CHAPTER 2: ASSESSMENT OF THE PACIFIC COD STOCK IN THE GULF OF ALASKA

Grant G. Thompson, Harold H. Zenger, and Martin W. Dorn

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way NE., Seattle, WA 98115-0070

EXECUTIVE SUMMARY

Summary of Major Changes

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

Changes in the Input Data

1) Catch data for 2003 were updated and preliminary catch data for 2004 were incorporated into the model.
2) Size composition data from the 2003 commercial fisheries were updated and preliminary size composition data from the 2004 commercial fisheries were incorporated into the model.
3) Errors in the size composition data from the January-May 2000 pot fishery and the June-August 2001 trawl fishery were corrected.

Changes in the Assessment Model

No changes were made to the structure of the assessment model.

Changes in Assessment Results

1) The estimated 2005 spawning biomass for the GOA stock is 91,700 t, down about 11% from last year’s estimate for 2004 and down about 2% from last year's F_{ABC} projection for 2005.
2) The estimated 2005 total age 3+ biomass for the GOA stock is 472,000 t, down about 2% from last year’s estimate for 2004 and up about 14% from last year's $F_{40\%}$ projection for 2005.
3) The recommended 2005 ABC for the GOA stock is 58,100 t, down about 7% from last year's recommendation for 2004 and almost unchanged from last year’s F_{ABC} projection for 2005.
4) The estimated 2005 OFL for the GOA stock is 86,200 t, down about 15% from last year's estimate for 2004.

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

SSC Comments Specific to the GOA Pacific Cod Assessment

From the December, 2003 minutes: *"For next year's assessment, the SSC encourages the authors to consider incorporation of ADF&G trawl survey data into the GOA cod assessment, as has been done for pollock. These data are particularly relevant for cod, because cod in state and federal waters are considered to be one stock."* The ADFG trawl surveys cover several subareas of the GOA, some of which largely overlap portions of the NMFS survey area. Use of data from these surveys is discussed in the "Survey Data" subsection of the "Data" section and in Attachment 2B. Attachment 2B presents time series of ADFG trawl survey biomass estimates for Kamishak Bay and Kachemak Bay along with time series of length frequencies for the ADFG Cook Inlet and Prince William Sound surveys. Length frequencies are compared for the 2003 NMFS GOA survey, 2003 ADFG Cook Inlet survey, and 2003 ADFG Prince William Sound survey. These data are presented for informational purposes only and are not used in this year's assessment model. However, a spatially explicit model is being developed for use in future assessments of Pacific cod. If successful, the new model should facilitate incorporation of data from subarea-specific surveys such as those conducted by ADFG.

SSC Comments on Assessments in General

From the December, 2003 minutes: *"The SSC is encouraged that several assessment authors are investigating spawner-recruit relationships in their assessments (e.g., Pacific cod, several BSAI flatfish). This raises the possibility that some assessments can move up to Tier 1 from Tier 3 and thus more fully consider stock productivity. The SSC encourages investigations of this type while recognizing some difficulties. In particular, there may be some confounding of environmental effects with density dependence in the time series. For example, many flatfish stocks had low biomass during the 1970s and early 1980s and then increased dramatically. The resultant spawner-recruit curves consist of data points on the left side of the graph from the early period and on the right side of the graph from the most recent period. Nevertheless, authors could explore alternative spawner-recruit analyses based on subsets of the data and contrast those with an analysis using all of the data."* Alternative stock-recruitment curves based on pre-1989 and post-1988 subsets of the data are compared and contrasted with an estimated curve using all of the data in the "Recruitment" subsection of the "Results" section. In addition, correlations between recruitment and the Pacific Decadal Oscillation are presented in the "Ecosystem Effects on the Stock" subsection of the "Ecosystem Considerations" section.

Also from the December, 2003 minutes: *"Variation in distribution or productivity of a species at the periphery of its range has different management implications than variation of a similar magnitude at the center of the range. At the periphery of a species range, small variations in the natural environment may exceed the tolerance of the species and cause large rapid changes in local population size and distribution. In contrast, changes of similar magnitude in the center of the species range may be within the limits of tolerance of the species and therefore may result in little or no change in productivity. Recognizing the above relationships, the SSC recommends that, where possible, the assessment teams differentiate stocks or portions of stocks at the periphery of their ranges."* Pacific cod in the Gulf of Alaska is not at the periphery of its range, as discussed in the "Introduction" section.

INTRODUCTION

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 63° N latitude. Pacific cod is distributed widely over Gulf of Alaska (GOA), as well as the eastern

Bering Sea (EBS) and the Aleutian Islands (AI) area. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and GOA, and genetic studies (e.g., Grant et al. 1987) have failed to show significant evidence of stock structure within these areas. Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the GOA.

FISHERY

During the two decades prior to passage of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976, the fishery for Pacific cod in the GOA was small, averaging around 3,000 t per year. Most of the catch during this period was taken by the foreign fleet, whose catches of Pacific cod were usually incidental to directed fisheries for other species. By 1976, catches had increased to 6,800 t. Catches of Pacific cod since 1978 are shown in Tables 2.1a and 2.1b. In Table 2.1a, catches for 1978-1990 are broken down by year, fleet sector, and gear type. In Table 2.1b, catches for 1991-2003 are broken down by year, jurisdiction, and gear type. The foreign fishery peaked in 1981 at a catch of nearly 35,000 t. A small joint venture fishery existed through 1988, averaging a catch of about 1,400 t per year. The domestic fishery increased steadily through 1986, then increased more than three-fold in 1987 to a catch of nearly 31,000 t as the foreign fishery was eliminated. Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components. Trawl gear has traditionally accounted for the bulk of the catch (nearly 60% on average since 1987), although pot gear has taken the largest share of the catch in each of the last two years. Figure 2.1 shows areas in which sampled hauls for each of the three main gear types (trawl, longline, and pot) were concentrated during 2003. To create this figure, the EEZ off Alaska was divided into 20 km × 20 km squares. A square is shaded if more than two hauls containing Pacific cod were sampled in it during 2003.

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 2004, TAC averaged about 82% of ABC and catch averaged about 89% of TAC. In 8 of these 19 years (42%), TAC equaled ABC exactly. In 7 of these 19 years (37%), catch exceeded TAC. However, it should be noted that all but two of these apparent overages occurred in the most recent six years, when a substantial fishery for Pacific cod was conducted inside State of Alaska waters, mostly in the Western and Central Regulatory Areas. To accommodate the State-managed fishery, TAC was set well below ABC in each of those years (15% in 1997 and 1998; 20% in 1999; 23% in 2000-2003; and 24% in 2004). Thus, the apparent overages in 1999, 2000, and 2002-2004 are basically an artifact of the bi-jurisdictional nature of the fishery. Catch has exceeded ABC only twice (in 1992 and 1996). Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. For example, from 1986 through 2004, three different assessment models were used (Table 2.2), though the present model has remained unchanged since 1997 (except for the addition of a new fishery selectivity era beginning in 2000).

Historically, the majority of the GOA catch has come from the Central regulatory area. To some extent the distribution of effort within the GOA is driven by regulation, as catch limits within this region have been apportioned by area throughout the history of management under the MFCMA. Changes in area-specific allocation between years have usually been traceable to changes in biomass distributions estimated by Alaska Fisheries Science Center trawl surveys or management responses to local concerns.

Currently, the ABC allocation follows the average biomass distribution estimated by the three most recent trawl surveys, and the TAC allocation is within one percent of this distribution on an area-by-area basis. The complete history of allocation (in percentage terms) by regulatory area within the GOA is shown below (some alternative apportionment methods are discussed in Attachment 2A):

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

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

The catches shown in Tables 2.1a-b and 2.2 include estimated discards. Discard rates of Pacific cod in the various GOA target fisheries are shown for each year 1991-2003 in Table 2.3.

DATA

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

Commercial Catch Data

Catch Biomass

Catches (including estimated discards) taken in the GOA since 1978 are shown in Table 2.4, broken down by the three main gear types and the following within-year time intervals, or "periods": January-May, June-August, and September-December. This particular division, which was suggested by participants in the BSAI fishery, is intended to reflect actual intra-annual differences in fleet operation (e.g., fishing operations during the spawning period may be different than at other times of year). In years for which estimates of the distribution by gear or period were not available, proxies based on other years' distributions were used.

Catch Size Composition

Fishery size compositions are presently available, by gear, for the years 1978 through the first part of 2004. As in all assessments since 1997, size composition data from trawl catches sampled on shore were not included in the set of input data, because a comparison of cruises for which both at-sea and shoreside size composition samples were available showed that, in the case of trawl catches, the shoreside data typically contained a smaller proportion of small fish than the at-sea data, indicating that these data may reflect post-discard landings rather than the entire catch. For ease of representation and analysis, length frequency data for Pacific cod can usefully be grouped according to the following set of 25 intervals or "bins," with the upper and lower boundaries shown in cm:

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

Total length sample sizes for each year, gear, and period are shown in Table 2.5. The collections of relative length frequencies are shown by year, period, and size bin for the pre-1987 trawl fishery in Table 2.6, the pre-1987 longline fishery in Table 2.7, the post-1986 trawl fishery in Tables 2.8a and 2.8b, the post-1986 longline fishery in Tables 2.9a and 2.9b, and the pot fishery in Tables 2.10a and 2.10b. Fishery length frequencies since 1997 include samples from the State-managed fishery.

Survey Data

Survey Size Composition and Abundance Estimates

The relative size compositions from trawl surveys of the GOA conducted triennially by the Alaska Fisheries Science Center since 1984 are shown in Table 2.11, using the same length bins defined above for the commercial catch size compositions. Total sample sizes are shown below:

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

Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl surveys are shown in Table 2.12, together with the standard errors and upper and lower 95% confidence intervals (CI) for the biomass estimates. The survey time series was recompiled for the 2003 assessment (Thompson et al. 2003). Most of the estimates changed relatively little, except for the 1987 survey estimate, which decreased by 29%.

The highest biomass ever observed by the survey was the 1984 estimate of 550,971 t, and the low point is the 2001 estimate of 279,332 t (the 2001 estimate was obtained by summing the 2001 estimate for the Western and Central areas with the 1999 estimate for the Eastern area, because the 2001 survey did not cover the Eastern area). In terms of population numbers, the record high was observed in 1984, when the population was estimated to include over 321 million fish.

The Alaska Department of Fish and Game (ADFG) also conducts trawl surveys covering several subareas of the GOA. Data from some of these surveys are presented in Attachment 2B. At present, ADFG survey data are not used in the GOA Pacific cod assessment. This is due in part to the difficulty of extrapolating results from subarea-specific surveys to the entire GOA. However, a spatially explicit model is being developed for use in future assessments of Pacific cod. If successful, the new model should facilitate incorporation of data from subarea-specific surveys such as those conducted by ADFG.

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

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

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

Although the supply of reliable length at age data has been severely limited in the past, it now appears likely that such data will become much more available in the future. Studies at the Alaska Fisheries Science Center have resulted in an ageing methodology for Pacific cod that gives reliable age determinations (Roberson 2001), and production ageing of Pacific cod samples from the BSAI is already underway.

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

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

The best available data on maturity consist of observers' visual determinations regarding the spawning condition of 2312 females taken in the EBS fishery in 1994. These are used as proxy data for the GOA stock. Of these 2312 females, 231 were smaller than 42 cm (the lower boundary of length bin 12). None of these sub-42 cm fish were mature. The observed proportions of mature fish in the remaining length bins, together with the numbers of fish sampled in those length bins, are shown below (bins are defined under "Catch Size Composition" above):

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

ANALYTIC APPROACH

Model Structure

This year's base model structure is identical to the base model structure used in all assessments of the GOA Pacific cod stock since 1997 (Thompson et al. 1997). Beginning with the 1994 SAFE report (Thompson and Zenger 1994), a length-structured Synthesis model (Methot 1986, 1990, 1998, 2000) has formed the primary analytical tool used to assess the GOA Pacific cod stock. Synthesis is a program that uses the parameters of a set of equations governing the assumed dynamics of the stock (the “model parameters”) as surrogates for the parameters of statistical distributions from which the data are assumed to be drawn (the “distribution parameters”), and varies the model parameters systematically in the direction of increasing likelihood until a maximum is reached. The overall likelihood is the product of the likelihoods for each of the model components. Each likelihood component is associated with a set of data assumed to be drawn from statistical distributions of the same general form (e.g., multinomial, lognormal, etc.). Typically, likelihood components are associated with data sets such as catch size (or age) composition, survey size (or age) composition, and survey biomass.

The Synthesis program permits each data time series to be divided into multiple segments, or “eras,” resulting in a separate set of parameter estimates for each era. To account for possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries, the fishery size composition time series in the base model has traditionally been split into pre-1987 and post-1986 eras. A minor modification of the base model was suggested by the SSC in 2001, namely, that consideration be given to dividing the domestic era into pre-2000 and post-1999 segments. This modification was tested in the 2002 assessment (Thompson et al. 2002) and was found to result in a statistically significant improvement in the model’s ability to fit the data. Therefore, the present assessment treats the post-1999 fisheries separately from the 1978-1986 and 1987-1999 fisheries.

Symbols used in the stock assessment model are listed in Table 2.13 (note that this list applies to the stock assessment model only, and does not include all symbols used elsewhere in this document). Full documentation of the equations used in Synthesis was given by Methot (2000) and functional representations of population dynamics using the notation of Table 2.13 were given in Appendix 2A of the 2002 stock assessment (Thompson et al. 2002). 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 2.13. 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 2.14, with a brief rationale given for each value used. In contrast to the quantities whose values are specified in Table 2.14, 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 2.13.

Parameters Estimated Independently

Table 2.15 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 2.15.

Natural Mortality

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

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

Trawl Survey Catchability

The trawl survey catchability coefficient was estimated independently of other parameters at a value of 1.0. This value was used in the present assessment mostly because it had been used in all previous assessments. Also, preliminary results of recent experimental work conducted in the EBS by the Alaska Fisheries Science Center’s Resource Assessment and Conservation Engineering Division tend to confirm that this is a reasonable value (Somerton 2004).

Weight at Length

Parameters (Table 2.13) governing the relationship between weight and length (Appendix 2A) were estimated by regression from the available data (see “Data” above), giving the following values (weights are in kg, lengths in cm): $W_1 = 5.80 \times 10^{-6}$, $W_2 = 3.159$.

Length at First Age of Survey Observation

Assuming that the first age at which Pacific cod are seen in the trawl survey (α_1, Table 2.13) is approximately 1.5 years, the length at this age (L_1, Table 2.13) was estimated to be 19.8 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 2.13) governing the amount of variability surrounding the length-at-age relationship (Appendix 2A) were estimated by linear regression from the observed standard deviations in the available length-at-age data (see “Data” above), giving the following values (in cm): $X_1 = 1.8$, $X_2 = 6.9$. Estimation of these two parameters constituted the only use of age data in the present assessment.

Maturity at Length

Maximum likelihood estimates of the parameters (Table 2.13) governing the female maturity-at-length schedule (Appendix 2A) were obtained using the method described by Prentice (1976), giving the following values: $P_1 = 0.142$, $P_2 = 67.1$ cm. The variance-covariance matrix of the parameter estimates gave a standard deviation of 0.006 for the estimate of P_1, a standard deviation of 0.39 cm for the estimate of P_2, and a correlation of -0.154 between the estimates of the two parameters.

Parameters Estimated Conditionally

Those Synthesis parameters that are estimated internally are listed in the second part of Table 2.15. 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. As in previous assessments, four fishery size composition likelihood components were included here: the January-May ("early") trawl fishery, the June-December ("late") trawl fishery, the longline fishery, and the pot fishery. In addition to the fishery size composition components, likelihood components for the size composition and biomass trend from the bottom trawl survey were included in the model.

The Synthesis program allows the modeler to specify "emphasis" factors that determine which components receive the greatest attention during the parameter estimation process. As in previous assessments, all components were given an emphasis of 1.0 in the present assessment.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery, and time period within the year. In the parameter estimation process, Synthesis weights a given size composition observation (i.e., the size frequency distribution observed in a given year, gear/fishery, and period) according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which Synthesis was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. As in previous assessments, the present assessment uses a multinomial sample size equal to the square root of the true sample size, rather than the true sample size itself. Given the true sample sizes observed in the present assessment, this procedure tends to give values somewhat below 400 while still providing the Synthesis program with usable information regarding the appropriate effort to devote to fitting individual samples. Multinomial sample sizes derived by this procedure for the commercial fishery size compositions are shown in Table 2.16. In the case of survey size composition data, the square root (SR) assumption was also used, giving the multinomial sample sizes shown below:

Year:	1984	1987	1990	1993	1996	1999	2001	2003
SR(sample size):	132	140	107	131	110	93	82	96

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

Evaluation Criteria

Three criteria were used to evaluate the stock assessment model: 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 of the results.

Effective Sample Size

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

Size composition likelihood component	Average effective sample size	Average input sample size	Ratio (effective divided by input)
Early-season trawl fishery	300	125	2.41
Late-season trawl fishery	83	39	2.14
Longline fishery	347	84	4.12
Pot fishery	391	94	4.14
Bottom trawl survey	159	111	1.43
All	281	83	3.39

The model produces average effective sample sizes considerably larger than the average input values for all components.

Observed and estimated size compositions in the January-May fisheries in 2000, 2001, and 2002 are compared in Figures 2.2, 2.3, and 2.4. Observed and estimated size compositions from the three most recent bottom trawl surveys are compared in Figure 2.5.

Fit to Survey Biomass Data

The root-mean-squared value of the lognormal "sigma" parameter in the survey biomass data is 0.165. The log-scale RMSE from the model is 0.145, very close to the root-mean-squared-sigma.

Overall Reasonableness of Results

The model's estimates of length-at-age parameters K and L_2 (L_1 was estimated independently, and thus did not vary with choice of model) are shown below:

Parameter	Estimate
K	0.147
L_2	85.5

Model estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a, and selectivity parameters $S_{1\text{-}7,g,e(y|g)}$ are shown in Tables 2.17, 2.18, and 2.19, respectively. Model estimates of age 3+ biomass, spawning biomass, and survey biomass are shown in Table 2.20 and Figure 2.6.

All of the above appear reasonable, with the possible exception of the relationship between age 3+ biomass and survey biomass (Table 2.20, Figure 2.6). On average (across years in which surveys were conducted), the model's estimate of age 3+ biomass exceeds the observed survey biomass by about 76%. While this result is biologically possible, there is no obvious reason why it should be expected.

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:	20	32	41	50	57	64	69	74	78	81	84	90

The distribution of lengths at age (measured in mid-year) defined by the final parameter estimates is shown in Table 2.21.

Weights at length and maturity proportions at length defined by the final parameters are shown in Table 2.22, and selectivities at length defined by the final parameter estimates are shown in Table 2.23.

RESULTS

Definitions

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

Biomass

The model's description of the recent history of the stock is shown in Table 2.24, together with estimates provided in last year's final SAFE report (Thompson et al. 2003). The biomass trends estimated in the present assessment are also shown in Figure 2.6. The age 3+ biomass trend shows an increase throughout the 1980s with a peak in 1990, 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 most of the past decade. The model's estimates of 2004 age 3+ and spawning biomass are the lowest in their respective time series since the 1970s.

Figure 2.7 compares this year's estimate of the survey biomass time series with those from all other assessments since 1997 (the year in which the base model was standardized). Except for the transition from the 2002 assessment to the 2003 assessment, these annual estimates have been remarkably consistent: If each assessment's estimate of the survey biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have ranged from a low of 0.406 (using the 2002 estimates to predict the 2003 estimates) to a high of 0.997 (using the 1998 estimates to predict the 1999 estimates), and no time trend is obvious. Excluding the transition from the 2002 assessment to the 2003 assessment, the next lowest R^2 is 0.939 (using the 2001 estimates to predict the 2003 estimates). The R^2 for the transition from the 2003 assessment to the present assessment is 0.972. The relatively large change between the 2002 and 2003 assessments is most likely due to the revised survey biomass time series used in the 2003 assessment, particularly the revised survey biomass for 1987, which was 29% lower than the value used previously.

Figure 2.8 compares this year's estimate of the age 3+ biomass time series with those from all other assessments since 1997. These annual estimates show less interannual consistency than the model's estimates of survey biomass. If each assessment's estimate of the age 3+ biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have exceeded 90% in half of the cases, but could also range as low as -0.102 (using the 2000 estimates to predict the 2001 estimates). Using the 2003 estimates to predict the 2004 estimates results in an R^2 of 0.864. As Figure 2.8 shows, the 2004 assessment resulted in an estimated age 3+ biomass time series that was just slightly higher than the estimated time series from the 2003 assessment. To attempt to measure whether there is a consistent trend (i.e., retrospective bias) between assessments, the relative change in each year's age 3+ biomass estimate as assessed between each pair of successive assessments was computed (e.g., the relative change in the estimated value of age 3+ biomass for 1985 as assessed in, say, the 2000 and 2001 assessments), then the relative changes were averaged for each pair of successive assessments, resulting in the values shown below:

First assessment year	1997	1998	1999	2000	2001	2002	2003
Second assessment year	1998	1999	2000	2001	2002	2003	2004
Average relative change in age 3+ biomass	0.022	-0.013	0.012	-0.142	0.038	-0.044	0.055

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

Figure 2.9 plots the trajectory of fishing mortality and female spawning biomass from 1978 through 2004, overlaid with the current harvest control rules. The entire trajectory lies underneath both harvest control rules. In other words, fishing mortality rates have been well within the current limits throughout the period in which those limits have been in effect, although it should be noted that the current harvest control rules did not go into effect until 1999.

Recruitment

Numbers at Age 3

Traditionally, recruitment strengths for Pacific cod have been assessed at age 3, because this is the approximate age of first significant recruitment to the fishery and because model estimates of relative year class strength tend to stabilize by this age. The model's estimated time series of age 3 recruitments is shown in Table 2.25, together with the estimates provided in last year's final SAFE report (Thompson et al. 2003). The model's recruitment estimates are also plotted in Figure 2.10. The current time series has a mean value of 127 million fish, a coefficient of variation of 31%, and an autocorrelation coefficient of 0.08.

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: 1976-1977 1979 1984 1987 1989

Average: 1980-1981 1983 1985-1986 1988 1990-1995 1998-2000

Below average: 1975 1978 1982 1996-1997 2001

With respect to last year's assessment (Thompson et al. 2003), the only changes in the above table consist of an upgrade in the strength of the 1998 year class from "below average" to "average" and the addition of the 2001 year class to the "below average" category.

Numbers at Age 1

The model's estimated time series of age 1 recruitments is shown in Table 2.18. This time series has a mean value of 262 million fish, a coefficient of variation of 33%, and an autocorrelation coefficient of 0.32. (It should be noted that the strength of the autocorrelation is heavily dependent on the estimate of the 2002 year class, which is probably the most imprecisely estimated year class in the time series. With this year class removed, the autocorrelation coefficient drops to 0.10.) The qualitative rankings of year class strengths at age 1 largely parallel the rankings at age 3, except that estimates for the 1975 and 1976 year classes do not exist at age 1 and the 2002 year class is added to the time series. The 2002 year class is presently estimated to be much weaker than any other year class in the time series except for the 2001 year class, which is estimated to be only slightly larger. However, it should be emphasized that the estimate of the 2002 year class is based almost entirely on its appearance in the 2003 survey length composition at age 1.

