Section 2

ASSESSMENT OF THE PACIFIC COD STOCK IN THE GULF OF ALASKA

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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 1998 and January-August 1999 commercial fisheries were incorporated into the model.
2) Size composition data from the 1999 GOA bottom trawl survey were incorporated.
3) The biomass estimate from the 1999 GOA bottom trawl survey was incorporated (the 1999 estimate of 305,823 t was down about 43% from the 1996 estimate).
4) Weight-at-length data from recent GOA bottom trawl surveys were incorporated.

Changes in the Assessment Model

There were no changes in the assessment model this year.

Changes in Assessment Results

1) The estimated 2000 spawning biomass for the GOA stock is 111,000 t, down about 15% from last year's estimate for 1999 and down about 3% from last year's F_{ABC} projection for 2000.
2) The estimated 2000 total age 3+ biomass for the GOA stock is 567,000 t, down about 13% from last year's estimate for 1999 and up about 7% from last year's F_{ABC} projection for 2000.
3) The recommended 2000 ABC for the GOA stock is 76,400 t, down about 16% from last year's recommendation for 1999 and down about 10% from last year's F_{ABC} projection for 2000.
4) The estimated 2000 OFL for the GOA stock is 102,000 t, down about 24% from last year's estimate for 1999 and down about 11% from last year's F_{OFL} projection for 2000.

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

SSC Comments Specific to the Pacific Cod Assessment

From the October, 1999 minutes: *"The SSC continues to be interested in the overall sampling program that develops the data base used by the models to arrive at ABC estimates. In testimony to the Senate Subcommittee on Oceans and Fisheries, NPFMC Chairman Richard Lauber noted that the SSC initiated a 'framework plan to evaluate and improve catch estimation,' and 'has developed a formal process to review annually the sampling methods and catch estimation procedures.' The SSC recommends that this process should next address the sampling scheme for Pacific cod in view of the complexities of the fishing gear types used in the cod fisheries, difficult age determinations, and the complex distribution of cod on the grounds. In particular, the SSC suggests planning an analysis of the Pacific cod length-frequency samples used in the catch-at-age calculations. Age compositions of the catches are determined through the length-frequency samples and as a consequence, the catch-age modeling is strongly influenced by that sampling program. The sampling might be examined with respect to a number of factors, in particular the influence of sample size, stratification by fleet sector (gear), time of year and fishing location (statistical area). The sizes of samples and the distributions of the samples through the data stratifications influence the values produced by the assessment model. Several outstanding questions need to be addressed: Is the sampling program adequate? If more fish cannot be measured, should more but smaller samples be taken? Does the spread of samples among the gear-month-area strata lead to biasing the results of the model? What distinctions between the GOA and BSAI suggest different sampling needs for the two areas? How are State of Alaska samples in the GOA entered into the model? A review of cod sampling procedures by observers needs to be conducted first. This would be a performance audit describing the current sampling protocols and how well the samples have met these protocols. In addition, a description of how the 'blend system' works in relation to Pacific cod catches would be desirable. This overview would require coordination with personnel from AFSC, the Observer Program and the NMFS Regional office. The SSC recommends planning the first review at it February 2000 meeting, but recognizes the need to coordinate scheduling and staff limitations with NMFS. In the second stage of this analysis, the SSC recommends that the analysts explore the impacts of the sampling program and resulting data base on ABC estimates made by the current model. The SSC notes that the Observer Program has contracted for review of the Observer Program and its sampling design. After these reviews are completed, more progress on this second stage is anticipated."* Per a similar minute from the SSC's October, 1998 meeting, last year's assessment included an examination of sampling from the 1994-1997 fisheries with respect to all of the factors requested. Similarly, the present assessment includes an examination of sampling from the 1998-1999 fisheries with respect to these factors in Tables 2.7-2.10. Sample sizes are discussed under the heading "Commercial Catch Data." The items suggested for analysis in February, 2000 and later are not addressed in the present assessment.

From the October, 1999 minutes: *"Difficulties with some aspects of the current Pacific cod stock assessment has lead the author to explore alternatives. The author has come up with a creative length-based model using the Kalman filter approach. The author noted several advantages of this new approach including fewer parameters, the ability to include both process and measurement error, and ease in estimating uncertainty in stock size. The estimates (or guesses) of process and measurement error will be difficult to arrive at and could strongly influence the modeling results. At this early stage it is difficult to judge the probability of success for this new model. Another approach would be to convert the current synthesis type model to an AD model builder approach. There the author can more easily explore different modeling approaches and assumptions concerning the data. This approach would be worthwhile in determining whether it is data characteristics rather than model characteristics that are causing problems."* No model changes model have been made in the present assessment.

SSC Comments on Assessments in General

From the October, 1999 minutes: *"The move by several analysts to use AD Model Builder is a welcome one, in that more formal risk assessments should be easier to carry out and present. The SSC is enthusiastic about this opportunity to present risk curves and decision tables and urges analysts and the Plan Teams to consider such approaches in their assessments."* As in the past three assessments, the present assessment contains a formal risk analysis which considers the implications of uncertainty in the true values of the survey catchability coefficient and the natural mortality rate. This analysis is described under the heading "ABC Recommendation." In addition, stochastic projections of spawning biomass, fishing mortality, and catch are presented in Tables 2.31-2.44 and described under the heading "Projections and Harvest Alternatives."

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 typically accounts for the bulk of the catch (over two-thirds on average since 1986).

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 1999, TAC averaged about 83% of ABC and catch averaged about 87% of TAC. In 8 of these 14 years (57%), TAC equaled ABC exactly. In 5 of these 14 years (36%), catch exceeded TAC. However, it should be noted that three of these apparent overages occurred in the most recent three 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). Thus, the apparent overages in those years 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 1999, three different assessment models were used (Table 2.2).

Historically, the majority of the GOA catch has come from the Central regulatory area. The distribution of federally observed hauls or sets in the GOA as well as the EBS and AI (BSAI) is shown for the 1998 trawl, longline, and pot fisheries for Pacific cod in Figures 2.1, 2.2, and 2.3, respectively. 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 allocation follows the biomass distribution estimated by the 1996 trawl survey. 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

The catches shown in Tables 2.1 and 2.2 include estimated discards. Recent (1998) discard rates are summarized in Tables 2.3 and 2.4. Table 2.3 shows species discards in the 1998 Pacific cod fisheries, expressed as percentages of the total catch of all species in those fisheries. Table 2.4 shows discards of Pacific cod in the 1998 fisheries, expressed as percentages of the total area-wide Pacific cod catch. In the GOA, the species category with the highest discard rate in the 1998 Pacific cod fisheries was sablefish in the longline fishery, and the fishery with the highest discard rate of Pacific cod was the trawl fishery for arrowtooth flounder.

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

Catch Size Composition

Fishery size compositions are presently available, by gear, for the years 1978 through the first part of 1999. As in the past two assessments, 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

The total sample sizes for each year, gear, and period are shown in Table 2.6. The State-managed fishery has been addressed in the past two assessments by adding the size composition data and catch totals from that fishery to those from the Federally managed fishery. The same practice was followed in the present assessment. Length samples contributed by the State of Alaska are compared to those contributed by National Marine Fisheries Service (NMFS) observers for the years 1998 and 1999 in Tables 2.7 and 2.8, which partition the size composition data with respect to size bin, time period, and sampling source (NMFS observer stationed at sea, NMFS observer stationed on shore, or State of Alaska). It should be noted that these data pertain to the pot fishery only, because trawl and longline gears are excluded from the State-managed fishery. The sample sizes shown in Table 2.6 for the years 1998 and 1999 are also subdivided by statistical area in Tables 2.9 and 2.10, respectively (differences between total sample sizes shown in Table 2.6 and the area-partitioned tables may be attributed to the fact that the data used in the former were retrieved on a different date than the data used in the latter and the fact that shore-side observations of trawl size compositions are included in the area-partitioned tables). Boundaries of the statistical areas referenced in these tables are illustrated in Figure 2.4. As anticipated in last year's assessment, the distribution of length samples in 1999 has changed somewhat relative to previous distributions due to a modification of the observer sampling protocol. In general, the modifications are intended to result in fewer cod being measured but a more evenly distributed sample overall (the goal is to obtain lengths from 20 fish of the predominant groundfish species in each sampled haul).

The collections of relative length frequencies are shown, by year, period, and size bin for the trawl fishery in Table 2.11, the longline fishery in Table 2.12, and the pot fishery in Table 2.13.

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 2.14, 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
Sample size:	17413	19589	11440	17152	12190	8645

Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl surveys are shown in Table 2.15, together with the standard errors and upper and lower 95% confidence intervals (CI) for the biomass estimates. The highest biomass ever observed by the survey was the 1984 estimate of 571,188 t, and the low point is the 1999 estimate of 305,823 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 1999 estimate is only about 1% 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%.

Survey Removals

The amount of Pacific cod removed from the population as a result of hydroacoustic, longline, and bottom trawl survey operations is summarized for the GOA in Table 2.16. 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 1977-1998 was approximately 0.002).

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

Reliable length at age data are few for GOA Pacific cod and 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

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 model structure is identical to the one used in the previous two assessments (Thompson et al. 1997, 1998). 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.

Symbols used in the stock assessment model are listed in Table 2.17 (note that this list applies to the stock assessment model only, and does not include all symbols used in the "Projections and Harvest Alternatives" section of this assessment). 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 2.17. 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 2.18, with a brief rationale given for each value used. In contrast to the quantities whose values are specified in Table 2.18, 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 2.17.

Functional representations of population dynamics are given in the Appendix, using the symbols defined on the first two pages of Table 2.17. It should be noted that, while the equations given in the Appendix 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 on the first two pages of Table 2.17.

As in previous assessments, the present assessment uses Bayesian methods to address uncertainty surrounding the true values of model parameters. Unfortunately, as presently configured, Synthesis is not equipped to handle a full Bayesian analysis. Therefore, a type of meta-analysis is used to implement the

Bayesian portion of this assessment (the term "meta-analysis" is used here to denote the fact that this analysis involves fitting a model to results obtained from a set of related but technically independent and self-contained primary analyses). The Bayesian meta-analysis exploits the fact that it is sometimes possible (e.g., Walters and Ludwig 1994) to obtain an approximate Bayesian solution by profiling over some subset of the complete parameter set, with all other parameters fixed at their conditional maximum likelihood values (conditional, that is, on the parameter values being considered at any given point in the profile). Although it represents an extreme simplification, the approach used here was to consider the uncertainty surrounding two parameters only, specifically the natural mortality rate M and the survey catchability Q. The Bayesian meta-analysis, which uses the set of parameters shown on the third page of Table 2.17, proceeds as follows:

1) Assume a bivariate normal prior distribution for M and Q.

2) Create a large number (thousands) of individual Synthesis models, each based on a unique pair of M and Q values and each resulting in a conditional maximum log-likelihood and a conditional 2000 catch (i.e., a conditional 2000 harvest under some specified harvest strategy).

3) Smooth the bivariate log-likelihood profile by regressing a sample of conditional maximum log-likelihood values against M and Q, assuming a bivariate quadratic relationship. (Even with the simplification afforded by limiting the analysis to uncertainty in M and Q only, describing the likelihood profile is an extremely difficult task. A requirement for the analysis' success is the ability to determine the maximum value of the log-likelihood function at each combination of M and Q values included in the profile. However, the log-likelihood function at many, if not all, combinations of M and Q values can be either very flat or very "ripply," meaning that it is often difficult to be confident that an *apparent* maximum is the *true* maximum. The smoothing procedure was undertaken in an effort to mitigate these problems.)

4) Add an appropriate constant to the smoothed log-likelihood profile so as to result in a rescaled likelihood profile which has the same form as a bivariate normal distribution.

5) Multiply the prior distribution by the rescaled likelihood, then rescale again to yield a bivariate normal posterior distribution.

6) Smooth the bivariate log-catch profile by regressing a sample of conditional log-catch values against M and Q, assuming a bivariate quadratic relationship. (The reasons for smoothing the log-catch profile are the same as given above in Step 3.)

7) Multiply the posterior distribution by the smoothed log-catch profile, integrate with respect to M and Q, then take the antilogarithm of the result to obtain the geometric mean catch.

The Bayesian meta-analysis provides a context within which the results of any of the thousands of individual Synthesis models described in Step 2 may be viewed. To keep the number of alternative models manageable, however, only three models will be focused upon in the present assessment: Model 1 sets M and Q equal to the best point estimates that can be obtained independently of the Synthesis models used in the present assessment, estimates which are also used to define the means of the marginal prior distributions for these two parameters. Model 2 sets M and Q equal to their maximum likelihood estimates. Model 3 sets M and Q equal to the means of their marginal posterior distributions.

Parameters Estimated Independently

Table 2.19 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 2.19.

Natural Mortality

For Model 1, 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 (December 1994 SSC minutes, item D-3(b)), 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

For Models 2 and 3, the natural mortality rate was not an independently estimated parameter.

Trawl Survey Catchability

For Model 1, 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.). For Models 2 and 3, the trawl survey catchability coefficient was not an independently estimated parameter.

Weight at Length

Parameters (Table 2.17) governing the relationship between weight and length (Appendix) 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) is approximately 1.5 years, the length at this age (L_1) was estimated to be 22.4 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 2.17) governing the amount of variability surrounding the length-at-age relationship (Appendix) 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 2.17) governing the female maturity-at-length schedule (Appendix) 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 of the Joint Prior Distribution of Natural Mortality and Survey Catchability

In addition to the Synthesis parameters discussed above, the Bayesian meta-analysis made use of certain non-Synthesis parameters that were estimated independently, namely the parameters of the joint prior distribution of Q and M, which consisted of a mean for the marginal distribution of each of the two variables (μ_{QI} and μ_{MI}), a standard deviation for the marginal distribution of each of the two variables (σ_{QI} and σ_{MI}), and a correlation coefficient (ρ_I). The values of these parameters, which have remained constant since their first use in the 1996 assessment, are intended to represent the SSC's collective prior belief regarding the relative plausibility of alternative pairings of Q and M values. Values of 1.0 and 0.37 were chosen for μ_{QI} and μ_{MI}, respectively, corresponding to the point estimates of Q and M used in Model 1. Values of 0.3 and 0.111 were chosen for σ_{QI} and σ_{MI}, respectively. These were chosen so as to imply 30% coefficients of variation for both Q and M. The value of ρ_I was set at -0.5, representing a compromise between no correlation and a perfect inverse correlation.

Parameters Estimated Conditionally

Those Synthesis parameters that are estimated internally are listed in the second part of Table 2.19. 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 period 1 ("early") trawl fishery, the periods 2-3 ("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. To account for possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries, the fishery size composition time series were split into pre-1987 and post-1986 eras.

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 the previous two 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 the previous three 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 2.20. 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
SR(sample size):	132	140	107	131	110	93

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, three models are focused upon in this assessment: Model 1 sets M and Q equal to the best point estimates that can be obtained independently of the Synthesis models used in the present assessment, estimates which are also used to define the means of the marginal prior distributions for these two parameters; Model 2 sets M and Q equal to their maximum likelihood estimates; and Model 3 sets M and Q equal to the means of their marginal posterior distributions.

