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). The age-structured models presented in last year's stock assessment (Thompson and Palsson 2013) were not accepted for use by the BSAI Plan Team or SSC.

Responses to SSC and Plan Team Comments on Assessments in General

Because last year's SSC and Plan Team comments pertaining to assessments in general all dealt with features of the final SAFE chapters, they will be addressed in this year's final assessment.

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

Note: In previous years, the full Joint Plan Teams have met in the spring to consider recommendations for models to be included in that year's Pacific cod assessments. In 2014, this task was delegated to a Joint Team Subcommittee (JTS) on Pacific Cod Models. All comments specific to AI Pacific cod from the September 2013 BPT and October 2013 SSC meetings were addressed in the 2013 final assessment.

BPT1 (11/13 minutes): *"For continued development of a Tier 3 assessment, the Team recommended:*

a. forcing the regime change recruitment offset to zero
b. examining the usefulness of IPHC longline survey data, and
c. continuing to monitor commercial CPUE."

Subsequent conversation with Team members clarified that only item (a) in the above list was a model proposal; the other two items were comments not directly related to development of a new model. For item (a), see comment JTS1. No progress has been made on items (b) or (c).

SSC1 (12/13 minutes): *"The SSC encourages further work on the age-structured models. Some of the issues are very similar to those in the Bering Sea, in particular the appropriate shape of the selectivity function. The SSC notes that selectivity was modeled differently in the AI model using an empirical and more flexible approach, although the model with asymptotic selectivity (and estimated Q) produced a better fit."* Further work on the age-structured models is described in this preliminary assessment. The empirical and more flexible approach described in this comment was retained, with some modification, in this preliminary assessment. One of the models described here imposes asymptotic selectivity, and all three models estimated survey catchability (*Q*) internally. See also response to comment JTS1.

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SSC2 (12/13 minutes): *"At this still early stage of model development, the SSC does not want to be overly prescriptive, but suggests bringing forward models that:*

a. focus on exploring the effects of different shapes of selectivity-at-age,
b. including a model with asymptotic selectivity."

Different shapes of the selectivity-at-age schedule are explored in the models presented in this preliminary assessment, and a model with forced asymptotic selectivity is included. See also response to comment JTS1.

JTS1 (3/14 minutes): *"For the AI, the subcommittee recommended that the following models be developed for this year's preliminary assessment:*

- *Model 1: A new model (author's choice) with the regime change recruitment offset fixed at 0.0*
- *Model 2: A new model (author's choice) with alternative selectivity specification(s)*
- *Model 3: A new model (author's choice) with forced asymptotic selectivity*

The subcommittee noted that the above list includes both of the model proposals contained in the SSC's December 2013 minutes. The subcommittee also suggested that obtaining a much larger supply of age data from the AI is more important than development of additional models at this point." This preliminary assessment includes all of the models requested in this comment. Additional age data are expected to be available in time for use in this year's final assessment.

SSC3 (4/14 minutes): *"The process for developing and refining appropriate models for Pacific cod still needs to mature and the SSC recommends that the assessment authors continue to work with the subcommittee to refine this process."* The authors will continue to work with the subcommittee to refine the process of developing appropriate models for Pacific cod. The next meeting of the subcommittee is anticipated to take place in the spring of 2015.

SSC4 (4/14 minutes): *"For 2014, the SSC recommends as an alternative model the use of the time-varying, non-parametric selectivity function described above"* (the reference to "above" in this comment pertains to a recommendation for modeling selectivity as a random walk with respect to age in the GOA Pacific cod assessment). Given the lack of any language to the contrary, it will be assumed that the SSC accepts the list of models recommended by the JTS, with the understanding that random walk selectivity is included in the "alternative selectivity specification(s)" requested for Model 2 in comment JTS1.

SSC5 (4/14 minutes): *"Additionally, profiling over the natural mortality rate should be conducted to gain a better understanding of the relationship between global scaling (Q and its associated priors) and natural mortality rate. The mode of the M-profile should not be used as a basis for setting the natural mortality rate in the model as it is conditional on other structural assumptions in the model."* Likelihood profiles with respect to the natural mortality rate are included for all models in this preliminary assessment. The mode is not used for setting the natural mortality rate in any of the models.

SSC6 (4/14 minutes): *"Lastly, the SSC recommends that as an overarching goal for these three areas, a common model structure be explored and based on the biology of Pacific cod and not devolve over time to address area-specific outliers or retrospective biases"* (the "three areas" referred to in this comment are the EBS, AI, and GOA). The model structures for all three areas already share several features in common. As further steps toward developing a common model structure, all models in this preliminary assessment of the AI stock and Model 6 in the preliminary assessment of the EBS stock use the same fleet structure and the same approach to selectivity.

SSC7 (4/14 minutes): *"The SSC clarified its intent regarding the use of the base model ('base' being used here to identify the model accepted by the SSC in the previous year) for 'several' years. While the SSC cannot be prescriptive about the exact length of time this would be, the idea is to continue the use of the model until there is general agreement by the stock assessment authors, the Plan Team, and the SSC on discontinuing its use."* This comment was directed primarily toward the EBS and GOA Pacific cod assessments, where age-structured models have been in use for several years. In the case of the AI Pacific cod stock, no age-structured model has yet been accepted for use. The existing management approach is based on Tier 5, applying a random effects model to the survey biomass time series in order to obtain the best estimate of current biomass. The authors understand that this approach will continue to be used until such time as the SSC adopts a different approach.

SSC8 (4/14 minutes): *"The SSC discussed the use of model averaging to ameliorate some of the problems of choosing among competing models with substantially different estimates. Essentially, the SSC agrees with the analyst that this approach should not be used until progress is made regarding issues about the selection of the competing models and averaging over models with nonlinearities in population and fishery processes."* Model averaging is not used in this preliminary assessment.

SSC9 (4/14 minutes): *"The SSC also discussed the nomenclature used to specify models in a historical context (when introduced and the model designator). While the SSC understands that this was useful for the historical presentation, it also notes that the nomenclature is confusing and probably not useful for the assessment in a given year. Furthermore, the use of "base model" to denote any model that is proposed seems overly inclusive and perhaps should be restricted to the chosen model in a previous assessment year."* Use of the term "base model" will henceforth be restricted to denoting the chosen model in a previous assessment year.

Data

The data file used for all three models presented here is identical to that used in last year's final assessment, with two exceptions:

1. Data prior to 1991 were removed, because last year's models had difficulty giving reasonable estimates of biomass and fishing mortality during the early years of the time series. Note that survey data from prior to 1991 had already been removed from last year's file.
2. Weighting of size composition data was adjusted so that the average (across years) was 300 for the fishery and 300 for the survey (in last year's assessment, the weighting achieved an average of 300 for the fishery and survey combined; the new adjustment results in more weight being given to the survey than before).

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	1991-2012
Fishery	Catch size composition	1991-2012
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

Analytic Approach

Model Structures

Per request of the Joint Team Subcommittee on Pacific Cod Models and the SSC, the following three models are presented in this preliminary assessment, all of which are estimated using Stock Synthesis (SS, Methot and Wetzel 2013):

- Model 1: A new model (author's choice) with the regime change recruitment offset fixed at 0.0
- Model 2: A new model (author's choice) with alternative selectivity specification(s)
- Model 3: A new model (author's choice) with forced asymptotic selectivity

All three are based on the models from last year's final AI assessment, which in turn were based on the accepted EBS model for 2012 (Thompson and Lauth 2012). Some of the main differences between last year's AI models and the 2012 EBS model were as follow:

1. In the data file, length bins (1 cm each) were extended out to 150 cm instead of 120 cm, because of the higher proportion of large fish observed in the AI.
2. Each year consisted of a single season instead of five.
3. A single fishery was defined instead of nine season-and-gear-specific fisheries.
4. The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667.
5. Initial abundances were estimated for the first ten age groups instead of the first three.
6. Selectivity for both the fishery and survey was modeled using a random walk with respect to age (SS selectivity-at-age pattern #17) instead of the usual double normal. 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 (i.e., the backward first difference on the log scale). 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 (see "Loop #1" under "Iterative Tuning Procedures Used for Model 2," below).

The three models presented in this preliminary assessment all include the following features, which represent additional departures from the 2012 EBS model:

1. The logarithm of survey catchability, ln(Q), was treated as a free parameter, with a normal prior distribution whose parameters were derived by averaging those used in other age-structured assessments of AI groundfish (similar to Model 2 in last year's preliminary and final assessments).
2. A normal prior distribution for each selectivity parameter was used, tuned so that the schedule of prior means (across age) was consistent with logistic selectivity, with a constant (across age) prior standard deviation.
3. Potentially, each selectivity parameter was allowed to be time-varying with annual additive *dev*s (normally distributed random deviations added to the base value of their respective parameter) where the sigma term was tuned according to the method described Thompson and Lauth (2012, Annex 2.1.1).

Except for the ln(Q) parameter and the selectivity and *dev* parameters in all models, all parameters were estimated with uniform prior distributions.

Model nomenclature follows that suggested in comment JTS1. Chronologically, model development proceeded as follows:

- Model 2 was developed first, with no constraint on the shape of the selectivity schedule other than that imposed by the prior distributions. For the vector of numbers at age in the initial year, SS allows the user to specify how many age groups to estimate as individual parameters, with the understanding that the remaining age groups are in equilibrium under an initial catch and mean recruitment level. The mean recruitment used to compute the equilibrium portion of the initial vector can be forced to equal the mean recruitment used for the remainder of the time series, or it can be allowed to differ, which is done by estimating a "recruitment offset" parameter. As in the EBS model, the recruitment offset parameter was estimated freely in Model 2.
- Model 1 was based on Model 2. The only change from Model 2 was that the recruitment offset parameter was fixed at a value of 0 in Model 1.
- Model 3 was also based on Model 2. The only changes from Model 2 were that survey selectivity first-differences were forced to equal zero after the age at which survey selectivity peaked in Model 2, and the lower bound on survey selectivity first-differences at all earlier ages was set at 0 (the combination of these two changes forced survey selectivity to increase monotonically until the age at which it peaked in Model 2, after which survey selectivity was constant at unity).

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 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 V3.24s, as compiled on 7/24/2013 (Methot 2013). 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).

Three main loops were involved in the iterative tuning procedure:

1. Tuning the means of the prior distributions for the selectivity parameters.
2. Estimating "unconstrained" values of the standard deviations of the selectivity *dev*s.
3. Estimating "equilibrium" values of the standard deviations for the selectivity *dev*s.

Following the iterative procedure, the model was run with final estimates of the standard deviations for the selectivity *dev*s, which were estimated from a formula involving the results of loops #2 and #3.

The loops are described in more detail below.

Loop #1: tuning the parameters of the prior distributions for the selectivity parameters

Initially, the model was run with recruitment as the only time-varying quantity, with the standard deviation of log-scale recruitment estimated internally (i.e., as a free parameter), and with large standard deviations in the prior distributions for all selectivity parameters.

Once the initial model converged, a pair of transformed logistic curves was fit to the point estimates of the fishery and survey selectivity schedules (a *transformed* logistic curve was used because the selectivity parameters in pattern #17 consist of the backward first differences of selectivity on the log scale, rather than selectivity itself ; Thompson and Palsson 2013). The respective transformed logistic curve (fishery or survey) was then used to specify a new set of means for the selectivity prior distributions (one for each age). A constant (across age) prior standard deviation was then computed such that no age had a prior CV (on the selectivity scale, not the transformed scale) less than 50%.