The present assessment model is not configured to estimate a stock-recruitment relationship. Estimation of stock-recruitment relationships is a notoriously difficult exercise in the field of stock assessment, because both the stock data and the recruitment data are measured with error and because the errors in the stock-recruitment data are autocorrelated (Walters and Ludwig 1981). Also, if the stock and recruitment data are generated by a model which assumes that no stock-recruitment relationship exists, these data will be biased. Nevertheless, the stock-recruitment relationship is potentially such an important component of stock dynamics that it seems prudent to provide some kind of investigation, albeit provisional, as to its possible shape. In addition, the SSC has requested that the assessment include a stock-recruitment relationship (SSC minutes, December, 2000; December, 2001; and December, 2002), and more recently has requested that stock-recruitment relationships be estimated separately for different portions of the time series (SSC minutes, December, 2003).

Based on evidence of a possible environmental regime shift in 1989 (Hare and Mantua 2000) and following the example of the 2003 BSAI rock sole assessment (Wilderbuer and Walters 2003), the age 1 recruitment time series was split into two portions, the first of which consisted of year classes spawned during the period 1977-1988 and the second of which consisted of year classes spawned during the period 1989-2001. Then, for each portion of the time series and for the overall time series, the following analysis was conducted (use of symbols in this description does not necessarily follow Table 2.13, which pertains to the Synthesis assessment model only):

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

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

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

2) The estimates of spawning biomass generated by Synthesis were treated as known constants (i.e., it was assumed that they are measured without error).
3) Parameters were estimated by the method of maximum likelihood.
4) The covariance of the parameter estimates was assumed to equal the inverse of the Hessian matrix.

The following parameter estimates resulted (ρ is the correlation between the estimates of α and β):

Parameter	Pre-1989	Post-1988	All years
α	-1.84	0.659	-1.04
β	0.00773	-0.00811	0.00313
σ	0.248	0.308	0.389
ρ	-0.973	-0.989	-0.982

Approximate 95% confidence ellipses for the estimated parameters of the three stock-recruitment relationships are shown in the upper panel of Figure 2.11 (these are “approximate” because maximum likelihood estimates are only asymptotically normal and the data sets considered here are fairly small). The fitted relationships are shown together with the data in the lower panel of Figure 2.11.

This analysis is useful mostly because it indicates a considerable level of uncertainty regarding the shape of the stock-recruitment relationship, manifested in the following ways: 1) As indicated by the correlation coefficients in the last row of the text table above and the shapes of the ellipses in the upper panel of Figure 2.11, the parameter estimates for each of the three curves are highly correlated. 2) The two portions of the time series seem to provide distinctly different pictures of the stock-recruitment relationship, as their approximate 95% confidence ellipses do not intersect (dotted and dashed ellipses in the upper panel of Figure 2.11). 3) The estimated value of β for the post-1988 portion of the time series is negative, which is biologically unrealistic in that it implies an infinite carrying capacity. 4) While the amount of uncertainty evidenced in this analysis is high, the true statistical uncertainty is likely greater because of the problems noted in the description of the method above. Therefore, the estimates given here are not recommended for use in estimating maximum sustainable yield.

Exploitation

The model’s estimated time series of the ratio between catch and age 3+ biomass is shown in Table 2.26, together with the estimates provided in last year’s final SAFE report (Thompson et al. 2003). The average value of this ratio over the entire time series is about 0.071. The estimated values meet or exceed the average for every year after 1989 except 1994, whereas the estimated values fall below the average for every year prior to 1990.

PROJECTIONS AND HARVEST ALTERNATIVES

Amendment 56 Reference Points

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

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

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

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

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

Reference point:	$B_{35\%}$	$B_{40\%}$	$B_{100\%}$
Spawning biomass:	73,900 t	84,400 t	211,000 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 271:124:236:369. These proportions result in a 2005 catch composition that matches the recent (2001-2003) average distribution of catches between the trawl and fixed-gear fisheries, between the early and late trawl fisheries, and between the longline and pot fisheries. It should be noted that this apportionment scheme is generally consistent with existing Steller sea lion protection measures. This apportionment results in the following estimates of $F_{35\%}$ and $F_{40\%}$:

$F_{35\%}$	$F_{40\%}$
0.36	0.31

Specification of OFL and Maximum Permissible ABC

Spawning biomass for 2005 is estimated at a value of 91,700 t. This is about 9% above the $B_{40\%}$ value of 84,400 t, thereby placing Pacific cod in sub-tier "a" of Tier 3. Given this, the model estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2005 as follows:

	Overfishing Level	Maximum Permissible ABC
Catch:	86,200 t	73,800 t
Fishing mortality rate:	0.36	0.31

The age 3+ biomass estimate for 2005 is 472,000 t.

ABC Recommendation

Review of Past Approaches

For the past several years, the GOA Pacific cod assessments have advocated a harvest strategy that attempted to address some of the statistical uncertainty in the assessment model, namely the uncertainty surrounding parameters the natural mortality rate M and survey catchability Q (Thompson et al. 1997, 1998, 1999). For the 2000-2003 assessments, the strategy was simplified by assuming that the ratio between the recommended F_{ABC} and $F_{40\%}$ estimate given in the 1999 assessment (0.87) was an appropriate factor by which to multiply the current maximum permissible F_{ABC} to obtain a recommended F_{ABC} (Thompson et al. 2003). If the 87% adjustment factor were applied again this year, the 2005 ABC would be 65,000 t. However, several years have now passed since the 87% adjustment factor was calibrated, during which time the survey time series has changed appreciably, most notably with the addition of two more survey biomass estimates in 2001 and 2003 and the recalibration of the entire time series in 2003. By way of comparison, the 87% adjustment factor has not been used to set the ABC for BSAI Pacific cod since the 2002 fishery (Thompson and Dorn 2003).

An Alternative Approach

The motivation for the adjustment factor used in the last several assessments was twofold: 1) to provide a method of adjusting the ABC recommendation to account for uncertainty and 2) to base this method on a formal definition of risk aversion. While the method used to arrive at the 87% adjustment factor was consistent with these objectives, it was admittedly only an approximation constrained by the assessment model's ability to provide more explicit estimates of statistical uncertainty. The version of the Synthesis software used in the last several assessments and the current assessment is not designed to provide formal estimates of all the types of statistical uncertainty that would ideally be used in a full decision-theoretic approach. These types include uncertainty in future recruitment, uncertainty in annual estimates of numbers at age, and uncertainty in parameter estimates.

An alternative to the 87% adjustment factor, which would also be just an approximation, might focus on tradeoffs between alternative trajectories of expected catches produced by the standard projection model (see "Standard Harvest and Recruitment Scenarios and Projection Methodology" below). Using the current catch and current vector of estimated numbers at age as starting points, the standard projection model produces a trajectory of expected catches extending 13 years into the future (the minimum number of years needed to produce determinations of stock status under the National Standard Guidelines). Discussions regarding ABC often focus on comparisons between the expected catch trajectories under alternative harvest strategies. Two highly simplified examples are presented below, in each of which only two harvest strategies (F1 and F2) are considered and in each of which the projections extend only two years (rather than 13 years) into the future:

Example #1: A pair of hypothetical catch trajectories is shown below (year 0 is the current year):

Year:	0	1	2
Expected catch under F1:	200	170	140
Expected catch under F2:	200	230	260

Here, the expected catch in both trajectories changes by 30 units in years 1 and 2, the variance in both trajectories is 600, but the first trajectory has a mean of 170 and the second has a mean of 230. If everything else (e.g., impacts on the stock's ability to sustain the prescribed catches, impacts on other species in the ecosystem, etc.) were similar, the expected catch trajectory corresponding to F2 would probably be preferred.

Example #2: A different pair of hypothetical catch trajectories is shown below:

Year:	0	1	2
Expected catch under F1:	200	170	140
Expected catch under F2:	200	140	170

Here, the trajectory for F2 consists of the same set of numbers as the trajectory for F1, but in a different order. Both trajectories have a mean of 170 and a variance of 600. However, in the first trajectory, expected catch decreases by 30 units in years 1 and 2, whereas in the second trajectory, expected catch decreases by 60 units in year 1 then increases by 30 units in year 2. Although expected catch in year 2 changes by the same amount (30 units) under both harvest strategies, the year 1 change expected under harvest strategy F1 (30 units) is half that expected under F2 (60 units). In this sense, overall year-to-year variability is less under F1 than under F2. For Example #2, then, the expected catch trajectory corresponding to F1 would probably be preferred.

Summarizing the above pair of examples, harvest strategy F2 was preferred over F1 in Example #1 because average yield was higher while variability was equal, whereas in Example #2, harvest strategy F1 was preferred over F2 because variability (in some sense) was lower while average yield was equal. However, if a third example were imagined in which both average yield and variability were higher under one harvest strategy than the other, the preferred strategy might be less obvious. In such circumstances, choosing a preferred strategy would be facilitated if two questions were answered: 1) What is an appropriate definition of variability in this context? 2) What is an appropriate tradeoff between average yield and variability?

Possible answers to these questions can be obtained by considering the "uncertainty adjustment" used in Alternative 3b of the Programmatic Supplemental Environmental Impact Statement for the Alaska Groundfish Fisheries (NMFS 2004). Like the 87% adjustment factor used in previous Pacific cod assessments, Alternative 3b provided a method of adjusting the ABC recommendation to account for uncertainty based on a formal definition of risk aversion. Using Alternative 3b as a starting point, possible answers to the two questions in the above paragraph can be suggested as follows:

1) The theory underlying the Alternative 3b uncertainty adjustment focused on the long-term ("stationary") yield distribution. In that context, the variance of the long-term yield distribution arose as the appropriate measure of variability. However, the Pacific cod assessment currently lacks a satisfactory estimate of the stock-recruitment relationship, so estimating the variance of the long-term yield distribution is problematic. If the focus is instead shifted to the distribution of yields over the short term, then the "average squared first difference" (ASFD) would be a natural analogue. For the two examples

described above, ASFD is computed as

$$[(\text{catch in year 1 - catch in year 0})^2 + (\text{catch in year 2 - catch in year 1})^2]/2$$

In Example #1, the ASFDs for the two harvest strategies are equal, as shown below:

Harvest Strategy	Average Squared First Difference
F1	$[(170\text{-}200)^2 + (140\text{-}170)^2]/2 = 900$
F2	$[(230\text{-}200)^2 + (260\text{-}230)^2]/2 = 900$

In Example #2, on the other hand, the ASFD for harvest strategy F1 is much lower than for harvest strategy F2, as shown below:

Harvest Strategy	Average Squared First Difference
F1	$[(170\text{-}200)^2 + (140\text{-}170)^2]/2 = 900$
F2	$[(140\text{-}200)^2 + (170\text{-}140)^2]/2 = 2250$

2) A special case of the Alternative 3b approach arises when yield is normally distributed. In this special case, the Alternative 3b objective would be to choose the harvest rate that maximizes the difference between average yield and half the variability. Although there is no reason to believe that the distribution of short-term future yields is exactly normal in the Pacific cod assessment, the normal distribution may be a reasonable first approximation.

Thus, an alternative approach for estimating ABC would be to find the harvest strategy that maximizes the difference between average yield and half the ASFD over the time frame covered by the standard projection model (13 years).

Recommendation for 2005

As shown in Figure 2.12, the objective function described above is maximized when the ABC fishing mortality rate is set at 77% of the maximum permissible ABC fishing mortality rate. A 77% adjustment factor results in a 2005 F_{ABC} of 0.24 and a 2005 ABC of 58,100 t. This ABC is very close both to the ABC projected for 2005 in last year's assessment (58,200 t) and to the projected year-end 2004 catch of 58,600 t (Tom Pearson, pers. commun., NMFS Alaska Region, Sustainable Fisheries Division). Because it is based on a method that views the tradeoff between average yield and variability in a systematic and reasonable fashion and because it is tied to a formal definition of risk aversion, a catch of 58,100 t is the recommended ABC for 2005.

In considering this recommendation, it should be understood that the methodology upon which it is based involves a substantial simplification of the full decision-theoretic approach and should therefore be viewed as a tool to be used temporarily until such time as a fuller quantification of the statistical uncertainty associated with the assessment becomes available.

Area Allocation of Harvests

Recently, ABC has been allocated on the basis of the three most recent surveys. If this approach is continued for the 2004 fishery, the proportions would be 36% Western, 57% Central, and 7% Eastern. Some alternative apportionment methods are discussed in Attachment 2A.

Standard Harvest and Recruitment Scenarios and Projection Methodology

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

For each scenario, the projections begin with the vector of 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. 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 2005, 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 2005 recommended in the assessment to the *max* F_{ABC} for 2005. (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 1999-2003 average F, which was 0.23. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

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

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2005 or 2) above ½ of its MSY level in 2005 and above its MSY level in 2017 under this scenario, then the stock is not overfished.)

Scenario 7: In 2005 and 2006, 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 2017 under this scenario, then the stock is not approaching an overfished condition.)

Projections and Status Determination

Table 2.27 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 2.28-34.

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

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2005:

a) If spawning biomass for 2005 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b) If spawning biomass for 2005 is estimated to be above $B_{35\%}$, the stock is above its MSST.
c) If spawning biomass for 2005 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 2.33). If the mean spawning biomass for 2015 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 2.34):

a) If the mean spawning biomass for 2007 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2007 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2007 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2017. If the mean spawning biomass for 2017 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 2005 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2007 in Table 2.34 is above ½ $B_{35\%}$ but below $B_{35\%}$, and mean spawning biomass for 2017 in Table 2.34 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Livingston, ed., 2002). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). One of the principal indices used to measure the state of the environmental regime is the Pacific Decadal Oscillation ("PDO," Mantua et al. 1997). The time series of age 1 recruits (listed by cohort year) is presented along with monthly PDO values in Table 2.35. The recruitment time series does not show a very strong correlation with any of the monthly PDO time series, with values ranging from -0.15 to 0.21. Ten of the 12 monthly correlations are positive. It is possible that stronger correlations would be found if the recruitment time series extended prior to 1977.

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

Fishery Effects on the Ecosystem

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

Bycatch of Nontarget and "Other" Species

The methods described by Gaichas (2002) were used to estimate the bycatch imposed by the GOA Pacific cod fisheries on various nontarget species and members of the "other species" group. Tables 2.36a-c show these estimates in terms of both absolute bycatch amounts (metric tons or number of individuals, depending on the species group) and proportions of the total bycatch for each species group. Table 2.36a shows estimates for the trawl fishery, Table 2.36b shows estimates for the longline fishery, and Table 2.36c shows estimates for the pot fishery.

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

Area	Species group	Trawl	Longline	Pot
GOA	sculpins	x	x	x
GOA	skates	x	x	
GOA	dogfish		x	
GOA	octopus			x
GOA	starfish		x	x

Steller Sea Lions

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

Seabirds

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

Fishery Usage of Habitat

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

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

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

Data Gaps and Research Priorities

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

SUMMARY

The major results of the Pacific cod stock assessment are summarized in Table 2.37.

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Table 2.1a--Summary of catches (t) of Pacific cod prior to 1991 by fleet sector and gear type. All catches since 1980 include discards. Jt. Vent. = joint venture.

Year	Fleet Sector			Gear Type				Total
	Foreign	Jt. Vent.	Domestic	Trawl	Longline	Pot	Other	
1978	11,370	7	813	4,547	6,800	0	843	12,190
1979	13,173	711	1,020	3,629	9,545	0	1,730	14,904
1980	34,245	466	634	6,464	27,780	0	1,101	35,345
1981	34,969	58	1,104	10,484	25,472	0	175	36,131
1982	26,937	193	2,335	6,679	22,667	0	119	29,465
1983	29,777	2,426	4,337	9,512	26,756	0	272	36,540
1984	15,896	4,649	3,353	8,805	14,844	0	249	23,898
1985	9,086	2,266	3,076	4,876	9,411	2	139	14,428
1986	15,211	1,357	8,444	6,850	17,619	141	402	25,012
1987	0	1,978	30,961	22,486	8,261	642	1,550	32,939
1988	0	1,661	32,141	27,145	3,933	1,422	1,302	33,802
1989	0	0	43,293	37,637	3,662	376	1,618	43,293
1990	0	0	72,517	59,188	5,919	5,661	1,749	72,517

Table 2.1b--Summary of catches (t) of Pacific cod since 1991 by management jurisdiction and gear type. Longl. = longline, Subt. = subtotal. All entries include discards. Catches for 2004 are complete through mid-October.

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

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 2004 is current through mid-October. The values in the column labeled "TAC" correspond to "optimum yield" for the years 1980-1986, "target quota" for the year 1987, and true TAC for the years 1988-2004.

Year	ABC	TAC	Catch	Stock Assessment Model
1980	n/a	60000	35345	n/a
1981	n/a	70000	36131	n/a
1982	n/a	60000	29465	n/a
1983	n/a	60000	36540	n/a
1984	n/a	60000	23898	n/a
1985	n/a	60000	14428	n/a
1986	136000	75000	25012	survey biomass
1987	125000	50000	32939	survey biomass
1988	99000	80000	33802	survey biomass
1989	71200	71200	43293	stock reduction analysis
1990	90000	90000	72517	stock reduction analysis
1991	77900	77900	76328	stock reduction analysis
1992	63500	63500	80746	stock reduction analysis
1993	56700	56700	56487	stock reduction analysis
1994	50400	50400	47484	stock reduction analysis
1995	69200	69200	68985	length-structured Synthesis model
1996	65000	65000	68280	length-structured Synthesis model
1997	81500	69115	77017	length-structured Synthesis model
1998	77900	66060	72524	length-structured Synthesis model
1999	84400	67835	81784	length-structured Synthesis model
2000	76400	58715	66559	length-structured Synthesis model
2001	67800	52110	51541	length-structured Synthesis model
2002	57600	44230	54483	length-structured Synthesis model
2003	52800	40540	52498	length-structured Synthesis model
2004	62810	48033	54591	length-structured Synthesis model

Table 2.3–Pacific cod discard rates by area, target species/group, and year. The discard rate is the ratio of discarded Pacific cod catch to total Pacific cod catch for a given area/target/year combination. An empty cell indicates that no Pacific cod were caught in that area/target/year combination. Note that the absolute amount of discards may be small even if the discard rate is large.

Target species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Arrowtooth flounder		0.98	0.59	0.00	0.10	0.09	0.00	1.00	0.63	0.06		0.00	0.40
Atka mackerel				0.81	1.00	0.00							
Deepwater Flat	1.00			0.43	0.00	0.68	0.53	0.00	0.36	0.00	0.75		0.01
Flathead sole				1.00		0.07	0.99	0.00		0.29	0.75	0.00	0.24
Other species	1.00	0.15	0.63		0.10	0.91	0.00	0.00	0.96	0.01	0.00	0.00	0.16
Pacific cod	0.05	0.03	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0.00	0.02	0.02	0.01
Pollock	0.82	0.59	0.15	0.15	0.95	0.17	0.98	0.75	0.89	0.44	0.00	1.00	0.05
Rex sole					0.16	0.25	0.61	0.57				1.00	0.22
Rockfish	0.15	0.11	0.13	0.16	0.11	0.13	0.14	0.17	0.17	0.17	0.00	0.04	0.13
Sablefish	0.84	0.72	0.72	0.77	0.55	0.78	0.54	0.66	0.52	0.25	0.27	0.22	0.64
Shallow-water flatfish	0.43	0.00	0.00	0.87	0.00	0.97	0.00	1.00	0.74	0.28		1.00	0.61
Unknown	0.01					1.00	1.00	1.00		1.00			
Grand Total	0.03	0.03	0.04	0.02	0.03	0.02	0.03	0.01	0.02	0.00	0.02	0.02	0.04

Table 2.4--Catch of Pacific cod by year, gear, and period as used in the stock assessment model. Jig catches have been merged with other gear types. Catch for 2004 is complete through August.

Year	Trawl			Longline			Pot		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
1978	0	0	4547	0	0	6800	0	0	0
1979	0	0	3629	0	0	9545	0	0	0
1980	0	0	6464	0	0	27780	0	0	0
1981	387	3532	6565	10504	5312	9656	0	0	0
1982	1143	2041	3495	9912	2890	9865	0	0	0
1983	2861	2844	3807	10960	4651	11145	0	0	0
1984	3429	2008	3368	11840	425	2579	0	0	0
1985	2427	571	1878	9127	6	278	0	0	2
1986	2999	431	3420	15922	401	1296	5	59	77
1987	5377	7928	9181	5343	983	1935	219	141	282
1988	16021	6569	4555	2979	507	447	1081	23	318
1989	24614	12857	166	2378	356	928	241	103	32
1990	43279	7514	8395	5557	109	253	2577	1008	2076
1991	55977	631	1484	7296	332	142	9591	0	873
1992	51911	1189	1494	12946	802	2251	9672	14	468
1993	33632	2624	1550	8485	307	181	9689	18	0
1994	29152	1421	873	6696	48	133	8742	0	418
1995	38476	802	2597	10662	166	227	15419	43	592
1996	41450	3048	1493	9991	152	106	12014	27	0
1997	40727	1638	6040	10931	967	424	14007	475	1807
1998	34690	3679	3200	10566	510	280	18479	0	1119
1999	30124	1501	5542	12782	555	191	25167	3374	2548
2000	22133	2574	750	12758	436	169	26947	154	638
2001	15234	2035	7113	11199	662	291	13047	37	1923
2002	15829	2705	1276	12963	259	3334	13602	83	4431
2003	10996	2565	5239	8416	407	768	20997	24	3087
2004	8923	2029		8285	95		23486	4	

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

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	0	0	634	0	0	18670	0	0	0
1979	0	0	0	0	0	14460	0	0	0
1980	0	0	783	0	0	18671	0	0	0
1981	0	0	461	0	0	19308	0	0	0
1982	0	0	1390	0	0	22856	0	0	0
1983	0	0	2896	0	0	127992	0	0	0
1984	0	0	1039	0	0	47485	0	0	0
1985	0	0	0	0	0	10141	0	0	0
1986	0	0	0	0	0	87304	0	0	0
1987	0	0	0	0	0	387	0	0	0
1988	0	0	0	0	0	2432	0	0	0
1989	660	0	312	0	0	0	0	0	0
1990	25396	10892	12025	9925	0	0	2783	2920	10711
1991	38514	0	131	12551	143	0	49453	139	0
1992	39683	0	2255	28817	577	3603	37177	664	5013
1993	26844	0	0	11748	0	0	20866	0	0
1994	12579	0	0	5201	0	0	16342	0	217
1995	26039	120	2402	24635	0	0	46625	0	1233
1996	17858	0	0	14706	0	0	35256	432	0
1997	22822	225	3746	7239	119	154	26880	252	1537
1998	52448	3465	6763	7981	410	148	31569	291	2902
1999	11550	232	1101	9013	86	396	33876	3719	3656
2000	6951	425	69	11426	47	20	28991	902	277
2001	6115	665	4560	12642	145	141	23290	0	3925
2002	6285	808	309	9583	134	3009	17235	0	4674
2003	4129	1187	1761	7941	375	2301	12019	9343	6168
2004	2539	471	1520	8800	451	503	24708	4549	4052

Table 2.6–Length frequencies of Pacific cod in the pre-1987 trawl fishery by year, period, and length bin.

