.17	0.07	0.02	0.01	0	0	0	0	0	0	0.03
1964	0.42	0.41	0.73	0.34	0.52	0.47	0.54	0.61	0.13	0.11	0.11	0.04	0.01	0	0	0	0	0	0	0.02
1965	0.58	0.37	0.36	0.64	0.3	0.46	0.41	0.44	0.45	0.08	0.07	0.06	0.03	0.01	0	0	0	0	0	0.01
1966	0.59	0.52	0.33	0.32	0.57	0.27	0.4	0.35	0.36	0.36	0.06	0.05	0.05	0.02	0.01	0	0	0	0	0.01
1967	1.15	0.52	0.46	0.29	0.28	0.5	0.23	0.34	0.28	0.27	0.25	0.04	0.04	0.03	0.01	0	0	0	0	0.01
1968	1.73	1.02	0.46	0.41	0.26	0.25	0.43	0.19	0.25	0.18	0.16	0.14	0.02	0.02	0.02	0.01	0	0	0	0
1969	1.72	1.54	0.9	0.41	0.36	0.23	0.22	0.37	0.15	0.19	0.13	0.11	0.1	0.02	0.01	0.01	0.01	0	0	0
1970	2.22	1.52	1.36	0.8	0.36	0.31	0.2	0.18	0.26	0.09	0.11	0.07	0.06	0.05	0.01	0.01	0.01	0	0	0
1971	2.51	1.97	1.35	1.21	0.71	0.32	0.27	0.16	0.13	0.16	0.05	0.06	0.04	0.03	0.03	0	0	0	0	0
1972	1.99	2.22	1.75	1.19	1.06	0.61	0.27	0.21	0.1	0.06	0.07	0.02	0.02	0.01	0.01	0.01	0	0	0	0
1973	1.4	1.77	1.97	1.55	1.06	0.94	0.53	0.22	0.16	0.07	0.05	0.05	0.01	0.02	0.01	0.01	0.01	0	0	0
1974	1.92	1.24	1.57	1.75	1.37	0.93	0.81	0.44	0.17	0.11	0.05	0.03	0.03	0.01	0.01	0.01	0	0	0	0
1975	2.31	1.7	1.1	1.39	1.55	1.21	0.81	0.69	0.36	0.13	0.08	0.03	0.02	0.02	0.01	0.01	0	0	0	0
1976	1.54	2.05	1.51	0.97	1.23	1.37	1.06	0.7	0.57	0.29	0.1	0.06	0.03	0.02	0.02	0	0	0	0	0
1977	1.93	1.36	1.82	1.34	0.86	1.09	1.2	0.92	0.59	0.47	0.23	0.08	0.05	0.02	0.01	0.01	0	0	0	0.01
1978	1.25	1.71	1.21	1.61	1.19	0.76	0.96	1.05	0.79	0.5	0.39	0.19	0.07	0.04	0.02	0.01	0.01	0	0	0.01
1979	0.79	1.11	1.51	1.07	1.43	1.05	0.67	0.83	0.88	0.64	0.39	0.3	0.15	0.05	0.03	0.01	0.01	0.01	0	0.01
1980	1.52	0.7	0.98	1.34	0.95	1.26	0.92	0.59	0.71	0.73	0.52	0.32	0.24	0.12	0.04	0.03	0.01	0.01	0.01	0.01

Table 4.17—Model estimates of yellowfin sole population numbers at age (billions) for 1954-2008 (continued).

	Males																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1981	1.11	1.35	0.63	0.87	1.19	0.84	1.11	0.81	0.51	0.6	0.61	0.43	0.26	0.2	0.1	0.03	0.02	0.01	0.01	0.01
1982	3.16	0.98	1.2	0.55	0.77	1.05	0.74	0.98	0.7	0.43	0.5	0.51	0.36	0.22	0.17	0.08	0.03	0.02	0.01	0.01
1983	0.58	2.8	0.87	1.06	0.49	0.68	0.93	0.65	0.85	0.6	0.36	0.42	0.43	0.3	0.18	0.14	0.07	0.02	0.01	0.02
1984	2.58	0.52	2.49	0.77	0.94	0.44	0.6	0.82	0.56	0.72	0.5	0.3	0.35	0.36	0.25	0.15	0.12	0.06	0.02	0.03
1985	0.89	2.29	0.46	2.21	0.69	0.83	0.38	0.53	0.7	0.47	0.59	0.41	0.25	0.29	0.29	0.2	0.12	0.1	0.05	0.04
1986	0.68	0.79	2.03	0.41	1.95	0.61	0.73	0.33	0.45	0.57	0.38	0.47	0.32	0.19	0.22	0.23	0.16	0.1	0.07	0.07
1987	0.93	0.6	0.7	1.8	0.36	1.73	0.53	0.64	0.28	0.36	0.46	0.3	0.37	0.25	0.15	0.18	0.18	0.13	0.08	0.11
1988	1.27	0.83	0.54	0.62	1.59	0.32	1.52	0.46	0.54	0.23	0.29	0.37	0.24	0.29	0.2	0.12	0.14	0.14	0.1	0.15
1989	1.24	1.12	0.73	0.48	0.55	1.41	0.28	1.32	0.39	0.44	0.18	0.23	0.28	0.18	0.23	0.16	0.09	0.11	0.11	0.19
1990	0.59	1.1	1	0.65	0.42	0.48	1.24	0.24	1.12	0.32	0.36	0.15	0.18	0.23	0.15	0.18	0.13	0.08	0.09	0.24
1991	0.64	0.53	0.98	0.88	0.58	0.37	0.43	1.09	0.21	0.97	0.28	0.3	0.13	0.16	0.19	0.12	0.15	0.11	0.06	0.28
1992	1.43	0.56	0.47	0.87	0.78	0.51	0.33	0.38	0.95	0.18	0.82	0.23	0.25	0.11	0.13	0.16	0.1	0.13	0.09	0.29
1993	0.81	1.27	0.5	0.41	0.77	0.69	0.45	0.29	0.32	0.79	0.15	0.67	0.19	0.21	0.09	0.11	0.13	0.09	0.11	0.31
1994	0.68	0.72	1.12	0.44	0.37	0.68	0.61	0.39	0.25	0.28	0.67	0.13	0.56	0.16	0.17	0.07	0.09	0.11	0.07	0.34
1995	0.66	0.61	0.64	1	0.39	0.33	0.6	0.54	0.34	0.21	0.23	0.55	0.1	0.46	0.13	0.14	0.06	0.07	0.09	0.34
1996	1.78	0.59	0.54	0.57	0.88	0.35	0.29	0.52	0.46	0.29	0.17	0.19	0.45	0.08	0.38	0.11	0.12	0.05	0.06	0.36
1997	0.74	1.58	0.52	0.48	0.5	0.78	0.31	0.25	0.45	0.39	0.24	0.14	0.16	0.37	0.07	0.31	0.09	0.1	0.04	0.34
1998	0.63	0.66	1.4	0.46	0.42	0.45	0.69	0.27	0.21	0.37	0.31	0.19	0.11	0.12	0.3	0.06	0.25	0.07	0.08	0.3
1999	0.92	0.56	0.58	1.24	0.41	0.37	0.39	0.6	0.23	0.18	0.31	0.26	0.16	0.09	0.1	0.25	0.05	0.2	0.06	0.31
2000	1.4	0.82	0.5	0.52	1.1	0.36	0.33	0.35	0.53	0.2	0.15	0.26	0.22	0.13	0.08	0.09	0.21	0.04	0.17	0.31
2001	0.69	1.25	0.72	0.44	0.46	0.98	0.32	0.29	0.3	0.45	0.17	0.13	0.22	0.19	0.11	0.07	0.07	0.17	0.03	0.41
2002	0.92	0.61	1.1	0.64	0.39	0.4	0.86	0.28	0.25	0.26	0.38	0.14	0.11	0.19	0.16	0.09	0.06	0.06	0.15	0.37
2003	0.81	0.82	0.55	0.98	0.57	0.34	0.36	0.76	0.24	0.22	0.22	0.32	0.12	0.09	0.16	0.13	0.08	0.05	0.05	0.44
2004	0.67	0.72	0.72	0.48	0.87	0.5	0.3	0.31	0.66	0.21	0.18	0.19	0.27	0.1	0.08	0.13	0.11	0.07	0.04	0.41
2005	0.68	0.59	0.64	0.64	0.43	0.77	0.45	0.27	0.27	0.57	0.18	0.16	0.16	0.23	0.09	0.07	0.11	0.09	0.06	0.38
2006	0.94	0.6	0.52	0.56	0.57	0.38	0.68	0.39	0.23	0.23	0.47	0.15	0.13	0.13	0.19	0.07	0.05	0.09	0.08	0.37
2007	1.03	0.83	0.53	0.46	0.5	0.5	0.34	0.6	0.34	0.2	0.19	0.39	0.12	0.11	0.11	0.16	0.06	0.05	0.08	0.37
2008	1.04	0.91	0.74	0.47	0.41	0.44	0.44	0.29	0.51	0.28	0.16	0.16	0.32	0.1	0.09	0.09	0.13	0.05	0.04	0.36

Table 4.18. Model estimates of yellowfin sole age 5 recruitment (millions) from the 2007 and 2008 stock assessments. Average from the 2008 assessment is 1,484 million.

Year class	2007 Assessment	2008 Assessment
1959	1,086	1,046
1960	630	604
1961	1,106	1,138
1962	564	568
1963	522	519
1964	720	717
1965	754	726
1966	1,580	1,412
1967	2,445	2,122
1968	2,099	2,110
1969	2,763	2,735
1970	3,074	3,092
1971	2,488	2,458
1972	1,802	1,726
1973	2,484	2,373
1974	2,897	2,851
1975	2,027	1,899
1976	2,383	2,380
1977	1,561	1,546
1978	1,010	983
1979	1,924	1,881
1980	1,356	1,370
1981	3,705	3,907
1982	639	720
1983	3,063	3,185
1984	1,011	1,095
1985	837	842
1986	1,137	1,151
1987	1,548	1,567
1988	1,501	1,534
1989	657	735
1990	749	785
1991	1,726	1,766
1992	939	1,007
1993	807	846
1994	780	818
1995	2,164	2,202
1996	839	914
1997	827	778
1998	1,290	1,139
1999	1,909	1,737
2000	1,181	857
2001	1,815	1,137
2002	2,629	1,001
2003	1,290	824

Table 4.19. 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
2008	637.707	112.00	0.08
2009	613.811	**133.96**	0.10
2010	584.648	127.18	0.10
2011	559.647	121.07	0.10
2012	533.644	115.11	0.10
2013	506.798	106.95	0.10
2014	485.331	99.86	0.10
2015	475.614	97.79	0.09
2016	470.826	97.47	0.09
2017	471.777	98.89	0.09
2018	479.237	102.39	0.10
2019	489.468	106.43	0.10
2020	497.377	109.45	0.10
2021	505.193	112.27	0.10

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2008	637.707	112.00	0.08
2009	624.397	67.00	0.05
2010	624.872	67.34	0.05
2011	626.86	66.91	0.05
2012	624.618	66.14	0.05
2013	616.871	65.42	0.05
2014	609.248	65.39	0.05
2015	610.331	66.42	0.05
2016	612.837	67.63	0.05
2017	619.382	69.11	0.05
2018	633.331	70.95	0.05
2019	651.345	72.84	0.05
2020	666.288	74.35	0.05
2021	681.799	75.75	0.05

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2008	637.707	112.00	0.08
2009	620.64	91.00	0.07
2010	611.469	82.47	0.06
2011	606.515	81.11	0.06
2012	597.991	79.43	0.06
2013	584.918	77.95	0.06
2014	572.828	77.41	0.06
2015	569.761	78.23	0.06
2016	568.947	79.36	0.06
2017	572.654	80.86	0.06
2018	583.628	82.80	0.06
2019	598.547	84.82	0.06
2020	610.949	86.40	0.06
2021	623.893	87.87	0.06

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2008	637.707	112.00	0.08
2009	634.675	0	0
2010	666.152	0	0
2011	699.795	0	0
2012	728.43	0	0
2013	749.17	0	0
2014	767.525	0	0
2015	794.045	0	0
2016	818.798	0	0
2017	845.542	0	0
2018	880.487	0	0
2019	920.248	0	0
2020	954.048	0	0
2021	988.543	0	0

Table 4.19—continued.