The model was then run with the new set of prior means and constant prior standard deviations (one for the fishery, one for the survey), then a new pair of transformed logistic curves was fit to the results, and the process was repeated until convergence was achieved. The converged set of prior means (on the transformed scale, not the selectivity scale) was as follows (ages 7+ all had prior means of 0 for both the fishery and the survey):

Age:	1	2	3	4	5	6
Fishery:	3.290	3.280	3.049	1.380	0.117	0.005
Survey:	5.295	0.846	0.004	0.000	0.000	0.000

The converged prior standard deviations were 0.342 for the fishery and 0.319 for the survey (both constant across age).

Loop #2: Estimating "unconstrained" values of the standard deviations of the selectivity devs

Loops #2 and #3 were designed to produce the quantities needed to use the method of Thompson and Lauth (2012, Annex 2.1.1) for estimating the standard deviation of a *dev* vector. The purpose of Loop #2 was to determine the value of the selectivity *dev* vector (for either the fishery or the survey) that would be obtained if the *dev*s were completely unconstrained by their respective σs. This was not always a straightforward process, as estimating a large matrix of age×year *dev*s is difficult if the *dev*s are unconstrained. In general, though, the procedure was to focus on one fleet (fishery or survey) at a time; begin with a small, constant (across age) value of σ; calculate the standard deviation of the estimated *dev*s; then increase the value of σ gradually until the standard deviation of the estimated *dev*s reached an asymptote.

Loop #3: Estimating "equilibrium" values of the standard deviations for the selectivity devs

Again proceeding one fleet (fishery or survey) at a time, this loop began with age-specific σs set at the unconstrained values estimated in Loop #2. The standard deviations of the estimated *dev*s then became the age-specific σs for the next run, and the process was repeated until the σs converged.

It is common for some ages to be "tuned" out during Loop #3 (i.e., the σs converge on zero). For Model 2, all ages were tuned out except the following (these are final values of σ, after application of the algorithm described by Thompson and Lauth (2013, Annex 2.1.1), shown in parentheses):

Fishery: age 4 (0.092), age 6 (0.237)
Survey: age 2 (0.194), age 3 (0.078), age 7 (0.442).

Because survey selectivity for Model 2 peaked at age 4, survey selectivity *dev*s were turned off for age 7 in Model 3 (because it required asymptotic selectivity).

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.
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=$A\times$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; ageing bias at ages 1 and 20; log mean recruitment since the beginning of the time series; offset for log mean recruitment prior to the beginning of the time series (Models 2 and 3 only); *dev*s for log-scale initial (i.e., 1991) abundance at ages 1 through 10; annual log-scale recruitment *dev*s for 1991-2011; initial (equilibrium) fishing mortality; base values for all fishery and survey selectivity parameters; and annual *dev*s for the selectivity parameters corresponding to ages 4 and 6 in the fishery, and ages 2, 3, and 7 (Models 1 and 2 only for age 7) in the survey.

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 annual fishing mortality rates are also estimated internally, but not in the same sense as the above parameters. The fishing mortality rates are determined (almost) 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. An option does exist in SS for treating the fishing mortality rates as full parameters, but previous explorations have indicated that adding these parameters has almost no effect on other model output (Methot and Wetzell 2013).

Likelihood Components

All three models include likelihood components for initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, survey age 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.

Results

Overview

The following table summarizes the status of the stock as estimated by the three models ("Value" is the point estimate, "SD" is the standard deviation to the point estimate, "FSB 2014" is female spawning biomass in 2014 (t), and "Bratio 2014" is the ratio of FSB 2014 to $B_{100\%}$:

	Model 1		Model 2		Model 3	
Quantity	Value	SD	Value	SD	Value	SD
FSB 2014	52,229	8,748	51,751	8,753	31,922	4,996
Bratio 2014	0.395	0.047	0.387	0.049	0.254	0.046

For these two quantities, the estimates from Models 1 and 2 are fairly similar, with the estimates from Model 3 being substantially lower.

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); note that the parameter counts include constrained deviations):

Component	Model 1	Model 2	Model 3
Survey index	-8.838	-9.129	-1.972
Size composition (fishery)	93.943	92.256	108.043
Size composition (survey)	190.720	190.479	217.886
Age composition	2.967	2.849	5.462
Recruitment	-0.303	2.171	21.367
Priors	17.463	16.606	17.808
"Softbounds"	0.001	0.001	0.006
Parameter devs	11.621	11.557	19.990
Total	307.574	306.789	388.591
Number of parameters	196	197	158
AIC	1007.148	1007.578	1093.182

Model 1 has one fewer parameter than Model 2 (the initial recruitment offset), and Model 3 has 39 fewer parameters than Model 2 (all selectivity parameters, although most of them are constrained deviations, and so should not be counted as full parameters).

Figure 2A.1.1 shows the fits of the three models to the trawl survey abundance data. All three models estimate a 2012 survey biomass close to the observed value. Models 1 and 2 tend to overestimate the survey abundance, although usually not by much. Model 3 has the best mix of positive and negative residuals, but does not perform as well as the other models by most other measures, as shown below (for comparison to the root mean squared residual, the average log-scale standard error in the data is 0.184; color scale extends from red (minimum) to green (maximum)):

Quantity	Model 1	Model 2	Model 3
Correlation (observed:expected)	0.959	0.954	0.695
Root mean squared residual	0.190	0.184	0.303
Mean standardized residual	-0.701	-0.656	-0.582
Root mean squared standardized residual	1.225	1.198	1.740

Models 1 and 2 do better than Model 3 by all of the above measures except mean standardized residual.

Figure 2A.1.2 shows the models' fits to the fishery size composition data, and Figure 2A.1.3 shows the models' fits to the survey size composition data. Effective sample sizes and negative log likelihoods for the size composition data are shown in Table 2A.1.1. All three models give effective sample sizes far above the mean input sample sizes for both the fishery and the survey. The performances of Models 1 and 2 are very similar, giving slightly higher effective sample sizes and slightly lower (better) negative log likelihoods than Model 1.

Figure 2A.1.4 shows the models' fits to the single available year of survey age composition data. Effective sample sizes and negative log likelihoods are shown below. Models 1 and 2 both give effective sample sizes far above the input sample size, while the effective sample size given by Model 1 is slightly below the input sample size. Again, Models 1 and 2 give slightly lower (better) negative log likelihoods than Model 1.

			Effective sample size			Negative log likelihood		
Fleet	Year	N	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Survey	2012	300	730	769	286	2.967	2.849	5.462

Parameters, Schedules, and Time Series Estimates

Table 2A.1.2 lists the constants and parameters listed in the SS control files for the three models, along with standard deviations ("SD") for all estimated parameters. Constants are listed in Table 2A.1.2a, main parameters (except selectivity) are listed in Table 2A.1.2b, base selectivity parameters are listed in Table 2A.1.2c, deviations (*dev*s) for fishery selectivity parameters are listed in Table 2A.1.2d, and deviations for survey selectivity parameters are listed in Table 2A.1.2e. Quantities with "n/a" listed under "SD" were fixed rather than estimated.

Selectivity schedules (fishery and survey) for Models 1, 2, and 3 are shown in Figures 2A.1.5a, 2A.1.5b, and 2A.1.5c, respectively. The schedules for Models 1 and 2 are very similar. The main difference between Model 3's selectivity schedules and those of Models 1 and 2 is the asymptotic nature of Model 3's survey selectivity (which was a design feature of Model 3).

Time series estimated by the three models are shown for female spawning biomass, relative (to $B_{100\%}$) female spawning biomass, and age 0 recruitment in Figures 2A.1.6, 2A.1.7, and 2A.1.8, respectively. Figures 2A.1.6 and 2A.1.7 are very similar except for scale. In these two figures, the values estimated by Model 1 are higher than those estimated by Model 2 for the early portion of the time series, but the two models converge by the end of the time series; both Models 1 and 2 estimate values that are higher than those estimated by Model 3 throughout the time series. In Figure 2A.1.8, the recruitments estimated by Models 1 and 2 are very similar, and again are consistently higher than those estimated by Model 3 throughout the time series.

Discussion

The structural differences between the three models presented in this preliminary assessment are simple: Models 2 and 3 estimate a recruitment offset which allows the average recruitment in the years preceding the start of the time series to differ from the average recruitment during the time series, whereas Model 1 forces the average recruitment to be the same during both periods. Models 1 and 2 allow survey selectivity to vary freely, except to the extent that they are constrained by their respective prior distributions, whereas Model 3 forces survey selectivity to be asymptotic.

In general, the differences between the estimates produced by Models 1 and 2 are small. However, some of the differences between Models 1 and 2 and Model 3 are substantial. For example, as reported in the "Overview" subsection of the "Results" section, Model 3's estimate of female spawning biomass in 2014 is 38-39% lower than those obtained by Models 1 and 2. The estimates of ln(Q), on the other hand, are fairly similar for all three models, with a range of -0.485 to -0.453, corresponding to a Q range of 0.616 to 0.636. These values imply that the survey misses at least 36-38% of even the most-selected age group.

Although the natural mortality rate M is not estimated internally in any of the models, Figure 2A.1.9 shows the likelihood profiles with respect to M for each of the models. If M were estimated internally, Models 1 and 2 would give an estimate (0.11) much lower than the value (0.34) that has been used in the EBS Pacific cod assessment for the last several years. This may indicate structural deficiencies in Models 1 and 2.

The three models presented here generally provide good-to-excellent fits to all three types of data (survey abundance index, size compostion, and age composition).

For all three models, data prior to 1991 were removed, because last year's models had difficulty giving reasonable estimates of biomass and fishing mortality during the early years of the time series (note that survey data from prior to 1991 had already been removed from last year's file). Although the problematic estimates are now gone, it may be worth considering further whether removal of all pre-1991 data is an appropriate way to address the issue.

Additional age data from the AI bottom trawl survey are expected to become available in time for use in this year's final assessment. Given that only a single year of age data was available for this preliminary assessment, it is possible that these additional data will affect the results of the models substantially.

Last year's preliminary assessment provided the first exploration of SS selectivity-at-age pattern #17 (random walk with age) for Pacific cod, and use of this pattern has been retained here. Some advantages of pattern #17 are the following:

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 means of the prior distributions provides a way to specify these quantities 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 the 2013 CAPAM selectivity workshop (Crone et al., 2013) seemed to favor allowing selectivity to vary over time.

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.

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Table 2A.1.1—Effective sample sizes for size composition fits.

			Effective sample size			Negative log likelihood		
Fleet	Year	N	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Fishery	1991	129	1540	1704	1710	6.121	5.852	6.334
Fishery	1992	586	13269	14622	17131	4.592	4.276	3.910
Fishery	1993	267	2034	2054	2285	4.759	4.669	4.272
Fishery	1994	170	4838	4675	2276	1.352	1.355	2.465
Fishery	1995	176	4794	4694	3894	5.416	5.408	4.957
Fishery	1996	243	5221	5342	5157	2.210	2.169	2.715
Fishery	1997	136	4350	4430	2109	1.281	1.258	2.394
Fishery	1998	424	9331	9337	7858	2.282	2.271	3.069
Fishery	1999	412	6641	6893	14991	3.063	2.971	2.479
Fishery	2000	636	6923	6938	4411	4.887	4.857	7.319
Fishery	2001	700	7972	7825	5376	6.902	7.033	11.226
Fishery	2002	284	3956	3905	4415	4.884	4.878	3.523
Fishery	2003	287	1280	1305	2458	6.308	6.198	4.443
Fishery	2004	291	2654	2688	2895	7.364	7.301	6.670
Fishery	2005	252	6135	6038	2856	1.550	1.556	2.742
Fishery	2006	248	3320	3287	1976	2.707	2.733	4.153
Fishery	2007	334	8089	8716	4439	2.621	2.572	4.078
Fishery	2008	319	3038	3161	1962	4.938	4.778	6.956
Fishery	2009	266	3213	3281	1882	5.297	5.198	7.216
Fishery	2010	416	2566	2553	2116	8.116	8.057	9.597
Fishery	2011	108	1886	2008	2364	1.915	1.835	1.767
Fishery	2012	143	2609	2730	2146	2.204	2.085	2.874
Fishery	2013	76	715	776	951	3.173	2.944	2.887
Fishery	Ave/sum	300	4625	4737	4246	93.943	92.256	108.043
Survey	1991	462	1620	1637	1145	12.828	12.835	18.038
Survey	1994	486	187	188	187	57.723	57.567	56.682
Survey	1997	300	413	413	381	54.466	54.430	58.205
Survey	2000	336	1395	1400	1025	14.436	14.411	19.027
Survey	2002	254	1294	1292	816	10.687	10.657	12.388
Survey	2004	241	1433	1430	1196	10.675	10.665	13.098
Survey	2006	181	1233	1235	895	9.664	9.638	12.268
Survey	2010	228	1768	1754	827	7.548	7.584	13.074
Survey	2012	213	958	948	573	12.694	12.692	15.106
Survey	Ave/sum	300	1144	1144	783	190.720	190.479	217.886

Table 2A.1.2a—Constants (not estimated internally) in the SS control file.