Evaluation Criteria

Three criteria will be used to evaluate the three 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, and 3) the overall reasonableness and robustness of the parameter estimates.

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. The effective sample size can be interpreted as the multinomial sample size that would typically be required in order to produce the given fit. A rule of thumb for viewing a fit as "good" might be based on the relationship between effective sample size and the input sample size (i.e., if effective sample size exceeds the input sample size, the fit is reasonably good). 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):

Likelihood Component	Average of Square Root of True Sample Size	Average Effective Sample Size Model 1	Model 2	Model 3
Early-season trawl fishery size composition	147	364	323	324
Late-season trawl fishery size composition	46	85	77	78
Longline fishery size composition	102	237	295	292
Pot fishery size composition	92	332	329	330
Survey size composition	119	130	135	134

All three models have average effective samples at least as great as the average input values (the average values of the square roots of the true sample sizes) for all likelihood components. Model 1 has the largest average effective sample sizes for three out of the five components, while Model 2 has the largest effective sample size for the other two. However, it should be noted that all size composition components do not contribute equally to the overall likelihood because of differences in total sample size (i.e., the sum of sample sizes across all years and periods). For example, because the longline fishery (where Model 2 performed best) is associated with many more years' and periods' worth of size composition data than the early-season trawl fishery (where Model 1 performed best), the longline component contributes more to the overall likelihood than does the early-season trawl component.

Fit to Survey Biomass Data

The log-scale RMSEs from the three models' fits to the survey biomass time series are shown below:

Model	RMSE
1	0.191
2	0.203
3	0.199

Model 1 has the lowest survey biomass RMSE, followed by Model 3.

Overall Reasonableness of Parameter Estimates

The following table gives the model-specific estimates of length-at-age parameters K and L_2 (L_1 was estimated independently, and thus did not vary with choice of model):

Parameter	Model 1	Model 2	Model 3
K	0.153	0.178	0.177
L_2	84.6	81.0	81.3

The estimates of these two parameters do not vary drastically between models. It may be noted that the estimates of L_2 from all three models are lower than the mean length of age group 12 observed in the available length-at-age data (95 cm).

Model-specific estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a, and selectivity parameters $S_{1\text{-}7,g,d(y|g)}$ are shown in Tables 2.21, 2.22, and 2.23, respectively. It is difficult to discern a consistent tendency for any of the models to give higher fishing mortality rates than the others. On the other hand, a clear ranking does exist between the models in terms of estimated recruitments and initial numbers at age, with Model 1 tending to produce the highest estimates and Model 2 the lowest. In terms of selectivity, Model 1 tends to produce the least sharply domed curves, while Models 2 and 3 appear virtually identical.

The parameter values associated with the prior distribution, smoothed and rescaled likelihood profile, and posterior distribution are shown below:

Parameter	Prior Distribution		Scaled Likelihood		Posterior Dist.	
	Label	Value	Label	Value	Label	Value
marginal mean of M	μ_{M1}	0.37	μ_{M2}	0.201	μ_{M3}	0.223
marginal mean of Q	μ_{Q1}	1.00	μ_{Q2}	1.35	μ_{Q3}	1.15
marginal standard deviation of M	σ_{M1}	0.111	σ_{M2}	0.102	σ_{M3}	0.034
marginal standard deviation of Q	σ_{Q1}	0.3	σ_{Q2}	1.70	σ_{Q3}	0.277
correlation between M and Q	ρ_1	-0.5	ρ_2	-0.956	ρ_3	-0.554

The distributions corresponding to the above parameter values are shown in Figure 2.5. It may be noted that the modes of the scaled likelihood and posterior distribution both fall within the 95% confidence interval of the prior distribution.

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. By definition, Model 2 is associated with a higher likelihood than either Model 1 or Model 3. However, as shown by the effective sample sizes associated with the size composition data and the RMSE of the survey biomass estimates, Model 1 and Model 3 perform as well or better than Model 2 in some areas.

In last year's assessment (Thompson et al. 1998), a key element in selecting the final model was the fact that the mode of the likelihood fell well outside of the 95% confidence interval of the prior distribution, thus suggesting the possibility of model mis-specification. Because both Models 2 and 3 are based to some extent on the likelihood surface, it seemed unwise to choose either of these Models until the possibility of model mis-specification could be addressed more thoroughly. In the present assessment, however, the mode of the likelihood is within the 95% confidence interval of the prior distribution, making it difficult to reject Model

2 or Model 3 on the basis of this year's results. However, when last year's results are considered together with this year's results, a related question arises: How reliable is the likelihood surface given that the addition of a single year's data can shift the mode so dramatically? A similar concern arises when the GOA Pacific cod assessment is compared to the EBS Pacific cod assessment (Thompson and Dorn 1998). In the latter, where the same model is applied to EBS data, the mode of the likelihood is extremely far from the prior distribution's 95% confidence interval. Therefore, until the reliability of the likelihood surface improves, it might be prudent to avoid moving to Model 2 or Model 3. It may also be noted that Model 1 has served as the baseline for reporting reference estimates in each of the three most recent assessments.

Given all of the above, it seems best to retain the use of Model 1 as a tool for generating reference estimates, for the time being at least. Nevertheless, selection of Model 1 for this specific purpose does not have to imply that other models or parameter combinations cannot be considered for other uses, such as recommending an acceptable biological catch for 2000.

Parameter Estimates Associated with the Final Model

The parameter estimates associated with Model 1 are shown in the columns labeled "Model 1" in the preceding section and in Tables 2.21, 2.22, and 2.23. In addition, the parameter estimates listed in the section entitled "Parameters Estimated Independently" also pertain to Model 1.

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:	25	36	45	53	59	65	70	75	78	81	84	89

The distribution of lengths at age (measured in mid-year) defined by the final parameter estimates is shown in Table 2.24.

Weights at length and maturity proportions at length defined by the final parameters are shown in Table 2.25, and selectivities at length defined by the final parameter estimates are shown in Table 2.26.

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); 2) spawning biomass, consisting of the biomass of all spawning females in March of a given year (vector *c* in Appendix); 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). The recruitment estimates presented here will be defined as numbers of age 3 fish in January of a given year (note that this is different from 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

Model 1's description of the recent history of the stock is shown in Table 2.27, together with estimates provided in last year's final SAFE report (Thompson et al. 1998). The biomass trends estimated in the present assessment are also shown in Figure 2.6. 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 1999 spawning and survey biomass are the lowest in their respective time series since 1978.

Recruitment

Model 1's estimated time series of age 3 recruitments is shown in Table 2.28, together with the estimates provided in last year's final SAFE report (Thompson et al. 1998). Model 1's recruitment estimates are also plotted in Figure 2.7. The current time series has a mean value of 143 million fish and shows only a moderate degree of variability, with an estimated coefficient of variation (assuming an inverse Gaussian distribution) of 35%, and an autocorrelation coefficient of -0.067.

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	1988	1990	1991	1995
Below average:	1975	1986	1992	1993	1994	1996				

With respect to last year's assessment (Thompson et al. 1998), the major change in the above table stems from the fact that the estimated strength of the 1995 year class has dropped by more than one-third, not only shifting this year class from "above average" to "average" status, but lowering the overall mean of the time series, thereby affecting the rankings of several other year classes as well. Specifically, the 1979 and 1980 year classes were upgraded from "average" to "above average," and the 1978 and 1991 year classes were upgraded from "below average" to "average." Also, the 1996 year class has been added to the table this year. It appears to be below average in strength, making it the fourth year class out of the last five to fall into that category. Furthermore, the model's present estimates of the age 1 recruitments from the 1997 and 1998 year classes (which are based almost entirely on the size composition from the 1999 trawl survey) are the two lowest in the time series.

Exploitation

Model 1's estimated time series of the ratio between catch and age 3+ biomass is shown in Table 2.29, together with the estimates provided in last year's final SAFE report (Thompson et al. 1998). The average value of this ratio over the entire time series is about 0.06. The estimated values meet or exceed the average for every year after 1989, 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:	86,400 t	98,800 t	247,000 t

For a stock exploited by multiple gear types, estimation of $F_{35\%}$ and $F_{40\%}$ requires an assumption regarding the apportionment of fishing mortality among those gear types. In this assessment, total fishing mortality was apportioned between gear types (early trawl, late trawl, longline, and pot) at a ratio of 498:69:133:300. These proportions result in a 2000 catch composition that matches the recent (1996-1998) 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. This assumption results in the following estimates of $F_{35\%}$ and $F_{40\%}$:

$F_{35\%}$	$F_{40\%}$
0.46	0.38

Specification of OFL and Maximum Permissible ABC

Under Model 1, spawning biomass for 2000 is estimated at a value of 111,000 t. This is about 12% above the $B_{40\%}$ value of 98,800 t, thereby placing Pacific cod in sub-tier "a" of Tier 3. Given this, Model 1 estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2000 as follows:

	Overfishing Level	Maximum Permissible ABC
Catch:	102,000 t	86,000 t
Fishing mortality rate:	0.46	0.38

For comparison, the age 3+ biomass estimate for 2000 is 567,000 t.

ABC Recommendation

It is important to remember that the maximum permissible ABC computed under Model 1 is only a point estimate, around which there is significant uncertainty. For the past three 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. This strategy relies on the Bayesian meta-analysis described under the heading "Model Structure" above. Given the posterior distribution for M and Q derived in the meta-analysis, the next step is to profile the 2000 catch obtained under an $F_{40\%}$ harvest strategy as a function of M and Q. The log-catch profile is then smoothed by fitting it to the following bivariate quadratic function:

$$\ln(\text{catch}) = \beta_0 + \beta_{M1}M + \beta_{Q1}Q + \beta_{M2}M^2 + \beta_{Q2}Q^2 + \beta_{MQ}MQ.$$

The current parameter estimates are as shown below, giving the relationship shown in the upper panel of Figure 2.8 (where the ranges of values along the M and Q axes represent plus or minus two standard deviations from the means of the respective marginal posterior distributions):

Parameter:	β_0	β_{M1}	β_{Q1}	β_{M2}	β_{Q2}	β_{MQ}
Value:	12.98	1.746	-2.478	-4.584	0.5415	0.8056

Next, multiplying the posterior distribution by the above equation gives the weighted log-catch profile shown in the lower panel of Figure 2.8. Taking the antilogarithm of the area under the curve gives the geometric mean 2000 catch obtained under an $F_{40\%}$ harvest strategy. This quantity has a value of 76,400 t, and is the recommended ABC for 2000. This catch corresponds to a Model 1 fishing mortality rate of about 0.33.

(Supplemental note: Another possible method of adjusting the maximum permissible ABC to account for uncertainty was suggested at the December, 1998 meeting of the SSC: Instead of weighting the log-catch profile by the posterior distribution, it could be weighted by the prior distribution. When weighted by the prior distribution, the geometric mean catch under an $F_{40\%}$ harvest strategy is 84,000 t. A third possibility would be to weight the log-catch profile by the scaled likelihood, giving a geometric mean catch under an $F_{40\%}$ harvest strategy of 239,000 t.)

Standard Harvest Scenarios and Projection Methodology

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

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

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

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

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

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

Scenario 7: In 2000 and 2001, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2012 under this scenario, then the stock is not approaching an overfished condition.)

Recruitment Scenarios

The projected 2000 catches described in the "Specification of OFL and Maximum Permissible ABC" and "ABC Recommendation" sections above are essentially independent of the level of age 1 recruitment assumed for 2000 because age 1 fish have almost negligible weight and the selectivities of this age group are approximately zero for all commercial gear types. However, catch projections beyond 2000 do depend on the level of age 1 recruitment assumed. To understand the sensitivity of catch projections to the recruitment assumption, two recruitment scenarios are examined in this assessment. Each scenario generates recruitment stochastically based on an assumed distribution. The scenarios differ only in terms of the length of the recruitment time series used to estimate the parameters of the assumed distribution. These are described in the table below:

Recruitment scenario:	Long-term (22 years)	Short-term (10 years)
Cohorts included:	1977-1998	1989-1998
Distribution mean:	294,000,000	238,000,000
Distribution coefficient of variation:	36%	31%

Projections and Status Determination

In addition to the reference points used in Amendment 56, projection of future harvests using the seven standard harvest scenarios requires two more reference points for a stock managed under Tier 3a: For harvest scenario #2, the ratio of the recommended F_{ABC} (0.33) to *max* F_{ABC} (0.38) is 0.87, and for harvest scenario #4, the average fishing mortality rate from the period 1994-1998 is 0.17 (Table 2.21, Model 1). Table 2.30 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 2.31-37 (long-term recruitment scenario) and Tables 2.38-2.44 (short-term recruitment scenario). Overall, these projections indicate that further declines in the GOA Pacific cod stock can be expected for the next few years, even under conservative exploitation strategies.

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). (When harvest strategies #6 and #7 are used for this purpose, the Alaska Fisheries Science Center has determined that the long-term recruitment scenario should be assumed unless a compelling case can be made for some other recruitment scenario. Tables 2.41 and 2.42, which implement harvest scenarios #6 and #7 under the short-term recruitment scenario, are thus presented for comparative purposes only and are not intended for official status determination.) 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 2000:

e) If spawning biomass for 2000 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
f) If spawning biomass for 2000 is estimated to be above $B_{35\%}$, the stock is above its MSST.

g) If spawning biomass for 2000 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 2.36). If the mean spawning biomass for 2010 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 2.37):

a) If the mean spawning biomass for 2002 is below ½$B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2002 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2002 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2012. If the mean spawning biomass for 2012 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 2000 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Likewise, mean spawning biomass for 2002 in Table 2.37 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

OTHER CONSIDERATIONS

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, sea lions, harbor porpoises, various whale species, and tufted puffin.

The above qualitative description of Pacific cod's trophic relationships notwithstanding, to date it has not been possible to incorporate ecosystem interactions into the model used to assess the Pacific cod stock. No recommendations regarding adjustment of the Pacific cod ABC on the basis of ecosystem considerations are made at this time.

If TAC is to be distributed between regulatory areas in proportion to the biomass estimates from the most recent trawl survey, the proportions are: Western–36%, Central–57%, and Eastern–7%.

SUMMARY

The major results of the Pacific cod stock assessment are summarized in Table 2.45.

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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 for 1999 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	76977	58091	7630	10464	792	76977
1992	0	0	80100	54305	15467	9984	344	80100
1993	0	0	56487	37806	8962	9707	12	56487
1994	0	0	47384	31446	6778	9160	0	47384
1995	0	0	69060	41877	11054	16050	79	69060
1996	0	0	68280	45991	10195	12041	53	68280
1997	0	0	77160	48405	10977	16416	1361	77160
1998	0	0	72320	41569	9993	19489	1269	72320
1999	0	0	73574	31664	12148	28327	1434	73574

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 1999 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 1988-1999.