Scenario 6
Determination of whether yellowfin sole are currently overfished **B35=456.400**

Year	Female spawning biomass	catch	F
2008	637.707	112.00	0.08
2009	609.866	158.39	0.12
2010	570.136	147.77	0.12
2011	536.136	138.43	0.12
2012	503.558	125.24	0.12
2013	473.789	111.79	0.11
2014	451.667	103.72	0.11
2015	441.712	101.52	0.10
2016	437.281	101.64	0.10
2017	438.708	103.99	0.10
2018	446.231	108.48	0.11
2019	456.083	113.42	0.11
2020	463.497	116.88	0.11
2021	470.329	119.70	0.11

Scenario 7
Determination of whether the stock is approaching an overfished condition **B35=456.400**

Year	Female spawning biomass	catch	F
2008	637.707	112.00	0.08
2009	613.811	133.96	0.10
2010	584.647	127.18	0.10
2011	556.041	143.15	0.12
2012	520.409	133.43	0.12
2013	486.533	117.53	0.12
2014	461.168	107.77	0.11
2015	448.755	104.44	0.11
2016	442.317	103.70	0.10
2017	442.179	105.40	0.10
2018	448.564	109.43	0.11
2019	457.606	114.03	0.11
2020	464.423	117.24	0.11
2021	470.855	119.89	0.11

Table 4-20. Yellowfin catch and bycatch (t) from 1992-2007 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	2006	2007
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	6,084	4,041
Arrowtooth Flounder	366	1,017	1,595	346	820	386	2,382	1,627	1,998	1,845	998	1,125	279	645	352	216
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	2,588	2,529
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	2,333	4003
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	8,113	8,218
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	2,039	1,744
Sablefish	0	0		0	0	0	0	4	0	0				1		
Atka Mackerel	1	0			0	0	1	33	0	0	0	17		110	17	
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	877	2,852
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	84,178	108,254
English Sole		1									1					
Unsp.demersal rockfish						12	0									
Greenland Turbot	1	5	5	67	8	4	103	70	24	32	2		1	7	8	1
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	14,043	16,389
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	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					

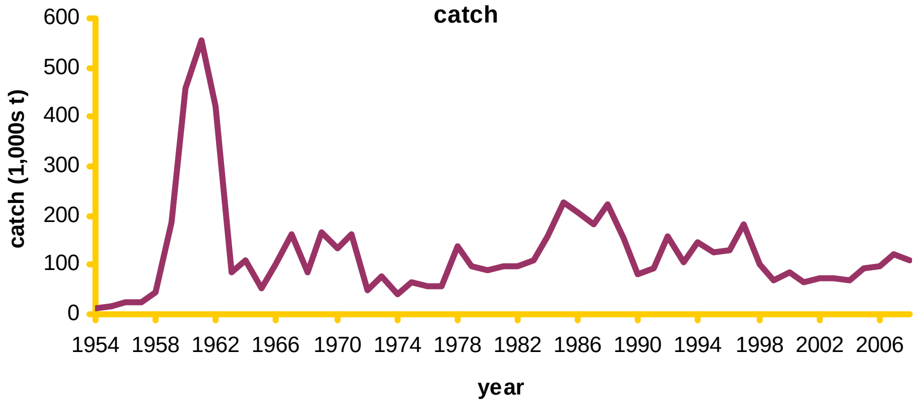


Figure 4.1—Yellowfin sole catch (1,000s t) in the Eastern Bering Sea from 1954-2008.

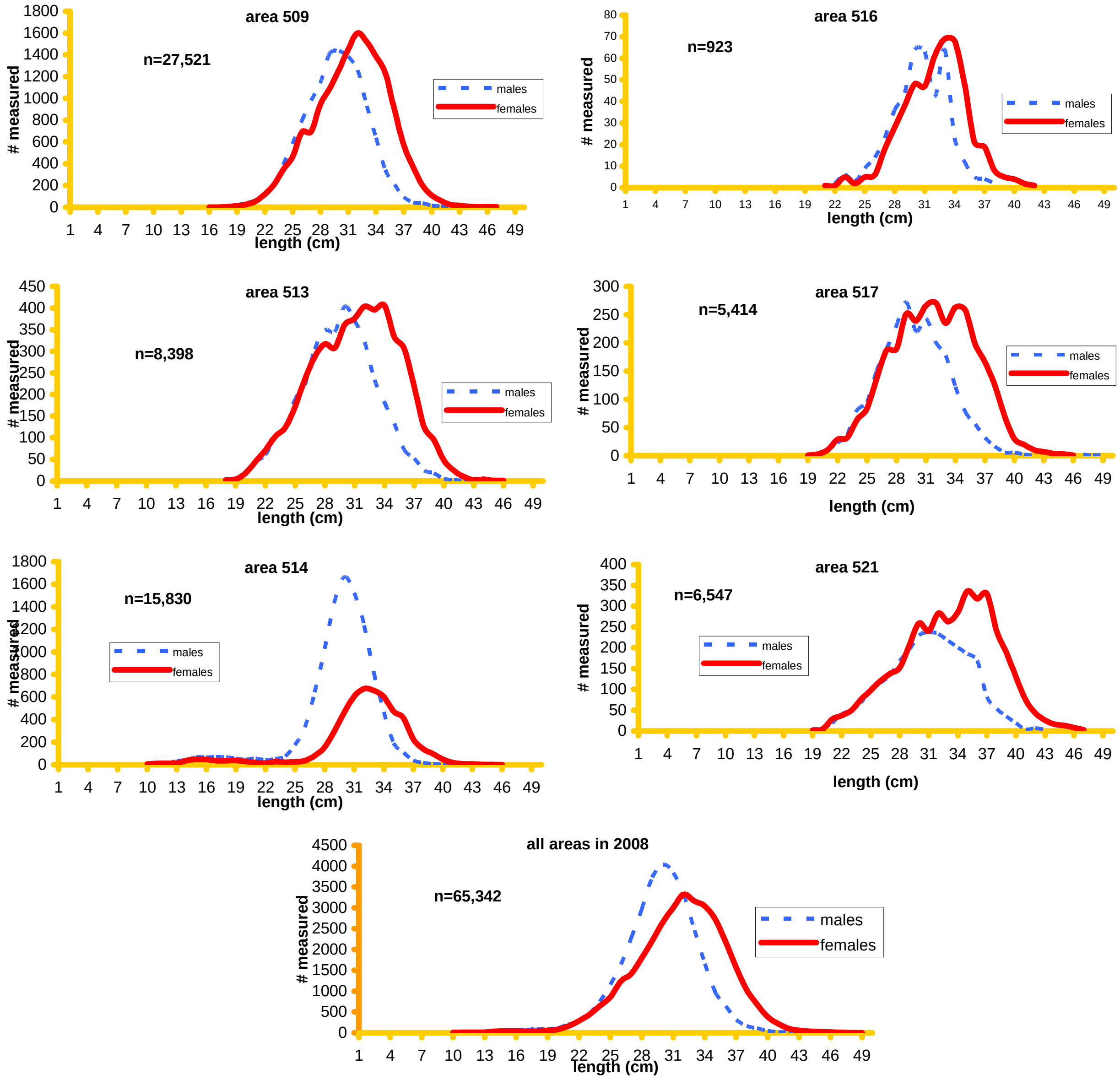
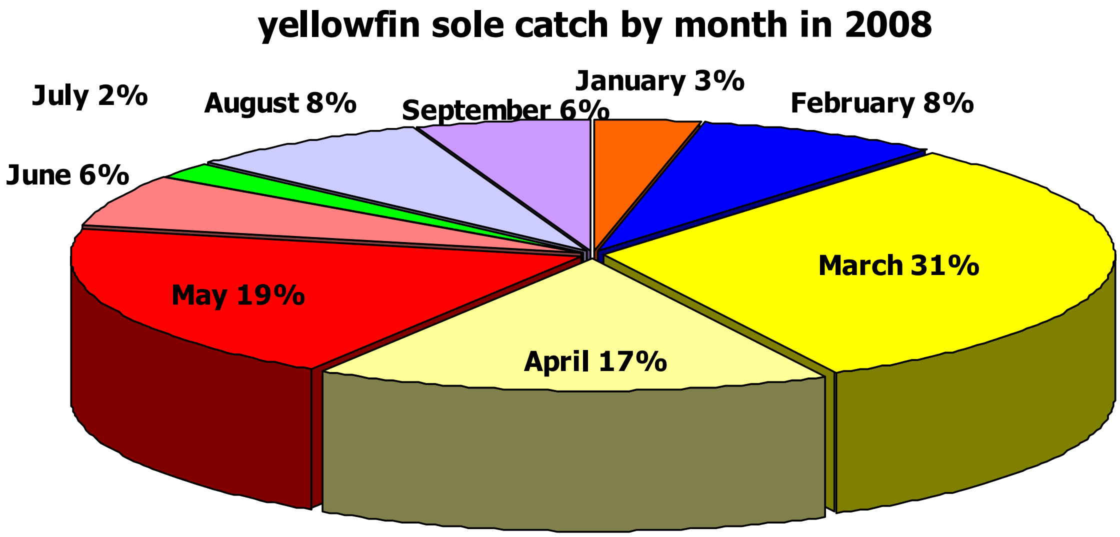


Figure 4.2—Size composition of the yellowfin sole catch in 2008, by subarea and total.



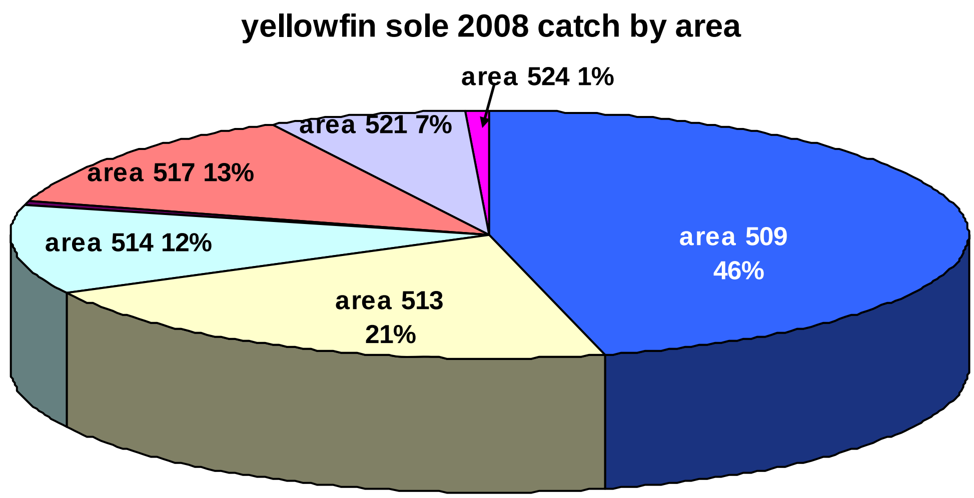


Figure 4.3—Yellowfin sole catch by month and area in the Eastern Bering Sea in 2008.

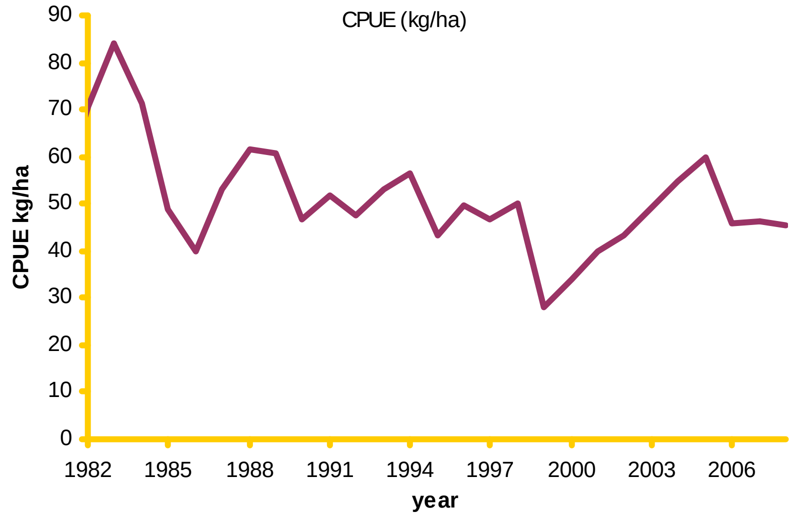


Figure 4.4. Yellowfn sole CPUE (catch per unit effort in kg/ha) from the annual Bering Sea shelf trawl surveys, 1982-2008.

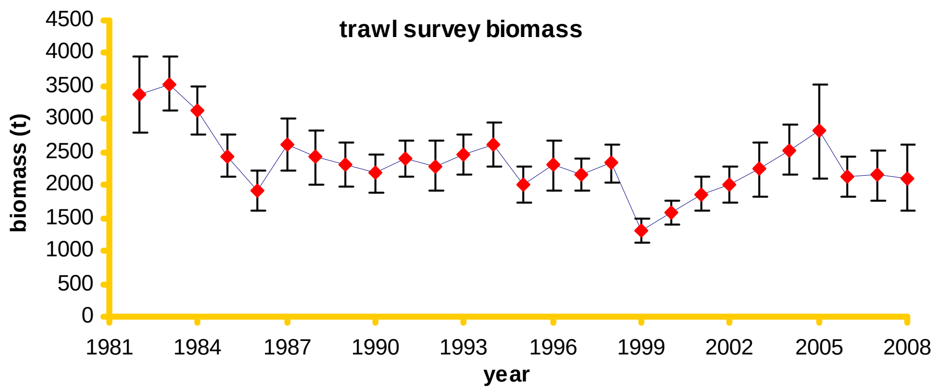


Figure 4.5. Annual bottom trawl survey biomass point-estimates and 95% confidence intervals for yellowfin sole, 1982-2008.