Parameter	Model 1	Model 2	Model 3
Natural mortality rate	3.40E-01	3.40E-01	3.40E-01
Weight-length a (proportionality)	5.68E-06	5.68E-06	5.68E-06
Weight-length b (exponent)	3.18E+00	3.18E+00	3.18E+00
Age at 50% maturity	4.88E+00	4.88E+00	4.88E+00
Maturity slope	-9.65E-01	-9.65E-01	-9.65E-01
Std. dev. of ageing error at age 1	9.30E-02	9.30E-02	9.30E-02
Std. dev. of ageing error at age 12	1.86E+00	1.86E+00	1.86E+00
Stock-recruitment "steepness"	1.00E+00	1.00E+00	1.00E+00

Table 2A.1.2b—Main parameters (except selectivity) parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Length at age 1 (cm)	1.79E+01	1.98E-01	1.79E+01	1.98E-01	1.79E+01	1.91E-01
Asymptotic length (cm)	1.09E+02	1.78E+00	1.09E+02	1.77E+00	1.11E+02	1.96E+00
Brody growth coefficient	2.19E-01	6.74E-03	2.19E-01	6.73E-03	2.18E-01	6.78E-03
SD of length at age 1 (cm)	3.15E+00	1.41E-01	3.14E+00	1.41E-01	2.97E+00	1.35E-01
SD of length at age 20 (cm)	7.98E+00	4.05E-01	8.02E+00	4.07E-01	9.81E+00	4.92E-01
Ageing bias at age 1 (years)	2.99E-01	1.74E-01	3.01E-01	1.79E-01	4.20E-01	7.58E-02
Ageing bias at age 20 (years)	1.47E+00	1.09E+00	1.40E+00	1.11E+00	-1.72E-01	6.10E-01
ln(mean post-1990 recruitment)	1.10E+01	8.40E-02	1.11E+01	8.81E-02	1.10E+01	1.36E-01
σ(recruitment)	5.56E-01	7.60E-02	5.99E-01	9.27E-02	9.56E-01	1.43E-01
ln(pre-1991 recruitment offset)	0.00E+00	n/a	-2.37E-01	2.03E-01	-1.29E+00	3.14E-01
Initial fishing mortality rate	5.82E-03	1.36E-03	7.67E-03	2.51E-03	3.07E-02	9.26E-03
ln(catchability)	-4.68E-01	8.59E-02	-4.53E-01	8.69E-02	-4.85E-01	8.20E-02
Initial age 1 ln(abundance) dev	3.69E-01	1.80E-01	5.55E-01	2.49E-01	1.30E+00	3.77E-01
Initial age 2 ln(abundance) dev	1.13E+00	1.53E-01	1.33E+00	2.36E-01	2.46E+00	3.18E-01
Initial age 3 ln(abundance) dev	-1.41E-01	1.91E-01	3.20E-02	2.49E-01	6.92E-01	3.68E-01
Initial age 4 ln(abundance) dev	5.98E-01	1.76E-01	7.80E-01	2.43E-01	1.91E+00	3.68E-01
Initial age 5 ln(abundance) dev	1.17E+00	2.16E-01	1.33E+00	2.64E-01	2.00E+00	3.68E-01
Initial age 6 ln(abundance) dev	1.06E+00	3.26E-01	1.22E+00	3.68E-01	2.07E+00	4.22E-01
Initial age 7 ln(abundance) dev	1.04E-01	5.08E-01	2.08E-01	5.69E-01	-3.35E-01	8.18E-01
Initial age 8 ln(abundance) dev	-4.42E-01	4.60E-01	-4.01E-01	4.99E-01	-7.50E-01	7.24E-01
Initial age 9 ln(abundance) dev	-6.61E-01	4.42E-01	-6.43E-01	4.74E-01	-9.98E-01	6.86E-01
Initial age 10 ln(abundance) dev	-7.43E-01	4.36E-01	-7.44E-01	4.65E-01	-1.07E+00	6.75E-01
Log-scale recruit. dev for 1991	2.85E-01	1.45E-01	2.59E-01	1.46E-01	8.19E-02	1.38E-01
Log-scale recruit. dev for 1992	-2.28E-01	2.34E-01	-2.51E-01	2.37E-01	-6.63E-01	1.85E-01
Log-scale recruit. dev for 1993	8.52E-01	1.26E-01	8.38E-01	1.26E-01	1.17E+00	9.67E-02
Log-scale recruit. dev for 1994	-1.43E-01	1.58E-01	-1.59E-01	1.60E-01	-3.19E-01	1.93E-01
Log-scale recruit. dev for 1995	4.95E-01	1.62E-01	4.83E-01	1.62E-01	2.15E-01	1.61E-01
Log-scale recruit. dev for 1996	9.39E-01	1.21E-01	9.30E-01	1.21E-01	1.15E+00	1.18E-01
Log-scale recruit. dev for 1997	6.33E-01	1.15E-01	6.28E-01	1.16E-01	6.87E-01	1.11E-01
Log-scale recruit. dev for 1998	9.86E-02	1.82E-01	9.45E-02	1.83E-01	-3.21E-01	2.05E-01
Log-scale recruit. dev for 1999	7.55E-01	1.21E-01	7.61E-01	1.21E-01	7.47E-01	1.21E-01
Log-scale recruit. dev for 2000	5.17E-02	1.54E-01	5.93E-02	1.55E-01	8.05E-01	1.13E-01
Log-scale recruit. dev for 2001	-1.92E-01	1.33E-01	-1.79E-01	1.34E-01	1.34E-02	1.54E-01
Log-scale recruit. dev for 2002	-5.86E-01	1.56E-01	-5.76E-01	1.59E-01	-5.20E-01	1.85E-01
Log-scale recruit. dev for 2003	-2.94E-01	1.36E-01	-2.75E-01	1.38E-01	-6.45E-03	1.39E-01
Log-scale recruit. dev for 2004	-6.21E-01	1.87E-01	-6.09E-01	1.91E-01	-1.01E+00	2.51E-01
Log-scale recruit. dev for 2005	-1.88E-01	1.59E-01	-1.70E-01	1.61E-01	1.08E-01	1.32E-01
Log-scale recruit. dev for 2006	-4.61E-01	1.60E-01	-4.58E-01	1.62E-01	-5.24E-01	2.15E-01
Log-scale recruit. dev for 2007	3.00E-01	1.24E-01	3.12E-01	1.25E-01	5.53E-01	1.16E-01
Log-scale recruit. dev for 2008	-9.69E-02	1.52E-01	-9.89E-02	1.54E-01	-3.89E-02	1.54E-01
Log-scale recruit. dev for 2009	-9.96E-01	2.06E-01	-1.00E+00	2.08E-01	-9.35E-01	2.00E-01
Log-scale recruit. dev for 2010	-4.38E-01	4.06E-01	-4.42E-01	4.22E-01	-8.68E-01	2.44E-01
Log-scale recruit. dev for 2011	-1.65E-01	5.09E-01	-1.44E-01	5.42E-01	-3.33E-01	4.31E-01

Table 2A.1.2c—Base selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Fishery age 1 selectivity parameter	3.29E+00	3.42E-01	3.29E+00	3.42E-01	3.29E+00	3.42E-01
Fishery age 2 selectivity parameter	3.41E+00	3.19E-01	3.41E+00	3.19E-01	3.42E+00	3.18E-01
Fishery age 3 selectivity parameter	3.20E+00	1.88E-01	3.20E+00	1.89E-01	3.41E+00	2.05E-01
Fishery age 4 selectivity parameter	1.24E+00	1.82E-01	1.25E+00	1.82E-01	1.28E+00	1.88E-01
Fishery age 5 selectivity parameter	2.92E-01	1.16E-01	2.95E-01	1.16E-01	2.60E-01	1.42E-01
Fishery age 6 selectivity parameter	1.51E-01	2.86E-01	1.54E-01	2.86E-01	1.77E-01	2.87E-01
Fishery age 7 selectivity parameter	-9.38E-02	1.99E-01	-8.94E-02	1.98E-01	-1.79E-03	2.07E-01
Fishery age 8 selectivity parameter	-4.88E-03	2.52E-01	1.71E-02	2.52E-01	4.23E-01	2.90E-01
Fishery age 9 selectivity parameter	1.02E-01	2.71E-01	1.23E-01	2.72E-01	3.73E-01	2.64E-01
Fishery age 10 selectivity parameter	2.79E-01	2.84E-01	2.93E-01	2.85E-01	2.30E-01	3.13E-01
Fishery age 11 selectivity parameter	1.14E-01	3.13E-01	1.26E-01	3.13E-01	-1.21E-01	3.21E-01
Fishery age 12 selectivity parameter	-2.21E-01	3.46E-01	-2.02E-01	3.45E-01	-2.73E-01	3.42E-01
Fishery age 13 selectivity parameter	-4.43E-01	3.20E-01	-4.35E-01	3.20E-01	-3.74E-01	3.19E-01
Fishery age 14 selectivity parameter	-3.35E-01	3.20E-01	-3.32E-01	3.20E-01	-2.80E-01	3.24E-01
Fishery age 15 selectivity parameter	-2.40E-01	3.23E-01	-2.38E-01	3.24E-01	-2.11E-01	3.27E-01
Fishery age 16 selectivity parameter	-2.06E-01	3.24E-01	-2.04E-01	3.24E-01	-1.68E-01	3.29E-01
Fishery age 17 selectivity parameter	-1.62E-01	3.26E-01	-1.60E-01	3.27E-01	-1.33E-01	3.30E-01
Fishery age 18 selectivity parameter	-1.22E-01	3.29E-01	-1.21E-01	3.29E-01	-9.80E-02	3.33E-01
Fishery age 19 selectivity parameter	-8.58E-02	3.32E-01	-8.52E-02	3.32E-01	-7.01E-02	3.35E-01
Fishery age 20 selectivity parameter	-6.74E-02	3.34E-01	-6.67E-02	3.34E-01	-5.22E-02	3.36E-01
Survey age 1 selectivity parameter	5.29E+00	3.19E-01	5.29E+00	3.19E-01	5.29E+00	3.19E-01
Survey age 2 selectivity parameter	9.25E-01	2.88E-01	9.26E-01	2.88E-01	1.26E+00	1.69E-01
Survey age 3 selectivity parameter	6.20E-01	2.17E-01	6.21E-01	2.17E-01	7.82E-01	1.26E-01
Survey age 4 selectivity parameter	3.45E-01	1.12E-01	3.53E-01	1.13E-01	6.05E-02	9.56E-02
Survey age 5 selectivity parameter	-3.95E-01	1.30E-01	-3.91E-01	1.30E-01	0.00E+00	n/a
Survey age 6 selectivity parameter	-1.95E-01	2.25E-01	-1.81E-01	2.26E-01	0.00E+00	n/a
Survey age 7 selectivity parameter	9.20E-03	3.12E-01	8.62E-03	3.12E-01	0.00E+00	n/a
Survey age 8 selectivity parameter	-4.12E-01	2.38E-01	-3.74E-01	2.41E-01	0.00E+00	n/a
Survey age 9 selectivity parameter	-2.97E-01	2.67E-01	-2.79E-01	2.68E-01	0.00E+00	n/a
Survey age 10 selectivity parameter	-1.14E-01	2.88E-01	-1.02E-01	2.88E-01	0.00E+00	n/a
Survey age 11 selectivity parameter	-1.35E-01	3.00E-01	-1.26E-01	3.00E-01	0.00E+00	n/a
Survey age 12 selectivity parameter	-1.77E-01	3.04E-01	-1.70E-01	3.05E-01	0.00E+00	n/a
Survey age 13 selectivity parameter	-1.54E-01	3.05E-01	-1.48E-01	3.05E-01	0.00E+00	n/a
Survey age 14 selectivity parameter	-1.18E-01	3.08E-01	-1.13E-01	3.08E-01	0.00E+00	n/a
Survey age 15 selectivity parameter	-1.02E-01	3.09E-01	-9.75E-02	3.09E-01	0.00E+00	n/a
Survey age 16 selectivity parameter	-7.96E-02	3.10E-01	-7.62E-02	3.11E-01	0.00E+00	n/a
Survey age 17 selectivity parameter	-5.27E-02	3.13E-01	-5.07E-02	3.13E-01	0.00E+00	n/a
Survey age 18 selectivity parameter	-3.64E-02	3.14E-01	-3.50E-02	3.14E-01	0.00E+00	n/a
Survey age 19 selectivity parameter	-2.55E-02	3.16E-01	-2.46E-02	3.16E-01	0.00E+00	n/a
Survey age 20 selectivity parameter	-1.81E-02	3.16E-01	-1.75E-02	3.17E-01	0.00E+00	n/a