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

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

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

Table 2.8a–Length frequencies of Pacific cod in the 1987-1999 trawl fishery by year, period, and 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
		Length Bin																								
1989	1	0	0	0	0	0	0	0	0	0	0	0	0	5	52	175	248	141	30	5	3	1	0	0	0	0
1989	3	0	0	0	0	0	6	28	41	29	17	3	3	16	37	50	39	14	4	6	2	7	4	4	2	0
1990	1	1	0	1	1	12	7	15	76	119	160	201	228	574	1322	3188	4903	4680	3357	2562	1572	1311	754	256	70	26
1990	2	41	36	15	0	0	1	0	1	3	31	81	169	419	954	1892	2562	2555	1323	510	181	90	24	3	0	1
1990	3	0	0	0	1	2	0	7	13	39	62	180	427	1447	1239	1240	1744	1726	1269	1101	860	434	133	67	18	16
1991	1	0	1	2	2	2	7	63	142	163	226	235	346	1905	3794	4421	5618	6609	5126	3629	2613	1621	1016	618	273	82
1991	3	0	0	0	0	0	0	0	0	0	0	0	0	2	5	15	15	24	28	24	6	9	3	0	0	0
1992	1	0	0	0	1	4	13	21	78	261	567	921	1084	1796	3160	4966	6796	5825	4257	3355	2548	1734	1143	749	280	124
1992	3	0	0	0	0	0	1	8	21	18	7	64	214	479	502	415	211	145	77	63	28	2	0	0	0	0
1993	1	0	0	1	4	2	5	4	58	234	469	547	544	2077	3445	3613	4744	4817	2832	1430	846	491	345	214	87	35
1994	1	0	0	0	0	0	0	0	7	31	83	115	138	499	1022	1734	2551	2642	1659	944	490	347	167	82	44	24
1995	1	0	0	0	0	0	0	1	8	60	91	204	316	1000	2363	3475	4628	5820	4040	1903	993	533	300	164	74	66
1995	2	0	0	0	0	0	1	1	0	0	1	1	9	26	15	20	19	19	6	2	0	0	0	0	0	0
1995	3	0	0	0	0	0	1	14	14	16	14	12	7	51	140	222	583	642	470	153	50	9	3	1	0	0
1996	1	0	0	0	1	6	28	39	64	105	187	250	230	290	690	1575	2924	3744	2948	1949	1237	793	437	217	96	48
1997	1	0	0	3	8	12	12	5	44	123	300	357	276	807	2271	2841	2945	4449	3874	2247	1140	562	288	174	67	17
1997	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	9	28	54	78	46	8	1	0	0	0	0
1997	3	0	0	0	1	3	8	29	49	100	62	56	96	318	374	477	823	589	342	262	100	46	10	1	0	0
1998	1	0	0	0	1	5	7	9	57	293	746	989	832	2009	4345	5676	9100	10443	8205	4970	2379	1278	652	327	98	27
1998	2	0	0	1	3	0	0	1	1	0	2	13	49	196	310	656	854	720	419	148	60	26	1	4	0	1
1998	3	3	4	0	0	5	35	112	133	209	209	146	225	1027	1139	906	1048	747	438	214	112	45	4	1	1	0
1999	1	0	0	1	4	4	4	4	21	73	144	184	215	453	1052	1797	2194	2226	1644	851	397	173	61	30	14	4
1999	2	0	0	0	0	0	5	0	0	0	0	0	1	5	8	34	52	65	36	18	6	2	0	0	0	0
1999	3	0	0	0	0	0	1	0	2	3	6	2	9	14	31	59	271	281	213	124	54	19	10	2	0	0

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

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	0	2	10	29	74	84	99	250	787	1091	1429	1310	806	475	243	163	72	20	6	1
2000	2	0	0	0	0	0	0	0	3	1	0	9	21	31	30	56	88	100	48	20	14	4	0	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	2	6	13	11	7	6	9	9	5	1	0	0	0	0	0
2001	1	0	1	2	2	1	1	4	7	37	97	158	146	287	694	947	1166	1183	803	336	147	63	22	8	1	2
2001	2	0	0	0	0	0	5	5	5	0	2	6	18	48	45	68	144	147	99	31	20	16	6	0	0	0
2001	3	0	0	0	0	1	0	10	45	100	154	123	80	303	633	669	783	677	496	301	122	46	14	3	0	0
2002	1	0	0	0	0	1	3	5	7	36	118	232	298	497	441	756	975	1123	936	508	218	80	36	8	5	2
2002	2	0	0	0	0	0	0	0	1	3	1	5	24	145	195	101	114	117	55	24	19	3	1	0	0	0
2002	3	0	0	0	0	0	0	0	3	4	6	12	14	36	39	49	51	37	21	12	12	8	4	1	0	0
2003	1	0	0	0	0	0	1	4	13	34	99	150	130	214	609	963	645	433	358	221	133	85	20	10	6	1
2003	2	0	0	0	2	1	2	10	8	7	19	27	59	193	170	162	220	136	101	37	26	5	1	1	0	0
2003	3	0	0	0	0	0	1	9	5	9	11	12	43	193	303	291	405	249	139	53	25	8	4	1	0	0
2004	1	0	0	1	0	2	0	0	2	17	40	61	70	175	431	520	513	408	166	83	34	11	4	1	0	0
2004	2	0	0	0	0	0	0	0	2	0	0	1	6	9	24	83	124	106	62	30	16	5	2	1	0	0
2004	3	0	0	0	0	0	0	3	6	5	0	2	13	98	182	198	243	310	279	113	50	14	4	0	0	0

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

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

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

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	0	0	1	2	3	2	25	197	797	1697	2548	2714	1747	946	422	179	97	36	10	3
2000	2	0	0	0	0	0	0	0	0	0	0	1	1	1	7	11	13	9	3	1	0	0	0	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7	10	2	0	0	0	0	0	0	0	0
2001	1	0	0	0	0	0	0	1	1	3	6	33	82	296	915	1969	2850	3074	1919	906	358	126	60	34	6	3
2001	2	0	0	0	0	0	0	0	0	0	0	1	4	3	9	8	24	43	18	14	12	6	2	1	0	0
2001	3	0	0	0	0	0	0	0	0	0	0	0	0	1	13	13	27	35	28	18	3	1	1	1	0	0
2002	1	0	0	0	0	1	0	0	5	3	13	32	77	246	542	1250	1849	2208	1712	939	447	161	69	21	7	1
2002	2	0	0	0	0	0	0	0	0	0	0	0	2	2	7	18	21	24	23	22	8	3	3	0	1	0
2002	3	0	0	0	0	1	2	9	24	16	16	18	38	103	279	424	618	622	440	263	95	31	8	0	2	0
2003	1	0	0	0	0	0	0	0	0	5	7	30	92	385	800	1337	1415	1523	1097	626	382	149	58	26	9	0
2003	2	0	0	0	0	0	0	0	0	0	1	3	1	5	18	47	47	76	60	45	37	27	7	0	1	0
2003	3	0	0	0	0	0	0	0	0	0	0	3	16	47	224	378	500	468	276	182	102	59	29	12	4	1
2004	1	0	3	0	0	0	0	0	0	1	3	11	21	197	871	1657	1961	1798	1101	586	340	154	65	22	8	1
2004	2	0	0	0	0	0	0	0	0	0	1	1	3	12	39	60	83	91	60	48	28	15	5	2	2	1
2004	3	0	0	0	0	0	0	0	0	0	0	0	0	2	18	59	125	124	87	54	22	10	0	2	0	0

Table 2.10a–Length frequencies of Pacific cod in the 1987-1999 pot fishery by year, period, and length bin.

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

Table 2.10b–Length frequencies of Pacific cod in the post-1999 pot fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	3	2	0	3	1	9	41	464	1839	3998	6894	6987	4694	2237	1055	454	203	73	25	9
2000	2	0	0	0	0	0	0	0	0	0	0	0	0	1	7	76	374	316	104	17	5	0	2	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	3	7	17	73	105	55	13	2	1	1	0	0	0
2001	1	1	0	0	0	0	0	0	1	0	4	13	62	310	1339	3324	6205	6366	3540	1202	525	222	106	49	16	5
2001	3	0	0	0	0	0	0	0	0	0	0	3	10	104	389	730	956	954	553	134	56	26	3	4	1	2
2002	1	0	0	0	0	0	0	0	0	0	0	15	39	323	1192	2507	3864	4315	3048	1245	427	159	68	24	8	1
2002	3	0	0	0	0	0	0	0	1	0	2	2	17	133	312	580	926	982	841	479	217	106	53	16	6	1
2003	1	0	0	0	0	0	1	0	2	3	9	46	82	369	1203	2059	2566	2267	1750	945	442	167	63	28	14	3
2003	2	0	0	0	0	0	0	0	0	0	0	0	9	144	717	1682	2186	2040	1421	689	281	113	39	15	5	2
2003	3	0	0	0	0	0	0	0	0	0	0	2	15	204	744	1232	1416	1093	768	392	181	78	35	7	0	1
2004	1	0	0	0	0	0	0	0	0	0	1	4	40	583	2223	4323	5579	5003	3266	1937	959	460	215	83	32	0
2004	2	0	0	0	0	0	0	0	0	0	0	0	5	83	527	1148	1254	822	363	183	94	49	15	4	2	0
2004	3	0	0	0	0	0	0	0	0	0	0	2	4	115	520	960	938	654	424	203	127	56	37	7	5	0

Table 2.11–Length frequencies of Pacific cod in the trawl survey by year (all surveys take place in period 2). Numbers shown are survey estimates of population numbers at length, rescaled so that the sum equals the total size of the actual survey length sample.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1984	2	174	34	34	121	104	87	104	469	992	1479	1653	1096	1566	3046	2576	1897	1131	469	226	69	52	17	17	0	0
1987	2	450	19	19	39	98	254	490	529	705	666	1234	1411	2822	4076	3116	1724	842	333	333	254	117	39	19	0	0
1990	2	251	0	11	103	217	137	57	114	240	286	435	549	1602	1774	1969	1683	973	549	194	160	80	34	11	11	0
1993	2	0	17	188	325	239	291	205	256	462	548	839	1318	2055	2620	3134	2055	1404	650	274	119	68	34	17	17	17
1996	2	0	35	232	875	1191	903	244	84	193	303	446	445	712	1043	1389	1668	1403	608	228	87	41	30	15	13	2
1999	2	1	17	68	154	166	97	75	142	310	352	402	582	1093	1142	1448	1208	793	416	168	11	0	0	0	0	0
2001	2	5	58	105	193	233	319	228	186	182	310	455	435	749	753	725	767	536	304	135	52	18	14	5	5	0
2003	2	0	5	28	76	137	88	66	65	160	297	500	755	1282	1315	1622	1306	698	371	190	112	36	15	3	0	0

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

Year	Biomass	Standard Error	Lower 95% CI	Upper 95% CI	Numbers
1984	550,971	80,385	393,417	708,525	321,950,465
1987	394,987	51,325	294,390	495,585	247,020,039
1990	418,200	63,757	293,236	543,164	212,131,668
1993	409,848	73,431	265,924	553,772	232,582,993
1996	538,154	107,736	326,991	749,316	319,068,011
1999	306,413	38,699	230,563	382,263	166,583,892
2001	279,332	62,031	157,751	400,912	168,424,041
2003	297,361	44,514	210,114	384,608	160,179,554

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

Table 2.13–Symbols used in the Synthesis assessment model for Pacific cod (page 1 of 2).

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

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

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

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

Continuous Variables	
α	age
λ	length
τ	time

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

Table 2.13–Symbols used in the Synthesis assessment model for Pacific cod (page 2 of 2).

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

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

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

Table 2.14–Dimensions and special values of indices and variables used in the Pacific cod assessment. Symbols are defined in Table 2.13.

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}	26	1978 through 2004

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

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

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

Table 2.16–Pacific cod commercial fishery length sample sizes used in the multinomial distribution. (These values correspond to the square roots of the true sample sizes shown in Table 2.5.)

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	0	0	25	0	0	137	0	0	0
1979	0	0	0	0	0	120	0	0	0
1980	0	0	28	0	0	137	0	0	0
1981	0	0	21	0	0	139	0	0	0
1982	0	0	37	0	0	151	0	0	0
1983	0	0	54	0	0	358	0	0	0
1984	0	0	32	0	0	218	0	0	0
1985	0	0	0	0	0	101	0	0	0
1986	0	0	0	0	0	295	0	0	0
1987	0	0	0	0	0	20	0	0	0
1988	0	0	0	0	0	49	0	0	0
1989	26	0	18	0	0	0	0	0	0
1990	159	104	110	100	0	0	53	54	103
1991	196	0	11	112	12	0	222	12	0
1992	199	0	47	170	24	60	193	26	71
1993	164	0	0	108	0	0	144	0	0
1994	112	0	0	72	0	0	128	0	15
1995	161	11	49	157	0	0	216	0	35
1996	134	0	0	121	0	0	188	21	0
1997	151	15	61	85	11	12	164	16	39
1998	229	59	82	89	20	12	178	17	54
1999	107	15	33	95	9	20	184	61	60
2000	83	21	8	107	7	4	170	30	17
2001	78	26	68	112	12	12	153	0	63
2002	79	28	18	98	12	55	131	0	68
2003	64	34	42	89	19	48	110	97	79
2004	50	22	39	94	21	22	157	67	64

Table 2.17–Estimates of Pacific cod fishing mortality rates, expressed on an annual time scale. Empty cells indicate that no catch was recorded.

Year	Trawl			Longline			Pot		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978			0.04			0.06			
1979			0.03			0.08			
1980			0.04			0.20			
1981	0.00	0.03	0.04	0.06	0.05	0.06			
1982	0.01	0.02	0.02	0.05	0.02	0.06			
1983	0.02	0.02	0.02	0.05	0.04	0.06			
1984	0.02	0.01	0.02	0.05	0.00	0.01			
1985	0.02	0.00	0.01	0.04	0.00	0.00			
1986	0.02	0.00	0.02	0.07	0.00	0.01			
1987	0.03	0.08	0.07	0.03	0.01	0.01	0.00	0.00	0.00
1988	0.09	0.07	0.04	0.02	0.00	0.00	0.01	0.00	0.00
1989	0.14	0.13	0.00	0.01	0.00	0.01	0.00	0.00	0.00
1990	0.24	0.08	0.07	0.03	0.00	0.00	0.02	0.01	0.02
1991	0.32	0.01	0.01	0.04	0.00	0.00	0.08		0.01
1992	0.31	0.01	0.01	0.08	0.01	0.02	0.08	0.00	0.01
1993	0.21	0.03	0.01	0.05	0.00	0.00	0.08	0.00	
1994	0.17	0.02	0.01	0.04	0.00	0.00	0.07		0.00
1995	0.22	0.01	0.02	0.06	0.00	0.00	0.12	0.00	0.01
1996	0.24	0.03	0.01	0.06	0.00	0.00	0.09	0.00	
1997	0.25	0.02	0.06	0.07	0.01	0.00	0.11	0.01	0.02
1998	0.23	0.05	0.03	0.07	0.01	0.00	0.17		0.01
1999	0.22	0.02	0.06	0.09	0.01	0.00	0.25	0.06	0.04
2000	0.15	0.04	0.01	0.11	0.01	0.00	0.25	0.00	0.01
2001	0.11	0.03	0.09	0.11	0.01	0.00	0.13	0.00	0.03
2002	0.12	0.05	0.02	0.13	0.00	0.05	0.15	0.00	0.07
2003	0.09	0.04	0.07	0.09	0.01	0.01	0.24	0.00	0.05
2004	0.07	0.03	0.06	0.09	0.00	0.02	0.26	0.00	0.05

Table 2.18–Estimates of Pacific cod recruitment at age 1 and initial numbers at age (in millions of fish).

Year	Recruitment at 1
1978	479
1979	206
1980	332
1981	281
1982	254
1983	200
1984	287
1985	388
1986	255
1987	279
1988	358
1989	290
1990	384
1991	302
1992	252
1993	231
1994	240
1995	269
1996	267
1997	169
1998	178
1999	230
2000	268
2001	254
2002	85
2003	72

Age	Numbers at age
2	244
3	46
4	49
5	33
6	62
7	9
8	12
9	11
10	0
11	0
12	0

Table 2.19–Estimates of Pacific cod selectivity parameters. The first column lists the parameter families for which the remaining columns contain era-specific estimates.

Trawl (Jan-May)	1978-86	1987-99	2000-04
$S_{1,g,e(y\|g)}$	n/a	0.00	0.00
$S_{2,g,e(y\|g)}$	n/a	63.52	58.06
$S_{3,g,e(y\|g)}$	n/a	0.19	0.20
$S_{4,g,e(y\|g)}$	n/a	113.70	96.11
$S_{5,g,e(y\|g)}$	n/a	1.00	0.31
$S_{6,g,e(y\|g)}$	n/a	113.83	98.80
$S_{7,g,e(y\|g)}$	n/a	0.17	1.74
Trawl (Jun-Dec)	1978-86	1987-99	2000-04
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	49.97	63.71	60.72
$S_{3,g,e(y\|g)}$	0.36	0.16	0.17
$S_{4,g,e(y\|g)}$	95.58	72.92	75.90
$S_{5,g,e(y\|g)}$	0.82	0.23	0.03
$S_{6,g,e(y\|g)}$	95.58	85.87	76.83
$S_{7,g,e(y\|g)}$	8.79	0.19	0.09
Longline	1978-86	1987-99	2000-04
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	53.07	62.13	63.04
$S_{3,g,e(y\|g)}$	0.33	0.25	0.26
$S_{4,g,e(y\|g)}$	80.46	92.97	78.61
$S_{5,g,e(y\|g)}$	1.00	0.80	0.27
$S_{6,g,e(y\|g)}$	111.34	93.92	79.60
$S_{7,g,e(y\|g)}$	9.28	2.86	0.12
Pot	1978-86	1987-99	2000-04
$S_{1,g,e(y\|g)}$	n/a	0.00	0.00
$S_{2,g,e(y\|g)}$	n/a	65.61	62.21
$S_{3,g,e(y\|g)}$	n/a	0.28	0.31
$S_{4,g,e(y\|g)}$	n/a	76.08	76.20
$S_{5,g,e(y\|g)}$	n/a	0.21	0.23
$S_{6,g,e(y\|g)}$	n/a	76.08	76.20
$S_{7,g,e(y\|g)}$	n/a	0.13	0.17
Survey	1984-03		
$S_{1,g,e(y\|g)}$	0.07		
$S_{2,g,e(y\|g)}$	54.09		
$S_{3,g,e(y\|g)}$	0.15		
$S_{4,g,e(y\|g)}$	60.72		
$S_{5,g,e(y\|g)}$	0.25		
$S_{6,g,e(y\|g)}$	76.28		
$S_{7,g,e(y\|g)}$	0.28		

Table 2.20–Time series of GOA Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated by the assessment model. The biomass time series obtained by the survey is shown in the right-hand column for comparison. All biomass figures are in 1000s of t.

Year	Age 3+	Spawning	Survey (est)	Survey (obs)
1978	494	85		
1979	560	100		
1980	630	110		
1981	677	113		
1982	713	123		
1983	742	136		
1984	747	147	439	551
1985	759	159		
1986	783	167		
1987	799	171	422	395
1988	808	168		
1989	820	167		
1990	828	163	441	418
1991	817	152		
1992	807	144		
1993	789	141	446	410
1994	782	145		
1995	773	149		
1996	741	146	396	538
1997	710	140		
1998	667	129		
1999	624	118	332	306
2000	576	108		
2001	553	104	293	279
2002	548	100		
2003	530	95	293	297
2004	501	93		

Table 2.21–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	0.037
100	0	0	0	0	0	0	0	0	0	0	0.003	0.086
95	0	0	0	0	0	0	0	0	0.001	0.006	0.028	0.174
90	0	0	0	0	0	0	0	0.001	0.010	0.051	0.128	0.241
85	0	0	0	0	0	0	0	0.013	0.076	0.192	0.290	0.227
80	0	0	0	0	0	0	0.011	0.095	0.249	0.340	0.323	0.147
75	0	0	0	0	0	0.005	0.095	0.291	0.360	0.281	0.175	0.065
70	0	0	0	0	0.001	0.070	0.312	0.367	0.230	0.109	0.047	0.020
65	0	0	0	0	0.028	0.299	0.380	0.190	0.065	0.020	0.006	0.004
60	0	0	0	0.003	0.222	0.413	0.172	0.040	0.008	0.002	0	0.001
55	0	0	0	0.080	0.459	0.185	0.029	0.003	0	0	0	0
50	0	0	0.003	0.412	0.252	0.027	0.002	0	0	0	0	0
45	0	0	0.127	0.418	0.037	0.001	0	0	0	0	0	0
42	0	0	0.304	0.072	0.001	0	0	0	0	0	0	0
39	0	0.002	0.352	0.013	0	0	0	0	0	0	0	0
36	0	0.042	0.173	0.001	0	0	0	0	0	0	0	0
33	0	0.257	0.036	0	0	0	0	0	0	0	0	0
30	0	0.447	0.003	0	0	0	0	0	0	0	0	0
27	0	0.221	0	0	0	0	0	0	0	0	0	0
24	0.022	0.031	0	0	0	0	0	0	0	0	0	0
21	0.331	0.001	0	0	0	0	0	0	0	0	0	0
18	0.543	0	0	0	0	0	0	0	0	0	0	0
15	0.102	0	0	0	0	0	0	0	0	0	0	0
12	0.002	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 2.22–Schedules of Pacific cod weight (kg) and maturity proportions at length (cm) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins.

Bin	Length	Weight	Maturity
1	9	0.010	0.000
2	12	0.022	0.001
3	15	0.042	0.001
4	18	0.070	0.001
5	21	0.110	0.002
6	24	0.163	0.003
7	27	0.231	0.004
8	30	0.316	0.006
9	33	0.421	0.010
10	36	0.547	0.015
11	39	0.697	0.023
12	42	0.873	0.035
13	45	1.159	0.061
14	50	1.588	0.117
15	55	2.114	0.210
16	60	2.748	0.347
17	65	3.501	0.514
18	70	4.385	0.678
19	75	5.411	0.808
20	80	6.590	0.894
21	85	7.933	0.945
22	90	9.453	0.972
23	95	11.160	0.986
24	100	13.067	0.993
25	105	14.072	0.995

Table 2.23–Schedules of Pacific cod selectivities as defined by final parameter estimates. Lengths (cm) correspond to lower bounds of size bins. Trawl(1) = period 1 (January-May) trawl fishery, Trawl(2-3) = periods 2-3 (June-December) trawl fishery.