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	76977	stock reduction analysis
1992	63500	63500	80100	stock reduction analysis
1993	56700	56700	56487	stock reduction analysis
1994	50400	50400	47384	stock reduction analysis
1995	69200	69200	69060	length-structured Synthesis model
1996	65000	65000	68280	length-structured Synthesis model
1997	81500	69115	77160	length-structured Synthesis model
1998	77900	66060	72320	length-structured Synthesis model
1999	84400	67835	73574	length-structured Synthesis model

Table 2.3--Species ("Spe") discards in the 1998 Pacific cod fisheries, expressed as percentages of the total catch of all species in those fisheries. All species whose discards comprised at least one percent of the total catch in a given fishery are shown. For example, the entries "SA" and "2.3" near the top of the list under "Gulf of Alaska" and "Longline" mean that discards of sablefish comprised 2.3% of the total catch of all species in the GOA longline fishery for Pacific cod in 1998. A column with no entries indicates that discards of each species comprised less than one percent of the total catch in that fishery.

Eastern Bering Sea						Aleutian Islands Region						Gulf of Alaska					
Longline		Pot		Trawl		Longline		Pot		Trawl		Longline		Pot		Trawl	
Spe	%	Spe	%	Spe	%	Spe	%	Spe	%	Spe	%	Spe	%	Spe	%	Spe	%
PC	3.0					PC	4.7					SA	2.3			SF	1.7
												PC	1.2				

Key:
PC = Pacific cod
SA = sablefish
SF = shallow water flatfish

Table 2.4--Discards of Pacific cod in the 1998 fisheries, expressed as percentages of the total area-wide Pacific cod catch. All fisheries in which Pacific cod discards comprised at least one percent of the total area-wide Pacific cod catch are shown. For example, the entries "AF," "TWL," and "2.8" near the top of the list under "Gulf of Alaska" mean that Pacific cod discards in the trawl fishery for arrowtooth flounder comprised 2.8% of the total Pacific cod catch from all GOA fisheries in 1998.

Eastern Bering Sea			Aleutian Islands Region			Gulf of Alaska		
Target	Gear	%	Target	Gear	%	Target	Gear	%
OT	LGL	6.0	OT	LGL	8.3	AF	TWL	2.8
RS	TWL	2.4	PC	LGL	4.0	OT	LGL	1.2
WP	TWL	1.8						
PC	LGL	1.4						
OT	TWL	1.0						

Key:

Target Fisheries		Gear Type	
AF	= arrowtooth flounder	LGL	= longline
OT	= other	TWL	= trawl
PC	= Pacific cod		
RS	= rock sole		
WP	= walleye pollock		

Table 2.5--Catch of Pacific cod by year, gear, and period as used in the stock assessment model. Jig catches have been merged with pot catches for 1997-1999. Catch for 1999 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	55976	631	1484	7239	324	67	9591	0	873
1992	51727	1140	1438	12636	628	2203	9641	13	330
1993	33632	2624	1550	8474	307	181	9689	18	0
1994	29152	1421	873	6678	48	52	8742	0	418
1995	38481	799	2597	10668	159	227	15415	43	592
1996	41450	3048	1493	9938	152	105	12014	27	0
1997	40727	1828	5850	10403	228	346	12601	2175	3002
1998	34693	3678	3197	9548	198	247	19466	358	935
1999	30111	1513	0	11846	260	0	25756	3408	0

Table 2.6--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	11254	0	0	8859	54	0	30122	2375	0

Table 2.7–Number of Pacific cod lengths sampled in the pot fishery during 1998, partitioned by period (1=Jan-May, 2=Jun-Aug, 3=Sep-Dec), sampling source (Sea = NMFS observer stationed at sea, Shore = NMFS observer stationed on shore, AK = State of Alaska), and size bin.

Bin	Period 1				Period 2				Period 3			
	Sea	Shore	AK	Total	Sea	Shore	AK	Total	Sea	Shore	AK	Total
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	1	1	0	2	0	0	0	0	3	0	0	3
9	0	0	0	0	0	0	0	0	2	0	0	2
10	0	0	1	1	0	0	0	0	7	0	0	7
11	10	4	0	14	0	0	0	0	6	0	1	7
12	10	6	3	19	0	0	0	0	8	0	1	9
13	131	115	35	281	1	0	0	1	59	3	0	62
14	407	447	227	1081	3	6	0	9	92	26	8	126
15	706	1033	774	2513	14	17	0	31	167	57	35	259
16	2137	2147	2078	6362	19	32	0	51	271	149	57	477
17	2938	2692	2458	8088	26	34	0	60	290	240	93	623
18	2676	2265	1518	6459	31	33	0	64	296	247	97	640
19	2014	1334	655	4003	24	14	0	38	196	117	49	362
20	881	558	260	1699	8	7	0	15	81	56	47	184
21	306	256	98	660	8	3	0	11	30	25	19	74
22	114	86	57	257	6	1	0	7	21	8	4	33
23	30	31	36	97	3	0	0	3	11	3	1	15
24	12	2	10	24	0	0	0	0	11	7	0	18
25	2	4	3	9	1	0	0	1	1	0	0	1
Total	12375	10981	8213	31569	144	147	0	291	1552	938	412	2902

Table 2.8–Number of Pacific cod lengths sampled in the 1999 pot fishery through the month of August, partitioned by period (1=Jan-May, 2=Jun-Aug), sampling source (Sea = NMFS observer stationed at sea, Shore = NMFS observer stationed on shore, AK = State of Alaska), and size bin.

Bin	Period 1				Period 2			
	Sea	Shore	AK	Total	Sea	Shore	AK	Total
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	1	0	1	0	0	0	0
10	0	1	0	1	0	0	0	0
11	2	11	2	15	0	0	0	0
12	9	24	13	46	0	0	0	0
13	76	161	102	339	6	0	0	6
14	234	688	585	1507	50	0	0	50
15	627	1744	1319	3690	274	0	0	274
16	1173	2969	2243	6385	530	0	0	530
17	1310	3608	2841	7759	464	0	0	464
18	1234	2683	1851	5768	406	0	0	406
19	578	1177	861	2616	319	0	0	319
20	282	494	369	1145	180	0	0	180
21	125	233	162	520	93	0	0	93
22	49	81	63	193	39	0	0	39
23	17	29	40	86	9	0	0	9
24	8	18	10	36	5	0	0	5
25	8	4	3	15	0	0	0	0
Total	5732	13926	10464	30122	2375	0	0	2375

Table 2.9–Number of Pacific cod lengths sampled by NMFS observers in 1998, partitioned by gear (trawl, longline, pot), location (at sea or on shore), period (1=Jan-May, 2=Jun-Aug, 3=Sep-Dec), and area (see Figure 2.4).

Per.	Area	Trawl			Longline			Pot			Total
		Sea	Shore	Subtot.	Sea	Shore	Subtot.	Sea	Shore	Subtot.	
1	610	4648	6134	10782	98	0	98	833	8323	9156	21096
1	620	2199	3107	5306	282	0	282	4083	1691	5774	11362
1	621	564	583	1147	0	0	0	1410	1712	3122	4667
1	630	20565	11163	31728	1058	1590	2648	6049	5650	11699	47861
1	631	128	2636	2764	116	7898	8014	0	1406	1406	12679
1	640	0	0	0	0	0	0	0	0	0	153
1	649	0	0	0	0	0	0	0	797	797	797
1	All	28104	23623	51727	1554	9488	11042	12375	19579	31954	98615
2	610	0	0	0	28	152	180	144	148	292	472
2	620	8	0	8	79	0	79	0	0	0	87
2	630	3188	179	3367	0	0	0	0	0	0	3367
2	640	88	0	88	0	0	0	0	0	0	88
2	All	3284	179	3463	107	152	259	144	148	292	4014
3	610	0	148	148	53	0	53	1552	1148	2700	2901
3	620	0	232	232	63	0	63	0	0	0	475
3	621	0	0	0	0	0	0	0	0	0	163
3	630	3568	1799	5367	31	0	31	0	0	0	5398
3	All	3568	2179	5747	147	0	147	1552	1148	2700	8937
Total		34956	25981	60937	1808	9640	11448	14071	20875	34946	111566

Table 2.10–Number of Pacific cod lengths sampled by NMFS observers in 1999, partitioned by gear (trawl, longline, pot), location (at sea or on shore), period (1=Jan-May, 2=Jun-Aug, 3=Sep-Dec), and area (see Figure 2.4).

Per.	Area	Trawl			Longline			Pot			Total
		Sea	Shore	Subtot.	Sea	Shore	Subtot.	Sea	Shore	Subtot.	
1	610	1861	104	1965	1889	5293	7182	3087	0	3087	12419
1	620	808	0	808	721	1344	2065	29	148	177	3074
1	621	199	0	199	390	805	1195	0	0	0	1394
1	630	8312	132	8444	2574	4808	7382	373	4876	5249	21174
1	631	0	0	0	0	1570	1570	0	246	246	1845
1	639	0	0	0	139	0	139	0	0	0	139
1	640	0	0	0	0	20	20	0	0	0	20
1	649	0	0	0	20	86	106	0	106	106	244
1	All	11180	236	11416	5733	13926	19659	3489	5376	8865	40309
2	610	0	0	0	262	0	262	0	0	0	386
2	620	27	0	27	1045	0	1045	0	0	0	1072
2	621	0	0	0	1068	0	1068	0	0	0	1068
2	630	20	0	20	0	0	0	42	0	42	89
2	640	0	0	0	0	0	0	13	0	13	13
2	All	47	0	47	2375	0	2375	55	0	55	2628
Total		11227	236	11463	8108	13926	22034	3544	5376	8920	42937

Table 2.11–Length frequencies of Pacific cod in the trawl fishery by year and period. Numbers shown are actual sample sizes for each year, period, and bin.

Yr.	Per.	Length Bin 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
78	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
80	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
81	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
82	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
83	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
84	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
89	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
89	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
90	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
90	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
90	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
91	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
91	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
92	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
92	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
93	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
94	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
95	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
95	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
95	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
96	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
97	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
97	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
97	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
98	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
98	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
98	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
99	1	0	0	1	4	4	2	4	17	73	143	179	211	439	1033	1719	2098	2124	1529	795	378	165	53	29	14	4

Table 2.12–Length frequencies of Pacific cod in the longline fishery by year and period. Numbers shown are actual sample sizes for each year, period, and 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
78	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
79	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
80	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
81	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
82	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
83	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
84	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
85	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
86	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
87	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
88	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
90	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
91	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
91	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
92	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
92	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
92	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
93	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
94	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
95	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
96	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
97	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
97	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
97	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
98	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
98	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
98	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
99	1	0	0	0	0	0	0	0	0	3	4	11	50	157	241	571	571	520	459	378	240	131	71	41	20	15
99	2	0	0	0	0	0	0	0	0	0	0	0	0	0	19	25	8	2	0	0	0	0	0	0	0	0

Table 2.13–Length frequencies of Pacific cod in the pot fishery by year and period. Numbers shown are actual sample sizes for each year, period, and 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
90	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
90	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
90	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
91	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
91	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
92	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
92	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
92	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
93	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
94	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
94	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
95	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
95	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
96	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
96	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
97	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
97	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
97	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
98	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
98	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
98	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
99	1	0	0	0	0	0	0	0	0	0	0	4	22	178	819	1946	3416	4151	3085	1439	651	287	112	57	18	11
99	2	0	0	0	0	0	0	0	0	0	0	0	0	6	50	274	530	464	406	319	180	93	39	9	5	0

Table 2.14--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
84	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
87	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
90	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
93	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
96	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
99	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

Table 2.15--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	405,431	77,490	253,551	557,311	164,652,074
1996	536,249	107,721	325,116	747,382	315,443,816
1999	305,823	38,699	229,974	381,672	166,145,850

Table 2.16–Magnitude of hydroacoustic, longline, and bottom trawl survey removals (t) in the GOA from 1979 through 1998. Cells with an entry of zero indicate that survey removals amounted to less than 0.5 t, whereas cells with no entry indicate that there was no survey in that region and year.

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		19	19

Table 2.17–Symbols used in the stock assessment model for Pacific cod (page 1 of 3).

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 2.17–Symbols used in the stock assessment model for Pacific cod (page 2 of 3).

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 2.17–Symbols used in the stock assessment model for Pacific cod (page 3 of 3).

Parameters Used in the Bayesian Meta-Analysis	
μ_{M1}	mean of the marginal prior distribution for M
μ_{M2}	mean of the marginal distribution for M obtained from the scaled likelihood
μ_{M3}	mean of the marginal posterior distribution for M
μ_{Q1}	mean of the marginal prior distribution for Q
μ_{Q2}	mean of the marginal distribution for Q obtained from the scaled likelihood
μ_{Q3}	mean of the marginal posterior distribution for Q
ρ_1	correlation between M and Q in the joint prior distribution
ρ_2	correlation between M and Q in the joint distribution obtained from the scaled likelihood
ρ_3	correlation between M and Q in the joint posterior distribution
σ_{M1}	standard deviation of the marginal prior distribution for M
σ_{M2}	standard deviation of the marginal distribution for M obtained from the scaled likelihood
σ_{M3}	standard deviation of the marginal posterior distribution for M
σ_{Q1}	standard deviation of the marginal prior distribution for Q
σ_{Q2}	standard deviation of the marginal distribution for Q obtained from the scaled likelihood
σ_{Q3}	standard deviation of the marginal posterior distribution for Q
β_0	coefficient for the zero-degree term used in the quadratic approximation of ln(catch)
β_{M1}	coefficient for the first-degree term in M used in the quadratic approximation of ln(catch)
β_{Q1}	coefficient for the first-degree term in Q used in the quadratic approximation of ln(catch)
β_{M2}	coefficient for the second-degree term in M used in the quadratic approximation of ln(catch)
β_{Q2}	coefficient for the second-degree term in Q used in the quadratic approximation of ln(catch)
β_{MQ}	coefficient for the cross-product term used in the quadratic approximation of ln(catch)

Table 2.18–Dimensions and special values of indices and variables used in the Pacific cod assessment. Symbols are defined in Table 2.17.

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 2.19–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). The parameters M and Q are unique in that they are estimated independently in Model 1, conditionally in Model 2, and through a type of meta-analysis in Model 3.

Parameters Estimated Independently	
L_1	length at age α_1
M	instantaneous natural mortality rate (Model 1 only)
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability (Model 1 only)
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
M	instantaneous natural mortality rate (Model 2 only)
N_a	initial population numbers at each age $a > a_{min}$
Q	survey catchability (Model 2 only)
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 2.20–Pacific cod commercial fishery length sample sizes used in the multinomial distribution. (These values correspond to the square roots of the true sample sizes shown in Table 2.6.)

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	106	0	0	94	7	0	174	49	0

Table 2.21–Estimates of Pacific cod fishing mortality rates obtained under three alternative models. Rates are expressed on an annual time scale. Empty cells indicate that no catch was recorded.