Table 2A.1.2d—Deviations (*dev*s) for fishery selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Fishery age 4 sel. dev for 1991	-2.66E-03	5.47E-02	-2.89E-03	5.49E-02	-3.57E-03	6.16E-02
Fishery age 4 sel. dev for 1992	8.03E-02	3.24E-02	8.19E-02	3.25E-02	1.02E-01	3.06E-02
Fishery age 4 sel. dev for 1993	-7.38E-02	3.66E-02	-7.47E-02	3.68E-02	-1.01E-01	4.05E-02
Fishery age 4 sel. dev for 1994	-1.33E-02	3.96E-02	-1.24E-02	3.96E-02	-2.46E-02	4.05E-02
Fishery age 4 sel. dev for 1995	-1.13E-02	4.72E-02	-1.09E-02	4.73E-02	-1.35E-02	4.81E-02
Fishery age 4 sel. dev for 1996	7.47E-02	3.58E-02	7.55E-02	3.59E-02	1.41E-01	3.66E-02
Fishery age 4 sel. dev for 1997	-3.29E-02	5.08E-02	-3.28E-02	5.10E-02	-4.66E-02	5.81E-02
Fishery age 4 sel. dev for 1998	-1.20E-02	2.99E-02	-1.20E-02	2.99E-02	-4.79E-02	2.95E-02
Fishery age 4 sel. dev for 1999	3.20E-02	3.18E-02	3.22E-02	3.19E-02	7.01E-02	3.41E-02
Fishery age 4 sel. dev for 2000	-1.92E-02	2.79E-02	-1.89E-02	2.79E-02	-1.92E-02	3.01E-02
Fishery age 4 sel. dev for 2001	-6.54E-02	2.94E-02	-6.51E-02	2.94E-02	-1.08E-01	3.02E-02
Fishery age 4 sel. dev for 2002	1.90E-04	3.68E-02	8.66E-04	3.68E-02	1.72E-02	3.85E-02
Fishery age 4 sel. dev for 2003	-1.15E-01	3.70E-02	-1.15E-01	3.70E-02	-4.95E-02	3.83E-02
Fishery age 4 sel. dev for 2004	-1.03E-01	3.15E-02	-1.03E-01	3.15E-02	-9.98E-02	3.38E-02
Fishery age 4 sel. dev for 2005	-1.99E-02	4.12E-02	-1.98E-02	4.13E-02	-5.07E-02	4.28E-02
Fishery age 4 sel. dev for 2006	2.77E-02	3.77E-02	2.83E-02	3.78E-02	3.08E-02	4.01E-02
Fishery age 4 sel. dev for 2007	3.59E-02	4.08E-02	3.56E-02	4.10E-02	-1.11E-04	4.55E-02
Fishery age 4 sel. dev for 2008	-1.06E-02	3.41E-02	-1.07E-02	3.41E-02	1.25E-02	3.44E-02
Fishery age 4 sel. dev for 2009	1.96E-02	3.71E-02	1.86E-02	3.72E-02	1.94E-02	4.15E-02
Fishery age 4 sel. dev for 2010	7.23E-03	2.96E-02	7.31E-03	2.97E-02	3.40E-02	2.97E-02
Fishery age 4 sel. dev for 2011	2.58E-02	5.30E-02	2.54E-02	5.32E-02	2.40E-02	5.80E-02
Fishery age 4 sel. dev for 2012	5.64E-02	5.95E-02	5.61E-02	5.96E-02	5.15E-02	6.25E-02
Fishery age 4 sel. dev for 2013	2.14E-02	6.58E-02	2.20E-02	6.60E-02	-5.61E-03	6.87E-02
Fishery age 6 sel. dev for 1991	5.24E-02	4.10E-02	5.81E-02	4.14E-02	9.57E-02	4.40E-02
Fishery age 6 sel. dev for 1992	-4.31E-02	3.54E-02	-3.90E-02	3.56E-02	-1.92E-02	3.68E-02
Fishery age 6 sel. dev for 1993	3.71E-02	3.86E-02	4.23E-02	3.88E-02	7.66E-02	3.84E-02
Fishery age 6 sel. dev for 1994	-2.05E-02	3.80E-02	-1.65E-02	3.81E-02	-1.03E-02	3.87E-02
Fishery age 6 sel. dev for 1995	1.90E-02	3.90E-02	2.21E-02	3.91E-02	8.58E-03	4.06E-02
Fishery age 6 sel. dev for 1996	-6.73E-02	3.75E-02	-6.46E-02	3.76E-02	-9.09E-02	3.88E-02
Fishery age 6 sel. dev for 1997	6.24E-02	3.95E-02	6.51E-02	3.96E-02	9.64E-02	4.10E-02
Fishery age 6 sel. dev for 1998	2.44E-03	3.36E-02	4.46E-03	3.37E-02	1.84E-02	3.45E-02
Fishery age 6 sel. dev for 1999	2.49E-02	3.57E-02	2.60E-02	3.57E-02	1.78E-03	3.67E-02
Fishery age 6 sel. dev for 2000	8.45E-02	3.45E-02	8.58E-02	3.45E-02	1.12E-01	3.68E-02
Fishery age 6 sel. dev for 2001	1.11E-02	3.31E-02	1.20E-02	3.32E-02	2.64E-02	3.46E-02
Fishery age 6 sel. dev for 2002	7.02E-02	3.87E-02	7.07E-02	3.88E-02	4.62E-02	4.06E-02
Fishery age 6 sel. dev for 2003	1.18E-01	3.81E-02	1.19E-01	3.81E-02	1.22E-01	4.07E-02
Fishery age 6 sel. dev for 2004	2.72E-02	3.59E-02	2.76E-02	3.58E-02	6.12E-02	3.75E-02
Fishery age 6 sel. dev for 2005	-4.87E-03	3.66E-02	-5.07E-03	3.66E-02	2.04E-02	3.75E-02
Fishery age 6 sel. dev for 2006	-5.35E-02	3.61E-02	-5.44E-02	3.61E-02	-6.62E-02	3.76E-02
Fishery age 6 sel. dev for 2007	-7.58E-03	3.56E-02	-8.82E-03	3.56E-02	-1.99E-02	3.72E-02
Fishery age 6 sel. dev for 2008	2.00E-02	3.57E-02	1.77E-02	3.58E-02	-2.60E-02	3.76E-02
Fishery age 6 sel. dev for 2009	2.62E-02	3.67E-02	2.35E-02	3.68E-02	3.84E-03	3.90E-02
Fishery age 6 sel. dev for 2010	5.78E-02	3.69E-02	5.39E-02	3.71E-02	4.71E-02	3.82E-02
Fishery age 6 sel. dev for 2011	1.08E-01	4.15E-02	1.04E-01	4.16E-02	1.31E-01	4.20E-02
Fishery age 6 sel. dev for 2012	7.31E-02	4.13E-02	6.87E-02	4.15E-02	9.20E-02	4.23E-02
Fishery age 6 sel. dev for 2013	1.07E-01	5.26E-02	1.03E-01	5.27E-02	1.01E-01	5.59E-02

Table 2A.1.2e—Deviations (*dev*s) for survey selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Survey age 2 sel. dev for 1991	3.43E-01	8.51E-02	3.42E-01	8.52E-02	5.12E-01	1.29E-01
Survey age 2 sel. dev for 1994	-1.24E-01	4.45E-02	-1.24E-01	4.46E-02	-5.08E-01	1.21E-01
Survey age 2 sel. dev for 1997	-6.81E-04	4.26E-02	-3.87E-04	4.26E-02	1.10E-01	1.05E-01
Survey age 2 sel. dev for 2000	2.55E-02	5.16E-02	2.62E-02	5.17E-02	2.06E-01	1.14E-01
Survey age 2 sel. dev for 2002	1.34E-01	5.12E-02	1.34E-01	5.12E-02	9.60E-02	1.30E-01
Survey age 2 sel. dev for 2004	8.21E-02	6.44E-02	8.24E-02	6.45E-02	2.44E-01	1.31E-01
Survey age 2 sel. dev for 2006	-1.29E-01	5.37E-02	-1.29E-01	5.38E-02	-2.30E-01	1.33E-01
Survey age 2 sel. dev for 2010	-5.10E-02	5.49E-02	-5.17E-02	5.49E-02	-8.11E-02	1.50E-01
Survey age 2 sel. dev for 2012	9.20E-03	7.16E-02	1.26E-02	7.45E-02	-1.58E-02	1.76E-01
Survey age 3 sel. dev for 1991	-4.29E-02	2.79E-02	-4.11E-02	2.79E-02	-9.77E-02	6.75E-02
Survey age 3 sel. dev for 1994	6.66E-03	3.64E-02	8.08E-03	3.66E-02	-1.03E-01	6.74E-02
Survey age 3 sel. dev for 1997	6.11E-02	3.11E-02	6.06E-02	3.11E-02	3.12E-02	7.28E-02
Survey age 3 sel. dev for 2000	1.07E-01	3.71E-02	1.07E-01	3.71E-02	8.56E-02	7.83E-02
Survey age 3 sel. dev for 2002	-1.16E-01	3.02E-02	-1.16E-01	3.02E-02	-6.81E-02	6.95E-02
Survey age 3 sel. dev for 2004	7.72E-02	3.77E-02	7.73E-02	3.78E-02	6.44E-02	7.70E-02
Survey age 3 sel. dev for 2006	1.12E-01	4.27E-02	1.12E-01	4.28E-02	7.86E-03	7.34E-02
Survey age 3 sel. dev for 2010	1.03E-01	3.44E-02	1.02E-01	3.45E-02	1.41E-01	7.54E-02
Survey age 3 sel. dev for 2012	5.95E-02	4.64E-02	5.82E-02	4.76E-02	5.68E-03	7.72E-02
Survey age 7 sel. dev for 1991	3.07E-02	5.58E-02	3.74E-02	5.64E-02	n/a	n/a
Survey age 7 sel. dev for 1994	6.88E-02	4.39E-02	6.93E-02	4.40E-02	n/a	n/a
Survey age 7 sel. dev for 1997	-1.94E-02	4.77E-02	-1.82E-02	4.78E-02	n/a	n/a
Survey age 7 sel. dev for 2000	-1.62E-02	5.00E-02	-1.66E-02	5.01E-02	n/a	n/a
Survey age 7 sel. dev for 2002	1.27E-01	4.11E-02	1.26E-01	4.12E-02	n/a	n/a
Survey age 7 sel. dev for 2004	-3.18E-02	4.89E-02	-3.37E-02	4.91E-02	n/a	n/a
Survey age 7 sel. dev for 2006	3.04E-02	4.56E-02	2.72E-02	4.58E-02	n/a	n/a
Survey age 7 sel. dev for 2010	3.32E-02	5.25E-02	2.68E-02	5.28E-02	n/a	n/a
Survey age 7 sel. dev for 2012	-4.62E-02	5.47E-02	-5.23E-02	5.51E-02	n/a	n/a