Bin	Len.	Trawl (1)		Trawl (2-3)			Longline			Pot		Survey
		87-99	00-04	78-86	87-99	00-04	78-86	87-99	00-04	87-99	00-04	84-03
1	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
2	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
3	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
4	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
5	21	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.08
6	24	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.09
7	27	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.11
8	30	0.01	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.13
9	33	0.01	0.02	0.01	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.17
10	36	0.02	0.03	0.03	0.04	0.04	0.02	0.01	0.00	0.00	0.00	0.22
11	39	0.03	0.06	0.09	0.06	0.07	0.04	0.01	0.01	0.00	0.01	0.30
12	42	0.05	0.10	0.23	0.10	0.11	0.11	0.03	0.02	0.01	0.01	0.40
13	45	0.09	0.18	0.46	0.15	0.17	0.26	0.06	0.04	0.02	0.03	0.53
14	50	0.20	0.37	0.84	0.29	0.33	0.65	0.18	0.14	0.07	0.13	0.77
15	55	0.38	0.62	0.97	0.50	0.55	0.91	0.42	0.38	0.24	0.41	1.00
16	60	0.62	0.82	0.99	0.75	0.77	0.98	0.72	0.70	0.59	0.77	0.96
17	65	0.81	0.93	1.00	0.97	0.93	1.00	0.90	0.91	0.89	0.96	0.82
18	70	0.91	0.97	1.00	0.92	0.93	1.00	0.97	0.99	0.93	0.93	0.57
19	75	0.96	0.99	1.00	0.75	0.71	1.00	0.99	0.82	0.69	0.65	0.37
20	80	0.99	1.00	1.00	0.55	0.51	1.00	1.00	0.63	0.50	0.45	0.28
21	85	0.99	1.00	1.00	0.39	0.34	1.00	0.86	0.48	0.36	0.33	0.26
22	90	1.00	0.40	0.82	0.30	0.22	1.00	0.80	0.38	0.28	0.27	0.26
23	95	1.00	0.31	0.82	0.25	0.12	1.00	0.80	0.32	0.24	0.24	0.26
24	100	1.00	0.31	0.82	0.24	0.06	1.00	0.80	0.29	0.21	0.23	0.25
25	105	1.00	0.31	0.82	0.23	0.03	1.00	0.80	0.27	0.21	0.23	0.25

Table 2.24–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	443	494	89	85		
1979	501	560	103	100		
1980	610	630	113	110		
1981	636	677	118	113		
1982	682	713	128	123		
1983	713	742	141	136		
1984	727	747	154	147	438	439
1985	723	759	165	159		
1986	735	783	174	167		
1987	773	799	177	171	424	422
1988	775	808	176	168		
1989	778	820	177	167		
1990	781	828	172	163	444	441
1991	752	817	162	152		
1992	757	807	153	144		
1993	757	789	150	141	453	446
1994	754	782	154	145		
1995	732	773	159	149		
1996	695	741	157	146	402	396
1997	669	710	150	140		
1998	649	667	139	129		
1999	609	624	129	118	352	332
2000	551	576	120	108		
2001	528	553	118	104	306	293
2002	512	548	113	100		
2003	501	530	106	95	278	293
2004	n/a	501	n/a	93		

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 2.25–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	47	46
1979	170	169
1980	237	228
1981	99	98
1982	165	158
1983	141	133
1984	126	120
1985	98	94
1986	140	135
1987	189	182
1988	125	120
1989	138	133
1990	180	171
1991	144	138
1992	193	183
1993	149	144
1994	125	120
1995	115	110
1996	118	115
1997	139	128
1998	148	127
1999	93	80
2000	77	85
2001	107	110
2002	111	128
2003	112	121
2004	n/a	40

Table 2.26–Time series of Pacific cod catch divided by age 3+ biomass as estimated in last year's and this year's assessments (the last entry in each column is based on partial catches for the respective year, because the year was/is still in progress at the time of the assessment).

Year	Catch Divided by Age 3+ Biomass	
	Last Year	This Year
1978	0.03	0.02
1979	0.03	0.03
1980	0.06	0.06
1981	0.06	0.05
1982	0.04	0.04
1983	0.05	0.05
1984	0.03	0.03
1985	0.02	0.02
1986	0.03	0.03
1987	0.04	0.04
1988	0.04	0.04
1989	0.06	0.05
1990	0.09	0.09
1991	0.10	0.09
1992	0.11	0.10
1993	0.07	0.07
1994	0.06	0.06
1995	0.09	0.09
1996	0.10	0.09
1997	0.12	0.11
1998	0.11	0.11
1999	0.13	0.13
2000	0.12	0.12
2001	0.10	0.09
2002	0.11	0.10
2003	0.10	0.10
2004	n/a	0.11

Table 2.27–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 2.28–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	211.1	0.00	0
40%	84.4	0.31	74.9
35%	73.9	0.36	81.0

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	91.7	91.7	91.7	91.7	0.00
2006	82.6	82.7	82.7	82.7	0.03
2007	72.9	73.2	73.3	73.8	0.27
2008	66.9	68.4	68.6	71.2	1.35
2009	65.5	69.6	70.2	77.0	3.66
2010	66.2	74.2	75.0	86.0	6.37
2011	68.0	78.5	79.5	93.6	8.29
2012	69.5	81.2	82.5	99.4	9.50
2013	70.0	82.2	83.9	101.6	10.26
2014	70.2	83.3	84.8	103.5	10.64
2015	71.5	84.0	85.7	105.0	10.72
2016	72.0	83.8	86.0	105.4	10.76
2017	72.6	84.3	86.2	106.3	10.83

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.31	0.31	0.31	0.31	0.000
2006	0.30	0.30	0.30	0.30	0.000
2007	0.26	0.26	0.26	0.27	0.001
2008	0.24	0.25	0.25	0.26	0.005
2009	0.23	0.25	0.25	0.28	0.014
2010	0.24	0.27	0.27	0.31	0.021
2011	0.24	0.28	0.28	0.31	0.022
2012	0.25	0.29	0.29	0.31	0.020
2013	0.25	0.30	0.29	0.31	0.019
2014	0.25	0.30	0.29	0.31	0.019
2015	0.26	0.30	0.29	0.31	0.018
2016	0.26	0.30	0.29	0.31	0.017
2017	0.26	0.31	0.29	0.31	0.017

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	73.8	73.8	73.8	73.8	0.00
2006	60.8	60.8	60.8	60.9	0.04
2007	45.3	45.8	45.9	46.8	0.47
2008	40.7	43.7	44.3	49.7	2.92
2009	41.5	50.3	52.0	68.0	8.57
2010	43.5	59.7	61.5	85.4	13.29
2011	45.9	66.7	67.9	91.9	14.67
2012	48.2	70.5	71.0	94.6	14.95
2013	49.4	71.6	72.2	97.3	15.06
2014	49.2	73.3	72.7	96.5	14.95
2015	50.8	72.8	73.1	97.5	14.50
2016	51.3	72.7	73.3	96.9	14.41
2017	51.6	72.5	73.3	97.7	14.37

Table 2.29–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that the ratio of F to $max\ F_{ABC}$ in each year 2005-2017 is fixed at a value of 0.77, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points					
SPR	Spawning Biomass	Fishing Mortality	Catch		
100%	211.1	0.00	0		
40%	84.4	0.31	74.9		
35%	73.9	0.36	81.0		
Spawning Biomass Projections					
Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	92.4	92.4	92.4	92.4	0.00
2006	87.4	87.4	87.4	87.5	0.03
2007	80.0	80.2	80.3	80.8	0.28
2008	74.3	75.7	76.0	78.6	1.37
2009	72.6	76.8	77.5	84.4	3.76
2010	73.1	81.5	82.4	94.5	6.80
2011	75.0	86.3	87.7	104.4	9.43
2012	76.7	90.2	91.9	111.7	11.34
2013	77.4	92.5	94.4	115.5	12.61
2014	78.3	94.4	96.2	119.6	13.32
2015	79.6	96.5	98.1	122.4	13.60
2016	80.5	97.5	99.1	123.3	13.70
2017	80.9	97.8	99.8	124.5	13.76
Fishing Mortality Projections					
Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.24	0.24	0.24	0.24	0.000
2006	0.24	0.24	0.24	0.24	0.000
2007	0.22	0.22	0.22	0.22	0.001
2008	0.20	0.21	0.21	0.22	0.004
2009	0.20	0.21	0.21	0.23	0.010
2010	0.20	0.23	0.22	0.24	0.012
2011	0.21	0.24	0.23	0.24	0.010
2012	0.21	0.24	0.23	0.24	0.009
2013	0.21	0.24	0.23	0.24	0.008
2014	0.22	0.24	0.23	0.24	0.007
2015	0.22	0.24	0.23	0.24	0.006
2016	0.22	0.24	0.23	0.24	0.005
2017	0.22	0.24	0.23	0.24	0.005
Catch Projections					
Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	58.1	58.1	58.1	58.1	0.00
2006	51.1	51.1	51.1	51.2	0.02
2007	41.6	42.0	42.1	42.9	0.41
2008	37.7	40.3	40.8	45.4	2.49
2009	38.1	45.6	47.0	60.8	7.05
2010	39.6	53.6	54.4	70.4	10.05
2011	41.9	59.3	59.2	76.9	10.95
2012	43.8	61.2	61.7	80.1	11.28
2013	45.1	62.3	63.1	82.9	11.49
2014	45.5	63.6	63.8	83.0	11.46
2015	47.2	63.3	64.3	83.3	11.17
2016	48.0	63.5	64.6	83.2	11.05
2017	48.6	63.5	64.7	84.0	10.97

Table 2.30–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that F = ½ *max* F_{ABC} in each year 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	211.1	0.00	0
40%	84.4	0.31	74.9
35%	73.9	0.36	81.0

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	93.3	93.3	93.3	93.3	0.00
2006	93.4	93.4	93.4	93.5	0.03
2007	89.9	90.2	90.3	90.8	0.29
2008	85.8	87.3	87.6	90.3	1.45
2009	84.3	88.8	89.6	97.3	4.12
2010	84.8	94.2	95.4	109.4	7.84
2011	86.8	101.0	102.4	121.1	11.33
2012	89.0	106.9	108.7	132.8	13.92
2013	90.8	111.2	113.1	139.5	15.62
2014	92.7	115.0	116.6	144.9	16.60
2015	96.2	118.2	120.1	149.9	17.02
2016	98.2	120.8	122.3	152.6	17.17
2017	99.3	122.0	123.8	152.9	17.19

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.15	0.15	0.15	0.15	0.000
2006	0.15	0.15	0.15	0.15	0.000
2007	0.15	0.15	0.15	0.15	0.000
2008	0.15	0.15	0.15	0.15	0.000
2009	0.15	0.15	0.15	0.15	0.001
2010	0.15	0.15	0.15	0.15	0.001
2011	0.15	0.15	0.15	0.15	0.001
2012	0.15	0.15	0.15	0.15	0.001
2013	0.15	0.15	0.15	0.15	0.001
2014	0.15	0.15	0.15	0.15	0.001
2015	0.15	0.15	0.15	0.15	0.000
2016	0.15	0.15	0.15	0.15	0.000
2017	0.15	0.15	0.15	0.15	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	38.8	38.8	38.8	38.8	0.00
2006	36.0	36.0	36.0	36.0	0.01
2007	32.4	32.6	32.6	33.0	0.18
2008	31.7	33.1	33.4	35.8	1.30
2009	31.9	36.6	37.1	44.0	3.77
2010	33.0	40.5	41.2	50.8	5.82
2011	34.4	43.4	44.1	56.3	7.00
2012	35.4	45.4	46.2	59.4	7.62
2013	36.4	46.7	47.6	60.7	7.92
2014	36.9	47.9	48.4	62.3	7.98
2015	37.7	47.8	48.8	62.1	7.89
2016	38.3	48.0	49.2	62.7	7.85
2017	38.4	48.3	49.4	63.2	7.81

Table 2.31–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that *F* = the 1999-2003 average in each year 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	211.1	0.00	0
40%	84.4	0.31	74.9
35%	73.9	0.36	81.0

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	92.5	92.5	92.5	92.5	0.00
2006	87.8	87.8	87.8	87.9	0.03
2007	80.5	80.8	80.8	81.4	0.29
2008	74.1	75.6	75.9	78.6	1.44
2009	71.2	75.8	76.4	84.0	4.04
2010	70.6	79.8	80.8	94.3	7.48
2011	71.6	84.8	86.1	103.7	10.44
2012	72.9	89.2	90.7	112.0	12.44
2013	74.3	91.9	93.7	116.3	13.64
2014	75.6	94.7	96.0	120.3	14.25
2015	77.9	96.9	98.2	123.5	14.43
2016	79.0	98.1	99.6	124.3	14.43
2017	80.3	98.8	100.5	125.9	14.39

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.23	0.23	0.23	0.23	0.000
2006	0.23	0.23	0.23	0.23	0.000
2007	0.23	0.23	0.23	0.23	0.000
2008	0.23	0.23	0.23	0.23	0.000
2009	0.23	0.23	0.23	0.23	0.000
2010	0.23	0.23	0.23	0.23	0.000
2011	0.23	0.23	0.23	0.23	0.000
2012	0.23	0.23	0.23	0.23	0.000
2013	0.23	0.23	0.23	0.23	0.000
2014	0.23	0.23	0.23	0.23	0.000
2015	0.23	0.23	0.23	0.23	0.000
2016	0.23	0.23	0.23	0.23	0.000
2017	0.23	0.23	0.23	0.23	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	56.8	56.8	56.8	56.8	0.00
2006	50.1	50.1	50.1	50.2	0.01
2007	43.5	43.7	43.8	44.3	0.27
2008	42.1	44.1	44.5	48.0	1.91
2009	42.8	48.8	49.7	59.5	5.32
2010	43.7	53.8	54.8	68.5	8.12
2011	44.8	57.3	58.4	75.2	9.62
2012	45.9	59.5	60.7	78.4	10.35
2013	47.1	60.9	62.1	80.9	10.68
2014	47.6	62.2	62.9	81.4	10.70
2015	48.5	61.9	63.3	81.9	10.55
2016	48.9	62.2	63.7	81.9	10.51
2017	49.1	62.3	63.8	82.4	10.46

Table 2.32–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = 0$ in each year 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	211.1	0.00	0
40%	84.4	0.31	74.9
35%	73.9	0.36	81.0

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	95.1	95.1	95.1	95.1	0.00
2006	105.7	105.8	105.8	105.8	0.03
2007	112.5	112.8	112.9	113.4	0.29
2008	116.3	117.9	118.1	120.9	1.46
2009	120.4	125.2	126.0	134.1	4.30
2010	125.7	136.1	137.5	153.1	8.75
2011	131.8	149.1	150.8	173.7	13.65
2012	138.0	161.0	163.4	194.6	17.98
2013	142.8	170.1	172.7	209.1	21.31
2014	147.3	178.6	181.1	220.4	23.62
2015	154.4	187.9	190.0	232.9	25.04
2016	159.8	193.8	196.1	241.3	25.99
2017	162.3	198.1	200.4	247.6	26.41

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
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
2013	0.00	0.00	0.00	0.00	0.000
2014	0.00	0.00	0.00	0.00	0.000
2015	0.00	0.00	0.00	0.00	0.000
2016	0.00	0.00	0.00	0.00	0.000
2017	0.00	0.00	0.00	0.00	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.0	0.0	0.0	0.0	0.00
2006	0.0	0.0	0.0	0.0	0.00
2007	0.0	0.0	0.0	0.0	0.00
2008	0.0	0.0	0.0	0.0	0.00
2009	0.0	0.0	0.0	0.0	0.00
2010	0.0	0.0	0.0	0.0	0.00
2011	0.0	0.0	0.0	0.0	0.00
2012	0.0	0.0	0.0	0.0	0.00
2013	0.0	0.0	0.0	0.0	0.00
2014	0.0	0.0	0.0	0.0	0.00
2015	0.0	0.0	0.0	0.0	0.00
2016	0.0	0.0	0.0	0.0	0.00
2017	0.0	0.0	0.0	0.0	0.00

Table 2.33–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = F_{OFL}$ in each year 2005-2017, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	211.1	0.00	0
40%	84.4	0.31	74.9
35%	73.9	0.36	81.0

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	91.0	91.0	91.0	91.0	0.00
2006	79.0	79.1	79.1	79.1	0.03
2007	68.2	68.5	68.6	69.1	0.27
2008	62.2	63.7	63.9	66.4	1.34
2009	61.0	65.1	65.7	72.4	3.60
2010	61.9	69.7	70.4	80.8	6.12
2011	63.6	73.6	74.5	87.5	7.66
2012	65.0	76.1	76.9	91.4	8.41
2013	65.4	76.6	77.7	93.0	8.80
2014	65.5	77.5	78.1	93.5	8.91
2015	66.8	77.4	78.6	94.4	8.85
2016	66.9	77.4	78.7	94.1	8.81
2017	67.3	77.4	78.8	94.4	8.85

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.36	0.36	0.36	0.36	0.000
2006	0.34	0.34	0.34	0.34	0.000
2007	0.29	0.29	0.29	0.29	0.001
2008	0.26	0.27	0.27	0.28	0.006
2009	0.26	0.28	0.28	0.31	0.016
2010	0.26	0.30	0.30	0.35	0.026
2011	0.27	0.32	0.32	0.36	0.029
2012	0.28	0.33	0.33	0.36	0.029
2013	0.28	0.33	0.33	0.36	0.029
2014	0.28	0.33	0.33	0.36	0.028
2015	0.28	0.33	0.33	0.36	0.027
2016	0.29	0.33	0.33	0.36	0.027
2017	0.29	0.33	0.33	0.36	0.027

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	86.2	86.2	86.2	86.2	0.00
2006	65.7	65.7	65.7	65.8	0.05
2007	47.2	47.8	47.9	48.9	0.52
2008	42.4	45.7	46.4	52.3	3.22
2009	43.6	53.3	55.1	72.7	9.46
2010	45.9	63.6	65.8	92.5	15.11
2011	48.7	70.9	72.9	103.5	17.07
2012	50.6	74.3	76.3	105.1	17.58
2013	52.0	75.2	77.3	107.5	17.70
2014	51.5	76.3	77.5	106.7	17.49
2015	53.2	76.1	77.7	107.6	17.06
2016	53.1	75.9	77.8	107.7	17.05
2017	53.8	75.2	77.8	107.8	17.06

Table 2.34–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2005-2006 and $F = F_{OFL}$ thereafter, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	211.1	0.00	0
40%	84.4	0.31	74.9
35%	73.9	0.36	81.0

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	91.7	91.7	91.7	91.7	0.00
2006	82.6	82.7	82.7	82.7	0.03
2007	72.5	72.8	72.8	73.4	0.27
2008	64.6	66.1	66.3	68.8	1.34
2009	62.3	66.4	67.0	73.6	3.59
2010	62.5	70.2	70.9	81.2	6.09
2011	63.9	73.8	74.6	87.7	7.64
2012	65.0	76.1	76.9	91.4	8.41
2013	65.4	76.5	77.7	92.9	8.80
2014	65.5	77.4	78.1	93.5	8.91
2015	66.7	77.3	78.6	94.3	8.85
2016	66.9	77.4	78.7	94.1	8.81
2017	67.3	77.3	78.8	94.4	8.85

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	0.31	0.31	0.31	0.31	0.000
2006	0.30	0.30	0.30	0.30	0.000
2007	0.31	0.31	0.31	0.31	0.001
2008	0.27	0.28	0.28	0.29	0.006
2009	0.26	0.28	0.29	0.32	0.016
2010	0.26	0.30	0.30	0.35	0.026
2011	0.27	0.32	0.32	0.36	0.029
2012	0.28	0.33	0.33	0.36	0.029
2013	0.28	0.33	0.33	0.36	0.029
2014	0.28	0.33	0.33	0.36	0.028
2015	0.28	0.33	0.33	0.36	0.027
2016	0.28	0.33	0.33	0.36	0.027
2017	0.29	0.33	0.33	0.36	0.027

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2005	73.8	73.8	73.8	73.8	0.00
2006	60.8	60.8	60.8	60.9	0.04
2007	52.8	53.3	53.5	54.5	0.55
2008	45.1	48.5	49.2	55.3	3.32
2009	44.8	54.6	56.5	74.2	9.55
2010	46.4	64.1	66.3	93.0	15.05
2011	48.7	70.9	72.9	103.5	17.01
2012	50.5	74.2	76.1	105.0	17.56
2013	51.9	75.0	77.2	107.5	17.71
2014	51.4	76.2	77.5	106.7	17.49
2015	53.1	76.1	77.7	107.6	17.07
2016	53.1	75.9	77.8	107.7	17.05
2017	53.8	75.2	77.8	107.8	17.06

Table 2.35–Correlations ("Corr.") between age 1 year class strength ("Nos.", expressed as millions of age 1 fish spawned in "Year") and monthly Pacific Decadal Oscillation indices.

Year	Nos.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1977	479	1.65	1.11	0.72	0.3	0.31	0.42	0.19	0.64	-0.55	-0.61	-0.72	-0.69
1978	206	0.34	1.45	1.34	1.29	0.90	0.15	-1.24	-0.56	-0.44	0.10	-0.07	-0.43
1979	332	-0.58	-1.33	0.30	0.89	1.09	0.17	0.84	0.52	1.00	1.06	0.48	-0.42
1980	281	-0.11	1.32	1.09	1.49	1.20	-0.22	0.23	0.51	0.10	1.35	0.37	-0.10
1981	254	0.59	1.46	0.99	1.45	1.75	1.69	0.84	0.18	0.42	0.18	0.80	0.67
1982	200	0.34	0.20	0.19	-0.19	-0.58	-0.78	0.58	0.39	0.84	0.37	-0.25	0.26
1983	287	0.56	1.14	2.11	1.87	1.80	2.36	3.51	1.85	0.91	0.96	1.02	1.69
1984	388	1.50	1.21	1.77	1.52	1.30	0.18	-0.18	-0.03	0.67	0.58	0.71	0.82
1985	255	1.27	0.94	0.57	0.19	0.00	0.18	1.07	0.81	0.44	0.29	-0.75	0.38
1986	279	1.12	1.61	2.18	1.55	1.16	0.89	1.38	0.22	0.22	1.00	1.77	1.77
1987	358	1.88	1.75	2.10	2.16	1.85	0.73	2.01	2.83	2.44	1.36	1.47	1.27
1988	290	0.93	1.24	1.42	0.94	1.20	0.74	0.64	0.19	-0.37	-0.10	-0.02	-0.43
1989	384	-0.95	-1.02	-0.83	-0.32	0.47	0.36	0.83	0.09	0.05	-0.12	-0.50	-0.21
1990	302	-0.30	-0.65	-0.62	0.27	0.44	0.44	0.27	0.11	0.38	-0.69	-1.69	-2.23
1991	252	-2.02	-1.19	-0.74	-1.01	-0.51	-1.47	-0.10	0.36	0.65	0.49	0.42	0.09
1992	231	0.05	0.31	0.67	0.75	1.54	1.26	1.90	1.44	0.83	0.93	0.93	0.53
1993	240	0.05	0.19	0.76	1.21	2.13	2.34	2.35	2.69	1.56	1.41	1.24	1.07
1994	269	1.21	0.59	0.80	1.05	1.23	0.46	0.06	-0.79	-1.36	-1.32	-1.96	-1.79
1995	267	-0.49	0.46	0.75	0.83	1.46	1.27	1.71	0.21	1.16	0.47	-0.28	0.16
1996	169	0.59	0.75	1.01	1.46	2.18	1.10	0.77	-0.14	0.24	-0.33	0.09	-0.03
1997	178	0.23	0.28	0.65	1.05	1.83	2.76	2.35	2.79	2.19	1.61	1.12	0.67
1998	230	0.83	1.56	2.01	1.27	0.70	0.40	-0.04	-0.22	-1.21	-1.39	-0.52	-0.44
1999	268	-0.32	-0.66	-0.33	-0.41	-0.68	-1.30	-0.66	-0.96	-1.53	-2.23	-2.05	-1.63
2000	254	-2.00	-0.83	0.29	0.35	-0.05	-0.44	-0.66	-1.19	-1.24	-1.30	-0.53	0.52
2001	85	0.60	0.29	0.45	-0.31	-0.30	-0.47	-1.31	-0.77	-1.37	-1.37	-1.26	-0.93
2002	72	0.27	-0.64	-0.43	-0.32	-0.63	-0.35	-0.31	0.60	0.43	0.42	1.51	2.10
Corr:		0.16	0.12	0.15	0.21	0.19	0.05	0.18	0.10	0.09	0.07	-0.07	-0.15

