Section 2

ASSESSMENT OF THE PACIFIC COD STOCK IN THE GULF OF ALASKA

Grant G. Thompson, Harold H. Zenger, 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 98115-0070

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) Size composition data from the 2001 and January-August 2002 commercial fisheries were incorporated into the model.
2) Catches from 2001 were updated and catches through August, 2002 were incorporated.

Changes in the Assessment Model

Separate selectivity schedules were estimated for the intervals 1978-1986, 1987-1999, and 2000-present. In previous assessments, only two intervals were specified: 1978-1986 and 1987-present.

Changes in Assessment Results

1) The estimated 2003 spawning biomass for the GOA stock is 88,300 t, up about 8% from last year's estimate for 2002 and up about 15% from last year's F_{ABC} projection for 2003.
2) The estimated 2003 total age 3+ biomass for the GOA stock is 452,000 t, up about 6% from last year's estimate for 2002 and up about 4% from last year's $F_{40\%}$ projection for 2003.
3) The recommended 2003 ABC for the GOA stock is 52,800 t, down about 8% from last year's recommendation for 2002 and up about 7% from last year's F_{ABC} projection for 2003.
4) The estimated 2003 OFL for the GOA stock is 70,100 t, down about 9% from last year's estimate for 2002.

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

SSC Comments Specific to the Pacific Cod Assessments

From the December, 2001 minutes: *"Current model configurations estimate fishery selectivity in two time stanzas. Given the regulatory changes of the last two years, the SSC recommends that the stock assessment authors evaluate selectivity to determine if additional divisions are appropriate. We also reiterate our call to attempt to calculate a statistically valid spawner-recruit relationship for this stock."* An alternative model configuration with a separate set of selectivity schedules for years 2000 and beyond is described in the "Model Structure" subsection of the "Analytic Approach" section and evaluated in the "Model Evaluation" section. As in last year's assessment, a provisional stock-recruitment relationship is described in the "Recruitment" subsection of the "Results" section. Additional research, not described in this assessment, has been conducted in support of a new assessment model capable of calculating a statistically valid spawner-recruit relationship for this stock.

SSC Comments on Assessments in General

From the December, 2001 minutes: *"The SSC encourages the use of retrospective analysis of stock abundance trends, (i.e. the sequential deletion of annual input data to check for changes in output trends.) The presence of a sustained retrospective pattern can be a diagnostic of model adequacy."* A retrospective analysis is provided in the "Biomass" subsection of the "Results" section.

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, and genetic studies (e.g., Grant et al. 1987) have failed to show significant evidence of stock structure within these areas. 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 Table 2.1, broken down by year, fleet sector, 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 (nearly two-thirds on average since 1987).

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 2002, TAC averaged about 82% of ABC and catch averaged about 87% of TAC. In 8 of these 17 years (47%), TAC equaled ABC exactly. In 5 of these 17 years (29%), catch exceeded TAC. However, it should be noted that three of these apparent overages occurred in the most recent five years, when a substantial fishery for Pacific cod was conducted inside State of Alaska waters. 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; and 23% in 2000, 2001, and 2002). Thus, the apparent overages in 1999, 2000, and 2002 is 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 2002, three different assessment models were used (Table 2.2), though the present model has remained unchanged since 1997.

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 (1996, 1999, and 2001) 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 below:

Year(s)	Regulatory Area		
	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

The catches shown in Tables 2.1 and 2.2 include estimated discards. Recent (2000-2001) discard rates of Pacific cod in the various GOA target fisheries are summarized in Table 2.3.

For the 2001 and 2002 fisheries, several new regulations were adopted in an attempt to mitigate possible fishery impacts on the endangered western population of Steller sea lion (*Eumetopias jubatus*). Some of these regulations were designed to spread the catch of Pacific cod more evenly throughout the year. The table below compares the distribution of catch during the periods January-May ("Per. 1"), June-August ("Per. 2"), and September-December ("Per. 3") for the 2001 fishery with the average for the preceding three years (for each gear type, the numbers in a given row sum to 1.0):

		Trawl			Longline			Pot		
Area	Year(s)	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
GOA	2001	0.63	0.08	0.29	0.98	0.01	0.01	0.84	0.04	0.12
GOA	1998-2000	0.84	0.07	0.09	0.97	0.02	0.01	0.90	0.07	0.03

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 1978 are shown in Table 2.4, 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 1978 through the first part of 2002. As in all assessments since 1997, size composition data from trawl catches sampled on shore were not included in the set of input data, because a comparison of cruises for which both at-sea and shoreside size composition samples were available showed that, in the case of trawl catches, the shoreside data typically contained a smaller proportion of small fish than the at-sea data, indicating that these data may reflect post-discard landings rather than the entire catch. 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 2.5. The collections of relative length frequencies are shown by year, period, and size bin for the pre-1987 trawl fishery in Table 2.6, the pre-1987 longline fishery in Table 2.7, the post-1986 trawl fishery in Table 2.8, the post-1986 longline fishery in Table 2.9, and the pot fishery in Table 2.10.

Survey Data

Survey Size Composition and Abundance Estimates

The relative size compositions from trawl surveys of the GOA conducted triennially by the Alaska Fisheries Science Center since 1984 are shown in Table 2.11, 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
Sample size:	17413	19589	11440	17152	12190	8645	6772

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. One potentially problematic aspect of the survey time series is that the 2001 survey did not cover the Eastern regulatory area. The 2001 survey produced a biomass estimate of 258,025 t with a standard error of 52,113 t and a numerical abundance estimate of 157,386,813 fish. To obtain an estimate of what the 2001 survey would have found had the Eastern regulatory area been surveyed, the biomass trends for the Eastern and combined Western/Central regulatory areas estimated by previous surveys were first compared to determine whether a consistent relationship existed. Finding no such relationship, the 1999 survey results for the Eastern regulatory area were assumed to represent the best point estimates of what the 2001 survey would have observed in that area. The 1999 survey estimates of biomass, biomass variance, and numbers for the Eastern regulatory area were therefore added to the respective 2001survey values for the combined Western/Central regulatory areas. This procedure resulted in a Gulf-wide biomass estimate of 277,743 t with a standard error of 52,355 t and a Gulf-wide numerical abundance estimate of 167,386,950 fish.

The highest biomass ever observed by the survey was the 1984 estimate of 571,188 t, and the low point is the 2001 estimate of 277,743 t. In terms of numbers (as opposed to biomass), the record high was observed in 1996, when the population was estimated to include over 315 million fish. This estimate was more than 90% higher than the previous survey's estimate of 165 million fish, which was the low point in the time series. The 2001 estimate is only about 2% above the all-time low.

The 1999 trawl survey biomass estimate was distributed by regulatory area as follows: Western–36%, Central–57%, and Eastern–7%. The 2001 trawl survey of the Western and Central regulatory areas estimated 51% of the biomass to be in the Western regulatory area and 49% to be in the Central regulatory area. If the procedure described above for extrapolating the actual 2001 survey biomass estimate into a Gulf-wide equivalent is accepted, the implied distribution of biomass by regulatory area is as follows: Western–47%, Central–45%, and Eastern–8%.

Survey Removals

The amount of Pacific cod removed from the population as a result of NMFS hydroacoustic, longline, and bottom trawl survey operations is summarized for the GOA in Table 2.13. In all years, the magnitude of these removals has been negligible in comparison to the commercial catch (the average ratio of survey removals to commercial removals in the GOA over the period 1978-2002 was approximately 0.001).

Length at Age, Weight at Length, and Maturity at Length

The set of reliable length at age data for GOA Pacific cod has been small for the past several years and such data are used only sparingly in this assessment. The otoliths which have been read provide the following data regarding the relationship between age and length and the amount of spread around that relationship (lengths are in cm and ages are back-dated to January 1):

Age group:	3	4	5	6	7	8	9	10	11	12
Average length:	45	52	60	66	74	81	85	90	94	95
St. dev. of length:	2.6	3.5	3.8	4.0	3.9	5.0	6.2	6.9	5.5	7.0

Although the supply of reliable length at age data has been severely limited in the past, it now appears likely that such data will become much more available in the future. Studies at the Alaska Fisheries

Science Center have resulted in an ageing methodology for Pacific cod that gives reliable age determinations (Roberson 2001), and production ageing of this species has recently begun (Delsa Anderl, pers. commun.).

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

In 1993, a sampling program was initiated to collect Pacific cod maturity information, using commercial fishery observers. So far, data have been analyzed for 1994 only. These data consist of observers' visual determinations regarding the spawning condition of 2312 females taken in the EBS fishery, which are used as proxy data for the GOA stock. 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

ANALYTIC APPROACH

Model Structure

This year's base model structure is identical to the base model structure used in all assessments of the GOA Pacific cod stock since 1997 (Thompson et al. 1997). Beginning with the 1994 SAFE report (Thompson and Zenger 1994), a length-structured Synthesis model (Methot 1986, 1989, 1990, 1998) has formed the primary analytical tool used to assess the GOA Pacific cod stock. Synthesis 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.

The Synthesis program permits each data time series to be divided into multiple segments, or "eras," resulting in a separate set of parameter estimates for each era. To account for possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries, the fishery size composition time series in the base model has traditionally been split into pre-1987 and post-1986 eras. A minor modification of the base model was suggested by the SSC at its December, 2001 meeting, namely, that consideration be given to dividing the domestic era into pre-2000 and post-1999 segments. Two models are therefore considered in this year's assessment: Model 1 is the base model, unchanged since 1997. Model 2 is identical to Model 1, except that an additional set of fishery selectivity schedules was estimated for the post-1999 era.

Symbols used in the stock assessment model are listed in Table 2.14 (note that this list applies to the stock assessment model only, and does not include all symbols used elsewhere in this document). Synthesis uses a total of 16 dimensional constants, special values of indices, and special values of continuous variables, all of which are listed on the first page of Table 2.14. The values of these quantities are not estimated statistically, in the strict sense, but are typically set by assumption or as a matter of structural specification. The values of these constants, indices, and variables are listed in Table 2.15, with a brief rationale given for each value used. In contrast to the quantities whose values are specified in Table 2.15, Synthesis uses a large number of parameters that are estimated statistically (though the estimation itself may not necessarily take place within Synthesis). For ease of reference, capital Roman letters are used to designate such "Synthesis parameters," which are listed on the second page of Table 2.14.

Functional representations of population dynamics are given in Appendix 2A, using the symbols defined in Table 2.14. It should be noted that, while the equations given in Appendix 2A are generally similar to those used in Synthesis, they may differ in detail. Also, only a subset of the equations actually used by Synthesis is shown. Basically, enough equations are shown to illustrate at least one use for each of the symbols shown in Table 2.14.

The assessments conducted during the period 1997-1999 (Thompson et al. 1997, Thompson et al. 1998, Thompson et al. 1999) used approximate Bayesian methods to address uncertainty surrounding the true values of two key model parameters, the natural mortality rate M and the survey catchability coefficient Q. Due to limitations of the Synthesis software, a type of meta-analysis was used to implement the Bayesian portion of those assessments. This meta-analysis involved fitting a pair of bivariate distributions to the log-likelihood maxima and projected $F_{40\%}$ catches returned from a very large number of individual model runs, each of which held M and Q constant at a unique pair of values. The pairs of M and Q values corresponded to points placed at regularly spaced intervals within a grid spanning the 95% confidence ellipse of the fitted bivariate log-likelihood surface. The purpose of the Bayesian meta-analysis was to recommend an ABC that accounted for parameter uncertainty in an appropriately risk-averse manner. This was accomplished by setting the recommended ABC equal to the geometric mean of the catch distribution corresponding to the product of the catch profile and the posterior distribution. However, the Bayesian meta-analysis was always extremely labor intensive. In the course of conducting the 2000 stock assessment (Thompson et al. 2000), it therefore seemed prudent to seek an efficient shortcut. Looking back at the results of the 1997-1999 stock assessments, it appeared that the ratio between the recommended F_{ABC} emerging from the Bayesian meta-analysis and the $F_{40\%}$ estimate emerging from the base model was converging over time. The average value of this ratio over the 1997-1999 period was 0.86, with a 1999 value of 0.87. Interestingly, identical three-year average and 1999 values were obtained in the 1997-1999 assessments of the BSAI Pacific cod stock (Thompson and Dorn 1997, Thompson and Dorn 1998, Thompson and Dorn 1999). Because the 1999 value represented the most recent estimate and was approximately equal to the 1997-1999 average, the 2000 stock assessment multiplied this value (0.87) by the maximum permissible F_{ABC} to obtain the recommended F_{ABC}. The resulting ABC recommendation was accepted by the SSC and the Council. The same procedure was used in the 2001 assessment (Thompson et al. 2001) and is retained in the present assessment as well, thereby eliminating the need to re-perform the Bayesian meta-analysis.

Parameters Estimated Independently

Table 2.16 divides the set of Synthesis parameters into two parts, the first of which lists those parameters that were estimated independently (i.e., outside of Synthesis), and the second of which lists those parameters that were estimated conditionally (i.e., inside of Synthesis). This section describes the estimation of parameters in the first part of Table 2.16.

Natural Mortality

The natural mortality rate was estimated independently of other parameters at a value of 0.37. This value was used in the present assessment for the following reasons: 1) it was derived as the maximum likelihood estimate of M in the 1993 BSAI Pacific cod assessment, 2) it has been used to represent M in all BSAI Pacific cod assessments since 1993 and in all GOA Pacific cod assessments except one since 1994, 3) it was explicitly accepted by the SSC for use as an estimate of M in the GOA Pacific cod assessment (SSC minutes, December, 1994), and 4) it lies well within the range of previously published estimates of M 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

Trawl Survey Catchability

The trawl survey catchability coefficient was estimated independently of other parameters at a value of 1.0. This value was used in the present assessment mostly because it had been used in all previous assessments. Also, preliminary results of recent experimental work conducted in the EBS by the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering Division tend to confirm that this is a reasonable value (David Somerton, pers. commun.).

Weight at Length

Parameters (Table 2.14) governing the relationship between weight and length (Appendix 2A) were estimated by regression from the available data (see "Data" above), giving the following values (weights are in kg, lengths in cm): $W_1 = 5.80 \times 10^{-6}$, $W_2 = 3.159$.

Length at First Age of Survey Observation

Assuming that the first age at which Pacific cod are seen in the trawl survey (α_1, Table 2.14) is approximately 1.5 years, the length at this age (L_1, Table 2.14) was estimated to be 23.2 cm by averaging the lengths corresponding to the first mode greater than or equal to 14 cm (bin 2) from each of the five most recent survey size compositions.

Variability in Length at Age

Parameters (Table 2.14) governing the amount of variability surrounding the length-at-age relationship (Appendix 2A) were estimated by linear regression from the observed standard deviations in the available length-at-age data (see “Data” above), giving the following values (in cm): X_1 = 1.8, X_2 = 6.9. Estimation of these two parameters constituted the only use of age data in the present assessment.

Maturity at Length

Maximum likelihood estimates of the parameters (Table 2.14) governing the female maturity-at-length schedule (Appendix 2A) were obtained using the method described by Prentice (1976), giving the following values: P_1 = 0.142, P_2 = 67.1 cm. The variance-covariance matrix of the parameter estimates gave a standard deviation of 0.006 for the estimate of P_1, a standard deviation of 0.39 cm for the estimate of P_2, and a correlation of -0.154 between the estimates of the two parameters.

Parameters Estimated Conditionally

Those Synthesis parameters that are estimated internally are listed in the second part of Table 2.16. The estimates of these parameters are conditional on each other, as well as on those listed in the first part of the table and discussed in the preceding section (i.e., those Synthesis parameters that are estimated independently).

Likelihood Components

As noted in the “Model Structure” section, Synthesis is a likelihood-based framework for parameter estimation which allows several data components to be considered simultaneously. In this assessment, four fishery size composition likelihood components were included: the January-May (“early”) trawl fishery, the June-September (“late”) trawl fishery, the longline fishery, and the pot fishery. In addition to the fishery size composition components, likelihood components for the size composition and biomass trend from the bottom trawl survey were included in the model.

The Synthesis program allows the modeler to specify “emphasis” factors that determine which components receive the greatest attention during the parameter estimation process. As in previous assessments, all components were 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, Synthesis weights 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 Synthesis 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 sample size, rather than the true sample size itself. Given the true sample sizes observed in the present assessment, this procedure tends to give values somewhat below 400 while still providing the Synthesis program with usable information regarding the appropriate effort to devote to fitting individual samples. Multinomial sample sizes derived by this procedure for the commercial fishery size compositions are shown in Table 2.17. In the case of survey size composition data, the square root (SR) assumption was also used, giving the multinomial sample sizes shown below:

Year:	1984	1987	1990	1993	1996	1999	2001
SR(sample size):	132	140	107	131	110	93	82

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.

MODEL EVALUATION

As discussed under "Model Structure" above, two models are focused upon in this assessment: Model 1 is the base model, unchanged since 1997. Model 2 is identical to Model 1, except that an additional set of fishery selectivity schedules was estimated for the post-1999 era, as requested by the SSC.

Evaluation Criteria

Four criteria will be used to evaluate the models developed in the present assessment: 1) the effective sample sizes of the size composition data, 2) the root mean squared error (RMSE) of the fit to the survey biomass data, 3) Akaike's Information Criterion (AIC), and 4) the overall reasonableness of the results.

Effective Sample Size

Once maximum likelihood estimates of the model parameters have been obtained, Synthesis computes an "effective" sample size for the size 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 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 and the average effective sample sizes for each of the size composition components (in each column, the average is computed with respect to all years and periods present in the respective time series):

Size composition	Ave. effective sample size		Ave. input	Effective size / input size	
likelihood component	*Model 1*	*Model 2*	sample size	*Model 1*	*Model 2*
Early-season trawl fishery	347	353	134	2.59	2.63
Late-season trawl fishery	75	81	41	1.83	1.99
Longline fishery	228	273	91	2.51	3.00
Pot fishery	315	302	94	3.35	3.22
Trawl survey	128	125	114	1.12	1.10
All	229	242	88	2.59	2.74

Both models produce average effective samples larger (usually much larger) than the average input values for all size composition components. Model 1 produces a higher ratio than Model 2 for two components (pot fishery and trawl survey), whereas Model 2 produces a higher ratio than Model 1 for the other three components (early-season trawl fishery, late-season trawl fishery, and longline fishery). Model 2 also produces a higher overall ratio (2.74) than Model 1 (2.59).