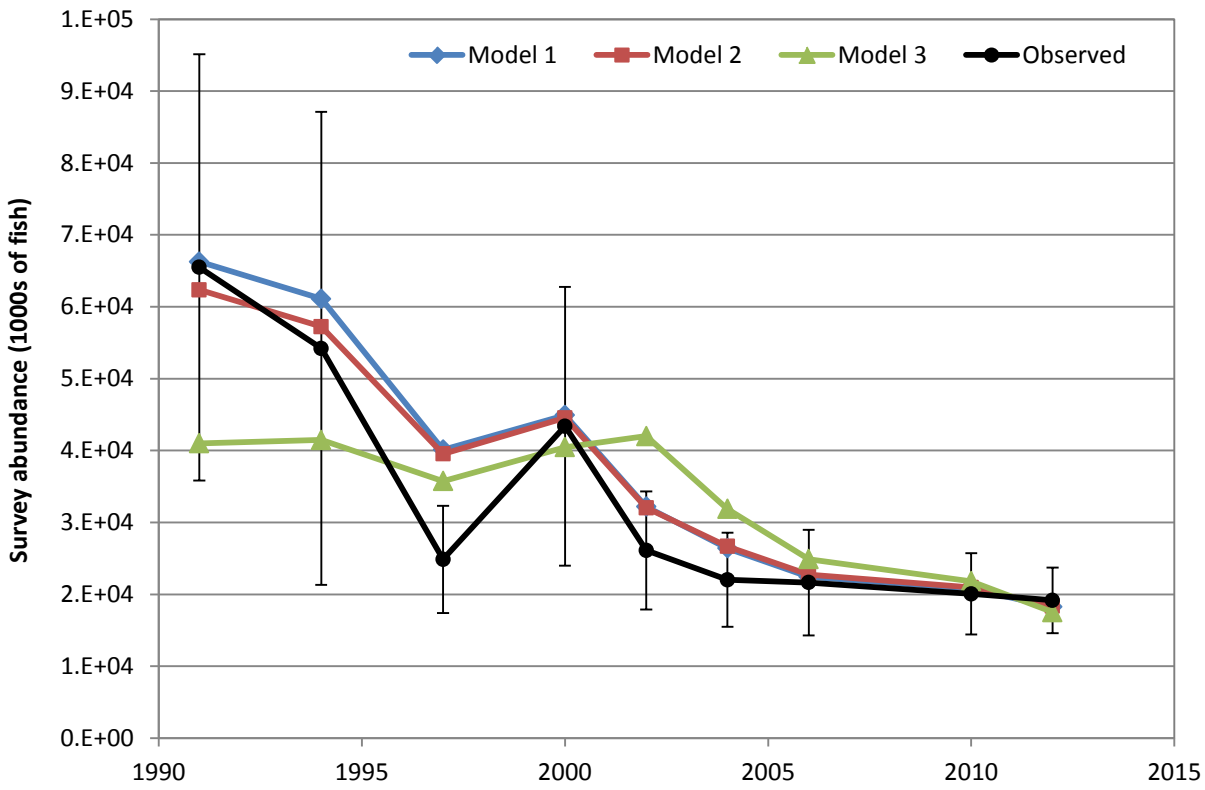


Figure 2A.1.1—Model fits to the survey abundance time series.

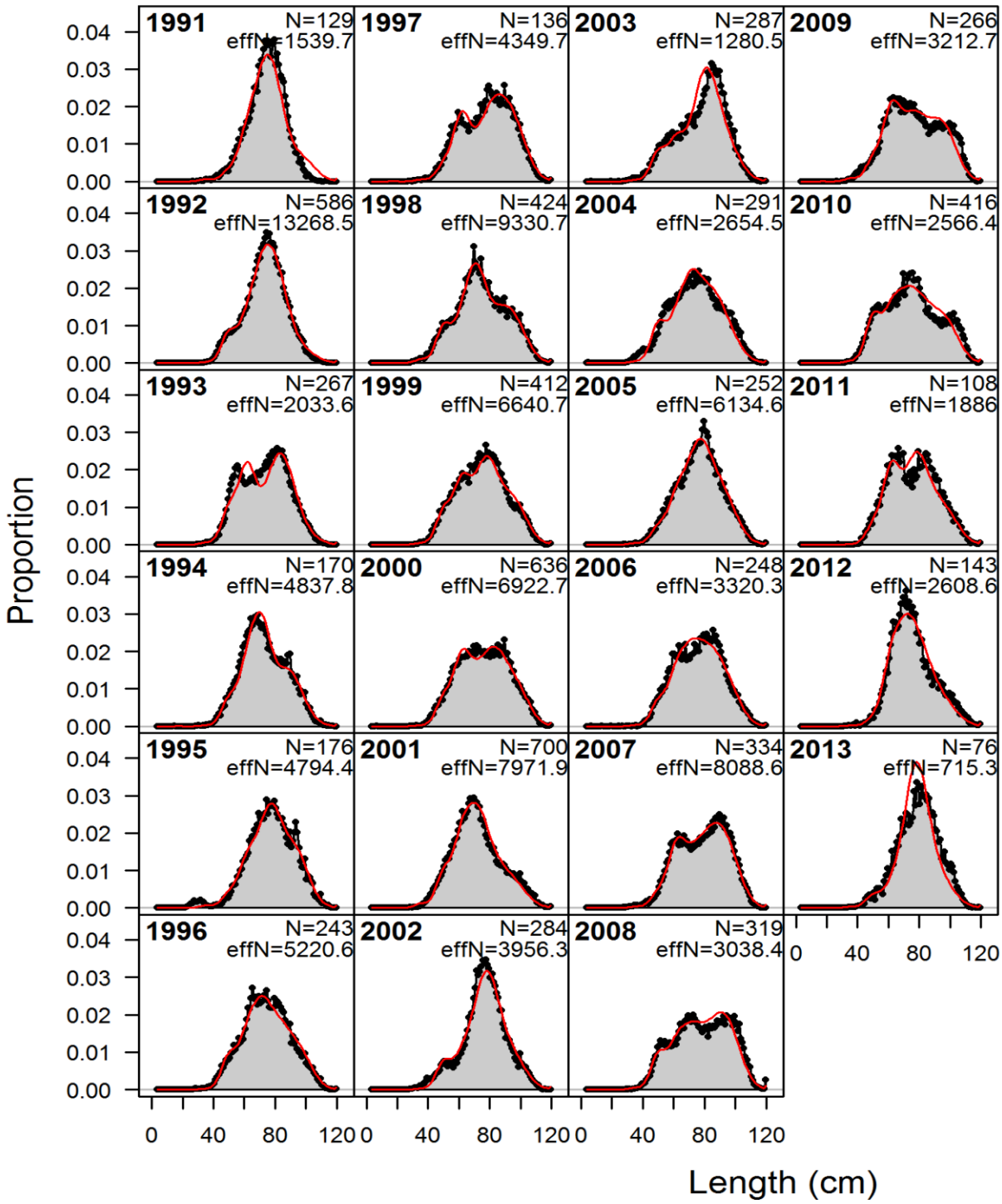


Figure 2.A.1.2a—Model 1 fits to the fishery size composition data.

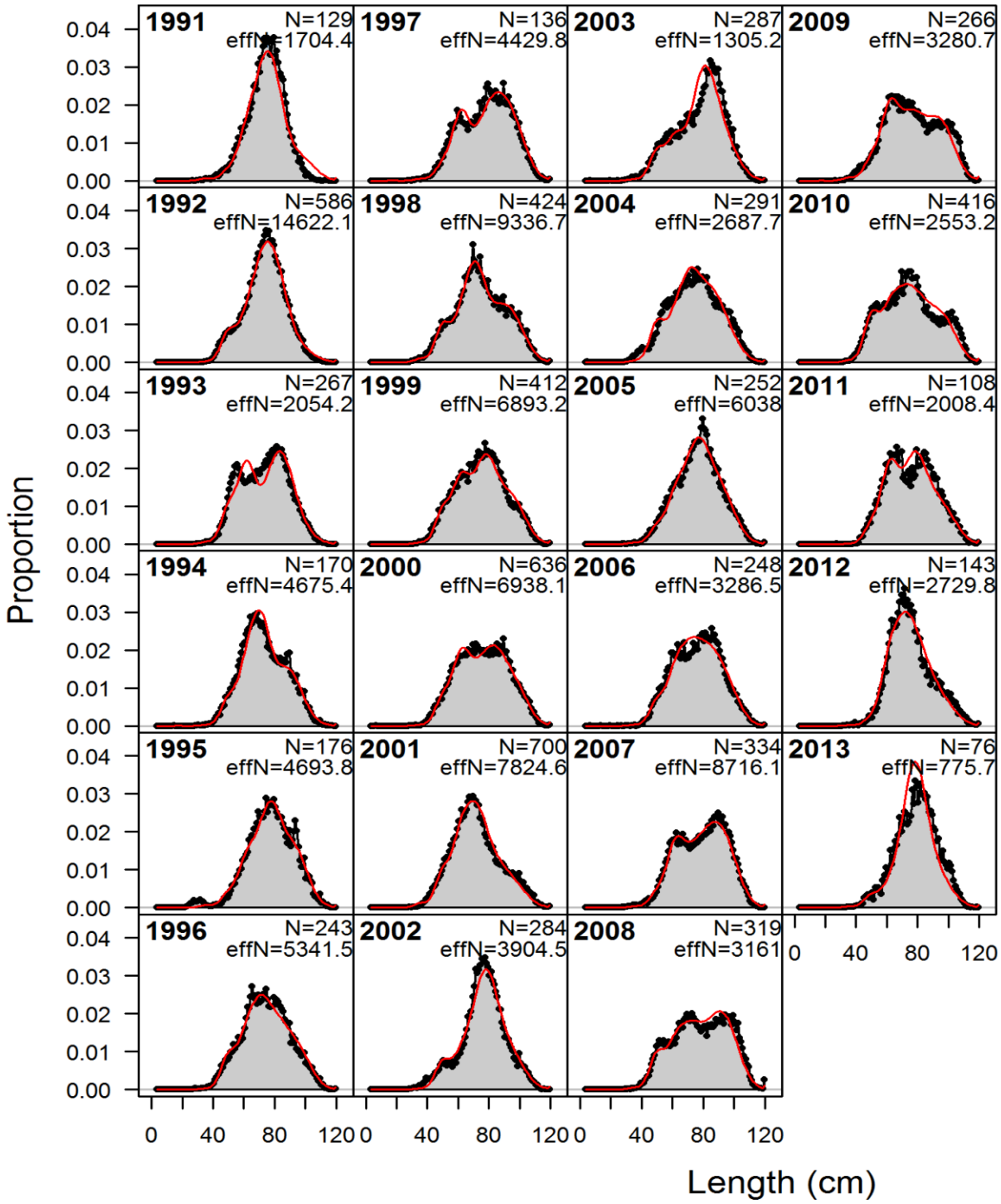


Figure 2A.1.2b—Model 2 fits to the fishery size composition data.