Table 2.36a–Bycatch of nontarget and "other" species taken in the GOA Pacific cod trawl fishery. The first part of the table ("Bycatch in...") shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the GOA Pacific cod trawl fishery, broken down by year. The second part of the table ("Proportion of...") shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod trawl fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	201	109	127	124	69	75	0.22	0.20	0.23	0.13	0.12	0.08
skates	476	411	385	219	272	120	0.15	0.09	0.19	0.07	0.15	0.02
shark	11	7	4	1	1	0	0.09	0.00	0.12	0.02	0.01	0.00
salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
dogfish	30	624	14	21	61	3	0.05	0.72	0.04	0.05	0.12	0.02
sleepershk	17	6	5	11	0	26	0.12	0.07	0.01	0.02	0.00	0.12
octopus	25	1	4	0	3	7	0.11	0.01	0.03	0.00	0.03	0.02
squid	1	1	1	0	1	0	0.01	0.01	0.03	0.01	0.01	0.00
smelts	0	1	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0		0		0.00	0.00	0.00		1.00	
sticheidae	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.56
sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
sandlance	0	0	0	0	0	0	0.00	1.00	1.00	0.97	0.12	1.00
grenadier	0	1	17	114	376	0	0.00	0.00	0.00	0.01	0.04	0.00
otherfish	58	211	110	43	68	42	0.10	0.03	0.13	0.04	0.10	0.02
crabs	1	12	1	0	0	0	0.08	0.47	0.06	0.03	0.06	0.04
starfish	63	59	62	22	27	22	0.06	0.05	0.04	0.02	0.06	0.04
jellyfish	7	5	1	1	13	1	0.18	0.03	0.01	0.02	0.05	0.00
invertunid	2	28	0	5	1	0	0.22	0.65	0.10	0.31	0.13	0.00
seapen/whip	0	0	3	0	0	0	0.00	0.01	0.99	0.00	0.00	0.00
sponge	0	1	1	1	1	0	0.04	0.24	0.10	0.12	0.26	0.09
anemone	3	3	11	1	3	6	0.17	0.20	0.65	0.07	0.21	0.27
tunicate	1	0	0	0	0	0	0.43	0.13	0.38	0.05	0.04	0.03
benthinv	3	22	11	1	1	0	0.11	0.72	0.42	0.07	0.06	0.09
snails	0	0	0	0	0	0						
echinoderm	3	23	2	2	1	2	0.13	0.72	0.24	0.31	0.12	0.26
coral	0	0	0	0	0	0	0.00	0.01	0.01	0.01	0.00	0.01
shrimp	0	0	0	0	0	0	0.00	0.08	0.02	0.01	0.03	0.01
birds	0	0	0	0	0	0	0.00	0.07	0.00	0.00	0.00	0.00

Table 2.36b–Bycatch of nontarget and “other” species taken in the GOA Pacific cod longline fishery. The first part of the table (“Bycatch in...”) shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the GOA Pacific cod longline fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod longline fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	63	181	207	203	197	291	0.07	0.33	0.38	0.22	0.33	0.31
skates	478	461	789	1823	617	5005	0.15	0.10	0.39	0.56	0.34	0.77
shark	2	4	8	2	1	5	0.02	0.00	0.25	0.03	0.01	0.19
salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
dogfish	28	104	146	8	111	7	0.04	0.12	0.47	0.02	0.23	0.06
sleepershk	42	14	501	366	66	40	0.31	0.19	0.90	0.60	0.26	0.18
octopus	1	25	17	16	6	7	0.00	0.22	0.10	0.09	0.07	0.02
squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0		0		0.00	0.00	0.00		0.00	
sticheidae	0	0	4	0	0	0	0.00	0.00	1.00	0.00	0.01	0.00
sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
sandlance	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
grenadier	191	0	423	0	0	92	0.02	0.00	0.04	0.00	0.00	0.01
otherfish	15	50	36	39	2	128	0.03	0.01	0.04	0.04	0.00	0.06
crabs	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
starfish	304	162	765	199	347	207	0.31	0.13	0.51	0.22	0.74	0.40
jellyfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
invertunid	0	0	0	5	0	4	0.05	0.00	0.17	0.34	0.05	0.32
seapen/whip	0	3	0	1	0	0	0.00	0.99	0.00	0.87	0.00	0.07
sponge	0	0	0	0	0	0	0.00	0.00	0.01	0.01	0.01	0.01
anemone	0	8	5	5	0	1	0.02	0.52	0.27	0.33	0.02	0.06
tunicate	0	0	0	1	0	0	0.00	0.00	0.00	0.17	0.00	0.00
benthinv	0	1	1	1	5	0	0.00	0.03	0.03	0.07	0.40	0.07
snails	0	0	0	0	0	0						
echinoderm	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.04
coral	0	0	0	0	0	0	0.00	0.00	0.05	0.00	0.00	0.02
shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
birds	0	1	1	1	1	0	0.13	0.12	0.16	0.21	0.43	0.40

Table 2.36c–Bycatch of nontarget and “other” species taken in the GOA Pacific cod pot fishery. The first part of the table (“Bycatch in...”) shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the GOA Pacific cod pot fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod pot fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	106	61	106	357	29	79	0.12	0.11	0.19	0.38	0.05	0.09
skates	1	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
shark	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
salmonshk	0	0	1	0	0	0	0.00	0.00	0.01	0.00	0.00	0.00
dogfish	0	0	0	0	1	0	0.00	0.00	0.00	0.00	0.00	0.00
sleepershk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
octopus	168	74	142	137	63	252	0.72	0.66	0.85	0.78	0.71	0.84
squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0		0		0.00	0.00	0.00		0.00	
sticheidae	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
sandlance	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
grenadier	0	0	0	0	1	0	0.00	0.00	0.00	0.00	0.00	0.00
otherfish	30	4	92	19	52	43	0.05	0.00	0.11	0.02	0.07	0.02
crabs	6	10	9	10	2	1	0.41	0.42	0.81	0.84	0.36	0.19
starfish	468	210	633	566	35	66	0.47	0.17	0.42	0.63	0.08	0.13
jellyfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
invertunid	0	0	0	0	0	0	0.00	0.00	0.00	0.01	0.01	0.03
seapen/whip	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sponge	0	0	5	0	0	0	0.03	0.00	0.39	0.04	0.01	0.01
anemone	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
tunicate	0	0	0	0	0	0	0.00	0.03	0.41	0.02	0.00	0.00
benthinv	10	2	10	4	1	2	0.40	0.08	0.40	0.34	0.08	0.28
snails	0	0	0	0	0	0						
echinoderm	1	0	1	1	1	1	0.06	0.00	0.09	0.14	0.16	0.09
coral	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
birds	0	0	0	0	0	0	0.00	0.00	0.01	0.00	0.02	106

Table 2.37--Summary of major results for the stock assessment of Pacific cod in the GOA region.

Tier	3a
Reference mortality rates	
M	0.37
$F_{40\%}$	0.31
$F_{35\%}$	0.36
Equilibrium spawning biomass	
$B_{35\%}$	73,900 t
$B_{40\%}$	84,400 t
$B_{100\%}$	211,000 t
Projected biomass for 2005	
Spawning (at *max* F_{ABC})	91,700 t
Age 3+	472,000 t
ABC for 2005	
F_{ABC} (maximum permissible)	0.31
F_{ABC} (recommended)	0.24
ABC (maximum permissible)	73,800 t
ABC (recommended)	58,100 t
Overfishing level for 2005	
Fishing Mortality	0.36
Catch	86,200 t

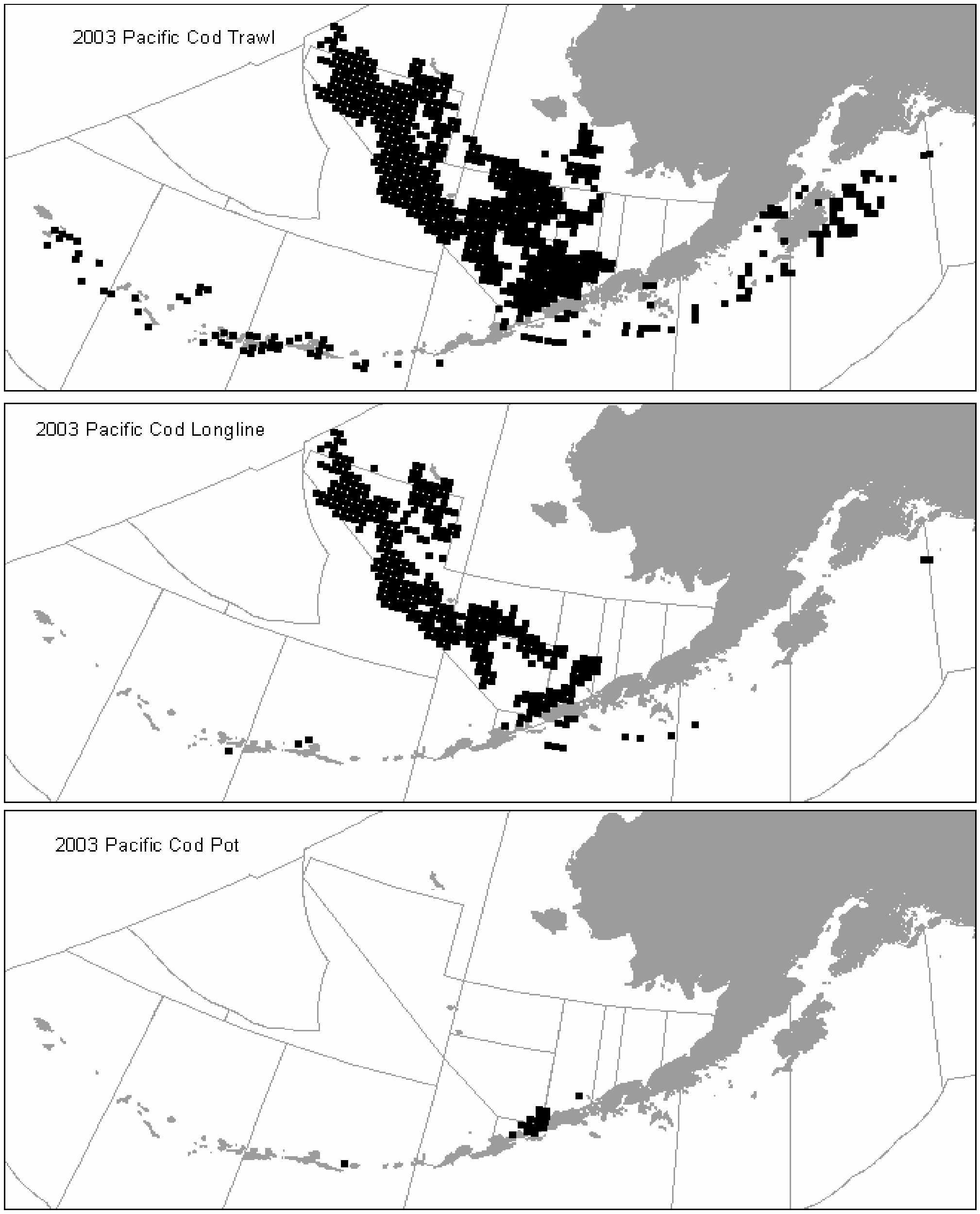
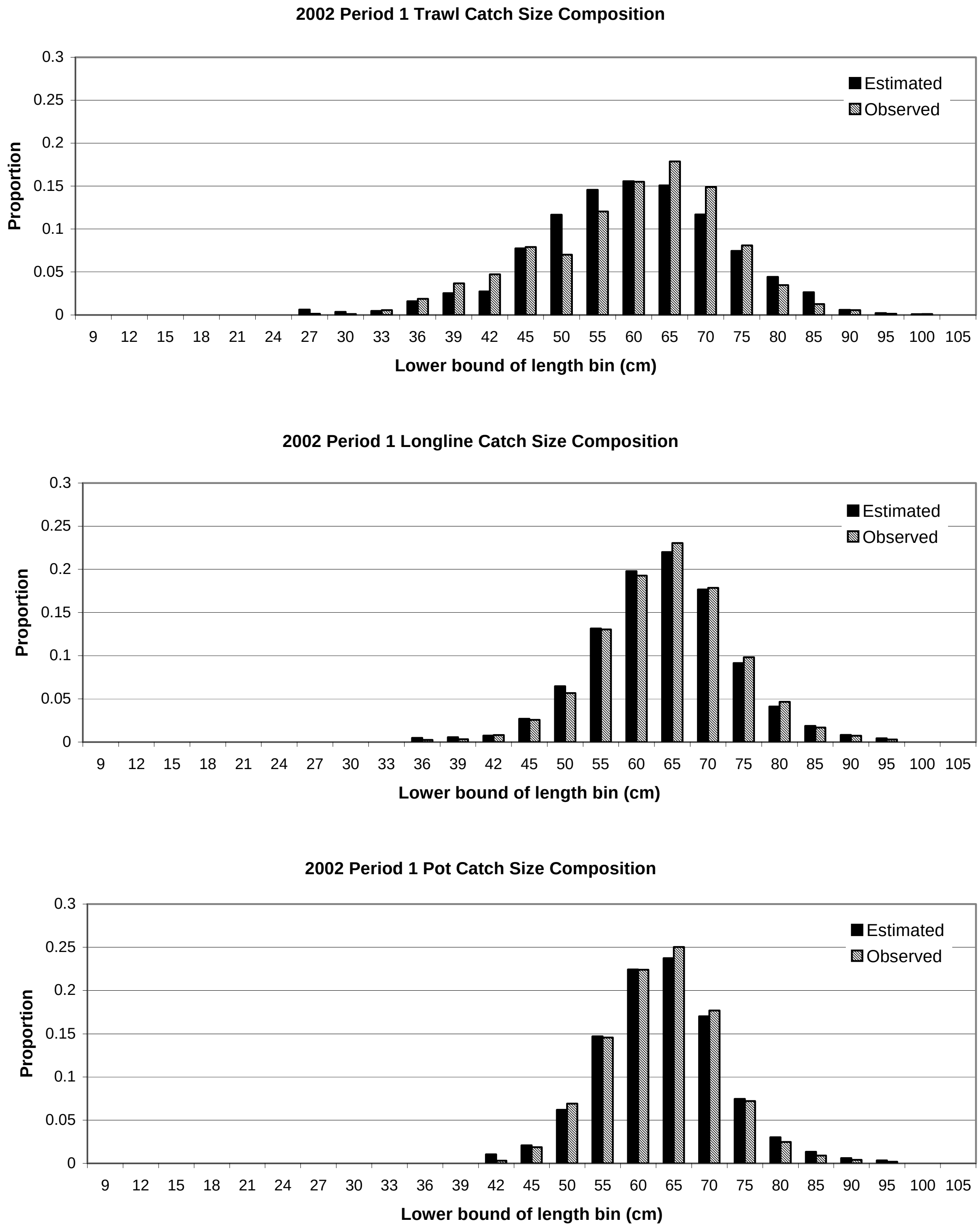


Figure 2.1. Maps showing each 20 km × 20 km square with at least 3 observed hauls/sets containing Pacific cod in 2003, by gear type.



Fi

gure 2.2–Estimated and observed size compositions from the 2002 period 1 fisheries.

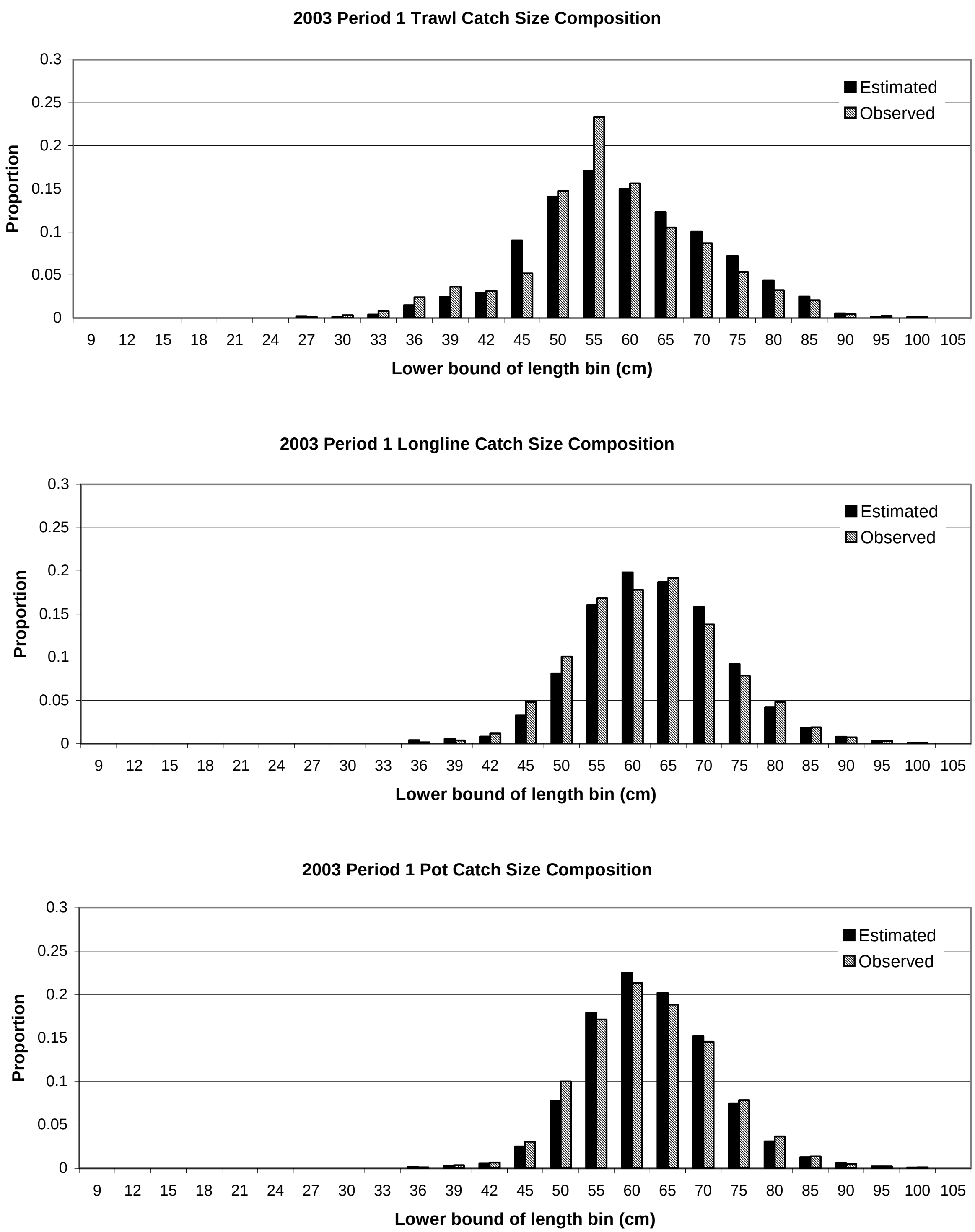


Figure 2.3–Estimated and observed size compositions from the 2003 period 1 fisheries.

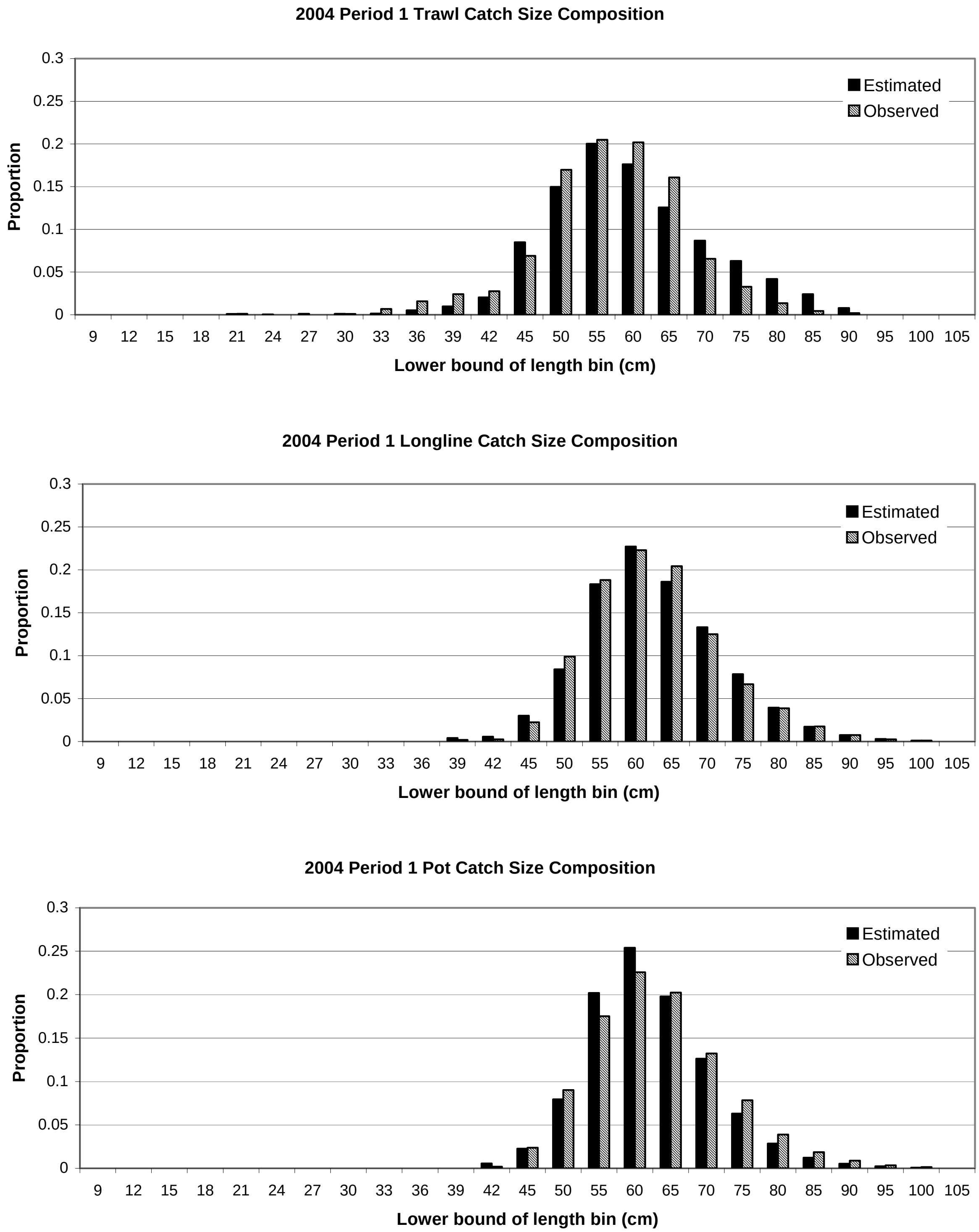


Figure 2.4–Estimated and observed size compositions from the 2004 period 1 fisheries.

