Chapter 2: Assessment of the Pacific Cod Stock in the Gulf of Alaska

Grant G. Thompson and Martin W. Dorn

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way NE., Seattle, WA 98115-6349

EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November edition of last year's GOA SAFE report, the following substantive changes have been made in the Pacific cod stock assessment.

Changes in the Input Data

1) Catch data for 1964-1977 were incorporated, catch data for 2004 were updated, and preliminary catch data for 2005 were incorporated.
2) Size composition data from the 1977 commercial fisheries were incorporated, size composition data from the 2004 commercial fisheries were updated, and preliminary size composition data from the 2005 commercial fisheries were incorporated.
3) Size composition data from the GOA bottom trawl survey were incorporated.
4) The biomass estimate from the GOA bottom trawl survey was incorporated (the 2005 estimate of 308,102 t was up about 4% from the 2003 estimate).
5) Age composition data from the 2003 GOA bottom trawl survey were incorporated.
6) Length-at-age data from the 2003 GOA bottom trawl survey were incorporated.
7) A new maturity-at-length schedule was incorporated.

Changes in the Assessment Model

Three alternative models are presented. Model 1 is identical to last year's model, which was developed using the Stock Synthesis 1 assessment software that has formed the basis of the GOA Pacific cod model since 1994. Models 2 and 3 were developed under the new Stock Synthesis 2 assessment software, which uses automatic differentiation (via the ADMB programming language) to minimize the objective function rather than the finite-difference algorithm used in Stock Synthesis 1. In addition, Stock Synthesis 1 and Stock Synthesis 2 differ with respect to several technical details which are described in the main text of this chapter. The primary difference between Model 2 and Model 3 is that Model 2 fixes the natural mortality rate M and the EBS bottom trawl survey catchability coefficient Q at values of 0.37 and 1.00, respectively (identical to the values assumed in Model 1), whereas Model 3 allows the values of these two parameters to be estimated internally.

Changes in Assessment Results

1) Based on Model 3, the estimated 2006 female spawning biomass for the GOA stock is 165,000 t, up about 80% from last year's estimate for 2005 and up about 89% from last year's F_{ABC} projection for 2006. These changes are due largely to use of the new maturity schedule.

2) Based on Model 3, the estimated 2006 total age 3+ biomass for the GOA stock is 453,000 t, down about 4% from last year's estimate for 2005 and up about 8% from last year's $F_{40\%}$ projection for 2006.

3) Based on Model 3, the recommended 2006 ABC for the GOA stock is 58,700 t, up about 1% from last year's estimate for 2005 and up about 15% from last year's F_{ABC} projection for 2006.

4) Based on Model 3, the estimated 2006 OFL for the GOA stock is 130,000 t, up about 51% from last year's estimate for 2005.

Responses to Comments of the Scientific and Statistical Committee (SSC)

SSC Comments Specific to the Pacific Cod Assessments

From the December, 2004 minutes: "The SSC was intrigued by the stock-recruit fits for the periods 1977-1988 and 1989-2002 and we thank the authors for including this analysis. For the 2006 assessment, the SSC asks the authors to explore whether these findings can be used to elevate the GOA cod stock to tier 1 or 2. If it is deemed that MSY is too variable between periods to apply any MSY estimates to this stock, then next year's assessment should consider potential implications of this variability in stock productivity on estimation of the F35% and F40% reference points." The Ricker stock-recruitment curves shown in last year's assessment were intended to be illustrative only, because the statistical technique used to compute the parameters of those curves has significant drawbacks, as described in last year's assessment. Therefore, it does not seem advisable to use those parameters as the basis for elevating the GOA Pacific cod stock to Tier 1 or 2. While statistically valid estimates of stock-recruitment parameters and the associated uncertainties may soon be available for GOA Pacific cod, it was not possible to develop them in time for this year's assessment. Most assessment effort this year went toward understanding and applying the new Stock Synthesis 2 modeling software. Unfortunately, Stock Synthesis 2 currently supports only the Beverton-Holt stock-recruitment function, although support for the Ricker function will undoubtedly be forthcoming. Regarding the issue of decadal-scale variability in stock-recruitment parameters, no determination has been made as to whether such variability would likely detract from the applicability of any future estimates of MSY or related quantities in the case of GOA Pacific cod. The subject of nonstationary stock-recruitment relationships is an active area of research at the Alaska Fisheries Science Center, and results of this research may be applicable to future assessments of the GOA Pacific cod stock. As a first, albeit small, step toward incorporating a stock-recruitment relationship into the provision of fishery management advice, the standard program used to make future projections in all Tier 1-3 BSAI and GOA groundfish assessments now includes an option to fit a Ricker stock-recruitment relationship by assuming that $F_{35\%}$ and $B_{35\%}$ correspond to F_{MSY} and B_{MSY}, respectively. The projections provided in the present assessment make use of this option.

From the December, 2004 minutes: "The authors are asked to examine interannual variability in cod weight-at-length estimates (index of condition) and potential relationships with cod density, stock-recruit, or environmental conditions. Condition indices have been useful metrics in analyses of the health of Atlantic cod stocks." Interannual variability of the weight-at-length relationship and condition factor is explored in the "Weight at Length" subsection of the "Data" section and in Figures 2.4 and 2.5.

From the December, 2004 minutes: "The SSC also requests that the authors provide justification for their assumption that there are no gender-based differences in length-at-age or weight-at-length for Pacific cod. If there is sexual dimorphism in growth, then size-based selection in the fisheries will generate time variations in sex ratios that can have important consequences to the stock's productivity." Sex-specific length at age and weight at length is explored in the "Length at Age" and "Weight at Length" subsections of the "Data" section and in Figures 2.2 and 2.3.

From the October, 2005 minutes: "Given the amount of time required to update the Bering Sea model, the feasibility of implementing a Gulf area model in SS2 this year is unclear. Nevertheless, the SSC encourages development of the Gulf model in SS2 for comparability with the Bering Sea assessment." Two SS2-based models have been developed for the GOA Pacific cod stock. These are described and evaluated in the "Analytic Approach" and "Model Evaluation" sections.

SSC Comments on Assessments in General

From the December, 2004 minutes: "In its review of the SAFE chapters, the SSC noted that there is variation in the information presented. Several years ago, the SSC developed a list of items that should be included in the document. The SSC requests that stock assessment authors exert more effort to address each item contained in the list." Every reasonable effort has been made to respond to all SSC requests and to ensure that the GOA Pacific cod assessment complies with the "Guide to the Preparation of Alaska Groundfish SAFE Report Chapters" produced by the Alaska Fisheries Science Center (last revised in June, 2003).

INTRODUCTION

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 63° N latitude. Pacific cod is distributed widely over Gulf of Alaska (GOA), as well as the eastern Bering Sea (EBS) and the Aleutian Islands (AI) area. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and GOA. Although at least one previous genetic study (Grant et al. 1987) failed to show significant evidence of stock structure within these areas, current genetic research underway at the Alaska Fisheries Science Center may soon shed additional light on the issue of stock structure of Pacific cod within the BSAI (M. Canino, AFSC, pers. commun.). Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the GOA.

Fishery

During the two decades prior to passage of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976, the fishery for Pacific cod in the GOA was small, averaging around 3,000 t per year. Most of the catch during this period was taken by the foreign fleet, whose catches of Pacific cod were usually incidental to directed fisheries for other species. By 1976, catches had increased to 6,800 t. Catches of Pacific cod since 1978 are shown in Tables 2.1a and 2.1b. In Table 2.1a, catches for 1978-1990 are broken down by year, fleet sector, and gear type. In Table 2.1b, catches for 1991-2005 are broken down by year, jurisdiction, and gear type. The foreign fishery peaked in 1981 at a catch of nearly 35,000 t. A small joint venture fishery existed through 1988, averaging a catch of about 1,400 t per year. The domestic fishery increased steadily through 1986, then increased more than three-fold in 1987 to a catch of nearly 31,000 t as the foreign fishery was eliminated. Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components. Trawl gear has traditionally accounted for the bulk of the catch (approximately 55% on average during the period 1997-2004), although pot gear took the largest share of the catch in 2003 and 2004. Figure 2.1 shows areas in which sampled hauls for each of the three main gear types (trawl, longline, and pot) were concentrated during 2004. To create this figure, the EEZ off Alaska was divided into 20 km × 20 km squares. A square is shaded if more than two hauls containing Pacific cod were sampled in it during 2004.

The history of acceptable biological catch (ABC) and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate commercial catches in Table 2.2. For the first year of management under the MFCMA (1977), the catch limit for GOA Pacific cod was established at slightly less than the 1976 total reported landings. During the period 1978-1981, catch limits varied between 34,800 and 70,000 t, settling at 60,000 t in 1982. Prior to 1981 these limits were assigned for "fishing years" rather than calendar years. In 1981 the catch limit was raised temporarily to 70,000 t and the fishing year was extended until December 31 to allow for a smooth transition to management based on calendar years, after which the catch limit returned to 60,000 t until 1986, when ABC began to be set on an annual basis. From 1986 (the first year in which an ABC was set) through 2005, TAC averaged about 84% of ABC and catch averaged about 96% of TAC. In 8 of these 20 years (40%), TAC equaled ABC exactly. In 9 of these 20 years (45%), catch exceeded TAC. However, it should be noted that all but two of these apparent overages occurred in the most recent nine years, when a substantial fishery for Pacific cod was conducted inside State of Alaska waters, mostly in the Western and Central Regulatory Areas. To accommodate the State-managed fishery, TAC was set well below ABC in each of those years (15% in 1997 and 1998; 20% in 1999; 23% in 2000-2003; and 24% in 2004-2005). Thus, the apparent overages in 1997-2000 and 2002-2004 are basically an artifact of the bi-jurisdictional nature of the fishery. Catch has exceeded ABC only twice (in 1992 and 1996). Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. For example, from 1986 through 2004, three different assessment models were used (Table 2.2), though the model was largely unchanged from 1997 through last year.

Historically, the majority of the GOA catch has come from the Central regulatory area. To some extent the distribution of effort within the GOA is driven by regulation, as catch limits within this region have been apportioned by area throughout the history of management under the MFCMA. Changes in area-specific allocation between years have usually been traceable to changes in biomass distributions estimated by Alaska Fisheries Science Center trawl surveys or management responses to local concerns. Currently, the ABC allocation follows the average biomass distribution estimated by the three most recent trawl surveys, and the TAC allocation is within one percent of this distribution on an area-by-area basis. The complete history of allocation (in percentage terms) by regulatory area within the GOA is shown in Table 2.3.

In addition to area allocations, GOA Pacific cod is also allocated on the basis of processor component (inshore/offshore) and season. The inshore component is allocated 90% of the TAC and the remainder is allocated to the offshore component. Within the Central and Western Regulatory Areas, 60% of each component's portion of the TAC is allocated to the A season (January 1 through June 10) and the remainder is allocated to the B season (June 11 through December 31, although the B season directed fishery does not open until September 1). The longline and trawl fisheries are also associated with a Pacific halibut mortality limit which sometimes constrains the magnitude and timing of harvests taken by these two gear types.

The catches shown in Tables 2.1a-b and 2.2 include estimated discards for all years since 1980. Discard rates of Pacific cod in the various GOA target fisheries are shown for each year 1991-2002 in Table 2.4a and for the years 2003-2004 in Table 2.4b.

DATA

This section describes data used in the current assessment. It does not attempt to summarize all available data pertaining to Pacific cod in the GOA.

Commercial Catch Data

Catch Biomass

Catches (including estimated discards) taken in the GOA since 1964 are shown in Table 2.5, broken down by the three main gear types and the following within-year time intervals, or "periods": January-May, June-August, and September-December. This particular division, which was suggested by participants in the BSAI fishery, is intended to reflect actual intra-annual differences in fleet operation (e.g., fishing operations during the spawning period may be different than at other times of year). In years for which estimates of the distribution by gear or period were not available, proxies based on other years' distributions were used.

Catch Size Composition
Fishery size compositions are presently available, by gear, for the years 1977 through the first part of 2004. For ease of representation and analysis, length frequency data for Pacific cod can usefully be grouped according to the following set of 25 intervals or "bins," with the upper and lower boundaries shown in cm:

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lower Bound:	9	12	15	18	21	24	27	30	33	36	39	42	45	50	55	60	65	70	75	80	85	90	95	100	105
Upper Bound:	11	14	17	20	23	26	29	32	35	38	41	44	49	54	59	64	69	74	79	84	89	94	99	104	115

Total length sample sizes for each year, gear, and period are shown in Table 2.6. The collections of relative length frequencies are shown by year, period, and size bin for the pre-1987, 1987-1999, and post-1999 trawl fisheries in Tables 2.7a, 2.7b, and 2.7c, respectively; the pre-1987, 1987-1999, and post-1999 longline fisheries in Tables 2.8a, 2.8b, and 2.8c, respectively; and the 1987-1999 and post-1999 pot fisheries in Tables 2.9a and 2.9b. Fishery length frequencies since 1997 include samples from the State-managed fishery.

Survey Data

Survey Size Composition
The relative size compositions from trawl surveys of the GOA conducted by the Alaska Fisheries Science Center since 1984 are shown in Table 2.10, using the same length bins defined above for the commercial catch size compositions. Total sample sizes are shown below:

Year:	1984	1987	1990	1993	1996	1999	2001	2003	2005
Sample size:	17413	19589	11440	17152	12190	8645	6772	9125	6844

Survey Age Composition
Following a decade-long hiatus in production ageing of Pacific cod, the Age and Growth Unit of the Alaska Fisheries Science Center began ageing samples of Pacific cod from the EBS shelf bottom trawl surveys a few years ago (Roberson 2001, Roberson et al. 2005). This year, age data have become available for the 2003 survey in the GOA as well. Age composition estimates for that survey are shown in Table 2.11 (sample size = 711). Age data are not yet available for any other year.

Abundance Estimates
Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl surveys are shown in Table 2.12, together with the standard errors and upper and lower 95% confidence intervals (CI) for the biomass estimates.

The highest biomass ever observed by the survey was the 1984 estimate of 550,971 t, and the low point is the 2001 estimate of 279,332 t (the 2001 estimate was obtained by summing the 2001 estimate for the Western and Central areas with the 1999 estimate for the Eastern area, because the 2001 survey did not cover the Eastern area). In terms of population numbers, the record high was observed in 1984, when the population was estimated to include over 320 million fish.

Length at Age

Production ageing of Pacific cod at the Alaska Fisheries Science Center was curtailed in the early 1990s and did not resume for approximately ten years. During the intervening period, age data were used only sparingly in the GOA Pacific cod assessment. However, as noted above, length-at-age data from the 2003 survey are now available. These data provide the following relationship between age and length (cm) and the amount of spread around that relationship (data were collected during summer; ages assume a January 1 birthdate):

Age:	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
Mean Length:	21.0	31.7	42.3	48.8	58.3	66.4	74.0	78.1	88.0	85.5	77.0	80.5
St. Deviation:	3.5	3.6	5.6	5.8	5.2	4.5	5.7	7.6	5.9	7.8	4.2	14.8
N:	54	45	119	141	140	91	62	41	12	2	2	2

The SSC has asked that the potential significance of sex-specific length at age be addressed (SSC minutes, December 2004). Figure 2.2 shows sex-specific schedules of mean length at age based on the 2003 surveys data, together with 95% confidence intervals (only ages 1.5-8.5 are shown because of small sex-specific sample sizes at ages 9.5-12.5). The sex-specific means appear to be very close throughout most of the age range. Although the female curve is slightly lower than the male curve at ages less than 6.5 and higher than the male curve at older ages, the confidence intervals for the two sexes overlap at all ages except 7.5 and 8.5. More data may be necessary to determine whether or not there is a consistent and biologically important difference between the length-at-age schedules of the two sexes in the GOA. However, in the BSAI Pacific cod assessment (Thompson and Dorn 2005), where eight years of survey ages are available, no major difference between the length-at-age schedules of the two sexes is apparent.

Weight at Length

Weight measurements taken during summer bottom trawl surveys since 1987 yield the following data regarding average weights (in kg) at length, grouped according to size composition bin (as defined under “Catch Size Composition” above):

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ave. weight:	n/a	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8	1.1	1.5	2.0	2.5	3.2	4.0	5.2	6.3	8.0	9.5	11.5	13.2	13.9

The SSC has asked that the potential significance of sex-specific weight at length be addressed (SSC minutes, December 2004). Figure 2.3 shows sex-specific schedules of mean weight at length based on the 2003 survey data, together with 95% confidence intervals. The sex-specific means appear to be very close throughout most of the length range. At longer lengths, the means may not overlap, but there is no obvious trend (i.e., males have higher average weight than females at some lengths but not at others) and the means for each sex typically fall within the confidence interval for the other sex.

The SSC has also asked that the potential significance of interannual variability in weight-at-length relationships and condition factor be addressed (SSC minutes, December 2004). For this purpose, a set of six example years was chosen: 1980, 1985, 1990, 1995, 2000, and 2005. For each of these years, all the available weight-at-length data from the commercial fisheries were compiled (commercial fishery data were chosen rather than survey data because Pacific cod weights were not collected in all surveys and because the commercial time series extends farther back than the survey time series). The average month of collection (where January=1) ranged from 2.3 to 5.7, with the data from the three most recent years (1995, 2000, and 2005) tending to be collected somewhat earlier in the respective year than the data from the other years. By gear type, the data for 1980 were collected predominantly from the longline fishery, the data for 1985 were collected predominantly from the trawl fishery, the data from 1990 and 1995 were collected predominantly from motherships, the data for 2000 were collected predominantly from the pot fishery, and the data for 2005 were collected predominantly from the jig fishery.

The mean weights at each length are shown for each year in Figure 2.4 (to reduce the possibility of outliers resulting from small sample sizes, only those points representing the average of at least 5 data points are shown). For the most part, the mean weights at length appear very close for all years.

"Condition factor," conventionally defined as the ratio of weight to the cube of length, is commonly used to compare the health of individual fish of the same species (Fulton 1911, Ricker 1975). The average condition factor (across lengths) for each of the six example years is plotted together with 95% confidence intervals in Figure 2.5. Because condition factor is a relative measure, the values in Figure 2.5 have been normalized by expressing each point as the ratio of the year-specific estimate to the estimate for the entire time series. Statistically speaking, the point estimates in Figure 2.5 are significantly different under any reasonable criterion. However, it should be emphasized that such a result would probably be expected, given that only one parameter is being estimated for each year and a total of approximately 20,000 points is used in the analysis. More important questions are, "How different are they?" and, "Would such differences be important to incorporate into the stock assessment?" It may be useful to pursue these questions further in future assessments, but for the time being it may be sufficient to note that there does not appear to be any obvious time trend to the points in Figure 2.5 (although there probably would be if the 2005 point were omitted), and all but one of the points is within 5% of the long-term average.

Maturity at Length

For many years, the GOA Pacific cod assessments have relied on maturity-at-length data collected from the Bering Sea. As different Bering Sea data sets have been compiled over the years, the schedule of maturity at length has changed from time to time. Prior to 1995, the Pacific cod assessments used a maturity schedule based on a gonadosomatic index calculated from a sample of 1900 fish collected during the 1981 and 1982 survey seasons and described by Teshima (1985).

More recently (since 1995 in the BSAI and 1996 in the GOA), the Pacific cod assessments have used a maturity schedule based on a sampling program conducted in 1993-1994, using observer data collected from the EBS commercial fisheries. The data consisted of observers' visual determinations regarding the spawning condition of 2312 females. Of these 2312 females, 231 were smaller than 42 cm (the lower boundary of length bin 12). None of these sub-42 cm fish were mature. The observed proportions of mature fish in the remaining length bins, together with the numbers of fish sampled in those length bins, are shown below (bins are defined under "Catch Size Composition" above):

Bin number:	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Prop. mature:	0.03	0.05	0.14	0.19	0.28	0.53	0.69	0.82	0.89	0.94	0.94	0.91	0.89	1.00
Sample size:	39	122	226	313	295	300	320	177	103	70	50	35	19	12

Recently, Stark (2005) completed an in-depth histological study of Pacific cod maturity in both the BSAI and GOA. In the GOA, 346 female fish were collected in the central GOA during October 1998, January 1999, April 1999, June 1999, and January 2004. Methods were the same as those used by Stark (2004). Oocytes within each ovary were classified into seven histological stages based on the criteria of Hunter et al. (1992) and Stark (2004). Fish with ovaries containing either hydrated oocytes or post-ovulatory follicles were classified as spawners. Specimens collected from the GOA ranged in size from 13-98 cm. The smallest spawning female collected from the GOA was 42 cm. Ovary weights were found to represent up to 30% of total body weight.

ANALYTIC APPROACH

Model Structure

Beginning with the 1994 SAFE report (Thompson and Zenger 1994), a model using the SS1 assessment program (Methot 1986, 1990, 1998, 2000) and based largely on length-structured data has formed the primary analytical tool used to assess the GOA Pacific cod stock. SS1 is a program that uses the parameters of a set of equations governing the assumed dynamics of the stock (the “model parameters”) as surrogates for the parameters of statistical distributions from which the data are assumed to be drawn (the “distribution parameters”), and varies the model parameters systematically in the direction of increasing likelihood until a maximum is reached. The overall likelihood is the product of the likelihoods for each of the model components. Each likelihood component is associated with a set of data assumed to be drawn from statistical distributions of the same general form (e.g., multinomial, lognormal, etc.). Typically, likelihood components are associated with data sets such as catch size (or age) composition, survey size (or age) composition, and survey biomass.

SS1 permits each data time series to be divided into multiple segments, resulting in a separate set of parameter estimates for each segment. In the base model for the GOA Pacific cod assessment, for example, possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries have traditionally been accommodated by splitting the fishery size composition time series into pre-1987 and post-1986 segments.

The base model for GOA Pacific cod remained completely unchanged from 1997 to 2001. A minor modification of the base model was suggested by the SSC in 2001, namely, that consideration be given to dividing the domestic era into pre-2000 and post-1999 segments. This modification was tested in the 2002 assessment (Thompson et al. 2002), where it was found to result in a statistically significant improvement in the model’s ability to fit the data.

However, after so many years of application, the SS1 architecture has by this time become somewhat dated. Three features can be identified as no longer state-of-the-art: First, SS1 uses a finite difference algorithm to minimize the objective function, whereas most state-of-the-art assessments use automatic differentiation (e.g., Greiwank and Corliss 1991), for example, as found in the ADMB modeling package (Fournier 2005). Benchmark tests have tended to indicate that automatic differentiation is a superior algorithm. Second, SS1 attempts to estimate all parameters simultaneously, whereas models programmed in ADMB can include “phased” estimation, where attention is focused initially on only a subset of parameters, and additional parameters are added to the “active” list with each subsequent phase, until finally all parameters are active in the final phase. By attempting to estimate all parameters simultaneously, SS1 is more likely to get trapped in a local minimum. Third, SS1 does not include utilities for estimating confidence intervals or posterior distributions of derived quantities (e.g, spawning biomass), whereas models programmed in ADMB can easily be tailored to estimate such confidence intervals or distributions so long as the estimated Hessian matrix is positive definite.

Therefore, SS1 is being replaced by a new program, SS2, which, for the most part, is simply SS1 rewritten in ADMB. A full description of SS2, including the equations used to model population dynamics and the various observation processes, is given by Methot (2005a). This year’s Pacific cod assessment includes three alternative models. Model 1 was configured under SS1, while Models 2 and 3 were configured under SS2 (see “Model Evaluation” below). The structure of Model 1 configured under SS1 is identical to that described in last year’s assessment (Thompson et al. 2004).

Although the main difference between SS1 and SS2 is the use of ADMB by SS2, there are a number of other technical differences. The most important of these, and how they were addressed in the present assessment, are described in the following paragraphs.

Minimum and Maximum Age

SS1 allowed the user to specify the minimum age in the model, whereas SS2 automatically sets the minimum age equal to zero. This does not mean, however, that the data have to include age 0 fish; it simply means that SS2 always begins calculating the age structure of the population at age 0. Moreover, the SS2 user can still specify a "summary age range" for use in reporting output, where the minimum age is completely flexible. Another difference between SS1 and SS2 is that users of SS1 were encouraged to set a fairly low age for the boundary of the "plus" group, with the age structure of the plus group governed by a user-specified "old age discount" parameter, whereas users of SS2 are encouraged to set a fairly high age for the boundary of the plus group, so that the age structure of the plus group essentially does not matter (again, setting a high maximum age does not mean that the data must include all ages up to that maximum, it simply means that SS2 will calculate the age structure of the population up to that maximum). In SS1, maximum age for the Pacific cod model has always been set equal to 12, and this assumption is retained for the SS1 model included in the present assessment. For the models developed under SS2 in this year's assessment, maximum age is set equal to 20.

Initial Numbers at Age

SS1 provided users with the choice of setting the numbers-at-age vector in the initial year equal to the equilibrium numbers-at-age vector associated with user-specified levels of catch and recruitment, or estimating each element of the numbers-at-age vector in the initial year as a free parameter. Previous GOA Pacific cod assessment models have always used the second option, where the initial year was set equal to 1978. However, SS2 requires use of the first option. Use of an equilibrium initial numbers-at-age vector necessitates a number of modifications to the GOA Pacific cod assessment model. This is because previous assessments of this stock, as well as conventional wisdom, have consistently indicated that one or more exceptionally large year classes spawned in or around 1977 were present in the population in 1978, but most other age groups were at very low levels of abundance in that year, meaning that the assumption of initial equilibrium would likely be very misleading (i.e, it would either cause the large year classes to be drastically under-estimated, or the other year classes to be drastically over-estimated).

It is clear that the assumption of initial equilibrium requires an earlier initial year for the assessment model. Annual catch data are available as far back as 1964. Setting the initial year equal to 1964 would give the model plenty of time to generate a reasonable age structure by the time the large year classes of the mid-to-late 1970s were spawned. However, setting the initial year any earlier than 1977 requires estimating one or more year classes prior to the well-documented 1977 environmental regime shift (e.g., Hare and Mantua 2000), which should have a lower median value than year classes spawned after the 1977 regime shift. Establishing different pre-1977 and post-1976 medians is easily accomplished in SS2 by creating a regime shift "dummy variable" for each year in the time series and estimating a link between median recruitment and the dummy variable. However, this creates another problem, because the parameter governing the amount of stochastic variability in recruitment (σ_R) cannot be linked to the dummy variable. This means that the mean recruitment deviation for each portion of the time series (pre-1977 and post-1976) will not necessarily equal zero, even though SS2 forces the mean recruitment deviation for the overall time series to equal zero. This, in turn, means that the estimates of the pre- and post-regime shift medians will be confounded with the estimate of σ_R.

To resolve the problem of confounding between the estimates of the pre-1977 and post-1976 recruitment medians with the estimate of σ_R, the following iterative algorithm was used to implement an environmental regime shift in SS2.

1. Candidate values for the pre-1977 log-scale mean and σ_R were chosen.
2. SS2 was allowed to estimate the post-1976 log-scale mean and the recruitment deviations for the entire time series (deviations are expressed as the difference between the logarithm of

annual recruitment at age 0 and the log-scale mean for the respective environmental regime), conditional on the candidate values for the pre-1977 log-scale mean and σ_R.

3. The mean of the estimated pre-1977 recruitment deviations and the standard deviation of the entire time series of recruitment deviations were computed.
4. If the absolute value of the mean computed in Step 3 was less than 0.005 and the standard deviation computed in Step 3 was equal to σ_R with three significant digits, the candidate values were determined to be the final estimates. If either of these conditions did not hold, the candidate value for the pre-1977 log-scale mean was set equal to the old value plus the mean computed in Step 3, the candidate value for σ_R was set equal to the standard deviation computed in Step 3, and the process returned to Step 2.

The above algorithm was tested many times under different initial candidate values and consistently returned the same final estimates.

Selectivity

As alluded to above, a total of eleven selectivity curves are specified by the GOA Pacific cod model. Three curves apiece are specified for the June-December trawl fishery and the longline fishery, corresponding to the time periods 1964-1986, 1987-1999, and 2000-2005. Two curves are specified for the January-May trawl fishery, corresponding to the time periods 1964-1999 and 2000-2005 (although a single selectivity curve is specified for the years 1964-1999 in the January-May trawl fishery, the parameters for this curve are estimated entirely from data collected during the 1987-1999 time period, because almost no size composition data were collected from the January-May trawl fishery during the 1964-1986 time period). Two curves are also specified for the pot fishery, corresponding to the time periods 1987-1999 and 2000-2005 (there was no significant pot fishery for Pacific cod prior to 1987). A single curve is specified for the GOA bottom trawl survey.