Observed and estimated size compositions in the January-May fisheries in 2000, 2001, and 2002 are compared for Model 1 in Figures 2.1, 2.2, and 2.3; and for Model 2 in Figures 2.4, 2.5, and 2.6. Observed and estimated size compositions from the three most recent bottom trawl surveys are compared for Model 1 in Figure 2.7 and Model 2 in Figure 2.8.

Fit to Survey Biomass Data

The root-mean-squared value of the lognormal "sigma" parameter in the survey biomass data is 0.158. The log-scale RMSEs from both models are slightly greater than this value. The log-scale RMSE from Model 1 is 0.184, slightly higher than Model 2's value of 0.173.

Akaike's Information Criterion

AIC is an information-theoretic measure which can be used as a practical guide to model selection (Burnham and Anderson 1998). For model *i* with *k* parameters, the AIC is defined as follows:

$$AIC_i = -2\ln(\max(\text{likelihood}_i)) + 2k.$$

When comparing two nested models (i.e., where one model contains the other as a special case), the model with the higher AIC is better supported by the data. Thus, when used to compare models, only the difference between AIC values is important. Model 2 has 28 more parameters than Model 1 (four additional sets of fishery-specific selectivity parameters, with seven parameters each), so Model 2 is better supported by the data if, following a bit of algebra, the following relationship holds:

$$\ln(\max(\text{likelihood}_2))\text{-}\ln(\max(\text{likelihood}_1) > 28,$$

whereas Model 1 is better supported by the data if the direction of the above inequality is reversed.

As it turns out, the difference between the maximum log likelihood for Model 2 and the maximum log likelihood for Model 1 in this assessment is 30.55. Therefore, the comparative AIC values indicate that Model 2 is better supported by the data. However, it should be remembered that previous explorations of alternative models for this stock (e.g., Thompson et al. 1999) have suggested the existence of subtle difficulties in the way the likelihood is specified for these models, in which case AIC may not be completely reliable as an indicator of support.

Overall Reasonableness of Results

The two models gave virtually identical estimates of length-at-age parameters K and L_2 (L_1 was estimated independently, and thus did not vary with choice of model), as shown below:

Parameter	Model 1	Model 2
K	0.143	0.143
L_2	84.8	85.0

Model-specific estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a, and selectivity parameters $S_{1\text{-}7,g,e(y|g)}$ are shown in Tables 2.18, 2.19, and 2.20, respectively. Again, estimated parameter values were fairly similar between the two models, although Model 2 tends to estimate slightly lower fishing mortality rates and recruitments toward the end of the respective time series and considerably lower terminal selectivities for the longline and early-season trawl fisheries during the 2000-2002 era.

Model-specific estimates of age 3+ biomass, spawning biomass, and survey biomass are shown in Table 2.21 and Figure 2.9. Here, too, results between the two models were fairly similar, although Model 2 tends to estimate slightly higher biomasses toward the end of the time series.

Given the degree of similarity between the two models with respect to all of the above measures, it seems fair to conclude that the results from the two models are equally reasonable. It is important to remember that the structural differences between the two models are relatively minor, so it is not surprising that they should give similar results.

Selection of Final Model

One of the main purposes of stock assessments such as the present one is to provide reference estimates of historic biomass trends, target and limit harvest rates, and biomass projections. It is therefore convenient to choose a single model which can be used to generate a set of such reference estimates. Based on the evaluation criteria described above, the evidence is not completely one-sided. The overall results from the two models appear equally reasonable. Model 2 tended to give better effective sample sizes for most (but not all) of the size composition components (as would be expected given the addition of 28 parameters designed to do exactly that), Model 2 gave a slightly better fit to the survey biomass data, and Model 2 had a higher AIC value than Model 1. On balance, therefore, the evidence supported selection of Model 2 as the final model.

Parameter Estimates Associated with the Final Model

The model estimated length-at-age parameter values of K = 0.143 and L_2 = 85.0. Estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a, and selectivity parameters $S_{1\text{-}7,g,e(y|g)}$ are shown in Tables 2.18, 2.19, and 2.20, respectively. In addition, the parameter estimates listed in the section entitled “Parameters Estimated Independently” also pertain.

Schedules Defined by Final Parameter Estimates

Lengths at age defined by the final parameter estimates are shown below (lengths are in cm and are evaluated at the mid-point of each age group):

Age group:	1	2	3	4	5	6	7	8	9	10	11	12
Average length:	24	34	43	51	58	64	69	74	78	81	84	89

The distribution of lengths at age (measured in mid-year) defined by the final parameter estimates is shown in Table 2.22.

Weights at length and maturity proportions at length defined by the final parameters are shown in Table 2.23, and selectivities at length defined by the final parameter estimates are shown in Table 2.24.

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 (vector *b* in Appendix 2A); 2) spawning biomass, consisting of the biomass of all spawning females in March of a given year (vector *c* in Appendix 2A); 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 (vector *d* in Appendix 2A). The recruitment estimates presented here will be defined in two ways: 1) as numbers of age 3 fish in January of a given year and 2) as the recruitment parameter R_y, which represents numbers at age 1 in January of year *y*. The fishing mortality rates presented here will be defined as full-selection, instantaneous fishing mortality rates expressed on a per annum scale.

Biomass

The model’s description of the recent history of the stock is shown in Table 2.25, together with estimates provided in last year’s final SAFE report (Thompson et al. 2001). The biomass trends estimated in the present assessment are also shown in Figure 2.9. The age 3+ biomass trend shows an increase during the early 1980s followed by a period of sustained high abundance throughout the rest of that decade, followed by a steady decline through the present. Roughly paralleling the estimated age 3+ biomass trend, the model's estimated spawning and survey biomass trends show declines throughout the past decade. The model's estimates of 2002 age 3+ and spawning biomass are the lowest in their respective time series.

Figure 2.10 compares this year's (Model 2) estimate of the survey biomass time series with those from all other assessments since 1997 (the year in which the base model was standardized). These annual estimates have been remarkably consistent. If each assessment's estimate of the survey biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have ranged from a low of 0.939 (using the 2001 estimates to predict the 2002 estimates) to a high of 0.997 (using the 1998 estimates to predict the 1999 estimates) . There is no obvious time trend in the survey biomass estimates between assessments.

Figure 2.11 compares this year's (Model 2) estimate of the age 3+ biomass time series with those from all other assessments since 1997. These annual estimates have not been quite as consistent as the model's estimates of survey biomass. If each assessment's estimate of the age 3+ biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have ranged as high as 0.977 (using the 1998 estimates to predict the 1999 estimates) and would have exceeded 0.854 in all years but one. The outlier arises when the 2000 estimates are used to predict the 2001 estimates, yielding an R^2 of -0.102. As Figure 2.11 shows, the 2001 assessment resulted in an estimated age 3+ biomass time series that was lower than any previous assessment. This year's assessment bridges the gap somewhat, by bringing the age 3+ biomass estimate back in line with those of the pre-2000 assessments by the end of the time series. To attempt to measure whether there is a consistent trend (i.e., retrospective bias) between assessments, the relative change in each year's age 3+ biomass estimate as assessed between each pair of successive assessments was computed (e.g., the relative change in the estimated value of age 3+ biomass for 1985 as assessed in, say, the 2000 and 2001 assessments), then the relative changes were averaged for each pair of successive assessments, resulting in the values shown below:

First assessment year	1997	1998	1999	2000	2001
Second assessment year	1998	1999	2000	2001	2002
Average relative change in age 3+ biomass	0.022	-0.010	0.010	-0.138	0.024

Given that the sign of the average relative change alternates every year, it is reasonable to conclude that these assessments do not show a retrospective bias.

Recruitment

<u>Numbers at Age 3</u>

Traditionally, recruitment strengths for Pacific cod have been assessed at age 3, because this is the approximate age of first significant recruitment to the fishery and because model estimates of relative year class strength tend to stabilize by this age. The model's estimated time series of age 3 recruitments is shown in Table 2.26, together with the estimates provided in last year's final SAFE report (Thompson et al. 2001). The model's recruitment estimates are also plotted in Figure 2.12. The current time series has a mean value of 126 million fish, a coefficient of variation of 36%, and an autocorrelation coefficient of 0.112.

One possible means of assigning a qualitative ranking to each year class within this time series is as follows: an "above average" year class can be defined as one in which numbers at age 3 are at least 120% of the mean, an "average" year class can be defined as one in which numbers at age 3 are less than 120% of the mean but at least 80% of the mean, and a "below average" year class can be defined as one in which numbers at age 3 are less than 80% of the mean. These criteria give the following classification of year class strengths:

Above average:	1977	1979	1980	1984	1987	1989							
Average:	1976	1978	1981	1982	1983	1985	1986	1988	1990	1991	1993	1994	1995
Below average:	1975	1992	1996	1997	1998	1999							

With respect to last year's assessment (Thompson et al. 2001), the changes in the above table consist of a downgrade in the relative strength of the 1976 year class from "above average" to "average" (returning it to the category in which it resided prior to last year's assessment), an upgrade in the relative strength of the 1993 and 1994 year classes from "below average" to "average," and the addition of the 1999 year class to the "below average" category. It may be noted that all four cohorts following the 1995 year class are in the "below average" category.

Numbers at Age 1

The model's estimated time series of age 1 recruitments is shown in Table 2.19. This time series has a mean value of 268 million fish, a coefficient of variation of 34%, and an autocorrelation coefficient of 0.153. The qualitative rankings of year class strengths at age 1 naturally parallel the rankings at age 3, except that estimates for the 1975 and 1976 year classes do not exist at age 1, the 2000 year class is added to the time series at age 1, and the ranking of the 1978 year classes changes from "below average" at age 1 to "average" at age 3 (it is very close to the boundary in both cases). The 2000 year class appears to be in the "average" category, but this estimate is based on relatively few data.

The present assessment model is not configured to estimate a stock-recruitment relationship. Estimation of stock-recruitment relationships is a notoriously difficult exercise in the field of stock assessment, because both the stock data and the recruitment data are measured with error and because the errors in the stock-recruitment data are autocorrelated (Walters and Ludwig 1981). Also, if the stock and recruitment data are generated by a model which assumes that no stock-recruitment relationship exists, these data will be biased. Nevertheless, the stock-recruitment relationship is potentially such an important component of stock dynamics that it seems prudent to provide some kind of investigation, albeit provisional, as to its possible shape. In addition, the SSC has requested that the assessment include a stock-recruitment relationship (SSC minutes, December, 2000 and December, 2001). To this end, the following analysis was conducted (use of symbols in this description does not necessarily follow Table 2.14, which pertains to the Synthesis assessment model only):

1) Age 1 recruitment R in year y+1 was assumed to be related to spawning biomass S in year y by the Ricker (1954) stock-recruitment relationship subject to lognormal error:

$$R_{y+1} = S_y \exp\left(-\alpha - \beta S_y + \varepsilon_y\right),$$

where α and β are parameters and the ε_y are drawn from a normal distribution with mean 0 and variance σ^2.

2) The estimates of spawning biomass generated by Synthesis were treated as known constants (i.e., it was assumed that they are measured without error).

3) Parameters were estimated by the method of maximum likelihood.
4) The covariance of the parameter estimates was assumed to equal the inverse of the Hessian matrix.

The point estimates of the parameters were α = -1.021, β = 0.003398, and σ = 0.235. The 95% confidence interval of the stock-recruitment parameters is shown in the upper panel of Figure 2.13. One of the attractive features of the method described above is that it implies that the stock-recruitment relationship $r(S) = S\exp(-\alpha-\beta S)$ is itself a lognormal random variable with parameters that are functions of stock size. The coefficient of variation for the relationship is minimized at the mean of the stock data. The lower panel of Figure 2.13 shows the data (solid squares), the stock-recruitment relationship defined by the point estimates of the parameters (thick curve), and the 95% confidence interval around the stock-recruitment relationship (thin curves). This analysis is useful mostly because it indicates a considerable level of uncertainty regarding the shape of the stock-recruitment relationship. Moreover, this description of uncertainty should be regarded as an underestimate because of the problems noted in the paragraph above. The estimates given here are not recommended for use in estimating maximum sustainable yield.

Exploitation

The model's estimated time series of the ratio between catch and age 3+ biomass is shown in Table 2.27, together with the estimates provided in last year's final SAFE report (Thompson et al. 2001). The average value of this ratio over the entire time series is about 0.068. The estimated values meet or exceed the average for every year after 1989 except 1994, whereas the estimated values fall below the average for every year prior to 1990.

PROJECTIONS AND HARVEST ALTERNATIVES

Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan 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:	$B_{35\%}$	$B_{40\%}$	$B_{100\%}$
Spawning biomass:	79,000 t	90,300 t	226,000 t

(For purposes of comparison, Model 1 estimates $B_{35\%}$ and $B_{40\%}$ at values of 76,000 t and 86,900 t, respectively.)

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. In this assessment, total fishing mortality was apportioned between gear types (early trawl, late trawl, longline, and pot) at a ratio of 290:53:173:484. These proportions result in a 2003 catch composition that matches the recent (1999-2001) average distribution of catches between the trawl and fixed-gear fisheries, between the early and late trawl fisheries, and between the longline and pot fisheries. It should be noted that this apportionment scheme is generally consistent with existing Steller sea lion protection measures. This apportionment results in the following estimates of $F_{35\%}$ and $F_{40\%}$:

$F_{35\%}$	$F_{40\%}$
0.42	0.35

(For purposes of comparison, Model 1 estimates $F_{35\%}$ and $F_{40\%}$ at values of 0.50 and 0.41, respectively.)

Specification of OFL and Maximum Permissible ABC

Spawning biomass for 2003 is estimated at a value of 88,300 t. This is about 2% below the $B_{40\%}$ value of 90,300 t, thereby placing Pacific cod in sub-tier “b” of Tier 3. Given this, the model estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2003 as follows:

	Overfishing Level	Maximum Permissible ABC
Catch:	70,100 t	59,900 t
Fishing mortality rate:	0.41	0.34

The age 3+ biomass estimate for 2003 is 452,000 t. (For purposes of comparison, Model 1 estimates the

OFL for 2003 at a value of 72,800 t, the maximum permissible ABC for 2003 at a value of 61,400 t, the F_{OFL} at a value of 0.46, the maximum permissible F_{ABC} at a value of 0.38, and the age 3+ biomass for 2003 at a value of 481,000 t.)

ABC Recommendation

It is important to remember that the maximum permissible ABC computed under the stock assessment model is only a point estimate, around which there is significant uncertainty. For the past several years, the BSAI and GOA Pacific cod assessments have advocated a harvest strategy that formally addresses some of this uncertainty, namely the uncertainty surrounding parameters M and Q (see "Model Structure" above). For the assessments conducted in 2000 and 2001, 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}. The same strategy is recommended for setting the 2003 ABC. This strategy results in a recommended 2003 ABC of 52,800 t, corresponding to a fishing mortality rate of 0.30. (For purposes of comparison, Model 1 results in a recommended 2003 ABC of 54,200 t, corresponding to a fishing mortality rate of 0.33.)

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 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2002. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2003, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

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

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2003 recommended in the assessment to the *max* F_{ABC} for 2003. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

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

Scenario 4: In all future years, F is set equal to the 1997-2001 average F, which was 0.30. (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 2003 or 2) above ½ of its MSY level in 2003 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

Scenario 7: In 2003 and 2004, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2015 under this scenario, then the stock is not approaching an overfished condition.)

Projections and Status Determination

Table 2.28 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 in Tables 2.29-35.

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 2003:

a) If spawning biomass for 2003 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b) If spawning biomass for 2003 is estimated to be above $B_{35\%}$, the stock is above its MSST.
c) If spawning biomass for 2003 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario #6 (Table 2.34). If the mean spawning biomass for 2013 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 2.35):

a) If the mean spawning biomass for 2005 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2005 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2005 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2015. If the mean spawning biomass for 2015 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

In the case of GOA Pacific cod, spawning biomass for 2003 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2005 is above ½ $B_{35\%}$ and below $B_{35\%}$, and mean spawning biomass for 2015 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

OTHER CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the BSAI 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 (Livingston, ed., 2002). 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). However, if regime shifts did occur in 1989 or 1999, it is not yet clear that they had any impact on Pacific cod.

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), and Westrheim (1996). In terms of percent occurrence, the most important items in the diet of Pacific cod in the BSAI and GOA are polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, the most important dietary items are euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, the most important dietary items are walleye pollock, fishery offal, and yellowfin sole. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include 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.

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).

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 longline fishery for Pacific cod. 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.

Area Allocation of Harvests

For the 2002 fishery, allocation of ABC among regulatory areas followed the average biomass distribution estimated by the three most recent (1996, 1999, and 2001) trawl surveys, giving the following apportionment: Western–39%, Central–55%, and Eastern–6%. Assuming that this apportionment is retained for the 2003 fishery, the recommended ABC would be allocated approximately as follows: Western–20,600 t, Central–29,000 t, and Eastern–3,200 t.

SUMMARY

The major results of the Pacific cod stock assessment are summarized in Table 2.36.

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.

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

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

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.

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.

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.

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. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. *In* E. Edwards and B. Megrey (editors), Mathematical analysis of fish stock dynamics: Reviews and current applications, p. 66-82. Amer. Fish. Soc. Symposium 6.

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.

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.

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

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 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. 2001. 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. 2.1-2.73. 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.

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.

Table 2.1--Summary of catches (t) of Pacific cod by fleet sector and gear type. All catches since 1980 include discards. Jt. Vent. = joint venture. Catches taken in the State-water fishery managed by ADFG are lumped into the "Pot" category. Catches for 2002 are through August.

Year	Fleet Sector			Gear Type				Total
	Foreign	Jt. Vent.	Domestic	Trawl	Longline	Pot	Other	
1978	11370	7	813	4547	6800	0	843	12190
1979	13173	711	1020	3629	9545	0	1730	14904
1980	34245	466	634	6464	27780	0	1101	35345
1981	34969	58	1104	10484	25472	0	175	36131
1982	26937	193	2335	6679	22667	0	119	29465
1983	29777	2426	4337	9512	26756	0	272	36540
1984	15896	4649	3353	8805	14844	0	249	23898
1985	9086	2266	3076	4876	9411	2	139	14428
1986	15211	1357	8444	6850	17619	141	402	25012
1987	0	1978	30961	22486	8261	642	1550	32939
1988	0	1661	32141	27145	3933	1422	1302	33802
1989	0	0	43293	37637	3662	376	1618	43293
1990	0	0	72517	59188	5919	5661	1749	72517
1991	0	0	76328	58093	7656	10464	115	76328
1992	0	0	80746	54593	15675	10154	325	80746
1993	0	0	56487	37806	8962	9708	11	56487
1994	0	0	47484	31446	6778	9160	100	47484
1995	0	0	68985	41875	10978	16055	77	68985
1996	0	0	68280	45991	10196	12040	53	68280
1997	0	0	68474	48405	10977	9065	26	68474
1998	0	0	62102	41569	9993	10510	29	62102
1999	0	0	68613	37167	12362	19015	70	68613
2000	0	0	65905	25457	11667	28728	54	65905
2001	0	0	51060	24382	9913	16613	151	51060
2002	0	0	44734	18541	11623	14565	4	44734

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 2002 is current through August 30. 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 1988-2001.