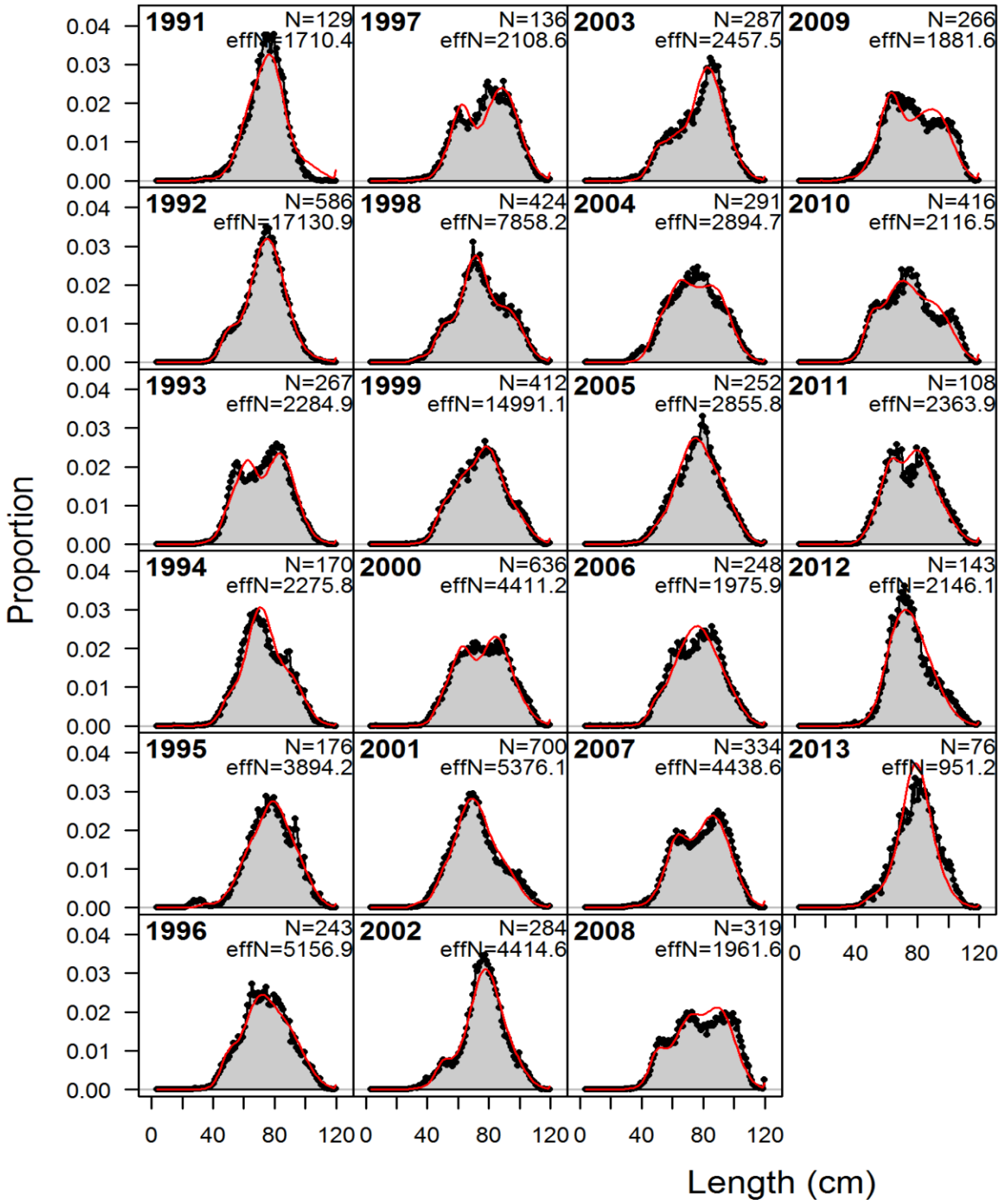


Figure 2A.1.2c—Model 3 fits to the fishery size composition data.

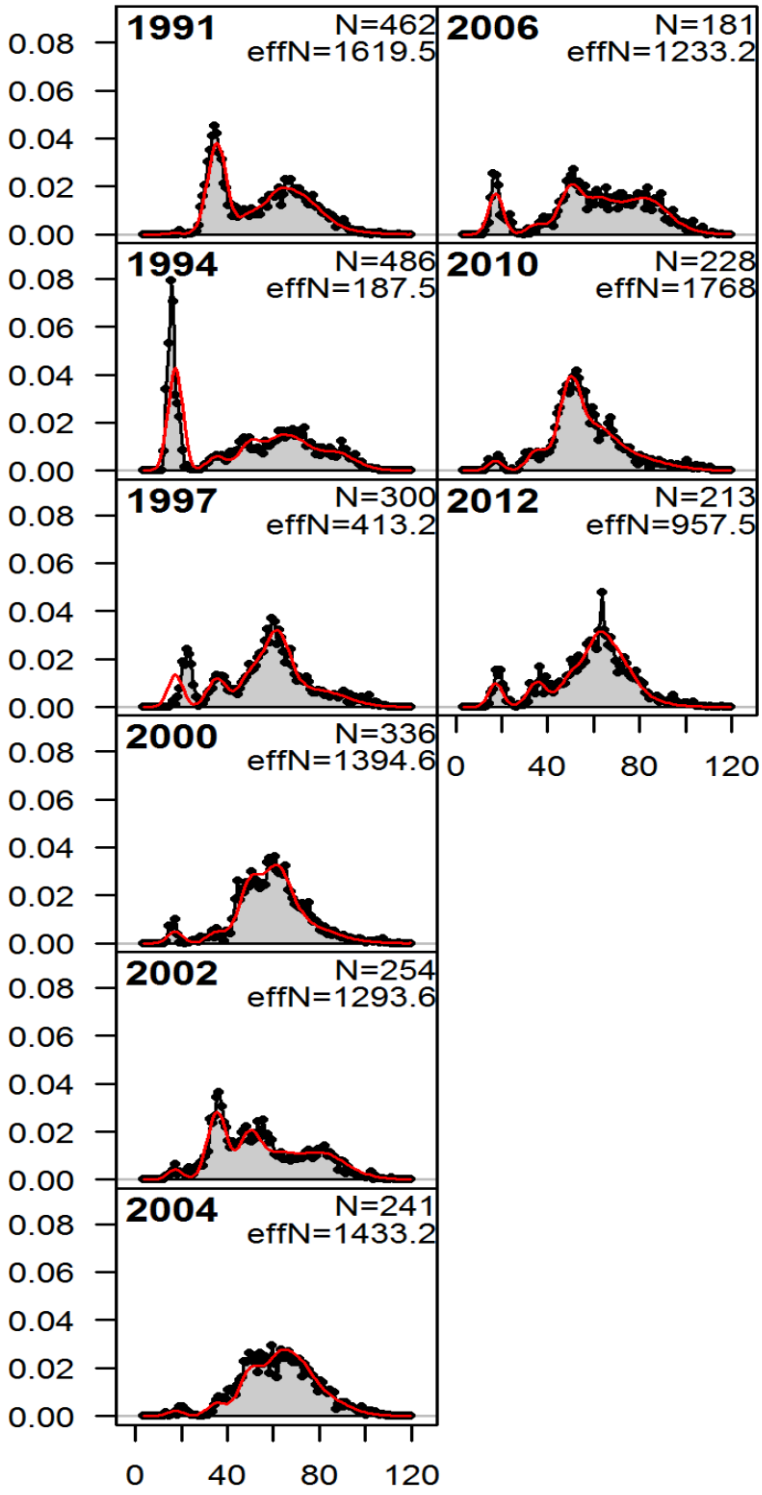


Figure 2A.1.3a—Model 1 fits to the survey size composition data.

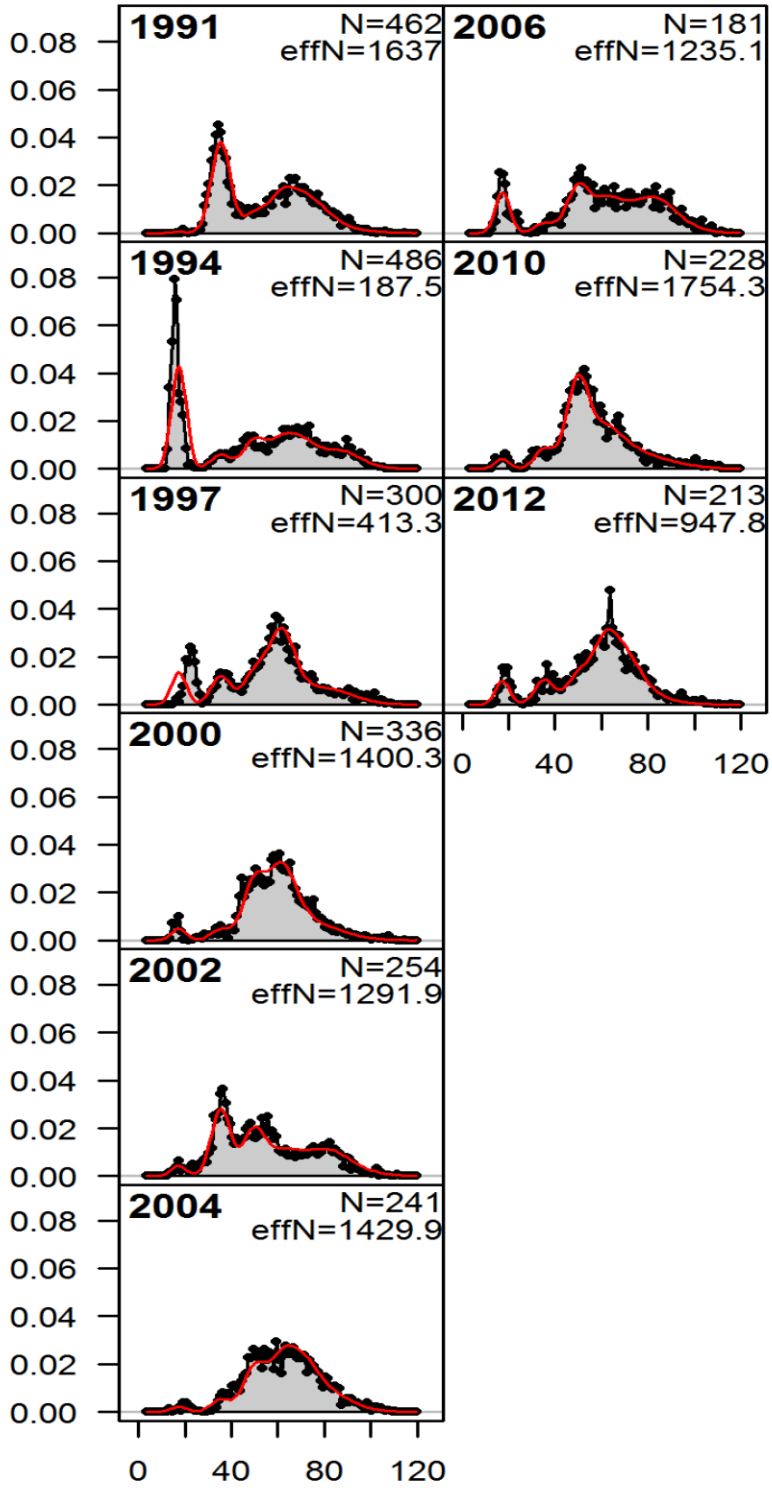


Figure 2A.1.3b—Model 2 fits to the survey size composition data.