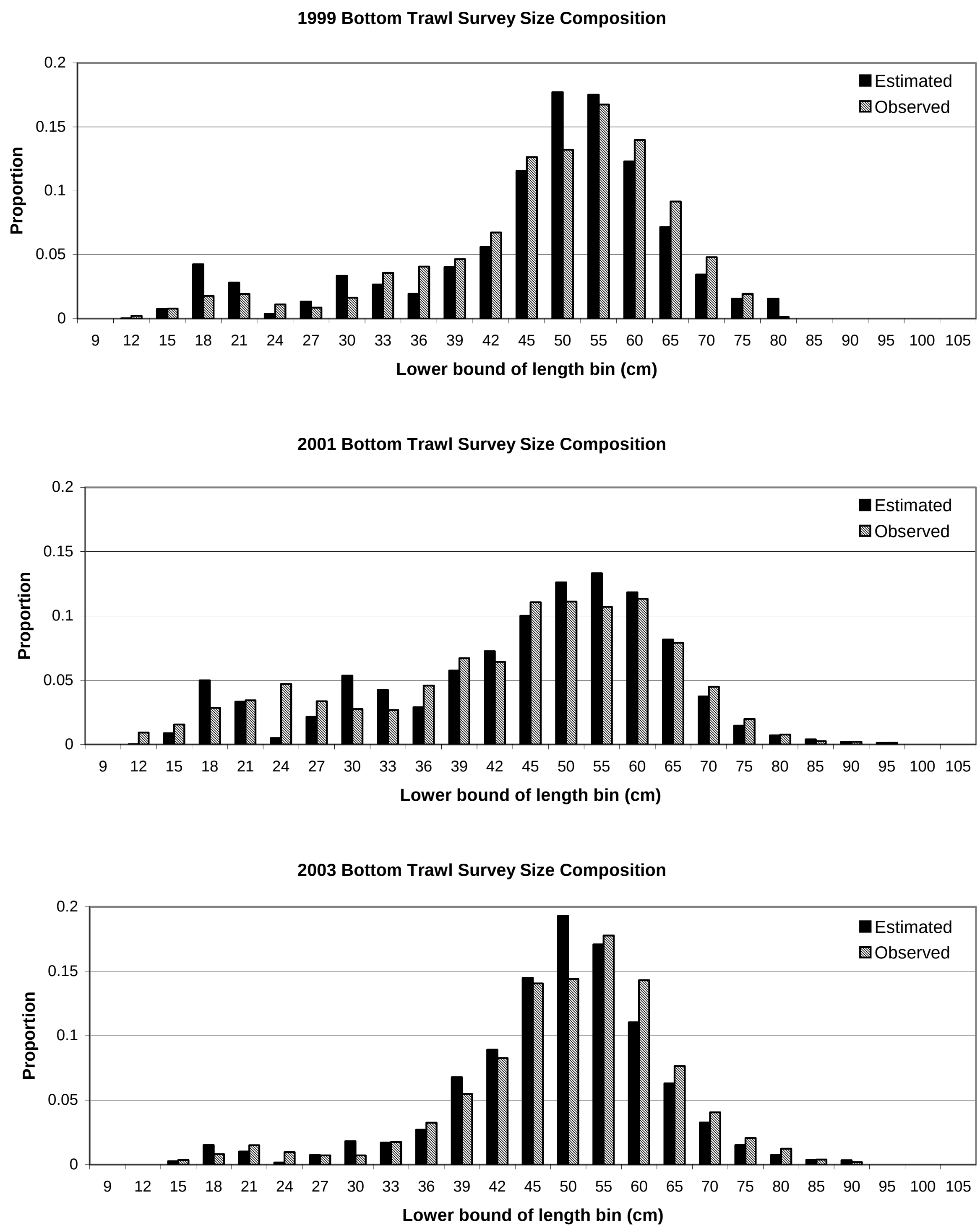


Figure 2.5–Estimated and observed size compositions from the 3 most recent surveys.

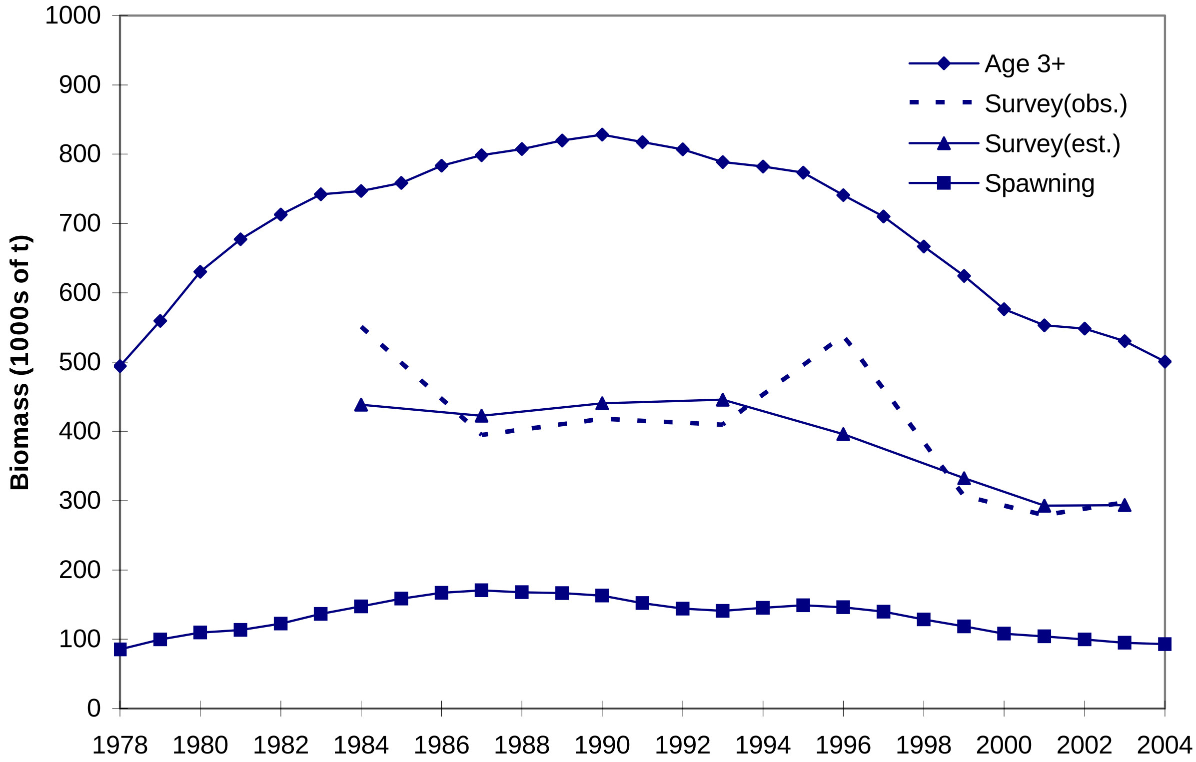


Figure 2.6–Time series of biomass estimates.

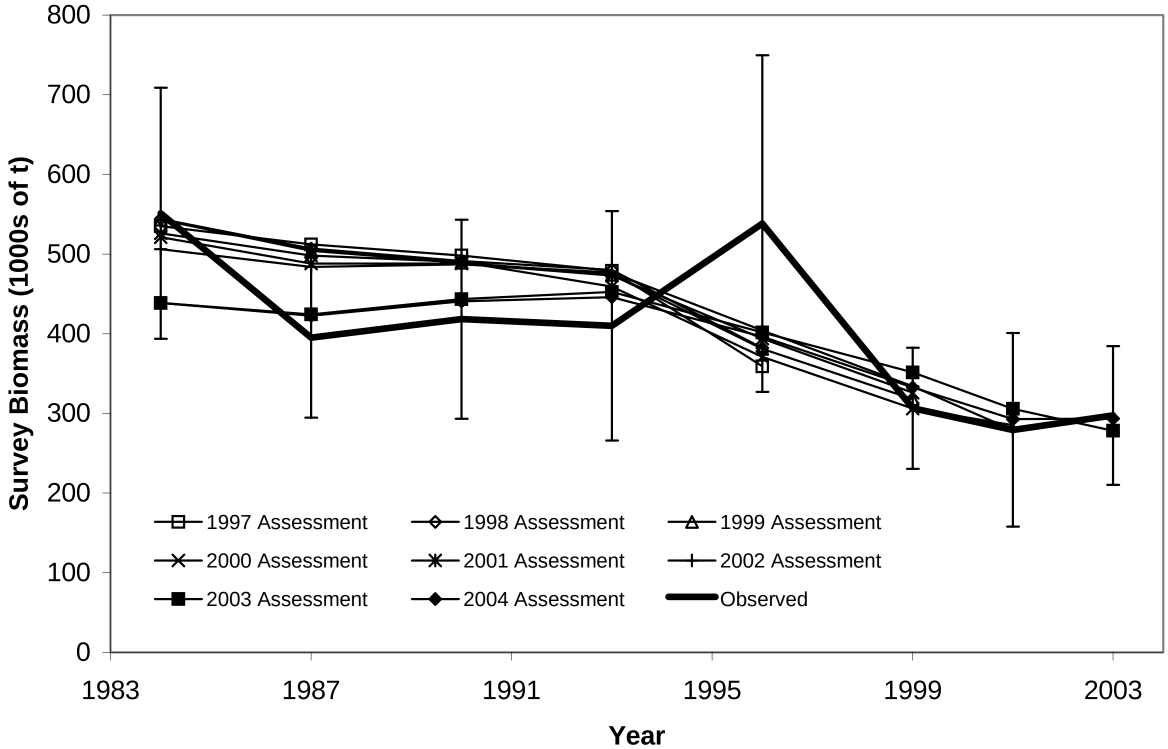


Figure 2.7–Retrospective analysis of estimated survey biomass, 1997-present. The vertical error bars around the observed survey biomass represent 1.96 standard deviations on either side of the mean.

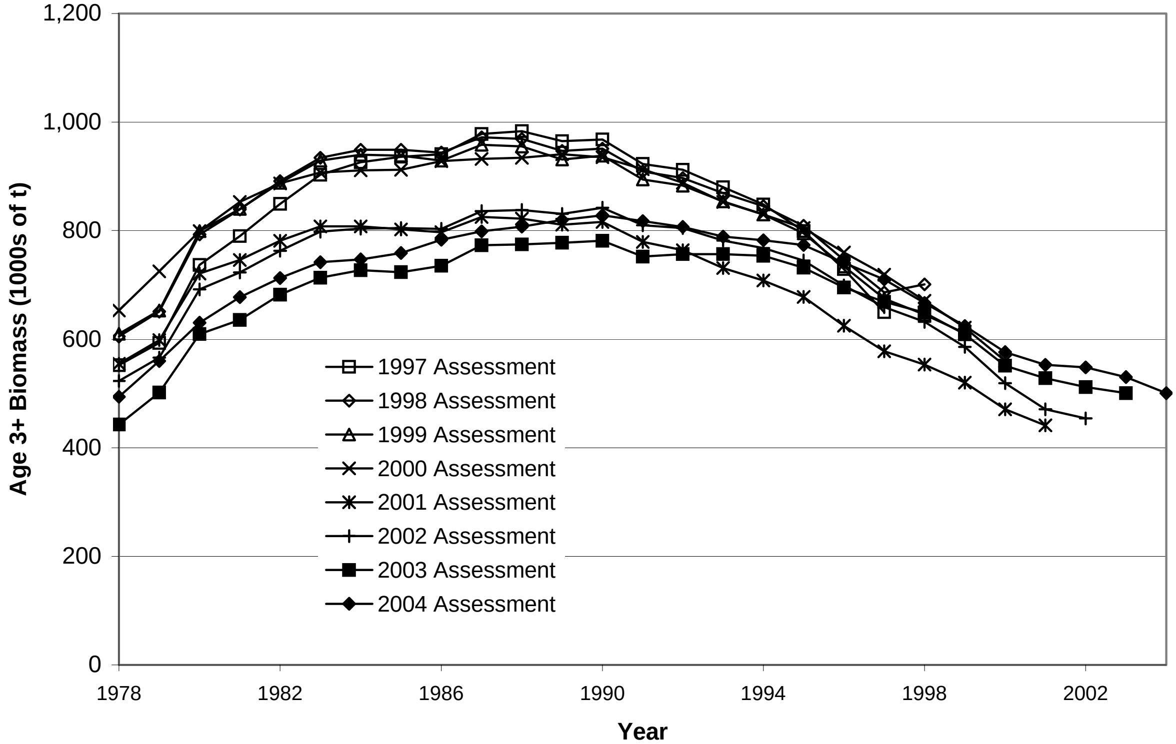


Figure 2.8–Retrospective analysis of estimated age 3+ biomass, 1997-present.

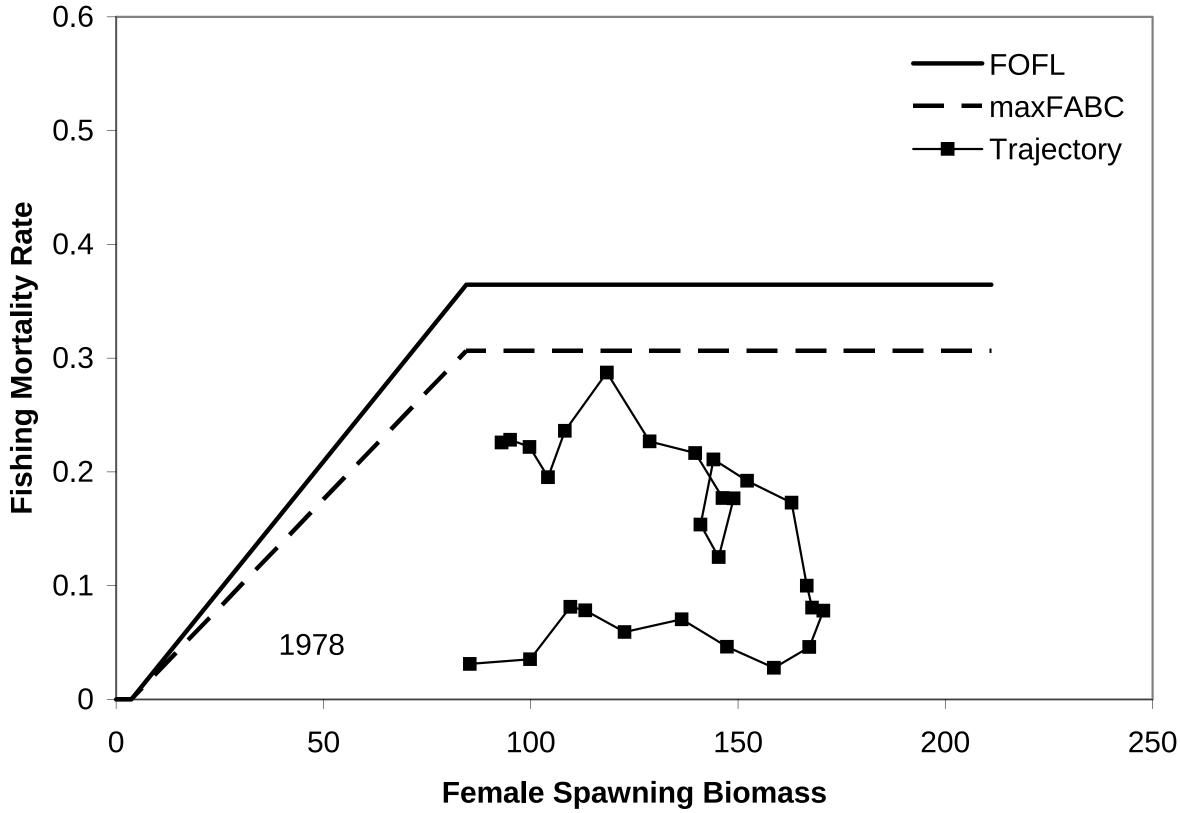


Figure 2.9–Trajectory of fishing mortality and female spawning biomass, 1978-present.

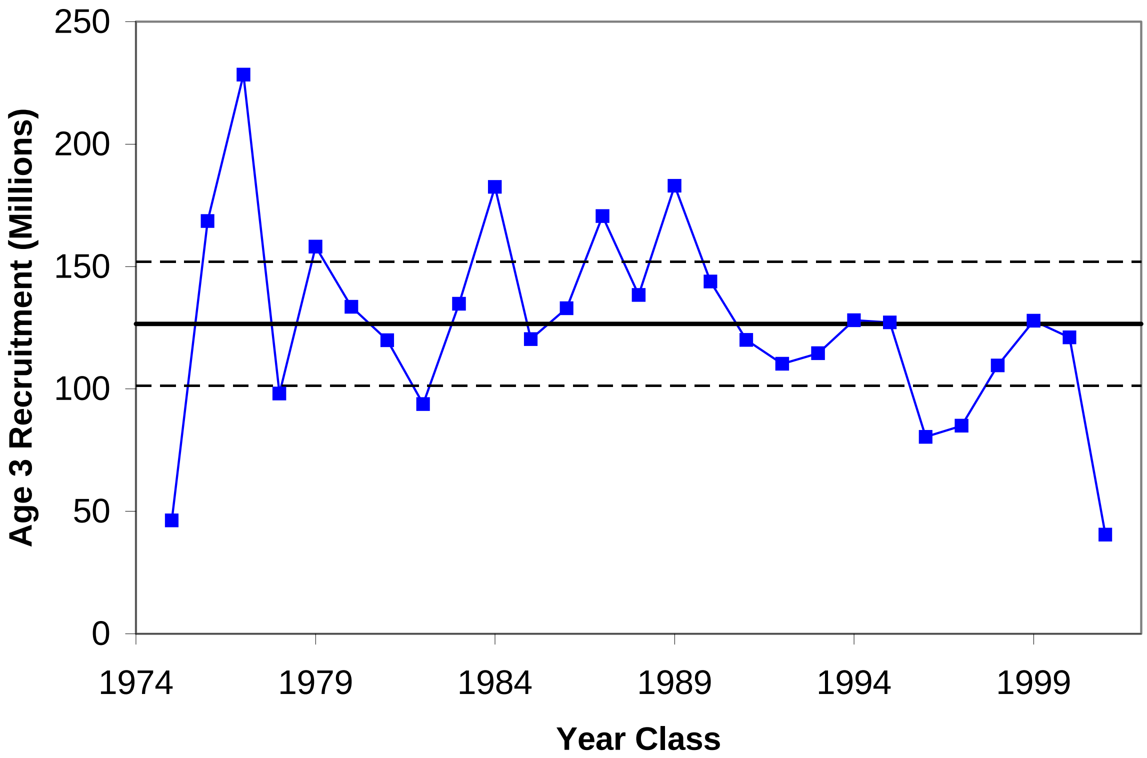


Figure 2.10–Pacific cod recruitment at age 3 as estimated by the assessment model. Points represent individual recruitment estimates. The bold horizontal line represents the mean of the time series. The lower and upper dashed horizontal lines represent 80% and 120%, respectively, of the time series mean.

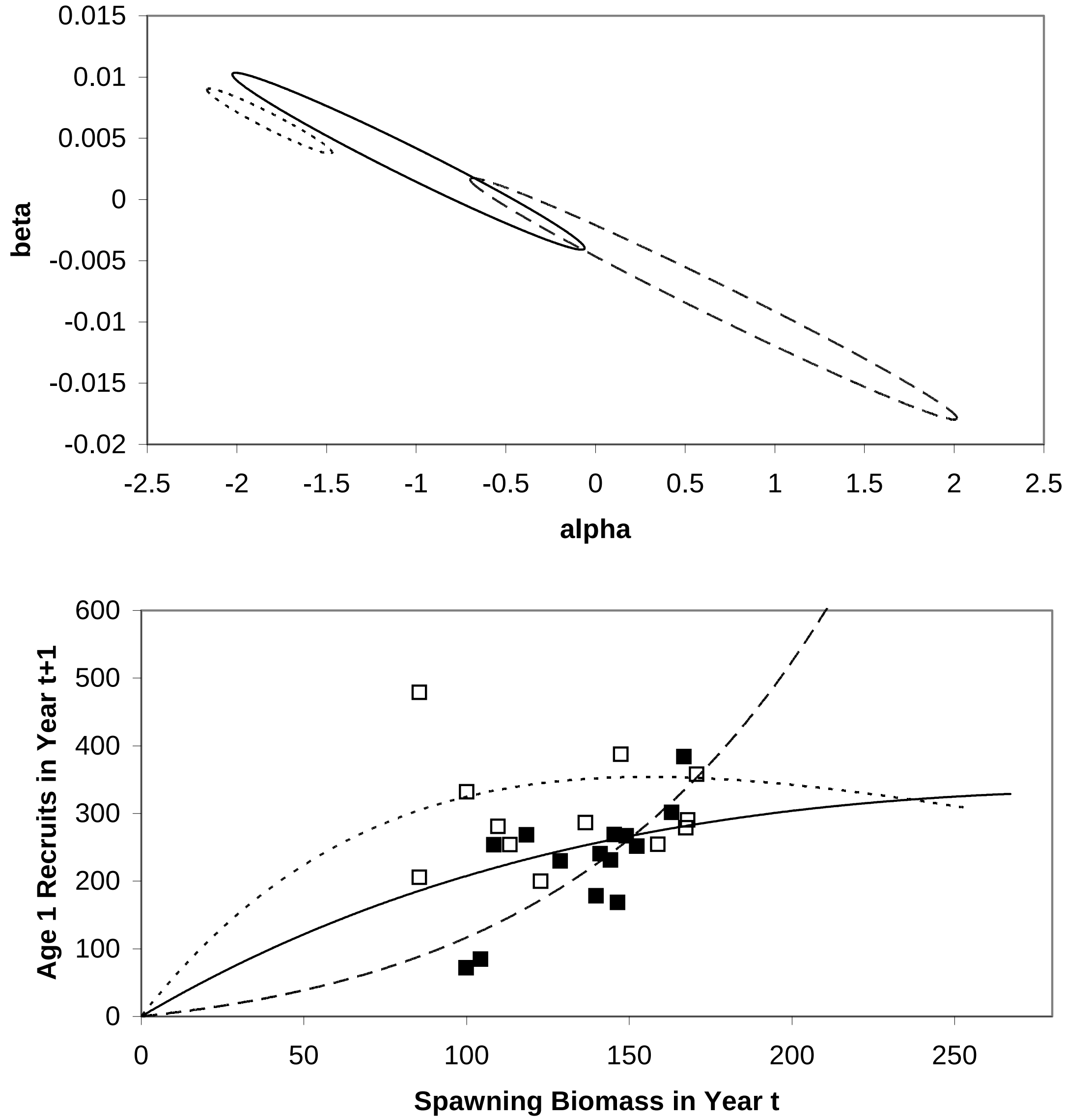


Figure 2.11–Some aspects of uncertainty surrounding the stock-recruitment relationship. The upper panel shows 95% confidence ellipses for the estimated parameters of the stock-recruitment relationship. The dotted, dashed, and solid ellipses correspond to the pre-1989 data subset, the post-1988 data subset, and the entire data set, respectively. The lower panel shows the data (squares) and estimated relationships (curves). The open and solid squares correspond to the pre-1989 data subset and the post-1988 data subset, respectively. The dotted, dashed, and solid curves correspond to the pre-1989 data subset, the post-1988 data subset, and the entire data set, respectively. See text for details and caveats.