Year	ABC	TAC	Catch	Stock Assessment Model
1980	n/a	60000	35345	n/a
1981	n/a	70000	36131	n/a
1982	n/a	60000	29465	n/a
1983	n/a	60000	36540	n/a
1984	n/a	60000	23898	n/a
1985	n/a	60000	14428	n/a
1986	136000	75000	25012	survey biomass
1987	125000	50000	32939	survey biomass
1988	99000	80000	33802	survey biomass
1989	71200	71200	43293	stock reduction analysis
1990	90000	90000	72517	stock reduction analysis
1991	77900	77900	76328	stock reduction analysis
1992	63500	63500	80746	stock reduction analysis
1993	56700	56700	56487	stock reduction analysis
1994	50400	50400	47484	stock reduction analysis
1995	69200	69200	68985	length-structured Synthesis model
1996	65000	65000	68280	length-structured Synthesis model
1997	81500	69115	68474	length-structured Synthesis model
1998	77900	66060	62102	length-structured Synthesis model
1999	84400	67835	68613	length-structured Synthesis model
2000	76400	58715	65905	length-structured Synthesis model
2001	67800	52110	42022	length-structured Synthesis model
2002	57600	44230	44734	length-structured Synthesis model

Table 2.3---Total catch and discards of Pacific cod in the 2001 and 2002 fisheries. Data for 2002 are through October 5. “Catcher-Proc.”=”CP”=catcher-processor, “Catch”=total catch (t), “Disc.”=discards (t), “Rate”=ratio of discards to total catch, “WGOA”=western GOA, “CGOA”=central GOA, “EGOA”=eastern GOA.

		Shoreside		Mothership		Catcher-Proc.		All		
Year	Sector	Catch	Disc.	Catch	Disc.	Catch	Disc.	Catch	Disc.	Rate
2001	WGOA-Inshore	8,374	105	0	0	4,087	97	12,461	202	0.016
2001	WGOA-Offshore	0	0	0	0	1,700	12	1,700	12	0.007
2001	CGOA-Inshore	24,423	1,606	0	0	832	42	25,255	1,648	0.065
2001	CGOA-Offshore	0	0	0	0	2,065	18	2,065	18	0.009
2001	EGOA-Inshore	132	24	0	0	0	0	132	24	0.182
2001	EGOA-Offshore	0	0	0	0	0	0	0	0	n/a
2001	Total	32,929	1,735	0	0	8,684	169	41,613	1,904	0.046

		Shoreside		Mothership		Catcher-Proc.		All		
Year	Sector	Catch	Disc.	Catch	Disc.	Catch	Disc.	Catch	Disc.	Rate
2002	WGOA-Inshore	8,457	134	0	0	4,159	57	12,616	191	0.015
2002	WGOA-Offshore	0	0	0	0	1,618	81	1,618	81	0.050
2002	CGOA-Inshore	22,222	3,175	0	0	352	28	22,574	3,203	0.142
2002	CGOA-Offshore	0	0	0	0	2,245	113	2,245	113	0.050
2002	EGOA-Inshore	53	8	0	0	0	0	53	8	0.151
2002	EGOA-Offshore	0	0	0	0	48	0	48	0	0.000
2002	Total	30,732	3,317	0	0	8,422	279	39,154	3,596	0.092

Table 2.4--Catch of Pacific cod by year, gear, and period as used in the stock assessment model. Jig catches have been merged with pot catches for 1997-2002. Catch for 2002 is complete through period 2.

Year	Trawl			Longline			Pot		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
1978	0	0	4547	0	0	6800	0	0	0
1979	0	0	3629	0	0	9545	0	0	0
1980	0	0	6464	0	0	27780	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	278	0	0	2
1986	2999	431	3420	15922	401	1296	5	59	77
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	7260	325	70	9627	7	945
1992	51911	1189	1494	12692	750	2232	9926	66	487
1993	33632	2624	1550	8474	307	181	9699	19	1
1994	29152	1421	873	6678	48	52	8760	0	500
1995	38476	802	2597	10591	160	227	15490	50	592
1996	41450	3048	1493	9938	152	105	12066	27	0
1997	40727	1638	6040	10403	195	379	8981	3	107
1998	34693	3678	3197	9548	198	247	10538	1	1
1999	30124	1501	5542	11937	268	157	14438	3302	1344
2000	22133	2574	750	11446	114	107	17142	113	149
2001	15234	2035	7113	9677	96	140	14169	599	1997
2002	15836	2705	n/a	11536	87	n/a	14406	164	n/a

Table 2.5--Pacific cod length sample sizes from the commercial fisheries.

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
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	790	n/a	9583	67	n/a	16430	0	n/a

Table 2.6–Length frequencies of Pacific cod in the pre-1987 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
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 2.7–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 2.8–Length frequencies of Pacific cod in the post-1986 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
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	2	6	18	48	45	68	144	147	99	31	20	16	6	0	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	144	188	101	107	114	55	24	19	3	1	0	0	0

Table 2.9–Length frequencies of Pacific cod in the post-1986 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
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	0	1	3	4	8	13	14	14	5	2	2	0	1	0

Table 2.10–Length frequencies of Pacific cod in the 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
2000	1	0	0	0	0	0	3	2		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	37	308	1136	2388	3681	4137	2890	1177	409	154	66	24	7	1

Table 2.11–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.

		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	174	34	34	121	104	87	104	469	992	1479	1653	1096	1566	3046	2576	1897	1131	469	226	69	52	17	17	0	0
1987	2	450	19	19	39	98	254	490	529	705	666	1234	1411	2822	4076	3116	1724	842	333	333	254	117	39	19	0	0
1990	2	251	0	11	103	217	137	57	114	240	286	435	549	1602	1774	1969	1683	973	549	194	160	80	34	11	11	0
1993	2	0	17	188	325	239	291	205	256	462	548	839	1318	2055	2620	3134	2055	1404	650	274	119	68	34	17	17	17
1996	2	0	35	232	875	1191	903	244	84	193	303	446	445	712	1043	1389	1668	1403	608	228	87	41	30	15	13	2
1999	2	1	17	68	154	166	97	75	142	310	352	402	582	1093	1142	1448	1208	793	416	168	11	0	0	0	0	0
2001	2	5	58	105	193	233	319	228	186	182	310	455	435	749	753	725	767	536	304	135	52	18	14	5	5	0

Table 2.12--Biomass, standard error, 95% confidence interval (CI), and population numbers of Pacific cod estimated by NMFS' triennial 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	Standard Error	Lower 95% CI	Upper 95% CI	Numbers
1984	571,188	85,600	403,412	738,964	217,187,811
1987	558,662	61,500	438,122	679,202	204,177,687
1990	379,494	53,100	275,418	483,570	196,188,094
1993	409,848	73,431	265,923	553,773	164,652,074
1996	538,154	107,736	326,991	749,317	315,443,816
1999	306,413	38,699	230,563	382,263	166,145,850
2001	277,743	52,355	175,127	380,359	167,386,950

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–Magnitude of hydroacoustic, longline, and bottom trawl survey removals (t) in the GOA from 1977 through 2002. Cells with an entry of zero indicate that survey removals amounted to less than 0.5 t, whereas cells with no entry indicate either that there was no survey in that region and year or that no data from any such surveys are available.

Year	Gulf of Alaska			
	Acoustic	Longline	Trawl	Total
1977			15	15
1978			32	32
1979		14	21	35
1980		25	65	90
1981	0	23	70	94
1982		20	41	61
1983	1	28	22	52
1984	0	24	104	128
1985	0	16	30	45
1986	0	17	194	210
1987	0	21	117	138
1988	0	66	1	68
1989	0	47	6	53
1990	0	48	38	87
1991	0	51		51
1992	0	68		68
1993	0	60	46	106
1994	0	42		43
1995	0	38		39
1996	1	39	35	75
1997	0	39		39
1998	0	30		30
1999	0	22	18	40
2000	1	15		16
2001	1	10	24	35
2002	4	16		20

Table 2.14–Symbols used in the Synthesis assessment model for Pacific cod (page 1 of 2).

Indices	
a	age group
g	gear type
i	time interval
j	size bin
y	year

Dimensions	
a_{min}	age of youngest group
a_{max}	age of oldest group
g_{max}	number of gear types
i_{max}	number of time intervals in each year
j_{max}	number of size bins
y_{max}	number of years

Special Values of Indices	
a_{rec}	index of age group used to assess recruitment strength
g_{sur}	index of survey gear type
i_{spa}	index of time interval during which spawning occurs
i_{sur}	index of time interval during which survey occurs

Operators	
$e(y\|g)$	returns the era containing year y given gear type g
l_{mid}	returns the length corresponding to the midpoint of bin j
l_{min}	returns the smallest length contained in bin j
t_{dur}	returns the duration (in years) of time interval i

Continuous Variables	
α	age
λ	length
τ	time

Special Values of Continuous Variables	
α_1	first reference age used in length-at-age relationship (in years)
α_2	second reference age used in length-at-age relationship (in years)
λ_{min}	minimum length used in assessment
λ_{max}	maximum length used in assessment
τ_{spa}	annual time of spawning (in years)
τ_{sur}	annual time of survey (in years)

Table 2.14–Symbols used in the Synthesis assessment model for Pacific cod (page 2 of 2).

Functions of Age or Length	
$h(\lambda \mid \alpha)$	probability density function describing distribution of length, conditional on age
$l(\alpha)$	length at age
$p(\lambda)$	proportion mature at length
$s(\lambda \mid g, y)$	selectivity at length, conditional on gear type and year
$w(\lambda)$	weight at length
$x(\alpha)$	standard deviation associated with the length-at-age relationship, as a function of age

Arrays Generated by Synthesis	
b_y	biomass of population aged $a \geq a_{rec}$ at start of year y
c_y	spawning biomass at time of spawning in year y
d_y	survey biomass at time of survey in year y
$n_{a,y,i}$	population numbers at age a, year y, and time interval i
$u_{a,y}$	population numbers at time of spawning at age a and year y
$v_{a,y}$	population numbers at time of survey at age a and year y
$z_{a,i,j}$	proportion of length distribution falling within size bin j at age a and time interval i

Parameters Used by Synthesis	
$F_{g,y,i}$	instantaneous fishing mortality rate at each gear g, year y, and time i for which catch>0
K	Brody's growth parameter
L_1	length at age α_1
L_2	length at age α_2
M	instantaneous natural mortality rate
N_a	initial population numbers at each age $a > a_{min}$
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability
R_y	recruitment at age a_{min} in year y
$S_{1,g,e(y\mid g)}$	selectivity at minimum length in gear type g and era e
$S_{2,g,e(y\mid g)}$	length at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{3,g,e(y\mid g)}$	relative slope at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{4,g,e(y\mid g)}$	length at maximum selectivity in gear type g and era e
$S_{5,g,e(y\mid g)}$	selectivity at maximum length in gear type g and era e
$S_{6,g,e(y\mid g)}$	length at inflection in descending part of selectivity schedule in gear type g and era e
$S_{7,g,e(y\mid g)}$	relative slope at inflection in descending part of selectivity schedule in gear type g and era e
W_1	weight-length proportionality
W_2	weight-length exponent
X_1	standard deviation of length evaluated at age α_1
X_2	standard deviation of length evaluated at age α_2

Table 2.15–Dimensions and special values of indices and variables used in the Pacific cod assessment. Symbols are defined in Table 2.14.

Dimensions

Term	Value	Comments/Rationale
a_{min}	1	assumed minimum age group observed in the trawl survey
a_{max}	12	a convenient place to insert an "age-plus" category
g_{max}	5	early trawl, late trawl, longline, pot, survey
i_{max}	3	January through March, June through August, September through December
j_{max}	25	bin boundaries are given in the "Data" section of the text
y_{max}	21	1978 through 1999

Special Values of Indices

Term	Value	Comments/Rationale
a_{rec}	3	age traditionally used to indicate first significant recruitment to the fishery
g_{sur}	5	index of survey gear type
i_{spa}	1	March (see τ_{spa} below) falls within the first intra-annual time period
i_{sur}	2	July (see τ_{sur} below) falls within the second intra-annual time period

Special Values of Continuous Variables

Term	Value	Comments/Rationale
α_1	1.5	assumed age of youngest fish seen in the trawl survey
α_2	12.0	set equal to the lower bound of the age-plus group for convenience
λ_{min}	9	close to the length of the smallest fish seen by the survey in a typical year
λ_{max}	115	close to the length of the largest fish seen by the survey in a typical year
τ_{spa}	3/12	March appears to be the month of peak spawning in the observer data
τ_{sur}	7/12	July is the approximate mid-point of the June-August trawl survey season

Table 2.16–Partitioning the list of parameters used in the Synthesis model of Pacific cod into those that are estimated independently (i.e., outside) of Synthesis and those that are estimated conditionally (i.e., inside of Synthesis).

Parameters Estimated Independently	
L_1	length at age α_1
M	instantaneous natural mortality rate
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability
W_1	weight-length proportionality
W_2	weight-length exponent
X_1	standard deviation of length evaluated at age α_1
X_2	standard deviation of length evaluated at age α_2

Parameters Estimated Conditionally	
$F_{g,y,i}$	instantaneous fishing mortality rate at each gear g, year y, and time i for which catch>0
K	Brody's growth parameter
L_2	length at age α_2
N_a	initial population numbers at each age $a > a_{min}$
R_y	recruitment at age a_{min} in year y
$S_{1,g,e(y\|g)}$	selectivity at minimum length in gear type g and era e
$S_{2,g,e(y\|g)}$	length at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{3,g,e(y\|g)}$	relative slope at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{4,g,e(y\|g)}$	length at maximum selectivity in gear type g and era e
$S_{5,g,e(y\|g)}$	selectivity at maximum length in gear type g and era e
$S_{6,g,e(y\|g)}$	length at inflection in descending part of selectivity schedule in gear type g and era e
$S_{7,g,e(y\|g)}$	relative slope at inflection in descending part of selectivity schedule in gear type g and era e

Table 2.17–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 2.5.)

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
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	n/a	98	8	n/a	128	0	n/a

Table 2.18–Estimates of Pacific cod fishing mortality rates, expressed on an annual time scale (page 1 of 2). Empty cells indicate that no catch was recorded.

Model 1

Year	Trawl			Longline			Pot		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978			0.03			0.05			
1979			0.02			0.07			
1980			0.04			0.18			
1981	0.00	0.02	0.03	0.05	0.04	0.05			
1982	0.01	0.01	0.02	0.04	0.02	0.05			
1983	0.02	0.02	0.02	0.04	0.03	0.06			
1984	0.02	0.01	0.02	0.05	0.00	0.01			
1985	0.01	0.00	0.01	0.04	0.00	0.00			
1986	0.02	0.00	0.02	0.06	0.00	0.01			
1987	0.03	0.07	0.06	0.03	0.01	0.01	0.00	0.00	0.00
1988	0.08	0.06	0.03	0.02	0.00	0.00	0.01	0.00	0.00
1989	0.13	0.12	0.00	0.01	0.00	0.01	0.00	0.00	0.00
1990	0.23	0.07	0.06	0.03	0.00	0.00	0.02	0.01	0.02
1991	0.33	0.01	0.01	0.04	0.00	0.00	0.08		0.01
1992	0.32	0.01	0.01	0.08	0.01	0.02	0.08	0.00	0.01
1993	0.22	0.03	0.01	0.05	0.00	0.00	0.08	0.00	
1994	0.19	0.01	0.01	0.04	0.00	0.00	0.07		0.00
1995	0.25	0.01	0.02	0.07	0.00	0.00	0.13	0.00	0.01
1996	0.28	0.04	0.01	0.07	0.00	0.00	0.11	0.00	
1997	0.31	0.02	0.06	0.08	0.00	0.00	0.14	0.02	0.01
1998	0.30	0.06	0.04	0.08	0.00	0.00	0.22	0.01	0.01
1999	0.29	0.03	0.07	0.12	0.00	0.00	0.34	0.09	0.05
2000	0.24	0.05	0.01	0.12	0.00	0.00	0.40	0.01	0.01
2001	0.17	0.04	0.09	0.11	0.00	0.00	0.20	0.01	0.04
2002	0.18	0.05	0.06	0.13	0.00	0.00	0.20	0.00	0.03

Table 2.18–Estimates of Pacific cod fishing mortality rates, expressed on an annual time scale (page 2 of 2). Empty cells indicate that no catch was recorded.

Model 2

Year	Trawl			Longline			Pot		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978			0.03			0.05			
1979			0.02			0.07			
1980			0.04			0.18			
1981	0.00	0.02	0.03	0.05	0.04	0.05			
1982	0.01	0.01	0.02	0.04	0.02	0.05			
1983	0.02	0.02	0.02	0.04	0.03	0.06			
1984	0.02	0.01	0.02	0.05	0.00	0.01			
1985	0.01	0.00	0.01	0.04	0.00	0.00			
1986	0.02	0.00	0.02	0.06	0.00	0.01			
1987	0.03	0.08	0.07	0.03	0.01	0.01	0.00	0.00	0.00
1988	0.08	0.06	0.03	0.01	0.00	0.00	0.01	0.00	0.00
1989	0.12	0.13	0.00	0.01	0.00	0.01	0.00	0.00	0.00
1990	0.23	0.08	0.06	0.03	0.00	0.00	0.02	0.01	0.02
1991	0.32	0.01	0.01	0.04	0.00	0.00	0.07		0.01
1992	0.31	0.01	0.01	0.07	0.01	0.02	0.08	0.00	0.00
1993	0.20	0.03	0.01	0.05	0.00	0.00	0.08	0.00	
1994	0.17	0.01	0.01	0.04	0.00	0.00	0.07		0.00
1995	0.23	0.01	0.02	0.06	0.00	0.00	0.12	0.00	0.01
1996	0.26	0.04	0.01	0.06	0.00	0.00	0.10	0.00	
1997	0.27	0.02	0.06	0.07	0.00	0.00	0.13	0.02	0.01
1998	0.26	0.05	0.03	0.07	0.00	0.00	0.19	0.01	0.01
1999	0.24	0.02	0.06	0.09	0.00	0.00	0.29	0.07	0.04
2000	0.17	0.03	0.01	0.10	0.00	0.00	0.30	0.01	0.01
2001	0.13	0.03	0.07	0.09	0.00	0.00	0.16	0.01	0.03
2002	0.14	0.04	0.05	0.12	0.00	0.00	0.18	0.00	0.03

Table 2.19–Estimates of Pacific cod recruitment at age 1 and initial numbers at age (in millions of fish).