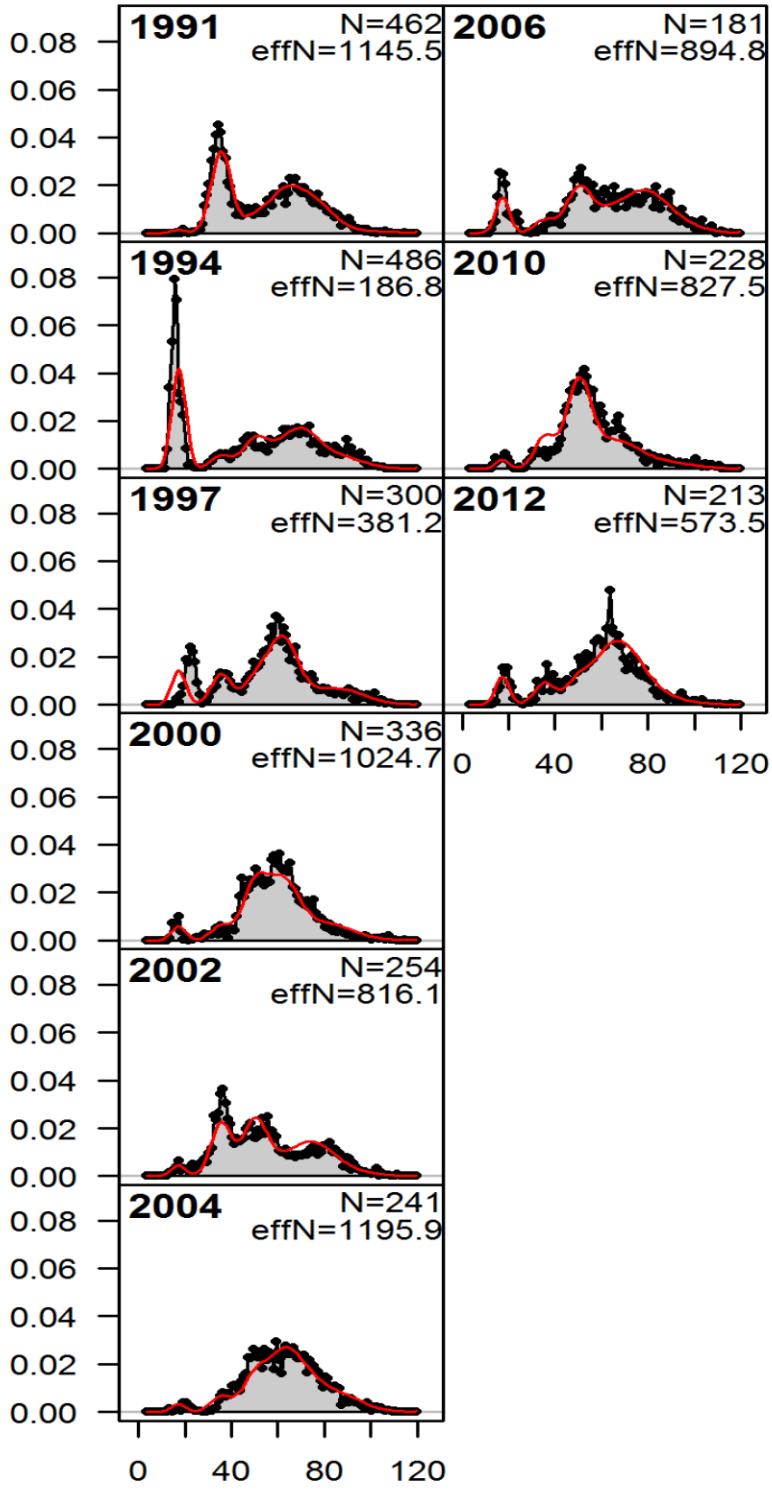


Figure 2A.1.3c—Model 3 fits to the survey size composition data.

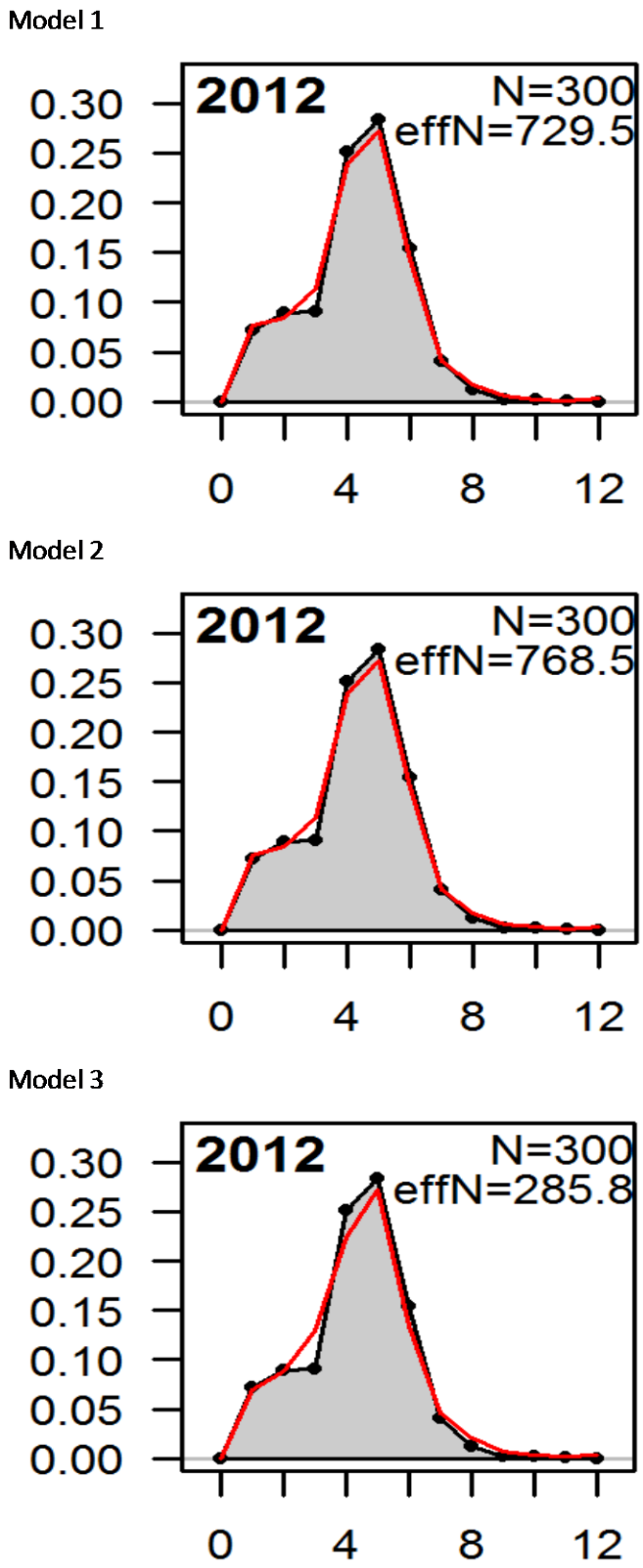
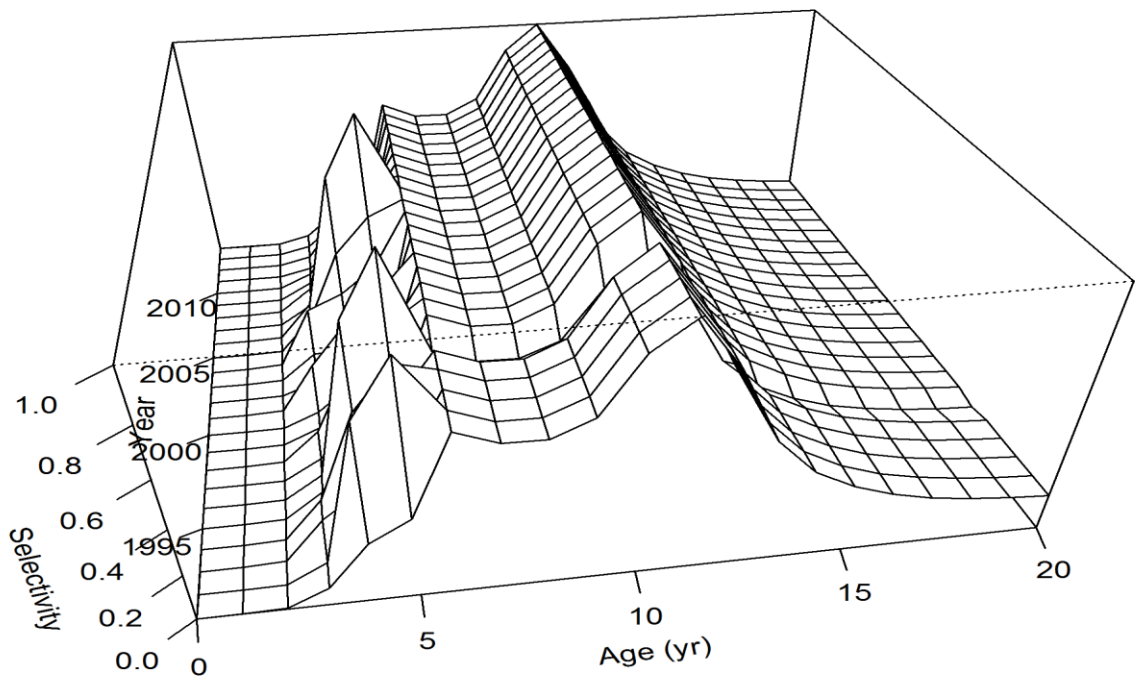


Figure 2A.1.4—Model fits to the single year of age data.

