Attachment 2A.1:
Exploration of alternative assessment models for Pacific cod in the Aleutian Islands

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Introduction

This document represents an effort to respond to comments made by the BSAI Plan Team, the joint BSAI and GOA Plan Teams, and the SSC regarding the need to develop an age-structured model of the Pacific cod (*Gadus macrocephalus*) stock in the Aleutian Islands (AI). Throughout the history of management under the Magnuson-Stevens Fishery Conservation and Management Act, Pacific cod in the eastern Bering Sea (EBS) and AI have been managed as a unit. Since at least the mid-1980s, harvest specifications for the combined BSAI unit have been extrapolated from an age-structured model for Pacific cod in the EBS.

The importance of recognizing stock distinctions in management of gadids in general has received attention in recent years (e.g., Fu and Fanning 2004, Hutchinson 2008). In particular, several white papers and a stock structure report provide various lines of evidence suggesting that Pacific cod in the EBS and AI should be viewed as separate stocks. Recent studies provide evidence for genetic distinctiveness and lack of gene flow between the Aleutian Islands and Eastern Bering Sea (e.g., Canino et al. (2005), Cunningham et al. (2009), Canino et al. (2010), Spies (2012)).

In light of this evidence, in 2010 the SSC requested that a separate assessment be prepared for Pacific cod in the AI. In response, the 2011 assessment contained a Tier 5 assessment of Pacific cod in the AI (Thompson and Lauth 2011). However, in December 2011, the SSC determined that it would be preferable to wait until an age-structured model was accepted for AI Pacific cod before splitting the BSAI harvest specifications. In response, the 2012 assessment contained a set of alternative age-structured models for AI Pacific cod (Thompson and Lauth 2012). In December 2012, the SSC did not accept any of these models for use in setting harvest specifications. Although the SSC did not split the harvest specifications at that time, it determined that it would begin splitting the harvest specifications in December 2013, regardless of whether an age-structured model is accepted at that time.

Responses to SSC and Plan Team Comments on Assessments in General

SSC minutes (June, 2012)

SSC1: "We note that stock assessment authors are free to develop and bring forward an alternative model or models in both the preliminary and final assessment." All of the models in this preliminary assessment are new models developed by the authors (see also comment JPT1).

SSC minutes (December, 2012)

SSC2: "The SSC recommends that the authors consider whether it is possible to estimate *M* with at least two significant digits in all future stock assessments to increase validity of the estimated OFL." The natural mortality rate *M* is reported to two significant digits in this preliminary assessment.

Joint Plan Team minutes (May, 2013)

JPT1: "For the last two years, the Teams have reserved the right to request that the author's preferred model be excluded from the final assessment. Upon further reflection and consideration of the SSC's June 2012 minute stating that authors are free to include their own models in both the preliminary and final assessments, the Teams decided to abandon their previous policy. The Teams recommend that authors feel free to include their own models in both the preliminary and final assessments." See comment SSC1.

Responses to SSC and Plan Team Comments on Aleutian Islands Assessments in General

SSC minutes (December, 2012)

SSC3: "The SSC requests that all assessment authors of AI species evaluate AI survey information to ensure that the same standardized survey time series is used." See comments SSC4 and SSC5.

SSC minutes (April, 2013)

SSC4: "Aleutian Islands groundfish stock assessment authors asked for a clarification from the SSC about its December 2012 recommendation for AI assessments to use the same set of years in the AI survey time series. The SSC was asked to comment on whether it would be acceptable for assessment authors to deviate from this recommendation if there was a strong rationale for doing so. The SSC had a brief discussion on this matter and determined that it would be acceptable for assessments to use different sets of years in the AI survey time series if this was accompanied by a scientific rationale for doing so." The authors of all AI assessments containing age-structured models discussed the SSC request for standardization of the years included in the time series. These authors noted the following difficulties with the pre-1991 surveys:

- The dimensions and configurations of the nets used in the pre-1991 surveys varied among nations and years.
- Data from the Japanese vessels were excluded from the 1980 biomass estimate, but the two U.S. vessels in that year used two different nets: one used an Eastern trawl, the other a Noreastern trawl very similar to the one used in recent surveys (high rise Polynoreastern).
- In 1983 and 1986, data from both Japanese and U.S. vessels are used in the estimates, but the Japanese used different gears in those two years.
- For both 1983 and 1986, the U.S. vessels used the Noreastern net.

Because of these difficulties, the authors recommended omitting the pre-1991 survey data from the standard time series (see also comments SSC3 and SSC5).

SSC minutes (June, 2013)

SSC5: "The SSC agrees with the Team and the AI authors that pre-1991 survey data should be omitted from the assessment." Pre-1991 survey data are omitted from this preliminary assessment (see also comments SSC3 and SSC4).

Responses to SSC and Plan Team Comments Specific to Aleutian Islands Pacific Cod

SSC minutes (December, 2012)

SSC6: "The SSC encourages further model development but had no specific suggestions beyond those identified in Plan Team discussions and the possibility of obtaining additional age composition data from archived otoliths." Age data from the entire AI bottom trawl survey time series were requested this year. Data from the 2006, 2010, and 2012 surveys were identified as "mission critical," and were originally scheduled to be available in time for this year's final assessment. However, an unexpected loss of personnel in the Alaska Fisheries Science Center's Age and Growth Program has resulted in the removal of the 2006 and 2010 collections from this list. Age data from the 2012 AI bottom trawl are still scheduled to be available in time for use in this year's final assessment.

Joint Plan Team minutes (May, 2013)

JPT2: **"**For the preliminary AI assessment, the Teams recommend that the author have discretion over any and all models to be included. The Teams noted that no model for this stock has been accepted by the SSC and that a significant amount of development and analysis still needs to occur before a model for this stock can be recommended with confidence. The Teams understand that the SSC will recommend separate EBS and AI harvest specifications for 2014 regardless of whether a model is accepted this year. Although the Teams are not recommending any specific models for the AI stock, one member suggested that the author might consider starting the model in 1977 but omitting survey data prior to 1991, as was done in last year's AI Model 4." The authors have used their best judgment in arriving at a set of alternative models for this preliminary assessment, in the hope that these will provide a sound basis for Team and SSC recommendations regarding a set of models to be included in the final assessment (see also comment SSC7). As noted under comments SSC4 and SSC5, survey data prior to 1991 have been omitted from the models.

SSC minutes (June, 2013)

SSC7: "For the preliminary AI assessment, the SSC has no additional suggestions at this time and is looking forward to a revised and updated assessment model." See response to comment JPT2.

SSC8: "To improve biomass estimates in the Aleutians, we further encourage an examination of existing longline survey data (sablefish and IPHC) to determine if a cooperative, cost-effective longline survey could be developed in the Aleutians and to determine if these data should be incorporated into the AI Assessment." Existing longline survey data were not examined for use in this preliminary assessment, in part because there was insufficient time to do so, and in part because previous experiences with use of longline survey data in the EBS Pacific cod model were not encouraging. Here is a brief history of the use of longline survey data in the EBS Pacific cod model:

- Data from the sablefish longline survey were included in some of the models explored in the 2006 assessment, but the authors concluded that these were unhelpful: "While it may be possible to develop usable indices from these surveys in the future, the present indices seem too problematic, for the following reasons: 1) the available abundance indices for Pacific cod (unlike those for sablefish) do not include appropriate area expansion factors, 2) the interannual variability in the available abundance indices from the Japanese longline survey is extreme, and 3) the sample size in the U.S. longline survey is small (only 11 stations have been successfully sampled in every year)" (Thompson et al., 2006, p. 258). The SSC concurred: "With regard to the longline data, the SSC suggests excluding them from future assessments" (December 2006 minutes).
- Data from the IPHC longline survey were included in at least one model in all assessments from 2007-2010. In the 2009 assessment, the observed values of the IPHC survey index were negatively correlated with the estimated values from all 14 models included in that assessment (Thompson et al. 2009, p. 301). As a result, the SSC concluded, "The IPHC survey does not appear to inform the model and should be removed" (December 2009 minutes). The SSC reiterated this conclusion the following June: "(One) SSC proposal … is to exclude IPHC survey

data in the BSAI, because it conflicts with other data series" (June 2010 minutes).

Although previous experiences with use of longline survey data in the EBS model were not encouraging, it should be noted that one of the previous problems with use of the sablefish longline survey data (*viz*., lack of area expansion factors) has since been resolved. Also, the fact that use of longline survey data did not appear to be helpful in the EBS Pacific cod model does not preclude the possibility that use of such data would be helpful in the AI Pacific cod model, so this possibility will be explored in the future, with a particular eye toward whether the usefulness of the existing data merit development of an entire new longline survey.

Data

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

The following table summarizes the sources, types, and years of data included in the data file for one or more of the stock assessment models:

Source	Type	Years
Fishery	Catch biomass	1977-2012
Fishery	Catch size composition	1978-2012
AI bottom trawl survey	Numerical abundance	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012
AI bottom trawl survey	Size composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012

Fishery

Catch biomass

Total catch data are shown in Tables 2A.1.1a, 2A.1.1b, and 2A.1.1c for the years 1964-2012. The catch data used in the models begin in 1977.

Compared to earlier years, catches dropped sharply in 2011 and remained low in 2012, which may have been due, at least in part, to recent management measures designed to protect Steller sea lions.

Size Composition

Table 2A.1.2 shows the total number of fish measured at each 1 cm interval from 4-120+ cm, by year, in the fishery. Overall, the AI fishery size compositions reflect a higher proportion of fish 100 cm or greater than is the case in the EBS fishery (6.7% in the AI versus 0.6% in the EBS).

The actual sample sizes for the fishery size composition data are shown below:

Year:	1978	1979	1982	1983	1984	1985	1990	1991
N:	1729	1814	4437	5072	5565	3602	4206	22653
Year:	1992	1993	1994	1995	1996	1997	1998	1999
N:	10265	46775	29716	30870	42610	23762	74286	34027
Year:	2000	2001	2002	2003	2004	2005	2006	2007

N:	52435	57750	23442	23690	23990	20754	20446	27543

Year:	2008	2009	2010	2011	2012
N:	26282	21954	34329	8879	8922

Fishery length composition sample sizes in the AI tend to be much lower than those in the EBS; the average in the AI is 27,000 fish, which is only 13.5% of the 200,000 fish average in the EBS.

Survey

Biomass and Numerical Abundance

The time series of trawl survey biomass and numerical abundance are shown for Areas 541-543, together with their respective coefficients of variation, in Table 2A.1.3. These estimates pertain to the Aleutian *management* area, and so are smaller than the estimates pertaining to the Aleutian *survey* area that have been reported in past BSAI Pacific cod stock assessments.

As in recent assessments of Pacific cod in the EBS, the models developed here use survey estimates of population size measured in units of individual fish rather than biomass.

Trawl survey estimates of Pacific cod in the AI tend to be much less precise than their EBS counterparts. The table below compares coefficients of variation from the surveys in the two areas, in terms of both biomass and numerical abundance:

	Biomass		Numbers	
Statistic	EBS	AI	EBS	AI
Min.	0.055	0.134	0.060	0.122
Mean	0.085	0.195	0.106	0.189
Max.	0.183	0.288	0.267	0.310

Size Composition

Table 2A.1.4 shows the total number of fish measured at each 1 cm interval from 4-120+ cm, by year, in the survey. As with the fishery, the overall AI survey size compositions reflect a higher proportion of fish 100 cm or greater than is the case in the EBS survey (0.8% in the AI versus 0.1% in the EBS).

The actual sample sizes for the survey size composition data are shown below:

Year:	1991	1994	1997	2000	2002	2004	2006	2010	2012
N:	7125	7497	4635	5178	3914	3721	2784	3521	3278

Analytic Approach

Model Structure

Three models are presented in this assessment, all of which are estimated using Stock Synthesis (SS, Methot and Wetzel 2013). All three models differ from last year's accepted EBS model (Thompson and Lauth 2012) in the following respects:

1. In the data file, length bins (1 cm each) are extended out to 150 cm instead of 120 cm, because of the higher proportion of large fish observed in the AI.
2. Each year consists of a single season instead of five.
3. A single fishery is defined instead of nine season-and-gear-specific fisheries.
4. The survey samples age 1 fish at true age 1.5 instead of 1.41667.
5. Ageing bias is not estimated (because there are no age data) instead of estimated.
6. Selectivity for both the fishery and survey is modeled using a random walk with respect to age (SS selectivity-at-age pattern #17, described below) instead of the usual double normal (SS selectivity-at-length pattern #24 for the fisheries and SS selectivity-at-age pattern #20 for the survey).

Selectivity-at-age pattern #17 in SS has one parameter for each age in the model. Except for age 0, the parameter for any given age represents the logarithm of the ratio of selectivity at that age to selectivity at the previous age (*d*). Age 0 fish are often expected to have a selectivity of zero, which can be achieved in this selectivity pattern by setting the parameter for age 0 equal to -1000, as was done for all three models presented here. As with other parameters in SS, each parameter in this selectivity pattern is associated with a prior distribution (which can be uniform, if desired).

The three models presented here are, to some extent, hybrids of last year's AI Models 1 and 4 (Attachment 2.2 in Thompson and Lauth 2012). Like last year's AI Model 1, survey catchability (*Q*) is constant, and survey selectivity is not constrained to be asymptotic. Like last year's AI Model 4, pre-1991 survey data are excluded, the standard deviation of log-scale age 0 recruitment is estimated internally, length composition sample sizes are (potentially) tuned iteratively, and fishery selectivity is (potentially) time-varying.