Recruitment at age 1

Year	Model 1	Model 2
1978	555	557
1979	208	213
1980	325	327
1981	313	322
1982	234	240
1983	248	255
1984	231	235
1985	398	407
1986	255	268
1987	233	243
1988	354	373
1989	255	269
1990	342	367
1991	260	287
1992	219	244
1993	184	207
1994	185	216
1995	198	233
1996	268	280
1997	180	164
1998	171	135
1999	197	151
2000	259	209
2001	244	229

Numbers at age

Age	Model 1	Model 2
2	555	557
3	210	202
4	54	54
5	56	55
6	36	37
7	79	76
8	0	0
9	21	20
10	13	12
11	0	0
12	1	0

Table 2.20–Estimates of Pacific cod selectivity parameters. The first column in each half of the table lists the parameter families for which the remaining columns contain era-specific estimates.

Model 1

Trawl (Jan-May)	1978-86	1987-02
$S_{1,g,e(y\|g)}$	n/a	0.00
$S_{2,g,e(y\|g)}$	n/a	64.11
$S_{3,g,e(y\|g)}$	n/a	0.19
$S_{4,g,e(y\|g)}$	n/a	114.36
$S_{5,g,e(y\|g)}$	n/a	1.00
$S_{6,g,e(y\|g)}$	n/a	114.42
$S_{7,g,e(y\|g)}$	n/a	0.15
Trawl (Jun-Dec)	1978-86	1987-02
$S_{1,g,e(y\|g)}$	0.00	0.00
$S_{2,g,e(y\|g)}$	50.47	62.69
$S_{3,g,e(y\|g)}$	0.35	0.17
$S_{4,g,e(y\|g)}$	96.13	72.92
$S_{5,g,e(y\|g)}$	0.84	0.43
$S_{6,g,e(y\|g)}$	96.13	86.34
$S_{7,g,e(y\|g)}$	9.59	0.33
Longline	1978-86	1987-02
$S_{1,g,e(y\|g)}$	0.00	0.00
$S_{2,g,e(y\|g)}$	53.66	63.15
$S_{3,g,e(y\|g)}$	0.33	0.25
$S_{4,g,e(y\|g)}$	80.34	93.48
$S_{5,g,e(y\|g)}$	0.93	0.77
$S_{6,g,e(y\|g)}$	109.11	94.41
$S_{7,g,e(y\|g)}$	10.00	1.90
Pot	1978-86	1987-02
$S_{1,g,e(y\|g)}$	n/a	0.00
$S_{2,g,e(y\|g)}$	n/a	65.63
$S_{3,g,e(y\|g)}$	n/a	0.28
$S_{4,g,e(y\|g)}$	n/a	76.73
$S_{5,g,e(y\|g)}$	n/a	0.23
$S_{6,g,e(y\|g)}$	n/a	76.73
$S_{7,g,e(y\|g)}$	n/a	0.14
Survey	1984-02	
$S_{1,g,e(y\|g)}$	0.10	
$S_{2,g,e(y\|g)}$	51.59	
$S_{3,g,e(y\|g)}$	0.19	
$S_{4,g,e(y\|g)}$	61.26	
$S_{5,g,e(y\|g)}$	0.31	
$S_{6,g,e(y\|g)}$	77.33	
$S_{7,g,e(y\|g)}$	0.33	

Model 2

Trawl (Jan-May)	1978-86	1987-99	2000-02
$S_{1,g,e(y\|g)}$	n/a	0.00	0.00
$S_{2,g,e(y\|g)}$	n/a	63.94	59.34
$S_{3,g,e(y\|g)}$	n/a	0.19	0.19
$S_{4,g,e(y\|g)}$	n/a	114.26	101.54
$S_{5,g,e(y\|g)}$	n/a	1.00	0.29
$S_{6,g,e(y\|g)}$	n/a	114.33	102.55
$S_{7,g,e(y\|g)}$	n/a	0.17	9.35
Trawl (Jun-Dec)	1978-86	1987-99	2000-02
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	50.42	64.54	52.61
$S_{3,g,e(y\|g)}$	0.35	0.16	0.24
$S_{4,g,e(y\|g)}$	96.03	73.66	69.74
$S_{5,g,e(y\|g)}$	0.83	0.24	0.71
$S_{6,g,e(y\|g)}$	96.03	84.08	84.95
$S_{7,g,e(y\|g)}$	9.24	0.16	0.66
Longline	1978-86	1987-99	2000-02
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	53.52	62.41	62.28
$S_{3,g,e(y\|g)}$	0.33	0.25	0.28
$S_{4,g,e(y\|g)}$	80.23	93.38	92.00
$S_{5,g,e(y\|g)}$	0.89	0.83	0.38
$S_{6,g,e(y\|g)}$	109.51	94.31	92.99
$S_{7,g,e(y\|g)}$	10.00	1.31	1.64
Pot	1978-86	1987-99	2000-02
$S_{1,g,e(y\|g)}$	n/a	0.00	0.00
$S_{2,g,e(y\|g)}$	n/a	65.94	61.47
$S_{3,g,e(y\|g)}$	n/a	0.28	0.29
$S_{4,g,e(y\|g)}$	n/a	76.31	76.10
$S_{5,g,e(y\|g)}$	n/a	0.21	0.19
$S_{6,g,e(y\|g)}$	n/a	76.31	76.10
$S_{7,g,e(y\|g)}$	n/a	0.13	0.23
Survey	1984-02		
$S_{1,g,e(y\|g)}$	0.10		
$S_{2,g,e(y\|g)}$	51.32		
$S_{3,g,e(y\|g)}$	0.19		
$S_{4,g,e(y\|g)}$	61.58		
$S_{5,g,e(y\|g)}$	0.27		
$S_{6,g,e(y\|g)}$	76.21		
$S_{7,g,e(y\|g)}$	0.28		

Table 2.21–Time series of GOA Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated by Models 1 and 2. All biomass figures are in t.

Year	Model 1			Model 2			Survey (obs)
	Age 3+	Spawning	Survey (est)	Age 3+	Spawning	Survey (est)	
1978	536	107		523	104		
1979	579	122		566	119		
1980	702	131		692	129		
1981	730	136		723	134		
1982	766	145		763	144		
1983	796	156		798	156		
1984	798	167	520	804	169	506	571
1985	796	175		805	178		
1986	792	182		803	185		
1987	823	183	496	836	188	484	559
1988	822	181		838	185		
1989	811	180		831	185		
1990	816	173	488	842	178	487	379
1991	778	159		810	166		
1992	765	148		805	156		
1993	733	141	459	782	150	477	410
1994	711	141		768	152		
1995	681	140		745	153		
1996	628	133	372	699	148	404	538
1997	580	122		659	139		
1998	552	108		632	126		
1999	517	95	303	586	115	334	306
2000	470	83		519	103		
2001	450	80	291	471	99	279	278
2002	464	79		454	92		

Table 2.22–Distribution of Pacific cod lengths (in cm) at age (mid-year) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins. Columns sum to 1.0.

Len.	Age Group											
	1	2	3	4	5	6	7	8	9	10	11	12+
105	0	0	0	0	0	0	0	0	0	0	0	0.023
100	0	0	0	0	0	0	0	0	0	0	0.002	0.061
95	0	0	0	0	0	0	0	0	0	0.004	0.020	0.140
90	0	0	0	0	0	0	0	0.001	0.008	0.041	0.107	0.221
85	0	0	0	0	0	0	0	0.011	0.066	0.171	0.272	0.241
80	0	0	0	0	0	0	0.010	0.087	0.234	0.333	0.334	0.179
75	0	0	0	0	0	0.006	0.095	0.284	0.364	0.299	0.199	0.092
70	0	0	0	0	0.002	0.079	0.315	0.373	0.246	0.125	0.057	0.033
65	0	0	0	0	0.040	0.319	0.382	0.198	0.073	0.024	0.008	0.008
60	0	0	0	0.007	0.269	0.409	0.168	0.042	0.009	0.002	0.001	0.001
55	0	0	0	0.137	0.461	0.166	0.027	0.004	0.001	0	0	0
50	0	0	0.015	0.484	0.205	0.021	0.002	0	0	0	0	0
45	0	0	0.275	0.329	0.023	0.001	0	0	0	0	0	0
42	0	0.001	0.372	0.038	0.001	0	0	0	0	0	0	0
39	0	0.026	0.256	0.005	0	0	0	0	0	0	0	0
36	0	0.207	0.074	0	0	0	0	0	0	0	0	0
33	0	0.447	0.009	0	0	0	0	0	0	0	0	0
30	0	0.271	0	0	0	0	0	0	0	0	0	0
27	0.034	0.046	0	0	0	0	0	0	0	0	0	0
24	0.394	0.002	0	0	0	0	0	0	0	0	0	0
21	0.499	0	0	0	0	0	0	0	0	0	0	0
18	0.071	0	0	0	0	0	0	0	0	0	0	0
15	0.001	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.23–Schedules of Pacific cod weight (kg) and maturity proportions at length (cm) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins.

Bin	Length	Weight	Maturity
1	9	0.010	0
2	12	0.022	0.001
3	15	0.042	0.001
4	18	0.070	0.001
5	21	0.110	0.002
6	24	0.163	0.003
7	27	0.231	0.004
8	30	0.316	0.006
9	33	0.421	0.010
10	36	0.547	0.015
11	39	0.697	0.023
12	42	0.873	0.035
13	45	1.159	0.061
14	50	1.588	0.117
15	55	2.114	0.210
16	60	2.748	0.347
17	65	3.501	0.514
18	70	4.385	0.678
19	75	5.411	0.808
20	80	6.590	0.894
21	85	7.933	0.945
22	90	9.453	0.972
23	95	11.160	0.986
24	100	13.067	0.993
25	105	14.072	0.995

Table 2.24–Schedules of Pacific cod selectivities as defined by final parameter estimates. Lengths (cm) correspond to lower bounds of size bins. Trawl(1) = period 1 (January-May) trawl fishery, Trawl(2-3) = periods 2-3 (June-December) trawl fishery.

Bin	Len.	Trawl (1)		Trawl (2-3)			Longline			Pot		Survey
		87-99	00-02	78-86	87-99	00-02	78-86	87-99	00-02	87-99	00-02	84-02
1	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
2	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
3	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
4	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
5	21	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.11
6	24	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.11
7	27	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.12
8	30	0.01	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.14
9	33	0.01	0.02	0.01	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.17
10	36	0.02	0.03	0.03	0.04	0.06	0.02	0.01	0.00	0.00	0.00	0.23
11	39	0.03	0.06	0.09	0.06	0.12	0.04	0.01	0.01	0.00	0.01	0.30
12	42	0.05	0.10	0.22	0.10	0.22	0.11	0.03	0.02	0.01	0.02	0.42
13	45	0.09	0.16	0.45	0.15	0.36	0.25	0.06	0.04	0.02	0.05	0.56
14	50	0.19	0.34	0.83	0.28	0.66	0.64	0.18	0.16	0.07	0.18	0.80
15	55	0.38	0.57	0.96	0.49	0.88	0.90	0.42	0.43	0.24	0.49	0.99
16	60	0.61	0.78	0.99	0.74	0.98	0.98	0.72	0.75	0.59	0.81	0.95
17	65	0.80	0.90	1.00	0.96	1.00	1.00	0.90	0.93	0.89	0.96	0.81
18	70	0.91	0.96	1.00	0.89	0.99	1.00	0.97	0.98	0.93	0.86	0.56
19	75	0.96	0.99	1.00	0.72	0.91	1.00	0.99	1.00	0.69	0.50	0.37
20	80	0.99	1.00	1.00	0.54	0.73	1.00	1.00	1.00	0.50	0.30	0.30
21	85	0.99	1.00	1.00	0.40	0.71	1.00	0.91	0.42	0.37	0.23	0.27
22	90	1.00	1.00	0.83	0.32	0.71	1.00	0.83	0.38	0.29	0.20	0.27
23	95	1.00	0.29	0.83	0.27	0.71	1.00	0.83	0.38	0.25	0.19	0.27
24	100	1.00	0.29	0.83	0.25	0.71	0.89	0.83	0.38	0.22	0.19	0.27
25	105	1.00	0.29	0.83	0.24	0.71	0.89	0.83	0.38	0.21	0.19	0.27

Table 2.25–Time series of Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated in last year's and this year's assessments.

Year	Age 3+ Biomass		Spawning Biomass		Survey Biomass	
	Last Year	This Year	Last Year	This Year	Last Year	This Year
1978	555	523	111	104		
1979	598	566	126	119		
1980	721	692	135	129		
1981	746	723	140	134		
1982	781	763	148	144		
1983	808	798	158	156		
1984	808	804	170	169	526	506
1985	802	805	177	178		
1986	797	803	183	185		
1987	825	836	184	188	498	484
1988	822	838	180	185		
1989	811	831	179	185		
1990	816	842	171	178	490	487
1991	779	810	158	166		
1992	764	805	147	156		
1993	731	782	140	150	459	477
1994	708	768	140	152		
1995	678	745	138	153		
1996	625	699	131	148	371	404
1997	578	659	120	139		
1998	553	632	106	126		
1999	520	586	94	115	306	334
2000	471	519	83	103		
2001	441	471	80	99	285	279
2002	n/a	454	n/a	92		

Notes: Spawning biomass is computed as the sum of March female numbers at age times population weight at age times fraction mature at age.

"Survey biomass" is the model's estimate of what the actual survey should have observed.

All biomass figures are in 1000s of t.

Table 2.26–Time series of Pacific cod age 3 recruitment as estimated in last year's and this year's assessments.

Year	Recruitment (millions of age 3 fish)	
	Last Year	This Year
1978	55	54
1979	150	140
1980	268	265
1981	100	101
1982	157	156
1983	149	153
1984	112	114
1985	118	120
1986	111	111
1987	188	192
1988	122	127
1989	114	116
1990	171	178
1991	122	128
1992	162	175
1993	124	137
1994	103	116
1995	88	99
1996	89	103
1997	96	111
1998	131	133
1999	89	78
2000	76	64
2001	80	72

Table 2.27–Time series of Pacific cod catch divided by age 3+ biomass as estimated in last year's and this year's assessments (the entry for 2002 under "This Year" is based on catch through August, 2002; the entry for 2001 under "Last Year" was based on catch through August, 2001).

Year	Catch Divided by Age 3+ Biomass	
	Last Year	This Year
1978	0.02	0.02
1979	0.02	0.03
1980	0.05	0.05
1981	0.05	0.05
1982	0.04	0.04
1983	0.05	0.05
1984	0.03	0.03
1985	0.02	0.02
1986	0.03	0.03
1987	0.04	0.04
1988	0.04	0.04
1989	0.05	0.05
1990	0.09	0.09
1991	0.10	0.09
1992	0.11	0.10
1993	0.08	0.07
1994	0.07	0.06
1995	0.10	0.09
1996	0.11	0.10
1997	0.12	0.10
1998	0.11	0.10
1999	0.13	0.12
2000	0.14	0.13
2001	0.10	0.11
2002	n/a	0.10

Table 2.28–Definitions of symbols 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
St. Dev.	Standard deviation of the projection outputs

Table 2.29–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2000. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	225.8	0	0
40%	90.3	0.35	74.4
35%	79.0	0.42	80.3

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	88.3	88.3	88.3	88.3	0.00
2004	79.4	79.5	79.5	79.6	0.06
2005	77.4	77.9	78.0	78.7	0.40
2006	78.4	80.3	80.4	83.2	1.51
2007	79.4	83.7	84.2	90.2	3.54
2008	79.0	86.3	87.0	96.3	5.70
2009	78.8	87.9	89.0	101.9	7.29
2010	79.2	89.2	90.2	105.0	8.20
2011	79.8	89.6	91.1	106.5	8.66
2012	79.5	90.3	91.5	107.8	8.87
2013	80.0	90.1	91.7	107.7	8.85
2014	80.0	90.1	91.7	107.7	8.76
2015	80.2	90.3	91.7	107.7	8.72

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.34	0.34	0.34	0.34	0.000
2004	0.31	0.31	0.31	0.31	0.000
2005	0.30	0.30	0.30	0.30	0.002
2006	0.30	0.31	0.31	0.32	0.006
2007	0.31	0.32	0.32	0.35	0.013
2008	0.30	0.33	0.33	0.35	0.016
2009	0.30	0.34	0.34	0.35	0.016
2010	0.30	0.35	0.34	0.35	0.016
2011	0.31	0.35	0.34	0.35	0.016
2012	0.31	0.35	0.34	0.35	0.016
2013	0.31	0.35	0.34	0.35	0.015
2014	0.31	0.35	0.34	0.35	0.015
2015	0.31	0.35	0.34	0.35	0.015

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	59.9	59.9	59.9	59.9	0.00
2004	50.6	50.7	50.7	50.8	0.06
2005	51.4	52.0	52.0	53.0	0.50
2006	55.0	57.9	58.3	62.9	2.51
2007	56.3	64.5	65.3	77.8	6.72
2008	55.0	68.8	69.7	84.1	9.50
2009	54.8	71.5	71.7	88.3	10.66
2010	55.5	73.1	72.6	90.6	11.09
2011	55.4	73.1	73.1	91.2	11.22
2012	55.3	74.0	73.3	90.7	11.21
2013	56.1	73.3	73.2	91.1	10.92
2014	56.0	73.3	73.2	90.5	10.75
2015	55.7	73.3	73.2	90.9	10.78

Table 2.30–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that the ratio of F to $max\ F_{ABC}$ in each year 2003-2015 is fixed at a value of 0.87, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2000. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	225.8	0	0
40%	90.3	0.35	74.4
35%	79.0	0.42	80.3