Although SS2 includes several options for specifying the functional form of the selectivity curve, the most flexible and commonly used option involves a pair of scaled logistic curves joined by a horizontal linear segment. The first (ascending) logistic curve begins at the minimum length specified in the data file (9 cm in the case of the GOA Pacific cod model), where the selectivity is less than 1.0, and ends at some intermediate length, where selectivity is exactly 1.0. A horizontal linear segment extends from the right-hand end of the first logistic to the left-hand end of the second logistic. Selectivity equals 1.0 throughout this linear segment. The second (descending) logistic curve begins at the end of the horizontal linear segment, where selectivity is still exactly 1.0, and ends at the maximum length specified in the data file (110 cm in the case of the GOA Pacific cod model), where the selectivity is less than 1.0. This selectivity function is similar to the primary selectivity function used in SS1, except that the function used in SS1 omits the horizontal linear segment that joins the two logistic curves in the SS2 version of the function (i.e., selectivity in the SS1 version equals 1.0 at a single point only, whereas the SS2 version allows selectivity to equal 1.0 throughout a range of values).

Eight parameters are used to define the SS2 selectivity function: the size at which selectivity first reaches a value of 1.0 (*peak location*), the selectivity at the minimum length represented in the data (*S*(*Lmin*)), the logit transform of the size corresponding to the inflection of the ascending logistic curve (logit(*infl1*)), the relative slope of the ascending logistic curve (*slope1*), the logit transform of the size corresponding to the inflection of the descending logistic curve (logit(*infl2*)), the relative slope of the descending logistic curve (*slope2*), the logit transform of the selectivity at the maximum length represented in the data (logit(*S*(*Lmax*))), and the width of the length range at which selectivity equals 1 (*peak width*). The parameters are similar in the SS1 version of the selectivity function, except that *peak width* is implicitly set equal to zero.

Prior Distributions
A potentially major difference between SS1 and SS2 is that SS2 is explicitly cast in a Bayesian framework, with specification of a prior distribution required for each parameter. Of course, a noninformative prior can be chosen for any or all parameters if so desired. However, use of informative priors is probably appropriate for many of the parameters in the GOA Pacific cod model, because one or both Plan Teams and the SSC have indicated in the past that certain values, or ranges of values, of various parameters are either relatively likely or unlikely. For example, the SSC has indicated that a natural mortality rate of 0.37 is likely close to the true value (SSC minutes, December 1994). As another example, the BSAI Plan Team has expressed concern that previous assessments' estimates of large-fish selectivity in the EBS shelf bottom trawl survey may be too low (BSAI Plan Team minutes, November 2004), and the GOA Pacific cod assessment has typically produced survey selectivity patterns similar to those obtained in the BSAI assessment. By utilizing a Bayesian framework, SS2 provides a logical means of integrating perspectives such as these into the stock assessment model. The specific priors used in this assessment are described under "Parameters Estimated Conditionally" below.

Parameters Estimated Independently

Natural Mortality
In the 1993 BSAI Pacific cod assessment (Thompson and Methot 1993), the natural mortality rate M was estimated using SS1 at a value of 0.37. All subsequent assessments of the BSAI and GOA Pacific cod stocks (except the 1995 GOA assessment) have used this value for M. Other published estimates of M for Pacific cod are shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

As the above table indicates, the natural mortality rate for Pacific cod is either highly variable by time or area or it is very hard to estimate. In Models 1 and 2, M is fixed at the traditional value of 0.37. In Model 3, M is estimated internally.

Trawl Survey Catchability
The base model used in all previous GOA Pacific cod assessments has fixed the catchability coefficient (Q) for the GOA bottom trawl survey independently of other parameters at a value of 1.0. Somerton (2004) has shown that Q for Pacific cod in the GOA is very unlikely to be greater than 1.0. In Models 1 and 2, the survey catchability is set equal to 1.0. In Model 3, the values of this parameter is estimated internally.

Weight at Length
Parameters governing the allometric relationship between weight and length were estimated in a previous assessment by log-log regression from the available data (see "Data" above, with weights given in kg and lengths in cm), giving a multiplicative constant of 5.80×10^{-6} and an exponent of 3.159.

Variability in Estimated Age

In keeping with the assumptions used in last year's assessment, Model 1 does not use age data. Models 2 and 3, however, do use age data. To use age data, SS2 requires an estimate of the standard deviation of estimated age at each age. Weighted least squares regression was used to estimate a linear relationship between standard deviation and age. The resulting estimates of the intercept and slope were 0.161 and 0.038, respectively. This relationship was used in Models 2 and 3.

Maturity at Length

As in previous assessments of GOA Pacific cod, the present assessment uses a single (i.e., time-invariant), length-based maturity schedule. Although the maturity schedule is constant within a given assessment, the values of the parameters describing the maturity schedule have changed over time. As noted in the "Data" section above, the GOA Pacific cod assessments have always relied on maturity-at-length data collected from the Bering Sea. As different Bering Sea data sets have been compiled over the years, the schedule of maturity at length has changed from time to time. The history of maturity schedules used previously or now available for use in the GOA Pacific cod assessment may be summarized as follows, where the length at 50% maturity (*L50*) and slope of the linearized logistic equation (*A*) are used to characterize each schedule:

1) From 1984 through 1994, the maturity schedule was based on gonado-somatic index values from the 1981-1982 surveys, with *L50* and *A* values of 61 cm and -0.248, respectively (Teshima 1985).
2) From 1995 through 2004, the maturity schedule was based on macroscopic observations ("scans") from the 1994 commercial fishery, with *L50* and *A* values of 67 cm and -0.142, respectively (Thompson 1995).
3) For this year's assessment, another possible candidate is Stark's (2005) maturity schedule, based on histological samples collected in the central GOA at various times of year during the period 1998-2004, with *L50* and *A* values of 50 cm and -0.222, respectively.

To provide some context for the above schedules, it may be helpful to consider alternative estimates. Two categories of alternative estimates are those derived from "rules of thumb" based on life history parameters and those derived from biological samples. The method suggested by Roff (1984), based on the Brody growth coefficient *K* and the natural mortality rate, falls within the "rules of thumb" category. The available length-at-age data (see "Length at Age" under "Data" above) suggest a *K* value of about 0.094 (based on maximum likelihood). Using this estimate of *K* and the conventional Pacific cod *M* value of 0.37, Roff's method implies an age at maturity of about 6 years, corresponding to a length of about 62 cm (based on linear interpolation). However, an age at maturity of 6 years seems very high given that the maximum age observed in the 2003 survey was only 12 years. Royce (1972) suggested another rule of thumb, namely, that the age at maturity should typically be less than one-third of the maximum age. For a maximum age of 12 years, Royce's method would imply an age at maturity around 4 years or lower, corresponding to a length of about 46 cm (based on linear interpolation). In the category of estimates derived from biological samples, Rovnina et al. (1997) estimated *L50* at 55-60 cm for Pacific cod in the Sea of Okhotsk, Welch and Foucher (1988) estimated *L50* at 45-55 cm for Pacific cod in British Columbia, and Hattori et al. (1992) estimated that 50% of Pacific cod in the Sea of Japan were mature by age 4 which, for GOA Pacific cod, corresponds to a length of about 46 cm (based on linear interpolation). All of these alternative estimates are closer to Stark's (2005) estimate of *L50* than the estimate used in recent assessments.

In addition to the above, the following reasons support use of Stark's (2005) maturity-at-length schedule (the "new schedule"):

1) The new schedule is based on a published methodology (Stark 2004) that is the source of the maturity schedules used in several other BSAI and GOA groundfish assessments (BSAI flathead sole, GOA flathead sole, GOA northern rock sole, GOA southern rock sole).

2) The author of the new maturity schedule has extensive experience in both macroscopic and histological estimation of Pacific cod maturity and is convinced that the histological methods are more accurate.
3) The method used to determine the maturity schedule used in recent Pacific cod assessments is subject to factors that might cause the resulting *L50* value to be biased high, whereas the method used to determine the new schedule is not subject to these factors, as described below.

Ova that contain yolk (mature ova) appear transparent, in contrast to the opaque appearance of ova that do not contain yolk. The success of macroscopic maturity classification systems depends in part on the ability of observers to distinguish transparent ova from opaque ova. This distinction can be difficult to make, because the ova are not observed directly, but through the ovary wall. The difficulty is greater for smaller fish, and can bias classifications of smaller fish in favor of immaturity. The reason for this is that, as fish grow, the number of ova contained in each ovary increases more than proportionally, which in turn causes greater distention of the ovary wall when yolk accumulates in the ova. Greater distention results in greater transparency of the ovary wall, which in turn increases observers' ability to identify transparent ova through the ovary wall. Conversely, it is harder for observers to detect mature ova in smaller fish, because the ovary wall is typically less distended than in large fish, even when the ova are mature. For the same reason (disproportionately less stretching of the ovary wall in small fish), macroscopic observation of small fish that have already spawned during the year may result in an incorrect classification of "developing" or "immature" because it is difficult to detect the presence of disintegrating ova (a criterion used to distinguish "spent" ovaries) through the ovary wall in such fish.

In contrast, histological maturity classifications are not subject to these biases because the maturity classifications are based on a comprehensive microscopic assessment of each ovum and associated structures, such as post ovulatory follicles, contained within each ovary section. The examinations are conducted under controlled laboratory conditions. The probability of detecting yolk within an ovary is very high because all ovary slide sections are stained with eosin dye which attaches to any yolk protein present, giving it a distinctive pink coloration.

Parameters Estimated Conditionally

With a few exceptions, Models 1, 2, and 3 estimate similar parameters, although the number of parameters of a given type estimated by the three models may differ in some cases due to the fact that Model 1 sets the initial year at 1978 while Models 2 and 3 set the initial year at 1964. The parameters that all three models attempt to estimate internally consist of the following:

1) mean length at age 1.5, mean length at age 12, Brody growth coefficient *K*
2) log-scale mean recruitment for the post-1976 environmental regime
3) annual recruitments (Model 1) or annual recruitment deviations (Models 2 and 3)
4) selectivity parameters (7 for Model 1, 8 for Models 2 and 3) for each of 11 selectivity curves
5) initial fishing mortality (initial year = 1978 for Model 1, 1964 for Models 2 and 3)
6) year-, gear-, and season-specific fishing mortality rates

It should be noted that the fishing mortality rates in (6) are somewhat different from the other parameters in that their values are determined exactly given the values of the other parameters and the input catch data, which are assumed to be true values rather than estimates.

In addition to the parameters estimated internally by all three models, the following parameters are estimated by some subset of the three models:

1) Model 1 estimates each element of the initial numbers-at-age vector.

2) Models 2 and 3 estimate the log-scale mean recruitment for the pre-1977 environmental regime and the standard deviation of the recruitment deviations (though not quite internally, but rather through an iterative process described under "Model Structure" above).
3) Model 3 estimates the natural mortality rate *M* and the logarithm of the bottom trawl survey catchability coefficient *Q*.

In the case of Model 1, the estimator used is the peak of the logarithm of the likelihood function (see below). In the cases of Models 2 and 3, the estimator used is the mode of the logarithm of the joint posterior distribution, which is in turn calculated as the sum of the logarithms of the parameter-specific prior distributions (see below) and the logarithm of the likelihood function.

Prior Distributions
For the two models developed under SS2 in this year's assessment, the informative prior distributions described in the following paragraphs were specified (all distributions are normal):

<u>Parameters with priors based on a specified coefficient of variation (CV)</u>
Initial fishing mortality: The mean was set at 0.1, reflecting the conventional wisdom that the stock was lightly exploited during the 1960s. The standard deviation was set at 0.03, corresponding to a CV of 30%.

Selectivity parameter *S*(*Lmin*): For the commercial fisheries, this was not an estimated parameter, but was set at a fixed value of 0.001. This choice was based on the fact that almost no fish in the sub-30 cm range are taken in the commercial fisheries and because preliminary model runs invariably resulted in this parameter being bound at whatever minimum value was specified. For the surveys, the prior distribution was assigned a mean of 0.1 and a standard deviation of 0.03, corresponding to a 30% CV. In contrast to the commercial fisheries, 10% of the average bottom trawl survey size composition has consisted of fish smaller than 30 cm.

Selectivity parameters *slope1* and *slope2*: These two parameters had identical priors, with the mean set at 0.2 and the standard deviation set at 0.06, corresponding to a 30% CV. The choice of mean was based on a subjective examination of the shape of the selectivity curve under different values of these parameters.

Selectivity parameter *peak width*: The mean was set at 10 and the standard deviation was set at 3, corresponding to a 30% CV. The choice of mean was based on a subjective examination of the shape of the selectivity curve under different values of this parameter, in addition to results from preliminary model runs which indicated that values much higher than 10 tended to cause the model to get "stuck."

Log survey catchability ln(*Q*): Model 3 treats ln(*Q*) as a free parameter with a prior distribution. This prior distribution was assigned a mean of -0.29 and a standard deviation of 0.05, corresponding to a lognormal prior for *Q* with a median of 0.75 and CV of 5%. The choices of mean and standard deviation for this prior distribution were difficult ones. In previous assessments, *Q* has always been fixed at a value of 1.0, which equates to a log value of 0. One natural way to convert a fixed constant into a free parameter with a normal prior is to treat the former fixed value as the mean of the new prior distribution and set a reasonable value for the standard deviation. However, this is not the only logical option. In the case of ln(*Q*) for GOA Pacific cod, for example, a value of 0 was used in last year's assessment not only because it was *consistent* with the results of Somerton (2004), but because it was the *upper limit* implied by those results (i.e., the results showed that it is very unlikely for the true value of ln(*Q*) to be positive). If the former fixed value of 0 is viewed as an upper limit, it does not make sense to treat it as the mean of the new prior. Rather, the mean and standard deviation of the new prior distribution should be set so that exceeding the upper limit is highly unlikely. The choice of -0.29 as the mean for the prior distribution was largely a subjective one, although it has some support in that the implied median value of 0.75 for *Q* is close to, and midway between, the estimates of 0.7 and 0.8 obtained for this parameter in the 2001 and 2004 GOA walleye pollock assessments (Dorn et al. 2001 and 2004). The choice of 0.05 for the standard deviation was pragmatic. A standard deviation of 0.05 probably underestimates the true uncertainty that ought to be associated with this prior distribution. However, preliminary model runs with higher values for the standard deviation inevitably resulted in point estimates for *Q* that were much higher than 1.0 (often in the neighborhood of 2.0), which cannot presently be reconciled with the results of Somerton (2004).

Natural mortality *M*: As with ln(*Q*), Model 2 fixes *M* at the value used in last year's assessment (0.37), while Model 3 treats it as a free parameter with a prior distribution. The prior distribution was assigned a mean of 0.37 and a standard deviation of 0.019, corresponding to a CV of 5%. Similar to the situation with ln(*Q*), the choice of 0.019 for the standard deviation was a pragmatic one. Although it probably underestimates the true uncertainty that ought to be associated with this prior distribution, preliminary model runs in this year's BSAI Pacific cod assessment (Thompson and Dorn 2005) with higher values for the standard deviation inevitably resulted in point estimates for *M* that were much lower than 0.37 (often in the neighborhood of 0.20), which are so far from the traditionally accepted value that it does not seem wise to accept them without further investigation. Furthermore, higher values of the standard deviation for *M* tended to push the point estimates of *Q* in the BSAI assessment to very high values that cannot be presently be reconciled with the results of Somerton (2004). Because it would be hard to justify different standard deviations for the prior distribution on *M* in the EBS and GOA given current knowledge, a CV of 5% was used for this prior in both the EBS and GOA assessments.

Parameters with priors based on one or both endpoints of the 98% confidence interval

Selectivity parameters logit(*infl1*) and logit(*infl2*): These two parameters had identical priors, with the mean set at 0 and the standard deviation set at 0.944. The mean corresponds to an inflection point located midway between *Lmin* and *peak location*, in the case of *infl1*, or between *peak location* and *Lmax*, in the case of *infl2*. The mean and standard deviation together imply a 98% confidence interval extending from 10% to 90% of the difference between *Lmin* and *peak location*, in the case of *infl1*, or between *peak location* and *Lmax*, in the case of *infl2*. The choice of mean was based on a subjective examination of the shape of the selectivity curve under different values of these parameters.

Selectivity parameter logit(*S*(*Lmax*)): The mean was set at 2.197 and the standard deviation was set at 0.944. The mean corresponds to a selectivity of 0.9 at *Lmax*. The mean and standard deviation together imply a 1% chance of selectivity at *Lmax* being less than 0.5. These parameter values were chosen in part to reflect the Plan Team's belief that selectivity of large fish in the bottom trawl survey should be fairly high.

Parameters with priors based on the data

Length at age parameters: Mean values for length at age 1.5, length at age 12, and the Brody growth coefficient *K* were set at 20.7, 95.5, and 0.094, respectively, corresponding to the maximum likelihood estimates obtained from the data collected during the 2003 GOA bottom trawl survey. The standard deviations for these parameters were set at 0.232, 1.616, and 0.008, respectively, corresponding to the values associated with the inverted Hessian matrix obtained in the process of estimating the means.

Selectivity parameter *peak location*: The mean and standard deviation were set individually for each selectivity curve by identifying the length associated with the maximum frequency in each length frequency record, then computing the mean and standard deviation for each respective gear type and portion of the time series. This was done in order to give the model a reasonable starting value and place reasonable constraints on *peak location*, a parameter which is typically very difficult to estimate. The SS2 User Manual suggests that this parameter "should be an integer and should be at bin boundary and not estimated," but it also suggests that recent improvements to the code "may allow estimation" (Methot 2005b). Extensive testing during preliminary runs of the EBS Pacific cod model (Thompson and Dorn 2005) revealed that the value of this parameter can be quite important in determining model results and that free estimation (with a reasonably strong prior) was much more likely to find an optimal value than profiling manually over the range of possible integer values, especially considering the practical difficulty of manually tuning 11 parameters (one *peak location* for each selectivity curve) at the same time. The resulting means (cm) and standard deviations (cm) for *peak location* in each of the 11 selectivity curves were as follow:

Fishery/Survey	Years	Mean	Std. Dev.
Jan-May Trawl	1964-1999	63.8	2.12
Jan-May Trawl	2000-2005	61.1	4.32
Jul-Dec Trawl	1964-1986	54.1	5.71
Jul-Dec Trawl	1987-1999	58.7	5.68
Jul-Dec Trawl	2000-2005	61.4	5.22
Longline	1964-1986	58.3	6.96
Longline	1987-1999	63.1	3.10
Longline	2000-2005	63.1	2.42
Pot	1987-1999	64.5	2.53
Pot	2000-2005	61.9	2.99
Bottom Trawl Survey	1984-2005	54.5	3.60

Likelihood Components

Likelihood components included in all three models are of four types: size composition, age composition, survey biomass, and mean size at age. There are five size composition components in the likelihood: one each for the January-May trawl fishery, the June-December trawl fishery, the longline fishery, the pot fishery, and the bottom trawl survey. There is only one age composition component and one size-at-age component in the likelihood, because all age data currently come from the trawl survey. There is one survey biomass component in the likelihood, corresponding to the bottom trawl survey. In addition to the above, Models 2 and 3 include a recruitment deviations component.

Both SS1 and SS2 allow the user to specify "emphasis" factors that determine which components receive the greatest attention during the parameter estimation process. As in previous assessments, each component in each model was given an emphasis of 1.0 in the present assessment.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery, and time period within the year. In the parameter estimation process, SS1 and SS2 weight a given size composition observation (i.e., the size frequency distribution observed in a given year, gear/fishery, and period) according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which SS1 was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. As in previous assessments, the present assessment uses a multinomial sample size equal to the square root of the true length sample size, rather than the true length sample size itself. Given the true length sample sizes observed in the present assessment, this procedure tends to give values somewhat below 400 while still providing the SS1 and SS2 programs with usable information regarding the appropriate effort to devote to fitting individual length samples. Multinomial length sample sizes derived by this procedure for the commercial fishery size compositions are shown in Table 2.13. In the case of GOA bottom trawl survey size composition data, the square root assumption was also used. The square roots (sqrt) of the true survey length sample sizes are shown below:

Year	sqrt(N)
1984	132
1987	140
1990	107
1993	131
1996	110
1999	93
2001	82
2003	96
2005	83

Use of Age Composition Data in Parameter Estimation

Like the size composition data, the age composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery (in this case, the GOA bottom trawl survey), and time period within the year (in this case, the June-August period). However, selection of an appropriate input sample size is more complicated for age composition data than for length composition data, because age composition data are generated not only from the set of otolith readings but from the estimated size composition as well. Therefore, even if a square root transformation is appropriate for size composition data, taking the square root of the number of otoliths read may underestimate the weight that should be given to the age composition data. Last year's assessment BSAI Pacific cod assessment (Thompson and Dorn 2004) introduced a method for setting an input sample size appropriate to age composition, a method which is retained in the present assessment. The steps are as follow:

1) The proportions of age at length are assumed to be approximately multivariate normally distributed, with a variance-covariance matrix determined by the matrix of proportions and the number of otoliths actually read at each length. A set of 10,000 random age-length keys was then simulated.
2) Survey numbers at each length are assumed to be approximately lognormally distributed with a mean equal to the point estimate and for that length and a constant (across lengths) coefficient of variation (CV) equal to the amount that sets the sum of the variances in numbers at length equal to the variance of the survey estimate of population size. A set 10,000 of random numbers-at-length distributions was then simulated.
3) For each combination of randomly simulated age-key and numbers-at-length distribution, an effective sample size was computed.

4) The "true" input sample size was set equal to the harmonic mean of the distribution of randomly simulated effective sample sizes, based on the asymptotic equivalence of these two quantities. The following table was thereby obtained for the age composition data (the last row shows the value used as "true" input sample sizes):

Year	2003
Number of fish aged:	711
Square root of number of fish aged:	27
CV of numbers at length:	0.83
Harmonic mean effective sample size:	80

Note that this procedure gives an input sample size larger than would be achieved simply by taking the square root of the number of fish aged (third row in the above table). This reflects the added precision achieved by use of both age-at-length and numbers-at-length data in constructing a numbers-at-age estimate. To avoid double counting of the same data, Models 2 and 3 ignore length composition data from the 2003 GOA bottom trawl survey.

It may be noted that the harmonic mean effective sample size computed above (80) is smaller than the sample size (96) obtained for the corresponding length composition using the "square root method" in the preceding subsection, suggesting that the two methods of computing sample sizes are not entirely consistent. This is not surprising, given that the square root method was adopted only as a simple approximation in the first place, but it does suggest a need for further work in this area.

Use of Size-at-Age Data in Parameter Estimation
Each size at age datum is assumed to be drawn from a normal distribution specific for that age and year. The model's estimate of mean size at age serves as the mean for that year's distribution, and the standard deviation is inversely proportional to the sample size (Methot 2000, Methot 2005a).

Use of Survey Biomass Data in Parameter Estimation
Each year's survey biomass datum is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey biomass in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey biomass datum's standard error to the survey biomass datum itself serves as the distribution's coefficient of variation.

Use of Recruitment Deviation "Data" in Parameter Estimation
The recruitment deviations likelihood component is different from traditional likelihoods because it does not involve "data" in the same sense that traditional likelihoods do. Instead, the log-scale recruitment deviation plays the role of the datum and the log-scale recruitment mean and σ_R play the role of the parameters in a normal distribution, but, of course, all of these are treated as parameters by SS2.

MODEL EVALUATION

As described in the preceding section, three alternative models are evaluated in the present assessment. Model 1 is identical to the SS1 model used in the 2004 assessment, where the natural mortality rate *M* and the trawl survey catchability coefficient *Q* were fixed at values of 0.37 and 1.0, respectively. Model 2 is developed under SS2 and differs from Model 1 in several respects, such as use of an earlier initial year and use of prior distributions for many model parameters, but retains Model 1's assumptions regarding the values of *M* and *Q*. Model 3 is also developed under SS2 and is identical to Model 2, except that the values of *M* and *Q* are estimated rather than fixed.

Evaluation Criteria

In previous GOA Pacific cod assessments, evaluation criteria have typically focused on effective sample sizes of the size composition data (and, more recently, the age composition data), the root mean squared error (RMSE) of the fit to the survey biomass data, and the overall reasonableness of the parameter values. These criteria are retained in the present assessment, not so much to determine which one of the three models is "best," but as a check to see whether any of the three can reasonably be rejected. Given that a model passes these tests, two additional evaluation criteria are as follow:

1) Do the model's estimates of total biomass achieve a reasonable relationship with the trawl survey's estimates of biomass? (This is different from the question of how well the model's estimates of *survey* biomass fit the survey's own estimates, which is addressed by the RMSE.)
2) Does the model appropriately reflect the uncertainty associated with key assessment outputs?

Effective Sample Size

Once maximum likelihood estimates of the model parameters have been obtained, SS1 and SS2 compute an "effective" sample size for the size or age composition data specific to a particular year, gear/fishery, and time period within the year. Roughly, the effective sample size can be interpreted as the multinomial sample size that would typically be required in order to produce the given fit. More precisely, it is the sample size that sets the sum of the marginal variances of the proportions implied by the multinomial distribution equal to the sum of the squared differences between the sample proportions and the estimated proportions (McAllister and Ianelli 1997). As a function of a multinomial random variable, the effective sample size has its own distribution. The harmonic mean of the distribution is asymptotically equal to the true sample size in the multinomial distribution. Thus, if the effective sample size is less than the true sample size in the multinomial distribution, it is reasonable to conclude that the fit is not as good as expected. The following table shows the average of the input sample sizes (Ninp), the average of the effective sample sizes (Neff), and the ratio of Neff to Ninp for each of the size composition components and the trawl survey age composition component in each of the three models:

	Model 1			Model 2			Model 3		
Likelihood component	Ninp	Neff	Ratio	Ninp	Neff	Ratio	Ninp	Neff	Ratio
Jan-May trawl fishery length	120	279	2.33	120	332	**2.78**	120	322	2.69
Jun-Dec trawl fishery length	38	80	2.09	37	88	**2.34**	37	87	2.32
Longline fishery length	82	367	4.50	82	439	**5.37**	82	423	5.18
Pot fishery length	90	363	**4.03**	90	264	2.93	90	266	2.95
Non-2003 shelf survey length	110	151	**1.38**	110	124	1.13	110	129	1.17
2003 shelf survey length	96	231	2.41	-96	-150	-1.56	-96	-157	-1.63
2003 shelf survey age	n/a	n/a	n/a	80	39	**0.49**	80	39	0.48

Notes:

1) For each row, the average values of Ninp and Neff are computed with respect to all years and periods present in the respective time series.
2) The average input sample size for the Jun-Dec trawl fishery lengths in Model 1 is slightly different from those in Models 2 and 3 because more years of data are included in Models 2 and 3.
3) The negative values in the row for 2003 trawl survey lengths indicate that those data are "turned off" in the Models 2 and 3 to avoid double-counting of length data in the year with age data.
4) Bold font indicates the maximum ratio for the respective row.

All three models produce average effective sample sizes larger than the average input values for all length components. Neither Model 2 nor Model 3 produces an average effective sample size greater than the average input value for the trawl survey age component (the age component is not applicable to Model 1), which is somewhat disappointing. Of the six components (not counting the 2003 trawl survey length component), Model 1 had the highest ratio in two cases, Model 2 had the highest ratio in four cases, and Model 3 never had the highest ratio. However, nearly all of the differences between models are extremely small. It should also be noted that the use of prior distributions by Models 2 and 3 might be expected to cause those models to perform less well than Model 1 with respect to likelihood components such as these, but this does not appear to be the case, as both Models 2 and 3 outperformed Model 1 (though only slightly) in three of the five likelihood components shared by all three models. In summary, the main conclusion to be drawn from the above table is that all three models are performing reasonably well with respect to most or all of the size composition components.

Fit to Survey Biomass Data

The average value of the lognormal "sigma" parameter in the trawl survey biomass data is 0.169. The log-scale root-mean-squared-errors (log-scale RMSEs) from Models 1, 2, and 3 are 0.162, 0.195, and 0.190, respectively. Although Model 1 performs slightly better than the other two models, all three log-scale RMSEs are close to the value of the average sigma. With respect to the trawl survey point estimates of biomass, all three models had the greatest difficulty fitting the 1984 and 1996 values (all three models indicate that the survey point estimates in those two years were likely overestimates).

Reasonableness of Parameter Values

Although hundreds of parameters are estimated by all three models, three items of special interest are the natural mortality rate *M*, the survey catchability coefficient *Q*, and the trawl survey's selectivity at *Lmax*. The values of these parameters (to two significant digits) for each of the three models are shown below:

Parameter	Model 1	Model 2	Model 3
M	0.37	0.37	0.38
Q	1.00	1.00	0.78
S(*Lmax*)	0.29	0.60	0.50

Of course, the values of *M* and *Q* in Models 1 and 2 are fixed rather than estimated, so presumably those values are reasonable, although the *Q* value of 1.0 from Models 1 and 2 should probably be considered to be at the upper limit of the reasonable range. The values of *M* and *Q* in Model 3 are estimated, but with very tight prior distributions, and their final estimates are extremely close to their respective prior medians. The values of *S*(*Lmax*) produced by the three models provide more contrast than the values of *M* and *Q*. Model 1's estimate of 0.29 is similar to the value of 0.25 estimated in last year's assessment. The estimates given by Models 2 and 3 are higher and seem easier to reconcile with the design of the survey.