The three models are distinguished from one another by their respective treatments of the natural mortality rate (*M*) and *Q*:

- Model 1 (fixed *M*, tuned *Q*): The natural mortality rate is fixed at the accepted EBS value of 0.34. Catchability is tuned so that the average of the product of *Q* and selectivity across the 60-81 cm size range matches the value of 0.92 estimated by Nichol et al. (2007) for the AI survey net. These two assumptions match those used in all four of last year's AI models, and are similar to the assumptions used in the accepted EBS model (except that the EBS model uses a value of 0.47 to tune *Q* rather than 0.92, due to the use of a survey net with a lower headrope in the EBS).
- Model 2 (fixed *M*, constrained *Q*): As in Model 1, *M* is fixed at the accepted EBS value of 0.34. A meta-analytic prior distribution for ln(*Q*) was derived by averaging the parameters (or transformed parameters) of the prior distributions used in the other age-structured assessments of AI stocks. These are shown below:

Stock	Form	Mean	CV	Equivalent lognormal sigma
Atka mackerel	Normal	1	0.2	0.198042
Blackspotted/rougheye	Lognormal	1	0.05	0.049969
Northern rockfish	Lognormal	1	0.001	0.001000
Pacific ocean perch	Lognormal	1	0.45	0.429421
Pollock	Fixed	1	0	0.000000
Shortraker	Fixed	1	0	0.000000
Average		1	0.12	0.11

Because SS requires *Q* to be modeled on a log scale, Model 2 uses a normal prior distribution for ln(*Q*) with $\mu = 0.00$ (=ln(1.0)) and $\sigma = 0.11$.

- Model 3 (free *M*, free *Q*): Both *M* and *Q* are estimated with non-constraining uniform prior distributions.

Development of the final versions of all models included calculation of the Hessian matrix. These models also passed a "jitter" test of 50 runs with a jitter parameter (equal to half the standard deviation of the logit-scale distribution from which initial values are drawn) of 0.01. In the event that a jitter run produced a better value for the objective function than the base run, then: 1) the model was re-run starting from the final parameter file from the best jitter run, 2) the resulting new control file became the new base run, and 3) the entire process (starting with a new set of jitter runs) was repeated until no jitter run produced a better value for the objective function than the most recent base run.

Except for the ln(*Q*) parameter in Model 2 and the selectivity and *dev* parameters in all models, all parameters were estimated with uniform prior distributions. Bounds were non-constraining in all cases.

The software used to run all models was SS V3.24q, as compiled on 5/20/2013 (the most recent user manual is for SS V3.24f, Methot 2012). Stock Synthesis is programmed using the ADMB software package (Fournier et al. 2012).

Iterative Tuning Procedures Used for Model 2

Because this preliminary assessment is only an exploration of alternative models, and in the interest of time, the following procedures were applied to Model 2 only (i.e., Models 1 and 3 used the tuned quantities from Model 2, rather than retuning these quantities individually for Models 1 and 3).

Length Composition Sample Sizes

The following procedure was used to allow for the possibility of downweighting the length composition sample sizes:

1. Initially, set the "multiplier" (a weight applied to the input sample sizes specified in the data file) for the fishery and survey length compositions to unity.
2. Compute the arithmetic mean input sample size for each year in the fishery and survey (*ave_inp*).
3. Run SS to obtain the harmonic mean effective sample size for the fishery and survey (*har_eff*).
4. For both the fishery and the survey, compute a new value for the multiplier as min(1.0, multiplier× *har_eff*/*ave_inp*). The idea behind setting an upper value of unity on the multiplier is that obtaining a better-than-expected fit is not particularly undesirable, but obtaining a worse-than-expected fit indicates that some tuning is appropriate.
5. Return to step 3. Repeat until the multipliers (fishery and survey) stop changing.

Parameters of Selectivity Prior Distributions

As noted above, each age-specific parameter *d*(*a*) in SS selectivity-at-age pattern #17 is associated with a prior distribution. One special case consists of a normal prior distribution with a constant mean and variance. If the constant variance is specified *a priori* and the constant mean is estimated iteratively, this special case should be equivalent to the second-difference approach used in some other BSAI groundfish stock assessments, and will tend as a default (i.e. in the absence of information to the contrary) to produce a selectivity curve that increases (for positive mean) exponentially with age (assuming that the second differences are computed with respect to the logarithm of selectivity rather than selectivity itself). As an alternative to exponential selectivity, the models presented here utilized logistic selectivity as the default form. This was accomplished as follows:

1. Choose a value for the age above which selectivity is not expected to change (*amax*, which was set equal to age 10 here).
2. Parameterize the default selectivity equation as $s(a|\alpha,\beta)=(1+\exp(\alpha\cdot(a-\beta)))^{-1}$, where s represents selectivity, a represents age, and α and β are parameters. A negative value of α causes selectivity to increase with age in this default equation, but note that this does *not* necessarily imply that the final selectivity schedule (i.e., as estimated by SS) will be monotone increasing.
3. Uncertainty in the values of α and β are represented by a pair of normal distributions. Set initial guesses as to the mean values of α and β (μ_α, μ_β) and a common standard deviation ($\sigma_{\alpha\beta}$). The quantities μ_α, μ_β, and $\sigma_{\alpha\beta}$ serve a role akin to the hyper-parameters in a hierarchical Bayes approach.
4. Generate a large sample of $N(\mu_\alpha,\sigma_{\alpha\beta}^2)$ and $N(\mu_\beta,\sigma_{\alpha\beta}^2)$ random values for α and β.
5. For each pair of α and β values generated above and each age 1 through *amax*, compute $d(a|\alpha,\beta)=\ln(s(a|\alpha,\beta)/s(a-1|\alpha,\beta))$. This will result in a vector of values for d at each age (with each element in the vector corresponding to one random (α,β) pair).
6. Set the prior mean and prior standard deviation for each parameter (i.e., age) in SS equal to the mean (μ_d) and standard deviation (σ_d) of the corresponding age-specific d vector. Fix parameters for all a>*amax* at 0.
7. Run SS to obtain a vector of selectivity parameter estimates δ.
8. Determine new values for μ_α and μ_β by minimizing the sum (across age) of squared differences between the estimated value of d and the corresponding prior mean.
9. Form a vector of standardized residuals as $(\delta(a)-\mu_d(a))/\sigma_d(a)$ for each age 1 through *amax*.
10. Determine a new value for $\sigma_{\alpha\beta}$ by setting the root-mean-squared-standardized residual equal to unity. This is done iteratively by trial and error, using interpolation or extrapolation to arrive at each new candidate value of $\sigma_{\alpha\beta}$, and repeating steps 4 through 6 for each candidate value until the desired result is achieved.
11. Return to step 4. Repeat until the values of μ_α, μ_β, and $\sigma_{\alpha\beta}$ stop changing.
12. Fix (i.e., turn off estimation of) any parameters with prior standard deviations so small that estimation is superfluous.

As indicated in step 2 above, the fact that the default selectivity curve is logistic does *not* necessarily imply that the final selectivity schedule (i.e., as estimated by SS) will be logistic, or even monotone increasing. This is one of the potential advantages of SS selectivity-at-age pattern #17: Because the parameters describe *changes in selectivity between ages*, rather than *selectivity at age*, it is possible to specify prior distributions that are *consistent* with logistic selectivity without *forcing* the estimated selectivity schedule to be logistic. This is not the case, for example, with double-normal selectivity, because it is impossible to specify a prior mean of unity for selectivity at the maximum age unless the prior standard deviation is zero, because it is impossible for selectivity at any age to exceed unity.

Time-Varying Selectivity

The following procedure was used to allow for the possibility of time-varying selectivity:

1. Initially, allow additive *dev*s for each selectivity parameter, and specify a moderate standard deviation for each.
2. Run SS to obtain a vector of estimated *dev*s for each selectivity parameter.
3. Compute the standard deviation of the estimated *dev*s for each selectivity parameter.
4. Change each specified standard deviation in the SS control file to the value computed in step 3.
5. Return to step 2. Repeat until the specified standard deviations stop changing.
6. Remove *dev* vectors for any parameter where the *dev*s are so small as to have negligible effect.

To keep the selectivity parameters from becoming too small or large to exponentiate accurately once *dev*s were added the *d* vector (recall that *d* is expressed on a logarithmic scale), an option in SS was invoked to scale the *dev*s using a logistic transform as follows:

$$par_{a,y} = \frac{(d_a - lo)\cdot hi + (hi - d_a)\cdot lo \cdot \exp(-2\cdot dev_{a,y})}{(d_a - lo) + (hi - d_a)\cdot \exp(-2\cdot dev_{a,y})} \quad ,$$

where *par* is the *dev*-adjusted selectivity parameter, *a* is age, *y* is year, and *lo* and *hi* are the user-specified lower and upper bounds on admissible values of *par*.

Parameters Estimated Outside the Assessment Model

Some parameters were fixed externally at values borrowed from the EBS Pacific cod model:

1. The natural mortality rate was fixed at 0.34 in Models 1 and 2 (*M* was estimated in Model 3).
2. The parameters of the logistic maturity-at-age relationship were set at values of 4.88 years (age at 50% maturity) and –0.965 (slope) in all models.

In all three models, weight (kg) at length (cm) was assumed to follow the usual form weight=A×length^B and to be constant across the time series, with *A* and *B* estimated at 5.683×10^{-6} and 3.18, respectively, based on 8,126 samples collected from the AI fishery between 1974 and 2011.

Parameters Estimated Inside the Assessment Model

Parameters estimated inside SS for all models include the von Bertalanffy growth parameters, standard deviation of length at ages 1 and 20, log mean recruitment since the 1976-1977 regime shift, offset for log-scale mean recruitment prior to the 1976-1977 regime shift, *dev*s for log-scale initial (i.e., 1977) abundance at ages 1 through 3, annual log-scale recruitment *dev*s for 1977-2011, initial (equilibrium) fishing mortality, base values for all fishery and survey selectivity parameters, and annual *dev*s for the parameters corresponding to ages 2 and 3 in the survey selectivity function (all fishery *dev*s, and survey *dev*s at all ages other than 2 and 3, were "tuned out" during the iterative tuning process).

Log-scale survey catchability was estimated iteratively in Model 1 by matching the average (weighted by numbers at length) of the product of catchability and selectivity for the 60-81 cm size range equal to the point estimate of 0.92 obtained by Nichol et al. (2007). Log-scale survey catchability was estimated internally in Models 2 and 3.

For all parameters estimated within individual SS 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 and the logarithm of the likelihood function.

In addition to the above, the full set of year-specific fishing mortality rates are also estimated internally, but not in the same sense as the above parameters. The fishing mortality rates are determined exactly rather than estimated statistically because SS 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.

Likelihood Components

All three models include likelihood components for initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, recruitment, prior distributions, "softbounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations.

In SS, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. As in the EBS Pacific cod assessment, all likelihood components were given an emphasis of 1.0 here.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular fleet (fishery or survey) and year. In the parameter estimation process, SS weights a given size composition observation 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. The steps used to scale the sample sizes here were nearly identical to those used in the EBS Pacific cod assessment: 1) Records with fewer than 400 observations were omitted. 2) The sample sizes for fishery length compositions from years prior to 1999 were tentatively set at 16% of the actual sample size, and the sample sizes for fishery length compositions after 1998 and all survey length compositions were tentatively set at 34% of the actual sample size. 3) All sample sizes were adjusted proportionally to achieve an overall average sample size of 300.

The resulting input sample sizes for *fishery* length composition data are shown below:

Year:	1978	1979	1982	1983	1984	1985	1990	1991	1992	1993	1994	1995
N:	15	16	39	44	49	31	37	198	897	409	260	270

Year:	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
N:	372	208	649	632	973	1072	435	440	445	385	379	511

Year:	2008	2009	2010	2011	2012
N:	488	407	637	165	166

The resulting input sample sizes for *survey* length composition data are shown below:

Year:	1991	1994	1997	2000	2002	2004	2006	2010	2012
N:	132	139	86	96	73	69	52	65	61

Use of Survey Relative Abundance Data in Parameter Estimation

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 abundance datum itself serves as the distribution's coefficient of variation, which is then transformed into the "sigma" parameter for the lognormal distribution.

Use of Recruitment Deviation "Data" in Parameter Estimation

The likelihood component for recruitment is different from traditional likelihoods because it does not involve "data" in the same sense that traditional likelihoods do. Instead, the log-scale recruitment *dev* plays the role of the datum in a normal distribution with mean zero and specified (or estimated) standard deviation; but, of course, the *dev*s are parameters, not data.

Results

Overview

The following table summarizes the status of the stock as estimated by the three models ("Estimate" is the point estimate, "CV" is the ratio of the standard deviation to the point estimate, "SB(2012)" is female spawning biomass in 2012 (t), and "Bratio(2012)" is the ratio of SB(2012) to $B_{100\%}$):

	Model 1		Model 2		Model 3	
	Estimate	CV	Estimate	CV	Estimate	CV
SB(2012)	62,715	0.123	114,456	0.147	1,021,380	0.528
Bratio(2012)	0.247	0.135	0.336	0.133	0.599	0.099

The estimates of both absolute and relative spawning biomass in 2012 are lowest in Model 1 and highest in Model 3. The CVs associated with these estimates are not dramatically different between models, except for Model 3's estimate of absolute spawning biomass in 2012, which has a much higher CV than the estimates of the other two models (in contrast, the CV of Model 3's estimate of relative spawning biomass in 2012 is slightly lower than those of the other two models).

Model 2 has one more free parameter (ln(Q)) than Model 1, and Model 3 has one more free parameter (M) than Model 2, giving totals of 114, 115, and 116 parameters for Models 1, 2, and 3, respectively. Other differences are that Model 1 tunes ln(Q) iteratively to satisfy a criterion external to the maximum likelihood criterion used to estimate other parameters and Model 2 has a prior distribution on ln(Q).

Here are the values of ln(Q), Q, and M assumed or estimated in the three models:

Parameter	Model 1	Model 2	Model 3
ln(Q)	0.29	-0.43	-2.67
Q	1.33	0.65	0.07
M	0.34	0.34	0.36

Note that the Q values differ by about an order of magnitude between Model 2 and Model 1 and again between Model 3 and Model 2, but Model 3's internal estimate of M is very close to the value assumed for the other two models.