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	88.7	88.7	88.7	88.7	0.00
2004	81.8	81.9	81.9	82.0	0.06
2005	80.7	81.2	81.2	82.0	0.40
2006	82.2	84.1	84.2	87.0	1.52
2007	83.5	87.9	88.4	94.7	3.63
2008	83.3	90.8	91.8	102.1	6.08
2009	83.2	93.0	94.3	108.6	8.07
2010	83.8	94.9	96.2	112.5	9.29
2011	84.4	96.0	97.6	114.7	9.95
2012	84.3	97.2	98.4	116.2	10.26
2013	84.9	97.8	98.8	117.0	10.30
2014	84.8	97.7	99.0	117.4	10.22
2015	85.1	97.9	99.2	117.3	10.17

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.30	0.30	0.30	0.30	0.000
2004	0.27	0.27	0.27	0.27	0.000
2005	0.27	0.27	0.27	0.27	0.001
2006	0.27	0.28	0.28	0.29	0.005
2007	0.28	0.29	0.29	0.30	0.009
2008	0.28	0.30	0.30	0.30	0.009
2009	0.28	0.30	0.30	0.30	0.009
2010	0.28	0.30	0.30	0.30	0.009
2011	0.28	0.30	0.30	0.30	0.008
2012	0.28	0.30	0.30	0.30	0.008
2013	0.28	0.30	0.30	0.30	0.008
2014	0.28	0.30	0.30	0.30	0.007
2015	0.28	0.30	0.30	0.30	0.007

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	52.8	52.8	52.8	52.8	0.00
2004	46.7	46.8	46.8	46.9	0.05
2005	48.3	48.8	48.9	49.7	0.46
2006	52.1	54.8	55.1	59.3	2.29
2007	53.7	61.3	61.7	70.9	5.56
2008	52.7	65.6	65.3	77.0	7.75
2009	52.6	67.1	67.2	81.4	8.95
2010	53.2	68.2	68.2	84.1	9.42
2011	53.9	68.3	68.8	84.9	9.58
2012	53.5	68.9	69.0	84.5	9.59
2013	54.3	68.6	69.1	84.9	9.36
2014	54.5	68.5	69.1	84.5	9.19
2015	54.4	68.6	69.2	84.4	9.14

Table 2.31–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that F = ½ $max\ F_{ABC}$ in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2000. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	225.8	0	0
40%	90.3	0.35	74.4
35%	79.0	0.42	80.3

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	90.0	90.0	90.0	90.0	0.00
2004	89.2	89.3	89.3	89.4	0.06
2005	91.8	92.3	92.3	93.1	0.42
2006	96.0	97.9	98.1	101.1	1.64
2007	100.0	105.0	105.5	112.5	4.10
2008	102.0	111.3	112.3	124.3	7.23
2009	103.8	116.9	118.2	135.4	9.98
2010	105.5	121.6	122.9	143.3	11.87
2011	108.1	125.5	126.6	149.4	12.98
2012	109.5	128.0	129.1	152.6	13.57
2013	110.8	129.8	130.9	155.8	13.77
2014	111.8	130.9	132.0	156.0	13.76
2015	112.2	131.6	132.7	156.2	13.68

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.17	0.17	0.17	0.17	0.000
2004	0.17	0.17	0.17	0.17	0.000
2005	0.17	0.18	0.17	0.18	0.000
2006	0.18	0.18	0.18	0.18	0.000
2007	0.18	0.18	0.18	0.18	0.000
2008	0.18	0.18	0.18	0.18	0.000
2009	0.18	0.18	0.18	0.18	0.000
2010	0.18	0.18	0.18	0.18	0.000
2011	0.18	0.18	0.18	0.18	0.000
2012	0.18	0.18	0.18	0.18	0.000
2013	0.18	0.18	0.18	0.18	0.000
2014	0.18	0.18	0.18	0.18	0.000
2015	0.18	0.18	0.18	0.18	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	31.6	31.6	31.6	31.6	0.00
2004	31.9	32.0	32.0	32.0	0.03
2005	35.4	35.7	35.7	36.0	0.17
2006	38.2	39.2	39.3	40.9	0.84
2007	39.4	42.6	42.9	47.4	2.57
2008	39.6	45.1	45.7	52.7	4.29
2009	39.9	46.9	47.6	56.9	5.35
2010	40.5	48.3	48.8	59.0	5.85
2011	40.9	48.9	49.6	60.0	6.07
2012	41.1	49.6	50.0	60.5	6.14
2013	41.8	49.7	50.3	60.8	6.05
2014	41.7	49.8	50.4	60.7	5.95
2015	41.8	49.9	50.5	61.2	5.92

Table 2.32–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that *F* = the 1997-2001 average in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2000. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	225.8	0	0
40%	90.3	0.35	74.4
35%	79.0	0.42	80.3

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	89.2	89.2	89.2	89.2	0.00
2004	84.4	84.4	84.4	84.6	0.07
2005	83.7	84.2	84.3	85.1	0.43
2006	85.5	87.5	87.7	90.7	1.64
2007	87.4	92.3	92.8	99.7	4.05
2008	87.7	96.7	97.6	109.2	6.94
2009	88.3	100.6	101.7	117.9	9.30
2010	89.2	103.8	104.9	123.1	10.77
2011	90.7	106.3	107.3	127.3	11.56
2012	91.8	108.1	108.9	129.2	11.93
2013	92.6	109.3	109.9	130.5	11.99
2014	93.0	109.3	110.5	131.3	11.89
2015	93.1	109.7	110.9	130.6	11.80

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.25	0.25	0.25	0.25	0.000
2004	0.25	0.25	0.25	0.25	0.000
2005	0.25	0.25	0.25	0.25	0.000
2006	0.25	0.25	0.25	0.25	0.000
2007	0.25	0.25	0.25	0.25	0.000
2008	0.25	0.25	0.25	0.25	0.000
2009	0.25	0.25	0.25	0.25	0.000
2010	0.25	0.25	0.25	0.25	0.000
2011	0.25	0.25	0.25	0.25	0.000
2012	0.25	0.25	0.25	0.25	0.000
2013	0.25	0.25	0.25	0.25	0.000
2014	0.25	0.25	0.25	0.25	0.000
2015	0.25	0.25	0.25	0.25	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	45.0	45.0	45.0	45.0	0.00
2004	44.1	44.2	44.2	44.2	0.02
2005	46.4	46.6	46.6	47.0	0.21
2006	49.1	50.6	50.7	52.9	1.20
2007	49.9	54.4	54.8	61.1	3.58
2008	49.6	57.2	57.9	67.4	5.81
2009	49.6	59.0	59.9	72.1	7.08
2010	50.1	60.5	61.1	74.3	7.62
2011	50.8	61.0	61.9	75.5	7.84
2012	50.7	61.8	62.3	75.5	7.89
2013	51.6	61.6	62.4	76.0	7.75
2014	51.3	61.6	62.5	75.8	7.62
2015	51.6	61.8	62.6	76.2	7.58

Table 2.33–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = 0$ in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2000. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	225.8	0	0
40%	90.3	0.35	74.4
35%	79.0	0.42	80.3

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	91.8	91.8	91.8	91.8	0.00
2004	100.9	101.0	101.0	101.1	0.07
2005	112.6	113.1	113.1	113.9	0.43
2006	125.9	127.9	128.1	131.1	1.66
2007	139.0	144.2	144.7	152.1	4.27
2008	149.2	159.3	160.4	174.1	7.99
2009	157.7	173.0	174.7	194.8	11.90
2010	165.0	185.2	187.1	212.6	15.23
2011	171.8	195.6	197.6	228.4	17.68
2012	177.9	203.9	205.6	238.2	19.32
2013	182.2	209.6	211.6	247.6	20.28
2014	185.4	214.6	215.7	253.0	20.87
2015	187.2	217.3	218.6	254.8	21.07

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0
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

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0
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

Table 2.34–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = F_{OFL}$ in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2000. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	225.8	0	0
40%	90.3	0.35	74.4
35%	79.0	0.42	80.3

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	87.6	87.6	87.6	87.6	0.00
2004	76.0	76.1	76.1	76.2	0.06
2005	73.0	73.5	73.6	74.3	0.40
2006	73.5	75.3	75.5	78.2	1.49
2007	74.1	78.4	78.8	84.7	3.45
2008	73.5	80.5	81.2	89.8	5.34
2009	73.2	81.9	82.6	93.5	6.46
2010	73.7	82.8	83.4	95.3	6.95
2011	73.9	83.0	83.8	96.2	7.12
2012	73.8	83.3	83.9	96.5	7.16
2013	74.2	83.1	83.8	96.3	7.06
2014	74.1	82.9	83.8	95.8	6.95
2015	74.0	82.9	83.8	95.9	6.90

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.41	0.41	0.41	0.41	0.000
2004	0.35	0.35	0.35	0.35	0.000
2005	0.34	0.34	0.34	0.34	0.002
2006	0.34	0.35	0.35	0.36	0.007
2007	0.34	0.36	0.36	0.39	0.017
2008	0.34	0.37	0.38	0.42	0.023
2009	0.34	0.38	0.38	0.42	0.026
2010	0.34	0.38	0.38	0.42	0.027
2011	0.34	0.38	0.38	0.42	0.027
2012	0.34	0.39	0.39	0.42	0.027
2013	0.34	0.39	0.39	0.42	0.026
2014	0.34	0.38	0.38	0.42	0.026
2015	0.34	0.38	0.39	0.42	0.026

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	70.1	70.1	70.1	70.1	0.00
2004	55.5	55.6	55.6	55.7	0.07
2005	55.0	55.7	55.8	56.8	0.56
2006	58.4	61.7	62.0	67.2	2.80
2007	59.4	68.4	69.4	83.0	7.76
2008	57.9	72.6	74.3	94.1	11.50
2009	57.6	75.1	76.5	98.7	12.88
2010	57.8	76.3	77.4	100.1	13.32
2011	58.0	76.2	77.7	100.6	13.46
2012	58.0	76.8	77.7	99.5	13.36
2013	58.4	76.1	77.4	99.8	12.99
2014	57.9	76.0	77.3	99.8	12.89
2015	57.8	76.0	77.4	99.7	12.96

Table 2.35–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2003-2004 and $F = F_{OFL}$ thereafter, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2000. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	225.8	0	0
40%	90.3	0.35	74.4
35%	79.0	0.42	80.3

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	88.3	88.3	88.3	88.3	0.00
2004	79.4	79.5	79.5	79.6	0.06
2005	76.9	77.4	77.5	78.2	0.40
2006	75.6	77.4	77.6	80.2	1.48
2007	75.0	79.3	79.7	85.7	3.43
2008	73.9	80.9	81.5	90.0	5.32
2009	73.3	81.9	82.7	93.6	6.46
2010	73.6	82.8	83.4	95.3	6.95
2011	73.9	82.9	83.7	96.1	7.13
2012	73.8	83.3	83.8	96.4	7.16
2013	74.2	83.0	83.8	96.3	7.06
2014	74.1	82.9	83.8	95.8	6.95
2015	74.0	82.9	83.8	95.9	6.90

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.34	0.34	0.34	0.34	0.000
2004	0.31	0.31	0.31	0.31	0.000
2005	0.36	0.36	0.36	0.36	0.002
2006	0.35	0.36	0.36	0.37	0.007
2007	0.35	0.37	0.37	0.40	0.017
2008	0.34	0.37	0.38	0.42	0.023
2009	0.34	0.38	0.38	0.42	0.026
2010	0.34	0.38	0.38	0.42	0.027
2011	0.34	0.38	0.38	0.42	0.027
2012	0.34	0.39	0.38	0.42	0.027
2013	0.34	0.39	0.39	0.42	0.026
2014	0.34	0.38	0.38	0.42	0.026
2015	0.34	0.38	0.39	0.42	0.026

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	59.9	59.9	59.9	59.9	0.00
2004	50.6	50.7	50.7	50.8	0.06
2005	60.4	61.1	61.1	62.2	0.59
2006	61.0	64.4	64.7	70.0	2.85
2007	60.4	69.4	70.5	84.1	7.76
2008	58.1	72.8	74.5	94.3	11.46
2009	57.5	75.0	76.4	98.6	12.86
2010	57.7	76.2	77.3	100.0	13.32
2011	58.0	76.1	77.6	100.5	13.46
2012	57.9	76.8	77.6	99.5	13.37
2013	58.4	76.1	77.4	99.8	12.99
2014	57.9	76.0	77.3	99.8	12.89
2015	57.8	76.0	77.4	99.7	12.96

Table 2.36--Summary of major results for the stock assessment of Pacific cod in the GOA region.

Natural mortality rate:		0.37
Reference fishing mortalities:	Rate	Value
	$F_{35\%}$	0.42
	$F_{40\%}$	0.35
	$max\ F_{ABC}$	0.34
Reference spawning biomass:	Type	Value
	$B_{35\%}$	79,000 t
	$B_{40\%}$	90,300 t
Projected biomass for 2003:	Type	Value
	Age 3+	452,000 t
	Spawning (at $max\ F_{ABC}$)	88,300 t
Recommended ABC for 2003:	Units	Value
	Fishing Mortality	0.30
	Catch	52,800 t
Overfishing level for 2003:	Units	Value
	Fishing Mortality	0.41
	Catch	70,100 t

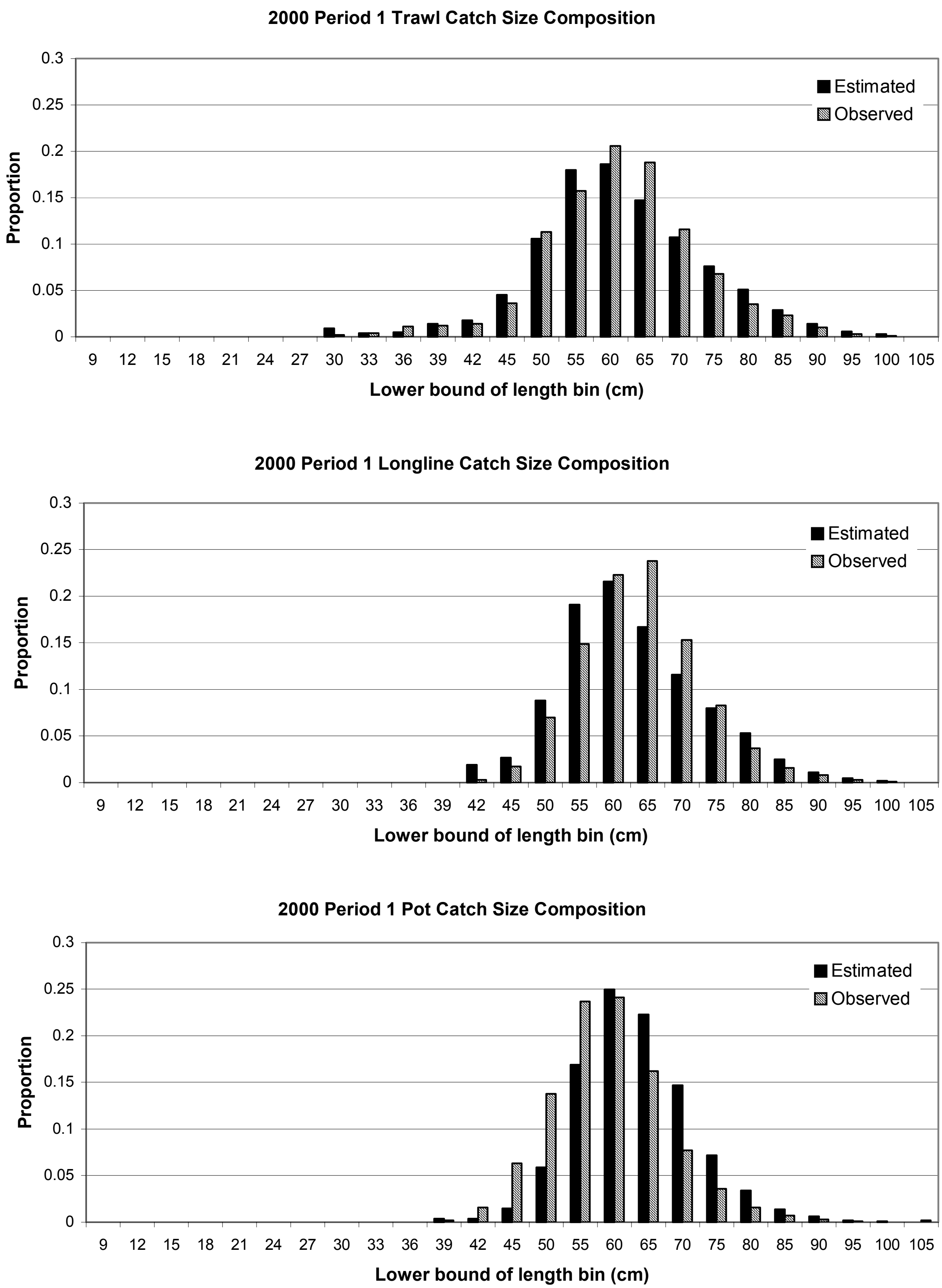
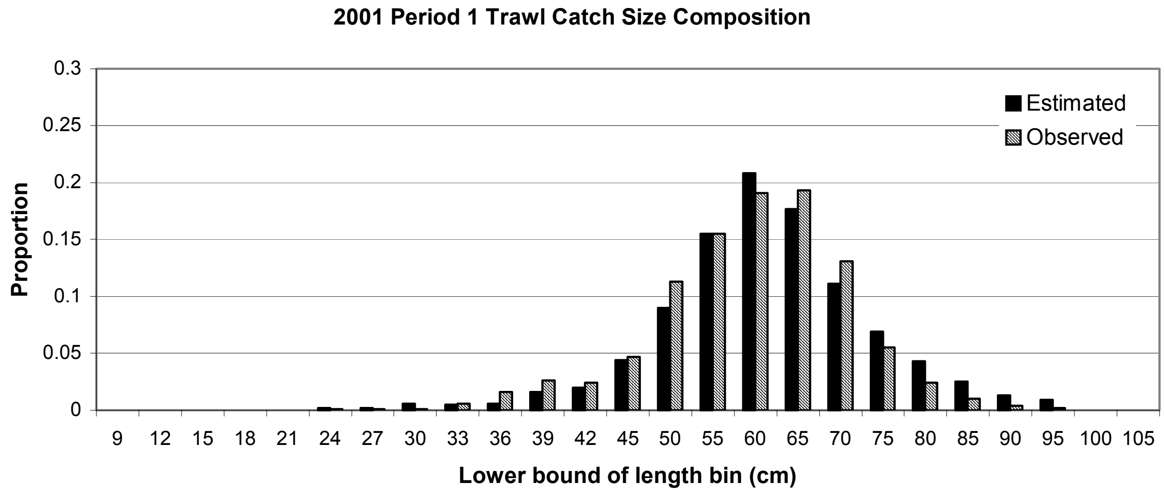
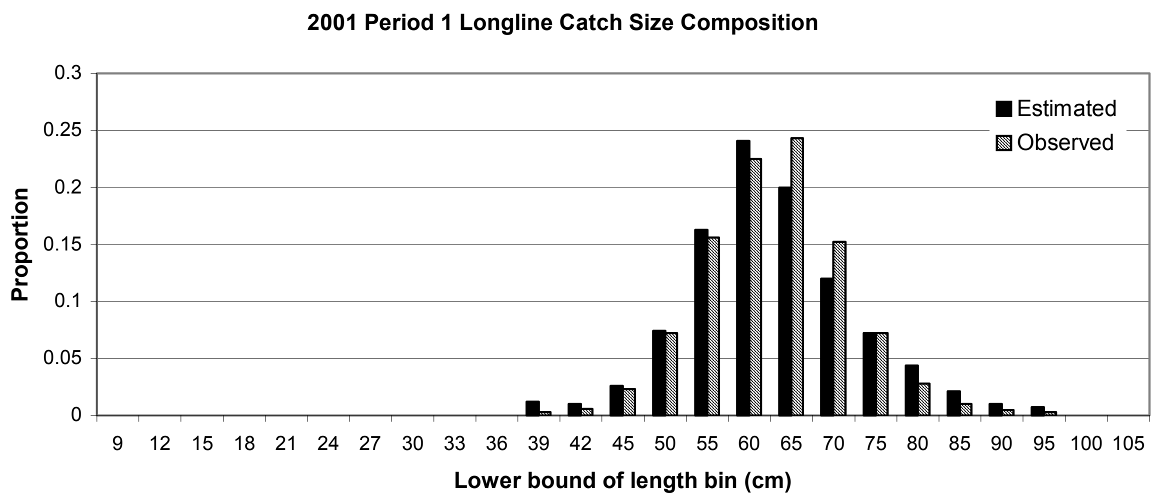


Figure 2.1–Estimated and observed size compositions from the 2000 period 1 fisheries (Model 1).