Relationship of Total Biomass to Survey Biomass

The time series of age 3+ biomass, spawning biomass, and survey biomass estimated by the three models, along with the observed survey biomass time series, in Table 2.14. The past several assessments have tended to result in estimates of age 3+ biomass that were much greater than the survey biomass. All three models in the present assessment behave likewise, although the biomass estimates produced by Model 2 tend not to be as high as those produced by Models 1 and 3. On average, the estimates of age 3+ biomass exceed the observed survey biomass by about 80%, 31%, and 78% for Models 1, 2, and 3, respectively. While it is possible to imagine mechanisms that could cause the bottom trawl survey to underestimate the total biomass of Pacific cod (e.g., a large portion of the population occurring in the water column above the headrope), the existence of any such mechanism has yet to be verified experimentally. Until such verification takes place, age 3+ biomass estimates in the neighborhood of those produced by Model 2 should probably be viewed as more realistic than estimates in the neighborhood of those produced by Models 1 and 3, all else being equal.

Characterization of Uncertainty

One of the main drawbacks of SS1 is that it does not include utilities for estimating the statistical uncertainty surrounding derived quantities such as spawning biomass. Because the SS1-based Model 1 provides only point estimates, it can represent uncertainty adequately only if the true uncertainty is very small or if the most important uncertainties consist of natural random variability rather than statistical imprecision. However, because SS2 is coded in ADMB, it provides for straightforward estimation of the statistical uncertainty surrounding any quantity of interest, which gives some hope that the SS2-based Models 2 and 3 can do an adequate job of describing uncertainty. As an example, the three models' estimates of spawning biomass for the years 1978-2005 (the years that all three models have in common) are shown in Figure 2.6, together with 95% confidence intervals for Models 2 and 3. The relative trend of the point estimates is qualitatively similar across models although the magnitudes differ, with Model 1 giving the highest estimates during the years 1978-1988, Model 3 giving just slightly higher estimates than Model 1 during the years 1989-2005, and Model 2 consistently giving the lowest estimates. From the point of view of uncertainty, however, the key feature of Figure 2.6 is that the confidence intervals from Model 3 are noticeably broader than the confidence intervals from Model 2 (Model 1, of course, cannot generate confidence intervals). Averaged across the entire time series (1964-2005), the confidence intervals from Model 3 are 52% wider than those from Model 2. The confidence intervals from Model 3 encompass the point estimates from Model 1 for every year from 1984 to the present and they substantially overlap the confidence intervals from Model 2 in all years. The fact that Model 3 produces wider confidence intervals than Model 2 is likely due to the fact that natural mortality and survey catchability are estimated in Model 3 but not Model 2.

A related issue has to do with whether statistical estimates of key parameters such as M and Q are preferable to assumed values. It should be remembered that the traditional M value of 0.37 was produced by a model very similar to Model 3, but with fewer data and a less sophisticated estimation algorithm. Although the prior distributions used by Model 3 to help estimate M and Q were very tight, at least they were broader than the prior distributions implicitly assumed by Models 1 and 2, each of which had a CV of zero.

Selection of Final Model

Evaluation of the three models using the above criteria may be summarized as follows: 1) For the length composition likelihood components, all three models performed reasonably well in all categories and performed extremely well in at least some categories. 2) For the age composition likelihood component, neither Model 2 nor Model 3 performed very well (Model 1 did not use age data). 3) For the fit to the survey biomass time series, all three models performed approximately the same, with RMSEs close to the value that would be predicted from the sampling variation in the surveys. 4) For the overall reasonableness of the parameter values, all three models are associated with reasonable values of M and Q, although the Q value of 1.0 from Models 1 and 2 should probably be considered to be at the upper limit of the reasonable range. Also, Model 3 has the advantage of being associated with values of M and Q that are not only reasonable but estimated (albeit with very tight priors) rather than assumed. Model 2 probably gives the most reasonable estimates of large-fish selectivity in the trawl bottom trawl survey, followed fairly closely by Model 3. 5) Relative to the survey biomass time series, the estimated age 3+ biomass time series obtained under Model 2 is considerably closer than the time series obtained under Models 1 or 3. 6) Regarding characterization of uncertainty, Models 2 and 3 obviously perform better than Model 1, because Model 1 was not designed to produce estimates of uncertainty. Model 3's confidence intervals around spawning biomass are much wider than those for Model 2. Given that Model

2's confidence intervals are predicated on the assumption that *M* and *Q* are known with certainty whereas Model 3's confidence intervals do not make this assumption, Model 3's representation of uncertainty is probably more realistic.

Whether Model 2 or Model 3 is the best choice depends on how the above evaluation criteria are weighted. Assuming that a high priority is placed on achieving a realistic representation of uncertainty (both in estimates of parameters such as *M* and *Q* and in derived quantities such as spawning biomass), Model 3 appears to be the best choice overall.

Final Parameter Estimates and Associated Schedules

Final estimates of some key scalar parameters are shown below:

Parameter	Value
Length at age 1.5	20.6
Length at age 12	88.3
Brody growth coefficient K	0.117
Natural mortality rate M	0.38
Trawl survey catchability Q	0.78
Recruitment variability σR	0.469

Estimates of fishing mortality rates are shown in Table 2.15, estimates of regime-specific median recruitments and annual recruitment deviations are shown in Table 2.16, and estimates of selectivity parameters are shown in Table 2.17.

Schedules of selectivity at length are shown for the commercial fisheries and bottom trawl survey in Table 2.18. The schedules in Table 2.18 are plotted in Figure 2.7. As examples of how the schedules of selectivity at length translate into size compositions, Figures 2.8a, 2.8b, 2.8c, and 2.9 show observed and estimated size compositions from the 2003 January-May fisheries, the 2004 January-May fisheries, the 2005 January-May fisheries, and the 2001-2005 trawl surveys, respectively.

Schedules of selectivity at age for the most recent portion of the time series are shown in Table 2.19 and Figure 2.10. To demonstrate how the schedules of selectivity at length translate into age compositions, Figure 2.11 shows observed and estimated age compositions from the 2003 trawl survey. Schedules of length at age, proportion mature at age, and weight at age are shown in Table 2.20.

RESULTS

Definitions

The biomass estimates presented here will be defined in three ways: 1) age 3+ biomass, consisting of the biomass of all fish aged three years or greater in January of a given year; 2) spawning biomass, consisting of the biomass of all spawning females in a given year; and 3) survey biomass, consisting of the biomass of all fish that the model estimates should have been observed by the survey in July of a given year. The recruitment estimates presented here will be defined as numbers of age 0 fish in a given year. The fishing mortality rates presented here will be defined as full-selection, instantaneous fishing mortality rates expressed on a per annum scale.

Biomass

Model 3's estimated time series (1977-2005) of GOA Pacific cod age 3+ biomass and spawning biomass are shown in Table 2.21, together with estimates provided in last year's SAFE report (Thompson et al. 2004) and 95% confidence intervals for the spawning biomass estimates from Model 3. The biomass trends (age 3+, spawning, and survey) estimated in the present assessment are also shown in Figure 2.12, with 95% confidence intervals for the spawning biomass estimates. The model's estimated age 3+ biomass shows a near-continual decline from about 1990 through the present. The model's estimated spawning biomass shows a near-continual decline from about 1995 through the present. It should be noted that the new maturity schedule used this year led to a significant increase in the overall magnitude of estimated spawning biomass.

Recruitment

Model 3's estimated time series (1977-2004) of age 0 recruitment is shown in Table 2.22, together with estimates inferred from last year's SAFE report (Thompson et al. 2004) and 95% confidence intervals for this year's estimates. Because last year's assessment used 1 as the initial age in the model, age 0 recruitments for last year's assessment were inferred here by multiplying last year's estimates of age 1 recruits by exp(0.37), where 0.37 is the value of the natural mortality rate used in last year's assessment. Values for this year's assessment that exceed Model 3's estimate of the 1977-2004 average recruitment of 401,982,571 fish are shown in bold in Table 2.22.

This year's recruitment estimates for the entire time series (1964-2004) are shown in Figure 2.13, along with their respective 95% confidence intervals and regime-specific averages. For the time series as a whole, the largest year class was the 1977 cohort. Other exceptional year classes include those spawned in 1980, 1984, 1987, 1989, and 1995. Of the 15 year classes that have followed the strong 1989 year class, only four (1990, 1995, 1999, and 2000) have point estimates higher than the 1977-2004 average, and only one (1995) has a confidence interval that falls entirely above the 1977-2004 average. Although the upper ends of the confidence intervals for all but four of these post-1989 year classes exceed the 1977-2004 average recruitment, three of the four most recent year classes (2001, 2002, and 2003) happen to be among those that do not. As these dramatically sub-par cohorts work their way through the age structure in the coming years, continued decreases in stock biomass are likely.

To date, it has not been possible to estimate a reliable stock-recruitment relationship for this stock. With the move to SS2, prospects for future estimation of such a relationship should improve. In the interim, Figure 2.14 is provided to give some indication of the relationship between stock and recruitment. The Ricker (1954) curve shown in this figure was not fit statistically, but rather by assuming that $F_{35\%}$ and $B_{35\%}$ correspond to F_{MSY} and B_{MSY}, respectively. This curve is intended to be illustrative only, and is not recommended for management purposes.

Exploitation

The model's estimated time series of the ratio between EBS catch and age 3+ biomass is shown in Table 2.23, together with the estimates provided in last year's SAFE report (Thompson et al. 2004). The average value of this ratio over the entire time series is about 0.08, slightly higher than the average value of 0.07 obtained in last year's assessment. The estimated values exceed the average for every year after 1989 except 1993 and 1994, whereas none of the estimated values exceed the average in any year prior to 1990 except for 1980 and 1981. This finding is basically similar to that obtained in last year's assessment.

Figure 2.15 plots the trajectory of relative fishing mortality and relative female spawning biomass from 1977 through 2005 based on Model 3, overlaid with the current harvest control rules (fishing mortality rates in the figure are standardized relative to $F_{35\%}$ and biomasses are standardized relative to $B_{100\%}$). The entire trajectory lies underneath both control rules. This figure indicates that, in spawning-per-recruit terms, the stock has been fished more lightly than previously thought (Thompson et al. 2004), a result due largely to the new maturity curve used in the present assessment.

PROJECTIONS AND HARVEST ALTERNATIVES

Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan (FMP) defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Pacific cod in the GOA are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The following formulae apply under Tier 3:

3a) *Stock status:* $B/B_{40\%} > 1$
$F_{OFL} = F_{35\%}$
$F_{ABC} \leq F_{40\%}$

3b) *Stock status:* $1/20 < B/B_{40\%} \leq 1$
$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 1/20) \times 20/19$
$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 1/20) \times 20/19$

3c) *Stock status:* $B/B_{40\%} \leq 1/20$
$F_{OFL} = 0$
$F_{ABC} = 0$

Estimation of the $B_{40\%}$ reference point used in the above formulae requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the post-1976 average (i.e., the arithmetic mean of all estimated recruitments from year classes spawned in 1977 or later). Other useful biomass reference points which can be calculated using this assumption are $B_{100\%}$ and $B_{35\%}$, defined analogously to $B_{40\%}$. These reference points are estimated as follows:

Reference point:	$B_{35\%}$	$B_{40\%}$	$B_{100\%}$
Value:	115,000 t	132,000 t	329,000 t

For a stock exploited by multiple gear types, estimation of $F_{35\%}$ and $F_{40\%}$ requires an assumption regarding the apportionment of fishing mortality among those gear types. For this assessment, the apportionment was based on Model 3's estimates of fishing mortality by gear for the three most recent complete years of data (2002-2004). The average fishing mortality rates for those years implied that total fishing mortality was divided among the three main gear types according to the following percentages: trawl 30.2%, longline 22.6%, and pot 47.2%. This apportionment results in estimates of $F_{35\%}$ and $F_{40\%}$ equal to 0.69 and 0.56, respectively. The differences between these values and last year's estimates of 0.36 and 0.31 are due largely to the use of the new maturity schedule in this year's assessment.

Specification of OFL and Maximum Permissible ABC

GOA Pacific cod spawning biomass for 2006 is estimated at a value of 165,000 t. This is about 26% above the $B_{40\%}$ value of 132,000 t, thereby placing Pacific cod in sub-tier "a" of Tier 3. Given this, the model estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2006 as follows:

Quantity	Overfishing Level	Maximum Permissible ABC
Catch:	130,000 t	109,000 t
Fishing mortality rate:	0.69	0.56

The age 3+ biomass estimate for 2006 is 453,000 t.

ABC Recommendation

Review of Past Approaches

For the years 1997-1999, the GOA Pacific cod assessments advocated a harvest strategy that attempted to address some of the statistical uncertainty in the assessment model, namely the uncertainty surrounding parameters the natural mortality rate M and survey catchability Q (Thompson et al. 1997, 1998, 1999). For the 2000-2003 assessments, the strategy was simplified by assuming that the ratio between the recommended F_{ABC} and $F_{40\%}$ estimate given in the 1999 assessment (0.87) was an appropriate factor by which to multiply the current maximum permissible F_{ABC} to obtain a recommended F_{ABC} (Thompson et al. 2003). By the time of the 2004 assessment, however, concern arose that the 87% adjustment factor might have outlived its usefulness, given that the survey time series had changed appreciably since the adjustment factor was last estimated, most notably with the addition of two more survey biomass estimates in 2001 and 2003 and the recalibration of the entire time series in 2003. It was also noted, by way of comparison, that the 87% adjustment factor had not been used to set the ABC for BSAI Pacific cod since the 2002 fishery (Thompson and Dorn 2003). Therefore, the 2004 assessment based its recommendation for the 2005 ABC on a new method. This method, which focused on the mean-variance tradeoff associated with future catches predicted by the standard projection model, resulted in a 2005 ABC of 58,100 t.

Recommendation for 2006

Based on Model 3, the maximum permissible ABC (Tier 3a) for 2006 is 109,000 t. An ABC of this magnitude would represent an increase of 50,900 t, or 88%, relative to the 2005 ABC. However, it should be remembered that the 2001-2003 year classes are almost certainly below average, meaning that biomass is very likely to decrease in coming years as these cohorts work their way through the age structure. For example, projections show that continued harvesting at the maximum permissible rate would be expected to result in ABCs for 2007 and 2008 of 71,400 t and 48,600 t, respectively. In other words, the 50,900 t increase in ABC between 2005 and 2006 would likely be followed by an even larger decrease (60,400 t) over the next two years.

In contrast, harvesting at 50% of the maximum permissible rate would result in a 2006 ABC of 58,700 t, an increase of 600 t, or 1%, relative to the 2005 ABC. Continued harvesting at 50% of the maximum permissible rate would still be expected to result in decreased ABCs during 2007 and 2008, but these decreases would likely be much smaller (both in absolute and relative terms) than they would be under the maximum permissible rate.

In conclusion, given the likelihood of decreases in future biomass and the volatility in future catches that would be expected if the stock were fished at the maximum permissible rate, it does not seem prudent to recommend harvesting at the maximum permissible rate in 2006. Harvesting at 50% of the maximum permissible rate is recommended instead, resulting in a 2006 ABC of 58,700 t.

Area Allocation of Harvests

For the past several years, ABC has been allocated among regulatory areas on the basis of the three most recent surveys. The recent time series of area-specific biomass estimates are shown below, together with the proportions corresponding to a three-year weighted average (in keeping with past calculations, the 1999 estimate of biomass in the Eastern regulatory area is used as a proxy for the 2001 value, because the 2001 survey did not include the Eastern regulatory area):

Year	Western	Central	Eastern	Total
2001	133214	124400	21718	279332
2003	75632	207080	14689	297402
2005	134029	160118	13954	308102
Average	114292	163866	16787	294945
Proportion	0.39	0.55	0.06	1.00

Thus, if the previous approach for allocating ABC is retained for the 2006 fishery, the proportions would be 39% Western, 55% Central, and 7% Eastern. Relative to the 2005 values, these proportions represent an increase of 3% in the Western regulatory area, a decrease of 2% in the Central regulatory area, and a decrease of 1% in the Eastern regulatory area (Table 2.3).

Standard Harvest and Recruitment Scenarios and Projection Methodology

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 2005 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2006 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2005. 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 2006, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2006 recommended in the assessment to the *max* F_{ABC} for 2006. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of *max* F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2001-2005 average F, which was 0.23. (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 1) above its MSY level in 2006 or 2) above ½ of its MSY level in 2006 and above its MSY level in 2016 under this scenario, then the stock is not overfished.)

Scenario 7: In 2006 and 2007, 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 2018 under this scenario, then the stock is not approaching an overfished condition.)

Projections and Status Determination

Scenario Projections and Two-Year Ahead Overfishing Level
Table 2.24 defines symbols used to describe projections of spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios. These projections are shown for Model 3 in Tables 2.25-2.30.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2006 (130,000 t), it does not provide the best estimate of OFL for 2007, because the mean 2007 catch under Scenario 6 is predicated on the 2006 catch being equal to the 2006 OFL, whereas the actual 2006 catch will likely be less than the 2006 OFL. Therefore, the projection model was re-run with the 2006 catch fixed at the recommended 2006 ABC value of 58,700 t and the 2007 fishing mortality rate fixed at F_{OFL}. The resulting estimate of the 2007 OFL was 106,000 t.

Status Determination
Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2006:

a. If spawning biomass for 2006 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2006 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2006 is estimated to be above ½ $B_{35\%}$ but below B35%, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 2.29). If the mean spawning biomass for 2016 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7 (Table 2.30):

a. If the mean spawning biomass for 2008 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2008 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2008 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2018. If the mean spawning biomass for 2018 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

In the case of BSAI Pacific cod, spawning biomass for 2006 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2008 in Table 2.30 is above ½ $B_{35\%}$ but below $B_{35\%}$, and mean spawning biomass for 2018 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Boldt (ed.), 2005). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). In the present assessment, an attempt was made to estimate the change in median recruitment of EBS Pacific cod associated with the 1977 regime shift. According to Model 3, pre-1977 median recruitment was only about 30% of post-1976 median recruitment. Establishing a link between environment and recruitment within a particular regime is more difficult. In last year's assessment (Thompson et al. 2004), for example, the correlations between age 1 recruits spawned since 1977 and monthly values of the Pacific Decadal Oscillation (Mantua et al. 1997) were computed and found to be very weak.

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), Lang et al. (2003), Westrheim (1996), and Yang (2004). The composition of Pacific cod prey varies to some extent by time and area. In terms of percent occurrence, some of the most important items in the diet of Pacific cod in the BSAI and GOA have been polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, some of the most important dietary items have been euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, some of the most important dietary items have been walleye pollock, fishery offal, yellowfin sole, and crustaceans. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include Pacific cod, halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Major trends in the most important prey or predator species could be expected to affect the dynamics of Pacific cod to some extent.

Fishery Effects on the Ecosystem

Potentially, fisheries for Pacific cod can have effects on other species in the ecosystem through a variety of mechanisms, for example by relieving predation pressure on shared prey species (i.e., species which serve as prey for both Pacific cod and other species), by reducing prey availability for predators of Pacific cod, by altering habitat, by imposing bycatch mortality, or by "ghost fishing" caused by lost fishing gear.

Bycatch of Nontarget and "Other" Species

Bycatch of nontarget species and members of the "other species" group are shown in the following set of tables (for the 2003-2005 tables, the "hook and line" gear type includes both longline and jig gear): Tables 2.31a and 2.31b show bycatch for the GOA Pacific cod trawl fishery in 1997-2002 and 2003-2005, respectively. Tables 2.32a and 2.32b show bycatch for the GOA Pacific cod longline fishery in 1997-2002 and the GOA Pacific cod hook and line fishery in 2003-2005, respectively. Tables 2.33a and 2.33b show bycatch for the GOA Pacific cod pot fishery in 1997-2002 and 2003-2005, respectively.

It is not clear how much bycatch of a particular species constitutes "too much" in the context of ecosystem concerns. As a first step toward possible prioritization of future investigation into this question, it might be reasonable to focus on those species groups for which a Pacific cod fishery had a bycatch in excess of 100 t and accounted for more than 10% of the total bycatch in at least two of the three most recent years. This criterion results in the following list of impacted species groups (an "X" indicates that the criterion was met for that area/species/gear combination).

Species group	Hook and Line	Pot
Large sculpins		X
Sea star	X	X
Skate	X	

Steller Sea Lions

Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Pitcher (1981) and Calkins (1998) also showed Pacific cod to be an important winter prey item in the GOA and BSAI, respectively. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery operates to some extent in the same geographic areas used by Steller sea lion as foraging grounds (Livingston (ed.), 2002).

The Fisheries Interaction Team of the Alaska Fisheries Science Center has been engaged in research to determine the effectiveness of recent management measures designed to mitigate the impacts of the Pacific cod fisheries (among others) on Steller sea lions. Results from studies conducted in 2002-2003 were summarized by Conners et al. (2004). These studies included a tagging feasibility study, which may evolve into an ongoing research effort capable of providing information on the extent and rate to which Pacific cod move in and out of various portions of Steller sea lion critical habitat. Nearly 6,000 spaghetti tags were released, of which approximately 1,000 had been returned as of September, 2003.

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the hook and line fishery for Pacific cod (Tables 2.36b and 2.39b). Shearwater (*Puffinus* spp.) distribution overlaps with the Pacific cod longline fishery in the Bering Sea, and with trawl fisheries in general in both the Bering Sea and GOA. Black-footed albatross (*Phoebastria nigripes*) is taken in much greater numbers in the GOA longline fisheries than the Bering Sea longline fisheries, but is not taken in the trawl fisheries. The distribution of Laysan albatross (*Phoebastria immutabilis*) appears to overlap with the longline fisheries in the central and western Aleutians. The distribution of short-tailed albatross (*Phoebastria albatrus*) also overlaps with the Pacific cod longline fishery along the Aleutian chain, although the majority of the bycatch has taken place along the northern portion of the Bering Sea shelf edge (in contrast, only two takes have been recorded in the GOA). Some success has been obtained in devising measures to mitigate fishery-seabird interactions. For example, on vessels larger than 60 ft. LOA, paired streamer lines of specified performance and material standards have been found to reduce seabird incidental take significantly.

Fishery Usage of Habitat

The following is a summary of information provided by Livingston (ed., 2002): The longline and trawl fisheries for Pacific cod each comprise an important component of the combined fisheries associated with the respective gear type in each of the three major management regions (BS, AI, and GOA). Looking at each gear type in each region as a whole (i.e., aggregating across all target species) during the period 1998-2001, the total number of observed sets was as follows:

Gear	BS	AI	GOA
Trawl	240,347	43,585	68,436
Longline	65,286	13,462	7,139

In the BS, both longline and trawl effort was concentrated north of False Pass (Unimak Island) and along the shelf edge represented by the boundary of areas 513, 517 (in addition, longline effort was concentrated along the shelf edge represented by the boundary of areas 521-533). In the AI, both longline and trawl effort was dispersed over a wide area along the shelf edge. The catcher vessel longline fishery in the AI occurred primarily over mud bottoms. Longline catcher-processors in the AI tended to fish more over rocky bottoms. In the GOA, fishing effort was also dispersed over a wide area along the shelf, though pockets of trawl effort were located near Chirikof, Cape Barnabus, Cape Chiniak and Marmot Flats. The GOA longline fishery for Pacific cod generally took place over gravel, cobble, mud, sand, and rocky bottoms, in depths of 25 fathoms to 140 fathoms.

Impacts of the Pacific cod fisheries on essential fish habitat were further analyzed in an environmental impact statement by NMFS (2005).

Data Gaps and Research Priorities

Understanding of the above ecosystem considerations would be improved if future research were directed toward closing certain data gaps. Such research would have several foci, including the following: 1) ecology of the Pacific cod stock, including spatial dynamics, trophic and other interspecific relationships, and the relationship between climate and recruitment; 2) behavior of the Pacific cod fishery, including spatial dynamics; 3) determinants of trawl survey selectivity; 4) ecology of species taken as bycatch in the Pacific cod fisheries, including estimation of biomass, carrying capacity, and resilience; and 5) ecology of species that interact with Pacific cod, including estimation of biomass, carrying capacity, and resilience.

SUMMARY

The major results of the Pacific cod stock assessment are summarized in Table 2.34.

ACKNOWLEDGMENTS

Jim Stark provided maturity data. Eric Brown and Mark Wilkins provided survey data. Andy Smoker, Josh Keaton, Tom Pearson, Kally Spalinger, and Kim Phillips provided fishery data. Angie Greig provided fishery data and produced Figure 2.1. Nathan Mantua provided values of the Pacific Decadal Oscillation. Dave Ackley, Sarah Gaichas, and Terry Hiatt provided bycatch data. Jim Ianelli answered numerous questions about ADMB and wrote the projection model. Rick Methot and David Sampson provided advice on SS2. Anne Hollowed and the GOA Groundfish Plan Team provided reviews of this assessment.

REFERENCES

Albers, W. D., and P. J. Anderson. 1985. Diet of Pacific cod, *Gadus macrocephalus*, and predation on the northern pink shrimp, *Pandalus borealis*, in Pavlof Bay, Alaska. Fish. Bull., U.S. 83:601-610.

Bakkala, R. G., and V. G. Wespestad. 1985. Pacific cod. *In* R. G. Bakkala and L. L. Low (editors),

Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1984, p. 37-49. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-83.

Boldt, J. (editor). 2005. Ecosystem Considerations for 2006. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Calkins, D. G. 1998. Prey of Steller sea lions in the Bering Sea. Biosphere Conservation 1:33-44.

Dorn, M. W., S. Barbeaux, S. Gaichas, M. Guttormsen, B. Megrey, K. Spalinger, and M. Wilkins. 2004. Assessment of walleye pollock in the Gulf of Alaska. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska. p. 35-129. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Dorn, M. W., A. B. Hollowed, E. Brown, B. Megrey, C. Wilson, and J. Blackburn. 2001. Assessment of the walleye Pollock stock in the Gulf of Alaska. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Fournier, D. 1983. An analysis of the Hecate Strait Pacific cod fishery using an age-structured model incorporating density-dependent effects. Can. J. Fish. Aquat. Sci. 40:1233-1243.

Fournier, D. 2005. An introduction to AD Model Builder Version 6.0.2 for use in nonlinear modeling and statistics. Otter Research Ltd. P.O. Box 2040, Sidney BC V8L3S3.

Fournier, D., and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 38:1195-1207.

Fulton, T. W. 1911. The Sovereignty of the Sea; an Historical Account of the Claims of England to the Dominion of the British Seas, and of the Evolution of the Territorial Waters: With Special Reference to the Rights of Fishing and the Naval Salute. William Blackwood and Sons, Edinburgh and London. 799 p.

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

Grant, W. S., C. I. Zhang, and T. Kobayashi. 1987. Lack of genetic stock discretion in Pacific cod (*Gadus macrocephalus*). Can. J. Fish. Aquat. Sci. 44:490-498.

Hare, S. R., and N. J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography 47:103-146.

Hattori, T., Y. Kasurai, and K. Shimazaki. 1992. Maturation and reproductive-cycle of female Pacific cod in waters adjacent to the southern coast of Hokkaido, Japan. Nihon Sujisan Gakkaishi 58:2245-2252.

Ketchen, K.S. 1964. Preliminary results of studies on a growth and mortality of Pacific cod (*Gadus macrocephalus*) in Hecate Strait, British Columbia. J. Fish. Res. Bd. Canada 21:1051-1067.

Lang, G. M., C. W. Derrah, and P. A. Livingston. 2003. Groundfish food habits and predation on commercially important prey species in the Eastern Bering Sea from 1993 through 1996. Alaska Fisheries Science Center Processed Report 2003-04. Alaska Fisheries Science Center, 7600 Sand Point Way NE., Seattle, WA 98115-6349. 351 p.

Livingston, P. A. 1989. Interannual trends in Pacific cod, Gadus macrocephalus, predation on three commercially important crab species in the eastern Bering Sea. Fish. Bull., U.S. 87:807-827.

Livingston, P. A. 1991. Pacific cod. *In* P. A. Livingston (editor), Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1984 to 1986, p. 31-88. U.S. Dept. Commer., NOAA Tech. Memo. NMFS F/NWC-207.

Livingston, P. A. (editor). 2003. Ecosystem Considerations for 2003. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Low, L. L. 1974. A study of four major groundfish fisheries of the Bering Sea. Ph.D. Thesis, Univ. Washington, Seattle, WA 240 p.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., & Francis, R. C.. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78, 1069-1079.

McAllister, M. K., and J. N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54:284-300.

Methot, R. D. 1986. Synthetic estimates of historical abundance and mortality for northern anchovy, *Engraulis mordax*. NMFS, Southwest Fish. Cent., Admin. Rep. LJ 86-29, La Jolla, CA.

Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. Int. N. Pac. Fish. Comm. Bull. 50:259-277.

Methot, R. D. 1998. Application of stock synthesis to NRC test data sets. *In* V. R. Restrepo (editor), Analyses of simulated data sets in support of the NRC study on stock assessment methods, p. 59-80. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-30.

Methot, R. D. 2000. Technical description of the stock synthesis assessment program. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-43, 46 p.

Methot, R. D. 2005a. Technical description of the Stock Synthesis II Assessment Program. Unpubl. manuscr. National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112-2097. 54 p.