Goodness of Fit

Objective function values are shown for each model below (lower values are better, all else being equal; objective function components with a value less than 0.0005 for all models are omitted for brevity; color scale extends from red (minimum) to green (maximum)):

Obj. func. component	Model 1	Model 2	Model 3
Survey abundance	9.502	-3.388	-10.252
Size composition	358.911	336.031	336.888
Recruitment	19.382	18.964	0.575

Priors	12.282	17.249	8.525
Deviations	8.902	8.086	7.467
Total	408.979	376.942	343.204

The table below shows four statistics related to goodness of fit with respect to the survey abundance data (color scale extends from red (minimum) to green (maximum)). Relative values of the four statistics can be interpreted as follows: correlation—higher values indicate a better fit, root mean squared error—lower values indicate a better fit, average of standardized residuals—values closer to zero indicate a better fit, root mean squared standardized residual—values closer to unity indicate a fit more consistent with the sampling variability in the data.

Statistic	Model 1	Model 2	Model 3
Correlation (observed:expected)	0.882	0.900	0.932
Root mean squared error	0.375	0.253	0.176
Average of standardized residuals	-1.467	-0.663	0.023
Root mean squared standardized residual	2.361	1.647	1.089

By any of the above measures, Model 3 fits the survey abundance data best and Model 1 fits them worst.

Figure 2A.1.1 shows the fits of the three models to the trawl survey abundance data. Model 1's estimates are higher than the observed values in all years prior to 2010. Model 2's estimates are also higher than the observed values on average, but not by as much as Model 1's estimates. Model 3 has a fairly good residual pattern. The point estimates from Models 1 and 2 fall within the 95% confidence intervals of the observations in 6 of the 9 years, while the point estimates from Model 3 do so in 8 of the 9 years (all three models miss the 95% confidence interval in 1997). All three models estimate a 2012 survey biomass lower than the observed value.

The table below shows the mean of the ratios between the harmonic mean effective sample size and average input sample size (*ave_inp*) for the size composition data, thus providing an alternative measure of how well the models are fitting these data (higher values are better, all else being equal). All three models give ratios much greater than unity for both the fleet and survey.

Fleet	*ave_inp*	Model 1	Model 2	Model 3
Fishery	366.5	2.06	2.07	1.82
Survey	85.9	3.49	4.58	5.45

Figures 2A.1.2 and 2A.1.3 show the three models' fits to the fishery size composition and survey size composition data, respectively.

Iterative Tuning of Model 2 and Parameter Estimates From All Models

Both the fishery and survey length composition components in Model 2 had harmonic mean effective sample sizes greater than the average input sample sizes with each multiplier set to unity, so no tuning of sample sizes was necessary.

In tuning the parameters of the selectivity prior distributions, the parameters for ages 7-10 in the fishery were "tuned out," because the estimated fishery selectivity schedule was strongly asymptotic, and the tuned values of σ_d were essentially zero after age 6. The tuned values of μ_d and σ_d are shown for both the fishery and survey below (values were tuned to two significant digits; i.e., one digit beyond the decimal point in scientific notation):

		Age					
Fleet	Parameter	1	2	3	4	5	6
Fishery	μ_d	4.0E+00	4.0E+00	3.5E+00	8.9E-01	2.6E-02	4.9E-04
Fishery	σ_d	3.8E-01	4.0E-01	7.5E-01	8.1E-01	1.3E-01	4.9E-03
Survey	μ_d	1.5E+00	1.3E+00	8.0E-01	2.8E-01	6.9E-02	1.4E-02
Survey	σ_d	9.8E-01	9.3E-01	7.9E-01	5.3E-01	2.7E-01	1.5E-01

		Age			
Fleet	Parameter	7	8	9	10
Survey	μ_d	2.9E-03	6.0E-04	1.2E-04	2.4E-05
Survey	σ_d	1.3E-01	1.3E-01	1.3E-01	1.3E-01

In terms of time-varying selectivity, all fishery dev vectors were tuned out (i.e., the fishery ended up exhibiting constant selectivity over time at all ages), and all survey dev vectors except those at ages 2 and 3 were tuned out. The tuned values of the sigma parameters for ages 2 and 3 in the survey were 0.114 and 0.045, respectively.

Table 2A.1.4 displays all of the parameters (except fishing mortality rates) estimated internally in any of the models. Table 2A.1.4a shows natural mortality, growth, recruitment (except annual *dev*s), initial fishing mortality, catchability, and initial age composition parameters as estimated internally by at least one of the models. Table 2A.1.4b shows annual log-scale recruitment *dev*s as estimated by all of the models. These are plotted in Figure 2A.1.4, where it is apparent that all models show a high degree of synchrony, particularly during the years covered by the survey. Table 2A.1.4c shows selectivity parameters and *dev*s for the age 2 and 3 survey selectivity parameters as estimated by all of the models.

The parameter estimates in Table 2A.1.4 imply the following values for the average of the product of catchability and survey selectivity across the 60-81 cm size range (note that the value corresponding to the height of the headrope in the AI bottom trawl survey net is 0.92, compared to 0.47 for the EBS bottom trawl survey net; the ln(*Q*) parameter in Model 1 was tuned explicitly to achieve a value of 0.92):

Model 1	Model 2	Model 3
0.92	0.48	0.06

Table 2A.1.5 shows estimates of average fishing mortality rates across ages 5-8 for the three models (note that these are not counted as parameters in SS, and so do not have estimated standard deviations).

Estimates of Time Series

Figure 2A.1.5 shows the time series of spawning biomass relative to $B_{100\%}$ as estimated by the three models (note that SS measures spawning biomass at the start of the year and uses a different estimator of mean recruitment than the AFSC's standard projection model). All of the models show a peak ratio in either 1994 or 1996, followed by a monotonic decline through 2012. Model 3 peaks at a ratio of about 1.4, but the ratios for Models 1 and 2 never reach unity.

Figure 2A.1.6 shows the time series of total (age 0+) biomass as estimated by the three models, with the trawl survey biomass estimates included for comparison. All models estimate biomasses much higher than observed by the survey. The biomasses estimated by Model 3 are truly immense, due to that model's very low estimate of survey catchability.

Figure 2A.1.7 shows fishery selectivity as estimated by the three models. The three curves are virtually indistinguishable, and indicate an asymptotic pattern with full selection occurring at age 5.

Figure 2A.1.8 shows time-varying trawl survey selectivity as estimated by the three models. The plots are qualitatively similar across models, with the largest change in age 1 selectivity occurring in 1994 and the largest change in age 2 selectivity occurring in 1991. All three models show a very sharp peak at age 4, followed by declines through age 10 (selectivity is constrained to be constant at ages 10 and above). The selectivities at age 10 are 0.26, 0.31, and 0.37 in Models 1, 2, and 3, respectively.

Discussion

The three models presented here provide good fits to the length composition data, but, except for Model 3, the fits to the survey abundance data are not particularly good, with a very strong residual pattern for Model 1 and a fairly strong residual pattern for Model 2.

Age data from the 2012 AI bottom trawl survey are expected to become available in time for use in this year's final assessment. It is possible that these data will help to inform whatever models are included in the final assessment, but it should be stressed that these will be the only age data available, and such a small dataset may not be sufficient to improve model performance appreciably.

This preliminary assessment provides the first exploration of SS selectivity-at-age pattern #17 (random walk with age) for Pacific cod. This exploration was undertaken for the following reasons:

1. Pattern #17 allows for use of prior distributions that are consistent with a logistic functional form without actually forcing the resulting selectivity schedule to be logistic.
2. Pattern #17 provides an alternative to the somewhat complicated parameterization of the double normal selectivity curve (which has been used in the EBS Pacific cod models for the last several years), in which the effects of some parameters are conditional on the values of other parameters, thus making it difficult to specify appropriate prior distributions.
3. The iterative tuning procedure used here for the parameters of the prior distributions provides a way to specify these priors objectively and uniquely for each age.
4. Estimation of individual selectivities at age avoids the problem of mis-specifying a functional form *a priori*, which can have significant consequences (e.g., Kimura 1990, Clark 1999).

This preliminary assessment also emphasized the potential time variability of both fishery and survey selectivity. Although a scientific consensus on how (or whether) to address this phenomenon has yet to be achieved, some of the presentations at this year's CAPAM selectivity workshop (Crone et al., 2013) seemed to favor allowing selectivity to vary over time. Time-varying survey catchability was also explored during the process of developing this preliminary assessment. However, unless catchability was estimated freely (as in Model 3), the primary effect of allowing time variability in catchability seemed to be compensation for an overall lack of fit resulting from a constrained (or fixed) base value for ln(Q), rather than estimating true time variability, so this feature was not included in the final models.

It should be emphasized that iterative tuning of the selectivity prior distributions and the sigma parameters for time-varying selectivity was applied only to Model 2, with Models 1 and 3 simply "borrowing" the resulting tuned quantities. If these iterative tuning procedures were also applied to Models 1 and 3, the performance of the latter models would likely change somewhat.

Finally, it may be noted that several of the questions raised in last year's AI Pacific cod assessment (Attachment 2.2 in Thompson and Lauth 2012) remain germane:

1. Correlations between recruitment in the AI and EBS are negative (= -0.38, -0.34, and -0.26 for Models 1, 2, and 3, respectively). Is this because recruitment dynamics are truly different in the AI, or is this evidence that the AI models are not giving good estimates?
2. Relative to Pacific cod in the EBS, Pacific cod in the AI have much larger survey CVs, much smaller length composition sample sizes, and virtually no age data. Is a reliable age-structured model of the AI stock possible under these conditions?
3. Unless constrained to be asymptotic, survey selectivity peaks sharply at age 4, with abrupt drops on either side of the peak. Is this reasonable?
4. Should catchability be tuned so that the average product of Q and selectivity across the 60-81 cm range matches the value of 0.92 estimated by Nichol et al. (2007)?

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Table 2A.1.1a—Summary of 1964-1980 catches (t) of Pacific cod in the AI. All catches are foreign reported. Catches by gear are not available for these years. Catches may not always include discards.

Year	Total
1964	241
1965	451
1966	154
1967	293
1968	289
1969	220
1970	283
1971	2078
1972	435
1973	977
1974	1379
1975	2838
1976	4190
1977	3262
1978	3295
1979	5593
1980	5788

Table 2A.1.1b—Summary of 1981-1990 catches (t) of Pacific cod in the AI by fleet sector and gear type. All catches include discards. "LLine" = longline, "Subt." = sector subtotal. Breakdown of domestic annual processing by gear is not available prior to 1988. Longline and pot gear have been combined ("LL+pot") under Domestic Annual Processing.

	Foreign			Joint Venture		Domestic Annual Processing			
Year	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LL+pot	Subt.	Total
1981	2680	235	2915	1749	1749	n/a	n/a	2770	7434
1982	1520	476	1996	4280	4280	n/a	n/a	2121	8397
1983	1869	402	2271	4700	4700	n/a	n/a	1459	8430
1984	473	804	1277	6390	6390	n/a	n/a	314	7981
1985	10	829	839	5638	5638	n/a	n/a	460	6937
1986	5	0	5	6115	6115	n/a	n/a	786	6906
1987	0	0	0	10435	10435	n/a	n/a	2772	13207
1988	0	0	0	3300	3300	1698	167	1865	5165
1989	0	0	0	6	6	4233	303	4536	4542
1990	0	0	0	0	0	6932	609	7541	7541

Table 2A.1.1c— Summary of 1991-2012 catches (t) of Pacific cod in the AI. The small catches taken by "other" gear types have been merged proportionally with the catches of the gear types shown. Longline and pot gear have been combined ("Long.+pot") due to confidentiality restrictions. Catches for 2012 are through September 29.

	Federal			State	Grand
Year	Trawl	Long.+pot	Subtotal	Subtotal	Total
1991	3,414	6,383	9,798		9,798
1992	14,587	28,481	43,068		43,068
1993	17,328	16,876	34,205		34,205
1994	14,383	7,156	21,539		21,539
1995	10,574	5,960	16,534		16,534
1996	21,179	10,430	31,609		31,609
1997	17,411	7,753	25,164		25,164
1998	20,531	14,196	34,726		34,726
1999	16,478	11,653	28,130		28,130
2000	20,379	19,306	39,685		39,685
2001	15,836	18,372	34,207		34,207
2002	27,929	2,872	30,801		30,801
2003	31,478	980	32,459		32,459
2004	25,770	3,103	28,873		28,873
2005	19,624	3,075	22,699		22,699
2006	16,963	3,530	20,493	3,717	24,210
2007	25,721	4,495	30,216	3,829	34,045
2008	19,405	7,192	26,597	4,462	31,059
2009	20,284	6,222	26,507	2,074	28,580
2010	16,757	8,365	25,122	3,878	29,000
2011	9,379	1,242	10,621	241	10,862
2012	9,516	2,777	12,294	5,229	17,523

Table 2A.1.2 (page 1 of 3)—Fishery size composition, by year and cm.