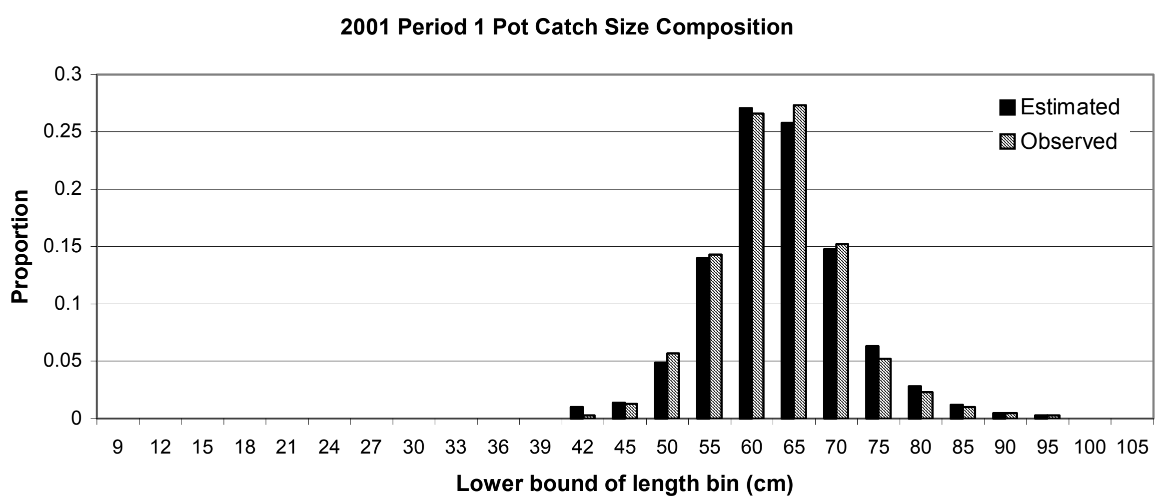
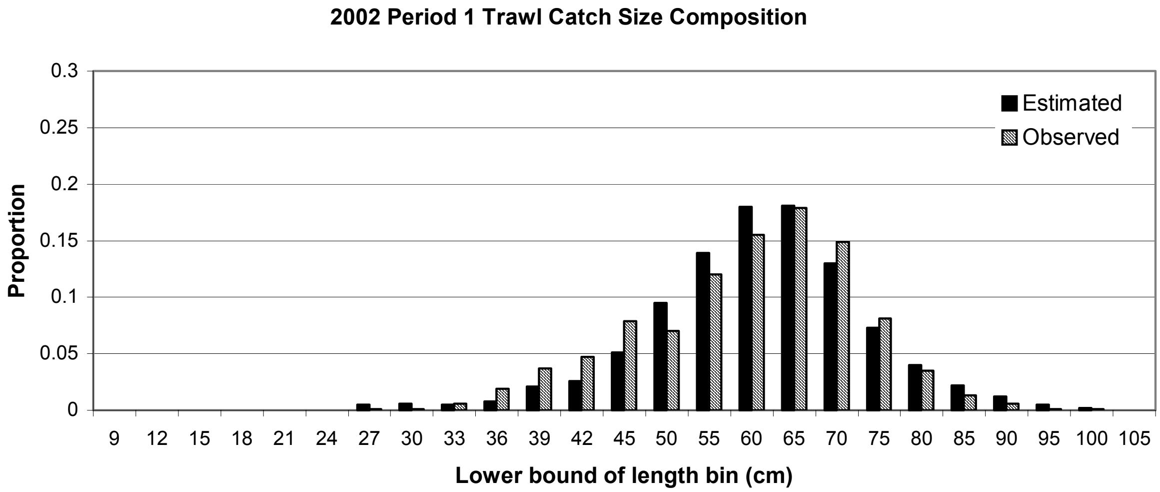
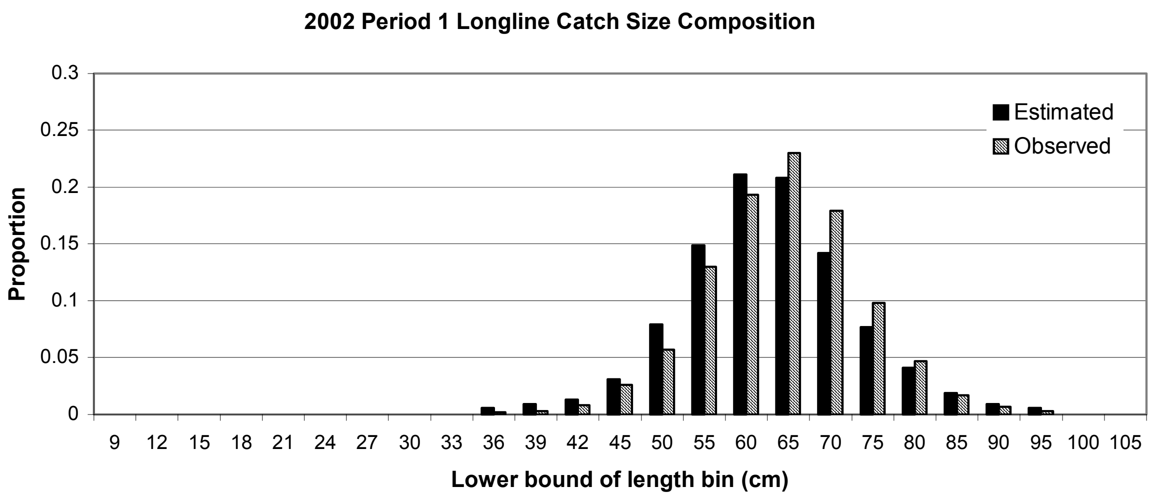


Figure 2.2–Estimated and observed size compositions from the 2001 period 1 fisheries (Model 1).





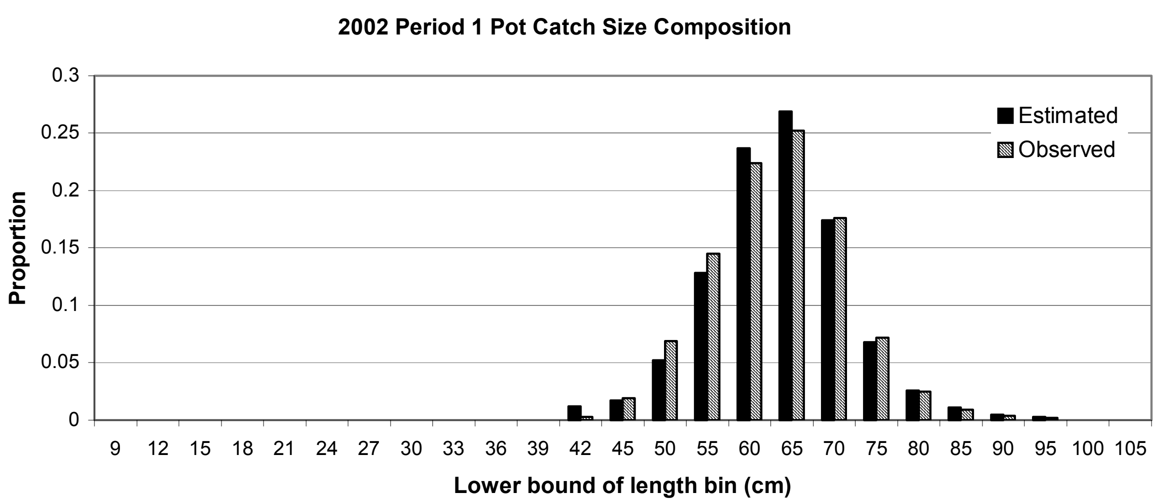
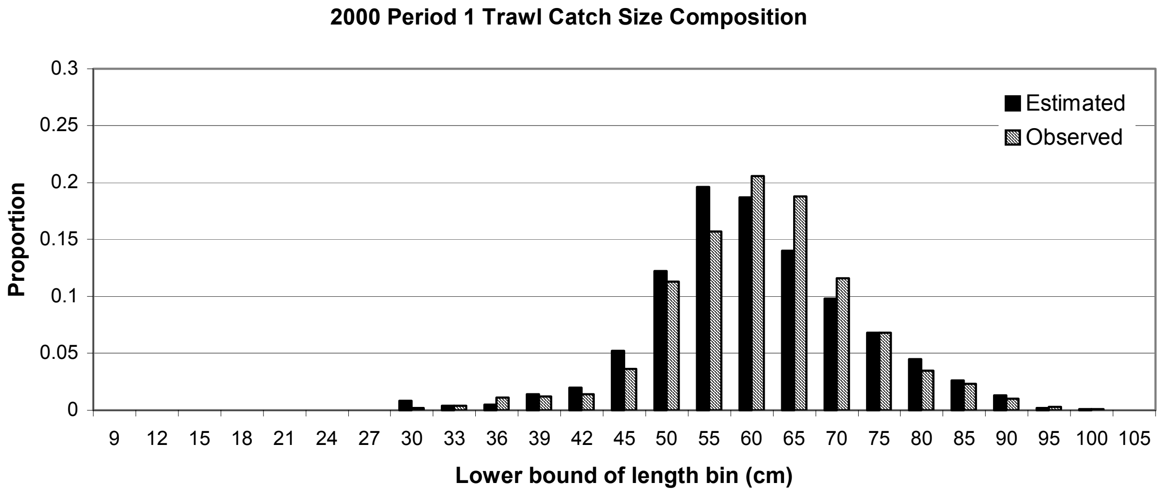
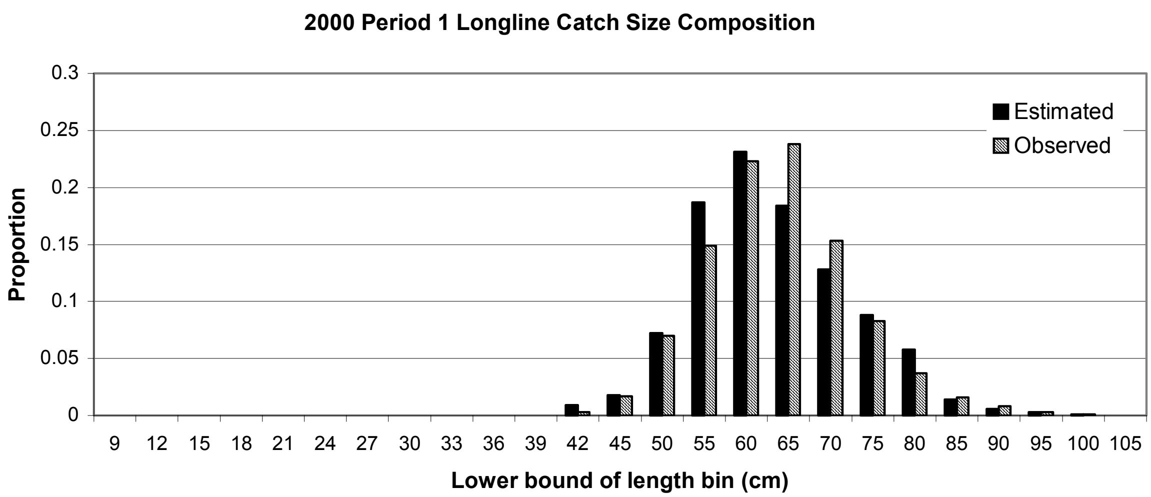


Figure 2.3–Estimated and observed size compositions from the 2002 period 1 fisheries (Model 1).





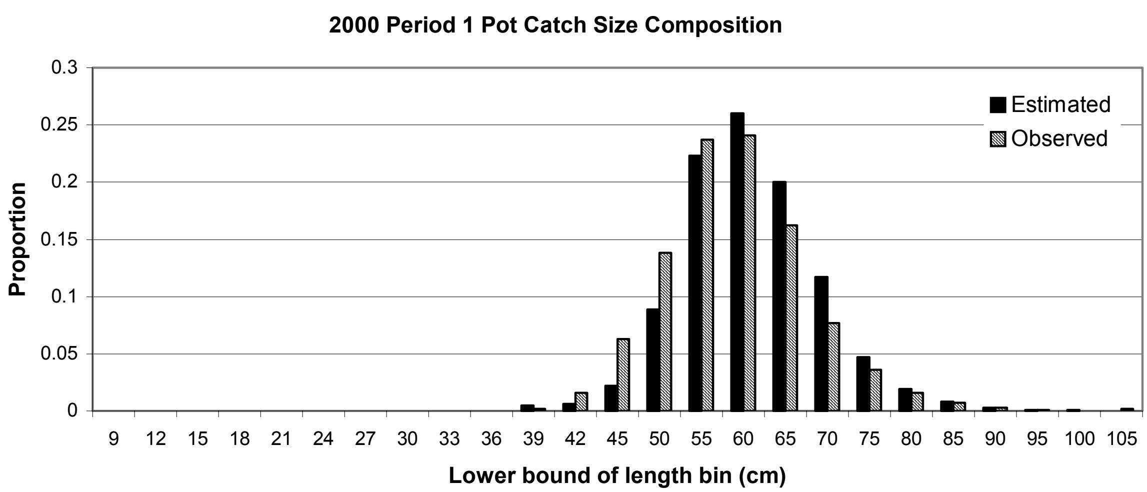


Figure 2.4–Estimated and observed size compositions from the 2000 period 1 fisheries (Model 2).