Methot, R. D. 2005b. User manual for the assessment program Strock Synthesis 2 (SS2), Model Version 1.19. National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112-2097. 47 p.

National Marine Fisheries Service (NMFS). 2004. Alaska Groundfish Fisheries Final Programmatic Supplemental Environmental Impact Statement. National Marine Fisheries Service, Alaska Region. PO Box 21668, Juneau, AK 99802-1668.

National Marine Fisheries Service (NMFS). 2005. Final environmental impact statement for essential fish habitat identification and conservation in Alaska. National Marine Fisheries Service, Alaska Region. P.O. Box 21668, Juneau, AK 99802-1668.

Pitcher, K. W. 1981. Prey of Steller sea lion, *Eumetopias jubatus*, in the Gulf of Alaska. Fishery Bulletin 79:467-472.

Prentice, R. L. 1976. A generalization of the probit and logit methods for dose response curves. Biometrics 32:761-768.

Ricker, W. E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559-63.

Ricker. W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin 191. Department of the Environment, Canada. 382 p.

Roberson, N. E. 2001. Age determination of Pacific cod (*Gadus macrocephalus*). MS thesis, University of Washington, Seattle, WA. 44 p.

Roberson, N. E., D. K. Kimura, D. R. Gunderson, and A. M. Shimada. 2005. Indirect validation of the age-reading method for Pacific cod (Gadus macrocephalus) using otoliths from marked and recaptured fish. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 103:153-160.

Roff, D. A. 1984. The evolution of life history parameters in teleosts. Can. J. Fish. Aquat. Sci. 41:989-1000.

Rovnina, O. A., N. V. Klovach, A. I. Glubokov, and A. P. Selyutin. 1997. On the biology of Pacific cod (Gadus macrocephalus) in the eastern part of the Sea of Okhotsk. J. Ichthyology 37:21-26.

Royce, W. F. 1972. Introduction to the fishery sciences. Academic Press, New York. 351 p.

Shimada, A. M., and D. K. Kimura. 1994. Seasonal movements of Pacific cod (*Gadus macrocephalus*) in the eastern Bering Sea and adjacent waters based on tag-recapture data. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 92:800-816.

Sinclair, E.S. and T. K. Zeppelin. 2002. Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). Journal of Mammalogy 83(4).

Somerton, D. A. 2004. Do Pacific cod (*Gadus macrocephalus*) and walleye pollock *(Theregra chalcogramma*) lack a herding response to the doors, bridles, and mudclouds of survey trawls? ICES Journal of Marine Science 61:1186-1189.

Stark, J. W. 2004. A comparison of the maturation and growth of female flathead sole in the central Gulf of Alaska and south-eastern Bering Sea. Journal of Fish Biology 64:876-889.

Stark, J. W. 2005. Length and age at maturity, seasonal maturation and growth of Pacific cod (*Gadus macrocephalus*) in the Gulf of Alaska and southeastern Bering Sea. Unpubl. manuscr. Alaska Fisheries Science Center, 7600 Sand Point Way NE., Seattle, WA 98115-6349. 23 p.

Teshima, K. 1985. Maturation of Pacific cod in the eastern Bering Sea. Bulletin of the Japanese Society of Scientific Fisheries 51:21-31.

Thompson, G. G., and M. W. Dorn. 1997. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 121-158. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and M. W. Dorn. 1998. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 113-181. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and M. W. Dorn. 1999. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 151-230. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and M. W. Dorn. 2003. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands Area. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 127-222. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and M. W. Dorn. 2005. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands Area. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. xxx-yyy. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and R. D. Methot. 1993. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 1994, chapter 2. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and A. M. Shimada. 1990. Pacific cod. *In* L. L. Low and R. E. Narita (editors), Condition of groundfish resources of the eastern Bering Sea-Aleutian Islands region as assessed in 1988, p. 44-66. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-178.

Thompson, G. G, and H. H. Zenger. 1993. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 1994, chapter 2. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G, and H. H. Zenger. 1994. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 1995, chapter 2. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and H. H. Zenger. 1995. Pacific cod. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 1996, chapter 2. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. W. Dorn. 1997. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 121-163. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. W. Dorn. 1998. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 91-155. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. W. Dorn. 1999. Pacific cod. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 105-184. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. K. Dorn. 2000. Pacific cod. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska p. 91-110. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. K. Dorn. 2002. Assessment of the Pacific cod stock in the Gulf of Alaska. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (compiler), Stock

Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska p. 89-167. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. K. Dorn. 2003. Assessment of the Pacific cod stock in the Gulf of Alaska. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska p. 149-241. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Thompson, G. G., H. H. Zenger, and M. K. Dorn. 2004. Assessment of the Pacific cod stock in the Gulf of Alaska. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska p. 131-232. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Walters, C. J., and D. Ludwig. 1981. Effects of measurement errors on the assessment of stock-recruitment relationships. Can. J. Fish. Aquat. Sci. 38:704-710.

Welch, D. W., and R. P. Foucher. 1988. A maximum-likelihood methodology for estimating length-at-maturity with application to Pacific cod (*Gadus macrocephalus*) population dynamics. Can. J. Fish. Aquat. Sci. 45:333-343.

Wespestad, V., R. Bakkala, and J. June. 1982. Current abundance of Pacific cod (*Gadus macrocephalus*) in the eastern Bering Sea and expected abundance in 1982-1986. NOAA Tech. Memo. NMFS F/NWC-25, 26 p.

Westrheim, S. J. 1996. On the Pacific cod (*Gadus macrocephalus*) in British Columbia waters, and a comparison with Pacific cod elsewhere, and Atlantic cod (*G. morhua*). Can. Tech. Rep. Fish. Aquat. Sci. 2092. 390 p.

Wilderbuer, T. K. and G. E. Walters. 2003. Rock sole. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 409-462. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Yang, M-S. 2004. Diet changes of Pacific cod (Gadus macrocephalus) in Pavlof Bay associated with climate changes in the Gulf of Alaska between 1980 and 1995. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 102:400-405.

Tables

Table 2.1a—Summary of catches (t) of Pacific cod by fleet sector and gear type, 1964-1990. All catches since 1980 include discards. Jt. Vent. = joint venture.

	Fleet Sector			Gear Type				
Year	Foreign	Jt. Vent.	Domestic	Trawl	Longline	Pot	Other	Total
1964	196	0	0	56	140	0	0	196
1965	599	0	0	172	427	0	0	599
1966	1,376	0	0	396	980	0	0	1,376
1967	2,225	0	0	640	1,585	0	0	2,225
1968	1,046	0	0	301	745	0	0	1,046
1969	1,335	0	0	384	951	0	0	1,335
1970	1,805	0	0	519	1,286	0	0	1,805
1971	523	0	0	150	373	0	0	523
1972	3,513	0	0	1,010	2,503	0	0	3,513
1973	5,963	0	0	1,715	4,248	0	0	5,963
1974	5,182	0	0	1,491	3,691	0	0	5,182
1975	6,745	0	0	1,940	4,805	0	0	6,745
1976	6,764	0	0	1,946	4,818	0	0	6,764
1977	2,267	0	0	652	1,615	0	0	2,267
1978	11,370	7	813	4,547	6,800	0	843	12,190
1979	13,173	711	1,020	3,629	9,545	0	1,730	14,904
1980	34,245	466	634	6,464	27,780	0	1,101	35,345
1981	34,969	58	1,104	10,484	25,472	0	175	36,131
1982	26,937	193	2,335	6,679	22,667	0	119	29,465
1983	29,777	2,426	4,337	9,512	26,756	0	272	36,540
1984	15,896	4,649	3,353	8,805	14,844	0	249	23,898
1985	9,086	2,266	3,076	4,876	9,411	2	139	14,428
1986	15,211	1,357	8,444	6,850	17,619	141	402	25,012
1987	0	1,978	30,961	22,486	8,261	642	1,550	32,939
1988	0	1,661	32,141	27,145	3,933	1,422	1,302	33,802
1989	0	0	43,293	37,637	3,662	376	1,618	43,293
1990	0	0	72,517	59,188	5,919	5,661	1,749	72,517

Table 2.1b—Summary of catches (t) of Pacific cod since 1991 by management jurisdiction and gear type. Longl. = longline, Subt. = subtotal. All entries include discards. Catches for 2005 are complete through early October.

	Federal					State			
Year	Trawl	Longl.	Pot	Other	Subt.	Pot	Other	Subt.	Total
1991	58,093	7,656	10,464	115	76,328	0	0	0	76,328
1992	54,593	15,675	10,154	325	80,746	0	0	0	80,746
1993	37,806	8,962	9,708	11	56,487	0	0	0	56,487
1994	31,446	6,778	9,160	100	47,484	0	0	0	47,484
1995	41,875	10,978	16,055	77	68,985	0	0	0	68,985
1996	45,991	10,196	12,040	53	68,280	0	0	0	68,280
1997	48,405	10,977	9,065	26	68,474	7,224	1,319	8,542	77,017
1998	41,569	10,011	10,510	29	62,120	9,088	1,316	10,404	72,524
1999	37,167	12,362	19,015	70	68,613	12,075	1,096	13,171	81,784
2000	25,457	11,667	17,351	54	54,528	10,388	1,643	12,031	66,559
2001	24,382	9,913	7,171	155	41,621	7,836	2,084	9,920	51,541
2002	19,809	14,666	7,694	176	42,345	10,423	1,714	12,137	54,483
2003	18,799	9,475	12,675	88	41,037	8,031	3,429	11,461	52,498
2004	17,351	10,337	13,671	310	17,351	10,117	2,804	12,922	54,591
2005	14,252	5,089	10,844	188	30,372	9,660	2,818	12,478	42,850

Table 2.2—History of Pacific cod ABC, TAC, total catch, and type of stock assessment model used to recommend ABC. ABC was not used in management of GOA groundfish prior to 1986. Catch for 2005 is current through early October. The values in the column labeled "TAC" correspond to "optimum yield" for the years 1980-1986, "target quota" for the year 1987, and true TAC for the years 1988-2005. "SS1" refers to Stock Synthesis 1. Each cell in the "Stock Assessment Model" column lists the type of model used to recommend the ABC in the corresponding row, meaning that the model was produced in the year previous to the one listed in the corresponding row.

Year	ABC	TAC	Catch	Stock Assessment Model (from previous year)
1980	n/a	60,000	35,345	n/a
1981	n/a	70,000	36,131	n/a
1982	n/a	60,000	29,465	n/a
1983	n/a	60,000	36,540	n/a
1984	n/a	60,000	23,898	n/a
1985	n/a	60,000	14,428	n/a
1986	136,000	75,000	25,012	survey biomass
1987	125,000	50,000	32,939	survey biomass
1988	99,000	80,000	33,802	survey biomass
1989	71,200	71,200	43,293	stock reduction analysis
1990	90,000	90,000	72,517	stock reduction analysis
1991	77,900	77,900	76,328	stock reduction analysis
1992	63,500	63,500	80,746	stock reduction analysis
1993	56,700	56,700	56,487	stock reduction analysis
1994	50,400	50,400	47,484	stock reduction analysis
1995	69,200	69,200	68,985	SS1 model (length-based data)
1996	65,000	65,000	68,280	SS1 model (length-based data)
1997	81,500	69,115	77,017	SS1 model (length-based data)
1998	77,900	66,060	72,524	SS1 model (length-based data)
1999	84,400	67,835	81,784	SS1 model (length-based data)
2000	76,400	58,715	66,559	SS1 model (length-based data)
2001	67,800	52,110	51,541	SS1 model (length-based data)
2002	57,600	44,230	54,483	SS1 model (length-based data)
2003	52,800	40,540	52,498	SS1 model (length-based data)
2004	62,810	48,033	54,591	SS1 model (length-based data)
2005	58,100	44,433	42,850	SS1 model (length-based data)

Table 2.3—History of GOA Pacific cod allocations by regulatory area.

	Regulatory Area		
Year(s)	Western	Central	Eastern
1977-1985	28	56	16
1986	40	44	16
1987	27	56	17
1988-1989	19	73	8
1990	33	66	1
1991	33	62	5
1992	37	61	2
1993-1994	33	62	5
1995-1996	29	66	5
1997-1999	35	63	2
2000-2001	36	57	7
2002 (ABC)	39	55	6
2002 (TAC)	38	56	6
2003 (ABC)	39	55	6
2003 (TAC)	38	56	6
2004 (ABC)	36	57	7
2004 (TAC)	35.3	56.5	8.2
2005 (ABC)	36	57	7
2005 (TAC)	35.3	56.5	8.2

Table 2.4a—Pacific cod discard rates by area, target species/group, and year for the period 1991-2002 (see Table 2.4b for the period 2003-2004). The discard rate is the ratio of discarded Pacific cod catch to total Pacific cod catch for a given area/target/year combination. An empty cell indicates that no Pacific cod were caught in that area/target/year combination. Note that the absolute amount of discards may be small even if the discard rate is large.

Target species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Arrowtooth flounder		0.98	0.59	0.00	0.10	0.09	0.00	1.00	0.63	0.06		0.00
Atka mackerel				0.81	1.00	0.00						
Deepwater Flat	1.00			0.43	0.00	0.68	0.53	0.00	0.36	0.00	0.75	
Flathead sole				1.00		0.07	0.99	0.00		0.29	0.75	0.00
Other species	1.00	0.15	0.63		0.10	0.91	0.00	0.00	0.96	0.01	0.00	0.00
Pacific cod	0.05	0.03	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0.00	0.02	0.02
Pollock	0.82	0.59	0.15	0.15	0.95	0.17	0.98	0.75	0.89	0.44	0.00	1.00
Rex sole					0.16	0.25	0.61	0.57				1.00
Rockfish	0.15	0.11	0.13	0.16	0.11	0.13	0.14	0.17	0.17	0.17	0.00	0.04
Sablefish	0.84	0.72	0.72	0.77	0.55	0.78	0.54	0.66	0.52	0.25	0.27	0.22
Shallow-water flatfish	0.43	0.00	0.00	0.87	0.00	0.97	0.00	1.00	0.74	0.28		1.00
Unknown	0.01					1.00	1.00	1.00		1.00		
All targets	0.03	0.03	0.04	0.02	0.03	0.02	0.03	0.01	0.02	0.00	0.02	0.02

Table 2.4b—Pacific cod discard rates by area, target species/group, and year for the period 2003-2004 (see Table 2.4a for the period 1991-2002; note that the IFQ halibut target does not exist in Table 2.4a). The discard rate is the ratio of discarded Pacific cod catch to total Pacific cod catch for a given area/target/year combination. An empty cell indicates that no Pacific cod were caught in that area/target/year combination. Note that the absolute amount of discards may be small even if the discard rate is large.

Target species/group	2003	2004
Arrowtooth flounder	0.40	0.27
Atka mackerel		
Deepwater flatfish	0.01	0.25
Flathead sole	0.25	0.33
IFQ halibut	0.61	0.59
Other species	0.16	0.07
Pacific cod	0.01	0.01
Pollock	0.05	0.26
Rex sole	0.22	0.15
Rockfish	0.14	0.04
Sablefish	0.64	0.23
Shallowwater flatfish	0.61	0.53
Unknown		
All targets	0.05	0.02

Table 2.5—Catch of Pacific cod by year, gear, and period as used in the stock assessment model. Jig catches have been merged with other gear types. Catches for period 3 in 2005 are based on 2002-2004 averages.

	Trawl			Longline			Pot		
Year	Period	Period	Period	Period	Period	Period	Period	Period	Period
1964	16	14	27	82	16	42	0	0	0
1965	48	42	82	249	50	127	0	0	0
1966	111	96	189	572	115	293	0	0	0
1967	180	155	305	926	186	473	0	0	0
1968	84	73	144	435	88	222	0	0	0
1969	108	93	183	555	112	284	0	0	0
1970	146	126	248	751	151	384	0	0	0
1971	42	36	72	218	44	111	0	0	0
1972	284	245	482	1461	294	747	0	0	0
1973	481	415	819	2480	499	1268	0	0	0
1974	418	361	711	2156	434	1102	0	0	0
1975	544	470	926	2806	565	1434	0	0	0
1976	546	471	929	2814	566	1438	0	0	0
1977	183	158	311	943	190	482	0	0	0
1978	916	790	1558	4720	950	2413	0	0	0
1979	1063	917	1809	5480	1103	2801	0	0	0
1980	2764	2384	4702	14245	2868	7282	0	0	0
1981	387	3532	6565	10504	5312	9656	0	0	0
1982	1143	2041	3495	9912	2890	9865	0	0	0
1983	2861	2844	3807	10960	4651	11145	0	0	0
1984	3429	2008	3368	11840	425	2579	0	0	0
1985	2427	571	1878	9127	6	280	0	0	0
1986	2999	431	3420	15927	460	1373	0	0	0
1987	5377	7928	9181	5343	983	1935	219	141	282
1988	16021	6569	4555	2979	507	447	1081	23	318
1989	24614	12857	166	2378	356	928	241	103	32
1990	43279	7514	8395	5557	109	253	2577	1008	2076
1991	55977	631	1484	7296	332	142	9591	0	873
1992	51911	1189	1494	12946	802	2251	9672	14	468
1993	33632	2624	1550	8485	307	181	9689	18	0
1994	29152	1421	873	6696	48	133	8742	0	418
1995	38476	802	2597	10662	166	227	15419	43	592
1996	41450	3048	1493	9991	152	106	12014	27	0
1997	40727	1638	6040	10931	967	424	14007	475	1807
1998	34690	3679	3200	10566	510	280	18479	0	1119
1999	30124	1501	5542	12782	555	191	25167	3374	2548
2000	22133	2574	750	12758	436	169	26947	154	638
2001	15234	2035	7113	11199	662	291	13047	37	1923
2002	15829	2705	1276	12963	259	3334	13602	83	4431
2003	10996	2565	5239	8416	407	768	20997	24	3087
2004	9137	2091	6339	8236	109	2027	24250	4	4461
2005	9561	1791	4285	3757	116	2043	22084	4	3993

Table 2.6—Pacific cod length sample sizes from the commercial fisheries.

	Trawl Fishery			Longline Fishery			Pot Fishery		
Year	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1977	0	210	0	0	0	0	0	0	0
1978	0	0	634	0	0	18670	0	0	0
1979	0	0	0	0	0	14460	0	0	0
1980	0	0	783	0	0	18671	0	0	0
1981	0	0	461	0	0	19308	0	0	0
1982	0	0	1390	0	0	22856	0	0	0
1983	0	0	2896	0	0	127992	0	0	0
1984	0	0	1039	0	0	47485	0	0	0
1985	0	0	0	0	0	10141	0	0	0
1986	0	0	0	0	0	87304	0	0	0
1987	0	0	0	0	0	387	0	0	0
1988	0	0	0	0	0	2432	0	0	0
1989	660	0	312	0	0	0	0	0	0
1990	25396	10892	12025	9925	0	0	2783	2920	10711
1991	38514	0	131	12551	143	0	49453	139	0
1992	39683	0	2255	28817	577	3603	37177	664	5013
1993	26844	0	0	11748	0	0	20866	0	0
1994	12579	0	0	5201	0	0	16342	0	217
1995	26039	120	2402	24635	0	0	46625	0	1233
1996	17858	0	0	14706	0	0	35256	432	0
1997	22822	225	3746	7239	119	154	26880	252	1537
1998	52448	3465	6763	7981	410	148	31569	291	2902
1999	11550	232	1101	9013	86	396	33876	3719	3656
2000	6951	425	69	11426	47	20	28991	902	277
2001	6115	665	4560	12642	145	141	23290	0	3925
2002	6285	808	309	9583	134	3009	17235	0	4674
2003	4129	1187	1761	7941	375	2301	12019	9343	6168
2004	2598	471	2545	6647	337	2906	16676	0	4817
2005	1760	496	1065	5978	417	0	17124	49	72

Table 2.7a—Length frequencies of Pacific cod in the pre-1987 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1977	2	0	0	0	0	0	0	0	0	0	4	16	21	38	49	38	8	6	16	10	3	1	0	0	0	0
1978	3	0	0	0	0	0	1	1	5	9	5	4	14	40	93	125	106	106	59	39	23	3	1	0	0	0
1980	3	0	0	0	0	0	0	1	0	0	0	1	6	60	162	96	71	91	134	93	48	17	3	0	0	0
1981	3	0	0	0	0	0	0	0	0	0	0	5	29	85	148	145	47	2	0	0	0	0	0	0	0	0
1982	3	0	0	0	0	0	0	0	0	1	3	26	39	118	255	280	294	174	111	52	14	15	5	2	1	0
1983	3	0	0	0	0	0	0	1	2	1	11	24	106	332	388	403	439	375	310	252	143	76	23	7	3	0
1984	3	0	0	0	0	0	0	0	0	1	7	49	135	265	127	140	122	70	47	23	19	13	10	6	4	1

Table 2.7b—Length frequencies of Pacific cod in the 1987-1999 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1989	1	0	0	0	0	0	0	0	0	0	0	0	0	5	52	175	248	141	30	5	3	1	0	0	0	0
1989	3	0	0	0	0	0	6	28	41	29	17	3	3	16	37	50	39	14	4	6	2	7	4	4	2	0
1990	1	1	0	1	1	12	7	15	76	119	160	201	228	574	1322	3188	4903	4680	3357	2562	1572	1311	754	256	70	26
1990	2	41	36	15	0	0	1	0	1	3	31	81	169	419	954	1892	2562	2555	1323	510	181	90	24	3	0	1
1990	3	0	0	0	1	2	0	7	13	39	62	180	427	1447	1239	1240	1744	1726	1269	1101	860	434	133	67	18	16
1991	1	0	1	2	2	2	7	63	142	163	226	235	346	1905	3794	4421	5618	6609	5126	3629	2613	1621	1016	618	273	82
1991	3	0	0	0	0	0	0	0	0	0	0	0	0	2	5	15	15	24	28	24	6	9	3	0	0	0
1992	1	0	0	0	1	4	13	21	78	261	567	921	1084	1796	3160	4966	6796	5825	4257	3355	2548	1734	1143	749	280	124
1992	3	0	0	0	0	0	1	8	21	18	7	64	214	479	502	415	211	145	77	63	28	2	0	0	0	0
1993	1	0	0	1	4	2	5	4	58	234	469	547	544	2077	3445	3613	4744	4817	2832	1430	846	491	345	214	87	35
1994	1	0	0	0	0	0	0	0	7	31	83	115	138	499	1022	1734	2551	2642	1659	944	490	347	167	82	44	24
1995	1	0	0	0	0	0	0	1	8	60	91	204	316	1000	2363	3475	4628	5820	4040	1903	993	533	300	164	74	66
1995	2	0	0	0	0	0	1	1	0	0	1	1	9	26	15	20	19	19	6	2	0	0	0	0	0	0
1995	3	0	0	0	0	0	1	14	14	16	14	12	7	51	140	222	583	642	470	153	50	9	3	1	0	0
1996	1	0	0	0	1	6	28	39	64	105	187	250	230	290	690	1575	2924	3744	2948	1949	1237	793	437	217	96	48
1997	1	0	0	3	8	12	12	5	44	123	300	357	276	807	2271	2841	2945	4449	3874	2247	1140	562	288	174	67	17
1997	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	9	28	54	78	46	8	1	0	0	0	0
1997	3	0	0	0	1	3	8	29	49	100	62	56	96	318	374	477	823	589	342	262	100	46	10	1	0	0
1998	1	0	0	0	1	5	7	9	57	293	746	989	832	2009	4345	5676	9100	10443	8205	4970	2379	1278	652	327	98	27
1998	2	0	0	1	3	0	0	1	1	0	2	13	49	196	310	656	854	720	419	148	60	26	1	4	0	1
1998	3	3	4	0	0	5	35	112	133	209	209	146	225	1027	1139	906	1048	747	438	214	112	45	4	1	1	0
1999	1	0	0	1	4	4	4	4	21	73	144	184	215	453	1052	1797	2194	2226	1644	851	397	173	61	30	14	4
1999	2	0	0	0	0	0	5	0	0	0	0	0	1	5	8	34	52	65	36	18	6	2	0	0	0	0
1999	3	0	0	0	0	0	1	0	2	3	6	2	9	14	31	59	271	281	213	124	54	19	10	2	0	0

Table 2.7c—Length frequencies of Pacific cod in the post-1999 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	0	2	10	29	74	84	99	250	787	1091	1429	1310	806	475	243	163	72	20	6	1
2000	2	0	0	0	0	0	0	0	3	1	0	9	21	31	30	56	88	100	48	20	14	4	0	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	2	6	13	11	7	6	9	9	5	1	0	0	0	0	0
2001	1	0	1	2	2	1	1	4	7	37	97	158	146	287	694	947	1166	1183	803	336	147	63	22	8	1	2
2001	2	0	0	0	0	0	5	5	5	0	2	6	18	48	45	68	144	147	99	31	20	16	6	0	0	0
2001	3	0	0	0	0	1	0	10	45	100	154	123	80	303	633	669	783	677	496	301	122	46	14	3	0	0
2002	1	0	0	0	0	1	3	5	7	36	118	232	298	497	441	756	975	1123	936	508	218	80	36	8	5	2
2002	2	0	0	0	0	0	0	0	1	3	1	5	24	145	195	101	114	117	55	24	19	3	1	0	0	0
2002	3	0	0	0	0	0	0	0	3	4	6	12	14	36	39	49	51	37	21	12	12	8	4	1	0	0
2003	1	0	0	0	0	0	1	4	13	34	99	150	130	214	609	963	645	433	358	221	133	85	20	10	6	1
2003	2	0	0	0	2	1	2	10	8	7	19	27	59	193	170	162	220	136	101	37	26	5	1	1	0	0
2003	3	0	0	0	0	0	1	9	5	9	11	12	43	193	303	291	405	249	139	53	25	8	4	1	0	0
2004	1	0	0	1	0	2	1	0	6	24	52	65	74	179	433	525	518	413	167	86	35	11	4	2	0	0
2004	2	0	0	0	0	0	0	0	2	0	0	1	6	9	24	83	124	106	62	30	16	5	2	1	0	0
2004	3	0	0	0	0	0	0	4	9	7	1	4	30	156	284	383	465	532	405	166	70	20	9	0	0	0
2005	1	0	0	0	0	0	0	0	2	5	7	26	24	58	98	177	318	437	300	143	75	51	21	8	8	2
2005	2	0	0	0	0	2	2	2	2	4	8	21	22	8	7	41	124	126	73	36	10	7	1	0	0	0
2005	3	0	0	0	0	0	0	0	0	1	3	10	22	17	12	32	131	266	274	164	82	36	11	4	0	0

Table 2.8a–Length frequencies of Pacific cod in the pre-1987 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1978	3	0	0	0	0	0	0	0	0	7	38	91	276	1160	2235	3077	4051	3359	2139	1261	696	224	49	6	1	0
1979	3	0	0	0	0	0	0	1	6	35	113	285	475	1124	1327	1744	2148	2534	2258	1401	651	271	75	12	0	0
1980	3	0	0	0	0	0	0	0	1	2	43	256	1184	3776	3199	1989	1555	1854	1998	1630	787	276	99	19	2	1
1981	3	0	0	0	0	0	0	0	0	9	29	83	263	1558	4685	5824	3243	1485	844	570	379	199	101	28	8	0
1982	3	0	0	0	0	0	0	0	5	40	106	280	498	1945	3992	5101	4586	3115	1729	815	351	181	80	26	6	0
1983	3	0	0	0	0	0	0	0	3	24	164	728	2661	11515	21037	24663	22224	17602	13130	7842	3868	1638	588	234	63	8
1984	3	0	0	0	0	0	1	1	5	40	135	341	885	4389	9372	10579	7666	4722	3612	2572	1666	958	380	134	23	4
1985	3	0	0	0	0	1	0	8	45	114	206	316	440	1036	990	1847	2170	1294	626	462	294	186	89	14	3	0
1986	3	0	0	0	0	0	0	0	10	133	387	487	681	2963	6979	11599	12075	10988	13158	12084	7943	4112	2254	1025	346	80