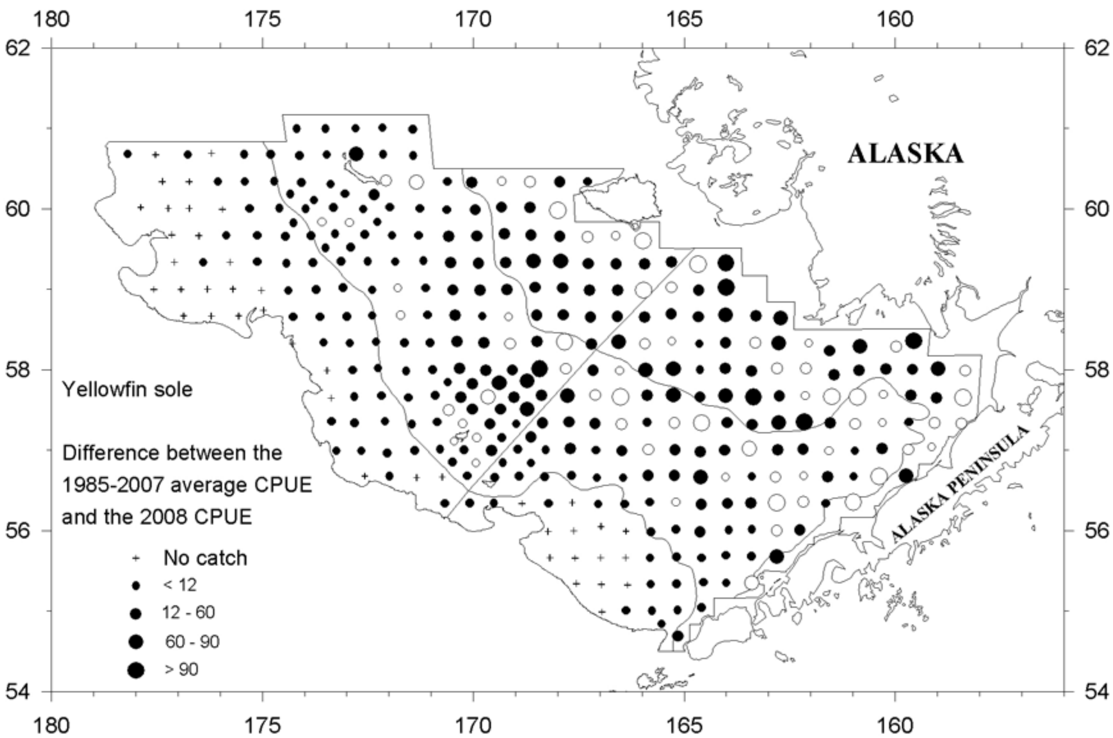


Figure 4.6. Difference between the 1985-2007 average trawl survey CPUE for yellowfin sole and the 2008 survey CPUE. Open circles indicate that the magnitude of the catch was greater in 2008 than the long-term average, closed circles indicate the catch was greater in the long-term average than in 2008.

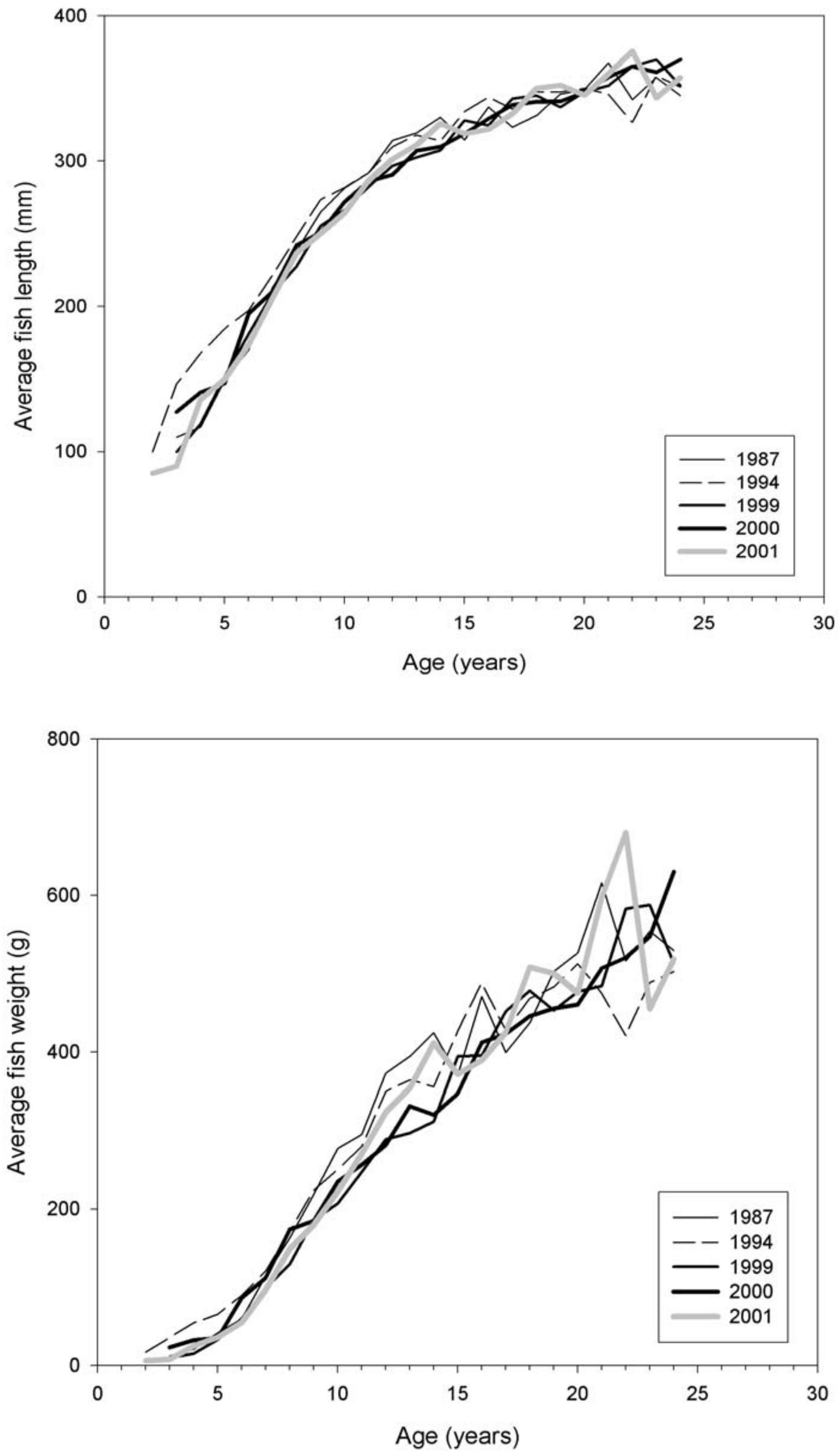


Figure 4.7. Comparison of yellowfin sole length at age (top panel) and weight at age (bottom panel) from biological samples collected in 1987, 1994, 1999, 2000 and 2001.

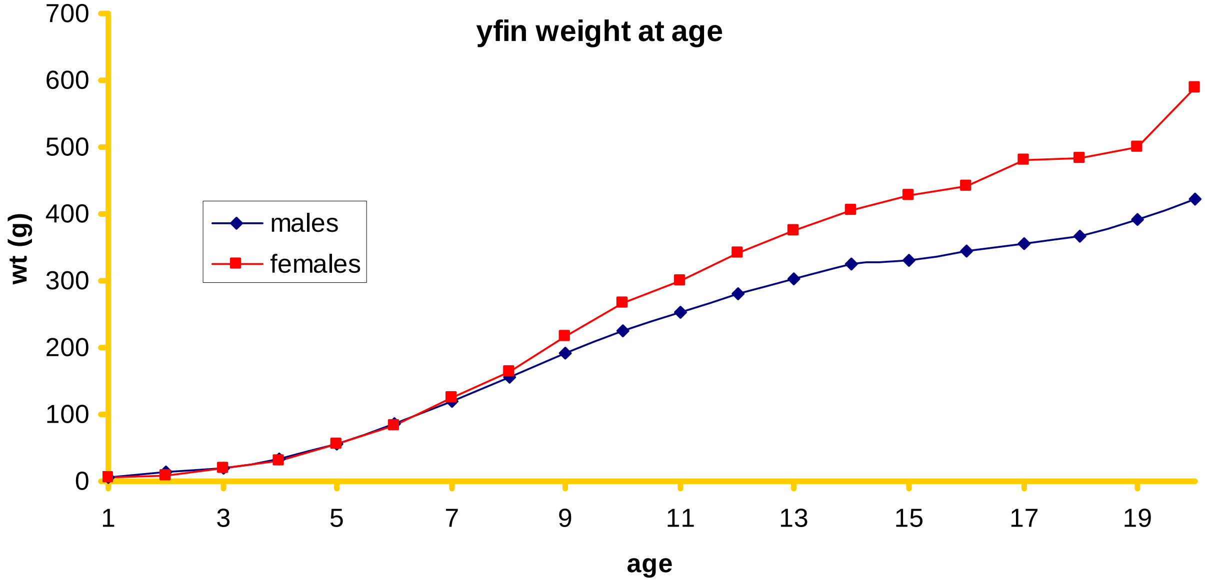


Figure 4.8--Estimates of yellowfin sole weight-at-age (g) from trawl survey observations.

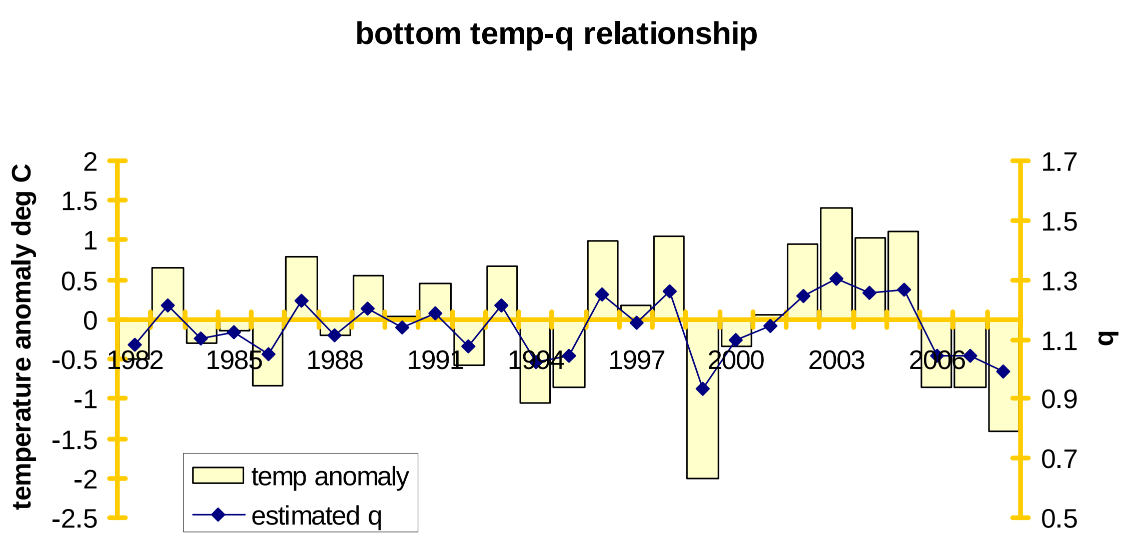


Figure 4.9.--Average bottom water temperature from stations less than or equal to 100 m in the Bering Sea trawl survey and the stock assessment model estimate of q for each year 1982-2008.