Year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	1	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	5
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1999	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	4	5	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2003	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2004	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
2005	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
2007	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Year	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
1978	0	0	1	0	0	0	0	0	2	0	0	2	1	1	5	3	7	4	9	18
1979	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	1
1982	0	0	0	1	0	0	0	0	0	0	5	4	2	6	7	7	9	15	19	14
1983	2	1	2	5	8	6	16	16	23	25	45	70	64	68	66	60	58	69	86	103
1984	0	0	1	0	2	0	0	1	2	2	7	12	13	17	31	28	21	22	6	6
1985	0	0	0	0	0	0	0	0	0	0	0	3	1	1	7	12	25	21	37	61
1990	0	0	0	0	0	0	0	0	1	0	1	0	1	1	4	2	5	7	15	17
1991	0	0	0	2	0	0	1	2	8	2	4	9	13	11	15	7	9	21	28	39
1992	0	0	0	0	0	0	0	3	4	4	9	21	27	46	40	62	116	153	226	310
1993	0	0	0	0	1	4	7	11	9	12	17	20	30	29	33	39	45	67	76	113
1994	0	0	0	0	1	2	4	7	5	3	8	3	14	8	19	19	26	33	52	73
1995	14	22	34	38	59	51	49	54	66	56	51	33	22	19	11	12	11	23	20	30
1996	0	2	0	2	5	15	6	9	8	14	18	15	12	29	39	39	50	63	108	136
1997	0	0	0	0	2	2	0	7	4	5	9	12	6	9	17	22	17	25	25	32
1998	1	1	4	1	8	9	25	28	43	51	47	88	92	94	87	122	183	200	212	296
1999	0	1	1	3	0	1	3	3	7	6	8	25	21	19	30	32	38	62	75	131
2000	0	1	0	0	0	4	6	5	6	13	7	6	7	20	30	52	62	98	140	169
2001	0	0	0	1	3	10	5	11	12	15	15	23	34	64	72	93	130	163	211	230
2002	0	1	0	1	2	5	3	9	11	12	8	24	22	33	37	48	71	65	68	65
2003	0	1	0	0	1	3	5	5	12	16	22	15	21	25	21	17	33	50	53	64
2004	1	0	1	1	2	2	5	5	14	22	17	44	43	49	69	71	81	94	81	86
2005	0	0	0	0	3	2	1	1	2	5	2	6	12	4	7	11	16	20	30	30
2006	0	1	0	1	0	0	1	3	4	0	4	3	5	0	3	6	14	11	31	33
2007	3	0	1	0	5	3	5	7	12	12	12	20	15	19	17	20	27	31	31	50
2008	0	1	1	2	0	1	3	0	3	2	7	5	10	9	19	21	43	41	47	67
2009	0	0	0	3	0	0	1	4	3	4	10	14	15	20	20	39	52	53	67	86
2010	1	0	0	2	0	0	2	1	0	6	12	14	13	22	40	45	72	87	120	143
2011	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	2	3	15
2012	0	0	0	0	0	0	0	0	1	2	0	0	1	2	3	0	11	2	1	5

Table 2A.1.2 (page 2 of 3)—Fishery size composition, by year and cm.

Year	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
1978	26	29	39	35	41	39	46	38	25	25	27	32	31	32	44	26	46	44	42	51
1979	4	2	8	10	9	26	25	28	40	47	60	62	71	81	82	84	71	79	64	67
1982	26	31	50	56	57	67	100	98	110	125	112	151	149	155	146	154	180	207	144	166
1983	130	138	149	181	170	171	191	182	182	143	133	146	127	121	123	118	115	116	127	101
1984	9	15	27	27	36	61	73	94	136	145	186	191	186	183	195	164	161	161	138	150
1985	58	74	75	68	85	85	63	60	36	37	32	35	49	52	59	73	96	85	120	122
1990	11	8	9	11	9	16	19	31	52	24	41	35	63	33	39	67	50	70	75	105
1991	24	36	56	63	62	76	62	92	103	141	140	186	214	255	252	312	285	324	359	360
1992	463	550	587	621	705	792	820	872	826	886	898	962	990	1025	1183	1297	1328	1454	1522	1752
1993	121	218	240	274	321	433	573	674	751	827	861	957	985	937	846	857	793	754	764	775
1994	101	83	139	160	161	223	233	257	291	297	333	359	389	466	512	572	632	654	720	750
1995	26	29	33	55	83	81	83	107	137	181	186	195	254	269	308	318	385	404	430	451
1996	168	197	268	249	296	334	335	362	416	423	508	453	502	583	534	558	572	685	800	926
1997	43	56	83	78	110	103	165	147	191	227	248	298	348	351	329	366	440	426	397	371
1998	359	455	483	523	639	629	793	723	718	804	822	798	867	808	882	931	1092	1143	1176	1298
1999	118	173	183	215	305	292	317	366	374	380	400	436	471	464	541	516	516	595	592	646
2000	170	246	286	291	362	375	367	462	488	559	582	658	752	825	841	855	875	946	971	968
2001	296	321	347	424	466	495	563	643	741	772	762	851	951	948	1041	1078	1195	1312	1324	1493
2002	74	89	102	110	122	152	164	179	156	147	154	174	165	139	172	164	198	218	224	255
2003	62	110	105	141	140	164	199	228	232	229	229	253	271	290	239	239	311	279	274	304
2004	84	82	112	116	145	174	186	237	264	307	320	362	381	348	398	371	367	405	399	439
2005	51	51	79	67	79	87	118	127	145	154	193	172	229	253	249	258	297	309	334	340
2006	41	49	70	108	121	137	154	163	199	186	215	211	261	298	315	314	395	395	378	388
2007	30	65	56	64	71	92	112	153	197	201	229	271	331	352	409	468	483	491	496	544
2008	88	96	128	172	209	235	299	308	341	323	316	338	300	310	331	301	308	335	316	358
2009	65	90	78	100	104	121	133	154	167	167	190	234	318	324	359	337	407	414	482	485
2010	184	226	232	307	370	399	444	490	459	519	530	496	490	499	504	531	502	493	509	531
2011	16	18	31	37	47	61	49	72	72	94	102	93	118	132	150	145	187	168	191	212
2012	3	9	8	12	16	28	21	16	31	26	31	52	61	81	88	136	118	151	182	212

Year	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
1978	59	72	58	69	73	62	71	62	48	51	47	45	50	45	25	18	28	20	12	9
1979	54	52	53	53	44	57	59	40	62	54	51	31	42	35	35	22	25	27	13	10
1982	173	151	155	122	131	126	106	116	77	86	89	67	60	64	52	47	32	41	51	41
1983	107	82	74	78	66	72	70	66	65	52	55	60	46	58	45	48	37	35	20	17
1984	178	154	201	155	175	166	144	157	143	117	116	111	73	90	84	79	78	61	59	59
1985	131	142	136	147	129	103	118	73	75	56	51	48	58	37	45	50	43	29	34	35
1990	128	167	179	174	158	157	168	140	170	113	132	162	155	122	150	153	140	106	85	92
1991	380	428	463	565	575	544	698	648	732	801	852	829	852	827	753	829	856	703	774	707
1992	1800	2141	2134	2337	2558	2797	2940	2871	3149	3267	3427	3578	3478	3549	3297	3289	3169	2878	2726	2644
1993	783	828	829	856	775	903	891	866	922	938	992	1035	972	1105	1007	1162	1105	1184	1208	1162
1994	762	853	800	865	828	881	827	808	780	804	766	730	617	655	598	545	550	520	535	498
1995	554	556	590	642	635	686	782	748	735	733	782	890	778	857	837	864	880	821	776	736
1996	914	1040	1158	1030	1056	965	1062	977	992	1071	1042	1125	1010	933	926	931	1037	954	1006	982
1997	363	352	349	317	362	371	351	355	402	383	407	489	458	445	513	582	608	572	548	531
1998	1407	1664	1689	1616	1766	1826	2306	1998	1888	1881	1781	2067	1667	1564	1513	1483	1604	1368	1262	1249
1999	621	616	628	560	717	715	702	664	735	783	829	797	773	808	906	800	836	826	820	808
2000	972	991	977	1054	1028	1040	1124	1002	1133	1112	1053	1053	1012	1050	990	1002	1053	972	1084	988
2001	1383	1452	1495	1607	1693	1659	1697	1651	1631	1558	1564	1361	1349	1263	1122	1076	973	962	898	924
2002	279	324	370	451	447	481	571	637	744	718	738	768	809	790	814	779	757	702	726	671
2003	277	272	357	337	307	366	408	415	372	398	349	420	418	432	469	500	547	580	593	688
2004	416	437	460	483	496	481	530	552	515	491	578	510	552	591	523	537	544	518	532	537
2005	340	366	319	362	408	405	464	454	460	518	534	561	559	561	563	637	685	632	623	598
2006	440	429	364	392	449	361	377	368	389	394	447	411	435	411	479	477	500	457	503	472
2007	461	498	466	532	488	493	456	453	428	440	473	458	491	472	519	502	523	532	531	539
2008	408	460	438	427	481	493	521	515	473	524	498	468	471	437	429	403	422	438	425	372
2009	491	452	486	447	486	404	475	406	414	453	434	457	413	451	413	390	379	400	359	363
2010	577	618	531	583	634	668	821	620	695	775	809	822	825	759	764	763	770	687	618	605
2011	210	210	208	228	195	214	217	155	162	147	145	172	135	179	155	161	221	182	184	201
2012	232	228	219	218	249	280	321	303	343	315	325	281	304	298	251	264	236	210	195	163

Table 2A.1.2 (3 of 3)—Fishery size composition, by year and cm.

Year	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
1978	8	8	3	4	1	2	4	2	0	1	0	0	0	0	1	0	0	0	0	0
1979	15	9	7	13	5	2	0	4	4	1	2	4	0	1	0	0	0	0	0	1
1982	32	37	32	22	24	20	27	17	6	10	12	6	3	6	4	3	0	4	3	3
1983	22	21	14	17	28	14	20	19	18	11	12	20	4	4	3	6	9	4	4	2
1984	55	52	36	52	48	37	48	25	33	33	28	26	22	17	31	21	18	17	12	9
1985	35	39	34	37	35	33	44	51	27	23	24	27	28	9	9	21	10	15	6	6
1990	82	64	58	55	40	55	38	21	13	28	15	11	8	9	7	10	5	8	1	2
1991	642	619	600	515	463	393	311	263	259	212	174	171	115	133	103	72	60	28	42	29
1992	2441	2466	2071	1887	1768	1679	1534	1265	1227	1047	982	879	750	690	635	592	406	314	270	237
1993	1165	1170	1104	1048	955	913	780	728	713	609	548	567	498	423	407	364	298	279	252	213
1994	533	480	480	516	499	564	573	423	391	388	344	395	293	255	276	271	269	178	143	145
1995	741	736	683	646	580	525	629	499	552	620	709	623	496	383	334	330	403	236	263	253
1996	936	903	876	791	761	750	747	524	607	522	564	459	427	428	376	392	409	299	273	267
1997	511	563	509	484	523	492	611	491	480	528	476	465	408	429	394	335	361	287	264	239
1998	1122	1276	1163	1043	1227	1098	1286	1038	910	1028	1066	1076	969	903	924	846	964	726	640	618
1999	775	747	738	655	640	581	569	514	473	413	382	354	362	330	357	328	360	300	287	249
2000	1066	1006	1139	991	1064	1102	1210	1008	1027	906	890	760	769	636	624	566	574	520	468	458
2001	834	722	678	662	653	677	655	611	543	546	525	509	534	481	460	492	527	408	371	384
2002	648	603	574	496	495	412	377	322	328	309	280	257	237	197	182	143	224	165	153	142
2003	669	748	731	710	685	675	699	604	560	556	485	430	406	362	319	282	320	201	213	160
2004	472	439	415	408	366	351	394	347	359	361	329	327	313	321	317	233	269	245	216	178
2005	485	516	466	445	387	421	408	336	311	340	296	261	240	238	202	205	188	182	158	155
2006	478	461	525	468	492	457	442	406	366	362	325	279	249	233	210	190	197	168	170	131
2007	596	559	634	593	662	659	689	640	611	662	585	606	544	550	518	474	418	363	357	315
2008	447	431	449	433	445	485	480	470	484	516	454	518	505	497	503	445	515	470	412	459
2009	346	322	322	279	322	301	304	342	336	318	342	341	309	314	320	323	343	286	318	326
2010	580	480	457	502	427	433	429	388	383	396	354	340	398	392	353	383	436	364	446	458
2011	210	216	213	198	182	179	157	164	152	153	125	116	123	113	97	97	87	80	72	55
2012	140	140	152	123	130	113	120	121	127	97	106	80	96	84	72	90	63	66	68	58

Year	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120+
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	2	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1983	2	3	0	1	0	1	0	1	0	0	0	0	0	1	0	0	1
1984	14	7	7	4	1	1	1	0	0	0	1	0	0	0	0	0	0
1985	3	1	9	0	0	0	0	3	0	0	0	0	1	0	0	0	0
1990	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	22	16	9	5	2	1	2	0	0	1	1	1	0	0	0	0	0
1992	211	147	128	115	82	59	67	49	26	16	14	5	3	0	6	1	1
1993	172	142	120	70	78	41	40	29	20	14	7	3	4	2	1	0	1
1994	107	81	59	40	34	27	44	18	11	16	5	9	5	4	3	1	1
1995	218	203	113	90	82	66	112	40	47	26	11	25	9	3	0	1	2
1996	239	247	191	166	120	98	123	50	55	18	18	6	4	5	1	0	5
1997	210	196	145	137	120	99	77	51	37	28	22	26	14	4	6	2	9
1998	586	619	419	331	299	250	244	134	99	74	50	48	24	14	4	9	24
1999	260	223	188	144	124	88	86	49	42	33	24	12	2	6	2	5	13
2000	406	384	343	338	244	177	194	126	93	46	27	29	17	8	3	3	14
2001	306	294	254	224	218	167	193	81	86	54	33	42	16	14	12	16	21
2002	140	111	102	81	64	53	46	27	29	12	5	1	4	1	1	1	0
2003	153	108	98	84	73	49	48	25	29	13	6	4	6	0	5	2	2
2004	193	128	117	98	78	72	64	30	29	16	10	4	4	1	5	3	2
2005	136	126	100	92	70	46	46	26	24	17	9	5	6	3	1	4	9
2006	130	115	94	94	79	65	57	34	26	25	15	12	1	2	4	2	6
2007	263	209	196	171	145	113	86	50	36	28	19	11	10	3	3	2	0
2008	357	328	287	231	209	169	156	89	63	35	21	18	15	10	7	5	67
2009	280	273	261	251	222	151	130	95	74	40	30	24	9	3	0	2	2
2010	387	391	343	316	306	257	218	148	117	62	51	47	20	13	4	1	8
2011	72	58	55	42	41	27	24	26	12	10	3	6	4	3	1	2	4
2012	58	43	42	26	32	25	19	18	19	10	10	7	5	5	2	4	6

Table 2A.1.3—Total biomass (t) and abundance, with coefficients of variation (CV), by subarea and year, as estimated by bottom trawl surveys.

