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

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EXECUTIVE SUMMARY

Summary of Major Changes

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

Changes in the Input Data

1) Catch data for 2006 were updated, and preliminary catch data for 2007 (total catch = 44,986 t) were incorporated.
2) Size composition data from the 2006 commercial fisheries were updated, and preliminary size composition data from the 2007 commercial fisheries were incorporated.
3) Relative abundance data from the GOA bottom trawl surveys were incorporated. Relative survey abundance was measured in terms of number of fish rather than biomass. The numeric abundance estimate from the 2007 survey was up 37% from the 2005 estimate. For comparison, the biomass estimate from the 2007 survey was 233,310 t, down 24% from the 2005 estimate. The reason for the difference in trend between the two measures of abundance was the occurrence of large numbers of very small fish in the 2007 survey.
4) Age composition data and mean-length-at-age data from the 1996, 1999, and 2001 GOA bottom trawl surveys were incorporated.

Changes in the Assessment Model

Many changes were made in the assessment model. The structure of the assessment model is similar to Model 1 from the BSAI Pacific cod assessment, except:

1) Natural mortality is fixed at a value of 0.38.
2) Catchability is fixed at a value of 0.92.
3) Trawl survey selectivity is based on length rather than age.
4) Trawl survey selectivity is constrained to be asymptotic.
5) All fishery selectivities are unconstrained.
6) Mean-length-at-age data are included.

Changes in Assessment Results

1) The projected 2008 female spawning biomass is 108,000 t, down about 15% from last year's projection for 2007.

2) The projected 2008 age 3+ biomass is 295,000 t, down about 21% from last year's projection for 2006.
3) The maximum permissible 2008 ABC is 46,100 t, down about 33% from the actual 2007 ABC of 68,859 t.
4) The estimated 2008 OFL is 54,200 t, down about 44% from the actual OFL for 2007.

Responses to Comments from the SSC

See BSAI Pacific cod assessment.

INTRODUCTION

Due to a number of complications which made the BSAI Pacific cod (*Gadus macrocephalus*) assessment take much more time to complete than anticipated, this year's GOA Pacific cod assessment has been abbreviated substantially. Some of the usual text sections and tables which have not changed substantially from last year's assessment have been omitted.

ANALYTIC APPROACH

Model Structure

The model structure used here is very similar to Model 1 from the BSAI Pacific cod assessment, except:

1) Natural mortality is fixed at a value of 0.38.
2) Catchability is fixed at a value of 0.92.
3) Trawl survey selectivity is based on length rather than age.
4) Trawl survey selectivity is constrained to be asymptotic.
5) All fishery selectivities are unconstrained.
6) Mean-length-at-age data are included.

The assessment was implemented using Stock Synthesis Model SS2 version 2.00i (Methot, 2007).

Parameters Estimated Independently

Natural Mortality

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

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

As the above table indicates, the natural mortality rate for Pacific cod is either highly variable by time or area or it is very hard to estimate. In the present model, a value of 0.38 is used, based on the life history theory of Jensen (1996). Recently published information on the age at maturity of GOA Pacific cod was used in this estimate (Stark 2007).

Trawl Survey Catchability

The base model used in all previous GOA Pacific cod assessments has fixed the catchability coefficient (Q) for the GOA bottom trawl survey independently of other parameters at a value of 1.0. In this year, a value of 0.92 is assumed, based on the study of Nichol et al. (2007).

Weight at Length

Parameters governing the allometric relationship between weight (kg) and length (cm) were re-estimated last year by log-log regression from the same data used to estimate the parameters of the length-at-age relationship. The curve described by the updated parameter values is close to last year's curve. The new parameter values are: multiplicative constant = 6.242×10^{-6}, and exponent = 3.137.

Maturity

A detailed history and evaluation of parameter values used to describe maturity of GOA Pacific cod was presented in the 2005 assessment (Thompson and Dorn 2005). This year, maturity is expressed as a function of age, using the parameters given by Stark (2007), with an age at 50% maturity of 4.35 years and a slope of -1.9632. The use of an age-based rather than a length-based schedule follows a recommendation from the author of the maturity study from which the parameter values were taken (James Stark, Alaska Fisheries Science Center, personal communication).

Parameters Estimated Conditionally

Parameters estimated conditionally (i.e., within individual SS2 runs, based on the data and the parameters estimated independently) include length-at-age parameters, parameters governing variability in length at age, log median recruitment, initial fishing mortality, selectivity parameters, annual recruitment deviations, and annual deviations in two parameters governing the ascending limb of the trawl survey selectivity schedule.

A new, "recommended" (Methot 2007) selectivity function has been implemented for the present assessment, as it was at the technical workshop and in the preliminary SAFE Report. The new form of the double-normal selectivity pattern is supposed to exhibit superior performance. As with the double-normal selectivity pattern used in last year's assessments, the new form is constructed from two underlying and rescaled normal distributions, with a horizontal line segment joining the two peaks. The new form uses the following six parameters:

1. Beginning of peak region (where the curve first reaches a value of 1.0)

2. Width of peak region (where the curve first departs from a value of 1.0)
3. Ascending “width” (equal to twice the variance of the underlying normal distribution)
4. Descending width
5. Initial selectivity (at minimum length/age; not used in old form)
6. Final selectivity (at maximum length/age; not used in old form)

All but the “beginning of peak region” parameter are transformed: The widths are log-transformed and the other parameters are logit-transformed.

For all parameters estimated within individual SS2 runs, the estimator used is the mode of the logarithm of the joint posterior distribution, which is in turn calculated as the sum of the logarithms of the parameter-specific prior distributions (see below) and the logarithm of the likelihood function.

In addition to the above, the full set of year-, season-, and gear-specific fishing mortality rates are also estimated conditionally, but not in the same sense as the above parameters. The fishing mortality rates are determined exactly rather than estimated statistically because SS2 assumes that the input total catch data are true values rather than estimates, so the fishing mortality rates can be computed algebraically given the other parameter values and the input catch data.

Uniform prior distributions were used for all parameters.

Likelihood Components

The model included likelihood components for trawl survey relative abundance, fishery and survey size composition, recruitment, and parameter deviations, age composition, mean size at age, initial catch.

In SS2, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. As in previous assessments, each likelihood component in each model was given an emphasis of 1.0 in the present assessment.

Use of Size Composition Data in Parameter Estimation
Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery, and time period within the year. In the parameter estimation process, SS2 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 SS1 was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. As in previous Pacific cod assessments, the present assessment assumed a multinomial sample size equal to the square root of the true length sample size, rather than the true length sample size itself. Given the true length sample sizes observed in the Pacific cod data, this procedure tended to give values somewhat below 400 while still providing SS2 with usable information regarding the appropriate effort to devote to fitting individual length samples.