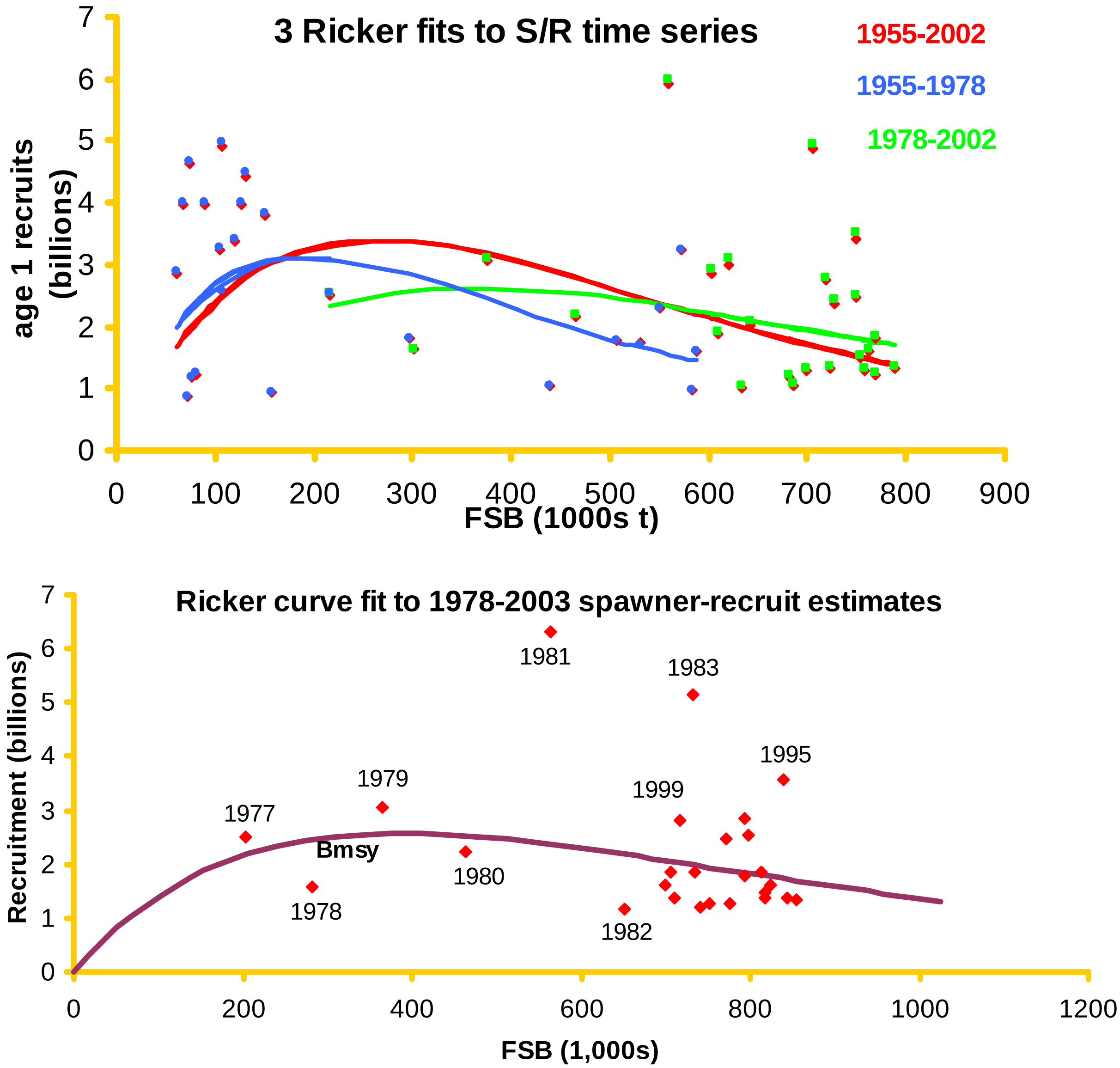


Figure 4.10--Fit of the Ricker (1958) stock recruitment model to three distinct stock recruitment time-series data sets (top panel), and the fit to the assessment preferred model (model 2, lower panel).

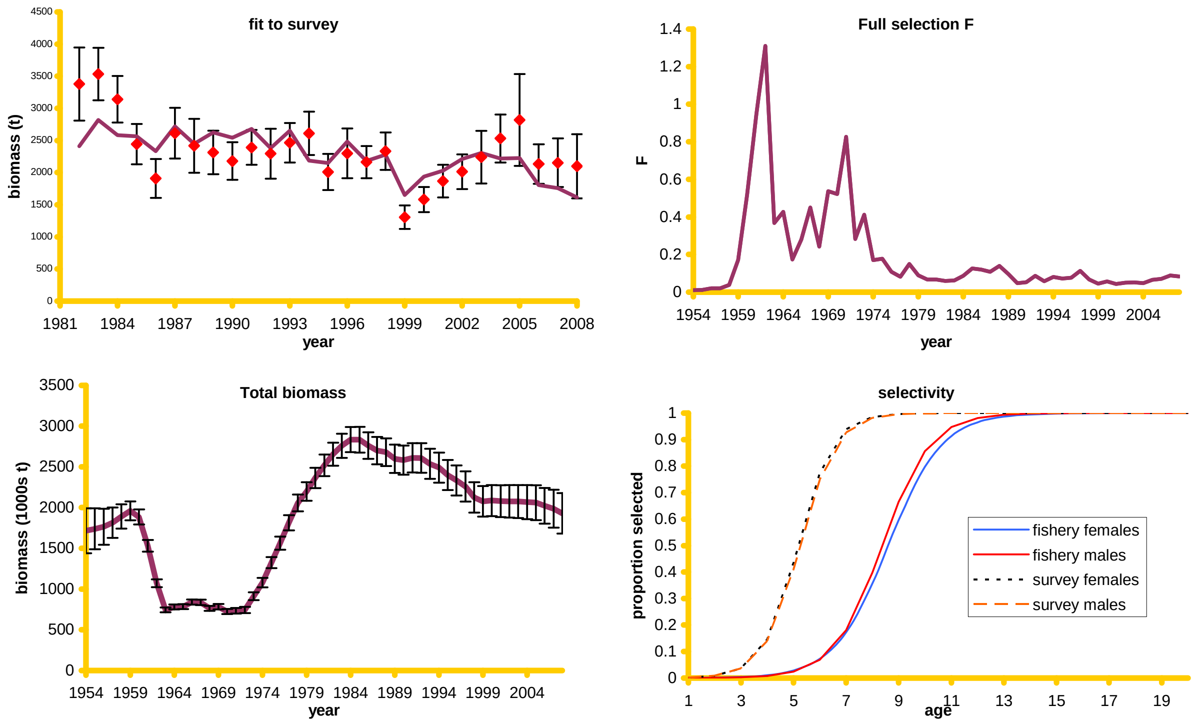


Figure 4.11. Model fit to the survey biomass estimates (top left panel), model estimate of the full selection fishing mortality rate throughout the time-series (top right panel), model estimate of total biomass (bottom left panel) and the model estimate of fishery and survey selectivity (bottom right panel).

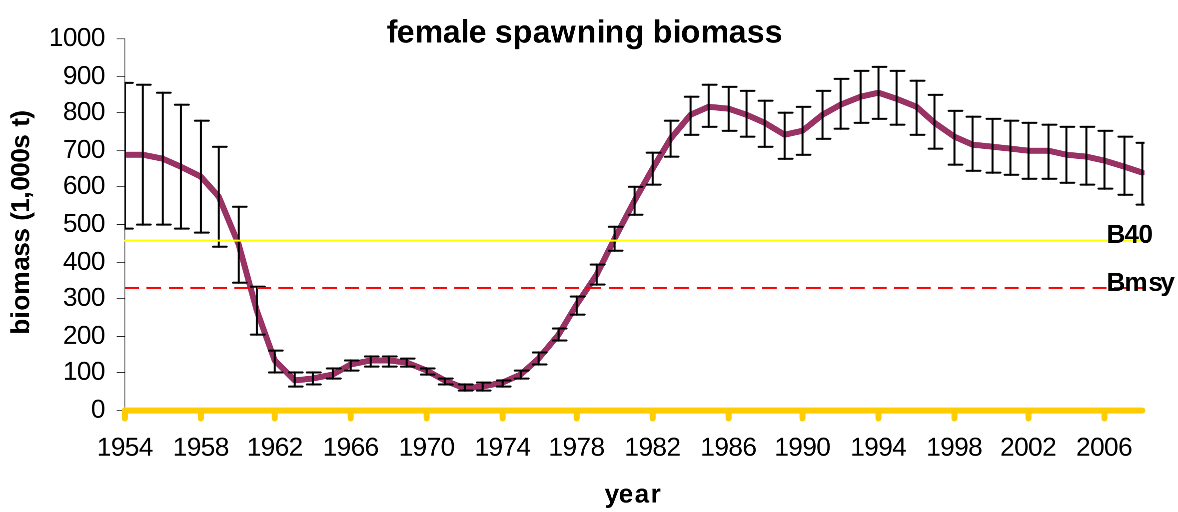


Figure 4.12--Model estimate of yellowfin sole female spawning biomass from 1955-2008 with B40 and Bmsy levels indicated.

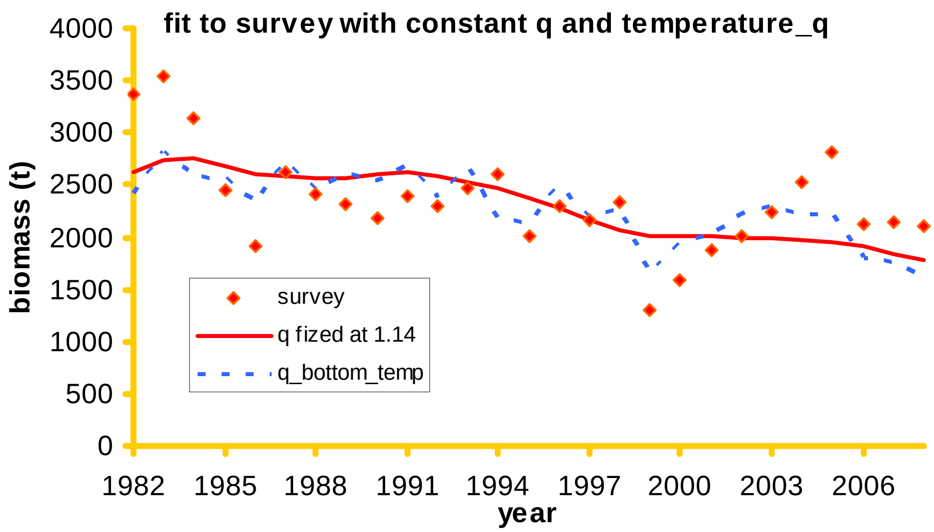


Figure 4.13--Comparison of the fit to the survey biomass using a fixed q and the q-bottom temperature relationship.

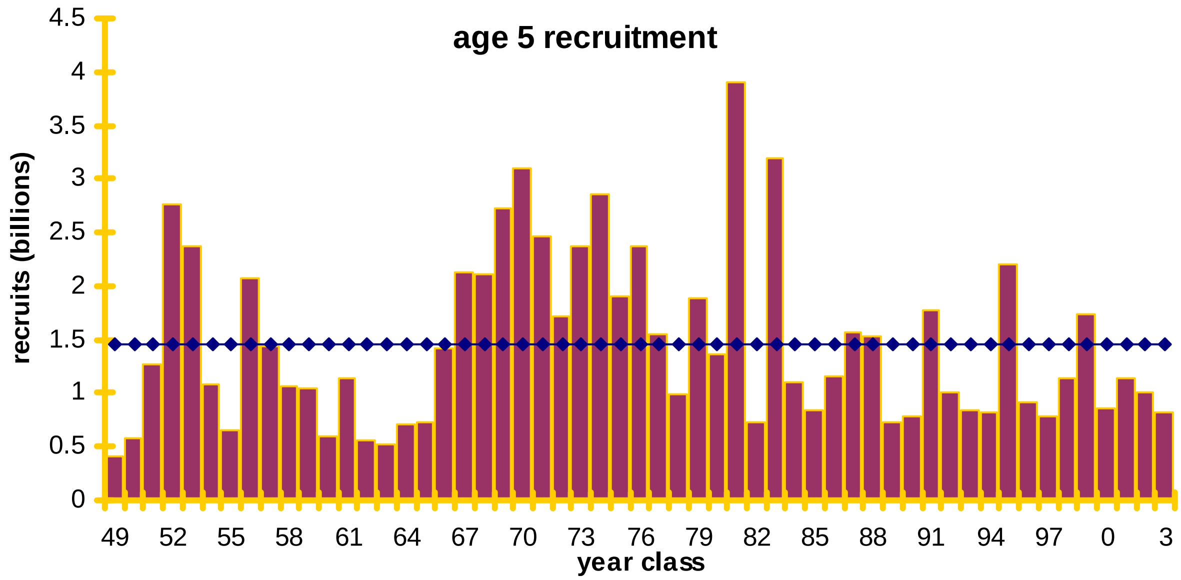


Figure 4.14 Year class strength of age 5 yellowfin sole estimated by the stock assessment model. The dotted line is the average of the estimates from 55 years of recruitment.