Biomass:

	Western Aleutians (543)		Central Aleutians (542)		Eastern Aleutians (541)		Aleutian management area	
Year	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV
1991	75,514	0.09	39,729	0.11	64,926	0.37	180,170	0.14
1994	23,797	0.29	51,538	0.39	78,081	0.30	153,416	0.21
1997	14,357	0.26	30,252	0.21	28,239	0.23	72,848	0.13
2000	44,261	0.42	36,456	0.27	47,117	0.22	127,834	0.18
2002	23,623	0.25	24,687	0.26	25,241	0.33	73,551	0.16
2004	9,637	0.17	20,731	0.21	51,851	0.30	82,219	0.20
2006	19,734	0.23	21,823	0.19	43,348	0.54	84,905	0.29
2010	21,341	0.41	11,207	0.26	23,277	0.22	55,826	0.19
2012	13,514	0.26	14,804	0.20	30,592	0.24	58,911	0.15

Abundance (1000s of fish):

	Western Aleutians (543)		Central Aleutians (542)		Eastern Aleutians (541)		Aleutian management area	
Year	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV
1991	18,679	0.15	13,138	0.13	33,669	0.44	65,486	0.23
1994	4,491	0.24	12,425	0.20	37,284	0.44	54,201	0.31
1997	4,000	0.25	12,014	0.28	8,859	0.16	24,873	0.15
2000	13,899	0.54	10,661	0.30	18,819	0.29	43,379	0.23
2002	6,840	0.30	6,704	0.17	12,579	0.28	26,123	0.16
2004	3,220	0.17	5,755	0.17	13,040	0.24	22,016	0.15
2006	6,521	0.32	6,243	0.16	8,882	0.33	21,646	0.17
2010	5,323	0.34	5,169	0.17	9,577	0.22	20,068	0.14
2012	4,100	0.14	5,596	0.20	9,480	0.21	19,176	0.12

Table 2A.1.4 (page 1 of 2)—Trawl survey size composition, by year and cm.

Year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	11	1	0	1
1994	0	0	0	0	0	0	0	0	0	62	254	398	595	529	236	211	167	63	12	16
1997	0	0	0	0	0	0	0	0	0	0	0	0	3	12	5	19	35	87	81	111
2000	0	0	0	0	0	0	0	0	0	0	5	38	33	37	51	20	2	6	0	2
2002	0	0	0	0	0	1	0	0	0	0	6	6	12	16	25	9	13	12	13	5
2004	0	0	0	0	0	0	0	0	0	0	5	0	1	3	6	2	14	14	8	8
2006	0	0	0	0	0	0	0	0	0	5	11	13	42	71	69	57	22	21	18	16
2010	0	0	0	0	0	0	0	0	0	0	6	16	12	14	15	23	17	10	3	0
2012	0	0	0	0	0	0	0	0	0	0	1	5	19	24	50	44	50	31	24	8

Year	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
1991	3	2	4	9	26	81	114	147	216	249	293	321	299	242	224	150	139	85	92	54
1994	7	4	4	4	3	3	9	18	24	34	40	44	48	43	47	38	30	44	59	46
1997	102	82	42	19	2	12	7	15	27	32	36	51	61	60	60	58	45	32	31	34
2000	1	4	7	4	3	14	10	13	13	15	26	12	32	14	17	4	27	24	21	52
2002	19	9	9	21	22	28	22	37	45	99	92	103	134	142	119	93	85	63	52	62
2004	5	1	1	1	0	0	0	3	1	5	6	17	25	30	24	28	26	40	41	38
2006	23	13	3	2	1	2	0	1	6	1	5	3	8	13	11	20	12	19	14	9
2010	0	3	1	1	2	10	15	26	22	27	23	23	27	16	23	28	25	28	35	44
2012	9	5	1	0	3	2	2	11	7	32	23	18	32	55	38	18	41	29	31	20

Year	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
1991	80	52	64	72	73	68	54	76	63	58	68	60	98	94	82	115	116	110	121	139
1994	60	63	90	90	102	83	102	67	68	66	72	62	53	93	78	76	84	93	95	123
1997	34	25	35	47	52	59	82	70	73	79	96	103	106	127	150	125	172	165	121	148
2000	96	134	93	117	110	131	123	154	131	136	125	119	130	125	175	183	165	187	156	151
2002	56	59	62	77	81	87	63	62	76	68	95	69	97	72	74	61	64	41	39	40
2004	32	48	56	60	84	83	97	86	84	91	67	98	81	92	83	66	109	80	60	89
2006	21	27	38	39	44	62	63	69	75	57	61	49	49	56	29	45	37	35	51	45
2010	63	84	92	114	117	126	113	121	138	146	135	118	112	116	93	69	93	81	65	45
2012	26	30	34	31	32	42	44	64	58	49	70	56	66	62	86	90	88	86	79	104

Year	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
1991	86	119	163	157	162	131	136	119	136	117	119	99	89	109	115	81	84	75	63	61
1994	119	124	102	125	114	128	109	118	124	111	133	77	79	86	78	50	71	47	72	62
1997	135	106	85	103	112	80	63	50	59	50	49	58	49	34	27	27	33	31	31	23
2000	154	148	168	115	112	97	84	86	77	86	70	82	88	59	46	49	42	28	27	36
2002	44	33	33	34	31	34	34	33	36	34	42	45	48	42	35	39	49	49	50	55
2004	102	90	89	100	92	83	84	83	88	61	81	68	72	65	62	48	38	55	52	40
2006	35	39	54	29	42	39	44	30	47	47	39	35	41	34	38	42	47	46	46	30
2010	54	56	56	69	78	58	47	43	35	35	31	33	33	24	23	13	9	23	19	19
2012	157	105	97	85	95	80	63	47	56	49	67	59	43	40	39	49	37	36	32	19

Table 2A.1.4 (page 2 of 2)—Trawl survey size composition, by year and cm.

Year	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
1991	65	46	56	50	22	31	30	43	30	20	11	14	6	12	4	12	4	1	5	0
1994	52	72	46	59	44	54	93	60	66	48	38	42	50	27	18	27	9	10	8	8
1997	25	19	23	24	23	18	22	31	26	9	25	8	20	13	16	20	9	10	22	7
2000	19	27	18	26	22	15	12	17	13	6	12	10	8	6	10	8	5	2	4	5
2002	39	44	38	38	32	15	30	29	10	21	16	12	9	7	8	4	5	3	6	13
2004	35	40	37	37	11	18	21	15	21	17	14	15	11	8	8	15	7	2	8	8
2006	54	32	28	41	37	39	47	28	17	17	13	28	19	15	10	14	13	5	10	4
2010	12	4	16	12	10	15	9	11	9	8	10	6	7	9	5	7	10	15	5	6
2012	20	11	14	13	15	7	10	8	7	9	5	16	9	5	4	5	6	6	5	4

Year	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120+
1991	3	3	1	6	0	1	0	0	0	0	0	1	0	0	0	0	0
1994	7	5	5	2	0	2	0	0	0	2	2	0	0	0	0	0	0
1997	3	10	8	1	3	3	2	0	0	0	0	0	0	0	0	0	0
2000	3	4	6	1	11	2	1	2	0	0	0	1	0	0	0	0	0
2002	1	6	2	2	2	0	1	0	3	0	0	1	0	0	0	0	0
2004	5	6	3	2	3	1	0	1	0	0	0	0	0	0	0	0	0
2006	15	3	3	6	8	3	0	1	3	2	1	0	1	0	0	0	0
2010	3	8	3	6	6	4	3	5	1	1	0	1	0	0	0	0	0
2012	7	1	1	1	1	1	0	1	0	0	0	0	1	0	0	0	0

Table 2A.1.4a— Natural mortality, growth, recruitment (except annual *devs*), initial fishing mortality, catchability, and initial age composition parameters as estimated internally by at least one of the assessment models; "n/a" means that the parameter is fixed (i.e., not estimated internally) in that particular model. "Est." = point estimate, "SD" = standard deviation.

	Model 1		Model 2		Model 3	
Parameter	Est.	SD	Est.	SD	Est.	SD
M	3.40E-01	n/a	3.40E-01	n/a	3.64E-01	1.72E-02
L_at_age01	1.67E+01	6.64E-01	1.74E+01	5.34E-01	1.80E+01	4.35E-01
L_at_age20	1.12E+02	1.01E+00	1.10E+02	1.02E+00	1.07E+02	1.12E+00
VonBert_K	2.42E-01	6.23E-03	2.34E-01	5.70E-03	2.29E-01	5.58E-03
SD_of_length_at_age01	6.15E+00	6.03E-01	4.98E+00	4.56E-01	3.93E+00	3.55E-01
SD_of_length_at_age20	5.48E+00	5.31E-01	6.04E+00	4.93E-01	6.86E+00	4.78E-01
Log_mean_post76_recruits	1.09E+01	1.15E-01	1.12E+01	1.31E-01	1.31E+01	5.50E-01
SD_of_log_recruitment	8.89E-01	1.02E-01	8.82E-01	1.09E-01	6.07E-01	9.78E-02
Pre1977_log_mean_offset	-1.73E+00	2.40E-01	-1.74E+00	2.70E-01	-9.92E-01	2.79E-01
Initial_F	2.11E-02	5.04E-03	1.56E-02	4.27E-03	1.37E-03	8.09E-04
log_Q	2.85E-01	n/a	-4.27E-01	8.77E-02	-2.67E+00	5.24E-01
InitAge_10	-5.64E-01	7.17E-01	-5.77E-01	7.09E-01	-2.98E-01	5.40E-01
InitAge_09	-6.90E-01	6.92E-01	-7.03E-01	6.85E-01	-3.85E-01	5.26E-01
InitAge_08	-8.25E-01	6.68E-01	-8.35E-01	6.62E-01	-4.83E-01	5.12E-01
InitAge_07	-9.59E-01	6.46E-01	-9.62E-01	6.41E-01	-5.80E-01	5.00E-01
InitAge_06	-1.07E+00	6.28E-01	-1.05E+00	6.26E-01	-6.47E-01	4.89E-01
InitAge_05	-1.06E+00	6.20E-01	-9.99E-01	6.20E-01	-6.08E-01	4.82E-01
InitAge_04	-6.58E-01	5.92E-01	-5.12E-01	5.71E-01	-3.17E-01	4.51E-01
InitAge_03	-1.03E-01	4.86E-01	-1.75E-01	4.93E-01	-2.27E-01	4.23E-01
InitAge_02	3.46E-01	4.19E-01	3.00E-01	4.13E-01	1.50E-01	3.62E-01
InitAge_01	-9.12E-03	5.44E-01	-2.72E-01	5.61E-01	-4.77E-01	4.44E-01

Table 2A.1.4b— Annual log-scale recruitment *dev*s estimated by the three models. "Est." = point estimate, "SD" = standard deviation.

	Model 1		Model 2		Model 3	
Parameter	Est.	SD	Est.	SD	Est.	SD
RecrDev_1977	-1.75E+00	4.56E-01	-1.81E+00	4.41E-01	-1.06E+00	4.08E-01
RecrDev_1978	-1.12E+00	2.74E-01	-1.14E+00	2.93E-01	-4.85E-01	3.11E-01
RecrDev_1979	-1.21E+00	2.63E-01	-1.20E+00	3.08E-01	-4.87E-01	3.10E-01
RecrDev_1980	-4.69E-01	2.30E-01	-3.13E-01	2.77E-01	4.34E-01	2.38E-01
RecrDev_1981	-4.83E-01	2.96E-01	-3.43E-01	3.14E-01	7.34E-02	3.06E-01
RecrDev_1982	-4.21E-01	3.58E-01	-2.29E-01	3.65E-01	1.31E-01	3.42E-01
RecrDev_1983	-6.67E-01	6.63E-01	-5.44E-01	6.97E-01	-3.29E-01	5.16E-01
RecrDev_1984	-2.51E-01	6.42E-01	4.51E-02	6.52E-01	1.57E-01	5.76E-01
RecrDev_1985	6.98E-01	2.86E-01	9.50E-01	2.91E-01	1.28E+00	2.61E-01
RecrDev_1986	7.59E-01	1.93E-01	8.21E-01	2.07E-01	7.82E-01	2.43E-01
RecrDev_1987	9.25E-01	1.10E-01	9.31E-01	1.19E-01	8.18E-01	1.50E-01
RecrDev_1988	3.84E-01	1.17E-01	2.15E-01	1.35E-01	-6.14E-02	1.67E-01
RecrDev_1989	6.11E-01	1.06E-01	6.90E-01	1.06E-01	6.94E-01	1.08E-01
RecrDev_1990	8.45E-01	9.21E-02	7.99E-01	1.02E-01	5.89E-01	1.26E-01
RecrDev_1991	4.88E-01	1.17E-01	4.08E-01	1.24E-01	2.05E-01	1.38E-01
RecrDev_1992	3.22E-01	1.28E-01	2.21E-01	1.41E-01	-2.45E-02	1.60E-01
RecrDev_1993	6.56E-01	9.88E-02	7.32E-01	9.38E-02	6.36E-01	9.81E-02
RecrDev_1994	5.57E-01	9.68E-02	3.53E-01	1.16E-01	-5.73E-02	1.40E-01
RecrDev_1995	4.38E-01	8.66E-02	4.20E-01	8.90E-02	2.83E-01	9.70E-02
RecrDev_1996	6.51E-01	7.84E-02	6.81E-01	7.60E-02	5.26E-01	8.27E-02
RecrDev_1997	9.58E-01	6.75E-02	8.23E-01	8.19E-02	4.76E-01	9.30E-02
RecrDev_1998	4.43E-01	1.00E-01	3.12E-01	1.07E-01	9.13E-03	1.12E-01
RecrDev_1999	3.00E-01	1.10E-01	2.52E-01	1.11E-01	1.83E-03	1.19E-01
RecrDev_2000	5.88E-01	9.71E-02	4.65E-01	1.12E-01	1.35E-01	1.16E-01
RecrDev_2001	3.15E-01	1.10E-01	8.44E-02	1.27E-01	-2.93E-01	1.31E-01
RecrDev_2002	-2.19E-01	1.29E-01	-3.07E-01	1.34E-01	-5.36E-01	1.38E-01
RecrDev_2003	-4.23E-03	1.02E-01	-1.04E-01	1.14E-01	-3.47E-01	1.24E-01
RecrDev_2004	-4.86E-01	1.35E-01	-5.64E-01	1.47E-01	-7.44E-01	1.56E-01
RecrDev_2005	3.65E-02	9.95E-02	2.40E-03	1.16E-01	-1.56E-01	1.25E-01
RecrDev_2006	-6.39E-01	1.45E-01	-6.43E-01	1.55E-01	-6.91E-01	1.59E-01
RecrDev_2007	8.27E-02	1.17E-01	1.79E-01	1.28E-01	1.64E-01	1.28E-01
RecrDev_2008	-3.24E-01	1.74E-01	-3.12E-01	1.95E-01	-4.87E-01	2.05E-01
RecrDev_2009	-1.04E+00	2.97E-01	-9.90E-01	2.96E-01	-9.73E-01	2.67E-01
RecrDev_2010	-6.48E-01	4.51E-01	-6.09E-01	4.53E-01	-5.23E-01	3.98E-01
RecrDev_2011	-3.13E-01	7.19E-01	-2.83E-01	7.16E-01	-1.38E-01	5.40E-01