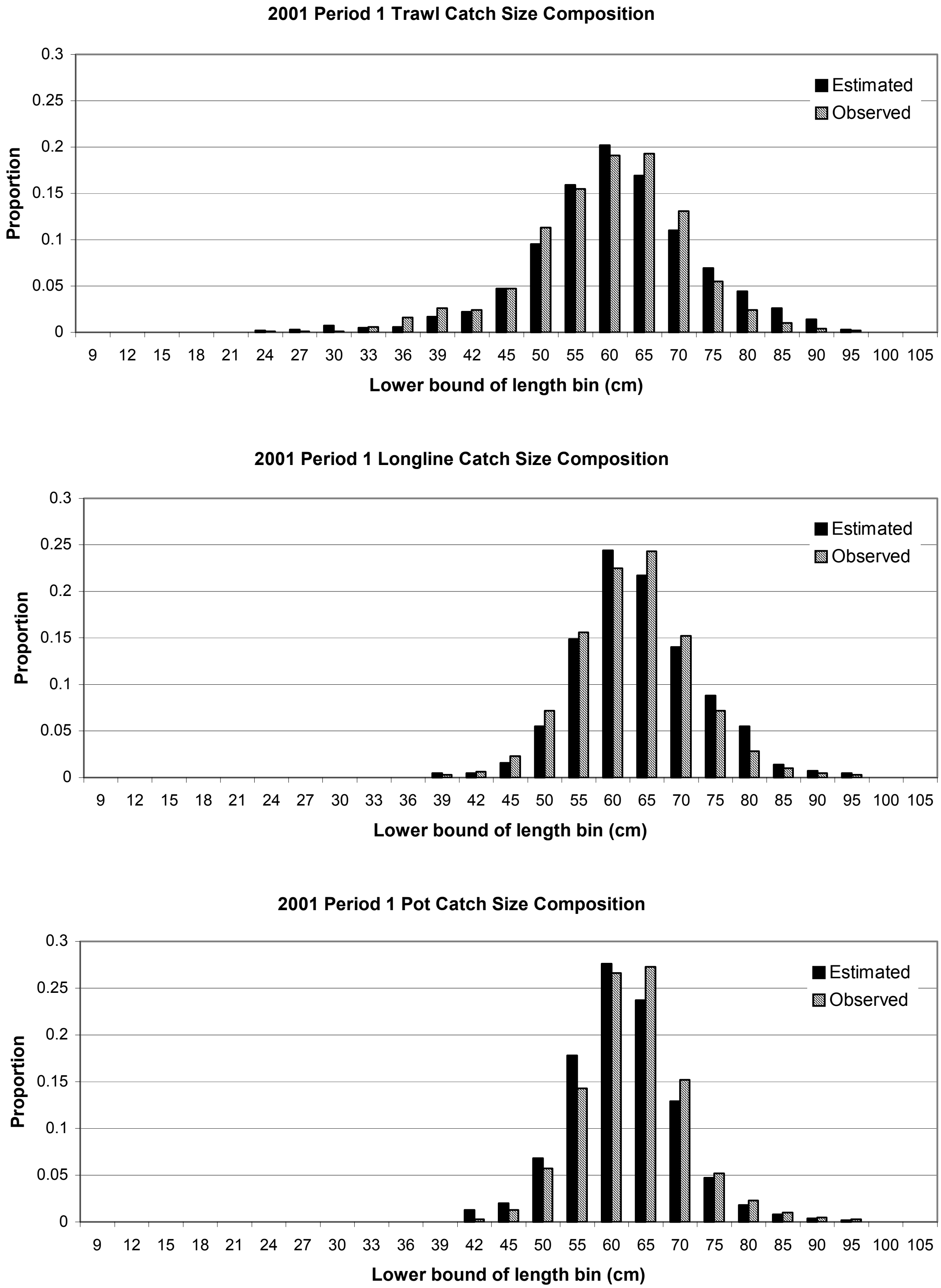
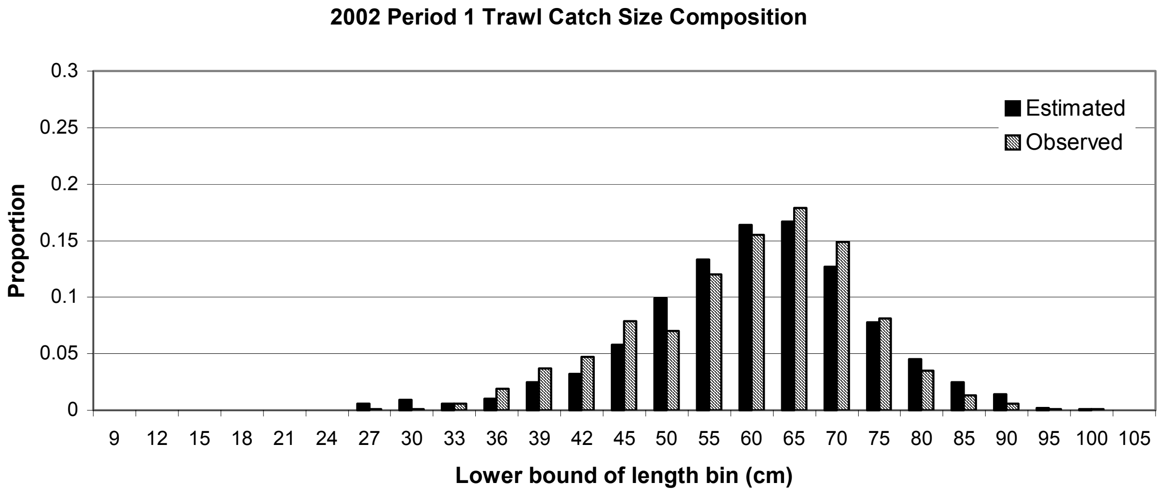
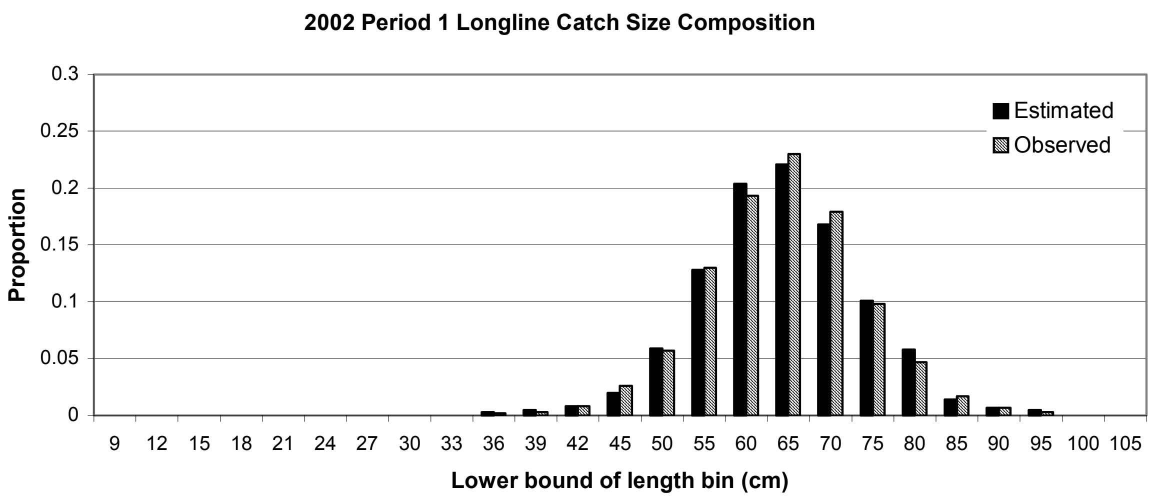


Figure 2.5–Estimated and observed size compositions from the 2001 period 1 fisheries (Model 2).





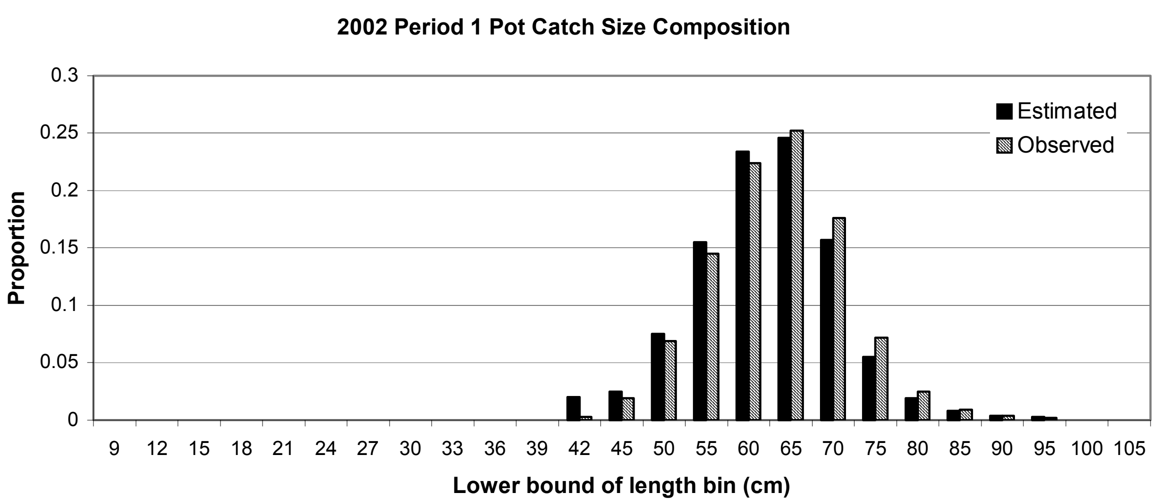


Figure 2.6–Estimated and observed size compositions from the 2002 period 1 fisheries (Model 2).

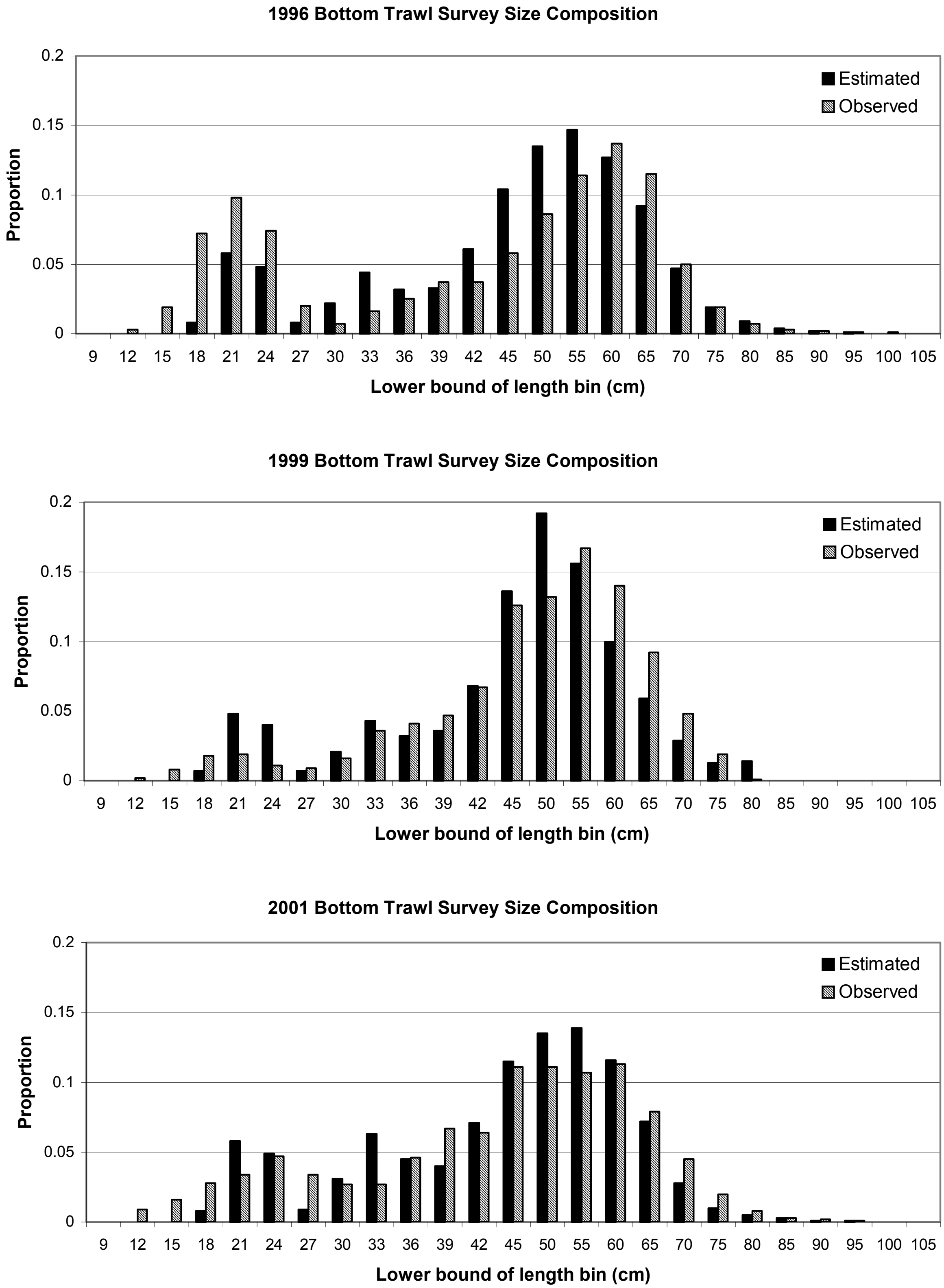


Figure 2.7–Estimated and observed size compositions from the 3 most recent surveys (Model 1).

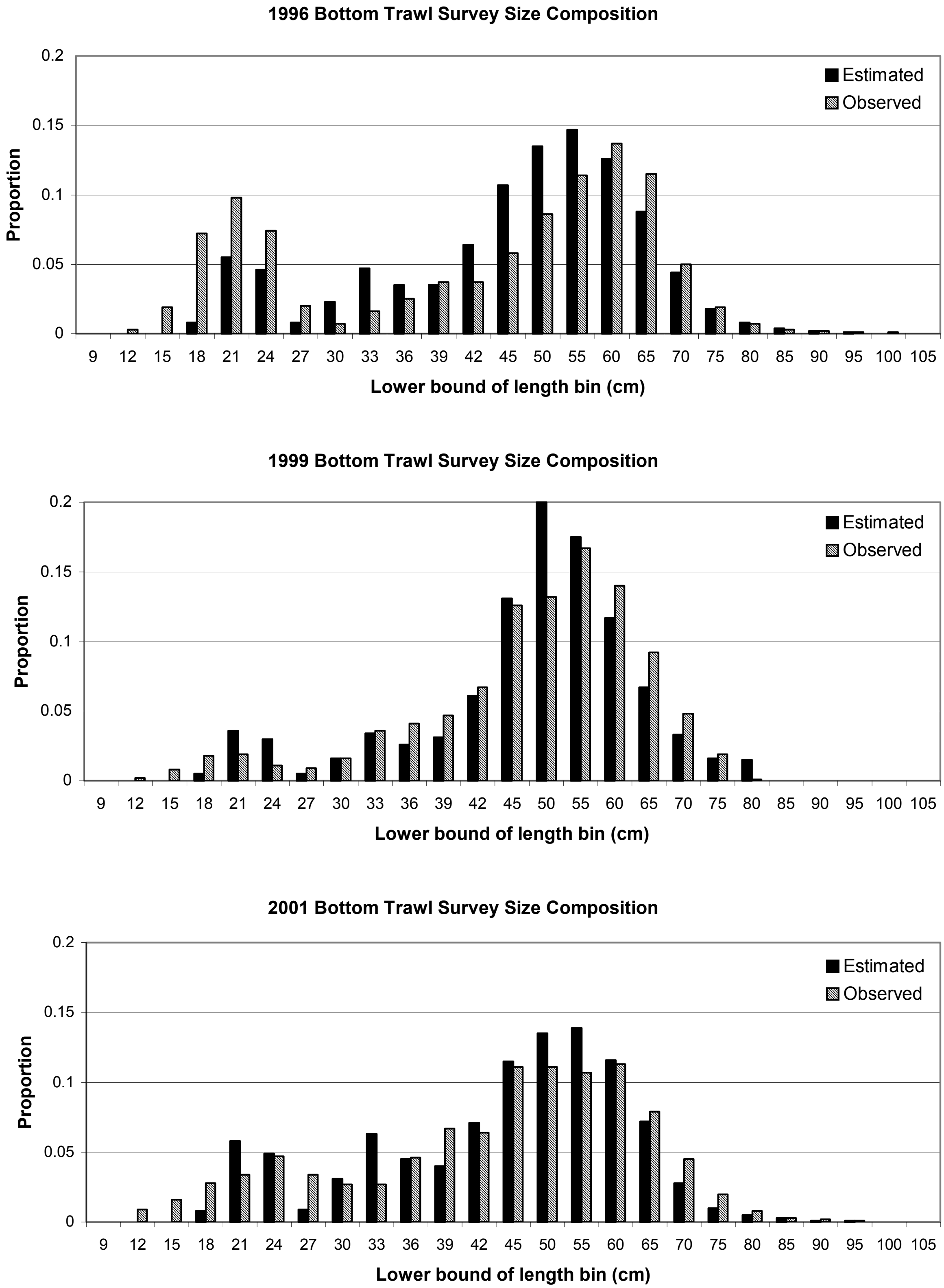


Figure 2.8–Estimated and observed size compositions from the 3 most recent surveys (Model 2).

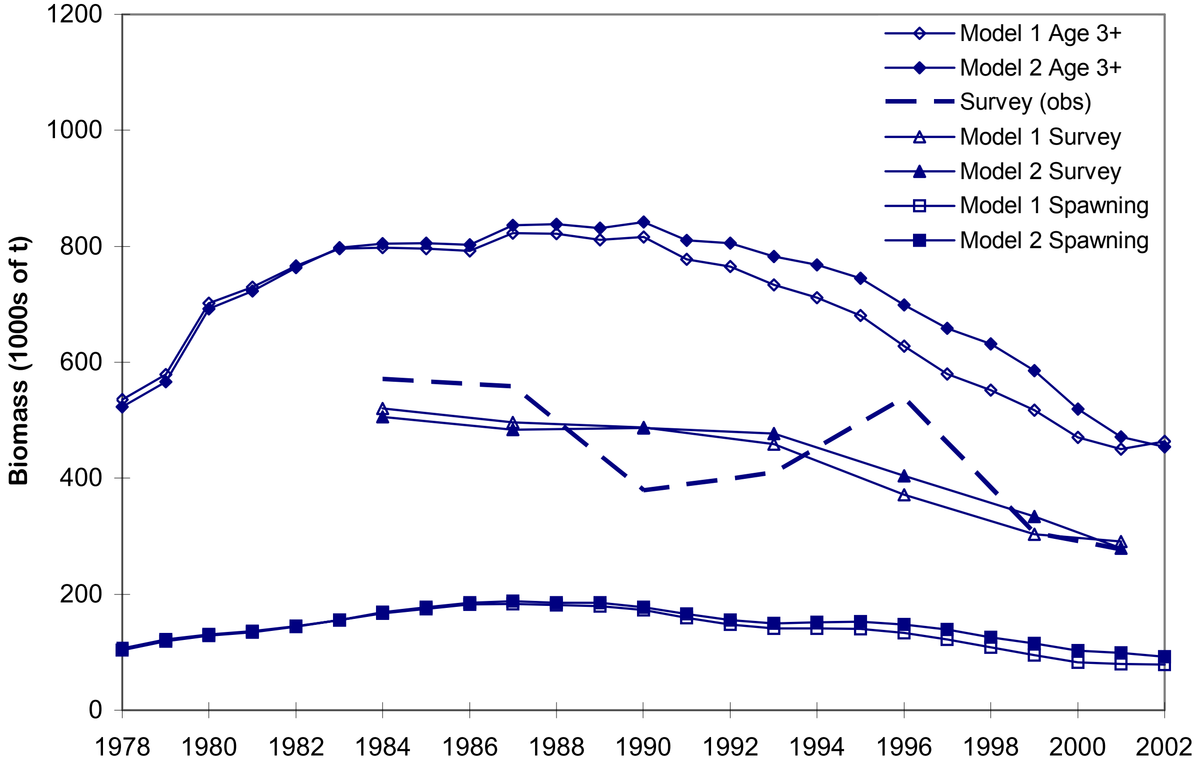


Figure 2.9–Comparison of biomass estimates resulting from Models 1 and 2.