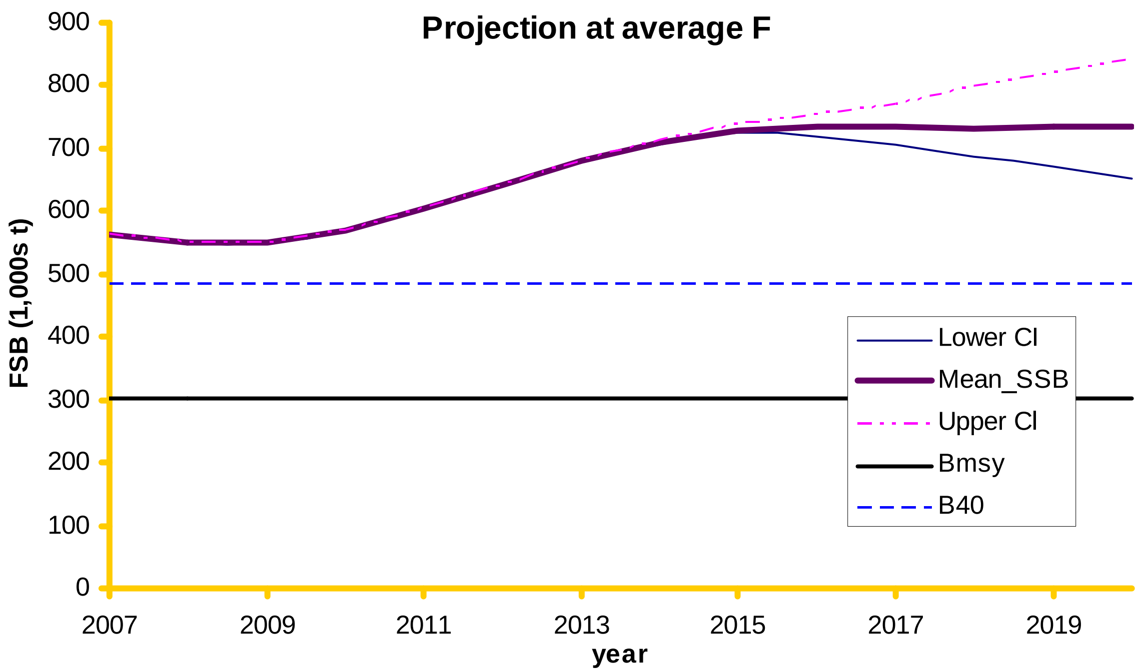
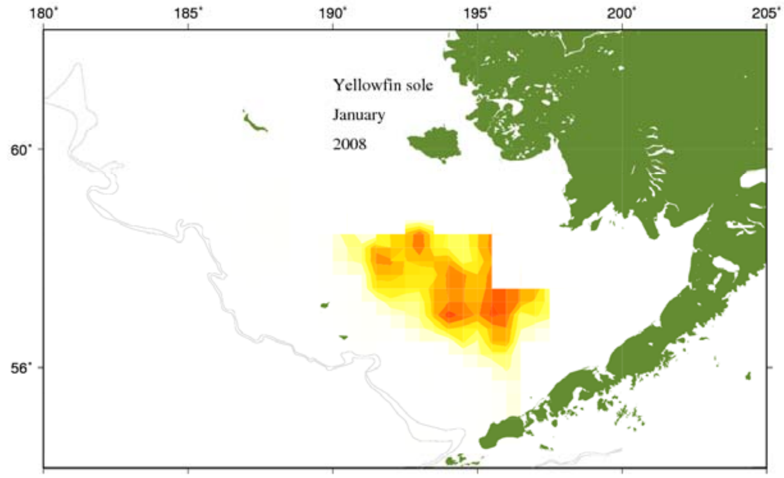


Figure 4.15. Projection of yellowfin sole female spawning biomass (1,000s t) at the average F from the past 5 years (0.055) through 2019 with $B_{40\%}$ and $B_{35\%}$ levels indicated.

Appendix

List of figures and tables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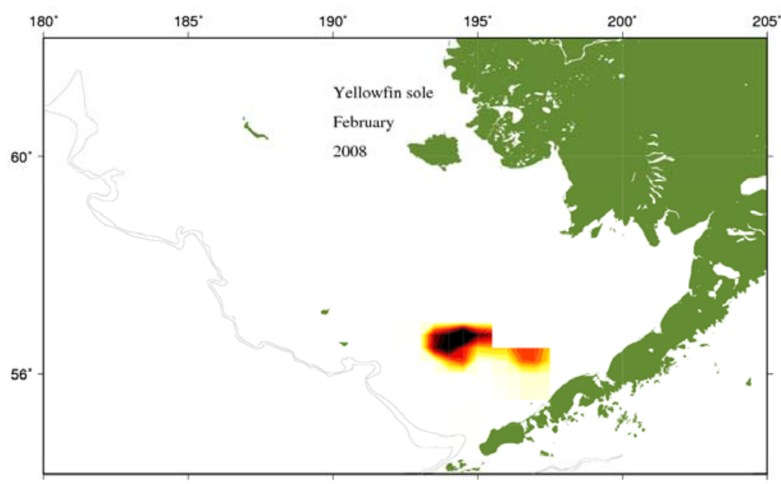
56°
Yellowfin sole
January
2008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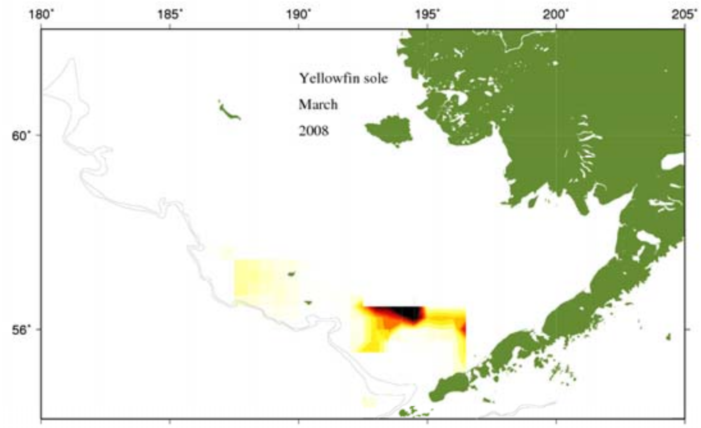
Yellowfin sole
February
2008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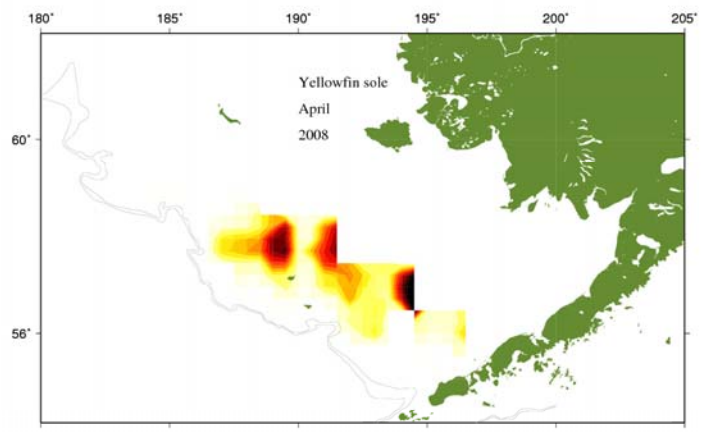
Yellowfin sole
March
2008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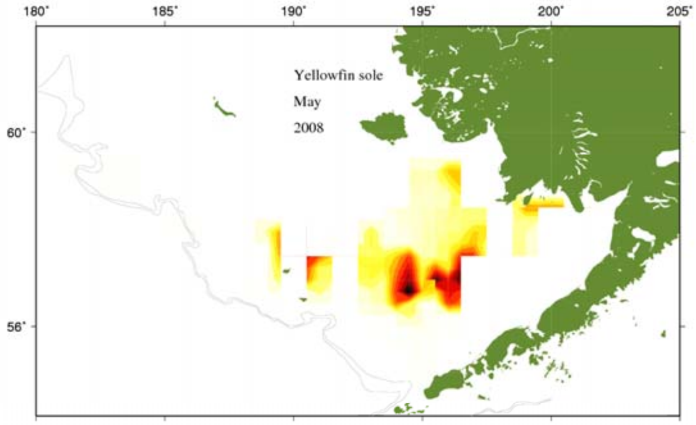
Yellowfin sole
April
2008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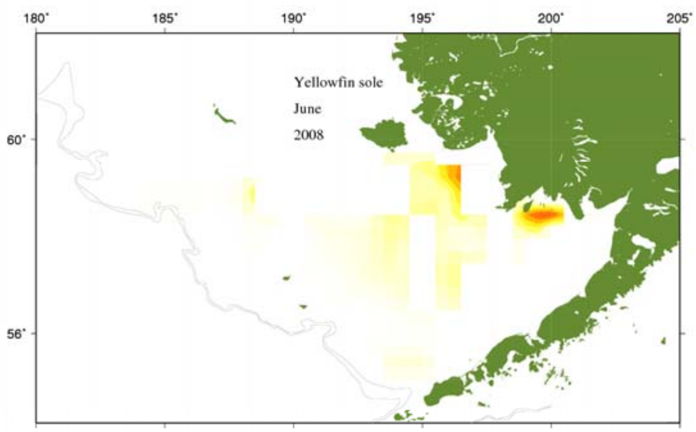
Yellowfin sole
May
2008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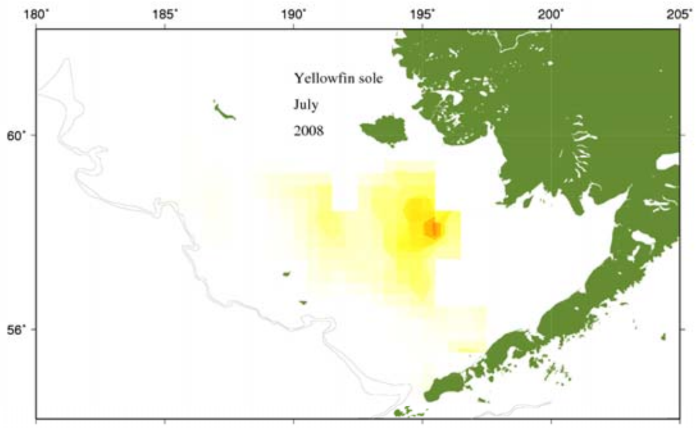
Yellowfin sole
June
2008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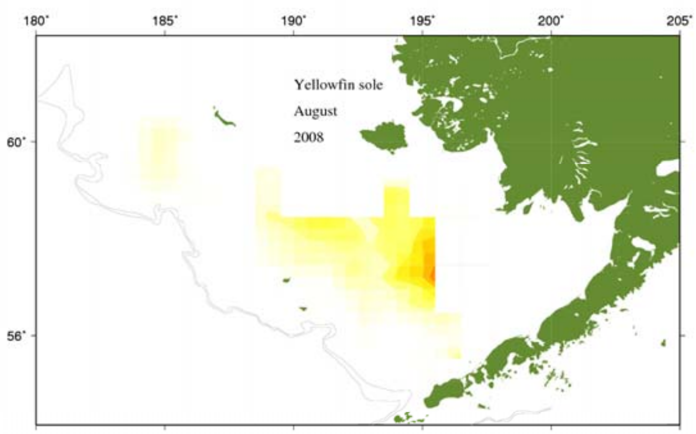
Yellowfin sole
July
2008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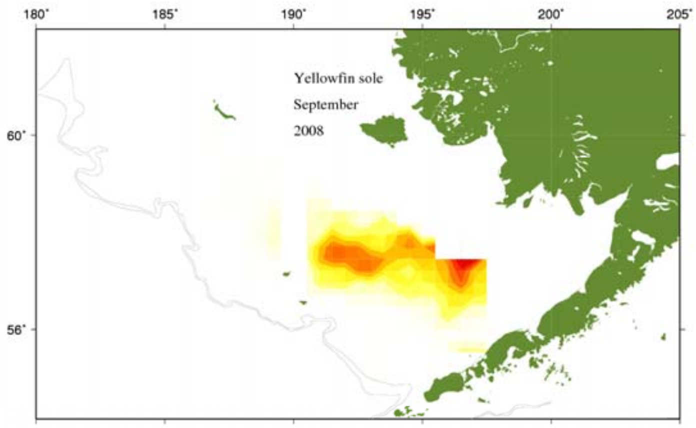
Yellowfin sole
August
2008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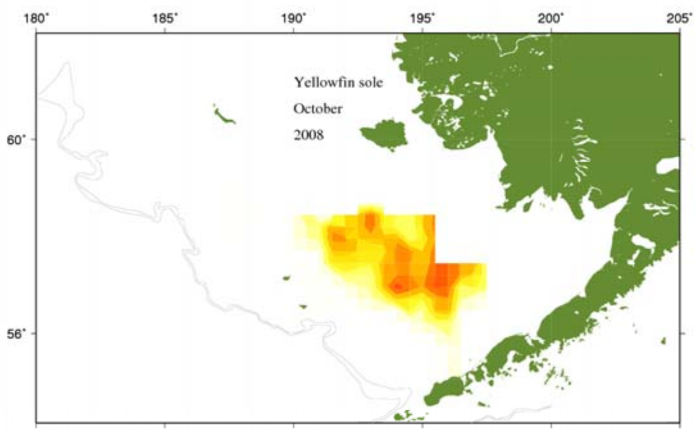
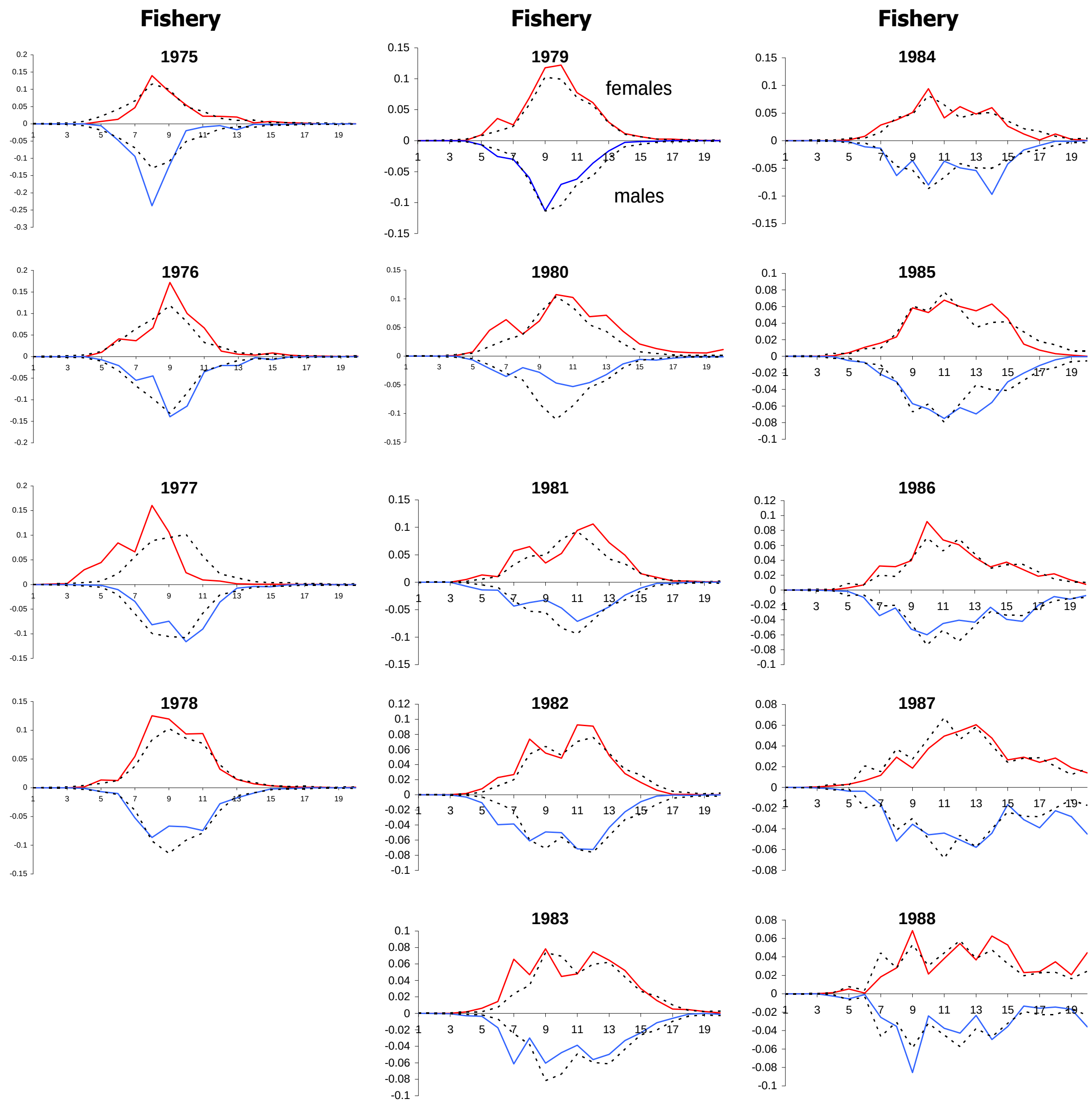
Yellowfin sole
September
2008
60°
56°