Table 2.8b—Length frequencies of Pacific cod in the 1987-1999 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1987	3	0	0	0	0	0	0	0	1	1	4	9	17	49	102	109	72	15	6	0	1	1	0	0	0	0
1988	3	0	0	0	0	0	0	0	1	2	17	58	76	252	580	662	412	165	115	39	27	13	3	6	1	3
1990	1	0	0	0	0	0	0	2	2	6	28	82	57	219	511	991	1633	1999	1535	1173	850	549	186	69	30	3
1991	1	0	0	0	0	0	0	0	1	3	8	56	155	670	1351	1839	2473	2486	1740	909	411	229	119	49	23	29
1991	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	16	34	50	22	12	4	1	0	3	0	0
1992	1	0	0	0	0	0	2	3	8	20	57	137	333	1078	2326	4103	5900	4910	3817	2585	1598	906	580	306	103	45
1992	2	0	0	0	0	0	0	0	0	1	2	6	8	13	76	84	119	145	71	28	11	11	2	0	0	0
1992	3	0	0	0	0	0	0	0	1	2	0	11	7	68	185	466	986	1130	541	142	43	15	1	2	2	1
1993	1	0	0	0	1	3	6	9	5	8	18	43	67	357	924	1503	2077	1959	1226	1036	947	856	413	163	75	52
1994	1	0	0	0	0	0	0	0	0	0	1	4	20	166	500	630	1000	1065	788	450	213	167	93	61	26	17
1995	1	0	0	0	0	1	0	3	2	3	24	96	173	692	1662	2521	4264	5252	4025	2628	1606	874	421	212	117	59
1996	1	0	0	0	0	0	0	1	4	21	42	54	79	260	516	1268	2763	3858	3178	1627	583	265	109	48	26	4
1997	1	0	0	0	0	0	0	0	0	3	3	10	12	159	559	925	1267	1575	1431	791	317	118	46	16	6	1
1997	2	0	0	0	0	0	0	0	0	0	0	0	0	0	4	19	27	24	28	15	2	0	0	0	0	0
1997	3	0	0	0	0	0	0	0	0	1	0	1	7	34	17	30	41	12	5	5	1	0	0	0	0	0
1998	1	0	0	0	0	0	0	0	0	2	9	18	53	277	748	1015	1458	1548	1197	833	473	243	78	27	2	0
1998	2	0	0	0	0	0	0	0	0	0	0	0	0	7	28	34	80	116	79	48	8	6	3	0	1	0
1998	3	0	0	0	0	0	0	0	0	0	0	1	0	0	6	18	29	35	38	12	7	1	1	0	0	0
1999	1	0	0	0	0	0	0	0	0	3	6	20	60	254	707	1385	1802	1679	1243	881	474	268	132	62	22	15
1999	2	0	0	0	0	0	0	0	0	0	0	0	0	0	21	36	15	8	6	0	0	0	0	0	0	0
1999	3	0	0	0	0	0	0	0	0	0	0	0	1	17	26	58	67	99	53	48	12	9	1	3	2	0

Table 2.8c–Length frequencies of Pacific cod in the post-1999 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	0	0	1	2	3	2	25	197	797	1697	2548	2714	1747	946	422	179	97	36	10	3
2000	2	0	0	0	0	0	0	0	0	0	0	1	1	1	7	11	13	9	3	1	0	0	0	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7	10	2	0	0	0	0	0	0	0	0
2001	1	0	0	0	0	0	0	1	1	3	6	33	82	296	915	1969	2850	3074	1919	906	358	126	60	34	6	3
2001	2	0	0	0	0	0	0	0	0	0	0	1	4	3	9	8	24	43	18	14	12	6	2	1	0	0
2001	3	0	0	0	0	0	0	0	0	0	0	0	0	1	13	13	27	35	28	18	3	1	1	1	0	0
2002	1	0	0	0	0	1	0	0	5	3	13	32	77	246	542	1250	1849	2208	1712	939	447	161	69	21	7	1
2002	2	0	0	0	0	0	0	0	0	0	0	0	2	2	7	18	21	24	23	22	8	3	3	0	1	0
2002	3	0	0	0	0	1	2	9	24	16	16	18	38	103	279	424	618	622	440	263	95	31	8	0	2	0
2003	1	0	0	0	0	0	0	0	0	5	7	30	92	385	800	1337	1415	1523	1097	626	382	149	58	26	9	0
2003	2	0	0	0	0	0	0	0	0	0	1	3	1	5	18	47	47	76	60	45	37	27	7	0	1	0
2003	3	0	0	0	0	0	0	0	0	0	0	3	16	47	224	378	500	468	276	182	102	59	29	12	4	1
2004	1	0	0	0	0	0	0	0	0	0	1	4	16	149	654	1188	1563	1367	803	434	257	129	55	19	7	1
2004	2	0	0	0	0	0	0	0	0	0	1	1	3	12	35	46	74	60	34	40	17	8	2	2	1	1
2004	3	0	0	0	0	0	0	0	0	0	0	4	4	31	203	505	694	633	407	230	96	62	23	10	3	1
2005	1	0	0	0	0	0	0	0	0	0	1	2	7	75	386	917	1466	1428	796	410	235	152	75	26	2	0
2005	2	0	0	0	0	0	0	0	0	0	0	0	0	2	14	57	99	91	51	37	27	14	13	7	5	0

Table 2.9a—Length frequencies of Pacific cod in the 1987-1999 pot fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1990	1	0	0	0	0	0	0	0	0	0	0	0	0	30	141	351	679	766	426	208	76	54	33	12	6	1
1990	2	0	0	0	0	0	0	0	0	0	0	1	3	39	144	525	845	748	382	151	62	14	3	2	1	0
1990	3	0	0	0	0	0	0	0	0	0	2	42	167	438	630	1172	1994	2355	1732	1139	579	313	123	23	2	0
1991	1	0	0	0	0	0	0	0	1	2	16	44	87	799	2413	5253	11348	13970	9321	4071	1403	487	180	49	8	1
1991	2	0	0	0	0	0	0	0	0	0	0	0	0	1	8	11	23	31	45	11	6	2	1	0	0	0
1992	1	0	0	0	0	0	0	0	1	10	29	58	148	700	2092	5494	9467	9042	5461	2671	1248	509	190	45	11	1
1992	2	0	0	0	0	0	0	0	0	0	0	0	1	10	45	81	118	164	118	71	34	12	5	4	0	1
1992	3	0	0	0	0	0	0	0	0	0	1	7	24	91	191	489	1073	1337	898	545	222	93	35	7	0	0
1993	1	0	0	0	0	0	0	0	0	0	0	13	51	319	1173	2529	4897	5815	3641	1546	566	201	78	28	7	2
1994	1	0	0	0	0	0	0	0	0	0	0	3	26	196	943	2218	4052	4217	2759	1228	428	160	71	28	13	0
1994	3	0	0	0	0	0	0	0	0	0	0	0	1	16	59	56	32	19	14	6	4	2	4	2	2	0
1995	1	0	0	0	0	0	0	0	0	1	4	12	33	607	2329	4778	9405	12541	8610	4502	2120	1026	403	170	59	25
1995	3	0	0	0	0	0	0	0	0	0	0	0	0	8	51	200	394	274	152	74	40	26	8	5	1	0
1996	1	0	0	0	0	0	0	0	2	4	6	5	23	174	954	3199	6690	9720	8399	3889	1431	489	184	67	15	5
1996	2	0	0	0	0	0	0	0	0	0	0	0	0	7	24	105	130	55	36	31	20	12	8	1	2	1
1997	1	6	0	1	1	4	9	12	18	43	45	43	53	263	969	2843	6289	7541	5200	2299	750	268	151	50	19	3
1997	2	0	0	0	0	0	0	0	0	0	0	0	0	0	5	26	84	82	38	9	5	2	1	0	0	0
1997	3	0	0	0	0	0	0	0	0	0	0	0	4	18	46	90	228	440	390	206	64	29	16	5	1	0
1998	1	0	0	0	0	0	0	0	2	0	1	14	19	281	1081	2513	6362	8088	6459	4003	1699	660	257	97	24	9
1998	2	0	0	0	0	0	0	0	0	0	0	0	0	1	9	31	51	60	64	38	15	11	7	3	0	1
1998	3	0	0	0	0	0	0	0	3	2	7	7	9	62	126	259	477	623	640	362	184	74	33	15	18	1
1999	1	0	0	0	0	0	0	0	0	1	1	15	51	392	1769	4157	7042	8712	6480	2980	1313	586	216	102	42	17
1999	2	0	0	0	0	0	0	0	0	0	0	0	0	7	56	317	653	720	838	626	306	131	48	11	5	1
1999	3	0	0	0	1	0	0	0	1	0	1	0	8	65	188	402	824	858	648	339	166	75	48	24	6	2

Table 2.9b—Length frequencies of Pacific cod in the post-1999 pot fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	3	2	0	3	1	9	41	464	1839	3998	6894	6987	4694	2237	1055	454	203	73	25	9
2000	2	0	0	0	0	0	0	0	0	0	0	0	0	1	7	76	374	316	104	17	5	0	2	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	3	7	17	73	105	55	13	2	1	1	0	0	0
2001	1	1	0	0	0	0	0	0	1	0	4	13	62	310	1339	3324	6205	6366	3540	1202	525	222	106	49	16	5
2001	3	0	0	0	0	0	0	0	0	0	0	3	10	104	389	730	956	954	553	134	56	26	3	4	1	2
2002	1	0	0	0	0	0	0	0	0	0	0	15	39	323	1192	2507	3864	4315	3048	1245	427	159	68	24	8	1
2002	3	0	0	0	0	0	0	0	1	0	2	2	17	133	312	580	926	982	841	479	217	106	53	16	6	1
2003	1	0	0	0	0	0	1	0	2	3	9	46	82	369	1203	2059	2566	2267	1750	945	442	167	63	28	14	3
2003	2	0	0	0	0	0	0	0	0	0	0	0	9	144	717	1682	2186	2040	1421	689	281	113	39	15	5	2
2003	3	0	0	0	0	0	0	0	0	0	0	2	15	204	744	1232	1416	1093	768	392	181	78	35	7	0	1
2004	1	0	0	0	0	0	0	0	0	0	1	2	26	422	1629	3197	3869	3233	1952	1132	599	344	177	64	29	0
2004	3	0	0	0	0	0	0	0	0	0	0	6	11	130	502	1147	1144	812	485	269	157	85	40	18	9	2
2005	1	0	0	0	0	0	0	0	0	0	1	3	10	249	1298	2984	4337	3695	2123	1010	662	340	253	113	33	13
2005	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	18	27	0	0	0	0	0	0	0
2005	3	0	0	0	0	0	0	0	0	0	0	0	0	0	5	17	25	11	5	2	4	2	0	1	0	0

Table 2.10—Length frequencies of Pacific cod in the trawl survey by year (all surveys take place in period 2). Numbers shown are survey estimates of population numbers at length, rescaled so that the sum equals the total size of the actual survey length sample. Note: The values for 1984-2003 have been recalibrated since last year's assessment.

		Length Bin																								
Yr.	Per.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1984	2	718	13	13	39	82	213	417	454	588	549	972	1124	2420	3577	2827	1631	772	329	299	233	96	34	11	1	1
1987	2	123	22	35	127	130	105	130	536	1128	1652	1823	1254	1721	3310	2947	2196	1300	597	273	96	57	14	10	3	2
1990	2	374	1	15	90	195	134	75	114	223	276	414	549	1645	1812	1928	1632	934	559	207	137	70	35	13	7	1
1993	2	46	20	307	372	233	284	191	261	445	513	800	1275	1998	2538	3079	2105	1476	694	294	109	59	22	17	10	1
1996	2	4	36	239	883	1177	891	240	91	193	314	459	458	732	1037	1378	1656	1388	604	225	86	40	30	15	12	2
1999	2	1	16	67	151	164	96	74	140	308	349	398	576	1085	1129	1432	1194	783	411	166	58	27	7	9	4	0
2001	2	6	57	105	192	233	320	229	187	183	310	455	437	749	753	726	764	534	302	133	52	19	15	5	5	0
2003	2	1	5	28	76	137	87	66	64	160	296	495	753	1280	1319	1624	1308	698	372	190	113	36	15	3	0	0
2005	2	10	10	106	182	195	113	69	101	188	242	203	216	422	847	1524	1257	485	214	103	72	45	88	98	45	7

Table 2.11—Age composition estimates from the 2003 GOA bottom trawl survey (expressed as numbers per 10,000).

Age	Number
1	336
2	343
3	1810
4	2676
5	2735
6	1327
7	487
8	226
9	33
10	9
11	9
12	9

Table 2.12—Biomass, standard error, 95% confidence interval (CI), and population numbers of Pacific cod estimated by NMFS' bottom trawl survey of the GOA. All figures except population numbers are expressed in metric tons. Population numbers are expressed in terms of individual fish.

Year	Biomass	Std. Error	Lower 95% CI	Upper 95% CI	Numbers
1984	550,971	80,385	393,417	708,525	320,524,532
1987	394,987	51,325	294,390	495,585	247,020,039
1990	416,788	63,706	291,925	541,651	212,131,668
1993	409,848	73,431	265,924	553,772	231,963,103
1996	538,154	107,736	326,991	749,316	319,068,011
1999	306,413	38,699	230,563	382,263	166,583,892
2001	257,614	52,457	154,799	360,429	158,424,464
2003	297,402	44,549	210,086	384,717	159,749,380
2005	308,102	80,862	149,613	466,591	139,860,010

Note: The 2001 survey did not cover the eastern GOA. To account for the missing stations, the 1999 survey estimates of biomass, biomass variance, and numbers for the eastern GOA were added to the respective 2001values to produce the figures shown in the above table.

Table 2.13—Pacific cod commercial fishery length sample sizes used in the multinomial distribution. (These values correspond to the square roots of the true sample sizes shown in Table 2.6.)

	Trawl Fishery			Longline Fishery			Pot Fishery		
Year	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1977	0	14	0	0	0	0	0	0	0
1978	0	0	25	0	0	137	0	0	0
1979	0	0	0	0	0	120	0	0	0
1980	0	0	28	0	0	137	0	0	0
1981	0	0	21	0	0	139	0	0	0
1982	0	0	37	0	0	151	0	0	0
1983	0	0	54	0	0	358	0	0	0
1984	0	0	32	0	0	218	0	0	0
1985	0	0	0	0	0	101	0	0	0
1986	0	0	0	0	0	295	0	0	0
1987	0	0	0	0	0	20	0	0	0
1988	0	0	0	0	0	49	0	0	0
1989	26	0	18	0	0	0	0	0	0
1990	159	104	110	100	0	0	53	54	103
1991	196	0	11	112	12	0	222	12	0
1992	199	0	47	170	24	60	193	26	71
1993	164	0	0	108	0	0	144	0	0
1994	112	0	0	72	0	0	128	0	15
1995	161	11	49	157	0	0	216	0	35
1996	134	0	0	121	0	0	188	21	0
1997	151	15	61	85	11	12	164	16	39
1998	229	59	82	89	20	12	178	17	54
1999	107	15	33	95	9	20	184	61	60
2000	83	21	8	107	7	4	170	30	17
2001	78	26	68	112	12	12	153	0	63
2002	79	28	18	98	12	55	131	0	68
2003	64	34	42	89	19	48	110	97	79
2004	51	22	50	82	18	54	129	0	69
2005	42	22	33	77	20	0	131	7	8

Table 2.14—Time series of GOA Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated by Models 1, 2, and 3 (M1, M2, and M3). The standard deviation for each estimated spawning biomass ("SB Std. Dev.") is shown for Models 2 and 3. The time series observed by the survey itself is shown on the far right ("Obs.") for comparison to model estimates. All biomass figures are in 1000s of t.

	Age 3+ Biomass			Spawning Biomass			SB Std. Dev.		Survey Biomass			
Year	M1	M2	M3	M1	M2	M3	M2	M3	M1	M2	M3	Obs.
1964		201	253		82	102	12.6	18.9				
1965		201	253		82	102	12.6	18.9				
1966		201	253		82	102	12.6	18.9				
1967		197	248		81	102	12.6	19.0				
1968		190	240		79	100	13.2	19.6				
1969		184	232		77	97	14.7	21.2				
1970		176	222		74	93	16.5	23.2				
1971		168	213		71	89	17.8	24.6				
1972		162	205		68	86	18.5	25.4				
1973		155	197		64	81	18.7	25.5				
1974		149	191		60	77	18.6	25.2				
1975		153	196		58	75	18.4	24.9				
1976		191	247		60	78	18.6	25.4				
1977		208	269		70	91	20.1	28.1				
1978	440	219	282	175	84	109	22.3	32.0				
1979	499	214	276	183	88	114	23.3	33.6				
1980	600	307	401	197	90	118	23.4	34.0				
1981	632	339	452	219	102	137	25.8	38.6				
1982	674	364	492	244	125	169	30.0	46.2				
1983	719	431	588	262	144	197	33.3	52.0				
1984	725	454	624	274	161	223	36.3	57.4	427	358	372	551
1985	726	467	643	285	180	249	39.2	62.2				
1986	733	475	651	288	192	264	40.7	64.2				
1987	771	540	732	287	194	267	40.7	63.9	408	399	401	395
1988	774	564	759	288	202	277	40.9	64.6				
1989	779	561	750	294	217	294	41.7	66.1				
1990	795	591	785	290	221	298	41.4	65.7	432	423	421	417
1991	777	561	750	277	213	289	40.7	64.8				
1992	781	579	776	271	206	281	40.0	64.1				
1993	773	577	777	273	203	280	39.9	64.3	439	422	426	410
1994	770	573	768	283	215	294	40.6	65.5				
1995	764	575	764	285	223	301	40.6	65.4				
1996	731	548	729	273	214	289	39.3	63.4	397	387	385	538
1997	708	511	683	258	201	273	37.8	60.9				
1998	682	509	683	243	184	252	36.3	58.5				
1999	641	476	643	232	176	243	35.9	57.7	346	328	335	306
2000	590	432	591	217	165	231	35.6	57.0				
2001	568	411	564	207	156	219	34.4	55.1	313	303	310	258
2002	575	421	575	201	151	212	33.3	53.2				
2003	574	428	584	201	150	210	33.3	53.0	315	305	312	297
2004	535	406	554	201	153	214	34.9	54.7				
2005	478	368	505	190	148	207	36.7	56.2	271	270	275	308

Table 2.15—Estimates of Pacific cod fishing mortality rates, expressed on an annual time scale. Empty cells indicate that no catch was recorded.

	Trawl			Longline			Pot		
Year	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1964	0.000	0.000	0.000	0.000	0.000	0.000			
1965	0.000	0.000	0.000	0.001	0.000	0.001			
1966	0.001	0.000	0.001	0.003	0.001	0.002			
1967	0.001	0.001	0.002	0.006	0.001	0.003			
1968	0.001	0.000	0.001	0.003	0.001	0.001			
1969	0.001	0.000	0.001	0.004	0.001	0.002			
1970	0.001	0.001	0.001	0.005	0.001	0.003			
1971	0.000	0.000	0.000	0.002	0.000	0.001			
1972	0.002	0.001	0.003	0.011	0.002	0.006			
1973	0.004	0.003	0.005	0.019	0.004	0.010			
1974	0.004	0.002	0.005	0.018	0.004	0.009			
1975	0.005	0.003	0.006	0.023	0.005	0.012			
1976	0.005	0.003	0.005	0.022	0.004	0.010			
1977	0.001	0.001	0.001	0.006	0.001	0.003			
1978	0.006	0.003	0.007	0.024	0.005	0.012			
1979	0.006	0.004	0.008	0.027	0.005	0.014			
1980	0.016	0.010	0.017	0.069	0.014	0.033			
1981	0.002	0.011	0.019	0.043	0.020	0.033			
1982	0.005	0.005	0.009	0.031	0.009	0.028			
1983	0.010	0.007	0.008	0.030	0.012	0.028			
1984	0.010	0.004	0.007	0.029	0.001	0.006			
1985	0.006	0.001	0.004	0.020	0.000	0.001			
1986	0.007	0.001	0.006	0.033	0.001	0.003			
1987	0.014	0.022	0.025	0.014	0.003	0.005	0.001	0.001	0.001
1988	0.041	0.018	0.012	0.008	0.001	0.001	0.004	0.000	0.001
1989	0.059	0.033	0.000	0.006	0.001	0.002	0.001	0.000	0.000
1990	0.100	0.019	0.022	0.014	0.000	0.001	0.008	0.003	0.007
1991	0.134	0.002	0.004	0.019	0.001	0.000	0.032		0.003
1992	0.129	0.003	0.004	0.034	0.002	0.006	0.033	0.000	0.002
1993	0.084	0.007	0.004	0.023	0.001	0.000	0.034	0.000	
1994	0.069	0.004	0.002	0.017	0.000	0.000	0.028		0.001
1995	0.087	0.002	0.007	0.025	0.000	0.001	0.047	0.000	0.002
1996	0.097	0.008	0.004	0.025	0.000	0.000	0.038	0.000	
1997	0.102	0.005	0.018	0.029	0.003	0.001	0.049	0.002	0.007
1998	0.096	0.012	0.010	0.031	0.002	0.001	0.072		0.005
1999	0.088	0.005	0.018	0.040	0.002	0.001	0.105	0.015	0.011
2000	0.065	0.009	0.002	0.044	0.002	0.001	0.099	0.001	0.002
2001	0.047	0.007	0.024	0.040	0.003	0.001	0.049	0.000	0.008
2002	0.051	0.010	0.004	0.049	0.001	0.013	0.055	0.000	0.019
2003	0.036	0.009	0.018	0.033	0.002	0.003	0.088	0.000	0.013
2004	0.029	0.007	0.021	0.031	0.000	0.008	0.097	0.000	0.018
2005	0.031	0.006	0.015	0.014	0.000	0.008	0.087	0.000	0.017

Table 2.16—Estimates of Pacific cod regime-specific median recruitments and recruitment deviations. Deviations are expressed as the difference between the logarithm of annual recruitment at age 0 and the logarithm of median recruitment for the respective environmental regime.

Year	ln(Median Recruitment)	Annual Deviation
1964	11.681	-0.139
1965	11.681	-0.172
1966	11.681	-0.208
1967	11.681	-0.242
1968	11.681	-0.264
1969	11.681	-0.255
1970	11.681	-0.185
1971	11.681	-0.010
1972	11.681	0.333
1973	11.681	1.351
1974	11.681	0.080
1975	11.681	-0.174
1976	11.681	-0.123
1977	12.891	0.964
1978	12.891	-0.177
1979	12.891	-0.138
1980	12.891	0.677
1981	12.891	-0.152
1982	12.891	-0.322
1983	12.891	-0.305
1984	12.891	0.870
1985	12.891	0.085
1986	12.891	-0.373
1987	12.891	0.623
1988	12.891	-0.161
1989	12.891	0.752
1990	12.891	0.307
1991	12.891	-0.149
1992	12.891	0.090
1993	12.891	-0.002
1994	12.891	-0.156
1995	12.891	0.605
1996	12.891	-0.453
1997	12.891	-0.284
1998	12.891	-0.007
1999	12.891	0.310
2000	12.891	0.166
2001	12.891	-0.844
2002	12.891	-0.833
2003	12.891	-0.912
2004	12.891	-0.174

Table 2.17—Estimates of Pacific cod selectivity parameters. The first column lists the eight parameters of the selectivity function: the size at which selectivity first reaches a value of 1 (“peak location”), selectivity at the minimum length represented in the data (“S(Lmin)”), the logit transform of the size corresponding to the inflection of the ascending logistic curve (“logit(infl1)”), the relative slope of the ascending logistic curve (“slope1”), the logit transform of the size corresponding to the inflection of the descending logistic curve (“logit(infl2)”), the relative slope of the descending logistic curve (“slope2”), the logit transform of selectivity at the maximum length represented in the data (“logit(S(Lmax))”), and the width of the length range at which selectivity equals 1 (“peak width”). The middle portion of the table lists the portion of the time series (“era”) to which each parameter value applies (FOR = pre-1987, DOM = 1987-1999, NEW = post-1999), for each of the four fisheries (TWL1 = January-May Trawl, TWL2 = June-December Trawl, LGL = longline, POT = pot). For the January-May trawl fishery, parameters for the pre-1987 selectivity curve were borrowed from the 1987-1999 estimates, because there were very few size composition data from the pre-1988 fishery. For the pot fishery, there was no catch prior to 1987, so no selectivity parameters are needed for that fishery during the pre-1987 portion of the time series. The right-most column lists the values of the selectivity parameters for the bottom trawl survey. Because the survey selectivity is assumed to be constant over the entire time series, the value of each survey selectivity parameter is shown in triplicate (once for each portion of the time series).

		Fishery Selectivity				
Parameter	Era	TWL1	TWL2	LGL	POT	Survey
peak location	FOR	66.119	58.624	66.584		57.622
peak location	DOM	66.119	65.271	65.930	65.804	57.622
peak location	NEW	64.941	65.630	65.089	64.077	57.622
S(Lmin)	FOR	0.001	0.001	0.001		0.009
S(Lmin)	DOM	0.001	0.001	0.001	0.001	0.009
S(Lmin)	NEW	0.001	0.001	0.001	0.001	0.009
logit(infl1)	FOR	1.920	1.486	1.078		0.902
logit(infl1)	DOM	1.920	1.602	1.882	2.267	0.902
logit(infl1)	NEW	1.586	1.501	1.978	2.079	0.902
slope1	FOR	0.089	0.242	0.295		0.053
slope1	DOM	0.089	0.116	0.180	0.185	0.053
slope1	NEW	0.137	0.135	0.206	0.232	0.053
logit(S(Lmax))	FOR	-0.633	1.943	-0.802		0.000
logit(S(Lmax))	DOM	-0.633	-1.373	-1.007	-2.308	0.000
logit(S(Lmax))	NEW	-0.744	-1.049	-1.390	-1.723	0.000
logit(infl2)	FOR	-0.301	0.036	-0.104		-1.302
logit(infl2)	DOM	-0.301	-1.228	-0.661	-1.353	-1.302
logit(infl2)	NEW	-1.062	-1.239	-0.996	-1.370	-1.302
slope2	FOR	0.161	0.203	0.221		0.202
slope2	DOM	0.161	0.218	0.184	0.195	0.202
slope2	NEW	0.210	0.217	0.207	0.193	0.202
peak width	FOR	8.842	10.054	10.916		9.879
peak width	DOM	8.842	8.343	8.863	7.924	9.879
peak width	NEW	8.732	8.288	8.748	8.374	9.879

Table 2.18—Selectivities of Pacific cod selectivities at length in the commercial fisheries and bottom trawl survey as defined by final parameter estimates. Lengths (cm) correspond to mid-points of size bins. Len. = length, FOR = 1964-1986, DOM = 1987-1999, NEW = 2000-2005.

	Jan-May Trawl		Jul-Dec Trawl Fishery			Longline Fishery			Pot Fishery		
Len.	DOM	NEW	FOR	DOM	NEW	FOR	DOM	NEW	DOM	NEW	Sur.
10.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
13.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
16.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
19.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
25.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
28.5	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.15
31.5	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.20
34.5	0.01	0.02	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.26
37.5	0.02	0.03	0.04	0.04	0.04	0.01	0.01	0.00	0.00	0.00	0.33
40.5	0.03	0.05	0.08	0.06	0.06	0.03	0.01	0.01	0.00	0.00	0.41
43.5	0.05	0.09	0.16	0.10	0.10	0.07	0.02	0.02	0.01	0.01	0.50
47.5	0.10	0.18	0.37	0.18	0.19	0.21	0.06	0.05	0.02	0.04	0.63
52.5	0.22	0.36	0.71	0.35	0.37	0.54	0.19	0.16	0.08	0.15	0.81
57.5	0.43	0.61	0.97	0.59	0.61	0.85	0.44	0.44	0.28	0.46	1.00
62.5	0.73	0.88	1.00	0.86	0.86	0.97	0.79	0.83	0.68	0.89	1.00
67.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
72.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.85
77.5	0.96	0.85	0.99	0.79	0.82	1.00	0.92	0.85	0.72	0.68	0.71
82.5	0.85	0.66	0.97	0.54	0.58	0.94	0.76	0.62	0.45	0.44	0.60
87.5	0.71	0.49	0.94	0.36	0.41	0.82	0.58	0.41	0.26	0.29	0.54
92.5	0.57	0.39	0.91	0.26	0.31	0.62	0.42	0.29	0.16	0.21	0.52
97.5	0.45	0.34	0.89	0.22	0.28	0.45	0.33	0.23	0.12	0.17	0.51
102.5	0.38	0.33	0.88	0.21	0.26	0.35	0.29	0.21	0.10	0.16	0.50
107.5	0.35	0.32	0.87	0.20	0.26	0.31	0.27	0.20	0.09	0.15	0.50

Table 2.19—Schedules of Pacific cod selectivities at age for the most recent portion of the time series as implied by final parameter estimates. Per. 1 = January-May, Per. 2 = June-August, Per. 3 = September-December. Because selectivity is defined as a function of length, not age, profiles of selectivity at age do not necessarily reach a peak value of 1.