Table 2.2.4c—Annual additive *dev*s applied to selectivity parameters as estimated by the three models. "Est." = point estimate, "SD" = standard deviation.

	Model 1		Model 2		Model 3	
Parameter	Est.	SD	Est.	SD	Est.	SD
Selparm_age01_fishery	4.00E+00	3.80E-01	4.00E+00	3.80E-01	4.00E+00	3.80E-01
Selparm_age02_fishery	4.13E+00	3.67E-01	4.13E+00	3.67E-01	4.12E+00	3.69E-01
Selparm_age03_fishery	3.34E+00	2.08E-01	3.18E+00	1.80E-01	3.10E+00	1.76E-01
Selparm_age04_fishery	9.13E-01	5.81E-02	9.48E-01	5.90E-02	1.01E+00	6.35E-02
Selparm_age05_fishery	3.92E-01	5.24E-02	4.16E-01	5.12E-02	4.10E-01	5.49E-02
Selparm_age06_fishery	1.59E-03	4.89E-03	1.48E-03	4.89E-03	9.26E-04	4.89E-03
Selparm_age01_survey	1.50E+00	9.80E-01	1.50E+00	9.80E-01	1.50E+00	9.80E-01
Selparm_age02_survey	1.37E+00	4.05E-01	1.28E+00	4.03E-01	1.23E+00	4.02E-01
Selparm_age03_survey	7.40E-01	2.20E-01	8.27E-01	2.19E-01	9.35E-01	2.22E-01
Selparm_age04_survey	7.17E-01	1.23E-01	4.30E-01	1.34E-01	1.41E-01	1.57E-01
Selparm_age05_survey	-9.27E-01	1.32E-01	-6.17E-01	1.41E-01	-2.75E-01	1.60E-01
Selparm_age06_survey	-1.07E-01	1.30E-01	-1.40E-01	1.30E-01	-1.95E-01	1.30E-01
Selparm_age07_survey	-9.63E-02	1.19E-01	-1.25E-01	1.17E-01	-1.65E-01	1.17E-01
Selparm_age08_survey	-8.54E-02	1.22E-01	-1.07E-01	1.20E-01	-1.39E-01	1.19E-01
Selparm_age09_survey	-7.27E-02	1.24E-01	-9.03E-02	1.22E-01	-1.15E-01	1.21E-01
Selparm_age10_survey	-5.67E-02	1.26E-01	-7.61E-02	1.24E-01	-1.06E-01	1.22E-01
Seldev_age02_survey_1991	2.35E-01	6.98E-02	2.31E-01	6.96E-02	2.19E-01	6.99E-02
Seldev_age02_survey_1994	-2.02E-01	4.94E-02	-1.85E-01	4.92E-02	-1.74E-01	4.94E-02
Seldev_age02_survey_1997	-3.77E-02	5.72E-02	-3.84E-02	5.52E-02	-3.94E-02	5.43E-02
Seldev_age02_survey_2000	-2.45E-02	6.43E-02	-2.18E-02	6.37E-02	-2.13E-02	6.35E-02
Seldev_age02_survey_2002	8.07E-02	6.74E-02	6.67E-02	6.59E-02	5.85E-02	6.53E-02
Seldev_age02_survey_2004	6.17E-02	7.68E-02	5.69E-02	7.53E-02	5.18E-02	7.48E-02
Seldev_age02_survey_2006	-8.15E-02	5.94E-02	-8.18E-02	5.91E-02	-8.29E-02	5.91E-02
Seldev_age02_survey_2010	-1.98E-02	7.44E-02	-2.34E-02	7.33E-02	-1.69E-02	7.23E-02
Seldev_age02_survey_2012	-1.72E-03	8.19E-02	-6.38E-03	8.14E-02	-6.08E-03	7.33E-02
Seldev_age03_survey_1991	-1.10E-01	2.46E-02	-1.00E-01	2.47E-02	-9.09E-02	2.48E-02
Seldev_age03_survey_1994	1.55E-03	3.06E-02	2.57E-03	3.08E-02	1.29E-03	3.14E-02
Seldev_age03_survey_1997	2.01E-02	2.93E-02	2.17E-02	2.93E-02	2.34E-02	2.94E-02
Seldev_age03_survey_2000	4.60E-02	3.20E-02	4.54E-02	3.22E-02	4.37E-02	3.26E-02
Seldev_age03_survey_2002	-3.37E-02	2.65E-02	-4.10E-02	2.68E-02	-5.39E-02	2.73E-02
Seldev_age03_survey_2004	3.55E-02	3.36E-02	3.42E-02	3.38E-02	3.30E-02	3.42E-02
Seldev_age03_survey_2006	2.69E-02	3.47E-02	2.47E-02	3.50E-02	2.32E-02	3.54E-02
Seldev_age03_survey_2010	1.70E-02	3.20E-02	1.95E-02	3.25E-02	1.86E-02	3.33E-02
Seldev_age03_survey_2012	-5.44E-03	3.85E-02	-5.81E-03	3.86E-02	6.00E-03	3.71E-02

Table 2A.1.5—Average fishing mortality rates across ages 5-8 as estimated by the three models.

Year	Model 1	Model 2	Model 3
1977	0.1760	0.1234	0.0075
1978	0.1970	0.1341	0.0076
1979	0.3481	0.2331	0.0124
1980	0.3952	0.2559	0.0125
1981	0.5794	0.3542	0.0155
1982	0.7062	0.3909	0.0157
1983	0.6297	0.3190	0.0128
1984	0.4242	0.2080	0.0092
1985	0.2514	0.1223	0.0063
1986	0.1876	0.0921	0.0055
1987	0.3071	0.1470	0.0098
1988	0.0905	0.0439	0.0034
1989	0.0485	0.0254	0.0023
1990	0.0518	0.0293	0.0031
1991	0.0508	0.0308	0.0036
1992	0.2039	0.1262	0.0155
1993	0.1647	0.1012	0.0124
1994	0.0992	0.0615	0.0078
1995	0.0722	0.0461	0.0061
1996	0.1394	0.0903	0.0124
1997	0.1134	0.0738	0.0102
1998	0.1593	0.1040	0.0146
1999	0.1332	0.0874	0.0123
2000	0.1897	0.1241	0.0175
2001	0.1612	0.1061	0.0150
2002	0.1447	0.0965	0.0139
2003	0.1596	0.1068	0.0155
2004	0.1478	0.0997	0.0145
2005	0.1205	0.0827	0.0122
2006	0.1395	0.0967	0.0144
2007	0.2296	0.1566	0.0224
2008	0.2557	0.1681	0.0226
2009	0.2871	0.1800	0.0226
2010	0.3515	0.2060	0.0240
2011	0.1413	0.0798	0.0091
2012	0.2280	0.1266	0.0146

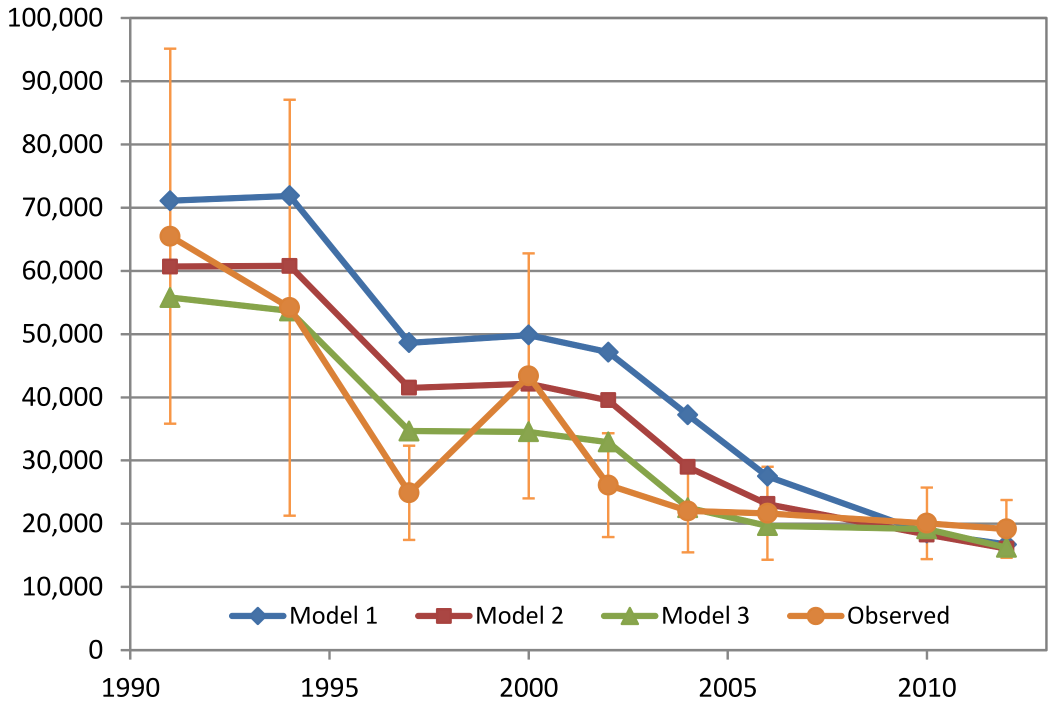


Figure 2A.1.1—Fit of the three models to the trawl survey abundance time series.

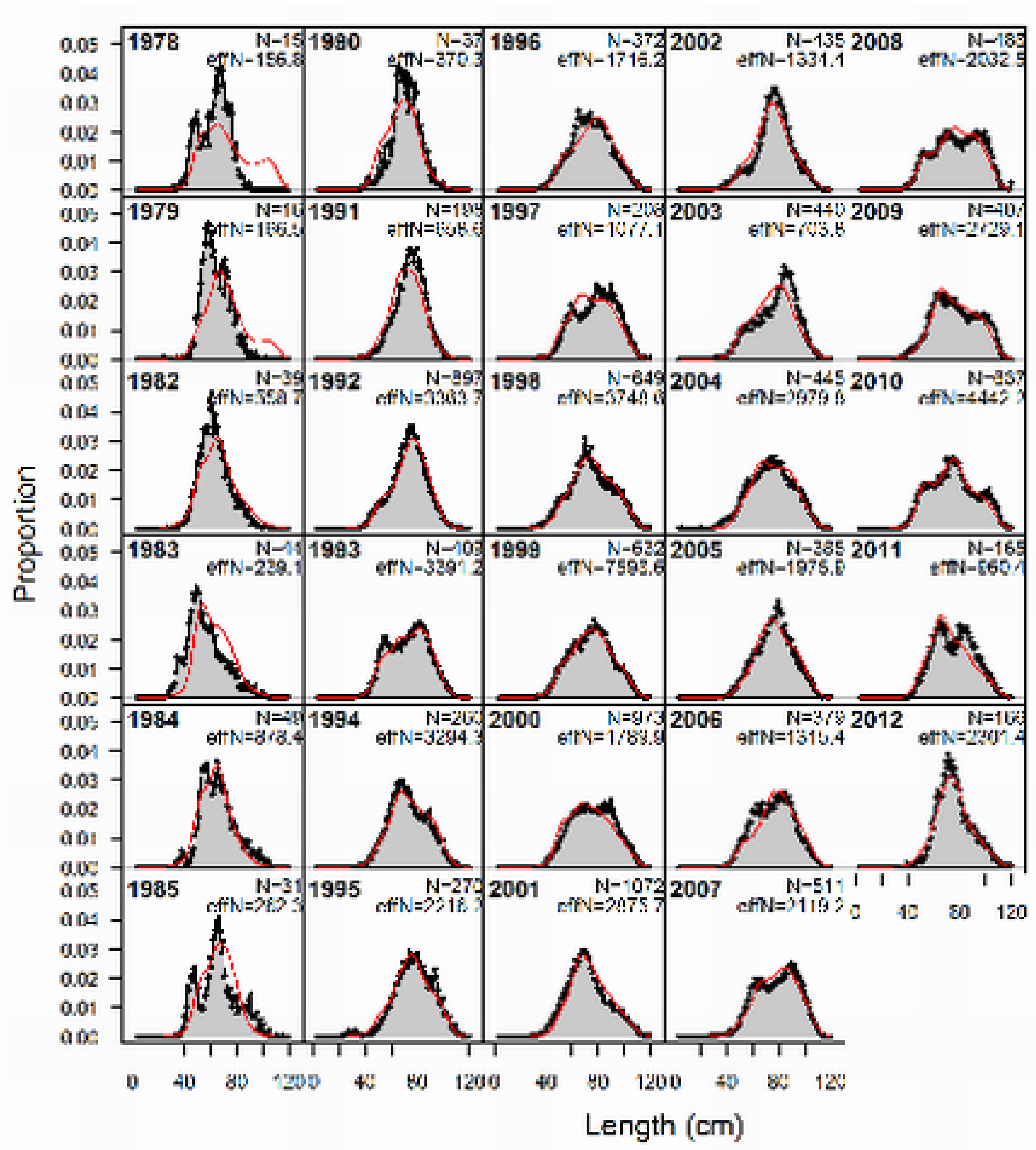


Figure 2A.1.2a—Fit to fishery size composition data obtained by Model 1 (grey = observed, red = estimated).