180° 185° 190° 195° 200° 205°
Yellowfin sole
October
2008
60°
56°


Fishery
Fishery
Fishery
1975
1979
1984
females
males
1976
1980
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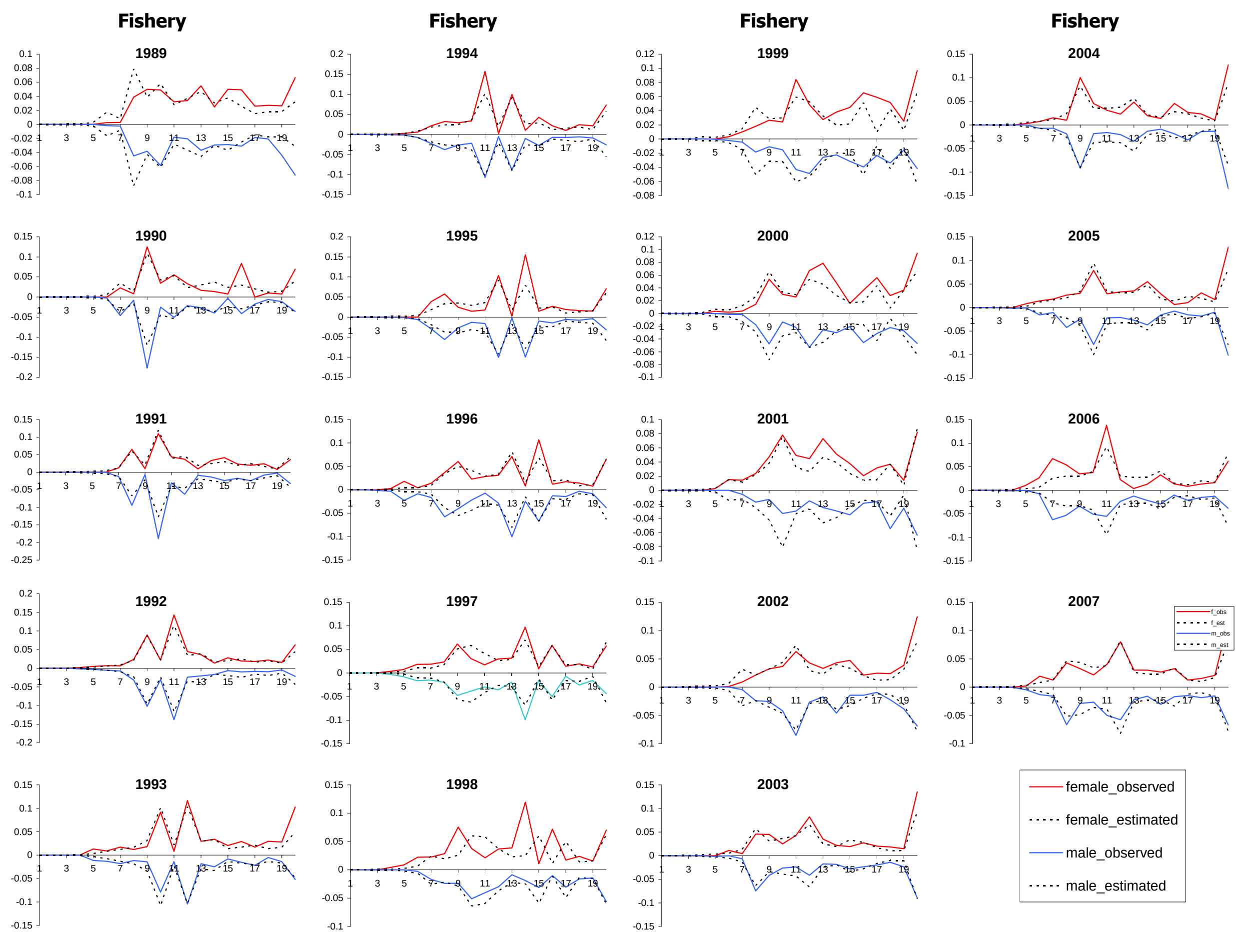
1983
1988


Fishery
Fishery
Fishery
Fishery
1989
1994
1999
2004
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2007
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1998
2003
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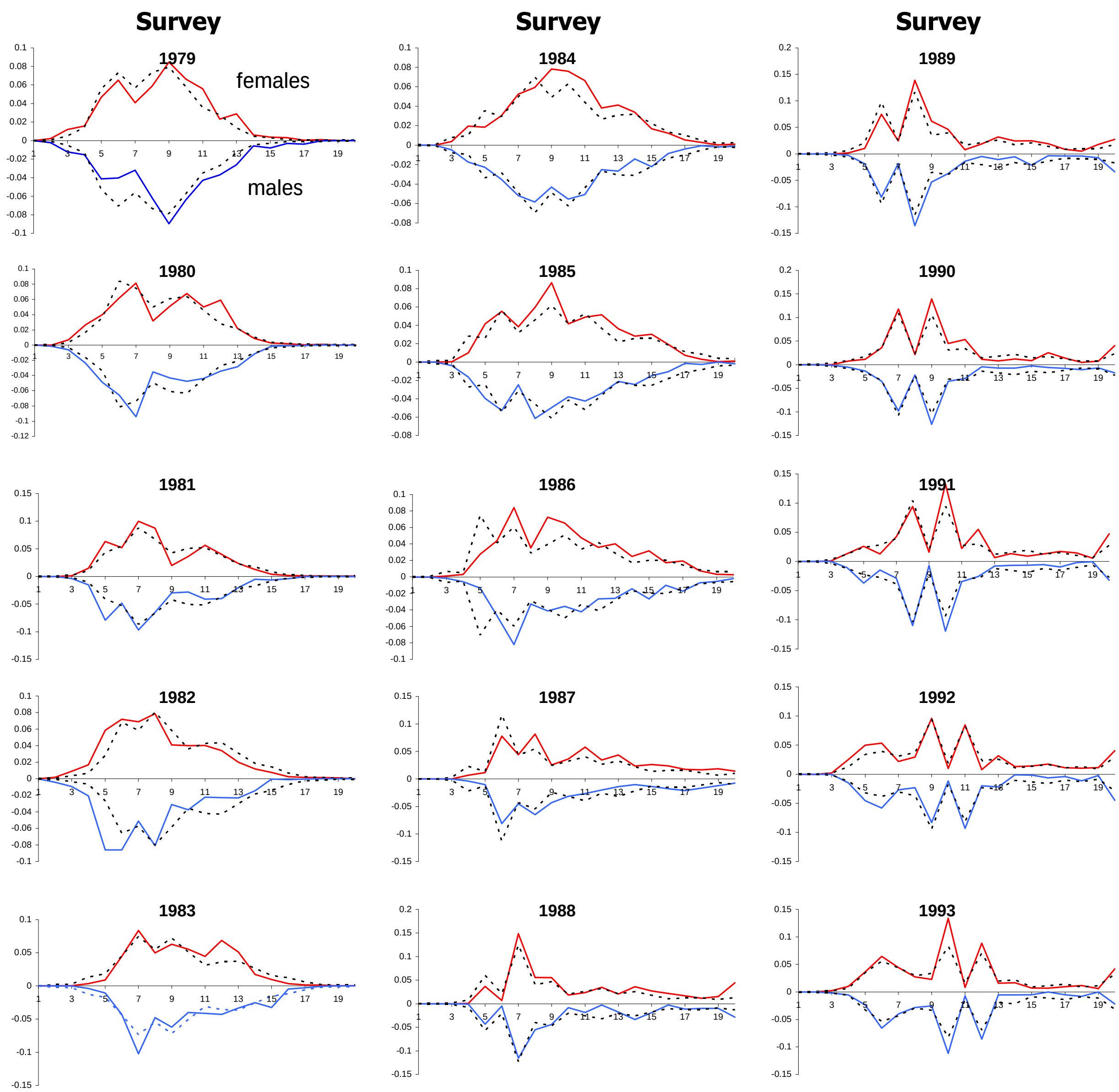
female_estimated
male_observed
male_estimated