	Trawl Fishery			Longline Fishery			Pot Fishery			
Age	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Survey
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
2	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.21
3	0.05	0.10	0.15	0.01	0.03	0.05	0.01	0.02	0.05	0.44
4	0.22	0.31	0.39	0.11	0.18	0.26	0.11	0.18	0.26	0.69
5	0.48	0.57	0.63	0.36	0.46	0.53	0.37	0.47	0.54	0.85
6	0.70	0.73	0.76	0.61	0.67	0.70	0.62	0.66	0.69	0.89
7	0.79	0.77	0.77	0.73	0.74	0.74	0.71	0.71	0.70	0.84
8	0.78	0.73	0.71	0.73	0.72	0.70	0.68	0.66	0.63	0.78
9	0.72	0.66	0.64	0.68	0.65	0.63	0.60	0.57	0.55	0.72
10	0.66	0.59	0.57	0.60	0.58	0.56	0.52	0.49	0.47	0.67
11	0.60	0.53	0.51	0.53	0.51	0.50	0.45	0.43	0.41	0.63
12	0.55	0.48	0.47	0.48	0.46	0.45	0.39	0.37	0.36	0.60
13	0.51	0.44	0.43	0.43	0.42	0.40	0.35	0.33	0.32	0.58
14	0.48	0.41	0.40	0.39	0.38	0.37	0.31	0.30	0.30	0.57
15	0.45	0.39	0.38	0.36	0.35	0.35	0.29	0.28	0.27	0.55
16	0.44	0.37	0.36	0.34	0.33	0.33	0.27	0.26	0.26	0.55
17	0.42	0.35	0.35	0.32	0.32	0.31	0.25	0.25	0.24	0.54
18	0.41	0.34	0.34	0.31	0.30	0.30	0.24	0.24	0.23	0.53
19	0.40	0.33	0.33	0.30	0.29	0.29	0.23	0.23	0.22	0.53
20	0.39	0.33	0.32	0.29	0.28	0.28	0.22	0.22	0.22	0.53

Table 2.20—Schedules of Pacific cod length (cm), proportion mature, and weight (kg) at period and age as estimated by Model 3. Pop. = population, Per. 1 = Jan-Jun, Per. 2 = Jul-Aug, Per. 3 = Sep-Dec, Beg. = beginning of period, Mid. = middle of period, SDev. = standard deviation, Mat. = proportion mature, Twl. = trawl fishery, Lgl. = longline fishery, pot = pot fishery, survey = bottom trawl survey.

		Length				Pop. Weight		Fishery/Survey Weight			
Per.	Age	Beg.	Mid.	S.Dev.	Mat.	Beg.	Mid.	Twl.	Lgl.	Pot	Survey
1	0	2.224	4.975	1.897	0.000	0.010	0.010	0.010	0.010	0.010	0.010
1	1	14.839	17.286	3.499	0.000	0.032	0.051	0.056	0.051	0.051	0.062
1	2	26.056	28.232	4.964	0.007	0.185	0.239	0.331	0.280	0.264	0.286
1	3	36.032	37.966	6.335	0.091	0.517	0.611	0.919	1.089	1.140	0.728
1	4	44.902	46.622	7.588	0.367	1.041	1.171	1.657	1.939	1.995	1.352
1	5	52.790	54.320	8.728	0.654	1.731	1.893	2.419	2.658	2.664	2.056
1	6	59.804	61.165	9.762	0.818	2.566	2.755	3.149	3.314	3.257	2.782
1	7	66.041	67.251	10.698	0.894	3.513	3.720	3.842	3.932	3.801	3.537
1	8	71.588	72.664	11.543	0.931	4.535	4.753	4.518	4.522	4.321	4.350
1	9	76.520	77.477	12.305	0.950	5.595	5.816	5.206	5.101	4.844	5.237
1	10	80.906	81.757	12.991	0.962	6.651	6.865	5.920	5.687	5.392	6.175
1	11	84.806	85.562	13.607	0.971	7.655	7.853	6.654	6.286	5.970	7.117
1	12	88.274	88.947	14.160	0.977	8.568	8.745	7.384	6.891	6.568	8.011
1	13	91.358	91.956	14.592	0.982	9.371	9.524	8.088	7.492	7.174	8.826
1	14	94.100	94.632	14.977	0.986	10.061	10.191	8.742	8.069	7.764	9.543
2	0	7.660	9.240	1.897	n/a	0.010	0.010	0.010	0.010	0.010	0.010
2	1	19.673	21.078	3.499	n/a	0.032	0.051	0.116	0.096	0.096	0.115
2	2	30.355	31.605	4.964	n/a	0.185	0.239	0.484	0.482	0.459	0.407
2	3	39.855	40.965	6.335	n/a	0.517	0.611	1.129	1.382	1.449	0.919
2	4	48.301	49.289	7.588	n/a	1.041	1.171	1.885	2.185	2.226	1.581
2	5	55.813	56.691	8.728	n/a	1.731	1.893	2.647	2.877	2.864	2.294
2	6	62.492	63.273	9.762	n/a	2.566	2.755	3.356	3.521	3.441	3.028
2	7	68.432	69.126	10.698	n/a	3.513	3.720	4.010	4.130	3.975	3.799
2	8	73.713	74.331	11.543	n/a	4.535	4.753	4.641	4.714	4.493	4.637
2	9	78.410	78.959	12.305	n/a	5.595	5.816	5.285	5.294	5.024	5.546
2	10	82.587	83.075	12.991	n/a	6.651	6.865	5.958	5.886	5.582	6.492
2	11	86.301	86.735	13.607	n/a	7.655	7.853	6.653	6.489	6.170	7.423
2	12	89.603	89.989	14.160	n/a	8.568	8.745	7.347	7.093	6.771	8.293
2	13	92.540	92.883	14.592	n/a	9.371	9.524	8.020	7.688	7.373	9.076
2	14	95.151	95.457	14.977	n/a	10.061	10.191	8.649	8.254	7.954	9.760
3	0	10.797	12.838	1.897	n/a	0.010	0.010	0.021	0.020	0.020	0.024
3	1	22.463	24.277	3.499	n/a	0.032	0.051	0.192	0.155	0.151	0.179
3	2	32.836	34.449	4.964	n/a	0.185	0.239	0.650	0.731	0.736	0.533
3	3	42.060	43.495	6.335	n/a	0.517	0.611	1.339	1.627	1.694	1.100
3	4	50.263	51.539	7.588	n/a	1.041	1.171	2.107	2.391	2.417	1.784
3	5	57.557	58.691	8.728	n/a	1.731	1.893	2.858	3.066	3.035	2.505
3	6	64.043	65.052	9.762	n/a	2.566	2.755	3.550	3.700	3.598	3.247
3	7	69.811	70.708	10.698	n/a	3.513	3.720	4.194	4.301	4.125	4.035
3	8	74.940	75.738	11.543	n/a	4.535	4.753	4.826	4.882	4.645	4.895
3	9	79.501	80.210	12.305	n/a	5.595	5.816	5.478	5.465	5.184	5.819
3	10	83.556	84.187	12.991	n/a	6.651	6.865	6.159	6.061	5.752	6.767
3	11	87.163	87.724	13.607	n/a	7.655	7.853	6.857	6.667	6.346	7.685
3	12	90.370	90.869	14.160	n/a	8.568	8.745	7.547	7.269	6.948	8.531
3	13	93.222	93.665	14.592	n/a	9.371	9.524	8.209	7.856	7.546	9.286
3	14	95.758	96.152	14.977	n/a	10.061	10.191	8.822	8.412	8.117	9.940

Table 2.21—Time series of EBS Pacific cod age 3+ biomass and spawning biomass for the years 1977-2005 as estimated in last year's and this year's assessments, with 95% confidence intervals ("SB 95% CI") for spawning biomass as estimated in this year's assessment. Note that last year's model used 1978 as the initial year, so age 3+ and spawning biomass for 1977 are not available from that assessment. Biomass values are in 1000s of t.

	Age 3+ Biomass		Spawning Biomass		SB 95% CI (This Year)	
Year	Last Year	This Year	Last Year	This Year	Lower	Upper
1977	n/a	269	n/a	91	64	119
1978	494	282	85	109	77	140
1979	560	276	100	114	81	147
1980	630	401	110	118	85	151
1981	677	452	113	137	99	175
1982	713	492	123	169	124	215
1983	742	588	136	197	147	248
1984	747	624	147	223	167	279
1985	759	643	159	249	188	310
1986	783	651	167	264	201	327
1987	799	732	171	267	204	329
1988	808	759	168	277	214	341
1989	820	750	167	294	230	359
1990	828	785	163	298	234	363
1991	817	750	152	289	226	353
1992	807	776	144	281	218	344
1993	789	777	141	280	217	343
1994	782	768	145	294	230	358
1995	773	764	149	301	237	365
1996	741	729	146	289	227	351
1997	710	683	140	273	213	332
1998	667	683	129	252	195	310
1999	624	643	118	243	186	299
2000	576	591	108	231	175	287
2001	553	564	104	219	165	273
2002	548	575	100	212	160	264
2003	530	584	95	210	158	262
2004	501	554	93	214	160	267
2005	n/a	505	n/a	207	152	262

Table 2.22—Time series of GOA Pacific cod age 0 recruitment (1000s of fish) as estimated in last year's and this year's assessments, 1977-2004. Because last year's assessment used 1 as the initial age in the model, age 0 recruitments for last year's assessment were inferred here by multiplying last year's estimates of age 1 recruits by exp(0.37), where 0.37 is the value of the natural mortality rate used in last year's assessment. The columns labeled "L95%CI" and "U95%CI" under this year's assessment represent the lower and upper bounds of the 95% confidence interval for each cohort. Bold font indicates a value from this year's assessment in excess of the 1977-2004 average of 401,982,571 fish.

	Last Year's Assess.	This Year's Assessment		
Year	Recruits	Recruits	L95%CI	U95%CI
1977	693465	**932492**	**1342981**	**647471**
1978	298233	298002	**583083**	152303
1979	480648	309685	**578388**	165814
1980	406813	**700002**	**1063491**	**460749**
1981	367725	305532	**550934**	169439
1982	289547	257677	**448290**	148113
1983	415500	261980	**476044**	144175
1984	561721	**849034**	**1269123**	**567997**
1985	369172	386918	**669788**	223512
1986	403918	244942	**448497**	133772
1987	518289	**663144**	**968392**	**454113**
1988	419843	302767	**539090**	170042
1989	555930	**754025**	**1108154**	**513064**
1990	437216	**483401**	**768915**	303904
1991	364829	306221	**533728**	175691
1992	334427	389203	**620570**	244097
1993	347456	354761	**580778**	216701
1994	389441	304335	**506306**	182932
1995	386545	**651067**	**931426**	**455096**
1996	244667	226004	384489	132846
1997	257697	267584	**417453**	171519
1998	332979	353197	**525372**	237447
1999	387993	**484700**	**711179**	330344
2000	367725	**419653**	**635794**	276990
2001	123057	152910	261956	89257
2002	104237	154540	274572	86981
2003	n/a	142874	262240	77841
2004	n/a	298862	**570400**	156589

Table 2.23—Time series of EBS Pacific cod catch divided by age 3+ biomass as estimated in last year's and this year's assessments, 1977-2005. Note that last year's model used 1978 as the initial year, so an estimate of the ratio for 1977 is not available from that assessment. Also, note that the last entry in each column is based on partial catches for the respective year, because the year was/is still in progress at the time of the assessment.

Year	Last Year	This Year
1977	n/a	0.01
1978	0.02	0.04
1979	0.03	0.05
1980	0.06	0.09
1981	0.05	0.08
1982	0.04	0.06
1983	0.05	0.06
1984	0.03	0.04
1985	0.02	0.02
1986	0.03	0.04
1987	0.04	0.05
1988	0.04	0.04
1989	0.05	0.06
1990	0.09	0.09
1991	0.09	0.10
1992	0.10	0.10
1993	0.07	0.07
1994	0.06	0.06
1995	0.09	0.09
1996	0.09	0.09
1997	0.11	0.11
1998	0.11	0.11
1999	0.13	0.13
2000	0.12	0.11
2001	0.09	0.09
2002	0.10	0.09
2003	0.10	0.09
2004	0.11	0.10
2005	n/a	0.08

Table 2.24—Definitions of labels and terms used in the Pacific cod projection tables.

Symbol	Definition
SPR	Equilibrium spawning per recruit, expressed as a percentage of the maximum level
L90%CI	Lower bound of the 90% confidence interval
Median	Point that divides projection outputs into two groups of equal size (50% higher, 50% lower)
Mean	Average value of the projection outputs
U90%CI	Upper bound of the 90% confidence interval
Std. Dev.	Standard deviation of the projection outputs

Table 2.25—Equilibrium reference points and projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2006-2018 (Scenario 1), with random variability in future recruitment. See Table 2.24 for label definitions.

Equilibrium Reference Points

SPR	Catch	Spawning Bio.	Fishing Mort.
100%	0	329000	0
40%	94700	132000	0.56
35%	102000	115000	0.69

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	108743	108744	108745	108746	1
2007	71368	71373	71374	71382	5
2008	48524	48589	48601	48715	61
2009	51197	52519	52769	55106	1250
2010	60559	69856	71293	88187	8171
2011	65810	88635	89084	113474	14894
2012	68588	98207	97887	127946	18230
2013	69396	100140	99968	129513	19031
2014	67831	99730	99174	130496	19026
2015	67124	98367	98395	128964	18826
2016	69005	98529	98847	131983	18748
2017	69881	100570	100320	131571	18946
2018	72371	101696	102055	134784	19010

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	165201	165201	165201	165201	0
2007	122263	122263	122263	122263	0
2008	102197	102267	102280	102400	65
2009	102599	104184	104473	107213	1466
2010	107445	116049	117318	131264	7509
2011	110605	127895	130358	156295	14428
2012	112390	135767	138007	172436	18532
2013	113476	137943	140435	174186	19812
2014	112371	137924	140313	175964	20002
2015	112057	137030	140056	174438	19959
2016	113820	137926	140788	178741	20187
2017	114505	140028	142496	179080	20595
2018	116384	141547	144216	182619	20875

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	0.558	0.558	0.558	0.558	0.000
2007	0.517	0.517	0.517	0.517	0.000
2008	0.427	0.427	0.427	0.428	0.000
2009	0.429	0.436	0.437	0.449	0.007
2010	0.450	0.489	0.493	0.557	0.030
2011	0.465	0.542	0.530	0.558	0.032
2012	0.473	0.558	0.540	0.558	0.029
2013	0.477	0.558	0.541	0.558	0.029
2014	0.472	0.558	0.541	0.558	0.030
2015	0.471	0.558	0.541	0.558	0.030
2016	0.479	0.558	0.542	0.558	0.028
2017	0.482	0.558	0.543	0.558	0.027
2018	0.490	0.558	0.545	0.558	0.025

Table 2.26—Equilibrium reference points and projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that F = ½ max F_{ABC} in 2006-2018 (Scenarios 2 and 3), with random variability in future recruitment. See Table 2.24 for label definitions.

Equilibrium Reference Points

SPR	Catch	Spawning Bio.	Fishing Mort.
100%	0	329000	0
40%	94700	132000	0.56
35%	102000	115000	0.69

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	58684	58685	58685	58686	0
2007	47581	47584	47584	47589	2
2008	39394	39437	39444	39518	39
2009	39848	40687	40832	42323	746
2010	45337	48457	48833	53521	2549
2011	48626	56526	57565	69772	6701
2012	50554	63610	64633	82169	9791
2013	52823	68166	69003	87456	11084
2014	54008	70647	71451	90817	11517
2015	55109	71689	72817	93151	11713
2016	56115	72477	73658	94370	11753
2017	57013	73616	74382	94915	11768
2018	57739	73997	75004	95290	11749

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	169803	169803	169803	169803	0
2007	144876	144876	144876	144876	0
2008	130035	130106	130119	130242	66
2009	129221	130831	131127	133910	1494
2010	133463	142539	143884	158707	7939
2011	137845	158132	160810	190719	16640
2012	143396	173884	176034	216046	22995
2013	149305	185550	187423	231705	26340
2014	153360	193091	195407	243285	28099
2015	157490	198964	200885	250165	28953
2016	160196	202707	204827	256500	29289
2017	163794	206375	207992	258593	29428
2018	167420	208520	210281	261956	29317

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	0.279	0.279	0.279	0.279	0.000
2007	0.279	0.279	0.279	0.279	0.000
2008	0.269	0.269	0.269	0.269	0.000
2009	0.268	0.271	0.272	0.278	0.003
2010	0.277	0.279	0.279	0.279	0.001
2011	0.279	0.279	0.279	0.279	0.001
2012	0.279	0.279	0.279	0.279	0.001
2013	0.279	0.279	0.279	0.279	0.000
2014	0.279	0.279	0.279	0.279	0.000
2015	0.279	0.279	0.279	0.279	0.000
2016	0.279	0.279	0.279	0.279	0.000
2017	0.279	0.279	0.279	0.279	0.000
2018	0.279	0.279	0.279	0.279	0.000

Table 2.27—Equilibrium reference points and projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that F = the 2001-2005 average in 2006-2018 (Scenario 4), with random variability in future recruitment. See Table 2.24 for label definitions.

Equilibrium Reference Points

SPR	Catch	Spawning Bio.	Fishing Mort.
100%	0	329000	0
40%	94700	132000	0.56
35%	102000	115000	0.69

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	40960	40961	40961	40961	0
2007	34829	34831	34831	34835	2
2008	30775	30790	30793	30819	14
2009	31290	31539	31583	32015	231
2010	34371	36310	36605	39867	1732
2011	36887	42428	43179	51775	4703
2012	38618	48089	48838	61540	7061
2013	40677	52137	52713	66799	8184
2014	42096	54579	55199	70027	8654
2015	43372	55928	56756	72206	8892
2016	44353	56820	57676	72969	8948
2017	44905	57642	58237	73833	8926
2018	45686	57818	58522	74061	8853

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	171301	171301	171301	171301	0
2007	153289	153289	153289	153289	0
2008	142332	142405	142418	142544	68
2009	142964	144620	144924	147789	1534
2010	148236	157551	158935	174173	8137
2011	154361	175324	177935	208737	17074
2012	161835	193696	196033	238230	24030
2013	169820	209032	210909	260303	28175
2014	176266	219790	222455	275476	30666
2015	182343	228694	230966	286536	32031
2016	187110	235035	237019	292857	32582
2017	192447	239872	241291	297039	32687
2018	196441	241747	243829	300419	32390

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	0.190	0.190	0.190	0.190	0.000
2007	0.190	0.190	0.190	0.190	0.000
2008	0.190	0.190	0.190	0.190	0.000
2009	0.190	0.190	0.190	0.190	0.000
2010	0.190	0.190	0.190	0.190	0.000
2011	0.190	0.190	0.190	0.190	0.000
2012	0.190	0.190	0.190	0.190	0.000
2013	0.190	0.190	0.190	0.190	0.000
2014	0.190	0.190	0.190	0.190	0.000
2015	0.190	0.190	0.190	0.190	0.000
2016	0.190	0.190	0.190	0.190	0.000
2017	0.190	0.190	0.190	0.190	0.000
2018	0.190	0.190	0.190	0.190	0.000

Table 2.28—Equilibrium reference points and projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that *F* = 0 in 2006-2018 (Scenario 5), with random variability in future recruitment. See Table 2.24 for label definitions.

Equilibrium Reference Points

SPR	Catch	Spawning Bio.	Fishing Mort.
100%	0	329000	0
40%	94700	132000	0.56
35%	102000	115000	0.69

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	0	0	0	0

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	174543	174543	174543	174543	0
2007	173164	173164	173164	173164	0
2008	174248	174321	174335	174460	68
2009	182792	184450	184755	187625	1536
2010	194103	203495	204897	220288	8215
2011	206113	227781	230610	262910	17732
2012	219463	254573	257162	304385	26228
2013	233504	279652	282005	338110	32565
2014	247769	299874	303842	368639	37210
2015	260745	318668	321510	391664	40232
2016	270858	331744	334402	404547	41671
2017	278755	341014	342556	415669	41887
2018	283928	344470	345966	416588	41107

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	0.000	0.000	0.000	0.000	0.000
2007	0.000	0.000	0.000	0.000	0.000
2008	0.000	0.000	0.000	0.000	0.000
2009	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.000	0.000	0.000	0.000
2011	0.000	0.000	0.000	0.000	0.000
2012	0.000	0.000	0.000	0.000	0.000
2013	0.000	0.000	0.000	0.000	0.000
2014	0.000	0.000	0.000	0.000	0.000
2015	0.000	0.000	0.000	0.000	0.000
2016	0.000	0.000	0.000	0.000	0.000
2017	0.000	0.000	0.000	0.000	0.000
2018	0.000	0.000	0.000	0.000	0.000

Table 2.29—Equilibrium reference points and projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2006-2018 (Scenario 6), with random variability in future recruitment. See Table 2.24 for label definitions.

Equilibrium Reference Points

SPR	Catch	Spawning Bio.	Fishing Mort.
100%	0	329000	0
40%	94700	132000	0.56
35%	102000	115000	0.69

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	130051	130052	130053	130054	1
2007	74777	74783	74784	74793	5
2008	49901	49974	49987	50115	68
2009	54261	55763	56047	58703	1420
2010	65168	75718	77538	96615	9799
2011	70241	95705	98244	130574	19061
2012	72135	106419	106936	145123	22475
2013	71687	105653	106440	142026	22817
2014	68906	101727	103094	141105	22354
2015	67808	98999	101344	137232	22041
2016	69339	100432	102287	140745	22088
2017	70421	104311	104853	139948	22469
2018	72583	106912	107123	144996	22630

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	163047	163047	163047	163047	0
2007	113345	113345	113345	113345	0
2008	93517	93587	93599	93719	65
2009	94941	96518	96805	99530	1458
2010	100118	108625	109866	123642	7390
2011	102780	119679	121853	147374	13705
2012	103684	125581	127110	157879	16604
2013	104090	125143	126803	156041	16819
2014	101840	122500	124801	155428	16363
2015	101596	121588	123884	152355	16088
2016	102207	122660	124680	155384	16369
2017	103682	124258	126485	155951	16793
2018	105004	125822	127954	159346	17020

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	0.692	0.692	0.692	0.692	0.000
2007	0.591	0.591	0.591	0.591	0.000
2008	0.481	0.482	0.482	0.482	0.000
2009	0.489	0.498	0.499	0.514	0.008
2010	0.518	0.565	0.571	0.648	0.039
2011	0.532	0.626	0.625	0.692	0.053
2012	0.537	0.659	0.641	0.692	0.053
2013	0.540	0.656	0.639	0.692	0.055
2014	0.527	0.642	0.633	0.692	0.057
2015	0.526	0.637	0.630	0.692	0.057
2016	0.529	0.642	0.633	0.692	0.055
2017	0.537	0.651	0.638	0.692	0.055
2018	0.545	0.660	0.643	0.692	0.053

Table 2.30—Equilibrium reference points and projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2006-2007 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment. See Table 2.24 for label definitions.

Equilibrium Reference Points

SPR	Catch	Spawning Bio.	Fishing Mort.
100%	0	329000	0
40%	94700	132000	0.56
35%	102000	115000	0.69

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	108743	108744	108745	108746	1
2007	71368	71373	71374	71382	5
2008	58243	58322	58336	58473	73
2009	57638	59176	59467	62187	1455
2010	66340	76953	78768	97966	9793
2011	70539	96054	98484	130483	18958
2012	72801	107221	107471	145475	22424
2013	72944	107689	108060	143465	22903
2014	70621	104665	105547	144076	22662
2015	69417	101819	103593	139796	22354
2016	70509	101853	103740	142315	22259
2017	71085	104990	105582	140792	22534
2018	72940	107336	107514	145592	22661

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	165201	165201	165201	165201	0
2007	122263	122263	122263	122263	0
2008	101351	101421	101433	101553	64
2009	98366	99939	100226	102945	1455
2010	101481	109972	111213	124962	7380
2011	103289	120191	122378	147927	13711
2012	104221	126215	127793	158676	16715
2013	104971	126584	128188	158426	17160
2014	103071	124105	126630	158537	16911
2015	102584	122946	125492	154677	16590
2016	102844	123514	125733	157289	16691
2017	104061	124803	127069	157131	16974
2018	105230	126180	128306	159965	17128

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2006	0.558	0.558	0.558	0.558	0.000
2007	0.517	0.517	0.517	0.517	0.000
2008	0.524	0.525	0.525	0.526	0.000
2009	0.508	0.517	0.518	0.533	0.008
2010	0.525	0.572	0.579	0.655	0.039
2011	0.535	0.629	0.628	0.692	0.052
2012	0.540	0.662	0.644	0.692	0.052
2013	0.545	0.664	0.644	0.692	0.053
2014	0.534	0.650	0.639	0.692	0.055
2015	0.531	0.644	0.635	0.692	0.055
2016	0.533	0.647	0.636	0.692	0.054
2017	0.539	0.654	0.640	0.692	0.054
2018	0.546	0.662	0.644	0.692	0.053

Table 2.31a—Bycatch of nontarget and “other” species taken in the GOA Pacific cod trawl fishery, 1997-2002. The first part of the table (“Bycatch in...”) shows the amount (t) of each species group taken as bycatch in the GOA Pacific cod trawl fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod trawl fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
Sculpin	201	109	127	124	69	75	0.22	0.20	0.23	0.13	0.12	0.08
Skates	476	411	385	219	272	120	0.15	0.09	0.19	0.07	0.15	0.02
Shark	11	7	4	1	1	0	0.09	0.00	0.12	0.02	0.01	0.00
Salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Dogfish	30	624	14	21	61	3	0.05	0.72	0.04	0.05	0.12	0.02
Sleepershk	17	6	5	11	0	26	0.12	0.07	0.01	0.02	0.00	0.12
Octopus	25	1	4	0	3	7	0.11	0.01	0.03	0.00	0.03	0.02
Squid	1	1	1	0	1	0	0.01	0.01	0.03	0.01	0.01	0.00
Smelts	0	1	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Gunnel	0	0	0		0		0.00	0.00	0.00		1.00	
Sticheidae	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.56
Sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
Sandlance	0	0	0	0	0	0	0.00	1.00	1.00	0.97	0.12	1.00
Grenadier	0	1	17	114	376	0	0.00	0.00	0.00	0.01	0.04	0.00
Otherfish	58	211	110	43	68	42	0.10	0.03	0.13	0.04	0.10	0.02
Crabs	1	12	1	0	0	0	0.08	0.47	0.06	0.03	0.06	0.04
Starfish	63	59	62	22	27	22	0.06	0.05	0.04	0.02	0.06	0.04
Jellyfish	7	5	1	1	13	1	0.18	0.03	0.01	0.02	0.05	0.00
Invertunid	2	28	0	5	1	0	0.22	0.65	0.10	0.31	0.13	0.00
seapen/whip	0	0	3	0	0	0	0.00	0.01	0.99	0.00	0.00	0.00
Sponge	0	1	1	1	1	0	0.04	0.24	0.10	0.12	0.26	0.09
Anemone	3	3	11	1	3	6	0.17	0.20	0.65	0.07	0.21	0.27
Tunicate	1	0	0	0	0	0	0.43	0.13	0.38	0.05	0.04	0.03
Benthinv	3	22	11	1	1	0	0.11	0.72	0.42	0.07	0.06	0.09
Snails	0	0	0	0	0	0						
echinoderm	3	23	2	2	1	2	0.13	0.72	0.24	0.31	0.12	0.26
Coral	0	0	0	0	0	0	0.00	0.01	0.01	0.01	0.00	0.01
Shrimp	0	0	0	0	0	0	0.00	0.08	0.02	0.01	0.03	0.01
Birds	0	0	0	0	0	0	0.00	0.07	0.00	0.00	0.00	0.00

Table 2.31b—Bycatch of nontarget and "other" species taken in the GOA Pacific cod trawl fishery, 2003-2005. The first part of the table ("Bycatch") shows the amount (t) of each species group taken as bycatch in the GOA Pacific cod trawl fishery, broken down by year. The second part of the table ("Proportion of total") shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year. Note that the list of nontarget species groups used for 2003-2005 differs from that used for 1997-2002.