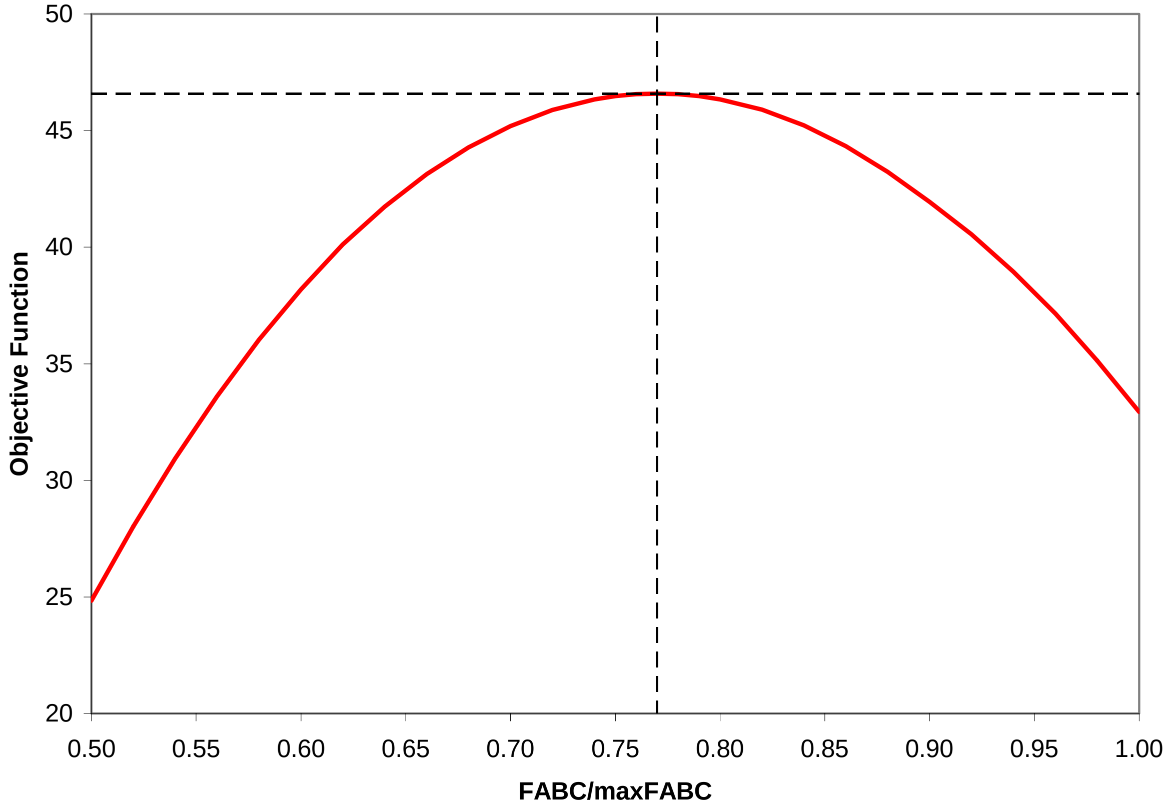


Figure 2.12–Relationship between fishing mortality (expressed as a proportion of the maximum permissible ABC fishing mortality rate, maxFABC) and the objective function used to recommend ABC. The objective function is maximized at a ratio of 0.77. See text for details.

Attachment 2A: Estimation of Pacific Cod Biomass Distributions Based on Alternative Weightings of Trawl Survey Estimates

INTRODUCTION

Management of the Pacific cod (*Gadus macrocephalus*) stocks in the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) is currently based on spatially aggregated models. However, the acceptable biological catch (ABC) for the GOA stock has traditionally been split among the three GOA regulatory areas (Western, Central, and Eastern) and interest has recently been expressed in doing likewise in the BSAI by splitting the ABC for that stock into Bering Sea (BS) and Aleutian Islands (AI) components. Absent a spatially disaggregated stock assessment model, the ABC split in the GOA has usually approximated the average distribution of the biomass estimates from the most recent bottom trawl surveys. In the BSAI, where no ABC split currently exists, the emphasis has been on identifying the long-term distribution of biomass between the two areas, so a long-term weighted average has been used in the BSAI rather than relying only on the most recent survey biomass estimates as is done in the GOA.

At its December, 2003 meeting, the Scientific and Statistical Committee made the following request: *"The ABC for BS/AI cod is not currently allocated by area. If the ABC were apportioned by the same multiplier used to expand the EBS assessment to the full BS/AI area, the ABC would be 191,000 mt and 32,000 mt for the EBS and AI areas, respectively. The team and authors were concerned that this apportionment may have implications on cod fishery management and allocation. The SSC believes that the ABC should be split among BS and AI areas, but we are not in a position to address the concerns expressed by the authors. Therefore, for the 2005 specification process, the SSC requests the authors to evaluate the methods used to split the ABC and their potential management implications, so that specific recommendations can be made to the Council on this issue in the future."*

This paper attempts to address the above request for an evaluation of alternative methods that could be used to apportion the BSAI Pacific cod ABC between areas. It is assumed that any actual distribution of Pacific cod ABC in the BSAI would be based on the distribution of biomass. Because the methods described here could also be applied to the Pacific cod ABC in the GOA, the distribution of Pacific cod biomass in the GOA is addressed here as well.

DATA AND METHODS

Data

The time series of bottom trawl survey biomass estimates and standard errors are shown in Tables 2A1 (BS and AI) and 2A2 (Western, Central, and Eastern GOA). The Aleutian Islands data cover the entire Aleutian Islands survey area, which includes both the Aleutian Islands management area and the southern portion of the Bering Sea management area that is not assessed by the Bering Sea bottom trawl survey.

General Considerations

Two issues are addressed in this study: First, how do alternative estimators of the *current* distribution of biomass perform and, second, how do alternative estimators of the *average* distribution of biomass perform? The methods presented here are predicated on the assumptions that the time series of bottom trawl biomass estimates by area are the only available information upon which to base an estimate of biomass distribution and that survey catchabilities and selectivities are constant across areas within a region (e.g., survey catchability and selectivity in the BS are equal to those in the AI). All of the methods presented here can be viewed as special cases of the following algorithm: 1) For each area, form an estimate for the biomass in that area by applying a vector of weights to the survey time series for that area; then 2) for each area, form a ratio between the estimated biomass in that area and the sum of the estimated biomasses in that region (BSAI or GOA).

The differences between the methods presented here are as follow: 1) For the estimators of *current* biomass, several alternative weighting vectors were applied to the survey time series, including sets of vectors corresponding to various exponential weighting systems and the vector implied by the Kalman filter. 2) For the estimators of *average* biomass, the weights were all equal to the inverse of the number of observations, but they are applied to two different time series: the survey estimates of biomass and the Kalman filter estimates of biomass.

The first observation in each survey time series is indexed i=1 and the terminal observation in each survey time series is indexed i=n. Index i=0, then, refers to the time period preceding the first observation.

Exponential Weighting Alternatives

For a given exponential rate parameter p, an exponential weighting vector starts with the following weight for index i=0:

$$\theta_0 = (1 - p)^n$$

For observations i=1 through i=n, the weight takes the form

$$\theta_i = p(1 - p)^{n-i}$$

Nine alternative vectors of exponential weights, corresponding to nine different values of the rate parameter p, are shown in Tables 2A3 (BS and AI) and 2A4 (Western, Central, and Eastern GOA).

Under certain special circumstances, the exponential weights described above correspond to the weights that would be implied by the Kalman filter. These circumstances are as follow: 1) the slope coefficients of the transition and observation equations are both unity and the intercept coefficients of the transition and observation equations are both zero (i.e., biomass tends to follow a trendless random walk and the survey tends to be an unbiased estimator of biomass), 2) process error variance is constant over time, 3) measurement error variance is constant over time, 4) observations are evenly spaced in time, 5) the exponential rate parameter is given by

$$p = \frac{2}{\sqrt{4r + 1} + 1}$$

where r is the ratio of measurement error variance to process error variance, and 6) the posterior estimate of the state at index i=0 is given by

$$\left(\frac{1-p}{p}\right)\sigma x^2$$

where σx^2 is the process error variance. Meinhold and Singpurwalla (1983) considered the special case of the above in which r=2 (resulting in p=1-p=0.5) and σx^2=1.

Kalman Filter

For the more general case in which conditions (3-6) are relaxed, the Kalman filter weights can be derived from a vector w where, given a value for w_0, elements w_1 through w_n are defined recursively by

$$w_i = \frac{w_{i-1}\sigma y_{i-1}^2 + \tau_i \sigma x^2}{w_{i-1}\sigma y_{i-1}^2 + \tau_i \sigma x^2 + \sigma y_i^2}$$

where σy_i is the standard error of the ith observation and τ_i represents the time elapsed between observation i-1 and observation i (for i=1, σy_{i-1} was set equal to zero and τ_i was set equal to unity). For this study, σx was estimated for each area by the method of maximum likelihood (Harvey 1990).

From the vector w, the Kalman weights ω can be defined recursively by the equations

$$\omega_i = \prod_{j=1}^{n}(1-w_j)$$

for i=0,

$$\omega_i = w_i \prod_{j=i+1}^{n}(1-w_j)$$

for i=1 through i=n-1, and

$$\omega_i = w_n$$

for i=n.

The above formulae are conditional on the value of w_0. If the initial size of the population is viewed as a parameter to be estimated, then the appropriate value of w_0 is zero (Harvey 1990).

The weighting vectors implied by the Kalman filter for the BSAI and GOA are shown in the right-hand column of Tables 2A3 and 2A4, respectively.

Application of Weights

In the Kalman filter, the posterior mean estimate of biomass at the time of the final observation is given by

$$\omega_0 \mu_0 + \sum_{i=1}^{n} \omega_i y_i$$

where μ_0 is the maximum likelihood estimate of the initial biomass (i.e., the biomass prior to the first observation) and y_i is the *i*th survey biomass estimate.

The above implies a potential problem for the exponential weighting alternatives, because it is not obvious how to compute μ_0 for those alternatives. To make the analyses comparable, the value of μ_0 obtained from the Kalman filter was used here for the exponential weighting alternatives as well. This gives the following estimate of current biomass for the exponential weighting alternatives:

$$\theta_0 \mu_0 + \sum_{i=1}^{n} \theta_i y_i$$

where the vector θ is prescribed by the value of *p* associated with a given exponential weighting alternative.

RESULTS

Parameters

The only parameters estimated in this analysis are the initial biomass (i.e., the biomass preceding the first observation) and the process error standard deviation.

The initial biomass estimates obtained from the Kalman filter are as follow:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ini):	810,420 t	166,611 t	89,010 t	310,679 t	26,141 t

The maximum likelihood estimates of the process error standard deviation obtained from the Kalman filter are as follow:

Area:	BS	AI	WGOA	CGOA	EGOA
σx:	125,103 t	22,886 t	12,850 t	25,846 t	2,208 t

The process error standard deviation can be divided by the initial biomass to give the following coefficients of variation:

Area:	BS	AI	WGOA	CGOA	EGOA
CV:	0.15	0.14	0.14	0.08	0.08

Current Biomass

Time series of biomass estimates and 95% confidence intervals are shown for both the raw survey data and the Kalman filter in Figures 2A1 (BS and AI) and 2A2 (WGOA, CGOA, and EGOA). Absolute and relative 2004 biomass estimates for the BSAI are given in Tables 2A5a and 2A5b, respectively. Absolute and relative 2003 biomass estimates for the GOA are given in Tables 2A6a and 6b, respectively. Current biomass proportions for the BS and AI range from 83% to 85% and 15% to 17%, respectively. Current biomass proportions for the Western, Central, and Eastern GOA range from 27% to 33%, 61% to 68%, and 5% to 6%, respectively.

Average Biomass

The average biomass estimates from the bottom trawl surveys are as follow:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ave):	834,300 t	156,564 t	125,561 t	250,518 t	23,559 t

The average biomass estimates from the Kalman filter are as follow:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ave):	804,214 t	145,481 t	101,784 t	232,464 t	20,442 t

Based on the raw survey data, the distribution of average biomass within each region (BSAI and GOA) is as follows:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ave):	0.84	0.16	0.31	0.63	0.06

Based on the Kalman filter estimates, the distribution of average biomass within each region (BSAI and GOA) is as follows:

Area:	BS	AI	WGOA	CGOA	EGOA
B(ave):	0.85	0.15	0.29	0.65	0.06

DISCUSSION

For the BSAI, all ten of the alternative estimates of current biomass distribution and both of the alternative estimates of average biomass distribution are fairly close to the estimate of average biomass distribution used in last year's stock assessment (Thompson et al. 2003). Adoption of any of the new alternatives would imply at most a 2% change from the biomass distribution used in last year's stock assessment, from 85% in the BS down to 83%. Given that the estimates are all so close and given that the assumptions used in this analysis are fairly strong, it is not clear that a compelling case can be made for one of the alternatives over any other. The Kalman filter probably has the strongest theoretical basis, but the exponential weighting alternatives are easier to understand and more predictable from year to year. It is also unclear whether it is necessary to maintain separate estimates for the current distribution of biomass and the average distribution of biomass. On the positive side, maintaining separate estimates would allow the stock assessment to use the average biomass distribution to describe the history of recruitment while allowing area-specific ABCs to be based on the current biomass distribution. On the negative side, maintaining separate estimates could cause confusion for managers and the public. Moreover, in the event that the BSAI ABC is split between the BS and AI areas, it is possible that the area-specific ABCs will be calculated independently of each other, as has been done for some other stocks. For example, the AI portion of the Pacific cod stock might be managed under Tier 5 with a biomass estimate based entirely on the AI survey time series, as opposed to a method in which the AI ABC is set equal to some fraction of the BS ABC.

In the GOA, the new alternative estimates do not bracket the estimate of average biomass distribution upon which the most recent distribution of ABC was based (Thompson and Dorn 2003). At a minimum, the Western ABC allocation would decrease from the current value of 36% down to 33% and the Central ABC allocation would increase from the current value of 57% up to 61%. In the most extreme case, the Western ABC allocation would decrease to 27% and the Central ABC allocation would increase to 68%. (The Eastern GOA would decrease from the current value of 7% down to 5% or 6% under any of the alternatives.) The main reason for the differences in the GOA biomass distribution is that the current formula gives equal weight to each of the last three surveys, while all of the alternatives give greatest weight to the most recent survey which observed a relatively low biomass in the Western area and a relatively high biomass in the Central area.

It should also be noted that considerable effort has recently gone into the development of improved methods for assessing the spatial dynamics of Pacific cod. Although these new methods have yet to be incorporated into the Pacific cod assessments, it is conceivable that more rigorous tools for estimating biomass distributions may be available in the next year or two.

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Meinhold, R. J. and N. D. Singpurwalla. 1983. Understanding the Kalman Filter. *American Statistician* 37:123-127.

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Thompson, G. G., H. H. Zenger, and M. W. Dorn. 2003. Assessment of the Pacific cod stock in the Gulf of Alaska. *In* Plan Team for Groundfish Fisheries of the Gulf of Alaska (editor), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p.

149-241. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Table 2A1a. BS survey biomass estimates (t) with standard errors (t).

Year	Biomass	Std. Error
1979	754,314	97,844
1980	905,344	87,898
1981	1,034,629	123,849
1982	1,020,550	73,392
1983	1,176,305	121,606
1984	1,001,940	64,127
1985	961,050	51,453
1986	1,134,106	71,813
1987	1,142,450	71,439
1988	959,544	76,284
1989	960,436	69,157
1990	708,551	53,728
1991	532,590	41,678
1992	546,707	45,754
1993	690,524	54,934
1994	1,368,109	254,435
1995	1,003,046	92,677
1996	890,793	120,522
1997	604,881	69,250
1998	534,141	42,942
1999	583,259	50,622
2000	528,466	43,037
2001	830,479	75,675
2002	616,923	69,586
2003	605,681	63,601
2004	596,988	35,135

Table 2A1b. AI survey biomass estimates (t) with standard errors (t).

Year	Biomass	Std. Error
1980	148,272	29,778
1983	215,755	30,993
1986	255,007	66,524
1991	189,190	25,532
1994	184,109	33,695
1997	83,416	10,499
2000	136,075	23,553
2002	82,853	12,018
2004	114,396	19,973

Table 2A2a. Western GOA survey biomass estimates (t) with standard errors (t).

Year	Biomass	Std. Error
1984	173,843	58,375
1987	72,312	6,877
1990	129,744	19,689
1993	120,122	10,960
1996	188,128	57,438
1999	112,076	19,395
2001	133,214	44,689
2003	75,052	18,546

Table 2A2b. Central GOA survey biomass estimates (t) with standard errors (t).

Year	Biomass	Std. Error
1984	340,336	53,505
1987	289,790	49,463
1990	262,732	60,531
1993	269,258	72,487
1996	337,388	91,105
1999	172,620	33,108
2001	124,400	27,470
2003	207,619	40,438

Table 2A2c. Eastern GOA survey biomass estimates (t) with standard errors (t). Note that the Western and Central GOA were surveyed in 2001, but the Eastern GOA was not.

Year	Biomass	Std. Error
1984	36,792	13,830
1987	32,886	11,848
1990	25,725	3,643
1993	20,468	4,185
1996	12,638	2,789
1999	21,718	5,032
2003	14,689	2,608

Table 2A3a. Alternative schedules of weights for the Bering Sea survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1978	0.0646	0.0030	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1979	0.0072	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1980	0.0080	0.0009	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1981	0.0089	0.0012	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1982	0.0098	0.0015	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1983	0.0109	0.0018	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1984	0.0122	0.0023	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1985	0.0135	0.0029	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1986	0.0150	0.0036	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1987	0.0167	0.0045	0.0007	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1988	0.0185	0.0056	0.0010	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1989	0.0206	0.0070	0.0014	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1990	0.0229	0.0088	0.0020	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1991	0.0254	0.0110	0.0029	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
1992	0.0282	0.0137	0.0042	0.0009	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
1993	0.0314	0.0172	0.0059	0.0015	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
1994	0.0349	0.0215	0.0085	0.0024	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000
1995	0.0387	0.0268	0.0121	0.0040	0.0010	0.0002	0.0000	0.0000	0.0000	0.0000
1996	0.0430	0.0336	0.0173	0.0067	0.0020	0.0004	0.0000	0.0000	0.0000	0.0000
1997	0.0478	0.0419	0.0247	0.0112	0.0039	0.0010	0.0002	0.0000	0.0000	0.0000
1998	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0000
1999	0.0590	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0000
2000	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0005
2001	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0015
2002	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.0084
2003	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.0505
2004	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.9390

Table 2A3b. Alternative schedules of weights for the Aleutian Island survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1979	0.3874	0.1342	0.0404	0.0101	0.0020	0.0003	0.0000	0.0000	0.0000	0.0000
1980	0.0430	0.0336	0.0173	0.0067	0.0020	0.0004	0.0000	0.0000	0.0000	0.0000
1983	0.0478	0.0419	0.0247	0.0112	0.0039	0.0010	0.0002	0.0000	0.0000	0.0000
1986	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0000
1991	0.0590	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0001
1994	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0002
1997	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0054
2000	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.0171
2002	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.2301
2004	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.7472

Table 2A4a. Alternative schedules of weights for the Western GOA survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1983	0.4305	0.1678	0.0577	0.0168	0.0039	0.0007	0.0001	0.0000	0.0000	0.0002
1984	0.0478	0.0419	0.0247	0.0112	0.0039	0.0010	0.0002	0.0000	0.0000	0.0000
1987	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0030
1990	0.0591	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0045
1993	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0460
1996	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0097
1999	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.1688
2001	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.0702
2003	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.6977

Table 2A4b. Alternative schedules of weights for the Central GOA survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1983	0.4305	0.1678	0.0577	0.0168	0.0039	0.0007	0.0001	0.0000	0.0000	0.0018
1984	0.0478	0.0419	0.0247	0.0112	0.0039	0.0010	0.0002	0.0000	0.0000	0.0004
1987	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0023
1990	0.0591	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0040
1993	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0060
1996	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0073
1999	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.0952
2001	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.3455
2003	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.5374

Table 2A4c. Alternative schedules of weights for the Eastern GOA survey time series. The first column shows the year of the survey. The next nine columns show alternative schedules of exponential weights. The right-hand column shows the weights implied by the Kalman filter. Note that while the Western and Central portions of the GOA were surveyed in 2001, the Eastern portion was not.

Year	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
1983	0.4783	0.2097	0.0824	0.0280	0.0078	0.0016	0.0002	0.0000	0.0000	0.0025
1984	0.0531	0.0524	0.0353	0.0187	0.0078	0.0025	0.0005	0.0001	0.0000	0.0001
1987	0.0591	0.0655	0.0504	0.0311	0.0156	0.0061	0.0017	0.0003	0.0000	0.0004
1990	0.0656	0.0819	0.0720	0.0518	0.0313	0.0154	0.0057	0.0013	0.0001	0.0071
1993	0.0729	0.1024	0.1029	0.0864	0.0625	0.0384	0.0189	0.0064	0.0009	0.0138
1996	0.0810	0.1280	0.1470	0.1440	0.1250	0.0960	0.0630	0.0320	0.0090	0.0759
1999	0.0900	0.1600	0.2100	0.2400	0.2500	0.2400	0.2100	0.1600	0.0900	0.0809
2003	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	0.8193

Table 2A5a. Absolute 2004 biomass estimates for BS and AI Pacific cod. The first column shows the area to which the biomass estimates in that row pertain. The next nine columns show 2004 biomass estimates for alternative exponential weighting schemes. The right-hand column shows the 2004 biomass estimate implied by the Kalman filter.

Area	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
BS	738,803	668,109	637,007	622,817	614,806	608,901	604,062	600,418	598,154	597,921
AI	154,053	139,332	126,724	117,724	112,294	109,720	109,165	109,961	111,731	107,359

Table 2A5b. Relative 2004 biomass estimates for BS and AI Pacific cod (column entries sum to 1.0). The first column shows the area to which the biomass estimates in that row pertain. The next nine columns show relative 2004 biomass estimates for alternative exponential weighting schemes. The right-hand column shows the relative 2004 biomass estimate implied by the Kalman filter.

Area	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
BS	0.8275	0.8274	0.8341	0.8410	0.8456	0.8473	0.8469	0.8452	0.8426	0.8478
AI	0.1725	0.1726	0.1659	0.1590	0.1544	0.1527	0.1531	0.1548	0.1574	0.1522

Table 2A6a. Absolute 2003 biomass estimates for Western, Central, and Eastern GOA Pacific cod. The first column shows the area to which the biomass estimates in that row pertain. The next nine columns show 2003 biomass estimates for alternative exponential weighting schemes. The right-hand column shows the 2003 biomass estimate implied by the Kalman filter.

Area	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
WGOA	108,303	114,294	113,497	109,439	103,970	98,035	92,099	86,339	80,726	88,794
CGOA	269,132	238,939	217,690	203,479	194,900	190,955	190,903	194,113	199,937	177,497
EGOA	24,027	21,800	19,894	18,451	17,442	16,755	16,252	15,805	15,310	15,297

Table 2A6b. Relative 2003 biomass estimates for Western, Central, and Eastern GOA Pacific cod (column entries sum to 1.0). The first column shows the area to which the biomass estimates in that row pertain. The next nine columns show relative 2003 biomass estimates for alternative exponential weighting schemes. The right-hand column shows the relative 2003 biomass estimate implied by the Kalman filter.