Use of Age Composition Data in Parameter Estimation
Like the size composition data, the age composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery (in this case, the bottom trawl survey), and time period within the year (in this case, the June-August period). An average multinomial sample size of 300 was assumed for the age compositions, scaled according to the number of otoliths aged.

To avoid double counting of the same data, the model ignores length composition data from the EBS shelf bottom trawl surveys in years where age data are available.

Use of Fishery CPUE and Survey Relative Abundance Data in Parameter Estimation
Fishery CPUE data are included in the models for comparative purposes only. Their respective catchabilities are estimated analytically, not statistically.

For the trawl surveys, each year's survey abundance datum is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey abundance in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey abundance datum's standard error to the survey estimate itself serves as the distribution's coefficient of variation.

The following abundance data are available from the survey time series. The numeric estimates of abundance are used for estimation in this model, although the biomass estimates are used for comparison.

	Numbers		Biomass (t)	
Year	Estimate	CV	Estimate	CV
1984	320,524,532	0.156	550,971	0.146
1987	247,020,039	0.185	394,987	0.130
1990	212,131,668	0.208	416,788	0.153
1993	231,963,103	0.190	409,848	0.179
1996	319,068,011	0.215	538,154	0.200
1999	166,583,892	0.112	306,413	0.126
2001	158,424,464	0.180	257,614	0.204
2003	159,749,380	0.129	297,402	0.150
2005	139,852,429	0.208	308,091	0.262
2007	192,025,235	0.175	233,310	0.139

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

MODEL EVALUATION

Evaluation Criteria

The basic evaluation criteria used here are: does the model give an adequate fit to the relative abundance and composition data?

Effective Sample Size
Once maximum likelihood estimates of the model parameters have been obtained, SS2 computes an "effective" sample size for the size or age composition data specific to a particular year, gear/fishery, and time season 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). The average input and effective sample sizes for the model are as follow:

Fishery/Survey	Input N	Effective N
Jan-May trawl fishery	113	258
Jun-Aug trawl fishery	29	51
Sep-Dec trawl fishery	39	105
Jan-May longline fishery	102	684
Jun-Aug longline fishery	15	65
Sep-Dec longline fishery	95	138
Jan-May pot fishery	154	297
Jun-Aug pot fishery	34	95
Sep-Dec pot fishery	56	119
Bottom trawl survey	121	67

For the age composition data, the average input sample size was 300 and the average effective sample size was 103.

Fit to Survey Abundance Data
For the trawl survey abundance data, the input average CV was 0.18 and the root-mean-squared error of the output was 0.20 (Figure 2.1)

Selection of Final Model

Given the above, the model seems adequate for the purpose of making harvest specifications.

Selectivity functions estimated by the model are shown in Figure 2.2.

Mean length at age is plotted in Figure 2.3.

RESULTS

Definitions

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

Biomass

Female spawning biomass, with 95% confidence intervals, is plotted in Figure 2.4. This year’s spawning biomass estimates are compared with those from last year’s assessment in Table 2.1. Age 3+ biomass and female spawning biomass from the model are plotted along with observed survey biomass in Figure 2.5.

Recruitment

Recruitment is plotted (log scale) in Figure 2.6. This year’s recruitment estimates are compared with those from last year’s assessment in Table 2.2. A stock-recruitment curve (for illustration only—not intended for management use) is shown in Figure 2.7.

Exploitation

Figure 2.8 plots the trajectory of relative fishing mortality and relative female spawning biomass from 1977 through 2007 based on the assessment model, overlaid with the current harvest control rules (fishing mortality rates in the figure are standardized relative to $F_{35\%}$ and biomasses are standardized relative to $B_{35\%}$, per SSC request). The entire trajectory lies underneath the F_{ABC} control rule.

PROJECTIONS AND HARVEST ALTERNATIVES

Amendment 56 Reference Points

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

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

3b) *Stock status:* $0.05 < B/B_{40\%} \leq 1$
$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$
$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

3c) *Stock status:* $B/B_{40\%} \leq 0.05$
$F_{OFL} = 0$
$F_{ABC} = 0$

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

Reference point:	$B_{35\%}$	$B_{40\%}$	$B_{100\%}$
Value:	106,000 t	121,000 t	302,000 t

Specification of OFL and Maximum Permissible ABC

GOA Pacific cod spawning biomass for 2008 is estimated at a value of 108,000 t. This is about 11% below the $B_{40\%}$ value of 121,000 t, thereby placing Pacific cod in sub-tier "b" of Tier 3. Given this, the model estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2008 as follows:

Quantity	Overfishing Level	Maximum Permissible ABC
Catch:	54,200 t	46,100 t
Fishing mortality rate:	0.59	0.49

The age 3+ biomass estimate for 2008 is 295,000 t.

ABC Recommendation

The maximum permissible vale of 46,100 t is the recommended ABC for 2008.

Area Allocation of Harvests

For the past several years, ABC has been allocated among regulatory areas on the basis of the three most recent surveys. The recent time series of area-specific biomass estimates are shown below, together with the proportions corresponding to a three-year weighted average:

Year	Western	Central	Eastern	Total
2003	75,632	207,080	14,689	297,402
2005	134,018	160,118	13,954	308,091
2007	114,207	110,406	8,697	233,310
Average	107,952	159,202	12,447	279,601
Proportion	39%	57%	4%	100%

Projections and Status Determination

Scenario Projections and Two-Year Ahead Overfishing Level

Projections corresponding to the standard harvest scenarios are shown in Tables 2.3-2.8.

For the authors' recommended 2008 ABC of 46,100 t, the two-year ahead projections are as follow:

Year	ABC	OFL
2008	46,100 t	54,200 t
2009	42,100 t	49,600 t

Status Determination

The GOA Pacific cod stock is not overfished and is not approaching an overfished condition.

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 2.9.

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Table 2.1—Estimated female spawning biomass (t) from this year's and last year's assessments.