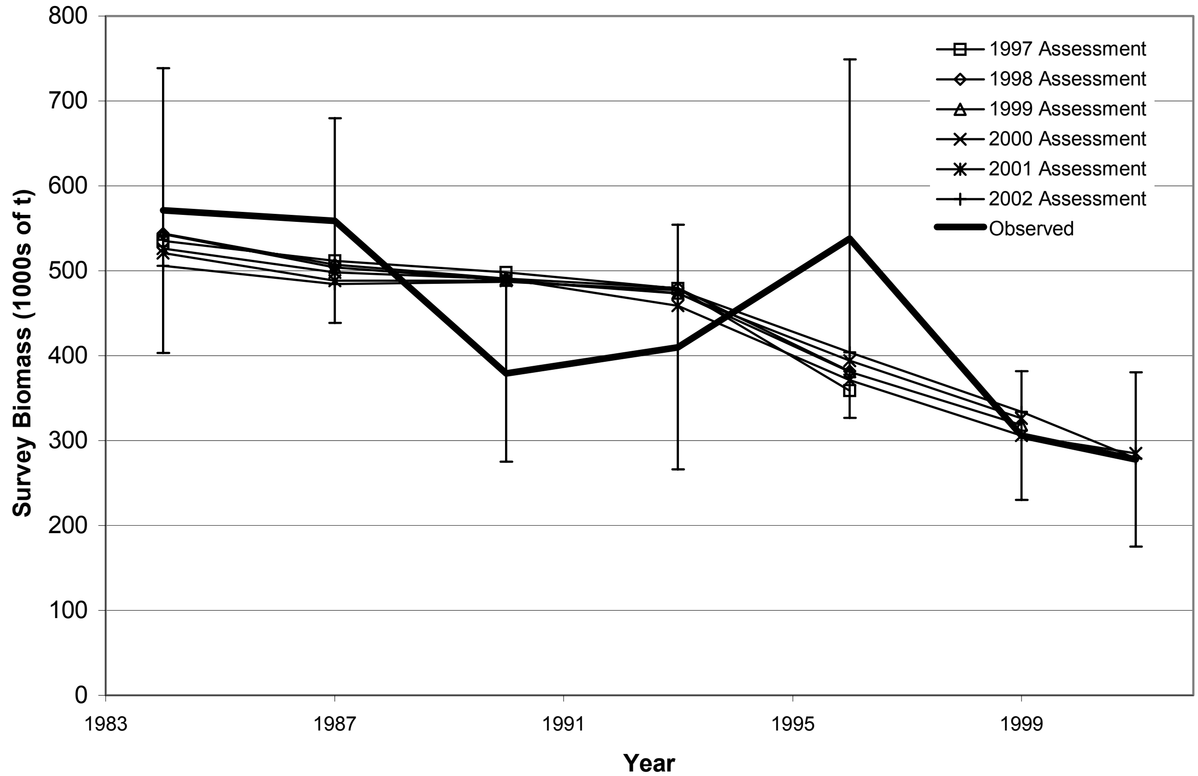


Figure 2.10–Retrospective analysis of estimated survey biomass, 1997-present. The vertical error bars around the observed survey biomass represent 1.96 standard deviations on either side of the mean.

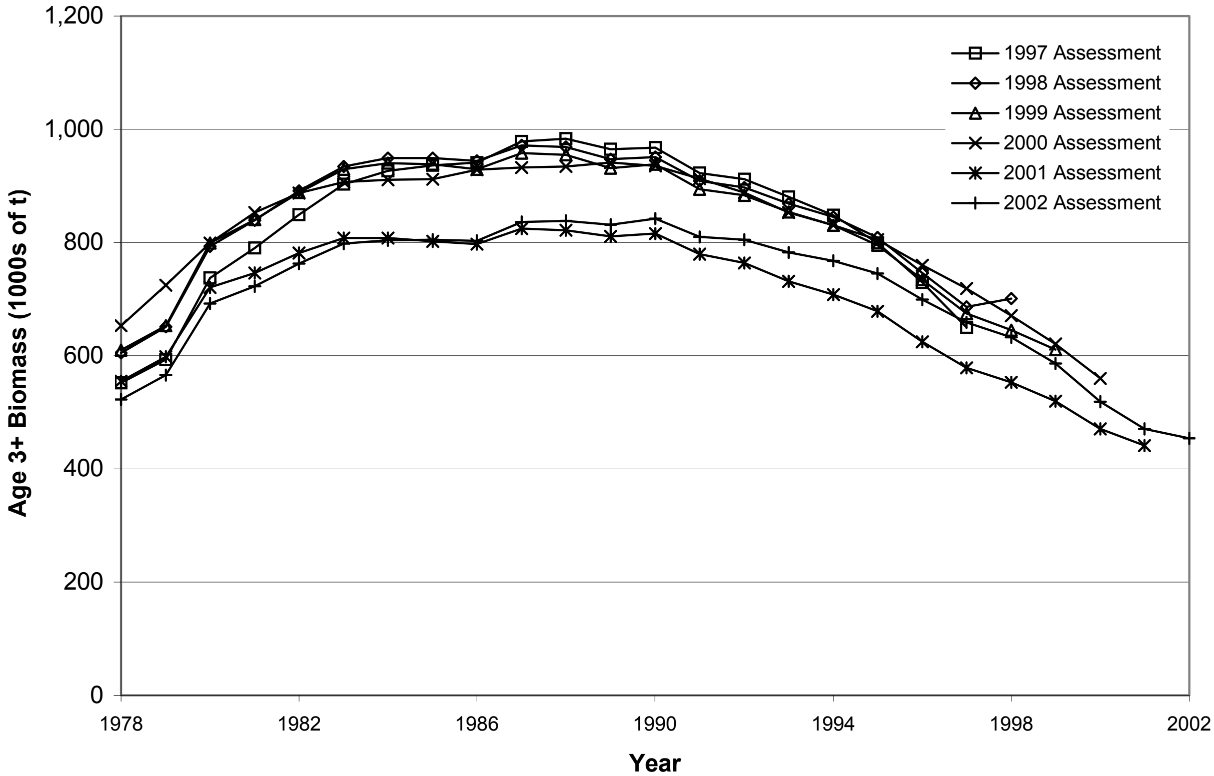


Figure 2.11–Retrospective analysis of estimated age 3+ biomass, 1997-present.

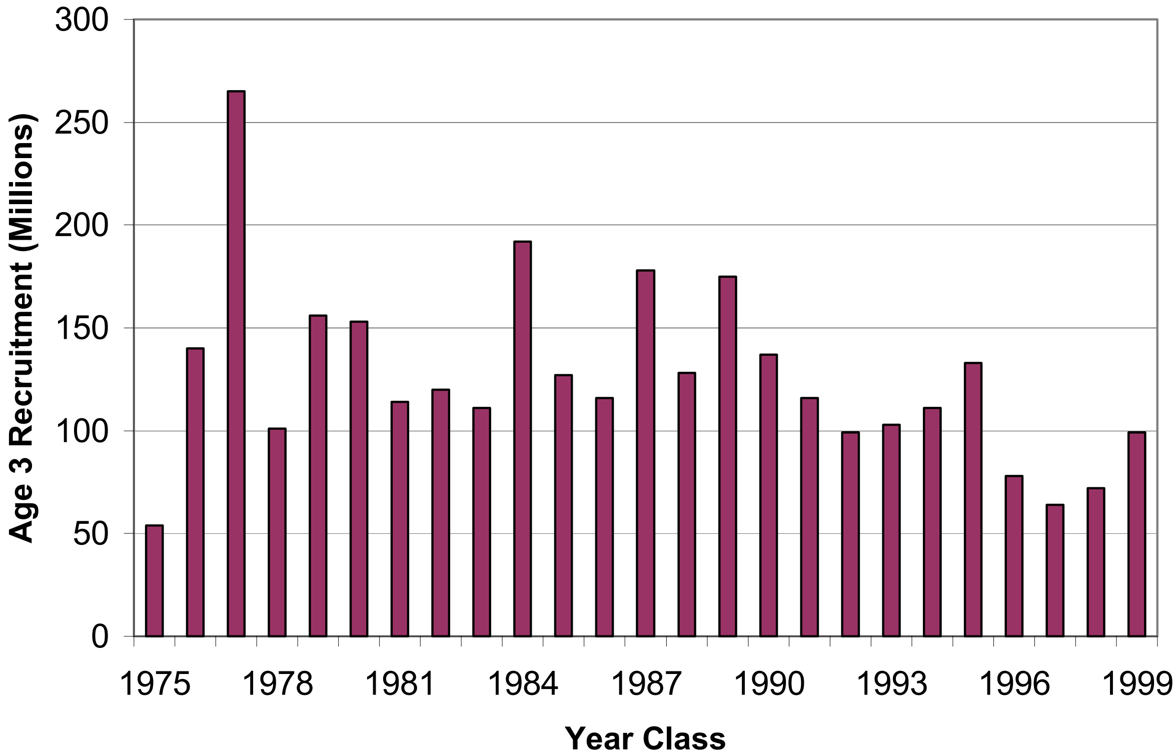


Figure 2.12–Pacific cod recruitment at age 3 as estimated by the assessment model.

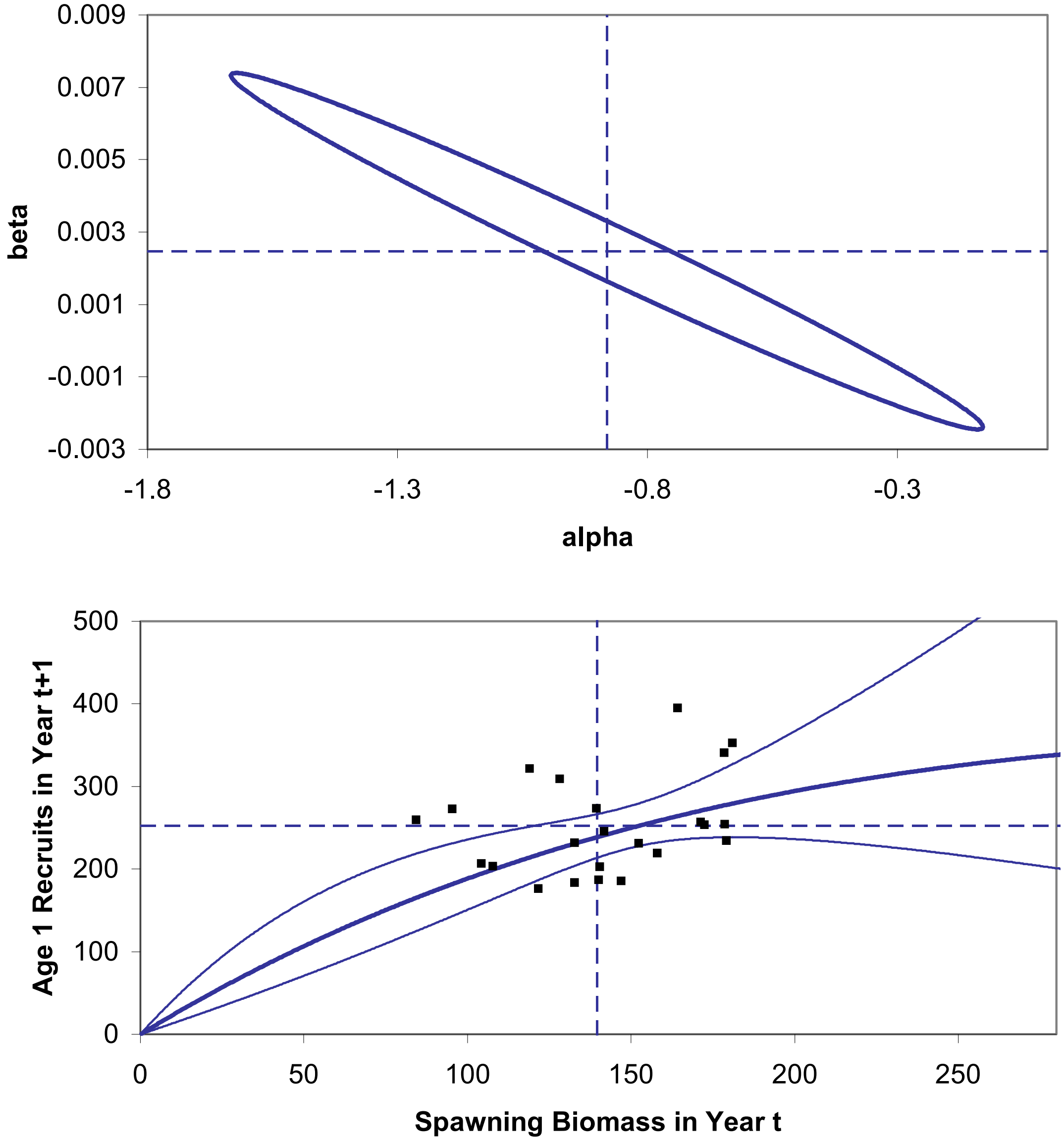


Figure 2.13–Some aspects of uncertainty surrounding the stock-recruitment relationship. The upper panel shows a 95% confidence ellipse for the estimated parameters of the stock-recruitment relationship, with dashed lines indicating the location of the point estimates. The lower panel shows the data (small squares), the estimated relationship (bold curve), and the 95% confidence interval around the curve (thin curves), with dashed lines indicating the locations of the data means. See text for details and caveats.

Appendix 2A: Approximate Functional Representations of Population Dynamics Used in Synthesis

These equations are similar to those used in Synthesis. Symbols are defined in Table 2.14.

Functions of Length or Age

Weight at length:

$$w(\lambda) = W_1 \lambda^{W_2}$$

Proportion mature at length:

$$p(\lambda) = \frac{1}{1 + \exp\left(-P_1(P_2 - \lambda)\right)}$$

Length at age:

$$l(\alpha) = L_1 + (L_2 - L_1)\left(\frac{1 - \exp\left(-K(\alpha - \alpha_1)\right)}{1 - \exp\left(-K(\alpha_2 - \alpha_1)\right)}\right)$$

Standard deviation of length at age:

$$x(\alpha) = X_1 + (X_2 - X_1)\left(\frac{l(\alpha) - L_1}{L_2 - L_1}\right)$$

Probability density function describing distribution of length, conditional on age:

$$h(\lambda \mid \alpha) = \sqrt{\frac{1}{2\pi}}\left(\frac{1}{x(\alpha)}\right)\exp\left(-\left(\frac{1}{2}\right)\left(\frac{\lambda - l(\alpha)}{x(\alpha)}\right)^2\right)$$

Selectivity at length $\lambda \le S_{g,4,e(y|g)}$ (ascending limb), conditional on gear type and year:

$$s(\lambda|g,y) = S_{g,1,e(y|g)} +$$
$$(1 - S_{g,1,e(y|g)})\left(\frac{\dfrac{1}{1+\exp\left(-S_{g,3,e(y|g)}(\lambda - S_{g,2,e(y|g)})\right)} - \dfrac{1}{1+\exp\left(-S_{g,3,e(y|g)}(\lambda_{min} - S_{g,2,e(y|g)})\right)}}{\dfrac{1}{1+\exp\left(-S_{g,3,e(y|g)}(S_{g,4,e(y|g)} - S_{g,2,e(y|g)})\right)} - \dfrac{1}{1+\exp\left(-S_{g,3,e(y|g)}(\lambda_{min} - S_{g,2,e(y|g)})\right)}}\right)$$

Selectivity at length $\lambda \ge S_{g,4,e(y|g)}$ (descending limb), conditional on gear type and year:

$$s(\lambda|g,y) = 1 + (1 - S_{g,5,e(y|g)}) \left(\frac{\dfrac{1}{1+\exp\left(-S_{g,7,e(y|g)}(\lambda - S_{g,6,e(y|g)})\right)} - \dfrac{1}{1+\exp\left(-S_{g,7,e(y|g)}(S_{g,4} - S_{g,6,e(y|g)})\right)}}{\dfrac{1}{1+\exp\left(-S_{g,7,e(y|g)}(\lambda_{max} - S_{g,6,e(y|g)})\right)} - \dfrac{1}{1+\exp\left(-S_{g,7,e(y|g)}(S_{g,4,e(y|g)} - S_{g,6,e(y|g)})\right)}} \right)$$

<u>Numbers at Age</u>

Matrix for converting numbers at length into numbers at age:

$$z_{a,i,j} = \frac{\int_{l_{min}(j)}^{l_{min}(j+1)} h(\lambda \mid a + t_{dur}(i))\, d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} h(\lambda \mid a + t_{dur}(i))\, d\lambda}$$

For all y :

$$n_{a_{min},y,1} = R_y$$

For all $a>a_{min}$:

$$n_{a,1,1} = N_a$$

For all $i<i_{max}$:

$$n_{a,y,i+1} = n_{a,y,i} \sum_{j=1}^{j_{max}} \left(z_{a,i,j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i}\, s(l_{mid}(j)|g,y) \right) t_{dur}(i) \right) \right)$$

For all $a<a_{max}$ and all $y<y_{max}$:

$$n_{a+1,y+1,1} = n_{a,y,i_{max}} \sum_{j=1}^{j_{max}} \left(z_{a,i_{max},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{max}}\, s(l_{mid}(j)|g,y) \right) t_{dur}(i_{max}) \right) \right)$$

For all $y<y_{max}$:

$$n_{a_{max},y+1,1} = n_{a_{max}-1,y,i_{max}} \sum_{j=1}^{j_{max}} \left(z_{a_{max}-1,i_{max},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{max}} s(l_{mid}(j)|g,y) \right) t_{dur}(i_{max}) \right) \right)$$

$$+ \; n_{a_{max},y,i_{max}} \sum_{j=1}^{j_{max}} \left(z_{a_{max},i_{max},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{max}} s(l_{mid}(j)|g,y) \right) t_{dur}(i_{max}) \right) \right)$$

At time of spawning:

$$u_{a,y} = n_{a,y,i_{spa}} \sum_{j=1}^{j_{max}} \left(z_{a,i_{spa},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{spa}} s(l_{mid}(j)|g,y) \right) \left(\tau_{spa} - \sum_{i=1}^{i_{spa}-1} t_{dur}(i) \right) \right) \right)$$

At time of survey:

$$v_{a,y} = n_{a,y,i_{sur}} \sum_{j=1}^{j_{max}} \left(z_{a,i_{sur},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{sur}} s(l_{mid}(j)|g,y) \right) \left(\tau_{sur} - \sum_{i=1}^{i_{sur}-1} t_{dur}(i) \right) \right) \right)$$

<u>Biomass</u>

Start-of-year biomass at ages $a > a_{rec}$:

$$b_y = \sum_{a=a_{rec}}^{a_{max}} \left(n_{a,y,1} \sum_{j=1}^{j_{max}} z_{a,1,j} w(l_{mid}(j)) \right)$$

Female spawning biomass:

$$c_y = \frac{1}{2} \sum_{a=a_{min}}^{a_{max}} \left(u_{a,y} \sum_{j=1}^{j_{max}} z_{a,i_{spa},j} w(l_{mid}(j))\, p(l_{mid}(j)) \right)$$

Survey biomass:

$$d_y = Q \sum_{a=a_{min}}^{a_{max}} \left(v_{a,y} \sum_{j=1}^{j_{max}} z_{a,i_{sur},j} w(l_{mid}(j))\, s(l_{mid}(j)|g_{sur},y) \right)$$