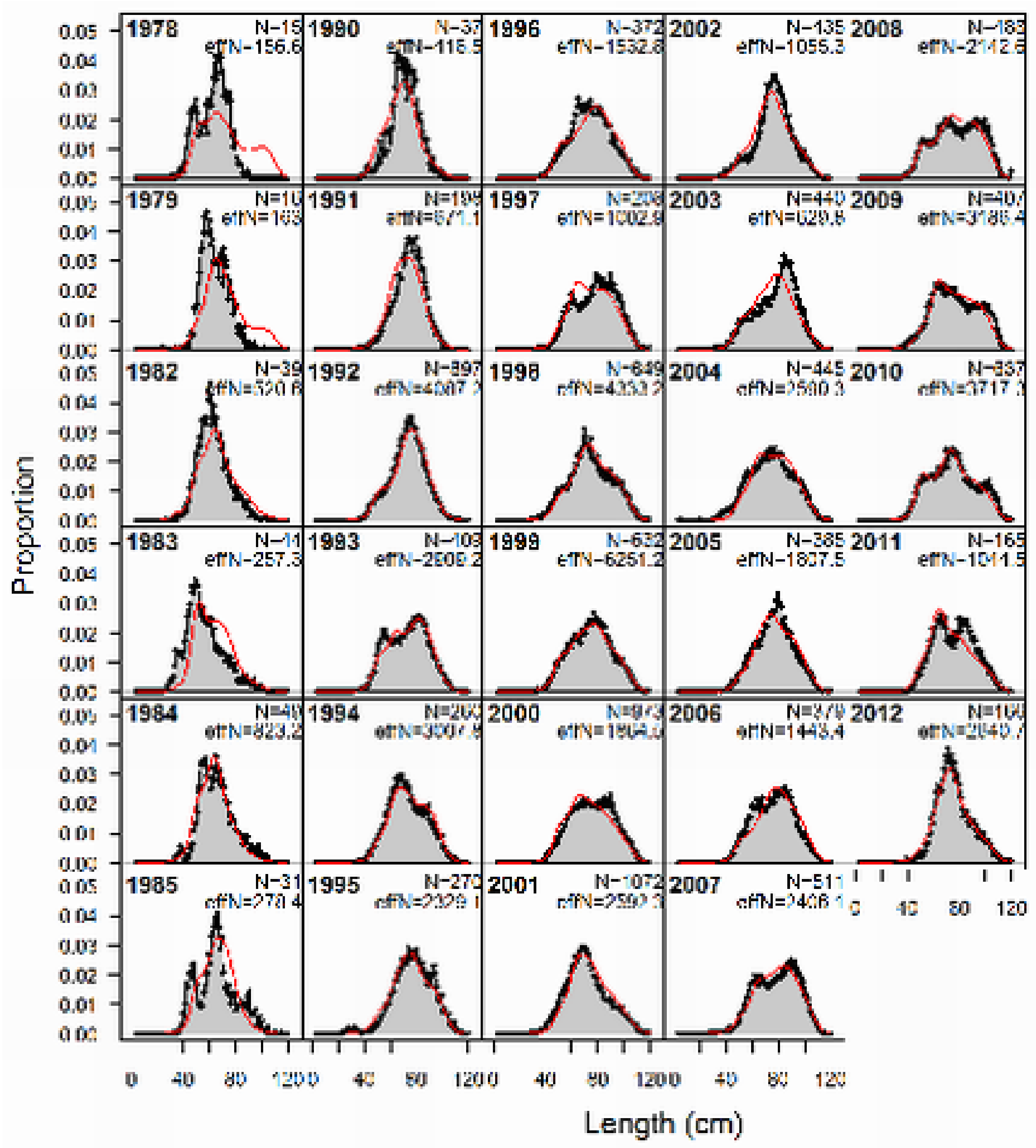


Figure 2A.1.2b—Fit to fishery size composition data obtained by Model 2 (grey = observed, red = estimated).

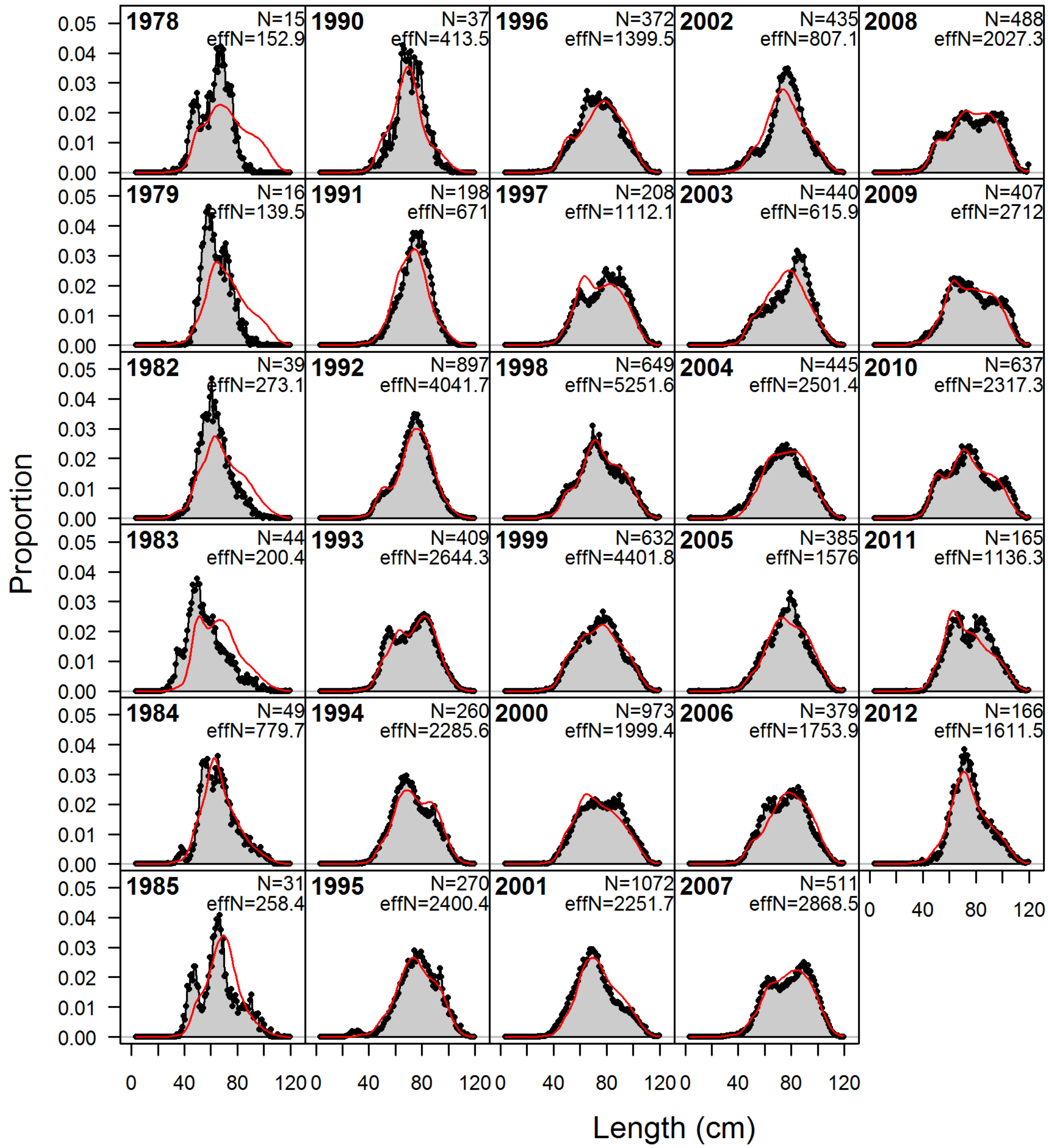


Figure 2A.1.2c—Fit to fishery size composition data obtained by Model 3 (grey = observed, red = estimated).

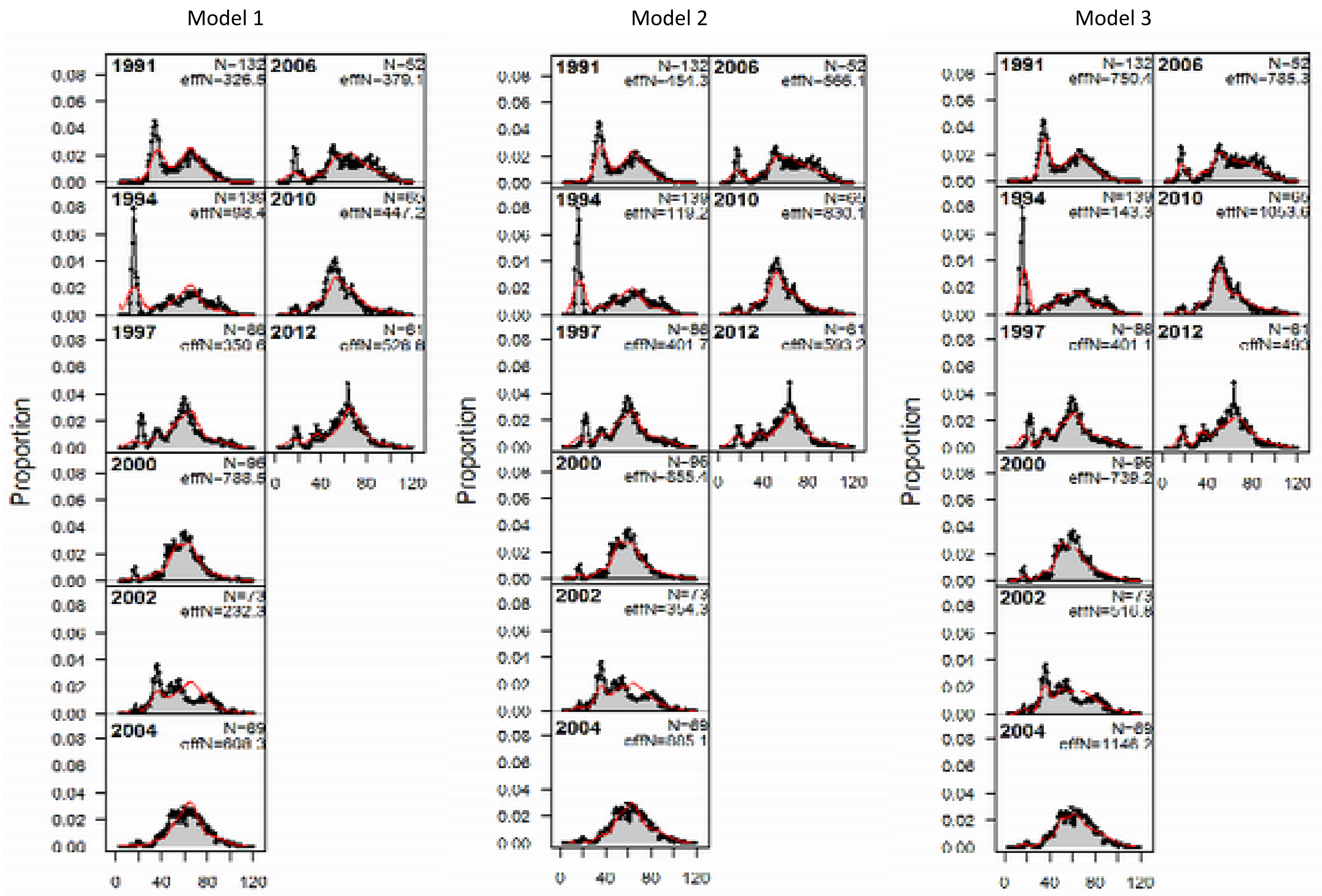


Figure 2A.1.3—Fits of the four models to the survey size composition data (grey = observed, red = estimated).