	Last Year's Values			This Year's Values		
Year	Sp. Bio.	L95%CI	U95%CI	Sp. Bio.	L95%CI	U95%CI
1977	73,085	59,747	86,423	119,910	84,873	154,947
1978	79,925	66,025	93,825	121,420	87,137	155,703
1979	80,850	66,758	94,942	117,255	84,804	149,706
1980	81,330	67,289	95,371	110,640	80,237	141,043
1981	84,160	69,426	98,894	106,210	76,528	135,892
1982	96,945	80,294	113,596	122,635	90,929	154,341
1983	110,700	92,048	129,352	138,915	105,433	172,397
1984	121,050	100,613	141,487	156,995	121,224	192,766
1985	135,030	113,033	157,027	185,595	146,933	224,257
1986	147,765	124,908	170,622	205,415	165,767	245,063
1987	152,995	129,983	176,007	214,720	175,743	253,697
1988	158,965	136,059	181,871	220,715	183,240	258,190
1989	169,150	146,300	192,000	232,005	195,982	268,028
1990	173,780	151,166	196,394	237,430	203,079	271,781
1991	165,530	143,151	187,909	221,530	189,302	253,758
1992	158,055	135,590	180,520	208,960	178,241	239,679
1993	153,010	130,177	175,843	199,410	169,792	229,028
1994	161,185	137,652	184,718	208,485	179,516	237,454
1995	170,535	146,366	194,704	218,385	190,332	246,438
1996	165,845	141,312	190,378	213,060	186,533	239,587
1997	158,500	133,551	183,449	200,170	175,536	224,804
1998	148,105	122,296	173,914	182,345	159,597	205,093
1999	143,420	116,123	170,717	169,105	147,875	190,335
2000	135,655	107,031	164,279	154,295	134,041	174,549
2001	131,060	101,906	160,214	143,245	123,645	162,845
2002	131,925	102,588	161,262	138,805	119,267	158,343
2003	136,720	106,550	166,890	138,200	117,584	158,816
2004	147,005	115,043	178,967	143,125	120,133	166,117
2005	150,505	116,755	184,255	141,685	115,988	167,382
2006	148,965	114,086	183,844	133,990	106,484	161,496
2007	n/a	n/a	n/a	121,105	92,409	149,801

Table 2.2—Estimated numbers at age 0 (1000s) from this year's and last year's assessments.

	Last Year's Values			This Year's Values		
Year	Recruits	L95%CI	U95%CI	Recruits	L95%CI	U95%CI
1977	438,779	354,819	542,579	564,300	424,879	703,721
1978	180,488	129,598	251,368	186,130	79,976	292,284
1979	240,515	180,205	321,005	302,740	166,114	439,366
1980	311,980	241,960	402,270	545,710	384,976	706,444
1981	193,887	143,107	262,687	170,690	75,720	265,660
1982	194,945	144,865	262,345	290,410	173,678	407,142
1983	219,354	162,574	295,964	257,370	139,441	375,299
1984	370,485	288,495	475,785	400,410	245,164	555,656
1985	284,807	216,907	373,957	440,220	308,226	572,214
1986	212,845	158,825	285,235	157,350	75,091	239,609
1987	364,291	293,401	452,311	442,220	335,286	549,154
1988	258,515	196,125	340,745	278,860	163,583	394,137
1989	388,069	309,589	486,439	507,820	381,298	634,342
1990	300,507	230,967	390,987	321,820	212,421	431,219
1991	279,940	214,710	364,990	375,420	287,087	463,753
1992	250,117	191,497	326,687	214,820	154,403	275,237
1993	256,261	196,421	334,331	288,790	230,882	346,698
1994	288,372	224,612	370,232	272,050	218,234	325,866
1995	337,740	271,240	420,550	344,260	292,347	396,173
1996	224,313	173,033	290,793	218,850	172,237	265,463
1997	219,034	169,864	282,434	217,710	170,313	265,107
1998	265,825	210,765	335,275	275,990	223,448	328,532
1999	392,405	316,715	486,175	348,180	281,467	414,893
2000	313,025	243,775	401,945	283,820	222,703	344,937
2001	181,555	132,545	248,685	157,190	110,517	203,863
2002	197,009	141,079	275,109	127,850	86,700	169,000
2003	232,720	156,600	345,820	196,460	126,913	266,007
2004	234,076	152,396	359,576	147,460	85,326	209,594
2005	n/a	n/a	n/a	283,250	111,236	455,264
2006	n/a	n/a	n/a	451,870	215,357	688,383

Table 2.3—Projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2008-2020 (Scenarios 1-2), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	46,100	46,100	46,100	46,100	0
2009	42,100	42,100	42,100	42,100	1
2010	53,100	53,100	53,100	53,200	50
2011	69,600	70,100	70,200	71,000	462
2012	72,500	75,800	76,300	81,500	2,977
2013	60,700	74,000	74,400	89,100	8,906
2014	50,200	70,900	71,000	93,100	13,633
2015	46,500	69,700	69,400	93,500	14,696
2016	45,400	69,300	68,800	92,600	14,660
2017	44,700	68,700	68,300	92,200	14,652
2018	44,000	68,600	68,000	91,500	14,493
2019	44,400	68,200	68,000	92,300	14,301
2020	45,500	68,400	68,100	92,300	14,458

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	108,000	108,000	108,000	108,000	0
2009	102,000	102,000	102,000	102,000	2
2010	111,000	111,000	111,000	111,000	53
2011	126,000	127,000	127,000	128,000	655
2012	126,000	131,000	131,000	139,000	4,638
2013	113,000	128,000	129,000	151,000	12,523
2014	105,000	124,000	127,000	157,000	17,143
2015	102,000	124,000	126,000	158,000	18,040
2016	101,000	123,000	126,000	158,000	17,964
2017	99,900	122,000	125,000	157,000	17,797
2018	99,600	122,000	125,000	156,000	17,595
2019	100,000	122,000	125,000	157,000	17,458
2020	101,000	121,000	125,000	158,000	17,816

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	0.49	0.49	0.49	0.49	0.00
2009	0.46	0.46	0.46	0.46	0.00
2010	0.50	0.50	0.50	0.50	0.00
2011	0.55	0.55	0.55	0.55	0.00
2012	0.55	0.55	0.55	0.55	0.00
2013	0.51	0.55	0.54	0.55	0.01
2014	0.47	0.55	0.53	0.55	0.03
2015	0.46	0.55	0.53	0.55	0.03
2016	0.45	0.55	0.53	0.55	0.03
2017	0.45	0.55	0.53	0.55	0.04
2018	0.45	0.55	0.53	0.55	0.03
2019	0.45	0.55	0.53	0.55	0.03
2020	0.46	0.55	0.53	0.55	0.03