Area	p=0.1	p=0.2	p=0.3	p=0.4	p=0.5	p=0.6	p=0.7	p=0.8	p=0.9	Kalman
WGOA	0.2698	0.3048	0.3233	0.3303	0.3287	0.3206	0.3078	0.2914	0.2727	0.3153
CGOA	0.6704	0.6371	0.6201	0.6141	0.6162	0.6246	0.6379	0.6552	0.6755	0.6303
EGOA	0.0598	0.0581	0.0567	0.0557	0.0551	0.0548	0.0543	0.0533	0.0517	0.0543

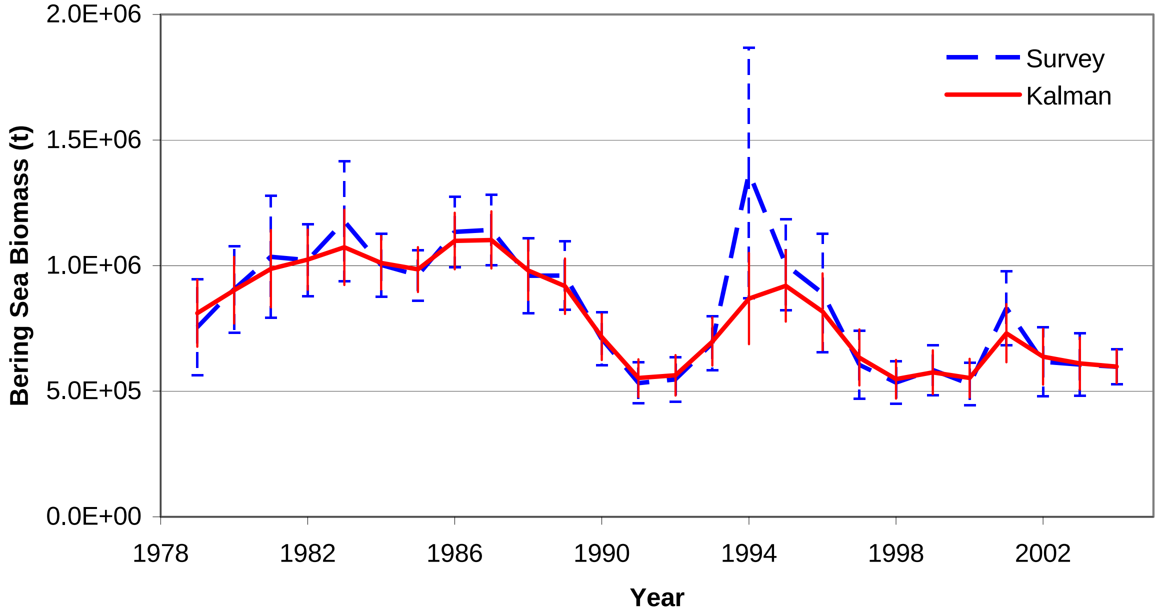

Figure 2A1a. BS biomass estimates with 95% confidence intervals.

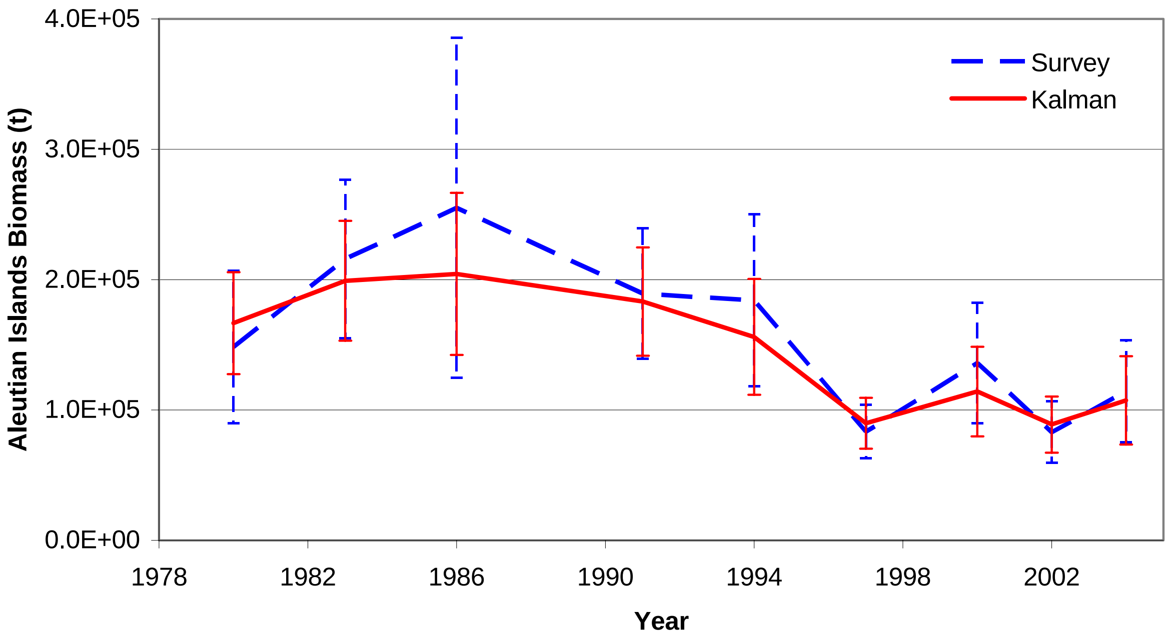

Figure 2A1b. AI biomass estimates with 95% confidence intervals.

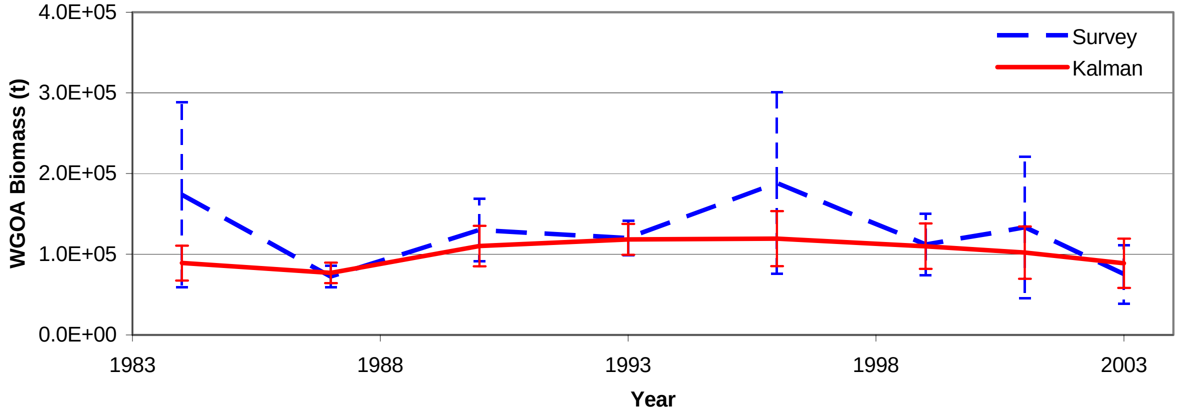

Fig. 2A2a. Western GOA biomass estimates with 95% confidence intervals.

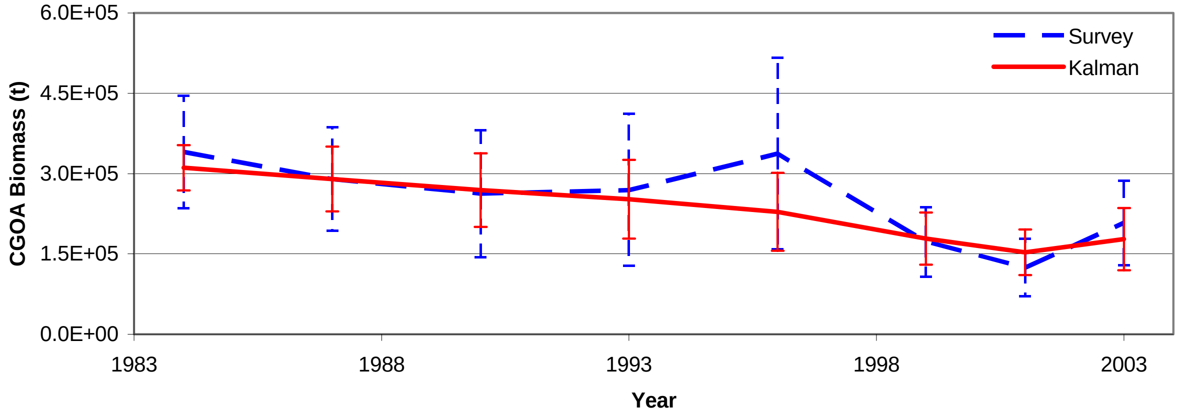

Fig. 2A2b. Central GOA biomass estimates with 95% confidence intervals.

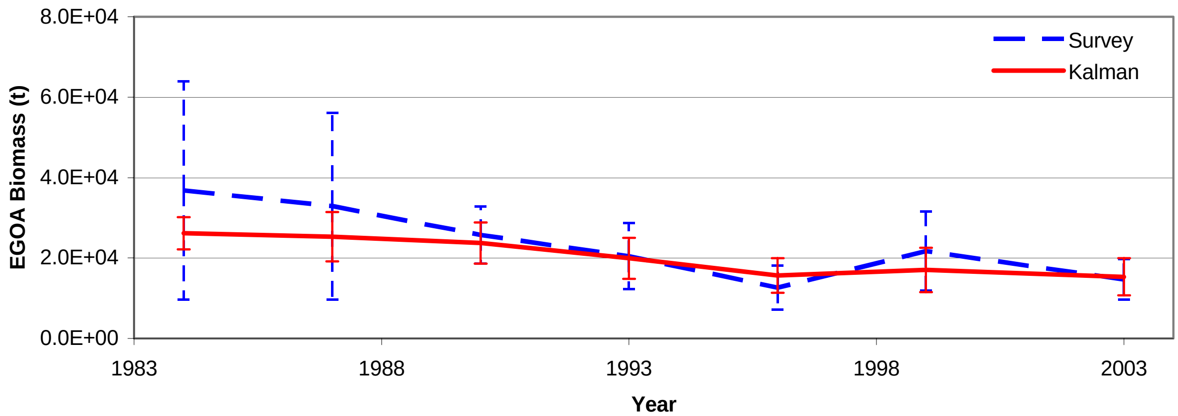

Fig. 2A2c. Eastern GOA biomass estimates with 95% confidence intervals.

Attachment 2B: Potential Use of Trawl Survey Data Collected by the Alaska Department of Fish and Game

INTRODUCTION

The Alaska Department of Fish and Game (ADFG) conducts trawl surveys of several subareas of the GOA, including the Kodiak, South Peninsula, and Chignik Districts (e.g., Spalinger 2003); Cook Inlet (e.g., Bechtol 2001); and Prince William Sound (e.g., Bechtol 1999). At present, these data are not used in the assessment model for GOA Pacific cod. However, the SSC has requested that consideration be given to incorporating these data into the assessment. The purpose of this attachment is to begin the process of gathering the available data and to consider how it might best be used in future assessments.

EXAMPLES OF AVAILABLE DATA

Biomass Estimates

Biomass estimates from ADFG trawl surveys are typically produced only for relatively small subareas of the GOA. As an example, the table below shows the time series of ADFG survey biomass estimates of Pacific cod for Kamishak Bay and Kachemak Bay ("Month" denotes month of the survey):

	Kamishak Bay		Kachemak Bay	
Year	Biomass (t)	Month	Biomass (t)	Month
1997	4,654	June	653	June
1998	2,343	June	660	August
1999	3,516	August	452	July
2000	1,862	June	476	July
2001	2,491	June	314	June
2002	n/a		n/a	
2003	2,390	June	500	July
2004	2,108	June	715	June

Length Frequency

The time series of length frequencies from the ADFG Cook Inlet and Prince William Sound surveys are shown in Tables 2B1 and 2B2. Figure 2B1 compares length frequencies from the 2003 NMFS GOA survey, 2003 ADFG Cook Inlet survey, and 2003 ADFG Prince William Sound survey.

Note that the sample sizes for the three surveys in Figure 2B1 decrease by about an order of magnitude respectively.

DISCUSSION

Because ADFG trawl surveys do not cover the entire GOA, incorporation of the results into the assessment model is not a straightforward exercise. For example, in the case of biomass estimates obtained from ADFG surveys conducted in subareas that overlap substantially with the area covered by the NMFS survey, it is probably not appropriate to treat the estimates additively. It may be possible to estimate the catchabilities of the various surveys, as is currently done for GOA walleye pollock (Dorn et al. 2003). However, this would involve some fairly strong assumptions about the extent to which the distribution of fish among subareas is constant. An alternative would be to develop a spatially explicit model that allows migration between subareas. Such a model has been in development for use in the Pacific cod assessments. It may be preferable to focus attention on completion of the new model rather than moving directly to incorporate the ADFG trawl survey data in the current assessment model.

ACKNOWLEDGMENTS

Bill Bechtol and Willy Dunne of ADFG supplied the data used in this attachment.

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Dorn, M., S. Barbeaux, M. Guttormsen, B. Megrey, A. Hollowed, M. Wilkins, and K. Spallinger. 2003. Assessment of walleye pollock in the Gulf of Alaska. *In* Plan Team for the Groundfish Fisheries of the Gulf of Alaska (compiler), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska, p. 33-148. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501.

Spalinger, K. 2003. Bottom trawl survey of crab and groundfish: Kodiak, Chignik, and South Peninsula management areas, 2002. Regional Information Report No. 4K03-32, Alaska Department of Fish and Game. 159 p.

Table 2B1a–Size frequencies in ADFG trawl surveys of Cook Inlet, 1982-2004. Lengths ("Len") are in cm. Lengths 7 through 53 are shown on this page, lengths 54 through 98 are shown on the next.

Len	1981	1982	1983	1990	1992	1993	1994	1995	1996	1997	1998	2000	2002	2003	2004
7											1				
9									1		1				
10									3						
11										1				7	
12									1	4				7	
13						1		1		2				21	
14				1		1		1	1	1				10	
15				2				2	6		2		1	4	
16				3		3		1	10		7				
17			1	16				8	33	1	9		1	2	
18	1			24		9		11	62	8	32		2	3	
19	1			23		10	1	7	72	24	45			2	
20				33		22		18	83	32	74	2	4	5	
21	2			26		15		21	95	38	79	2	8	18	
22			1	31		24		21	60	40	81	2	35	24	
23	2			19	1	18		16	67	48	90	3	18	7	1
24	2			21		22		14	36	47	62	3	63	16	
25	1			7		14	1	6	14	31	57	11	66	14	1
26	1		1	1		9		6	10	18	61	10	54	13	1
27				2		1		3	9	7	46	20	49	5	2
28			2	3		3		2	4	8	49	8	43	7	
29		1	3	2	1	1		5	6	10	44	3	21	4	2
30			4	6	1			2	1	14	18	2	3	3	5
31			1	13	3			4	2	23	24	1	3	2	10
32			1	11	3			2	5	27	16	2	2	12	8
33	1			12	7		2	2	3	42	9	1	4	11	26
34				15	25	1	4	3	13	43	5	1	1	12	28
35			3	28	14	4	6	4	16	46	4	5	8	33	28
36			1	30	18	3	6	5	15	61	6	1	7	30	39
37				32	17	5	6	3	13	57	11	6	18	23	37
38	2		1	34	23	7	16	2	28	34	20	9	14	38	38
39	1			37	23	6	12	4	21	39	24	12	22	30	52
40	1			20	21	6	13	4	20	28	36	7	24	34	43
41		1		30	18	7	15	10	16	28	25	21	46	31	30
42			1	15	17	3	15	10	16	18	24	9	9	4	17
43			2	30	11	16	15	9	10	12	17	13	59	39	31
44			2	16	5	11	13	12	8	18	25	13	50	16	14
45				16	12	8	9	10	11	12	22	15	33	9	23
46			4	6	11	8	9	8	6	16	17	26	44	10	22
47			6	4	8	6	1	6	6	14	21	23	27	13	25
48			4	4	8	15	5	5	6	13	22	25	23	10	22
49			1	7	22	15	3	5	4	19	8	20	16	14	27
50			7	4	21	14	3	6	1	20	20	35	14	12	34
51	1		6	6	15	20	1	11	4	22	20	23	17	10	35
52			5	9	24	29	10	6	4	27	17	31	11	13	31
53			7	9	19	22	9	13	4	28	19	19	18	15	36

Table 2B1b–Size frequencies in ADFG trawl surveys of Cook Inlet, 1982-2004 (continued). Lengths ("Len") are in cm, N = sample size.

Len	1981	1982	1983	1990	1992	1993	1994	1995	1996	1997	1998	2000	2002	2003	2004
54			7	6	19	32	9	16	5	40	22	16	15	35	28
55	1	2	9	8	15	22	13	18	5	26	23	21	6	9	29
56			8	10	9	24	12	19	5	34	13	14	15	29	21
57	2		14	18	20	14	15	18	10	28	18	18	12	34	27
58	2		11	16	12	15	11	18	8	17	15	20	17	25	21
59	2		9	13	14	22	17	23	14	19	12	16	23	24	38
60	1		6	25	10	20	24	11	8	19	11	15	19	17	37
61	4	2	6	30	20	16	24	20	10	13	13	13	8	15	20
62	2	1	4	29	5	14	25	20	21	17	6	18	7	11	23
63	1		2	25	6	12	8	4	7	10	7	23	7	8	18
64			2	18	16	8	19	14	8	20	9	20	12	12	21
65	3	1	1	35	19	13	26	14	13	19	11	31	7		28
66	1	1	2	20	11	16	21	17	21	21	6	12	25	15	23
67			1	17	8	9	26	14	13	20	8	20	11	8	11
68	2		2	16	11	5	12	16	14	24	6	24	13	9	11
69			1	25	7	10	7	14	10	18	6	18	12	9	11
70			2	19	6	5	12	16	3	15	4	23	8	8	7
71			1	16	6	12	9	13	6	15	2	21	15	6	7
72	1	1		11	7	11	6	14	5	19	1	15	11	6	5
73				18	8	15	10	13	9	15	5	13	9	8	4
74		2		13	3	3	2	14	5	8	6	7	7	6	4
75			1	5	4	4	7	6	8	4	1	7	4	3	5
76				10	5	5	4	4	5	4	4	10	4	5	6
77			1	1	2	6	3	3	2	9	2	6	6	5	5
78				4	5	4		6	3	3	1	6	1	1	2
79				1	2	3	1	2	1	4	1	8	3	7	2
80				1	1	3	1	2	1	2	2	3	2	2	3
81				2	3	2		1	2	2	2	2	2	2	2
82				2				4	1	3	1	2	1		3
83					1			5	1		1	2	1	1	3
84				1		4	1	1		2		1	1	1	
85						1	1		1	5	1	1		1	
86				1	1	1		4	1	3	1	2			2
87	2			1	4				1					1	3
88					1							1			
89				1	1	1		1				1			
90										1		1			1
91					1	1						1			
92								1			1	1			
93				2			2						1	1	
95					1									1	
96													1		
98								1							
N	40	12	154	1028	612	692	503	656	1033	1440	1392	817	1124	918	1099
Mean	50	60	53	46	52	49	57	51	35	44	35	55	43	45	50
Mode	61	55	57	39	34	54	65	59	21	36	23	50	25	43	39

Table 2B2–Size frequencies in ADFG trawl surveys of Prince William Sound, 1994-2003. Lengths ("Len") are in cm, N = sample size.

Len	1994	1995	1997	1999	2001	2003	Len	1994	1995	1997	1999	2001	2003
7							54		2		1	2	1
9							55	2		4	6	1	
10							56			2	6	4	1
11							57		1	2	13	1	2
12							58		3	10	4	1	1
13							59	5	3	5	16	2	2
14							60	2	1	8	11	2	2
15							61	5	1	8	6	6	2
16							62	5	3	6	8	2	1
17							63	4	1	3	2		1
18							64	6		12	3	2	2
19							65	6		5	5	4	
20							66	8	4	5	6	6	6
21							67	7	5	6	1	3	3
22			1				68	6	3	5	2	3	2
23							69	3	4	3	3	5	1
24							70	4	2	7	1	14	1
25			1				71	1		4	3	1	1
26			1				72	3	2	3		3	2
27							73	5		7	3	12	4
28			2				74	1	2	3	2	6	2
29	1						75	2	1	2	1	3	10
30							76	1	1	2	1	6	4
31					1		77	1		4	1	1	2
32							78	1	1			4	2
33						1	79	2		2	2	3	2
34						1	80	1				1	1
35						1	81	3				1	1
36						1	82	2	1	1	1	3	
37							83	1					2
38							84						
39			2				85	3					
40			3				86						1
41	1						87	1					
42	1		1				88		1			1	1
43							89					1	1
44					1	1	90						1
45					1		91						
46					2		92						
47			3				93					2	
48		1		1			95					1	
49				3			96						
50		1	4	1		2	98						
51			3	2	2	2	N	94	44	148	118	120	79
52			5	2	4	5	Mean	68	66	61	61	68	67
53			3	1	2		Mode	66	67	64	59	70	75

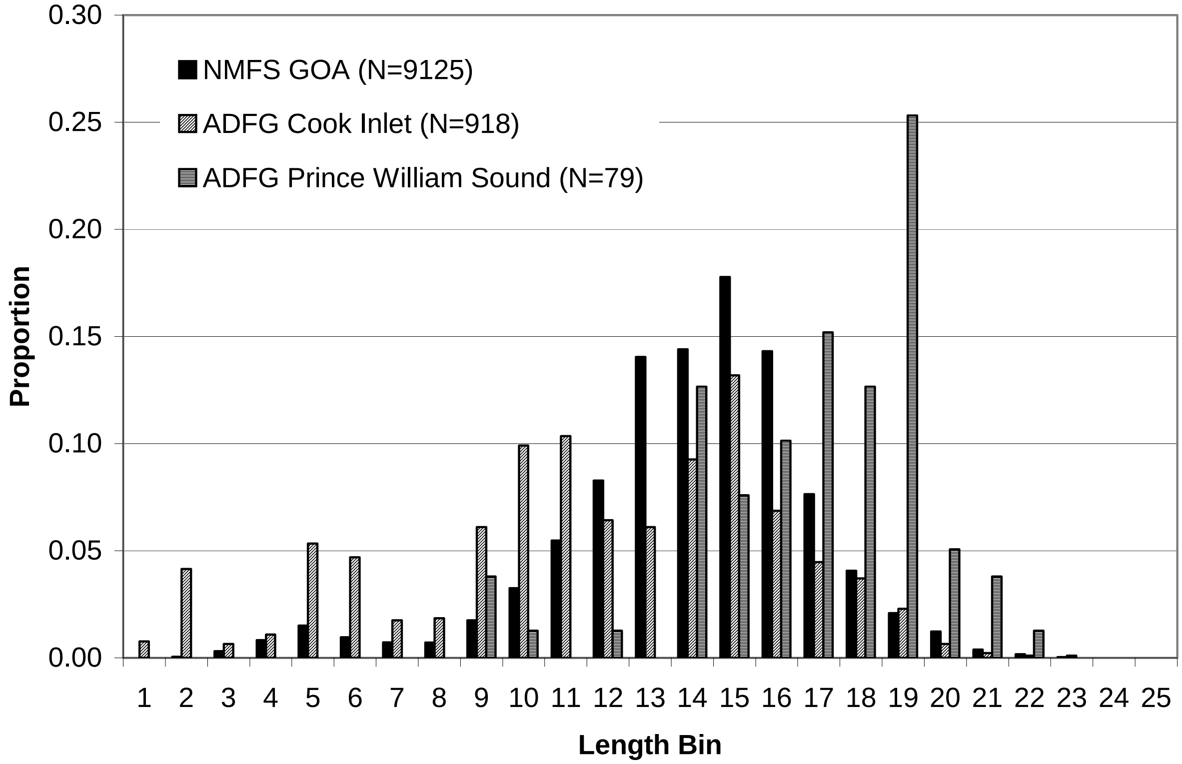

Figure 2B1–Comparison of length frequencies between the 2003 NMFS GOA survey, 2003 ADFG Cook Inlet survey, and 2003 ADFG Prince William Sound survey.