Yr.	Per.	Model 1			Model 2			Model 3		
		Trawl	Longl.	Pot	Trawl	Longl.	Pot	Trawl	Longl.	Pot
1978	1									
	2									
	3	0.04	0.04		0.07	0.07		0.05	0.06	
1979	1									
	2									
	3	0.03	0.06		0.05	0.09		0.04	0.08	
1980	1									
	2									
	3	0.05	0.15		0.08	0.23		0.07	0.19	
1981	1	0.00	0.04		0.00	0.06		0.00	0.05	
	2	0.02	0.03		0.03	0.05		0.03	0.04	
	3	0.03	0.05		0.04	0.07		0.03	0.05	
1982	1	0.01	0.04		0.01	0.05		0.01	0.04	
	2	0.01	0.02		0.02	0.02		0.01	0.02	
	3	0.01	0.04		0.02	0.06		0.02	0.05	
1983	1	0.01	0.04		0.02	0.05		0.02	0.04	
	2	0.02	0.03		0.02	0.03		0.02	0.03	
	3	0.02	0.05		0.02	0.06		0.02	0.05	
1984	1	0.01	0.04		0.02	0.05		0.02	0.04	
	2	0.01	0.00		0.01	0.00		0.01	0.00	
	3	0.01	0.01		0.02	0.01		0.01	0.01	
1985	1	0.01	0.03		0.01	0.03		0.01	0.03	
	2	0.00	0.00		0.00	0.00		0.00	0.00	
	3	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
1986	1	0.01	0.05	0.00	0.01	0.05	0.00	0.01	0.05	0.00
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00
1987	1	0.02	0.03	0.00	0.03	0.04	0.00	0.02	0.04	0.00
	2	0.07	0.01	0.00	0.06	0.01	0.00	0.06	0.01	0.00
	3	0.06	0.01	0.00	0.06	0.02	0.00	0.05	0.02	0.00
1988	1	0.07	0.01	0.01	0.07	0.01	0.01	0.06	0.01	0.01
	2	0.06	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.00
	3	0.03	0.00	0.00	0.03	0.00	0.00	0.02	0.00	0.00
1989	1	0.10	0.01	0.00	0.11	0.01	0.00	0.10	0.01	0.00
	2	0.11	0.00	0.00	0.10	0.00	0.00	0.09	0.00	0.00
	3	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
1990	1	0.19	0.02	0.02	0.20	0.03	0.02	0.17	0.02	0.01
	2	0.07	0.00	0.01	0.06	0.00	0.01	0.05	0.00	0.01
	3	0.06	0.00	0.02	0.05	0.00	0.02	0.05	0.00	0.01
1991	1	0.26	0.03	0.07	0.27	0.04	0.06	0.23	0.03	0.05
	2	0.01	0.00		0.01	0.00		0.00	0.00	
	3	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01
1992	1	0.26	0.06	0.07	0.26	0.06	0.07	0.22	0.06	0.06
	2	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00
	3	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00
1993	1	0.17	0.04	0.07	0.17	0.04	0.07	0.15	0.04	0.06
	2	0.03	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00
	3	0.01	0.00		0.01	0.00		0.01	0.00	
1994	1	0.15	0.03	0.06	0.14	0.03	0.06	0.13	0.03	0.05
	2	0.01	0.00		0.01	0.00		0.01	0.00	
	3	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
1995	1	0.20	0.05	0.11	0.19	0.05	0.10	0.17	0.05	0.09
	2	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
	3	0.02	0.00	0.01	0.02	0.00	0.01	0.02	0.00	0.00
1996	1	0.22	0.05	0.09	0.22	0.05	0.09	0.19	0.05	0.07
	2	0.03	0.00	0.00	0.03	0.00	0.00	0.03	0.00	0.00
	3	0.01	0.00		0.01	0.00		0.01	0.00	
1997	1	0.24	0.06	0.10	0.24	0.06	0.10	0.21	0.05	0.09
	2	0.02	0.00	0.03	0.02	0.00	0.03	0.02	0.00	0.03
	3	0.06	0.00	0.03	0.05	0.00	0.03	0.04	0.00	0.03
1998	1	0.23	0.06	0.18	0.22	0.06	0.16	0.20	0.06	0.14
	2	0.05	0.00	0.00	0.05	0.00	0.00	0.04	0.00	0.00
	3	0.03	0.00	0.01	0.03	0.00	0.01	0.03	0.00	0.01
1999	1	0.22	0.09	0.27	0.21	0.08	0.24	0.18	0.07	0.21
	2	0.02	0.00	0.06	0.02	0.00	0.05	0.02	0.00	0.04

Table 2.22–Estimates of Pacific cod recruitment and initial numbers at age in three alternative models.

Year	Recruitment at age 1 (millions)		
	Model 1	Model 2	Model 3
1978	652	214	284
1979	243	69	93
1980	368	126	166
1981	366	123	163
1982	279	102	134
1983	273	106	137
1984	256	75	98
1985	439	159	203
1986	294	102	130
1987	232	67	86
1988	421	161	204
1989	267	85	108
1990	393	134	171
1991	296	99	126
1992	243	76	97
1993	203	64	81
1994	199	74	93
1995	205	70	88
1996	314	112	141
1997	211	74	93
1998	185	64	81
1999	127	42	53

Age	Initial numbers at age (millions)		
	Model 1	Model 2	Model 3
2	223	75	96
3	60	19	25
4	63	28	35
5	43	11	15
6	89	51	63
7	0	0	0
8	20	0	0
9	17	20	24
10	0	0	0
11	0	1	1
12	1	0	1

Table 2.23–Estimates of Pacific cod selectivity parameters obtained under three alternative models. The first column lists the parameter families for which the remaining columns contain gear- and era- specific estimates. Gear types consist of period 1 (January-May) trawl, periods 2-3 (June-December) trawl, longline, and pot commercial gears, and the trawl survey. Eras consist of the ranges 1978-1986 and 1987-1999 (longline and periods 2-3 trawl gear types only).

Model 1	Trawl(1)	Trawl (2-3)		Longline		Pot	Survey
		1978-86	1987-99	1978-86	1987-99		
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00	0.00	0.00	0.00	0.08
$S_{2,g,e(y\|g)}$	63.80	51.17	63.93	54.27	63.23	66.92	55.31
$S_{3,g,e(y\|g)}$	0.19	0.36	0.18	0.34	0.25	0.29	0.16
$S_{4,g,e(y\|g)}$	115.00	96.66	75.99	78.54	95.07	77.79	63.17
$S_{5,g,e(y\|g)}$	1.00	0.87	0.26	1.00	0.82	0.21	0.22
$S_{6,g,e(y\|g)}$	115.00	96.66	83.13	115.00	95.93	77.79	76.23
$S_{7,g,e(y\|g)}$	0.20	4.30	0.15	7.53	1.32	0.14	0.25

Model 2	Trawl(1)	Trawl (2-3)		Longline		Pot	Survey
		1978-86	1987-99	1978-86	1987-99		
$S_{1,g,e(y\|g)}$	0.00	0.00	0.01	0.00	0.00	0.00	0.18
$S_{2,g,e(y\|g)}$	67.94	53.38	65.70	56.65	66.27	70.40	59.51
$S_{3,g,e(y\|g)}$	0.16	0.41	0.17	0.37	0.24	0.29	0.15
$S_{4,g,e(y\|g)}$	82.67	103.02	75.78	93.48	82.99	82.88	65.50
$S_{5,g,e(y\|g)}$	0.50	0.91	0.07	1.00	0.40	0.12	0.09
$S_{6,g,e(y\|g)}$	82.67	103.02	77.00	114.18	84.01	82.88	79.46
$S_{7,g,e(y\|g)}$	0.30	0.00	0.00	10.00	0.19	0.17	0.21

Model 3	Trawl(1)	Trawl (2-3)		Longline		Pot	Survey
		1978-86	1987-99	1978-86	1987-99		
$S_{1,g,e(y\|g)}$	0.00	0.00	0.01	0.00	0.00	0.00	0.17
$S_{2,g,e(y\|g)}$	67.75	53.21	65.56	56.50	66.09	70.04	59.43
$S_{3,g,e(y\|g)}$	0.16	0.40	0.17	0.36	0.24	0.29	0.15
$S_{4,g,e(y\|g)}$	82.35	102.28	75.46	93.38	82.67	82.46	65.29
$S_{5,g,e(y\|g)}$	0.51	0.92	0.07	1.00	0.41	0.12	0.09
$S_{6,g,e(y\|g)}$	82.35	102.28	76.69	114.18	83.70	82.46	79.11
$S_{7,g,e(y\|g)}$	0.31	0.00	0.00	10.00	0.19	0.17	0.21

Table 2.24–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	0.019
100	0	0	0	0	0	0	0	0	0	0	0.002	0.055
95	0	0	0	0	0	0	0	0	0.001	0.005	0.021	0.132
90	0	0	0	0	0	0	0	0.001	0.01	0.044	0.107	0.217
85	0	0	0	0	0	0	0.001	0.014	0.072	0.174	0.266	0.244
80	0	0	0	0	0	0	0.014	0.098	0.239	0.328	0.329	0.187
75	0	0	0	0	0	0.009	0.109	0.291	0.356	0.294	0.202	0.099
70	0	0	0	0	0.002	0.094	0.324	0.362	0.239	0.126	0.062	0.036
65	0	0	0	0	0.051	0.332	0.367	0.189	0.072	0.026	0.009	0.009
60	0	0	0	0.01	0.289	0.391	0.158	0.041	0.01	0.002	0.001	0.002
55	0	0	0	0.154	0.445	0.153	0.026	0.004	0.001	0	0	0
50	0	0	0.017	0.482	0.19	0.02	0.002	0	0	0	0	0
45	0	0	0.278	0.312	0.022	0.001	0	0	0	0	0	0
42	0	0.001	0.363	0.037	0.001	0	0	0	0	0	0	0
39	0	0.022	0.253	0.005	0	0	0	0	0	0	0	0
36	0	0.18	0.077	0	0	0	0	0	0	0	0	0
33	0	0.432	0.01	0	0	0	0	0	0	0	0	0
30	0	0.301	0.001	0	0	0	0	0	0	0	0	0
27	0.012	0.061	0	0	0	0	0	0	0	0	0	0
24	0.261	0.003	0	0	0	0	0	0	0	0	0	0
21	0.576	0	0	0	0	0	0	0	0	0	0	0
18	0.147	0	0	0	0	0	0	0	0	0	0	0
15	0.004	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 2.25–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	0.01	0.00
2	12	0.02	0.00
3	15	0.04	0.00
4	18	0.07	0.00
5	21	0.11	0.00
6	24	0.16	0.00
7	27	0.23	0.00
8	30	0.32	0.01
9	33	0.42	0.01
10	36	0.55	0.02
11	39	0.70	0.02
12	42	0.87	0.04
13	45	1.16	0.06
14	50	1.59	0.12
15	55	2.11	0.21
16	60	2.75	0.35
17	65	3.50	0.51
18	70	4.39	0.68
19	75	5.41	0.81
20	80	6.59	0.89
21	85	7.93	0.95
22	90	9.45	0.97
23	95	11.16	0.99
24	100	13.07	0.99
25	105	14.07	1.00

Table 2.26–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
			1978-86	1987-98	1978-86	1987-98		
1	9	0.00	0.00	0.00	0.00	0.00	0.00	0.08
2	12	0.00	0.00	0.00	0.00	0.00	0.00	0.08
3	15	0.00	0.00	0.00	0.00	0.00	0.00	0.09
4	18	0.00	0.00	0.00	0.00	0.00	0.00	0.09
5	21	0.00	0.00	0.00	0.00	0.00	0.00	0.10
6	24	0.00	0.00	0.00	0.00	0.00	0.00	0.10
7	27	0.00	0.00	0.01	0.00	0.00	0.00	0.12
8	30	0.01	0.00	0.01	0.00	0.00	0.00	0.14
9	33	0.01	0.01	0.02	0.01	0.00	0.00	0.17
10	36	0.02	0.04	0.03	0.02	0.01	0.00	0.22
11	39	0.04	0.10	0.05	0.05	0.01	0.00	0.29
12	42	0.07	0.24	0.09	0.12	0.03	0.01	0.39
13	45	0.11	0.48	0.14	0.27	0.06	0.02	0.51
14	50	0.24	0.84	0.29	0.66	0.19	0.08	0.75
15	55	0.45	0.97	0.51	0.91	0.46	0.27	0.98
16	60	0.67	0.99	0.77	0.98	0.75	0.63	0.92
17	65	0.84	1.00	0.96	1.00	0.91	0.91	0.72
18	70	0.93	1.00	0.88	1.00	0.97	0.90	0.47
19	75	0.97	1.00	0.68	1.00	0.99	0.65	0.31
20	80	0.99	1.00	0.50	1.00	1.00	0.46	0.25
21	85	1.00	0.98	0.38	1.00	0.87	0.33	0.23
22	90	1.00	0.87	0.32	1.00	0.82	0.26	0.22
23	95	1.00	0.87	0.28	1.00	0.82	0.23	0.22
24	100	1.00	0.87	0.26	1.00	0.82	0.21	0.22
25	105	1.00	0.87	0.26	1.00	0.82	0.21	0.22

Table 2.27–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	605	610	123	123		
1979	651	653	142	140		
1980	793	799	153	151		
1981	839	840	161	158		
1982	891	888	174	170		
1983	934	929	189	184		
1984	949	940	205	200	544	543
1985	949	938	217	210		
1986	944	929	226	218		
1987	972	958	228	220	507	504
1988	969	955	226	218		
1989	947	931	226	216		
1990	951	938	216	207	491	489
1991	909	894	200	192		
1992	897	883	187	179		
1993	869	854	179	172	480	474
1994	845	830	179	172		
1995	809	795	179	171		
1996	746	734	172	164	382	381
1997	686	675	159	151		
1998	701	645	142	134		
1999	n/a	611	n/a	128	n/a	318

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 2.28–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	61	60
1979	160	154
1980	315	311
1981	119	116
1982	181	176
1983	176	174
1984	137	133
1985	133	130
1986	127	122
1987	214	210
1988	140	138
1989	112	109
1990	203	200
1991	133	127
1992	192	187
1993	146	141
1994	116	116
1995	94	97
1996	96	95
1997	101	97
1998	236	150
1999	n/a	101

Table 2.29–Time series of Pacific cod catch divided by age 3+ biomass as estimated in last year's and this year's assessments.