Table 2.4—Projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that *F* = the 2002-2006 average in 2008-2020 (Scenario 3), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	34,200	34,200	34,200	34,200	0
2009	34,500	34,500	34,500	34,500	0
2010	40,400	40,500	40,500	40,500	18
2011	50,100	50,400	50,500	51,000	299
2012	54,900	57,000	57,300	60,700	1,931
2013	51,200	57,700	58,400	68,000	5,487
2014	45,900	56,200	57,300	71,900	8,567
2015	42,900	55,300	56,400	72,900	9,698
2016	41,300	54,900	55,800	73,100	9,796
2017	40,700	54,200	55,300	72,500	9,788
2018	40,500	54,300	55,000	71,900	9,720
2019	40,500	53,900	54,900	71,800	9,639
2020	41,100	53,600	55,000	71,900	9,717

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	109,000	109,000	109,000	109,000	0
2009	108,000	108,000	108,000	108,000	2
2010	121,000	121,000	121,000	121,000	55
2011	140,000	141,000	141,000	142,000	665
2012	147,000	152,000	153,000	161,000	4,687
2013	140,000	155,000	157,000	180,000	13,082
2014	133,000	156,000	158,000	191,000	19,130
2015	129,000	157,000	159,000	197,000	21,697
2016	127,000	158,000	160,000	200,000	22,664
2017	125,000	157,000	160,000	199,000	23,085
2018	124,000	158,000	160,000	200,000	23,194
2019	125,000	158,000	160,000	201,000	23,142
2020	126,000	157,000	160,000	202,000	23,418

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	0.35	0.35	0.35	0.35	0.00
2009	0.35	0.35	0.35	0.35	0.00
2010	0.35	0.35	0.35	0.35	0.00
2011	0.35	0.35	0.35	0.35	0.00
2012	0.35	0.35	0.35	0.35	0.00
2013	0.35	0.35	0.35	0.35	0.00
2014	0.35	0.35	0.35	0.35	0.00
2015	0.35	0.35	0.35	0.35	0.00
2016	0.35	0.35	0.35	0.35	0.00
2017	0.35	0.35	0.35	0.35	0.00
2018	0.35	0.35	0.35	0.35	0.00
2019	0.35	0.35	0.35	0.35	0.00
2020	0.35	0.35	0.35	0.35	0.00

Table 2.5—Projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{60\%}$ (Scenario 4), with random variability in future recruitment.

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
Catch projections:					
Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	26,700	26,700	26,700	26,700	0
2009	27,800	27,800	27,800	27,800	0
2010	32,900	32,900	32,900	33,000	14
2011	41,100	41,300	41,400	41,800	229
2012	45,600	47,300	47,500	50,100	1,487
2013	43,400	48,500	49,100	56,700	4,301
2014	39,200	47,600	48,500	60,200	6,891
2015	36,700	47,000	47,700	61,200	7,975
2016	35,400	46,400	47,200	61,600	8,131
2017	34,800	46,000	46,800	60,900	8,135
2018	34,400	46,000	46,600	60,800	8,086
2019	34,300	45,700	46,500	60,800	8,021
2020	34,800	45,500	46,500	60,700	8,072
Biomass projections:					
Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	110,000	110,000	110,000	110,000	0
2009	112,000	112,000	112,000	112,000	2
2010	127,000	128,000	128,000	128,000	55
2011	150,000	150,000	150,000	152,000	666
2012	159,000	165,000	165,000	173,000	4,704
2013	155,000	171,000	172,000	196,000	13,288
2014	150,000	174,000	176,000	210,000	19,821
2015	147,000	177,000	179,000	218,000	22,971
2016	145,000	178,000	181,000	225,000	24,365
2017	144,000	178,000	181,000	224,000	25,051
2018	142,000	180,000	182,000	227,000	25,317
2019	143,000	179,000	182,000	227,000	25,345
2020	145,000	179,000	182,000	228,000	25,632
Fishing mortality projections:					
Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	0.27	0.27	0.27	0.27	0.00
2009	0.27	0.27	0.27	0.27	0.00
2010	0.27	0.27	0.27	0.27	0.00
2011	0.27	0.27	0.27	0.27	0.00
2012	0.27	0.27	0.27	0.27	0.00
2013	0.27	0.27	0.27	0.27	0.00
2014	0.27	0.27	0.27	0.27	0.00
2015	0.27	0.27	0.27	0.27	0.00
2016	0.27	0.27	0.27	0.27	0.00
2017	0.27	0.27	0.27	0.27	0.00
2018	0.27	0.27	0.27	0.27	0.00
2019	0.27	0.27	0.27	0.27	0.00
2020	0.27	0.27	0.27	0.27	0.00

Table 2.6—Projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = 0$ in 2007-2019 (Scenario 5), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	112,000	112,000	112,000	112,000	0
2009	127,000	127,000	127,000	127,000	2
2010	154,000	154,000	154,000	154,000	55
2011	189,000	190,000	190,000	191,000	667
2012	214,000	220,000	220,000	229,000	4,762
2013	225,000	242,000	244,000	268,000	13,989
2014	232,000	259,000	262,000	300,000	22,347
2015	238,000	274,000	277,000	323,000	28,135
2016	241,000	283,000	287,000	343,000	32,051
2017	242,000	290,000	294,000	356,000	34,722
2018	243,000	294,000	298,000	363,000	36,362
2019	242,000	296,000	300,000	365,000	37,215
2020	246,000	298,000	302,000	369,000	37,826

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00	0.00
2012	0.00	0.00	0.00	0.00	0.00
2013	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00

Table 2.7—Projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2007-2019 (Scenario 6), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	54,200	54,200	54,200	54,200	0
2009	46,300	46,300	46,300	46,300	1
2010	57,600	57,600	57,700	57,800	57
2011	77,800	78,800	79,000	80,600	867
2012	77,500	84,100	84,000	90,800	4,275
2013	60,700	77,500	78,400	98,000	12,181
2014	50,900	72,500	74,500	101,000	16,592
2015	47,900	71,300	73,300	102,000	17,253
2016	47,200	71,300	72,800	100,000	17,142
2017	46,400	70,800	72,300	101,000	17,111
2018	46,000	71,100	72,000	100,000	16,927
2019	46,500	70,100	72,100	101,000	16,758
2020	47,300	70,500	72,300	101,000	16,963

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	107,000	107,000	107,000	107,000	0
2009	98,000	98,000	98,000	98,000	2
2010	106,000	106,000	106,000	106,000	53
2011	119,000	120,000	120,000	121,000	628
2012	116,000	121,000	121,000	129,000	4,427
2013	103,000	116,000	118,000	138,000	11,687
2014	95,800	113,000	115,000	142,000	15,182
2015	93,800	112,000	114,000	142,000	15,436
2016	92,700	112,000	114,000	141,000	15,225
2017	92,000	112,000	113,000	140,000	15,039
2018	91,700	112,000	113,000	140,000	14,884
2019	92,200	111,000	113,000	140,000	14,757
2020	93,000	111,000	113,000	142,000	15,105