Survey
Survey
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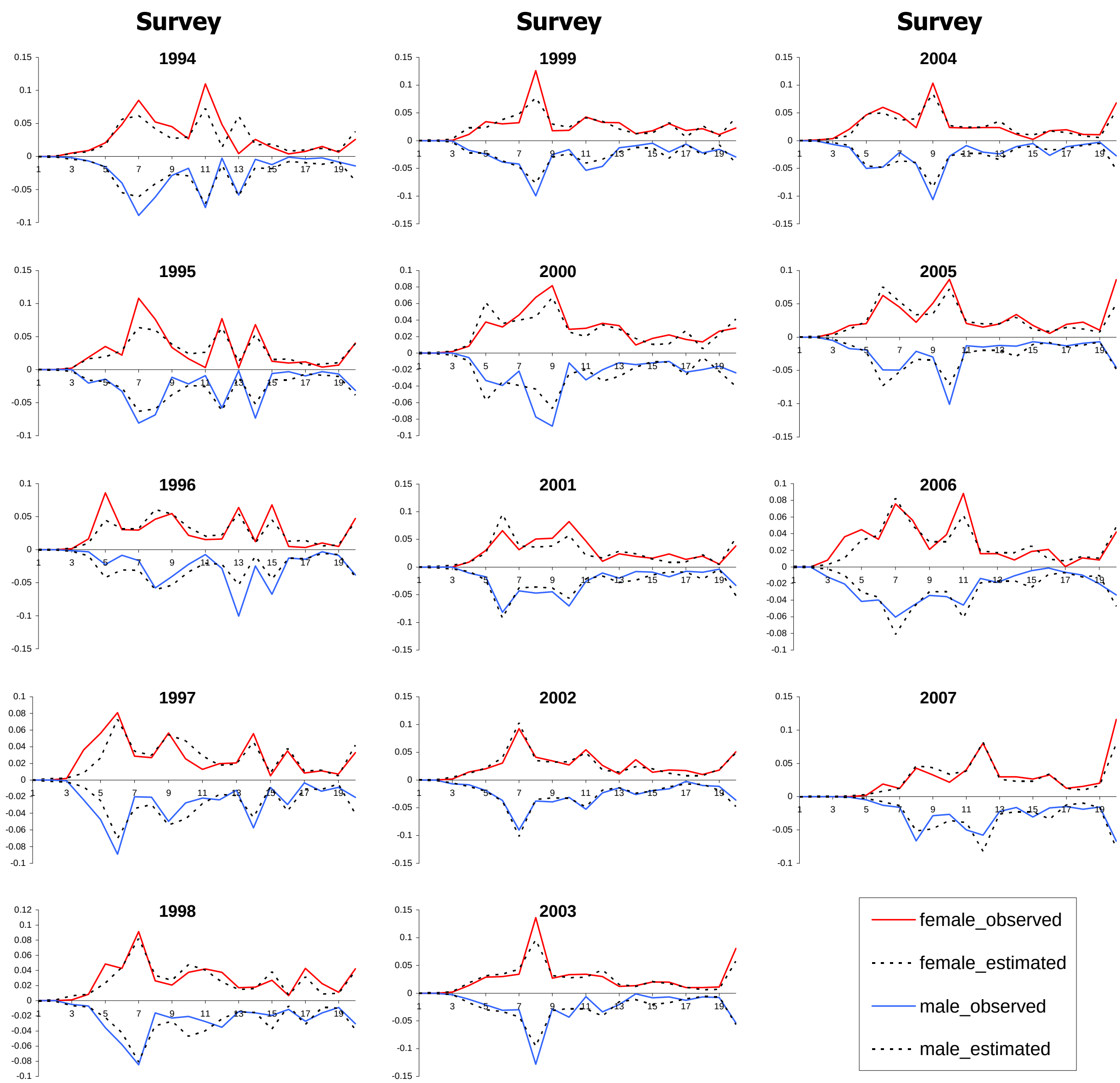
Survey
Survey
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1994
1999
2004
1995
2000
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1996
2001
2006
1997
2002
2007
1998
2003
female_observed
female_estimated
male_observed
male_estimated

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
2007	74
2008	69

Model estimates of yellowfin sole female spawners (millions) from 1954-2008.

year/age	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	1.7	2.2	8.3	18.4	37.7	67.3	103.5	133.4	151.5	160.5	164.5	166.1	166.8	167.2	167.2	167.2
1955	2.4	2.2	7.7	16.5	34.0	60.8	91.3	117.5	133.4	141.4	144.8	146.1	146.7	147.0	146.9	293.7
1956	5.7	3.1	7.6	15.2	30.5	54.7	82.4	103.5	117.3	124.3	127.4	128.4	128.7	129.0	128.9	386.3
1957	14.1	7.2	10.5	15.0	27.9	48.9	73.7	92.7	102.5	108.4	111.0	112.0	112.2	112.3	112.1	448.0
1958	9.9	17.8	24.6	20.9	27.5	44.8	65.8	82.9	91.8	94.7	96.8	97.6	97.8	97.8	97.6	486.9
1959	4.6	12.6	60.9	48.6	38.1	43.7	59.5	72.8	80.6	83.3	83.0	83.6	83.8	83.8	83.5	499.1
1960	2.7	5.8	42.5	117.6	84.5	55.9	52.2	58.2	62.3	64.2	64.0	62.8	62.8	62.8	62.6	435.6
1961	8.7	3.4	19.0	77.3	180.9	100.8	50.6	37.2	35.7	35.2	34.9	34.2	33.4	33.3	33.2	263.2
1962	6.0	10.7	10.8	32.1	102.0	166.9	64.8	24.4	15.1	13.2	12.5	12.2	11.8	11.5	11.5	102.0
1963	4.5	7.4	33.4	17.2	37.2	75.7	80.3	22.4	6.9	3.9	3.3	3.0	2.9	2.8	2.8	27.1
1964	4.4	5.6	24.6	62.5	27.8	48.5	77.3	65.7	15.9	4.6	2.5	2.0	1.9	1.8	1.7	18.4
1965	2.5	5.5	18.6	45.4	99.3	35.0	47.2	59.9	43.9	9.8	2.7	1.4	1.2	1.1	1.0	11.6
1966	4.8	3.2	18.5	36.0	79.0	145.3	41.7	46.1	51.1	34.9	7.5	2.0	1.1	0.9	0.8	9.5
1967	2.4	6.0	10.7	35.2	60.3	108.5	158.9	37.0	35.5	36.5	24.0	5.1	1.4	0.7	0.6	6.9
1968	2.2	3.0	19.9	19.7	55.4	74.8	103.7	120.7	24.2	21.5	21.3	13.8	2.9	0.8	0.4	4.2
1969	3.0	2.7	10.0	38.0	33.5	77.8	84.4	95.2	96.4	17.9	15.4	15.0	9.6	2.0	0.5	3.2
1970	3.0	3.8	9.0	18.2	58.0	39.4	69.4	59.2	57.2	53.5	9.6	8.1	7.8	5.0	1.0	2.0
1971	5.9	3.8	12.4	16.4	28.0	69.0	35.6	49.4	36.1	32.2	29.0	5.1	4.3	4.1	2.6	1.6
1972	8.9	7.3	12.3	21.4	22.6	27.7	48.8	19.2	22.4	15.0	12.9	11.4	2.0	1.7	1.6	1.6
1973	8.9	11.2	24.6	23.2	35.7	31.0	30.3	43.2	14.7	16.0	10.3	8.7	7.7	1.3	1.1	2.2
1974	11.5	11.1	37.2	45.6	37.1	45.4	30.5	23.8	29.3	9.2	9.7	6.2	5.2	4.5	0.8	1.9
1975	13.0	14.5	37.5	71.8	79.3	54.4	54.2	29.9	20.4	23.3	7.1	7.3	4.6	3.9	3.4	2.0
1976	10.3	16.4	48.9	72.3	124.6	115.8	64.6	52.7	25.4	16.1	17.8	5.3	5.5	3.4	2.9	4.0
1977	7.2	13.0	55.5	95.5	128.7	189.7	145.3	66.9	47.9	21.5	13.2	14.3	4.3	4.4	2.7	5.5
1978	10.0	9.2	44.3	109.0	171.6	199.0	243.1	154.4	62.5	41.7	18.1	10.9	11.8	3.5	3.6	6.7
1979	12.0	12.6	31.0	86.0	191.1	254.7	241.5	242.7	134.8	50.7	32.7	14.0	8.4	9.0	2.7	7.8

Model estimates of yellowfin sole female spawners (millions) from 1954-2008 (continued).

year/age	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	8.0	15.1	42.7	60.8	154.0	294.2	324.4	254.9	224.8	116.3	42.3	26.8	11.4	6.8	7.3	8.5
1981	10.0	10.1	51.5	84.1	109.7	240.3	381.3	349.3	241.1	198.1	99.1	35.5	22.4	9.5	5.6	13.1
1982	6.5	12.6	34.3	101.4	151.9	171.3	311.7	411.0	330.7	212.7	169.0	83.2	29.6	18.6	7.9	15.6
1983	4.1	8.2	43.1	67.7	183.6	238.1	223.5	338.2	391.9	294.0	182.8	142.9	69.9	24.8	15.6	19.6
1984	7.9	5.2	28.0	84.8	122.4	287.3	310.0	241.9	321.6	347.4	251.9	154.1	119.8	58.5	20.7	29.3
1985	5.8	10.0	17.7	54.9	152.1	188.7	366.5	327.8	224.4	278.0	290.2	207.0	125.9	97.6	47.5	40.6
1986	16.4	7.3	33.9	34.6	97.0	229.0	233.4	374.1	292.9	186.7	223.4	229.5	162.7	98.7	76.3	68.9
1987	3.0	20.7	24.6	66.0	61.3	146.6	284.6	239.5	336.2	245.1	150.9	177.7	181.4	128.3	77.6	114.2
1988	13.4	3.8	70.3	48.1	117.4	93.2	183.9	295.1	217.7	284.6	200.5	121.5	142.1	144.8	102.1	152.7
1989	4.6	16.9	12.9	136.7	84.7	175.5	114.1	185.4	260.4	178.7	225.7	156.4	94.2	110.0	111.7	196.6
1990	3.5	5.8	57.4	25.3	244.3	129.9	222.3	119.7	170.6	223.2	148.0	183.9	126.7	76.1	88.6	248.4
1991	4.8	4.5	19.8	113.2	46.0	385.5	171.0	243.7	115.4	153.4	193.9	126.6	156.3	107.5	64.4	285.0
1992	6.6	6.1	15.3	39.1	205.5	72.4	505.4	186.6	233.7	103.2	132.5	164.9	107.0	131.9	90.4	293.8
1993	6.4	8.3	20.8	29.9	70.1	316.8	92.4	534.6	173.1	202.1	86.2	109.0	134.8	87.2	107.2	312.4
1994	3.1	8.1	28.3	41.0	54.2	109.9	413.7	100.4	510.2	154.0	173.8	72.9	91.7	113.1	73.0	351.1
1995	3.3	3.9	27.7	55.6	73.6	83.9	141.0	440.1	93.7	443.9	129.5	143.8	60.0	75.2	92.6	347.1
1996	7.4	4.2	13.3	54.5	100.3	114.5	108.3	151.2	414.3	82.2	376.4	108.1	119.3	49.7	62.1	362.8
1997	4.2	9.4	14.2	26.1	98.1	155.5	147.3	115.6	141.6	361.7	69.4	312.6	89.2	98.2	40.8	348.8
1998	3.6	5.3	31.8	27.7	46.3	148.8	194.3	152.1	104.6	119.4	294.5	55.6	248.8	70.9	77.8	308.6
1999	3.4	4.5	18.2	62.6	50.0	72.3	193.0	209.3	143.9	92.2	101.7	247.0	46.3	207.0	58.8	320.5
2000	9.2	4.3	15.3	35.9	113.9	79.0	95.3	212.0	202.2	129.6	80.3	87.2	210.4	39.4	175.4	321.3
2001	3.8	11.7	14.8	30.2	65.1	178.8	103.2	103.6	202.5	180.0	111.5	68.0	73.4	176.7	33.0	416.1
2002	3.3	4.9	39.9	29.3	55.0	103.0	236.2	113.6	100.3	182.8	157.1	95.8	58.1	62.5	150.1	381.4
2003	4.8	4.1	16.6	78.7	53.2	86.6	135.4	258.3	109.2	89.9	158.3	134.0	81.2	49.1	52.7	448.2
2004	7.3	6.0	14.1	32.7	143.0	83.7	113.7	147.9	248.1	97.8	77.8	134.9	113.4	68.6	41.4	422.0
2005	3.6	9.2	20.6	27.8	59.4	225.7	110.2	124.6	142.6	223.0	85.0	66.5	114.7	96.2	58.0	391.8
2006	4.8	4.6	31.4	40.6	50.3	92.8	292.9	118.9	118.1	125.9	190.3	71.4	55.5	95.5	79.9	373.7
2007	4.2	6.0	15.5	61.8	73.2	78.3	120.0	314.6	112.1	103.8	107.0	159.1	59.3	46.1	79.0	375.0
2008	3.5	5.3	20.5	30.4	110.8	112.8	99.8	126.7	291.6	96.8	86.6	87.8	129.9	48.3	37.4	368.6

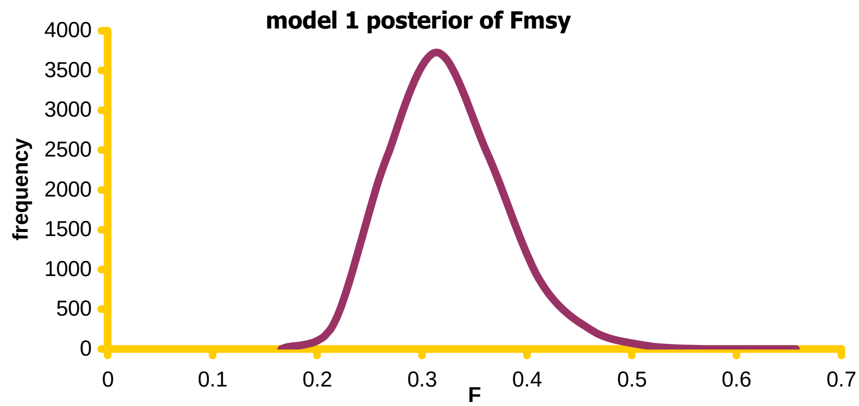
Selected parameter estimates and their standard deviation from the stock assessment model.