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

Table 2.30–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 2.31–Equilibrium reference points and projections for 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 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	247.0	0.00	0.0
40%	98.8	0.38	84.4
35%	86.4	0.46	90.9

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	110.5	110.5	110.5	110.5	0.0
2001	97.4	97.5	97.5	97.6	0.1
2002	87.0	87.5	87.6	88.5	0.5
2003	79.4	81.6	81.9	85.4	1.9
2004	75.4	80.8	81.5	89.4	4.6
2005	75.3	84.8	85.8	97.9	7.5
2006	78.3	90.4	91.5	107.7	9.4
2007	81.5	94.8	95.9	114.5	10.4
2008	83.6	96.6	98.3	117.9	10.9
2009	84.4	98.3	99.5	119.4	11.2
2010	85.1	97.9	99.9	120.0	11.2
2011	85.4	98.3	100.2	120.3	11.1
2012	85.8	98.3	100.4	121.0	11.2

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.38	0.38	0.38	0.38	0.000
2001	0.37	0.37	0.37	0.37	0.000
2002	0.33	0.33	0.33	0.34	0.002
2003	0.30	0.31	0.31	0.32	0.008
2004	0.28	0.30	0.31	0.34	0.018
2005	0.28	0.32	0.32	0.37	0.027
2006	0.29	0.34	0.34	0.38	0.027
2007	0.31	0.36	0.35	0.38	0.024
2008	0.32	0.37	0.36	0.38	0.022
2009	0.32	0.37	0.36	0.38	0.021
2010	0.32	0.37	0.36	0.38	0.020
2011	0.32	0.37	0.36	0.38	0.019
2012	0.32	0.37	0.36	0.38	0.019

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	86.0	86.0	86.0	86.0	0.0
2001	77.3	77.4	77.4	77.6	0.1
2002	62.1	62.9	63.0	64.2	0.6
2003	51.2	54.2	54.7	59.8	2.7
2004	46.2	54.2	55.5	68.9	7.5
2005	46.9	62.1	64.0	85.3	12.3
2006	51.8	71.5	73.0	95.9	14.2
2007	56.6	78.7	78.8	101.3	14.3
2008	59.2	81.2	81.3	104.1	14.1
2009	60.1	83.3	82.3	104.0	13.9
2010	61.3	82.9	82.5	104.8	13.6
2011	61.2	82.9	82.8	104.1	13.4
2012	61.7	82.7	82.8	104.8	13.5

Table 2.32–Equilibrium eference points and projections for 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 2000-2012 is fixed at a value of 0.87, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	247.0	0.00	0.0
40%	98.8	0.38	84.4
35%	86.4	0.46	90.9

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	111.1	111.1	111.1	111.1	0.0
2001	100.7	100.7	100.8	100.9	0.1
2002	91.5	92.0	92.1	93.1	0.5
2003	84.0	86.2	86.5	90.0	1.9
2004	79.7	85.2	85.8	93.9	4.6
2005	79.3	89.0	90.0	102.5	7.7
2006	82.1	94.6	95.9	113.1	9.9
2007	85.4	99.5	100.9	121.0	11.3
2008	87.6	101.8	103.9	125.2	12.1
2009	88.6	104.1	105.7	127.9	12.5
2010	89.7	104.8	106.5	129.1	12.6
2011	90.1	105.3	107.1	129.6	12.6
2012	90.8	105.7	107.5	130.4	12.6

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.33	0.33	0.33	0.33	0.000
2001	0.33	0.33	0.33	0.33	0.000
2002	0.30	0.30	0.30	0.31	0.002
2003	0.28	0.28	0.29	0.30	0.007
2004	0.26	0.28	0.28	0.31	0.016
2005	0.26	0.29	0.30	0.33	0.022
2006	0.27	0.31	0.31	0.33	0.021
2007	0.28	0.33	0.32	0.33	0.017
2008	0.29	0.33	0.32	0.33	0.014
2009	0.29	0.33	0.32	0.33	0.013
2010	0.30	0.33	0.32	0.33	0.012
2011	0.30	0.33	0.32	0.33	0.011
2012	0.30	0.33	0.32	0.33	0.011

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	76.4	76.4	76.4	76.4	0.0
2001	71.4	71.4	71.4	71.4	0.0
2002	60.0	60.7	60.8	61.9	0.6
2003	49.9	52.7	53.2	57.9	2.5
2004	44.9	52.4	53.6	66.1	6.9
2005	45.2	59.4	60.9	79.2	11.0
2006	49.6	68.2	68.9	88.4	12.4
2007	53.9	75.1	74.1	93.7	12.4
2008	56.9	76.7	76.7	96.8	12.3
2009	57.8	78.2	77.8	97.6	12.2
2010	59.2	78.0	78.3	98.2	12.0
2011	59.7	78.1	78.7	98.1	11.7
2012	60.1	78.3	78.9	98.6	11.8

Table 2.33–Equilibrium reference points and projections for Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = \frac{1}{2}\ max\ F_{ABC}$ in each year 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	247.0	0.00	0.0
40%	98.8	0.38	84.4
35%	86.4	0.46	90.9

Spawning Biomass Projections:

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	113.0	113.0	113.0	113.0	0.0
2001	111.6	111.6	111.7	111.8	0.1
2002	108.6	109.2	109.2	110.2	0.5
2003	103.6	106.0	106.3	110.2	2.1
2004	99.1	105.2	106.0	115.3	5.3
2005	97.5	108.8	110.2	126.2	9.3
2006	99.5	115.5	117.2	139.7	12.8
2007	103.4	123.0	124.6	150.5	15.1
2008	106.9	129.0	130.4	159.1	16.5
2009	110.1	133.2	134.7	163.2	17.1
2010	112.8	136.2	137.5	167.4	17.2
2011	114.7	138.6	139.9	169.8	17.1
2012	116.3	139.9	141.4	170.7	17.0

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.19	0.19	0.19	0.19	0.000
2001	0.19	0.19	0.19	0.19	0.000
2002	0.19	0.19	0.19	0.19	0.000
2003	0.19	0.19	0.19	0.19	0.000
2004	0.18	0.19	0.19	0.19	0.002
2005	0.18	0.19	0.19	0.19	0.003
2006	0.19	0.19	0.19	0.19	0.002
2007	0.19	0.19	0.19	0.19	0.001
2008	0.19	0.19	0.19	0.19	0.001
2009	0.19	0.19	0.19	0.19	0.001
2010	0.19	0.19	0.19	0.19	0.000
2011	0.19	0.19	0.19	0.19	0.000
2012	0.19	0.19	0.19	0.19	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	45.5	45.5	45.5	45.5	0.0
2001	46.0	46.0	46.0	46.0	0.0
2002	44.6	44.8	44.8	45.2	0.2
2003	41.6	42.7	42.9	44.7	1.0
2004	38.7	42.7	43.1	48.4	3.1
2005	38.0	45.5	46.1	54.8	5.3
2006	40.5	49.2	50.0	61.6	6.7
2007	43.0	52.5	53.3	66.0	7.4
2008	44.5	54.6	55.5	68.6	7.7
2009	45.7	56.3	56.8	70.5	7.8
2010	46.8	57.0	57.6	71.0	7.7
2011	47.4	57.5	58.3	71.8	7.6
2012	47.6	57.8	58.7	71.8	7.6

Table 2.34–Equilibrium reference points and projections for Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that F = the 1994-1998 average in each year 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	247.0	0.00	0.0
40%	98.8	0.38	84.4
35%	86.4	0.46	90.9

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	113.3	113.3	113.3	113.3	0.0
2001	113.1	113.2	113.2	113.3	0.1
2002	111.1	111.7	111.8	112.8	0.5
2003	106.9	109.3	109.6	113.5	2.1
2004	102.9	109.0	109.8	119.1	5.3
2005	101.3	112.9	114.3	130.4	9.4
2006	103.1	119.9	121.5	144.3	13.1
2007	107.0	127.6	129.3	156.1	15.6
2008	111.2	134.1	135.4	164.9	17.0
2009	114.7	138.6	140.0	169.7	17.7
2010	117.5	141.9	143.1	173.8	17.8
2011	119.8	144.4	145.8	177.0	17.7
2012	121.7	146.0	147.5	177.8	17.6

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.17	0.17	0.17	0.17	0.000
2001	0.17	0.17	0.17	0.17	0.000
2002	0.17	0.17	0.17	0.17	0.000
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	0.17	0.17	0.17	0.000
2006	0.17	0.17	0.17	0.17	0.000
2007	0.17	0.17	0.17	0.17	0.000
2008	0.17	0.17	0.17	0.17	0.000
2009	0.17	0.17	0.17	0.17	0.000
2010	0.17	0.17	0.17	0.17	0.000
2011	0.17	0.17	0.17	0.17	0.000
2012	0.17	0.17	0.17	0.17	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	41.3	41.3	41.3	41.3	0.0
2001	42.2	42.2	42.2	42.2	0.0
2002	41.2	41.4	41.4	41.8	0.2
2003	38.8	39.8	39.9	41.5	0.9
2004	36.8	39.9	40.3	45.0	2.6
2005	36.7	42.5	43.1	51.0	4.6
2006	38.3	45.9	46.7	57.3	6.0
2007	40.2	49.1	49.7	61.5	6.8
2008	41.6	51.0	51.8	63.8	7.1
2009	42.7	52.6	53.2	65.8	7.2
2010	43.7	53.4	54.0	66.4	7.1
2011	44.4	53.9	54.6	67.3	7.1
2012	44.7	54.2	55.1	67.3	7.0

Table 2.35–Equilibrium reference points and projections for Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = 0$ in each year 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	247.0	0.00	0.0
40%	98.8	0.38	84.4
35%	86.4	0.46	90.9

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	115.6	115.6	115.6	115.6	0.0
2001	128.3	128.3	128.4	128.5	0.1
2002	138.4	139.0	139.1	140.0	0.5
2003	144.6	147.1	147.4	151.3	2.1
2004	148.5	154.8	155.6	165.2	5.5
2005	152.2	164.6	166.2	183.8	10.2
2006	157.4	176.9	178.9	204.8	15.1
2007	165.5	190.0	192.8	225.7	19.3
2008	172.4	202.0	204.3	242.4	22.3
2009	179.1	211.6	214.0	255.7	24.2
2010	185.3	219.3	221.5	263.9	25.2
2011	191.4	226.9	228.9	273.8	25.8
2012	195.7	232.2	234.1	279.0	26.0

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.00	0.00	0.00	0.00	0.000
2001	0.00	0.00	0.00	0.00	0.000
2002	0.00	0.00	0.00	0.00	0.000
2003	0.00	0.00	0.00	0.00	0.000
2004	0.00	0.00	0.00	0.00	0.000
2005	0.00	0.00	0.00	0.00	0.000
2006	0.00	0.00	0.00	0.00	0.000
2007	0.00	0.00	0.00	0.00	0.000
2008	0.00	0.00	0.00	0.00	0.000
2009	0.00	0.00	0.00	0.00	0.000
2010	0.00	0.00	0.00	0.00	0.000
2011	0.00	0.00	0.00	0.00	0.000
2012	0.00	0.00	0.00	0.00	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.0	0.0	0.0	0.0	0.0
2001	0.0	0.0	0.0	0.0	0.0
2002	0.0	0.0	0.0	0.0	0.0
2003	0.0	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0	0.0
2005	0.0	0.0	0.0	0.0	0.0
2006	0.0	0.0	0.0	0.0	0.0
2007	0.0	0.0	0.0	0.0	0.0
2008	0.0	0.0	0.0	0.0	0.0
2009	0.0	0.0	0.0	0.0	0.0
2010	0.0	0.0	0.0	0.0	0.0
2011	0.0	0.0	0.0	0.0	0.0
2012	0.0	0.0	0.0	0.0	0.0

Table 2.36–Equilibrium reference points and projections for Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = F_{OFL}$ in each year 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	247.0	0.00	0.0
40%	98.8	0.38	84.4
35%	86.4	0.46	90.9

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	109.4	109.4	109.4	109.4	0.0
2001	92.2	92.2	92.3	92.4	0.1
2002	80.6	81.2	81.2	82.1	0.5
2003	73.1	75.3	75.5	79.0	1.9
2004	69.5	74.8	75.5	83.3	4.5
2005	69.9	79.1	80.0	91.8	7.2
2006	72.9	84.5	85.4	100.2	8.7
2007	76.2	88.4	89.2	104.8	9.2
2008	77.8	89.9	90.8	107.1	9.3
2009	78.1	90.5	91.3	107.7	9.3
2010	79.0	90.3	91.3	107.4	9.2
2011	79.1	90.2	91.4	107.4	9.0
2012	79.1	90.1	91.5	107.7	9.1

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.46	0.46	0.46	0.46	0.000
2001	0.43	0.43	0.43	0.43	0.000
2002	0.37	0.37	0.37	0.38	0.002
2003	0.33	0.34	0.35	0.36	0.009
2004	0.32	0.34	0.35	0.38	0.022
2005	0.32	0.36	0.37	0.42	0.034
2006	0.33	0.39	0.39	0.46	0.037
2007	0.35	0.41	0.41	0.46	0.036
2008	0.36	0.42	0.41	0.46	0.034
2009	0.36	0.42	0.42	0.46	0.033
2010	0.36	0.42	0.42	0.46	0.032
2011	0.36	0.42	0.42	0.46	0.032
2012	0.36	0.42	0.42	0.46	0.032

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	102.2	102.2	102.2	102.2	0.0
2001	83.7	83.8	83.8	84.0	0.1
2002	64.8	65.6	65.7	67.0	0.7
2003	52.8	56.1	56.6	62.3	3.0
2004	47.9	56.8	58.2	73.0	8.3
2005	49.4	66.0	68.2	91.4	14.0
2006	54.9	76.5	78.6	108.9	16.6
2007	60.2	83.4	84.8	113.4	16.9
2008	62.6	85.3	87.2	115.4	16.8
2009	63.1	86.7	87.7	114.2	16.5
2010	64.2	86.1	87.5	115.3	16.1
2011	63.6	85.7	87.5	114.5	16.0
2012	63.9	85.4	87.6	115.3	16.1

Table 2.37–Equilibrium reference points and projections for 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 2000-2001 and $F = F_{OFL}$ thereafter, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	247.0	0.00	0.0
40%	98.8	0.38	84.4
35%	86.4	0.46	90.9

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	110.5	110.5	110.5	110.5	0.0
2001	97.4	97.5	97.5	97.6	0.1
2002	86.3	86.8	86.9	87.8	0.5
2003	75.7	77.9	78.1	81.6	1.9
2004	70.6	75.9	76.6	84.3	4.5
2005	70.3	79.4	80.4	92.1	7.2
2006	73.0	84.5	85.5	100.2	8.7
2007	76.1	88.4	89.1	104.8	9.2
2008	77.7	89.8	90.8	107.1	9.3
2009	78.1	90.5	91.3	107.7	9.3
2010	79.0	90.3	91.3	107.3	9.2
2011	79.1	90.2	91.4	107.4	9.0
2012	79.1	90.1	91.5	107.7	9.1

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.38	0.38	0.38	0.38	0.000
2001	0.37	0.37	0.37	0.37	0.000
2002	0.40	0.40	0.40	0.41	0.002
2003	0.35	0.36	0.36	0.38	0.009
2004	0.32	0.35	0.35	0.39	0.022
2005	0.32	0.36	0.37	0.43	0.034
2006	0.33	0.39	0.39	0.46	0.037
2007	0.35	0.41	0.41	0.46	0.036
2008	0.36	0.42	0.41	0.46	0.034
2009	0.36	0.42	0.42	0.46	0.033
2010	0.36	0.42	0.42	0.46	0.032
2011	0.36	0.42	0.42	0.46	0.032
2012	0.36	0.42	0.42	0.46	0.032

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	86.0	86.0	86.0	86.0	0.0
2001	77.3	77.4	77.4	77.6	0.1
2002	73.5	74.3	74.5	75.9	0.7
2003	56.2	59.6	60.1	65.9	3.1
2004	49.2	58.1	59.5	74.5	8.4
2005	49.8	66.4	68.6	91.7	14.0
2006	54.9	76.4	78.5	108.8	16.5
2007	60.2	83.3	84.7	113.3	16.9
2008	62.5	85.2	87.1	115.3	16.8
2009	63.0	86.7	87.6	114.1	16.5
2010	64.2	86.0	87.4	115.3	16.1
2011	63.6	85.7	87.5	114.5	16.0
2012	63.9	85.4	87.6	115.3	16.1

Table 2.38–Equilibrium reference points and projections for 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 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1989-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	199.7	0.00	0
40%	79.9	0.38	68.3
35%	69.9	0.46	73.5