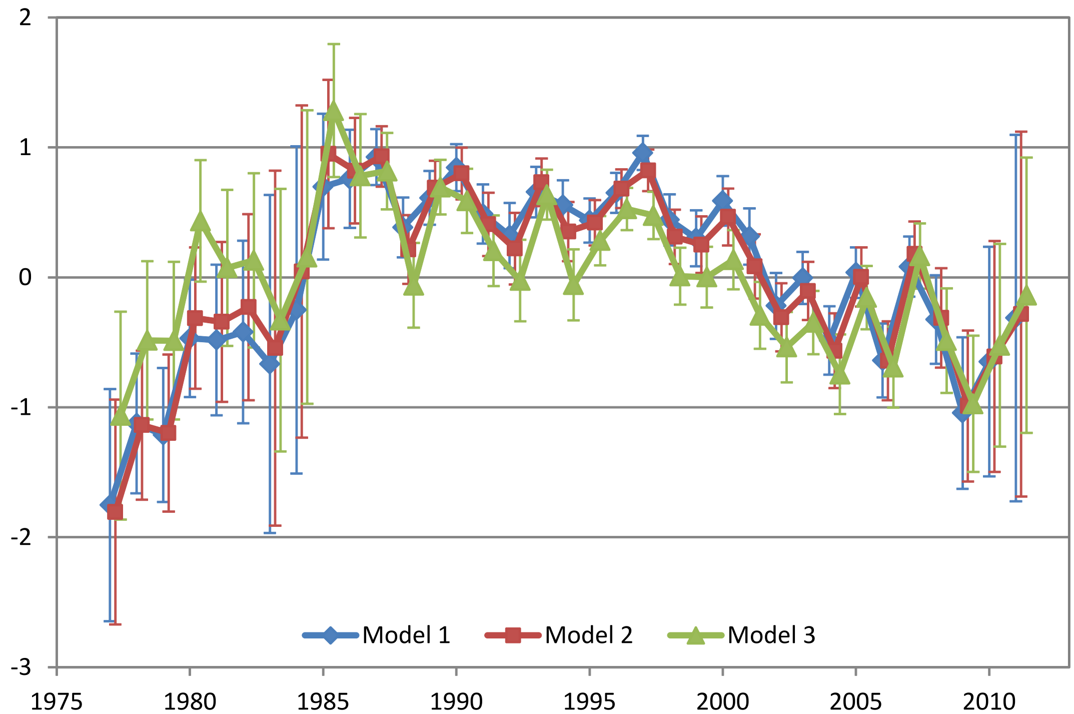


Figure 2A.1.4—Time series of log recruitment deviations estimated by the three models. Horizontal axis values have been offset slightly between models to improve visibility.

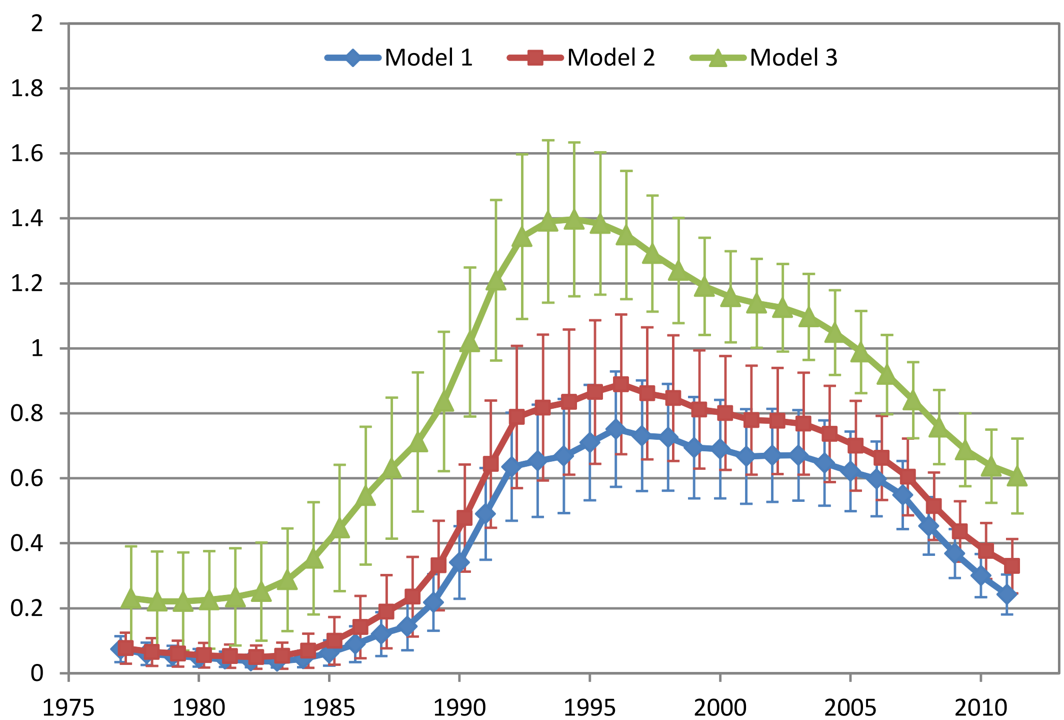


Figure 2A.1.5—Time series of spawning biomass relative to $B_{100\%}$ as estimated by the three models.

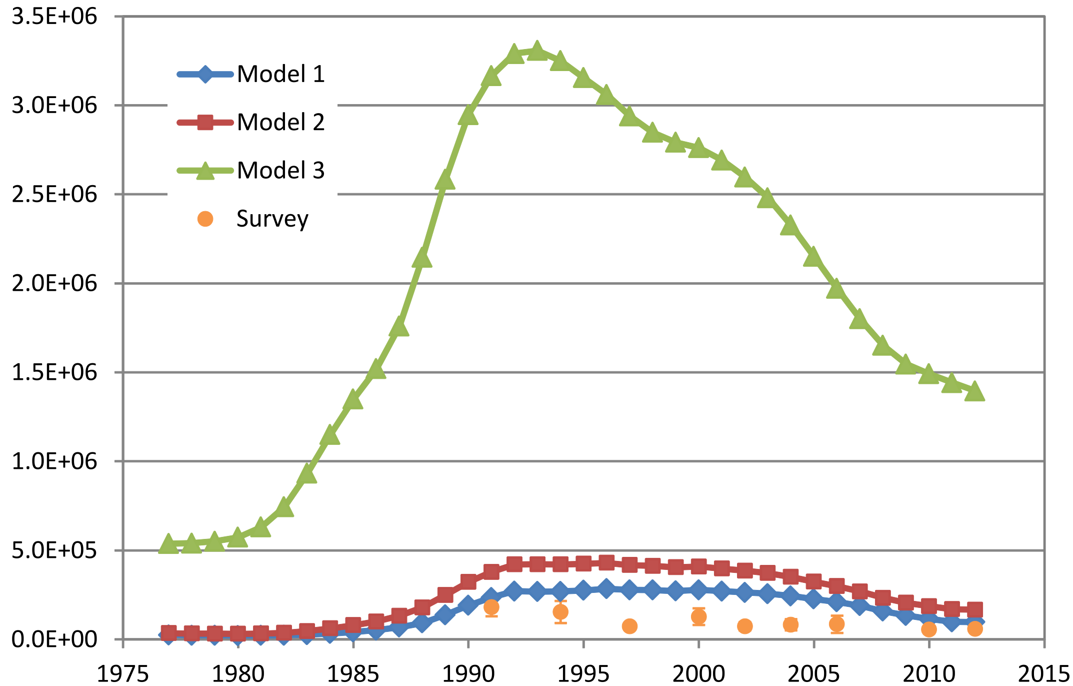


Figure 2A.1.6— Time series of total (age 0+) biomass as estimated by the three models. Survey biomass is shown for comparison.

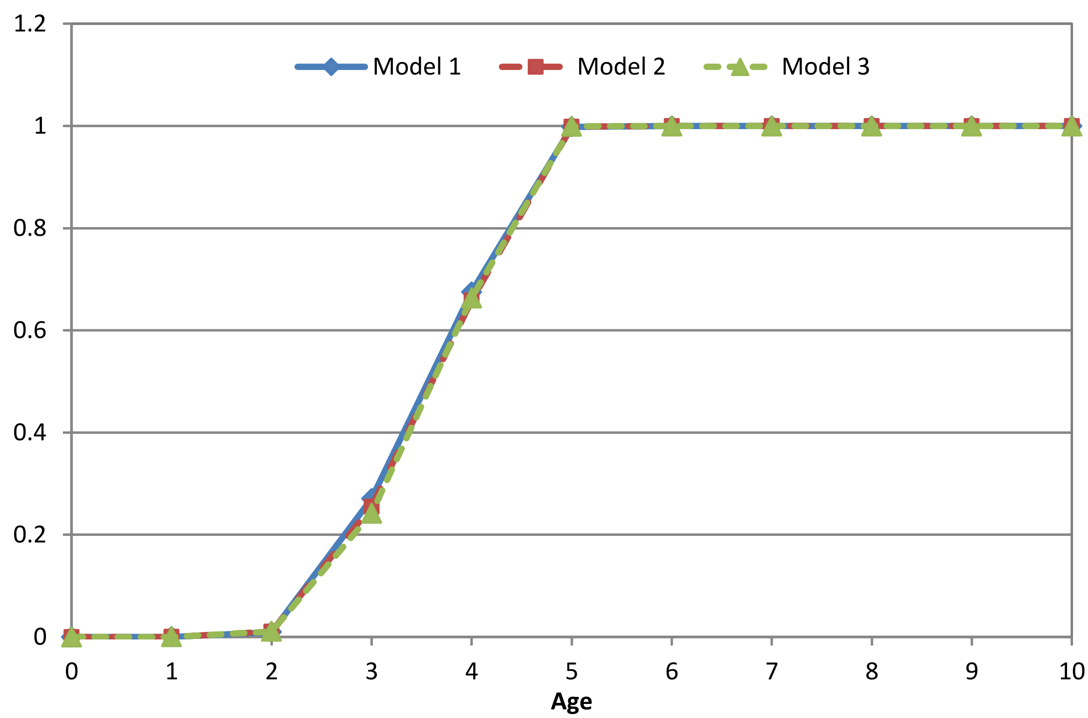
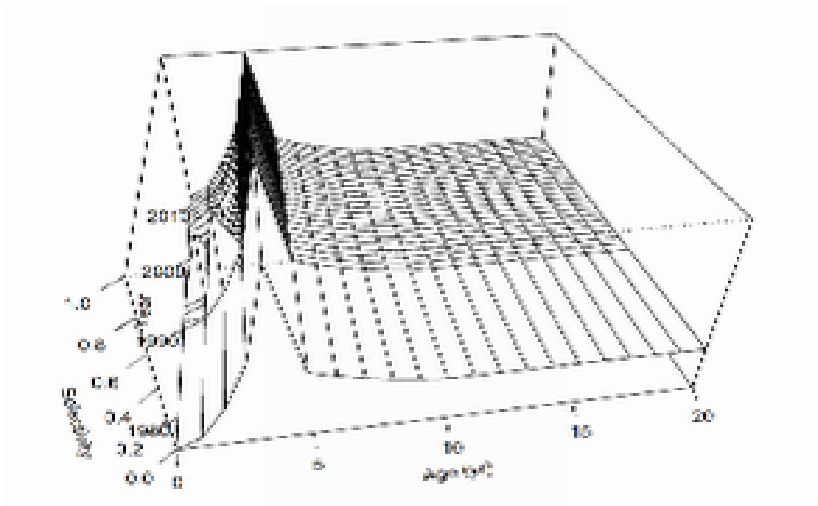
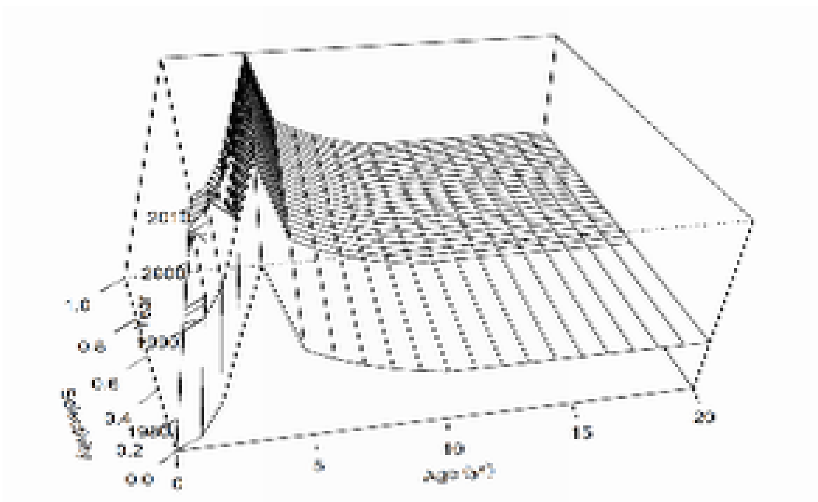


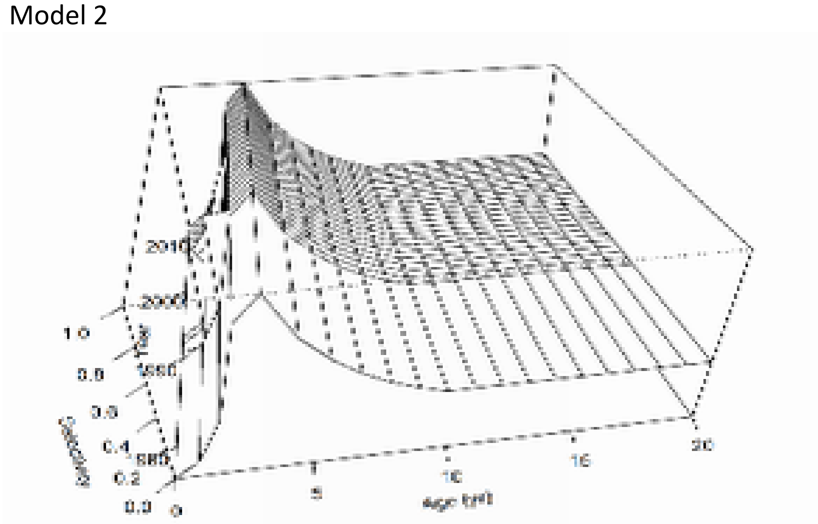
Figure 2A.1.7—Fishery selectivity at age as defined by parameters estimated by the four models.



Model 1



Model 2



Model 3

Figure 2A.1.8—Survey selectivity at age as estimated by the three models.