	parameter	value	std dev
	alpha	-0.13	0.04
	beta	0.10	0.02
	mean_log_rec	0.73	0.10
	sel_slope_fsh(female)	0.98	0.03
	sel50_fsh (female)	8.60	0.09
	sel_slope_fsh_male	0.11	0.05
	sel50_fsh_male	-0.03	0.01
	sel_slope_srv (female)	1.50	0.09
	sel50_srv (female)	5.18	0.08
	sel_slope_srv_male	-0.03	0.09
	sel50_srv_male	0.01	0.02
	F40	0.10	0.00
	F35	0.12	0.00
	F30	0.15	0.00
	Ricker SR logalpha	-4.01	0.49
	Ricker SR logbeta	-5.96	0.27
	Fmsy	0.21	0.08
	logFmsy	-1.57	0.40
	Fmsyr	0.13	0.03
	logFmsyr	-2.07	0.25
	msy	338.16	110.97
	Bmsy	328.98	52.35
1954	total biomass	1714.90	141.08
1955	total biomass	1739.30	127.26
1956	total biomass	1764.70	111.69
1957	total biomass	1814.90	93.53
1958	total biomass	1890.90	74.93
1959	total biomass	1960.00	58.20
1960	total biomass	1885.00	45.92
1961	total biomass	1530.80	35.87
1962	total biomass	1071.50	24.27
1963	total biomass	745.27	14.70
1964	total biomass	779.81	15.16
1965	total biomass	782.86	15.43
1966	total biomass	841.43	16.33
1967	total biomass	835.69	16.62
1968	total biomass	764.03	16.00
1969	total biomass	783.36	16.79

	parameter	value	std dev
1970	total biomass	724.28	16.73
1971	total biomass	732.69	18.06
1972	total biomass	743.71	19.93
1973	total biomass	910.40	24.09
1974	total biomass	1078.40	28.95
1975	total biomass	1323.90	34.61
1976	total biomass	1562.40	40.57
1977	total biomass	1814.10	46.51
1978	total biomass	2056.50	52.19
1979	total biomass	2197.80	57.18
1980	total biomass	2364.10	61.86
1981	total biomass	2519.10	65.97
1982	total biomass	2654.90	69.74
1983	total biomass	2759.00	72.86
1984	total biomass	2834.70	75.59
1985	total biomass	2833.60	77.66
1986	total biomass	2761.50	79.41
1987	total biomass	2700.30	81.09
1988	total biomass	2679.70	83.20
1989	total biomass	2597.70	84.75
1990	total biomass	2582.70	86.62
1991	total biomass	2610.60	87.90
1992	total biomass	2608.90	88.85
1993	total biomass	2535.70	89.60
1994	total biomass	2490.70	89.97
1995	total biomass	2399.40	90.01
1996	total biomass	2333.00	90.50
1997	total biomass	2257.70	90.93
1998	total biomass	2125.90	90.95
1999	total biomass	2076.60	91.62
2000	total biomass	2086.10	93.56
2001	total biomass	2077.90	95.71
2002	total biomass	2076.60	97.41
2003	total biomass	2074.30	99.83
2004	total biomass	2066.80	102.38
2005	total biomass	2060.00	105.17
2006	total biomass	2022.20	108.37
2007	total biomass	1985.70	112.93
2008	total biomass	1928.10	119.47

Yellowfin sole TAC and ABC levels, 1980-2008

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
2007	136,000	225,000
2008	225,000	248,000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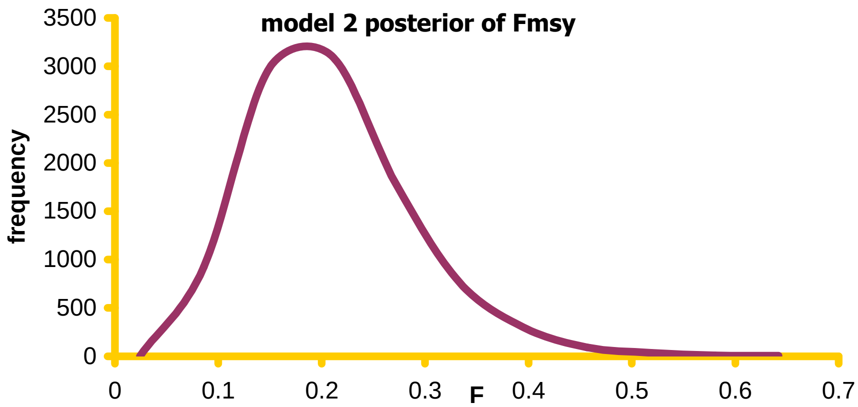
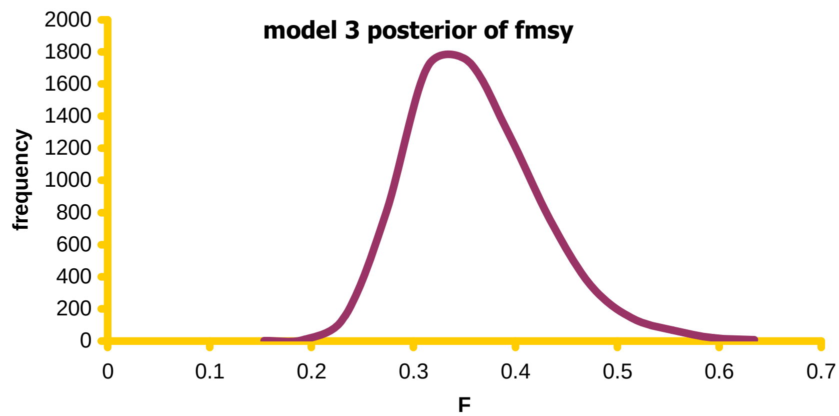
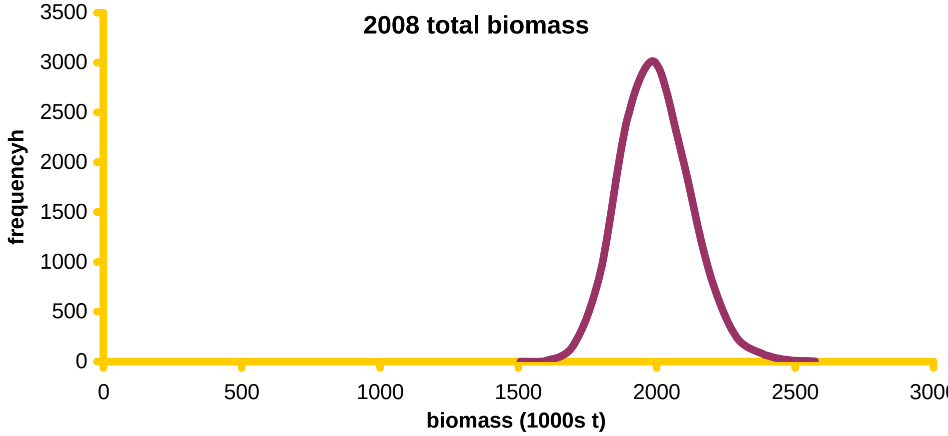
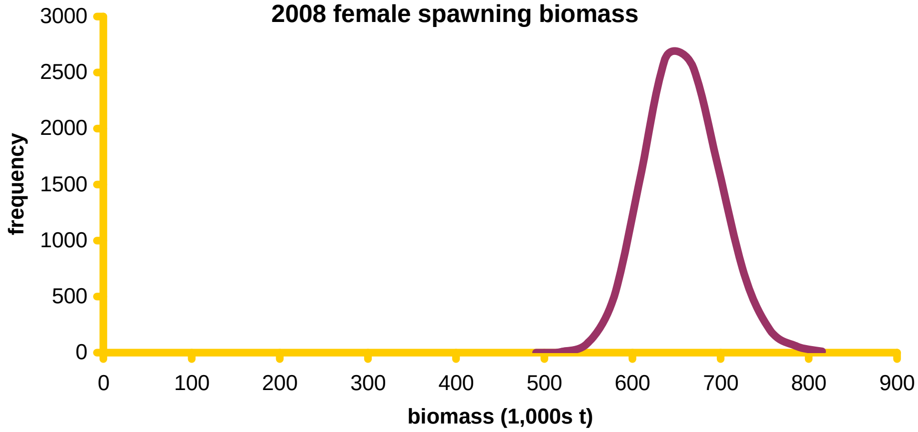
4000
3500
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
F

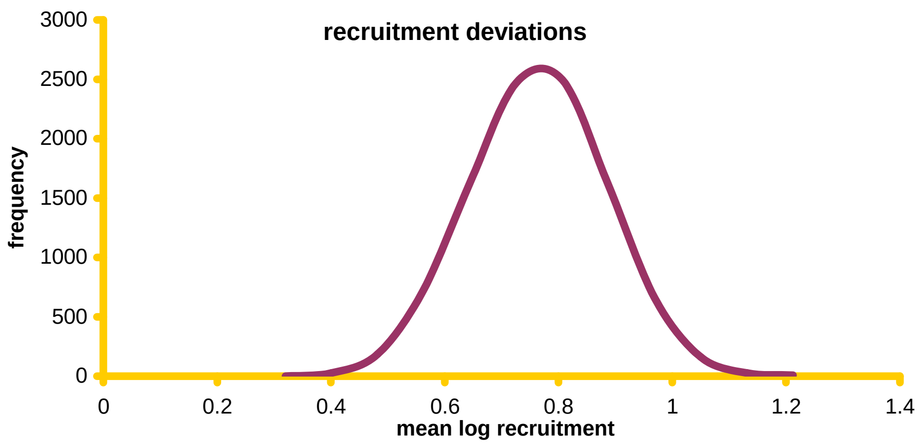

model 2 posterior of Fmsy
frequency
3500
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
F

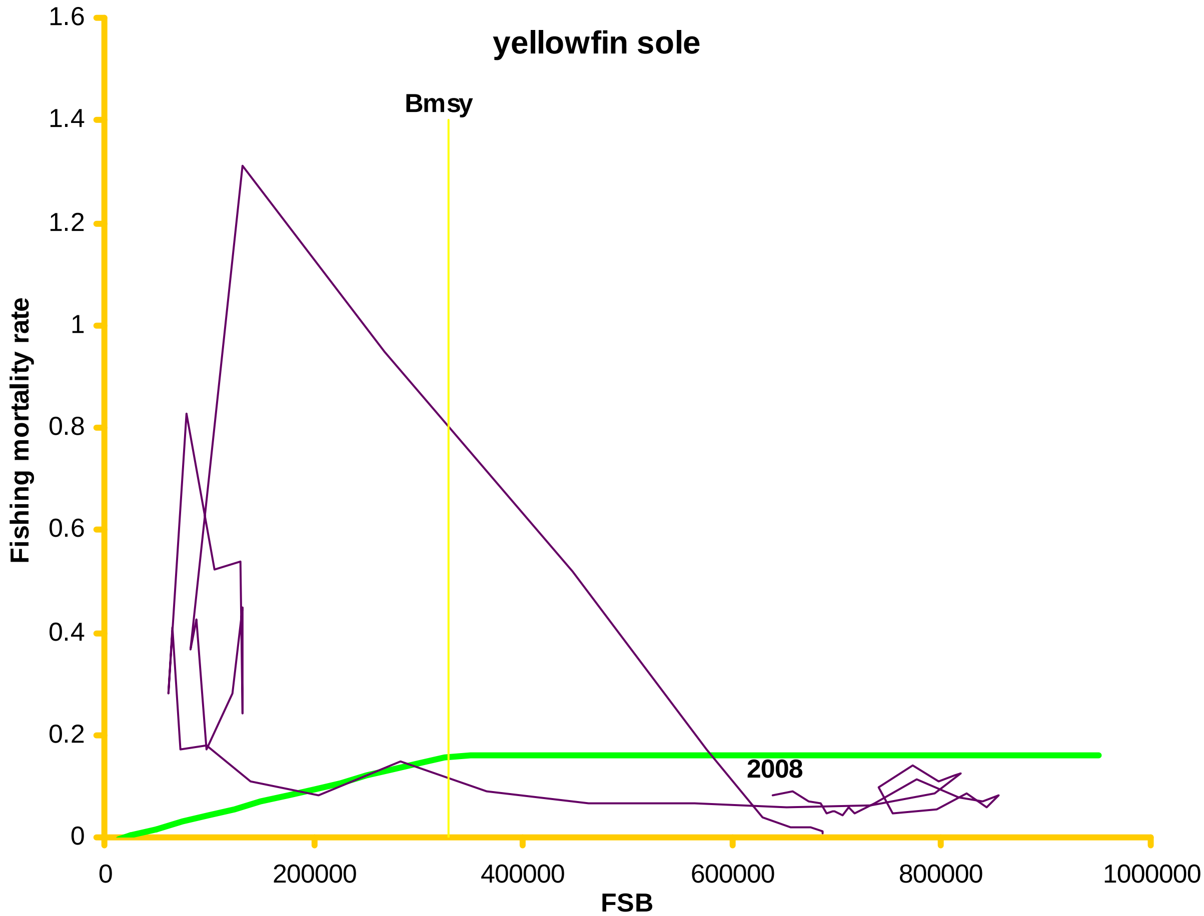

model 3 posterior of fmsy
frequency
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
F

Posterior distributions from the assessment model









yellowfin sole
Bmsy
2008
Fishing mortality rate
FSB
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
200000
400000
600000
800000
1000000

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