	Catch (t)			Proportion of total		
Species group	2003	2004	2005	2003	2004	2005
Benthic urochordata		0			0.02	
Birds						
Bivalves	1	0	1	0.33	0.18	0.22
Brittle star unidentified						
Capelin						
Corals Bryozoans		0			0.29	
Deep sea smelts (bathylagidae)						
Eelpouts			0			0.00
Eulachon	0		0	0.00		0.00
Giant Grenadier			0			0.00
Greenlings	1	5	0	0.11	0.36	0.03
Grenadier	5	0		0.00	0.00	
Gunnels						
Hermit crab unidentified	1	0	0	0.54	0.16	0.00
Invertebrate unidentified	0	2	0	0.01	0.20	0.25
Lanternfishes (myctophidae)						
Large Sculpins	11	20	88	0.09	0.03	0.16
Misc crabs	0	0	0	0.01	0.01	0.00
Misc crustaceans		0			0.06	
Misc deep fish						
Misc fish	32	108	35	0.07	0.36	0.11
Misc inverts (worms etc)						
Octopus	0	3	0	0.01	0.02	0.00
Other osmerids		0			0.00	
Other Sculpins	33	5	0	0.06	0.09	0.00
Pacific Sand lance		0			1.00	
Pandalid shrimp			0			0.00
Polychaete unidentified						
Scypho jellies	9	1	1	0.12	0.05	0.00
Sea anemone unidentified	0	1	0	0.02	0.06	0.00
Sea pens whips		0			0.05	
Sea star	19	9	3	0.03	0.01	0.00
Shark	6	5	7	0.02	0.04	0.03
Skate	151	49	26	0.04	0.02	0.01
Snails	0	0	0	0.01	0.17	0.00
Sponge unidentified	0	0		0.02	0.05	
Squid	1	0	0	0.01	0.00	0.00
Stichaeidae	0		0	0.00		0.00
Surf smelt			0			1.00
Urchins dollars cucumbers	1	0	1	0.11	0.18	0.26

Table 2.32a—Bycatch of nontarget and "other" species taken in the GOA Pacific cod longline fishery, 1997-2002. The first part of the table ("Bycatch in...") shows the amount (t) of each species group taken as bycatch in the GOA Pacific cod longline fishery, broken down by year. The second part of the table ("Proportion of...") shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod longline fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
Sculpin	63	181	207	203	197	291	0.07	0.33	0.38	0.22	0.33	0.31
Skates	478	461	789	1823	617	5005	0.15	0.10	0.39	0.56	0.34	0.77
Shark	2	4	8	2	1	5	0.02	0.00	0.25	0.03	0.01	0.19
Salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Dogfish	28	104	146	8	111	7	0.04	0.12	0.47	0.02	0.23	0.06
Sleepershk	42	14	501	366	66	40	0.31	0.19	0.90	0.60	0.26	0.18
Octopus	1	25	17	16	6	7	0.00	0.22	0.10	0.09	0.07	0.02
Squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Gunnel	0	0	0		0		0.00	0.00	0.00		0.00	
Sticheidae	0	0	4	0	0	0	0.00	0.00	1.00	0.00	0.01	0.00
Sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
Sandlance	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Grenadier	191	0	423	0	0	92	0.02	0.00	0.04	0.00	0.00	0.01
Otherfish	15	50	36	39	2	128	0.03	0.01	0.04	0.04	0.00	0.06
Crabs	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Starfish	304	162	765	199	347	207	0.31	0.13	0.51	0.22	0.74	0.40
Jellyfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Invertunid	0	0	0	5	0	4	0.05	0.00	0.17	0.34	0.05	0.32
seapen/whip	0	3	0	1	0	0	0.00	0.99	0.00	0.87	0.00	0.07
Sponge	0	0	0	0	0	0	0.00	0.00	0.01	0.01	0.01	0.01
Anemone	0	8	5	5	0	1	0.02	0.52	0.27	0.33	0.02	0.06
Tunicate	0	0	0	1	0	0	0.00	0.00	0.00	0.17	0.00	0.00
Benthinv	0	1	1	1	5	0	0.00	0.03	0.03	0.07	0.40	0.07
Snails	0	0	0	0	0	0						
echinoderm	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.04
Coral	0	0	0	0	0	0	0.00	0.00	0.05	0.00	0.00	0.02
Shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Birds	0	1	1	1	1	0	0.13	0.12	0.16	0.21	0.43	0.40

Table 2.32b—Bycatch of nontarget and "other" species taken in the GOA Pacific cod hook-and-line (including jigs) fishery, 2003-2005. The first part of the table ("Bycatch") shows the amount (t) of each species group taken as bycatch in the GOA Pacific cod hook-and-line fishery, broken down by year. The second part of the table ("Proportion of total") shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year. Note that the list of nontarget species groups used for 2003-2005 differs from that used for 1997-2002.

	Catch (t)			Proportion of total		
Species group	2003	2004	2005	2003	2004	2005
Benthic urochordata						
Birds	0	0		0.01	0.03	
Bivalves	0	0	0	0.11	0.00	0.02
Brittle star unidentified		0			0.30	
Capelin						
Corals Bryozoans			0			0.00
Deep sea smelts (bathylagidae)						
Eelpouts	0	0		0.00	0.00	
Eulachon						
Giant Grenadier						
Greenlings	1	1	1	0.05	0.06	0.16
Grenadier		0			0.00	
Gunnels						
Hermit crab unidentified						
Invertebrate unidentified	0	2		0.00	0.27	
Lanternfishes (myctophidae)						
Large Sculpins	39	129	49	0.33	0.20	0.09
Misc crabs	0	0	0	0.00	0.02	0.01
Misc crustaceans						
Misc deep fish						
Misc fish	11	6	2	0.03	0.02	0.01
Misc inverts (worms etc)						
Octopus	2	1	0	0.05	0.01	0.00
Other osmerids						
Other Sculpins	90	7	7	0.17	0.14	0.15
Pacific Sand lance						
Pandalid shrimp						
Polychaete unidentified						
Scypho jellies						
Sea anemone unidentified	1	1	0	0.06	0.09	0.02
Sea pens whips	0		0	0.40		0.05
Sea star	110	246	170	0.20	0.23	0.17
Shark	59	13	10	0.17	0.11	0.04
Skate	464	472	108	0.12	0.21	0.06
Snails	0	0	0	0.00	0.00	0.00
Sponge unidentified		0	1		0.07	0.34
Squid	10	0	0	0.13	0.00	0.00
Stichaeidae						
Surf smelt						
Urchins dollars cucumbers		0			0.00	

Table 2.33a—Bycatch of nontarget and "other" species taken in the GOA Pacific cod pot fishery, 1997-2002. The first part of the table ("Bycatch in...") shows the amount (t) of each species group taken as bycatch in the GOA Pacific cod pot fishery, broken down by year. The second part of the table ("Proportion of...") shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod pot fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
Sculpin	106	61	106	357	29	79	0.12	0.11	0.19	0.38	0.05	0.09
Skates	1	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Shark	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Salmonshk	0	0	1	0	0	0	0.00	0.00	0.01	0.00	0.00	0.00
Dogfish	0	0	0	0	1	0	0.00	0.00	0.00	0.00	0.00	0.00
Sleepershk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Octopus	168	74	142	137	63	252	0.72	0.66	0.85	0.78	0.71	0.84
Squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Gunnel	0	0	0		0		0.00	0.00	0.00		0.00	
Sticheidae	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
Sandlance	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Grenadier	0	0	0	0	1	0	0.00	0.00	0.00	0.00	0.00	0.00
Otherfish	30	4	92	19	52	43	0.05	0.00	0.11	0.02	0.07	0.02
Crabs	6	10	9	10	2	1	0.41	0.42	0.81	0.84	0.36	0.19
Starfish	468	210	633	566	35	66	0.47	0.17	0.42	0.63	0.08	0.13
Jellyfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Invertunid	0	0	0	0	0	0	0.00	0.00	0.00	0.01	0.01	0.03
seapen/whip	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Sponge	0	0	5	0	0	0	0.03	0.00	0.39	0.04	0.01	0.01
Anemone	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Tunicate	0	0	0	0	0	0	0.00	0.03	0.41	0.02	0.00	0.00
Benthinv	10	2	10	4	1	2	0.40	0.08	0.40	0.34	0.08	0.28
Snails	0	0	0	0	0	0						
echinoderm	1	0	1	1	1	1	0.06	0.00	0.09	0.14	0.16	0.09
Coral	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Birds	0	0	0	0	0	0	0.00	0.00	0.01	0.00	0.02	106

Table 2.33b—Bycatch of nontarget and “other” species taken in the GOA Pacific cod pot fishery, 2003-2005. The first part of the table (“Bycatch”) shows the amount (t) of each species group taken as bycatch in the GOA Pacific cod pot fishery, broken down by year. The second part of the table (“Proportion of total”) shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year. Note that the list of nontarget species groups used for 2003-2005 differs from that used for 1997-2002.

	Catch (t)			Proportion of total		
Species group	2003	2004	2005	2003	2004	2005
Benthic urochordata		0			0.01	
Birds	0	0	0	0.02	0.09	0.08
Bivalves	0	0	0	0.14	0.00	0.01
Brittle star unidentified	0	0	0	0.03	0.65	0.53
Capelin						
Corals Bryozoans	0	0		0.00	0.01	
Deep sea smelts (bathylagidae)						
Eelpouts	0		7	0.13		0.34
Eulachon						
Giant Grenadier						
Greenlings	1	1	0	0.10	0.04	0.04
Grenadier						
Gunnels						
Hermit crab unidentified	0	0	0	0.05	0.08	0.45
Invertebrate unidentified	0			0.02		
Lanternfishes (myctophidae)						
Large Sculpins	14	262	157	0.11	0.41	0.28
Misc crabs	1	0	2	0.44	0.23	0.54
Misc crustaceans						
Misc deep fish						
Misc fish	43	20	80	0.10	0.07	0.26
Misc inverts (worms etc)						
Octopus	42	135	88	0.88	0.86	0.96
Other osmerids						
Other Sculpins	195	7	8	0.38	0.15	0.18
Pacific Sand lance						
Pandalid shrimp						
Polychaete unidentified						
Scypho jellies	0	0	0	0.00	0.01	0.00
Sea anemone unidentified		0	0		0.01	0.01
Sea pens whips	0			0.01		
Sea star	341	756	748	0.61	0.71	0.73
Shark						
Skate	1	0	1	0.00	0.00	0.00
Snails	5	0	5	0.56	0.34	0.68
Sponge unidentified	0	0		0.00	0.00	
Squid		0	0		0.00	0.00
Stichaeidae						
Surf smelt						
Urchins dollars cucumbers	0	0	0	0.03	0.09	0.12

Table 2.34—Summary of major results for the stock assessment of Pacific cod in the GOA region.

Tier	3a
Reference mortality rates	
M	0.38
$F_{40\%}$	0.56
$F_{35\%}$	0.69
Equilibrium spawning biomass	
$B_{35\%}$	115,000 t
$B_{40\%}$	132,000 t
$B_{100\%}$	329,000 t
Projected biomass for 2006	
Spawning (at max FABC)	165,000 t
Age 3+	453,000 t
ABC for 2006	
FABC (maximum permissible)	0.56
FABC (recommended)	0.28
ABC (maximum permissible)	109,000 t
ABC (recommended)	58,700 t
Overfishing level for 2006	
Fishing Mortality	0.69
Catch	130,000 t

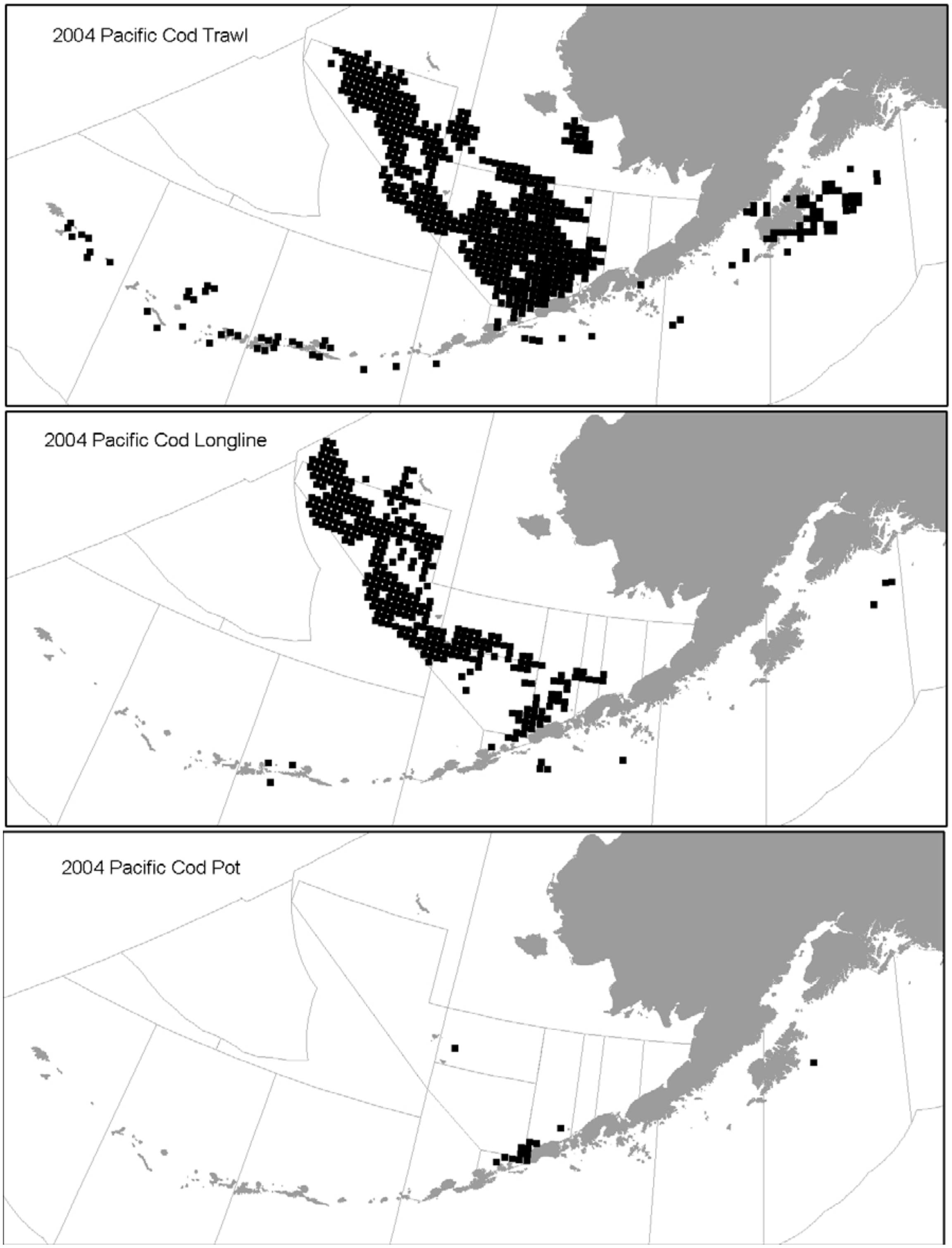

Figure 2.1—Maps showing each 400 square kilometer cell with at least 3 observed hauls/sets containing Pacific cod in 2004, by gear type, overlaid against NMFS 3-digit statistical areas.

Figure 2.2—Mean GOA Pacific cod length at age by sex, with sex-specific 95% confidence intervals. Values were computed from age and length data collected during the 2003 bottom trawl survey. Because these data were collected during summer surveys, ages are shown at mid-year. A few fish aged 9.5-12.5 were also observed, but these are not represented here due to extremely small sample sizes.

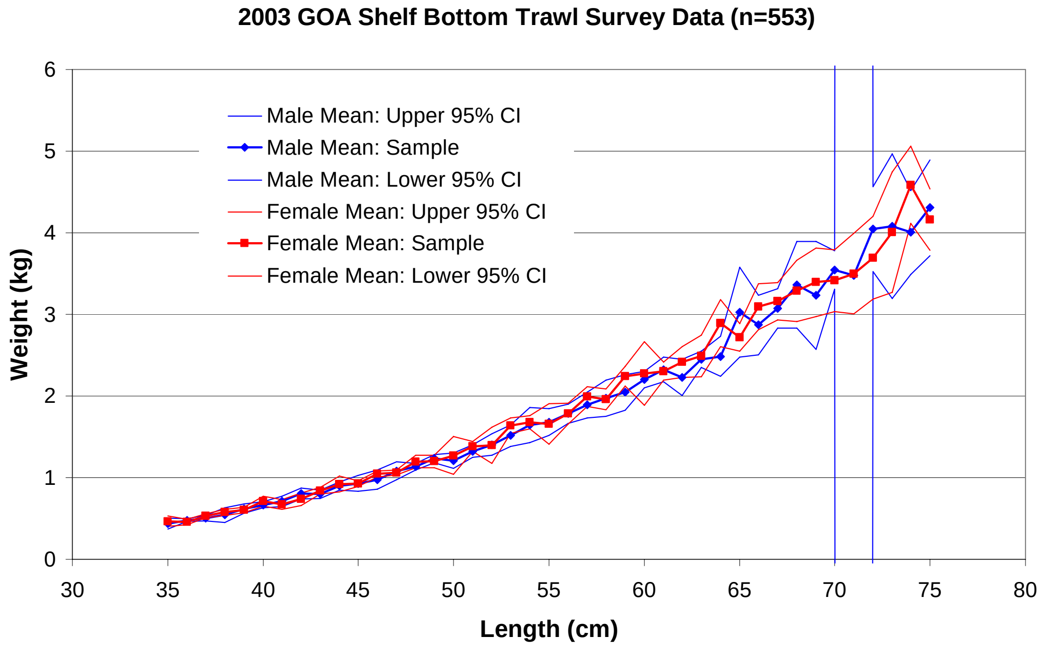

Figure 2.3—Mean GOA Pacific cod weight at length by sex, with sex-specific 95% confidence intervals. Values were computed from length and weight data collected during the 2003 bottom trawl survey. The full range of lengths in the sample extended from 14 cm to 98 cm. However, lengths shorter than 35 cm or longer than 75 cm are not represented here due to extremely small sample sizes. The sample size for 71 cm males was also extremely small (1 fish), so the confidence interval for male mean weight at 71 cm extends off the graph in both directions.

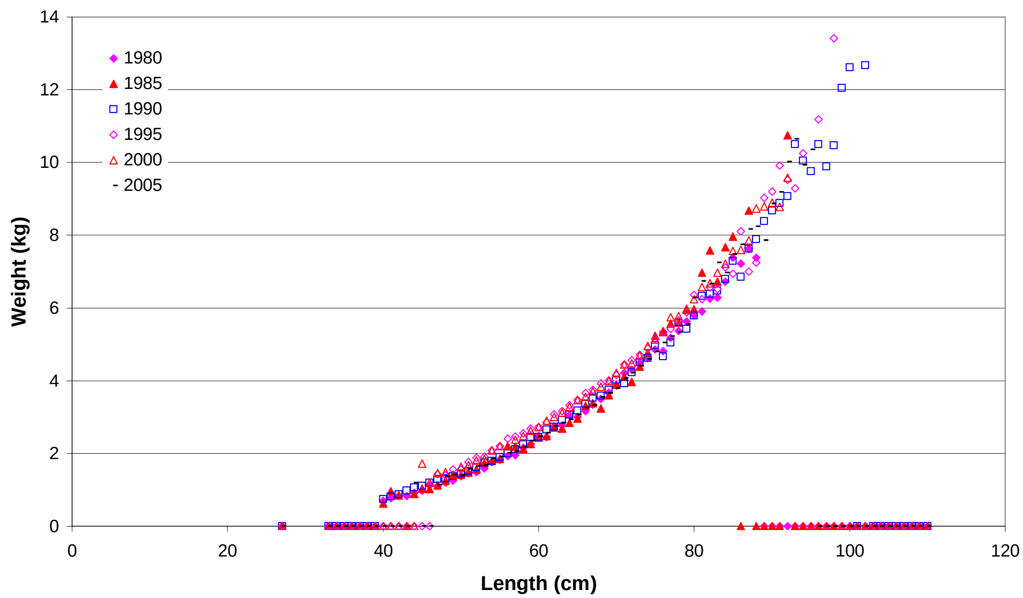

Figure 2.4—Mean GOA Pacific cod commercial fishery weight at length for six example years. Values were computed from aggregated length and weight data across all gear types and months. Because sample sizes in certain year/length combinations are very small, only those year/length combinations with at least 5 data points are shown.

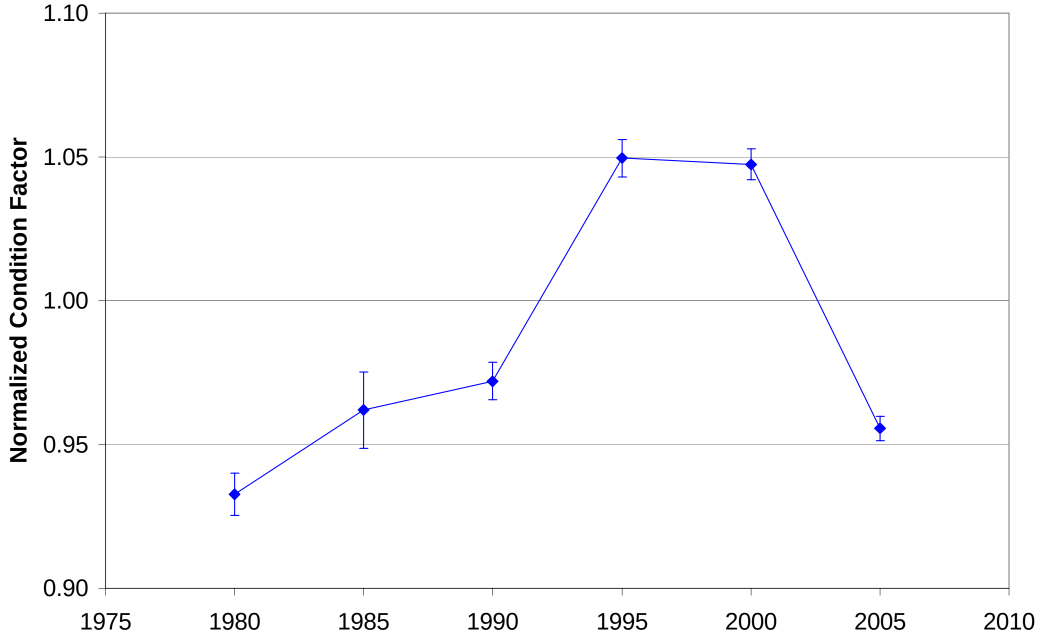

Figure 2.5—Condition factor of GOA Pacific cod for six example years, with 95% confidence intervals. Condition factor is defined as the average ratio of weight to the cube of length. Values in this figure have been normalized by expressing condition factor as the ratio of the year-specific estimate to the estimate for the entire time series.

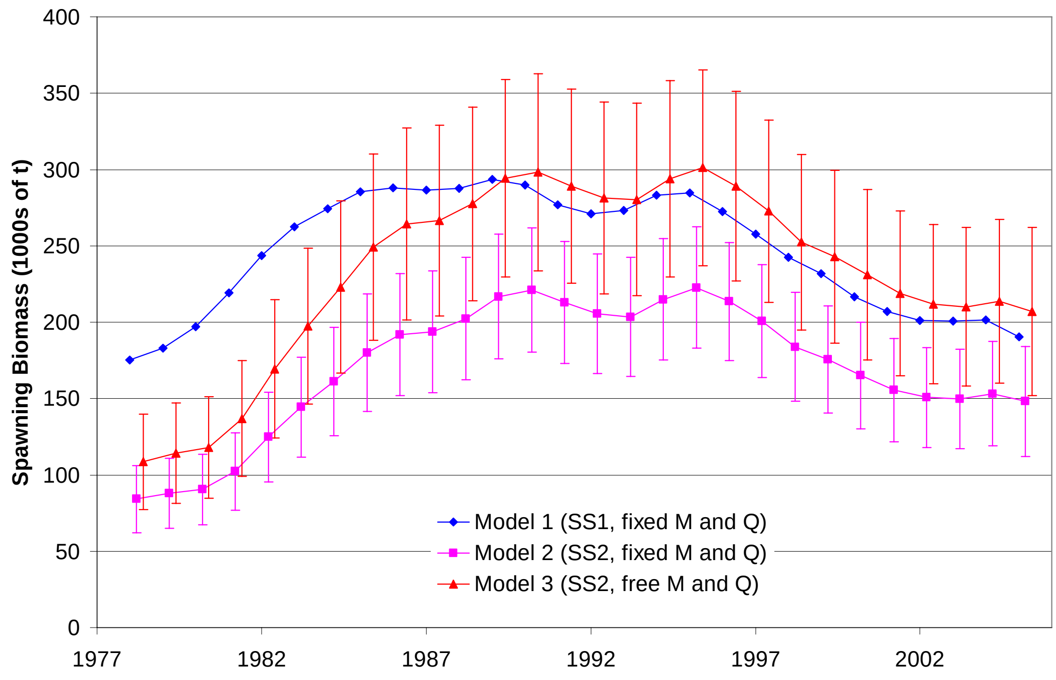

Figure 2.6—Time series of GOA Pacific cod female spawning biomass for 1978-2005 as estimated by Models 1, 2, and 3. The three points for each year have been displaced from one another slightly to improve readability. Error bars for Models 2 and 3 represent 95% confidence intervals (SS1 does not compute confidence intervals).

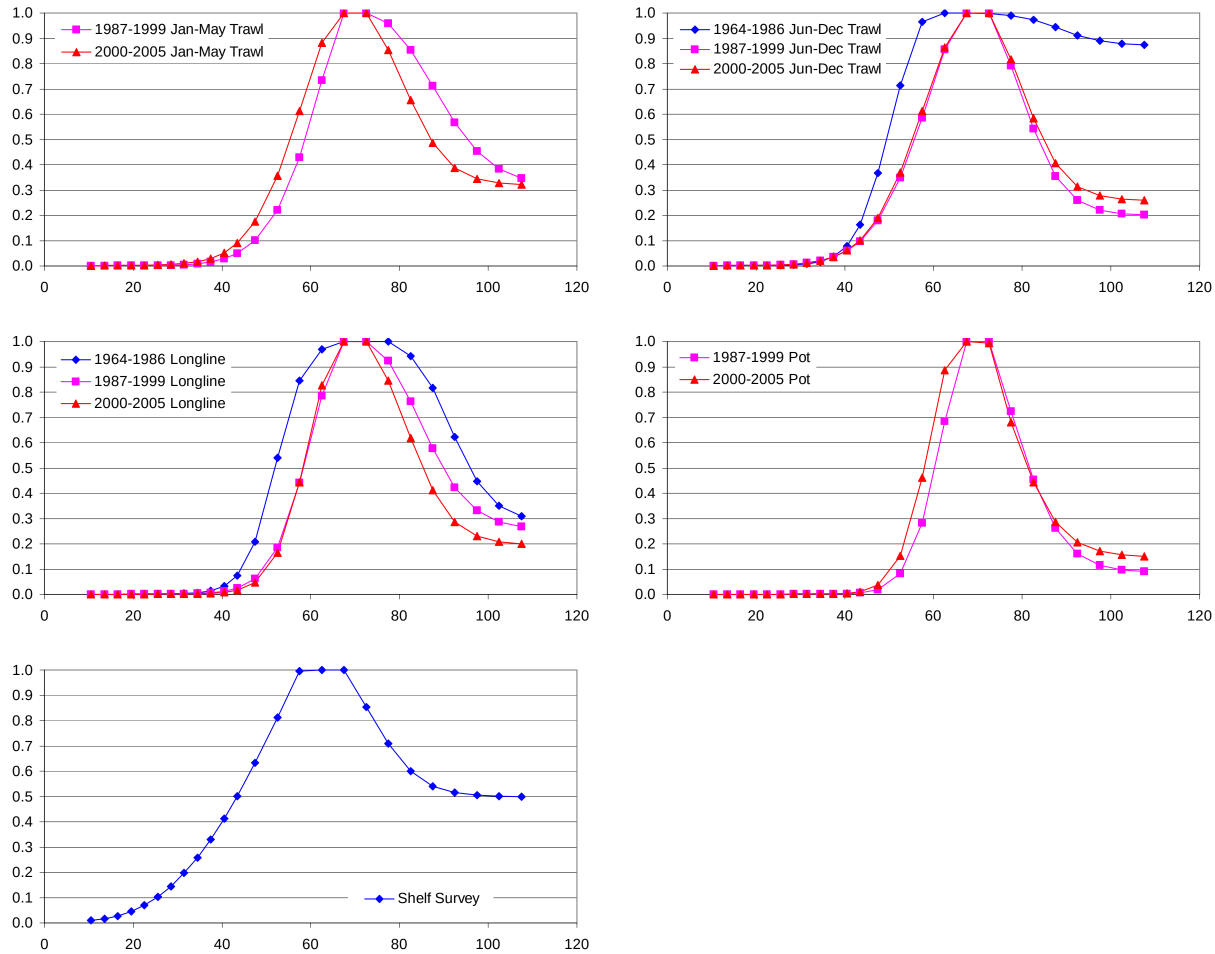

Figure 2.7—Selectivity at length (cm, evaluated at midpoints of length bins) as estimated by Model 3.