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	110.5	110.5	110.5	110.5	0.0
2001	97.3	97.4	97.4	97.5	0.1
2002	86.1	86.5	86.5	87.2	0.4
2003	75.7	77.4	77.6	80.1	1.4
2004	68.7	72.6	73.0	78.3	3.2
2005	66.1	72.8	73.5	82.0	5.1
2006	66.6	75.1	76.0	87.1	6.5
2007	68.5	77.6	78.4	91.2	7.2
2008	69.8	78.6	79.8	93.3	7.6
2009	70.0	79.5	80.5	94.8	7.8
2010	70.4	79.4	80.8	94.9	7.8
2011	70.7	79.7	81.0	94.9	7.7
2012	70.8	79.8	81.1	95.4	7.7

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.38	0.38	0.38	0.38	0.000
2001	0.38	0.38	0.38	0.38	0.000
2002	0.38	0.38	0.38	0.38	0.000
2003	0.36	0.36	0.37	0.38	0.006
2004	0.32	0.34	0.34	0.37	0.015
2005	0.31	0.34	0.34	0.38	0.021
2006	0.31	0.35	0.35	0.38	0.022
2007	0.32	0.37	0.36	0.38	0.020
2008	0.33	0.37	0.36	0.38	0.018
2009	0.33	0.38	0.36	0.38	0.018
2010	0.33	0.37	0.36	0.38	0.017
2011	0.33	0.38	0.37	0.38	0.016
2012	0.33	0.38	0.36	0.38	0.016

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	86.0	86.0	86.0	86.0	0.0
2001	78.3	78.3	78.4	78.4	0.0
2002	69.8	70.0	70.1	70.5	0.2
2003	57.6	60.4	60.6	64.7	2.1
2004	47.4	54.0	54.7	64.5	5.5
2005	44.6	55.9	57.1	71.2	8.5
2006	46.3	60.6	61.4	77.1	9.7
2007	49.2	64.9	64.7	80.7	9.9
2008	50.9	66.5	66.2	81.8	9.8
2009	51.2	67.8	66.9	82.0	9.8
2010	52.2	67.3	67.1	82.3	9.5
2011	52.4	67.5	67.2	82.2	9.4
2012	52.0	67.6	67.2	82.3	9.4

Table 2.39–Equilibrium reference points and projections for 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 2000-2012 is fixed at a value of 0.87, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1989-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	199.7	0.00	0
40%	79.9	0.38	68.3
35%	69.9	0.46	73.5

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	111.1	111.1	111.1	111.1	0.0
2001	100.6	100.7	100.7	100.8	0.1
2002	91.0	91.5	91.5	92.2	0.4
2003	81.3	83.1	83.3	85.9	1.4
2004	73.7	77.9	78.4	84.3	3.5
2005	70.3	77.3	78.1	87.7	5.6
2006	70.4	79.2	80.4	93.3	7.2
2007	72.1	81.8	83.0	97.7	8.1
2008	73.2	83.3	84.7	99.7	8.6
2009	73.7	84.7	85.7	101.5	8.9
2010	74.4	85.1	86.3	102.0	8.9
2011	74.7	85.5	86.7	102.8	8.8
2012	74.9	85.6	86.9	102.8	8.8

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.33	0.33	0.33	0.33	0.000
2001	0.33	0.33	0.33	0.33	0.000
2002	0.33	0.33	0.33	0.33	0.000
2003	0.33	0.33	0.33	0.33	0.000
2004	0.30	0.32	0.32	0.33	0.010
2005	0.29	0.32	0.31	0.33	0.015
2006	0.29	0.33	0.32	0.33	0.015
2007	0.29	0.33	0.32	0.33	0.013
2008	0.30	0.33	0.32	0.33	0.011
2009	0.30	0.33	0.33	0.33	0.010
2010	0.30	0.33	0.33	0.33	0.010
2011	0.31	0.33	0.33	0.33	0.009
2012	0.31	0.33	0.33	0.33	0.008

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	76.4	76.4	76.4	76.4	0.0
2001	71.4	71.4	71.4	71.4	0.0
2002	64.8	65.1	65.1	65.5	0.2
2003	57.2	58.6	58.7	60.8	1.1
2004	47.3	54.0	54.2	61.8	4.7
2005	43.8	54.7	55.2	66.7	7.3
2006	44.9	58.5	58.5	71.9	8.4
2007	47.3	61.7	61.1	75.1	8.5
2008	49.1	62.5	62.6	76.3	8.5
2009	49.5	63.5	63.4	76.9	8.5
2010	50.3	63.4	63.6	77.3	8.3
2011	50.9	63.5	63.9	77.2	8.1
2012	50.9	63.6	64.0	77.7	8.1

Table 2.40–Equilibrium reference points and projections for 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 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1989-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	199.7	0.00	0
40%	79.9	0.38	68.3
35%	69.9	0.46	73.5

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	113.0	113.0	113.0	113.0	0.0
2001	111.5	111.6	111.6	111.7	0.1
2002	108.4	108.9	108.9	109.6	0.4
2003	102.9	104.7	104.9	107.5	1.4
2004	96.9	101.4	101.9	108.1	3.7
2005	92.7	101.0	101.9	112.9	6.5
2006	91.4	103.0	104.2	119.7	9.0
2007	92.0	106.4	107.5	126.4	10.6
2008	93.7	109.2	110.1	130.4	11.5
2009	94.5	111.2	112.1	132.7	11.9
2010	95.7	112.5	113.3	134.5	12.0
2011	96.9	113.5	114.5	135.3	11.9
2012	97.6	114.3	115.3	135.3	11.8

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.19	0.19	0.19	0.19	0.000
2001	0.19	0.19	0.19	0.19	0.000
2002	0.19	0.19	0.19	0.19	0.000
2003	0.19	0.19	0.19	0.19	0.000
2004	0.19	0.19	0.19	0.19	0.000
2005	0.19	0.19	0.19	0.19	0.000
2006	0.19	0.19	0.19	0.19	0.000
2007	0.19	0.19	0.19	0.19	0.000
2008	0.19	0.19	0.19	0.19	0.000
2009	0.19	0.19	0.19	0.19	0.000
2010	0.19	0.19	0.19	0.19	0.000
2011	0.19	0.19	0.19	0.19	0.000
2012	0.19	0.19	0.19	0.19	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	45.5	45.5	45.5	45.5	0.0
2001	46.0	46.0	46.0	46.0	0.0
2002	44.5	44.7	44.7	44.9	0.1
2003	41.4	42.2	42.3	43.5	0.7
2004	38.3	40.8	41.0	44.6	2.0
2005	36.8	41.4	41.9	47.8	3.5
2006	37.0	43.0	43.6	51.5	4.6
2007	37.8	44.6	45.1	54.1	5.1
2008	38.4	45.6	46.2	55.3	5.3
2009	38.9	46.5	46.9	56.0	5.4
2010	39.6	46.8	47.3	56.4	5.4
2011	39.9	47.1	47.6	56.7	5.3
2012	40.0	47.3	47.8	57.1	5.3

Table 2.41–Equilibrium reference points and projections for Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that F = the 1994-1998 average in each year 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1989-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	199.7	0.00	0
40%	79.9	0.38	68.3
35%	69.9	0.46	73.5

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	113.3	113.3	113.3	113.3	0.0
2001	113.1	113.1	113.1	113.2	0.1
2002	111.0	111.4	111.5	112.1	0.4
2003	106.2	108.0	108.2	110.8	1.5
2004	100.7	105.2	105.7	111.9	3.7
2005	96.6	105.0	105.9	117.0	6.6
2006	95.3	107.2	108.4	124.3	9.1
2007	96.0	110.7	112.0	131.1	10.8
2008	97.8	113.8	114.7	135.5	11.8
2009	98.9	115.7	116.8	137.8	12.3
2010	100.0	117.3	118.2	140.3	12.4
2011	101.4	118.5	119.5	140.9	12.4
2012	102.1	119.4	120.4	141.3	12.3

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.17	0.17	0.17	0.17	0.000
2001	0.17	0.17	0.17	0.17	0.000
2002	0.17	0.17	0.17	0.17	0.000
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	0.17	0.17	0.17	0.000
2006	0.17	0.17	0.17	0.17	0.000
2007	0.17	0.17	0.17	0.17	0.000
2008	0.17	0.17	0.17	0.17	0.000
2009	0.17	0.17	0.17	0.17	0.000
2010	0.17	0.17	0.17	0.17	0.000
2011	0.17	0.17	0.17	0.17	0.000
2012	0.17	0.17	0.17	0.17	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	41.3	41.3	41.3	41.3	0.0
2001	42.2	42.2	42.2	42.2	0.0
2002	41.2	41.3	41.4	41.6	0.1
2003	38.6	39.3	39.4	40.4	0.6
2004	35.9	38.2	38.4	41.6	1.8
2005	34.6	38.7	39.2	44.5	3.2
2006	34.7	40.2	40.8	48.0	4.2
2007	35.4	41.7	42.2	50.5	4.7
2008	36.0	42.7	43.3	51.6	4.9
2009	36.6	43.6	43.9	52.4	5.0
2010	37.2	43.9	44.3	52.8	5.0
2011	37.4	44.2	44.6	53.3	4.9
2012	37.6	44.3	44.8	53.4	4.9

Table 2.42–Equilibrium reference points and projections for Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = 0$ in each year 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1989-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	199.7	0.00	0
40%	79.9	0.38	68.3
35%	69.9	0.46	73.5

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	115.6	115.6	115.6	115.6	0.0
2001	128.2	128.3	128.3	128.4	0.1
2002	138.2	138.7	138.7	139.4	0.4
2003	143.9	145.8	145.9	148.6	1.5
2004	146.3	150.9	151.4	157.9	3.8
2005	147.2	156.3	157.3	169.7	7.1
2006	149.0	162.6	164.1	181.9	10.5
2007	152.2	170.3	171.8	195.3	13.4
2008	155.0	176.1	177.6	204.9	15.5
2009	158.4	181.2	182.5	211.6	16.8
2010	160.7	184.6	186.2	216.9	17.5
2011	164.1	189.4	190.2	221.8	18.0
2012	166.0	191.8	192.9	224.1	18.1

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.00	0.00	0.00	0.00	0.000
2001	0.00	0.00	0.00	0.00	0.000
2002	0.00	0.00	0.00	0.00	0.000
2003	0.00	0.00	0.00	0.00	0.000
2004	0.00	0.00	0.00	0.00	0.000
2005	0.00	0.00	0.00	0.00	0.000
2006	0.00	0.00	0.00	0.00	0.000
2007	0.00	0.00	0.00	0.00	0.000
2008	0.00	0.00	0.00	0.00	0.000
2009	0.00	0.00	0.00	0.00	0.000
2010	0.00	0.00	0.00	0.00	0.000
2011	0.00	0.00	0.00	0.00	0.000
2012	0.00	0.00	0.00	0.00	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.0	0.0	0.0	0.0	0.0
2001	0.0	0.0	0.0	0.0	0.0
2002	0.0	0.0	0.0	0.0	0.0
2003	0.0	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0	0.0
2005	0.0	0.0	0.0	0.0	0.0
2006	0.0	0.0	0.0	0.0	0.0
2007	0.0	0.0	0.0	0.0	0.0
2008	0.0	0.0	0.0	0.0	0.0
2009	0.0	0.0	0.0	0.0	0.0
2010	0.0	0.0	0.0	0.0	0.0
2011	0.0	0.0	0.0	0.0	0.0
2012	0.0	0.0	0.0	0.0	0.0

Table 2.43--Equilibrium reference points and projections for Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = F_{OFL}$ in each year 2000-2012, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1989-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	199.7	0.00	0
40%	79.9	0.38	68.3
35%	69.9	0.46	73.5

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	109.4	109.4	109.4	109.4	0.0
2001	91.8	91.9	91.9	92.0	0.1
2002	78.2	78.6	78.6	79.3	0.3
2003	67.6	69.2	69.3	71.6	1.3
2004	62.1	65.9	66.3	71.5	3.1
2005	60.6	67.0	67.7	75.7	4.9
2006	61.7	69.7	70.4	80.3	5.9
2007	63.6	72.1	72.6	83.6	6.3
2008	64.7	72.9	73.6	84.4	6.4
2009	65.0	73.5	73.9	85.0	6.4
2010	65.3	73.2	73.9	84.8	6.3
2011	65.4	73.2	73.9	84.4	6.2
2012	65.3	73.2	74.0	84.7	6.2

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.46	0.46	0.46	0.46	0.000
2001	0.46	0.46	0.46	0.46	0.000
2002	0.45	0.45	0.45	0.46	0.002
2003	0.38	0.39	0.40	0.41	0.008
2004	0.35	0.37	0.38	0.41	0.019
2005	0.34	0.38	0.38	0.43	0.028
2006	0.35	0.40	0.40	0.46	0.032
2007	0.36	0.41	0.41	0.46	0.031
2008	0.37	0.42	0.42	0.46	0.030
2009	0.37	0.42	0.42	0.46	0.030
2010	0.37	0.42	0.42	0.46	0.029
2011	0.37	0.42	0.42	0.46	0.028
2012	0.37	0.42	0.42	0.46	0.029

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	102.2	102.2	102.2	102.2	0.0
2001	89.2	89.2	89.2	89.2	0.0
2002	75.3	76.0	76.1	77.2	0.6
2003	56.1	58.9	59.2	63.5	2.3
2004	47.5	54.5	55.3	65.8	6.1
2005	45.9	58.1	59.7	76.3	9.8
2006	48.7	63.9	65.5	87.0	11.5
2007	51.9	68.4	69.3	89.8	11.8
2008	53.5	69.6	70.8	90.4	11.8
2009	54.0	70.4	71.2	90.4	11.7
2010	54.4	69.7	71.0	90.4	11.4
2011	54.3	69.9	71.0	90.1	11.3
2012	54.0	69.8	71.1	90.4	11.4

Table 2.44–Equilibrium reference points and projections for 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 2000-2001 and $F = F_{OFL}$ thereafter, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1989-1998. See Table 2.30 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	199.7	0.00	0
40%	79.9	0.38	68.3
35%	69.9	0.46	73.5

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	110.5	110.5	110.5	110.5	0.0
2001	97.3	97.4	97.4	97.5	0.1
2002	85.2	85.6	85.7	86.3	0.4
2003	71.5	73.2	73.4	75.8	1.4
2004	63.7	67.5	67.9	73.1	3.1
2005	61.2	67.6	68.2	76.2	4.9
2006	61.8	69.9	70.5	80.4	5.9
2007	63.6	72.1	72.6	83.5	6.3
2008	64.7	72.9	73.5	84.4	6.4
2009	64.9	73.5	73.9	84.9	6.4
2010	65.2	73.2	73.9	84.8	6.3
2011	65.4	73.1	73.9	84.4	6.2
2012	65.3	73.2	74.0	84.7	6.2

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	0.38	0.38	0.38	0.38	0.000
2001	0.38	0.38	0.38	0.38	0.000
2002	0.46	0.46	0.46	0.46	0.000
2003	0.41	0.42	0.42	0.43	0.008
2004	0.36	0.38	0.39	0.42	0.019
2005	0.35	0.38	0.39	0.44	0.028
2006	0.35	0.40	0.40	0.46	0.031
2007	0.36	0.41	0.41	0.46	0.031
2008	0.37	0.42	0.42	0.46	0.030
2009	0.37	0.42	0.42	0.46	0.030
2010	0.37	0.42	0.42	0.46	0.029
2011	0.37	0.42	0.42	0.46	0.028
2012	0.37	0.42	0.42	0.46	0.029