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	0.59	0.59	0.59	0.59	0.00
2009	0.53	0.53	0.53	0.53	0.00
2010	0.58	0.58	0.58	0.58	0.00
2011	0.65	0.66	0.66	0.66	0.00
2012	0.64	0.66	0.66	0.66	0.01
2013	0.56	0.64	0.63	0.66	0.04
2014	0.52	0.62	0.61	0.66	0.05
2015	0.51	0.61	0.61	0.66	0.05
2016	0.50	0.61	0.60	0.66	0.06
2017	0.50	0.61	0.60	0.66	0.06
2018	0.50	0.61	0.60	0.66	0.06
2019	0.50	0.61	0.60	0.66	0.06
2020	0.50	0.61	0.60	0.66	0.06

Table 2.8—Projections for GOA Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2007-2008 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	46,100	46,100	46,100	46,100	0
2009	42,100	42,100	42,100	42,100	1
2010	62,500	62,500	62,500	62,600	59
2011	79,800	80,400	80,500	81,500	557
2012	78,100	84,300	84,400	91,100	4,136
2013	60,700	77,900	78,600	98,100	12,206
2014	50,800	72,600	74,500	101,000	16,616
2015	47,800	71,300	73,200	102,000	17,261
2016	47,200	71,300	72,800	100,000	17,143
2017	46,400	70,800	72,300	101,000	17,110
2018	46,000	71,100	72,000	100,000	16,926
2019	46,500	70,100	72,100	101,000	16,758
2020	47,300	70,500	72,300	101,000	16,963

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	108,000	108,000	108,000	108,000	0
2009	102,000	102,000	102,000	102,000	2
2010	111,000	111,000	111,000	111,000	53
2011	121,000	122,000	122,000	123,000	653
2012	117,000	122,000	123,000	131,000	4,565
2013	103,000	116,000	118,000	139,000	11,852
2014	96,000	113,000	116,000	143,000	15,299
2015	94,000	112,000	115,000	143,000	15,505
2016	92,700	112,000	114,000	141,000	15,262
2017	92,000	112,000	114,000	141,000	15,060
2018	91,700	112,000	113,000	140,000	14,896
2019	92,200	111,000	113,000	140,000	14,763
2020	93,000	111,000	113,000	142,000	15,109

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2008	0.49	0.49	0.49	0.49	0.00
2009	0.46	0.46	0.46	0.46	0.00
2010	0.61	0.61	0.61	0.61	0.00
2011	0.66	0.66	0.66	0.66	0.00
2012	0.64	0.66	0.66	0.66	0.01
2013	0.56	0.64	0.63	0.66	0.04
2014	0.52	0.62	0.61	0.66	0.05
2015	0.51	0.61	0.61	0.66	0.05
2016	0.50	0.61	0.61	0.66	0.06
2017	0.50	0.61	0.60	0.66	0.06
2018	0.50	0.61	0.60	0.66	0.06
2019	0.50	0.61	0.60	0.66	0.06
2020	0.50	0.61	0.60	0.66	0.06

Table 2.9—Summary of major results for the stock assessment of Pacific cod in the GOA region.

Tier	3b
Reference mortality rates	
M	0.38
$F_{40\%}$	0.55
$F_{35\%}$	0.66
Equilibrium spawning biomass	
$B_{35\%}$	106,000 t
$B_{40\%}$	121,000 t
$B_{100\%}$	302,000 t
Projected biomass for 2008	
Spawning (at max FABC)	108,000 t
Age 3+	295,000 t
ABC for 2008	
FABC (maximum permissible)	0.49
FABC (recommended)	0.49
ABC (maximum permissible)	46,100 t
ABC (recommended)	46,100 t
Overfishing level for 2008	
Fishing Mortality	0.59
Catch	54,200 t

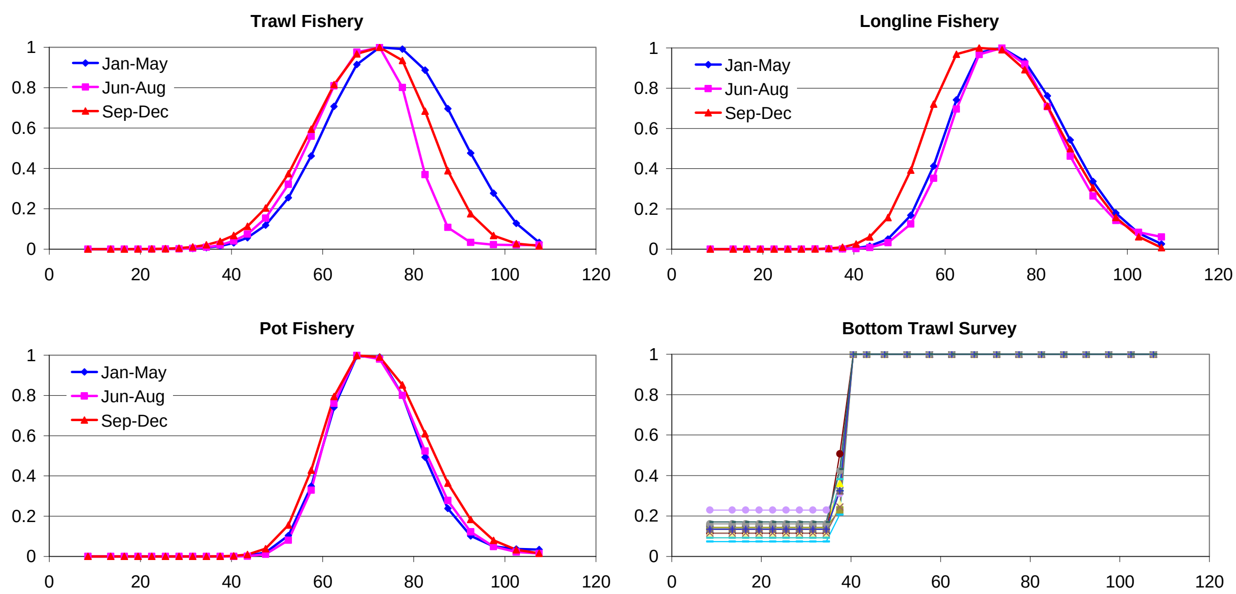

Figure 2.1—Selectivity at length (cm, evaluated at midpoints of length bins) as determined by final parameter estimates.