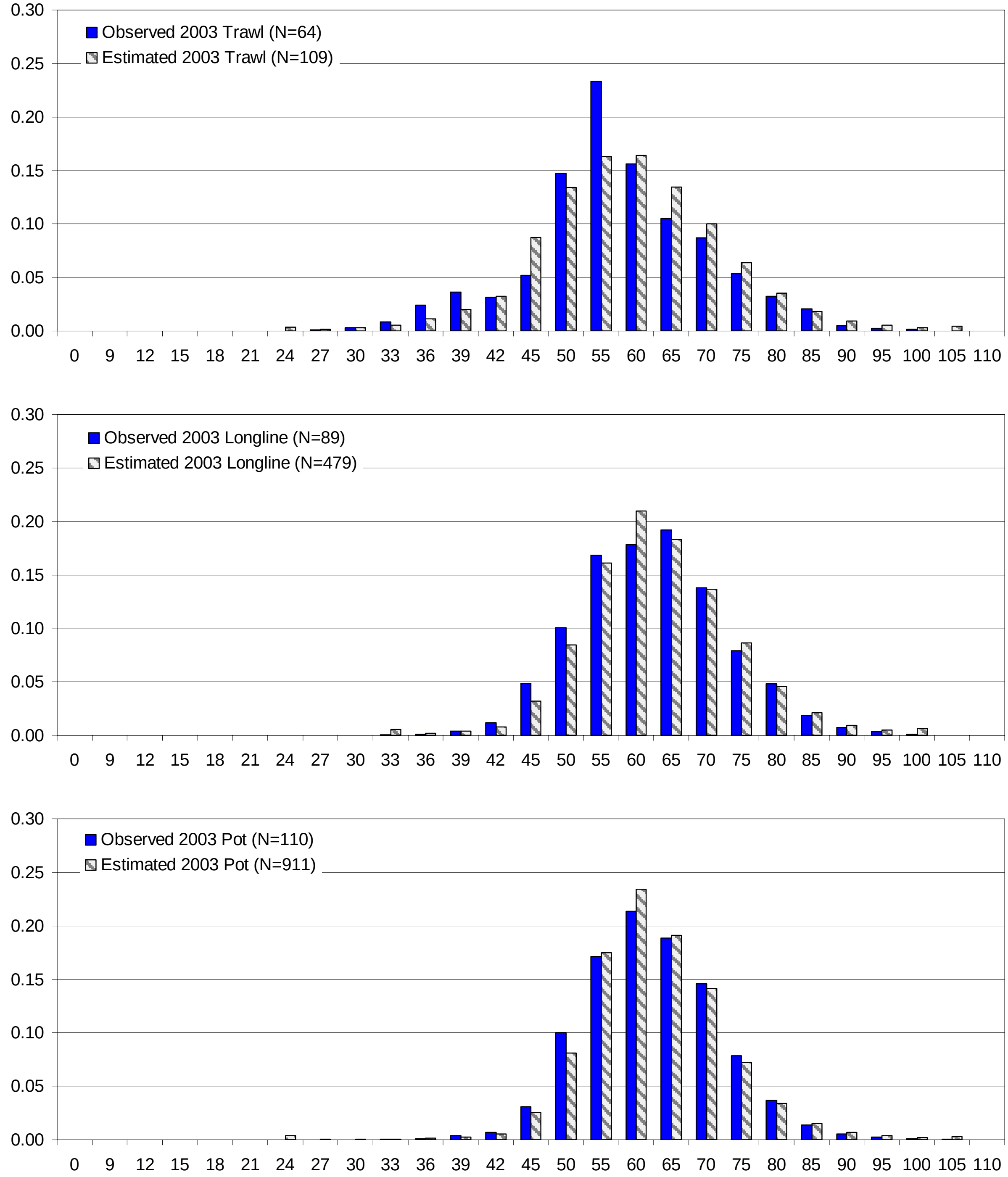

Figure 2.8a—Observed and estimated size compositions from the 2003 January-May fisheries.

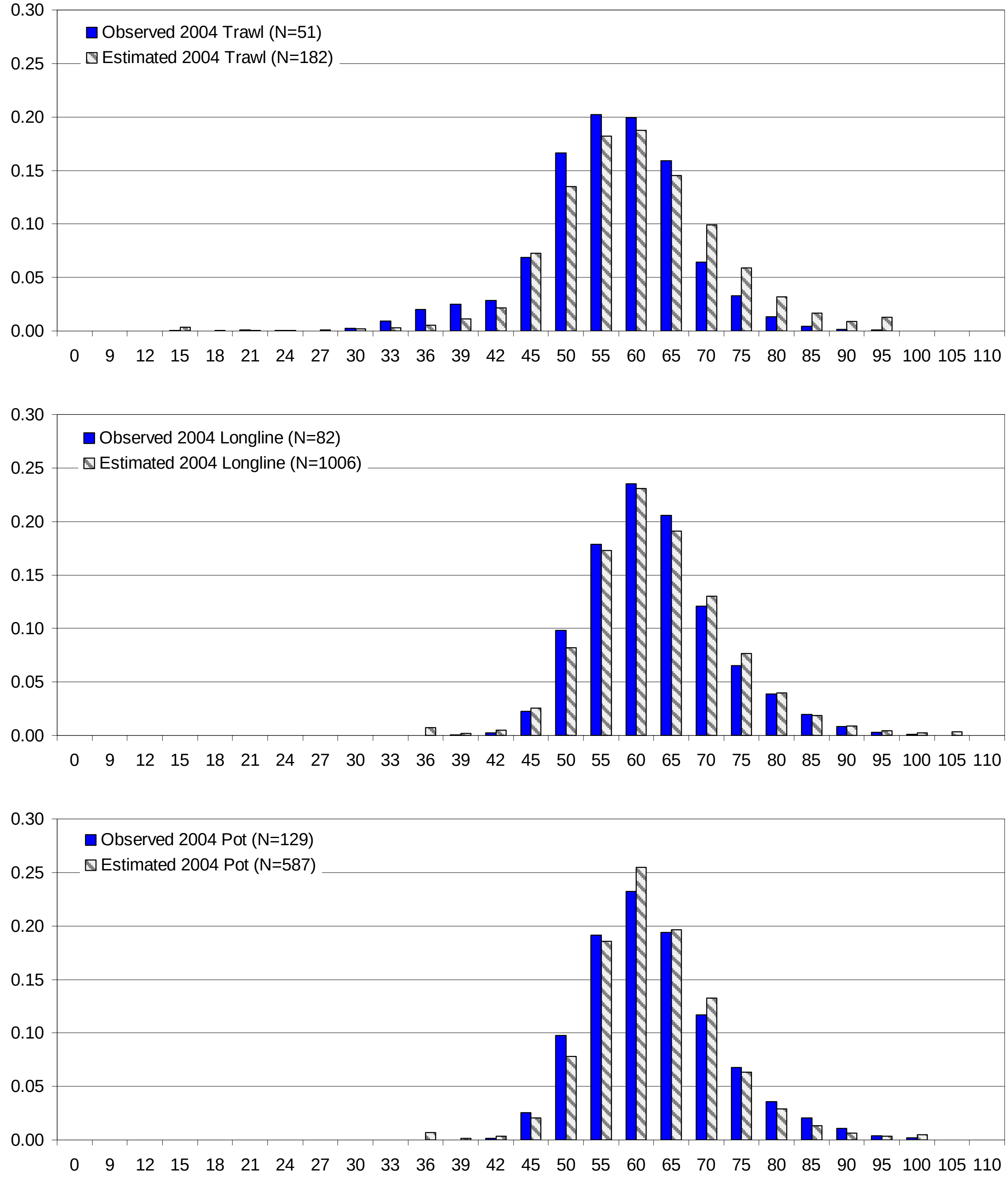

Figure 2.8b—Observed and estimated size compositions from the 2004 January-May fisheries.

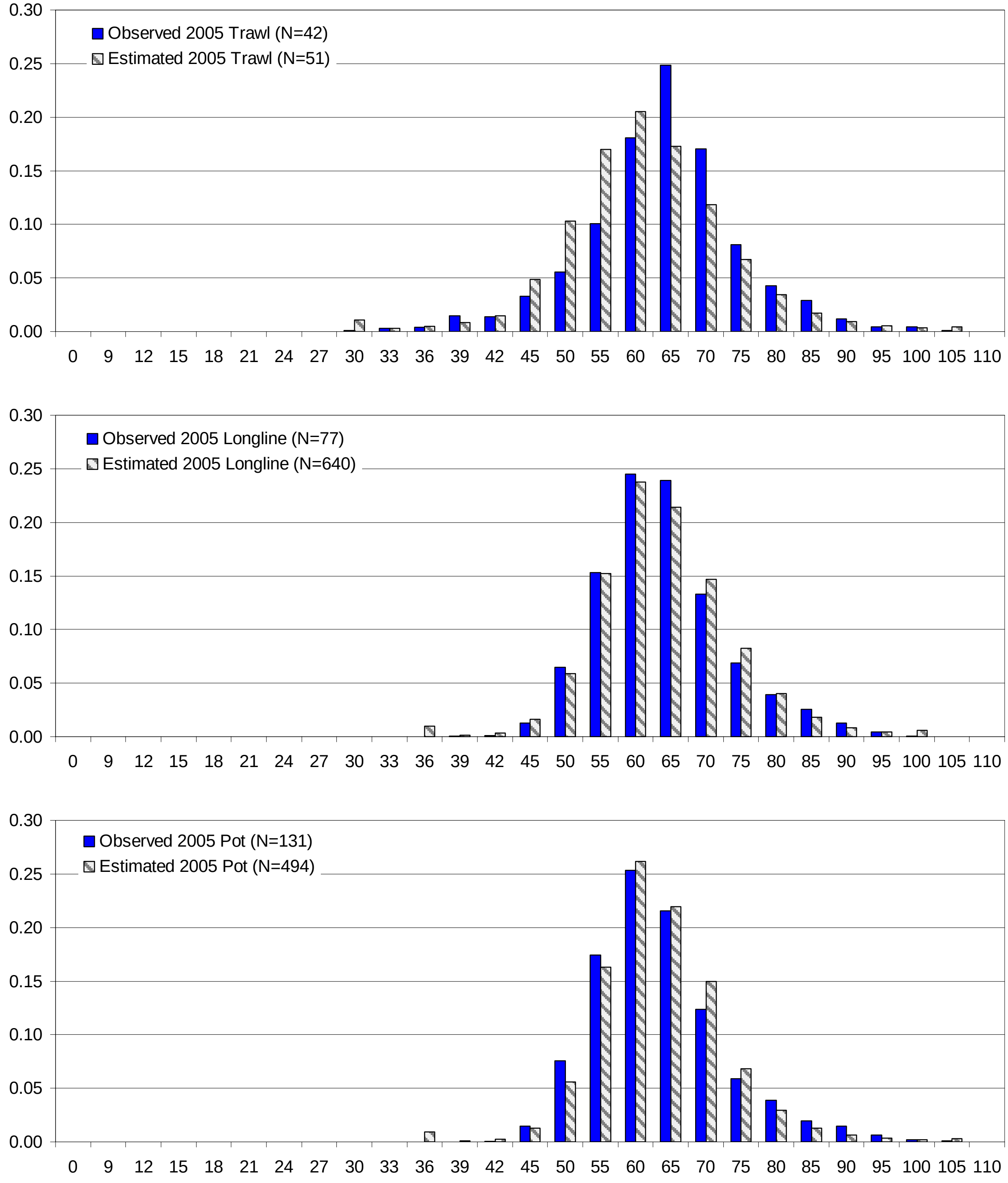

Figure 2.8c—Observed and estimated size compositions from the 2005 January-May fisheries.

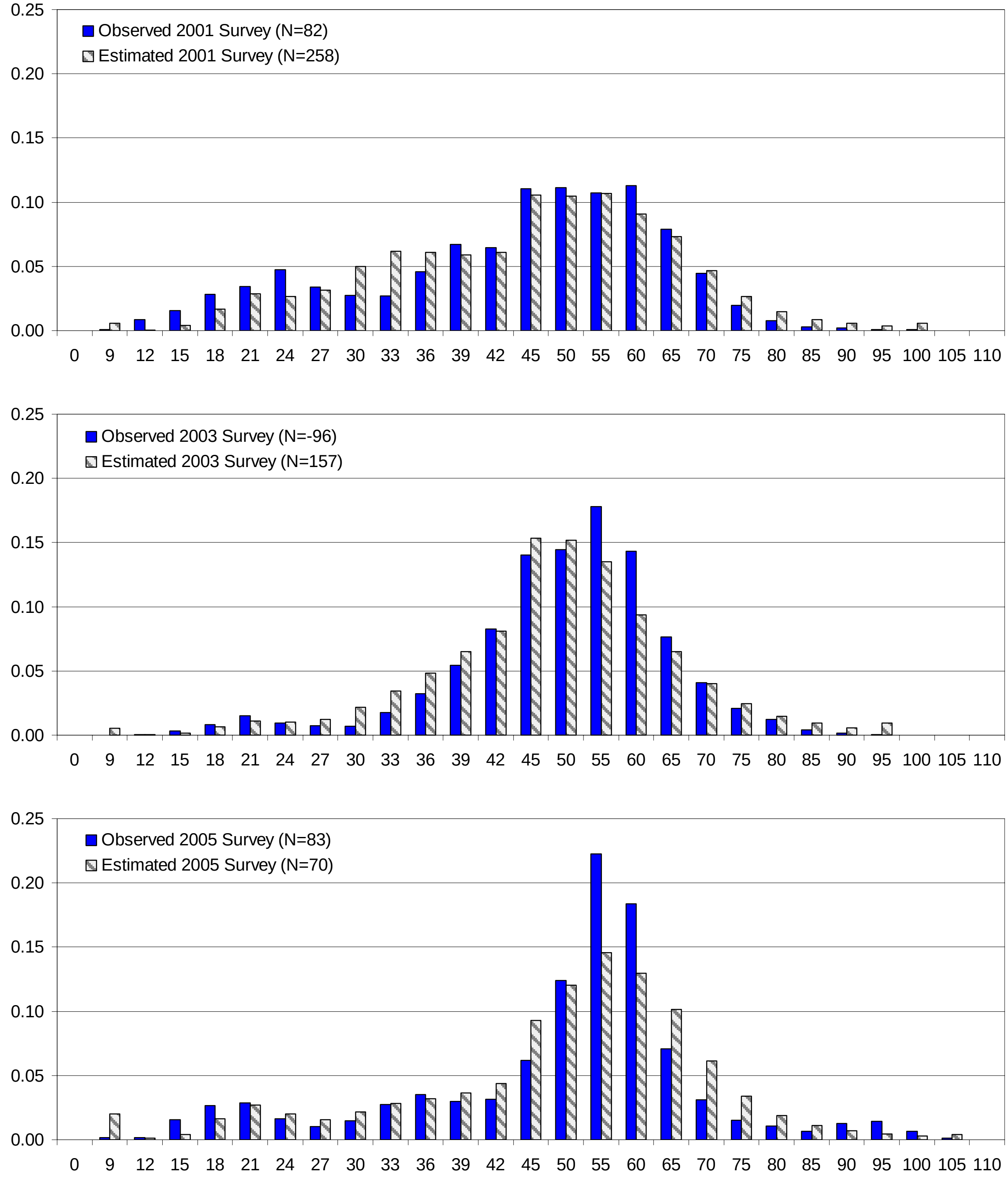

Figure 2.9—Observed and estimated size compositions from the 2001-2005 GOA bottom trawl surveys.

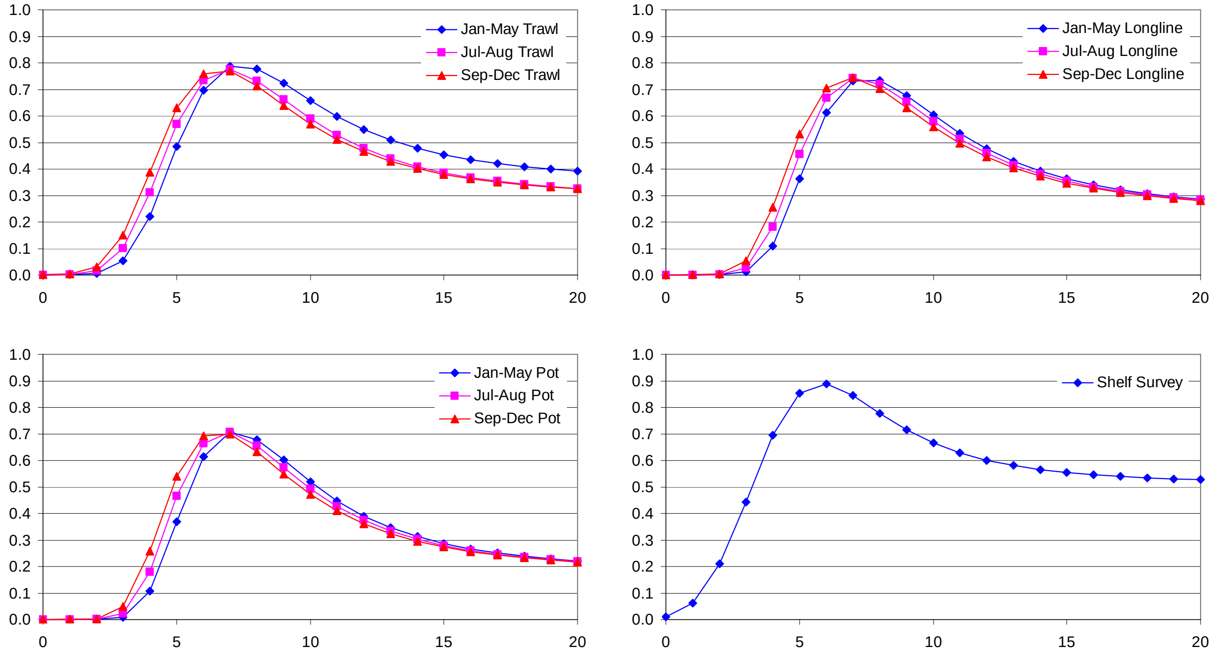

Figure 2.10—Selectivity at age (years) in 2005 as estimated by Model 3. Because selectivity is defined in the model as a function of length rather than age and because a range of lengths are associated with any given age, the above curves do not reach peak values of 1.

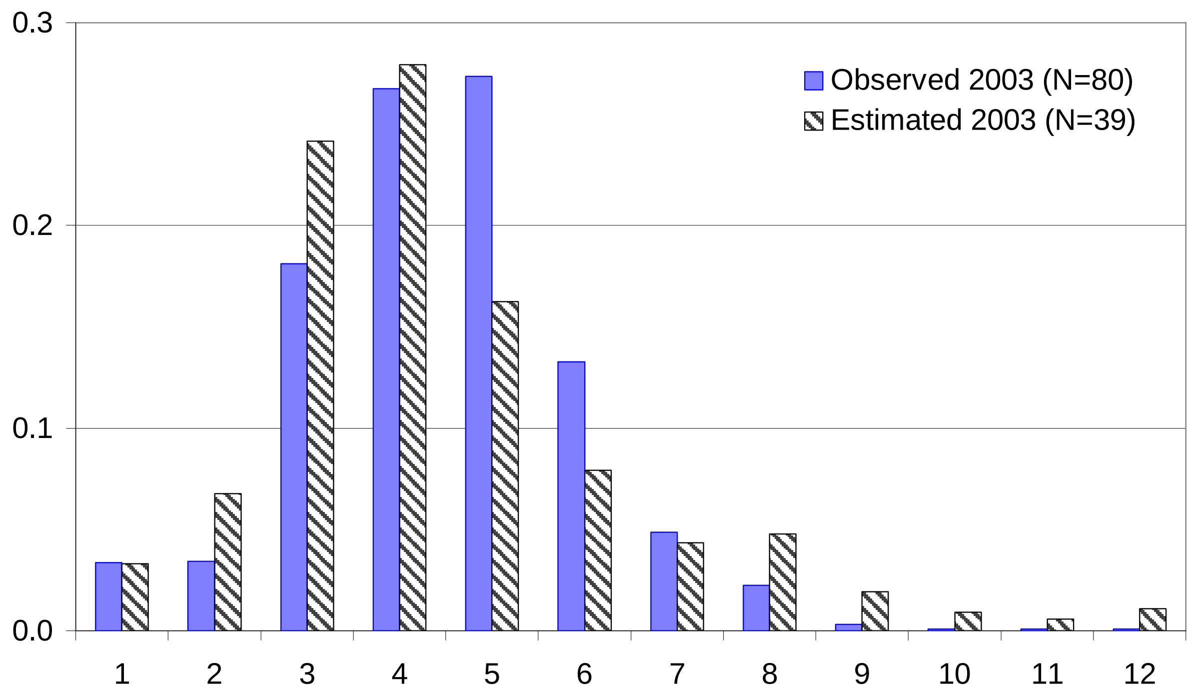

Figure 2.11—Observed and estimated age compositions from the 2003 GOA bottom trawl survey.

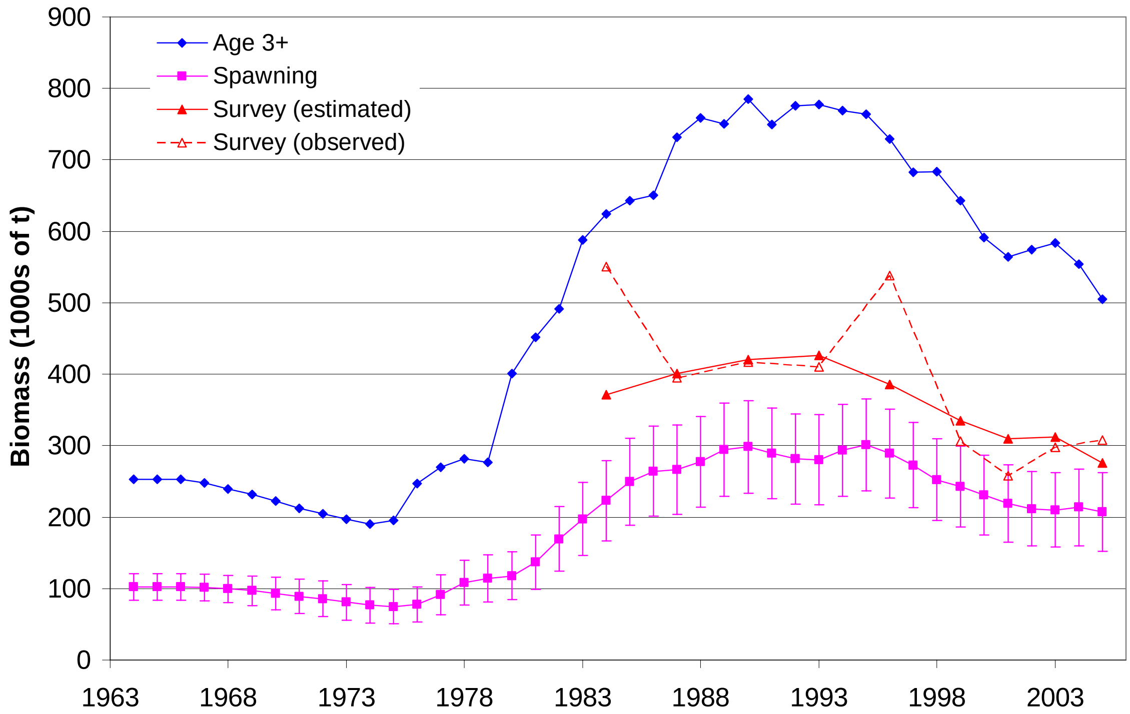

Figure 2.12—Biomass time trends (age 3+ biomass, female spawning biomass, survey biomass) of GOA Pacific cod as estimated by Model 3.

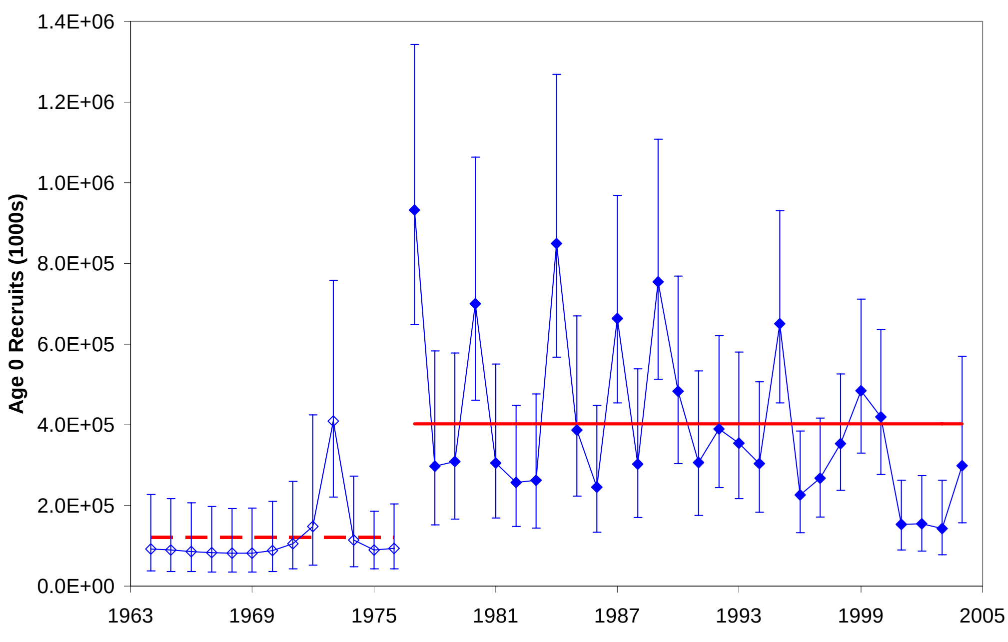

Figure 2.13—Time series of GOA Pacific cod recruitment at age 0, with 95% confidence intervals, as estimated by Model 3.

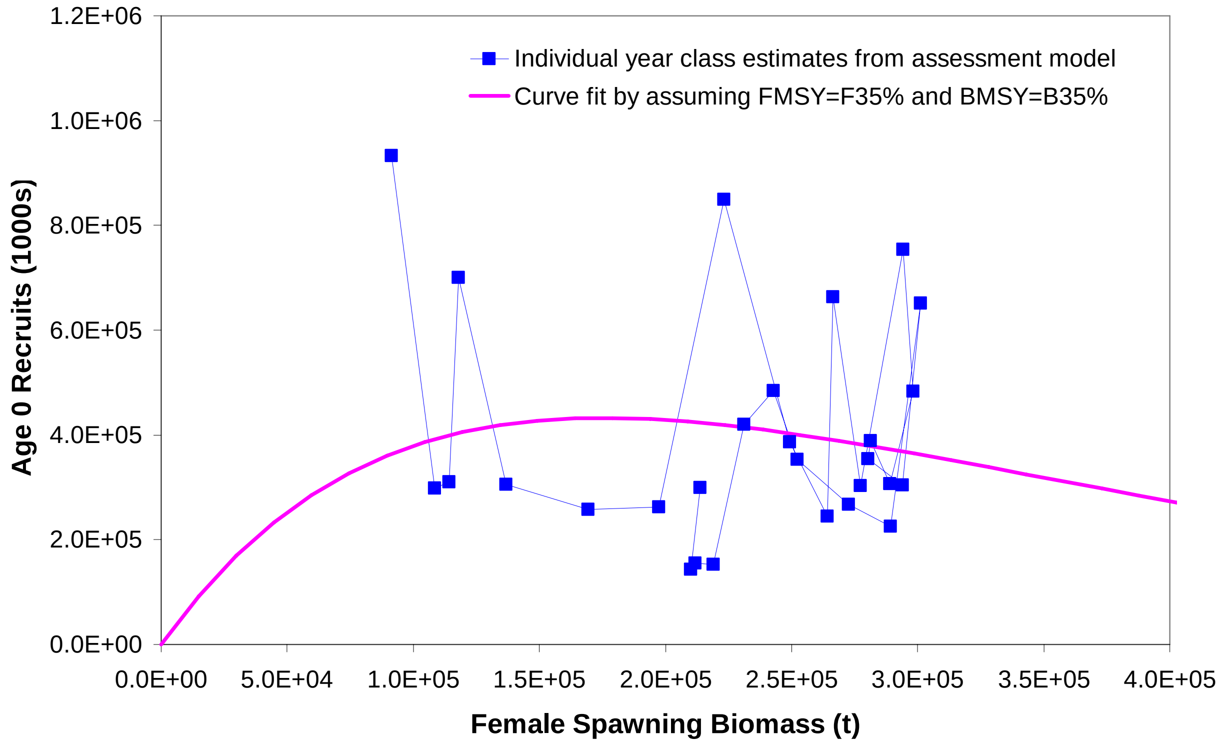

Figure 2.14—Age 0 recruitment versus female spawning biomass for GOA Pacific cod during the years 1977-2004 as estimated by Model 3, with Ricker stock-recruitment curve fit by assuming $F_{MSY}=F_{35\%}$ and $B_{MSY}=B_{35\%}$.

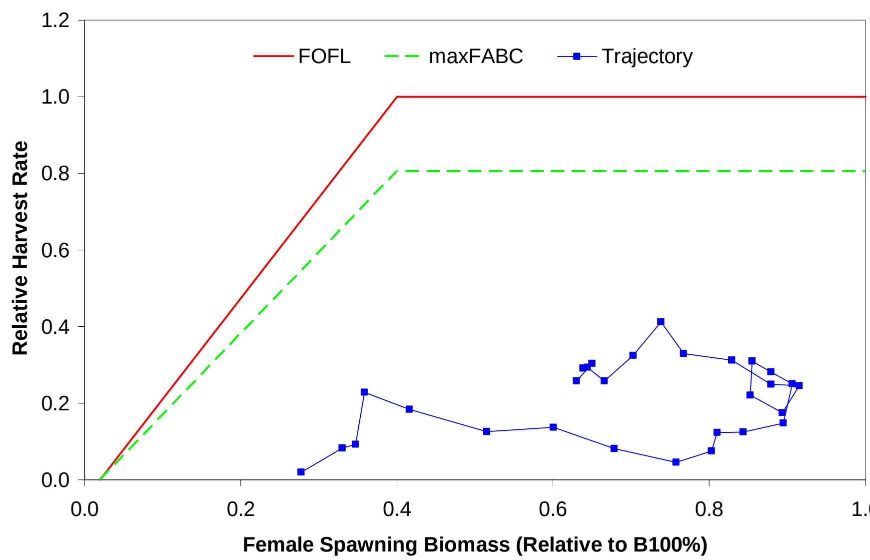

Figure 2.15—Trajectory of GOA Pacific cod fishing mortality and female spawning biomass as estimated by Model 3, 1977-present.

(This page intentionally left blank)