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2000	86.0	86.0	86.0	86.0	0.0
2001	78.3	78.3	78.4	78.4	0.0
2002	82.9	83.2	83.3	83.8	0.3
2003	62.1	65.2	65.5	70.2	2.6
2004	49.5	56.7	57.6	68.3	6.2
2005	46.5	58.8	60.3	77.0	9.8
2006	48.7	63.9	65.5	86.9	11.5
2007	51.8	68.2	69.2	89.8	11.8
2008	53.4	69.4	70.7	90.3	11.8
2009	53.9	70.4	71.1	90.4	11.7
2010	54.4	69.7	71.0	90.4	11.4
2011	54.3	69.9	71.0	90.1	11.3
2012	54.0	69.8	71.1	90.4	11.4

Table 2.45--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
	$F_{35\%}$	0.46
	$F_{40\%}$	0.38
	$max\ F_{ABC}$	0.38
Reference spawning biomass:	Type	Value
	$B_{35\%}$	86,400 t
	$B_{40\%}$	98,800 t
Projected biomass for 2000:	Type	Value
	Age 3+	567,000 t
	Spawning (at $max\ F_{ABC}$)	111,000 t
Recommended ABC for 2000:	Units	Value
	Fishing Mortality	0.33
	Catch	76,400 t
Overfishing level for 2000:	Units	Value
	Fishing Mortality	0.46
	Catch	102,000 t

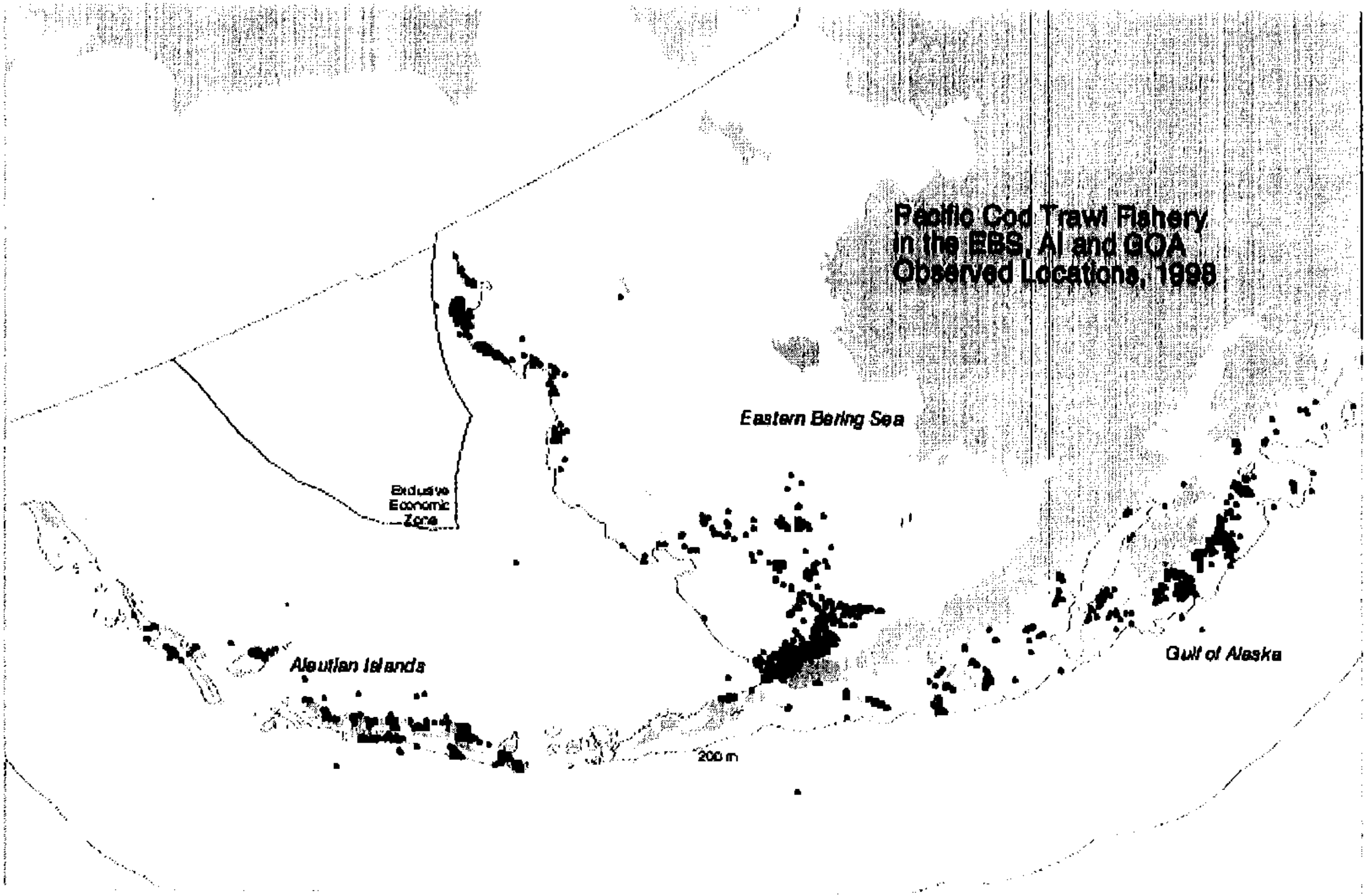

Figure 2.1–Observed fishing locations in the 1998 trawl fisheries for Pacific cod in the BSAI and GOA.

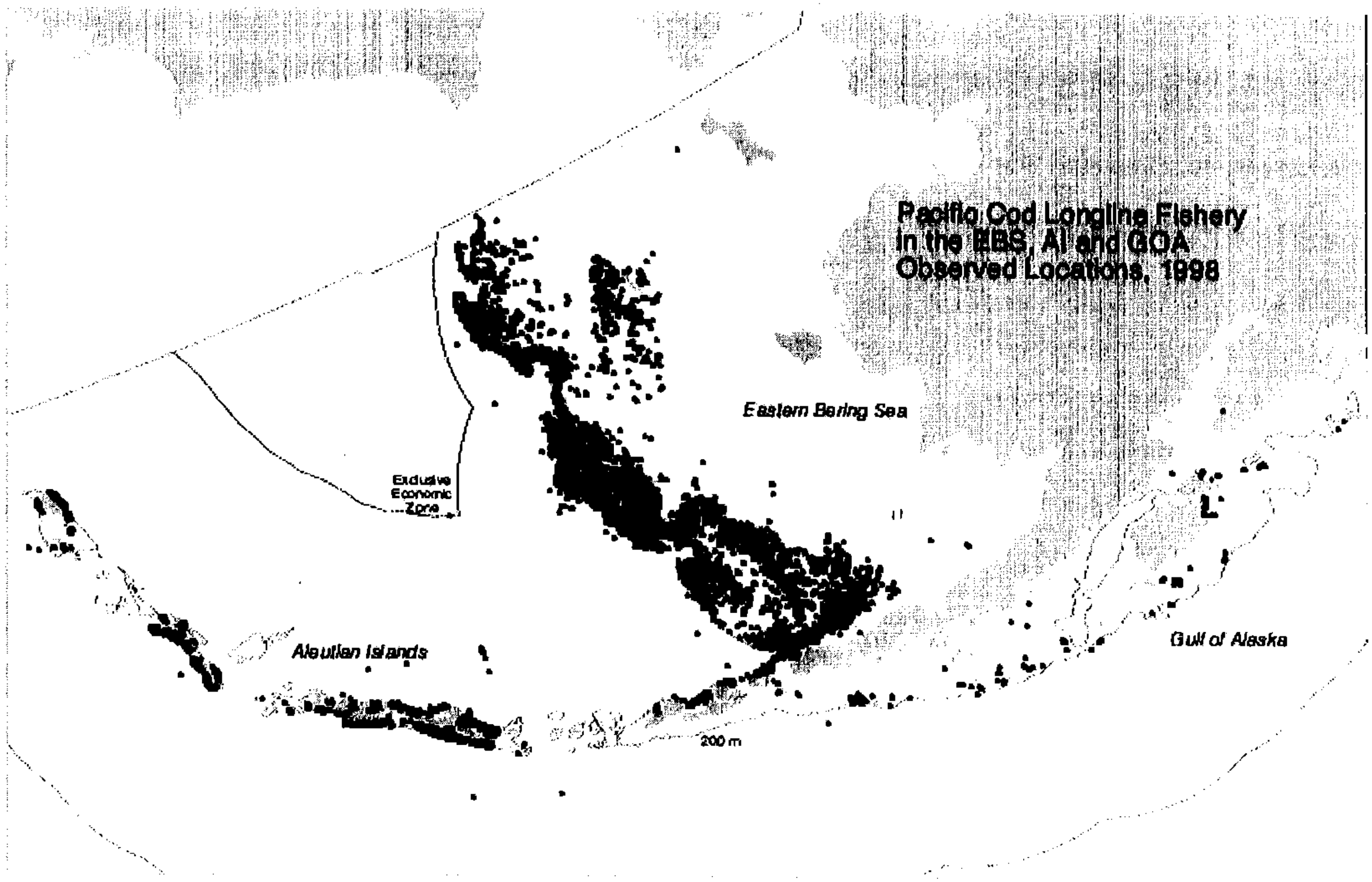

Figure 2.2–Observed fishing locations in the 1998 longline fisheries for Pacific cod in the BSAI and GOA.

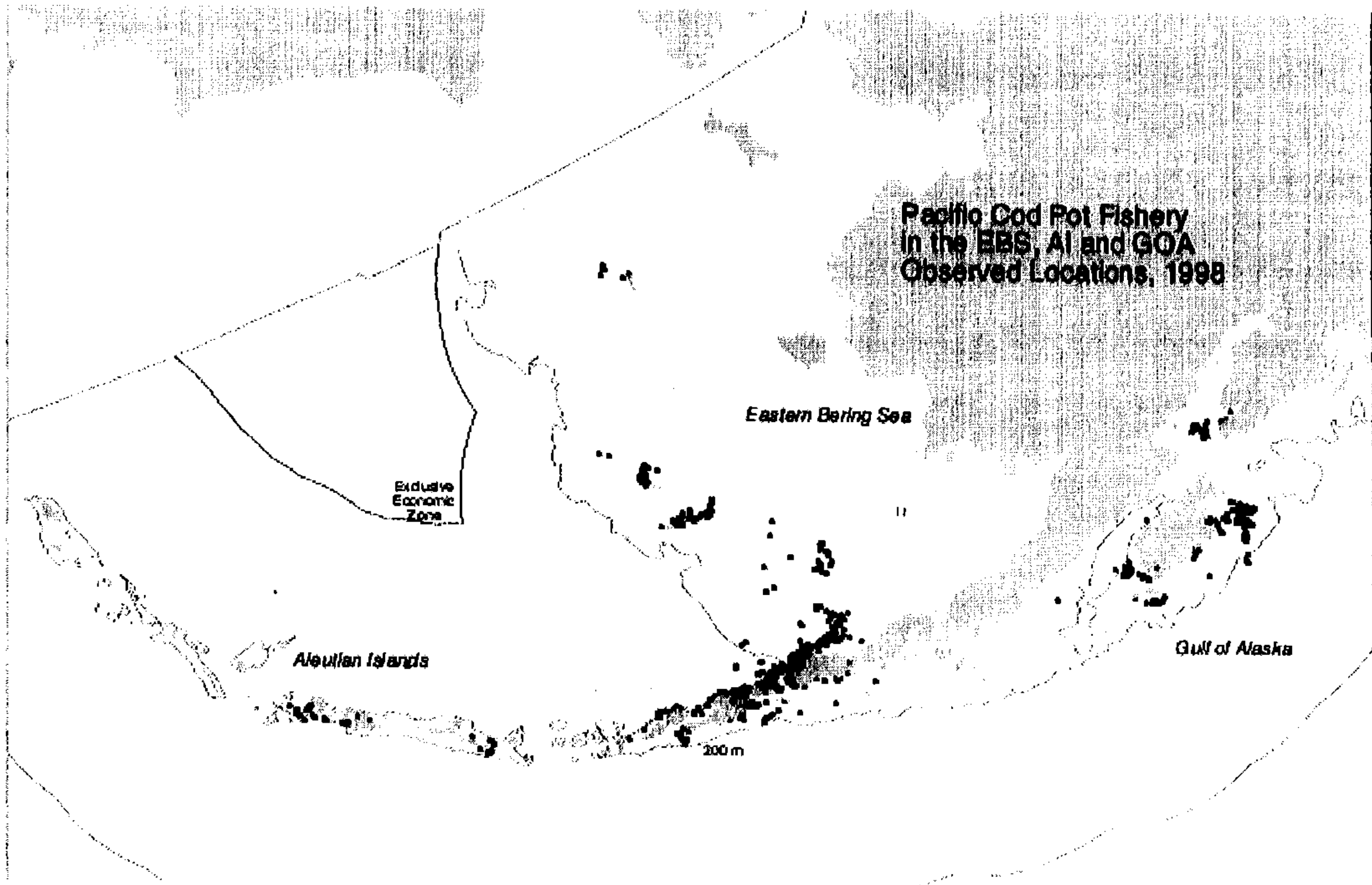

Figure 2.3–Observed fishing locations in the 1998 pot fisheries for Pacific cod in the BSAI and GOA.