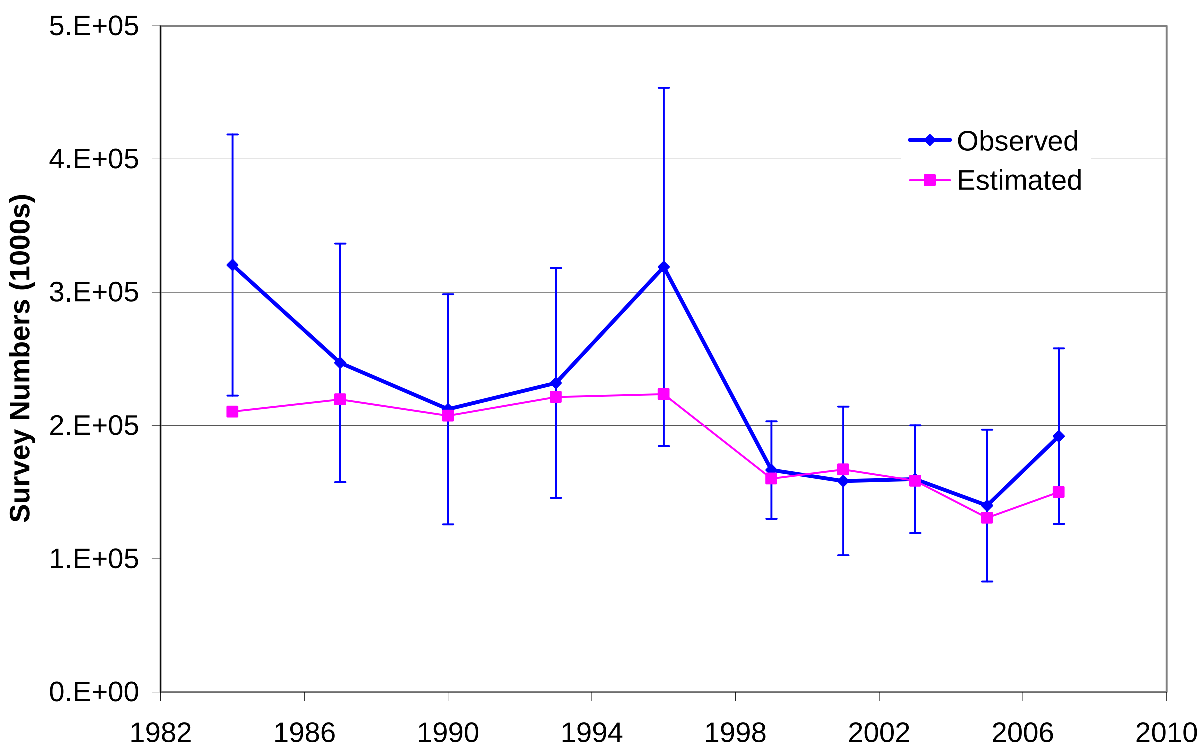

Figure 2.2—Relative abundance (in numbers) as observed by the survey and estimated by the model.

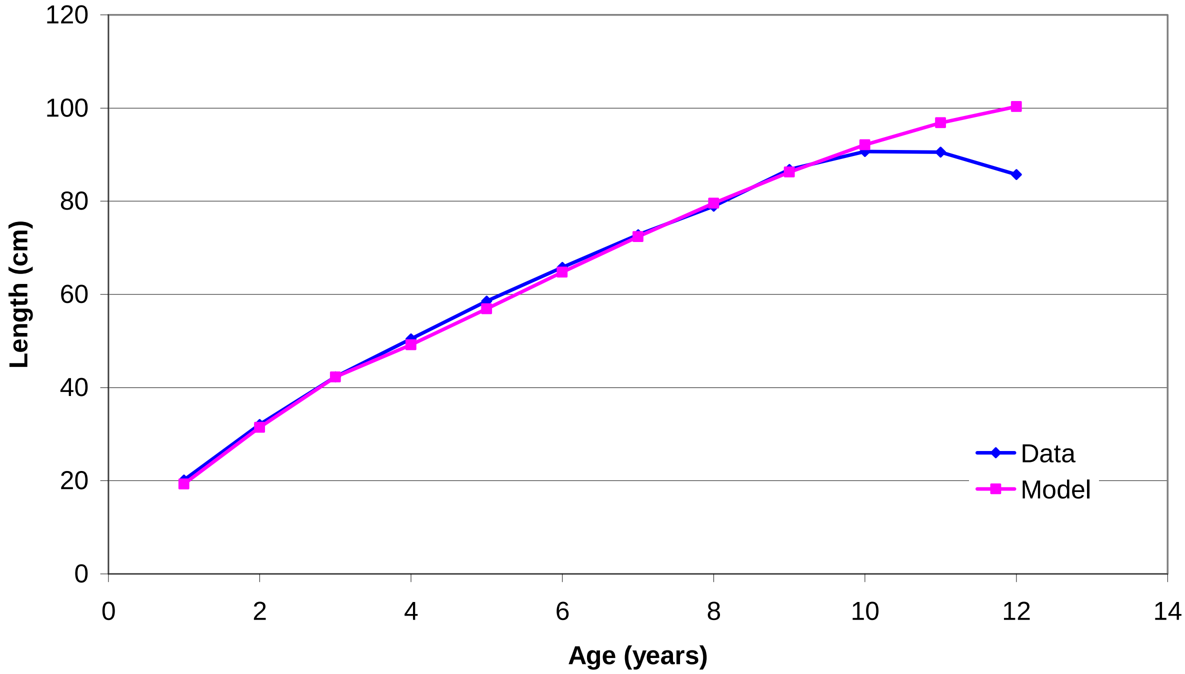

Figure 2.3—Mean length at age as measured during the trawl survey.

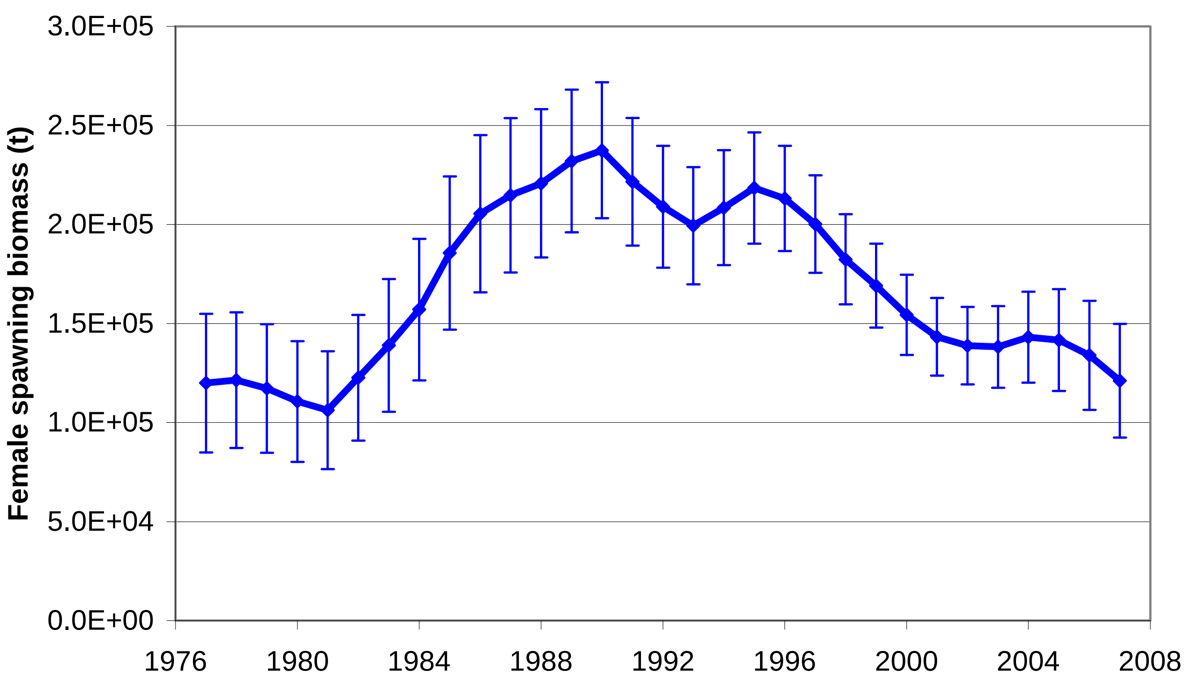

Figure 2.4—Time series of GOA Pacific cod female spawning biomass, with 95% confidence intervals, as determined by final parameter estimates.

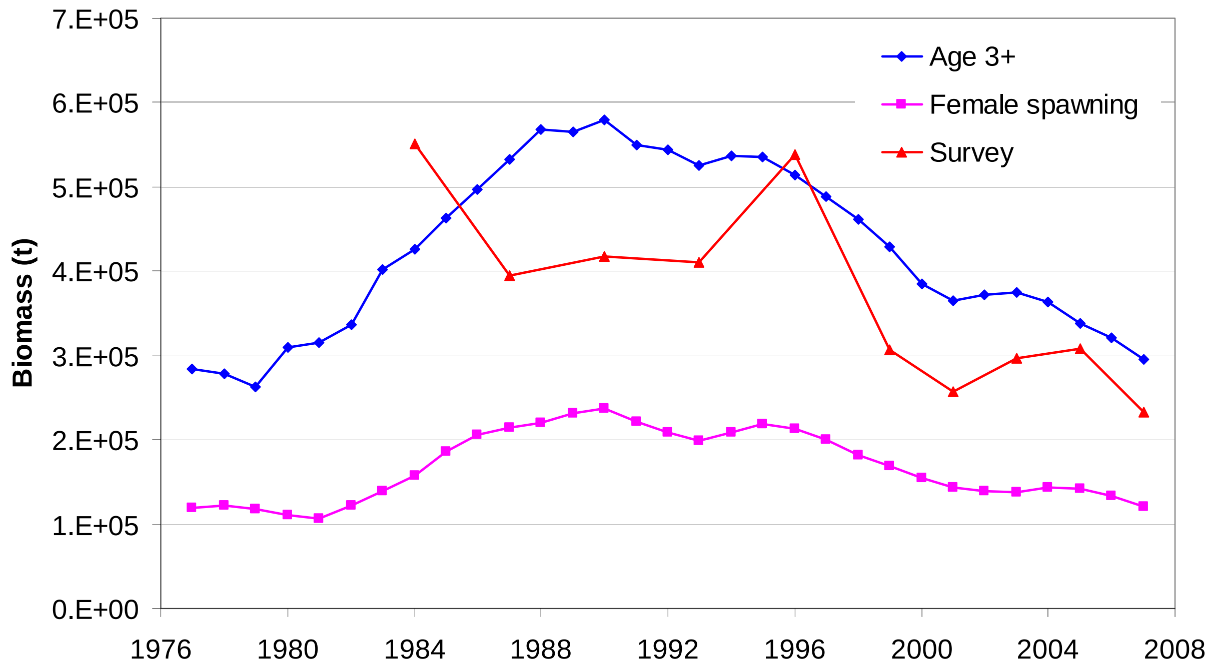

Figure 2.5—Biomass time trends (age 3+ biomass, female spawning biomass) of GOA Pacific cod as determined by final parameter estimates. Observed survey biomass shown for comparison.

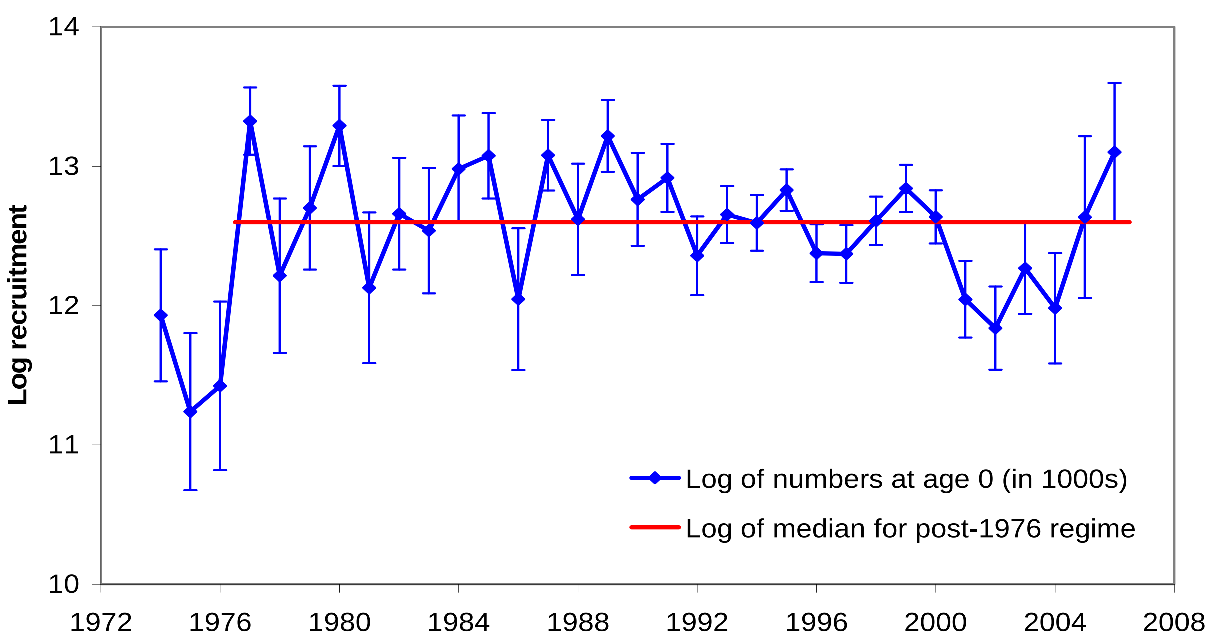

Figure 2.6—Time series of GOA Pacific cod recruitment at age 0, with 95% confidence intervals, as determined by final parameter estimates.