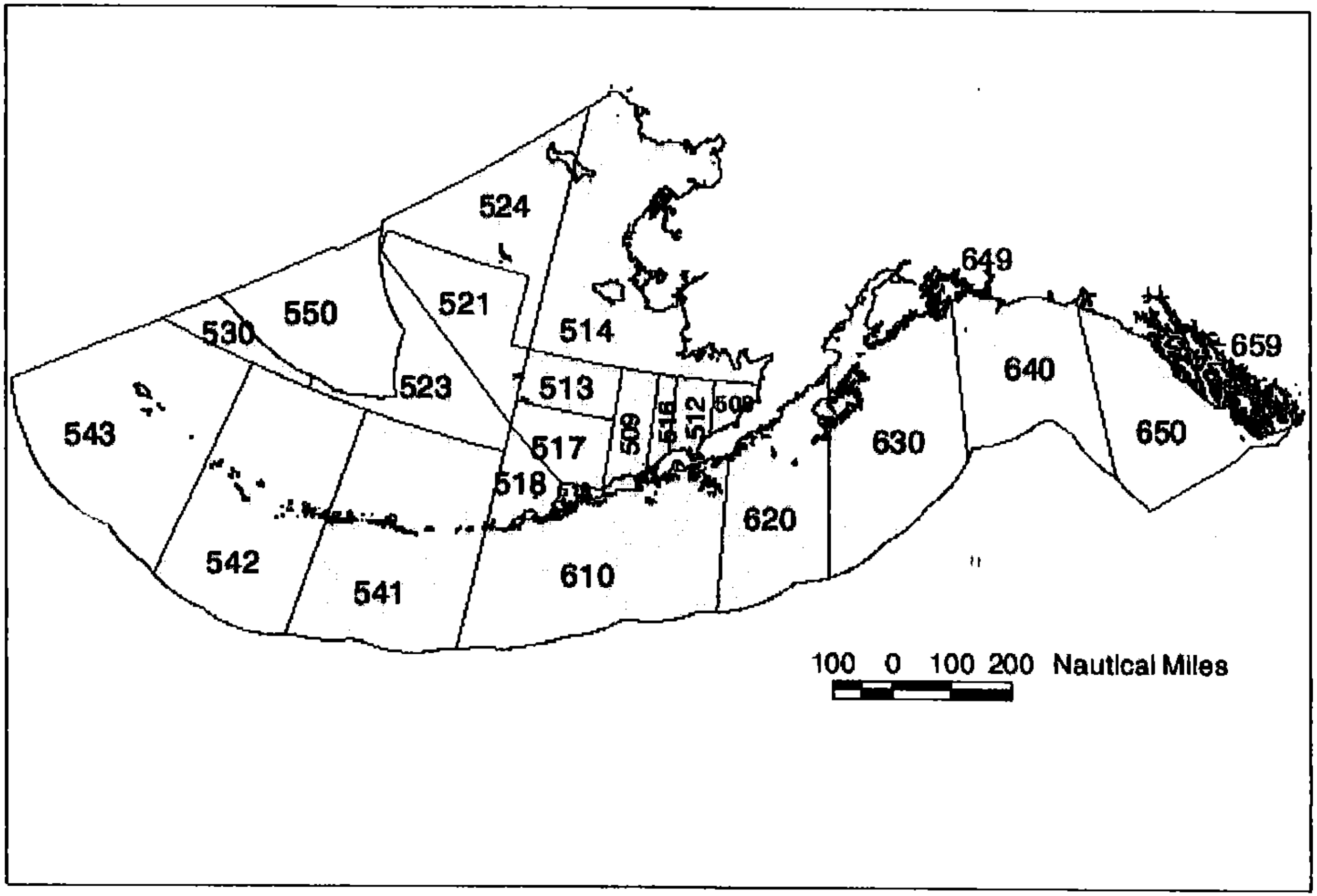

Figure 2.4–NMFS statistical areas in the EBS, AI, and GOA.

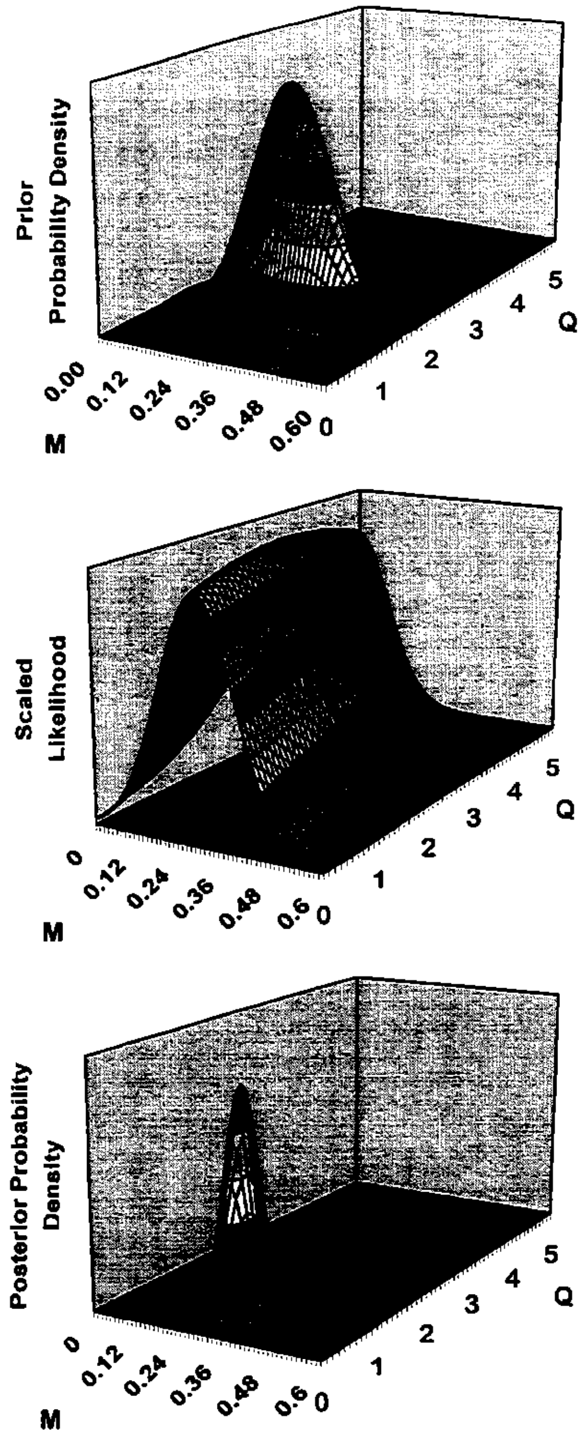

Figure 2.5–Prior distribution, scaled likelihood, and posterior distribution of M and Q for Pacific cod.

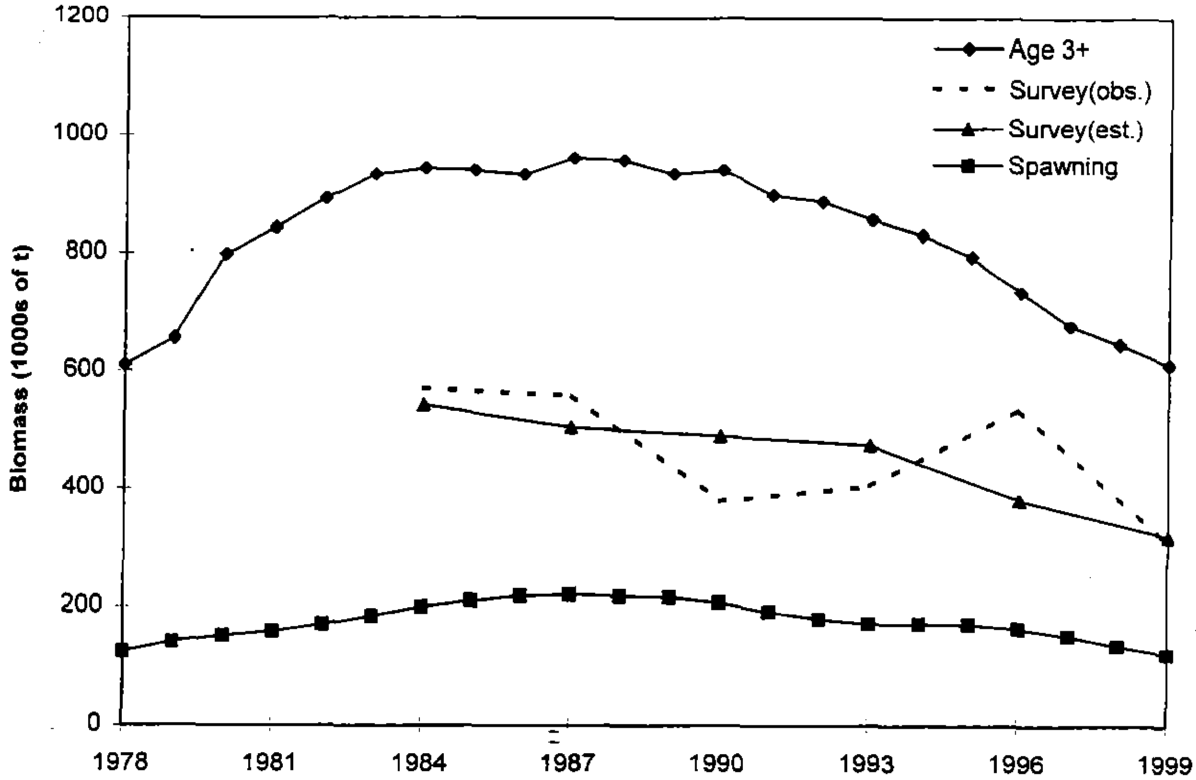

Figure 2.6–Three Pacific cod biomass time series estimated by Model 1, together with the time series of biomass levels observed by the survey.

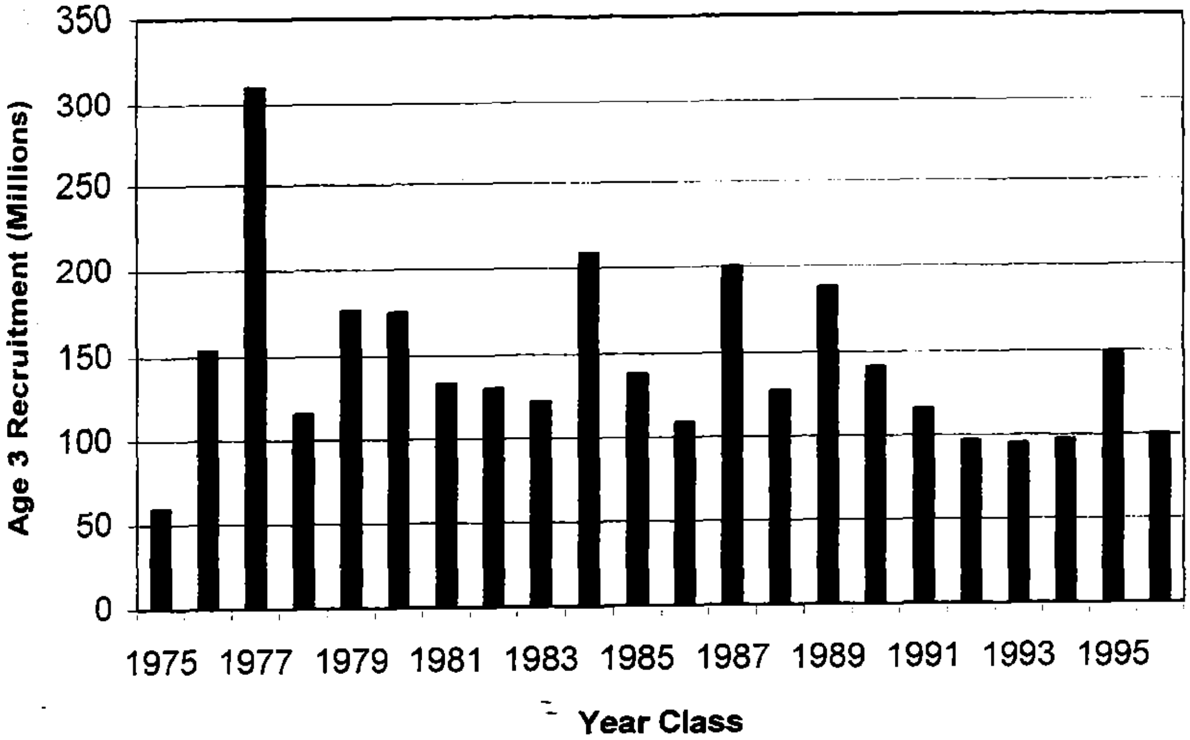

Figure 2.7–Pacific cod recruitment at age 3 as estimated by Model 1.

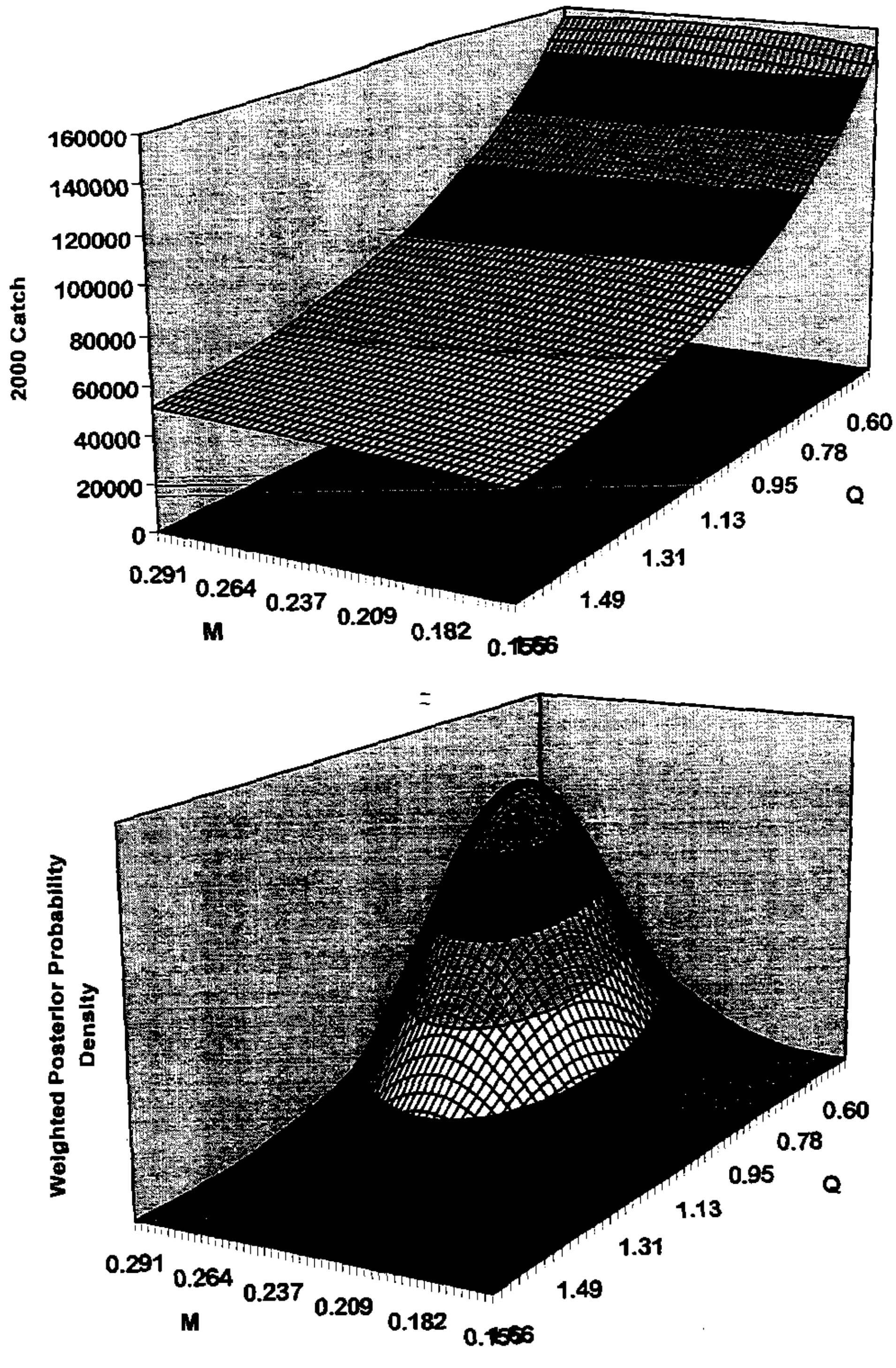

Figure 2.8–Profile of 2000 Pacific cod catch under an $F_{40\%}$ harvest rate and the log of the 2000 catch profile weighted by the posterior distribution of M and Q.

Appendix: Functional Representations of Population Dynamics

These equations are similar to those used in Synthesis. Symbols are defined in Table 2.17.

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:

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

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

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

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

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

Numbers at Age

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:

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