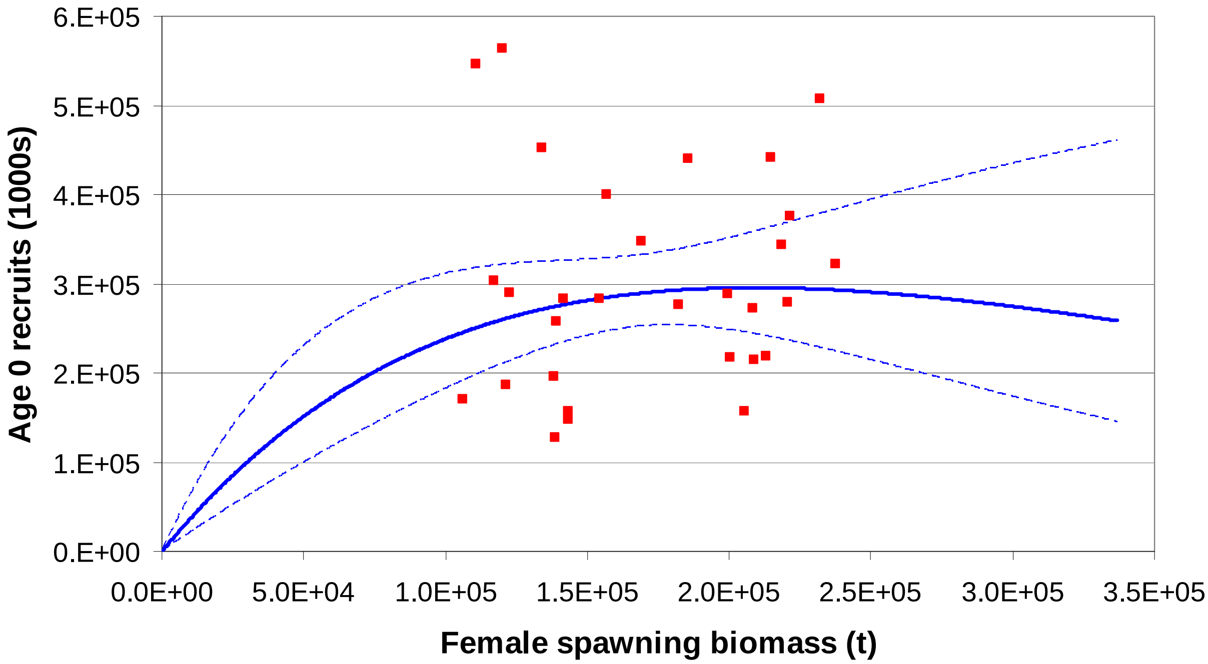

Figure 2.7—Age 0 recruitment versus female spawning biomass for Pacific cod during the years 1977-2006, with Ricker stock-recruitment curve (for illustrative purposes only).

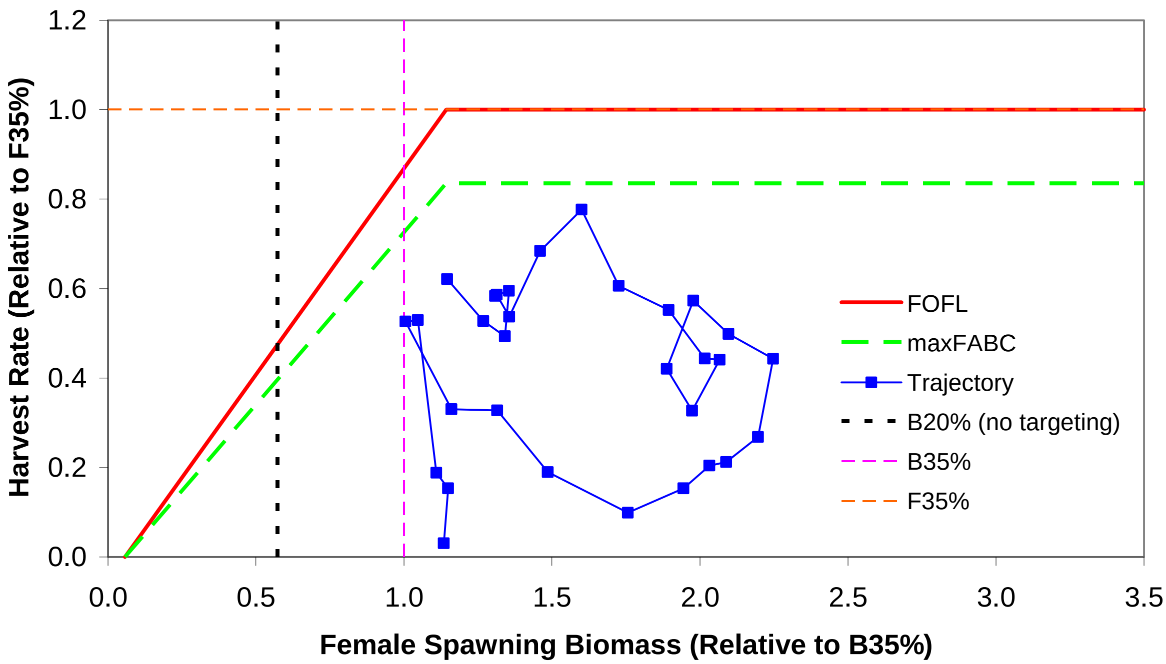

Figure 2.8—Trajectory of GOA Pacific cod fishing mortality and female spawning biomass as determined by final parameter estimates, 1977-2006. Because Pacific cod is a key prey of Steller sea lions, harvests of Pacific cod would be restricted to incidental catch in the event that spawning biomass fell below $B_{20\%}$. The values for 2007 are F/F35%=0.621, B/B35%=1.146.