Fishery



Survey

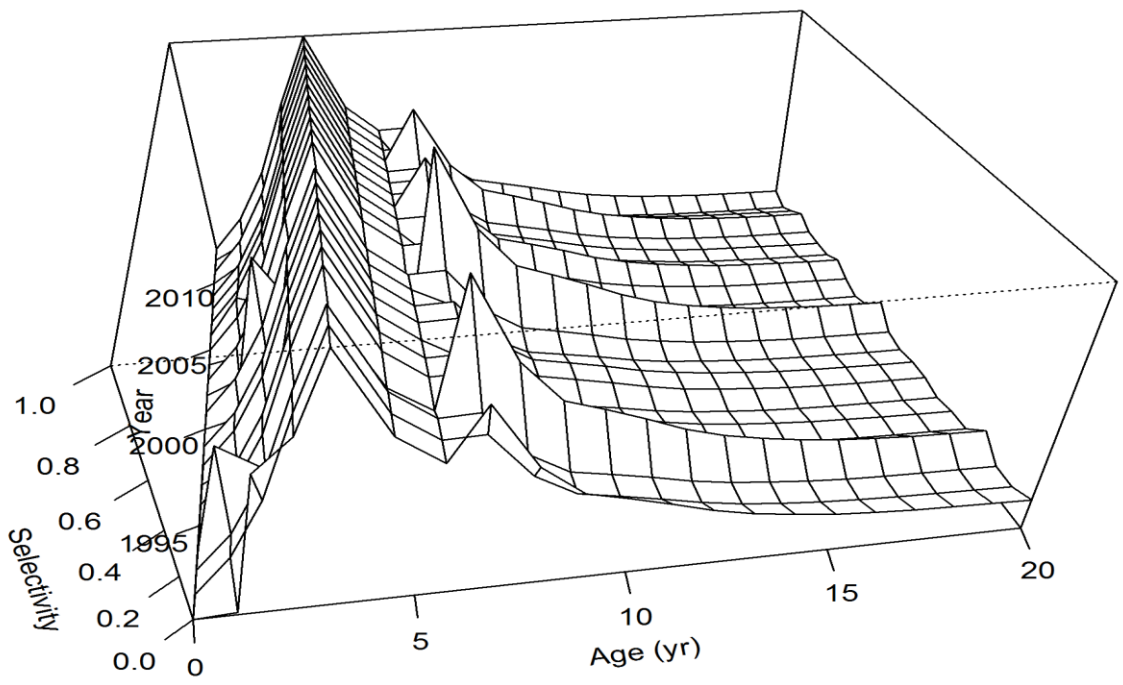
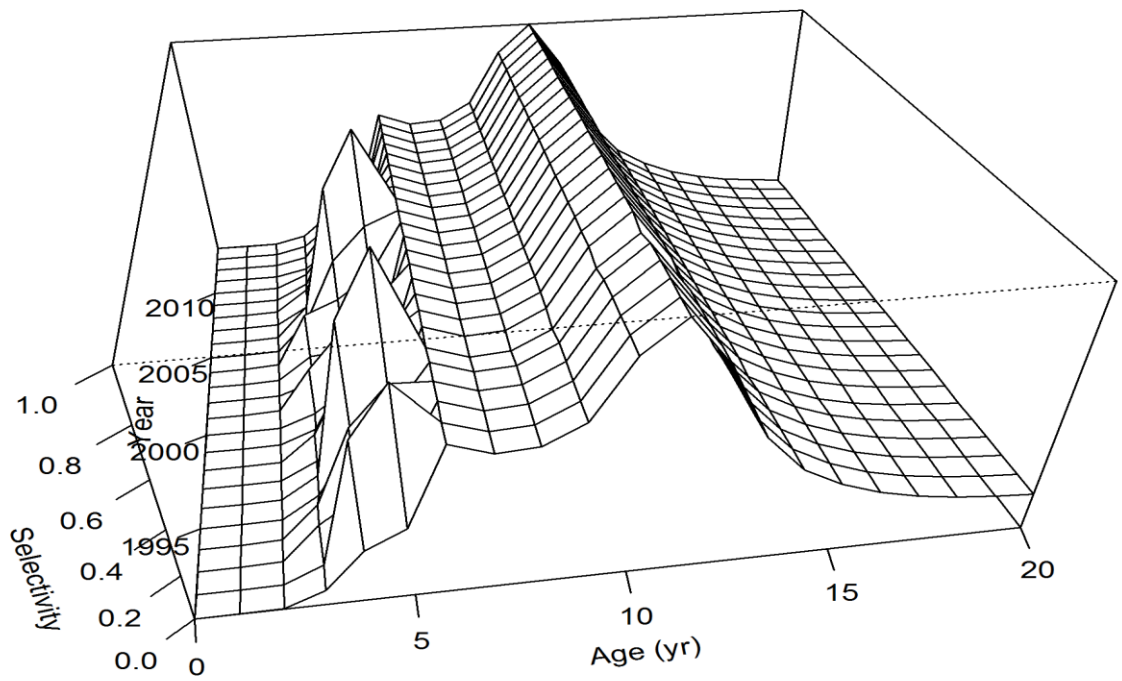


Figure 2A.1.5a—Model 1 selectivities.

Fishery



Survey

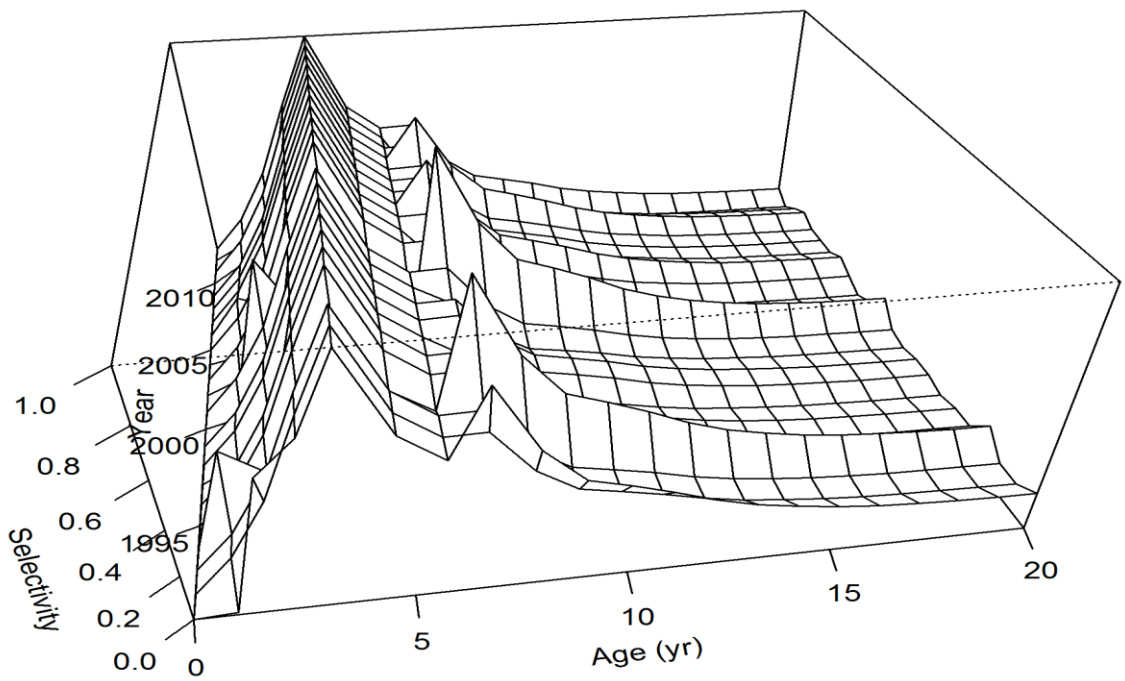
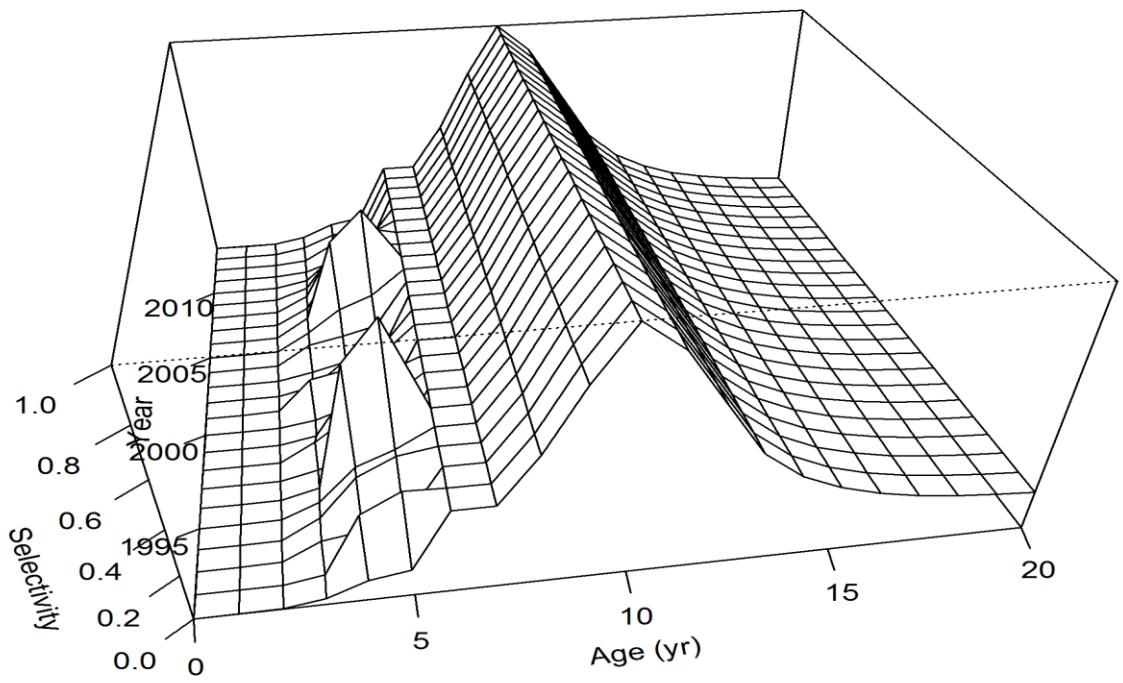


Figure 2A.1.5b—Model 2 selectivities.

Fishery



Survey

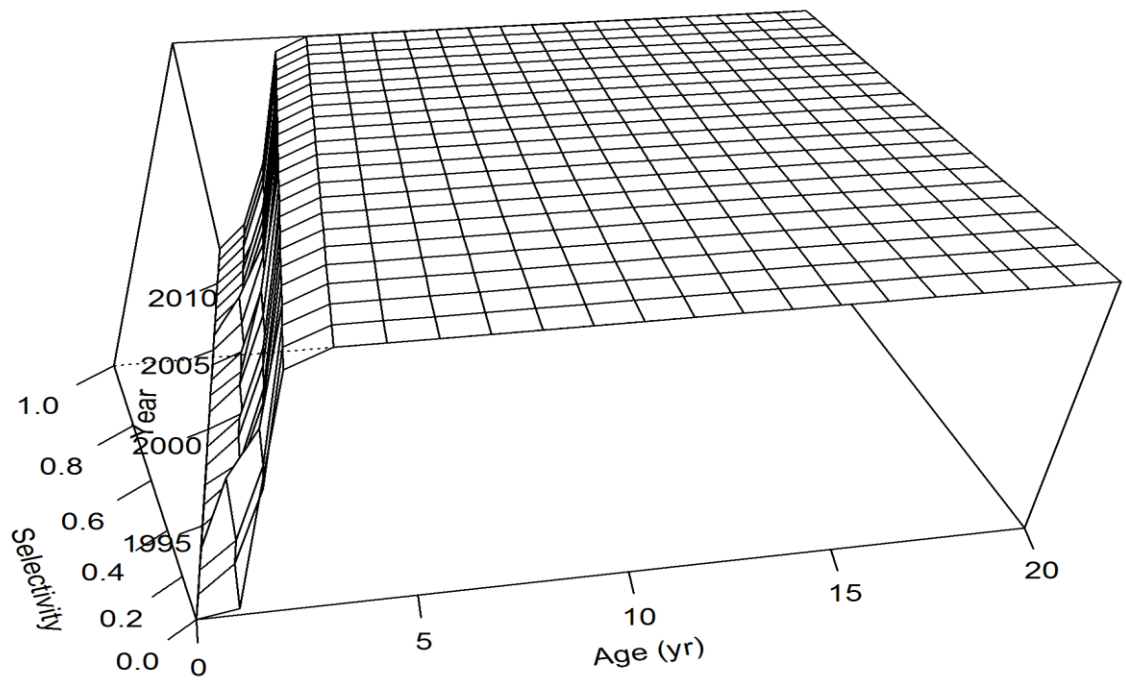


Figure 2A.1.5c—Model 3 selectivities.

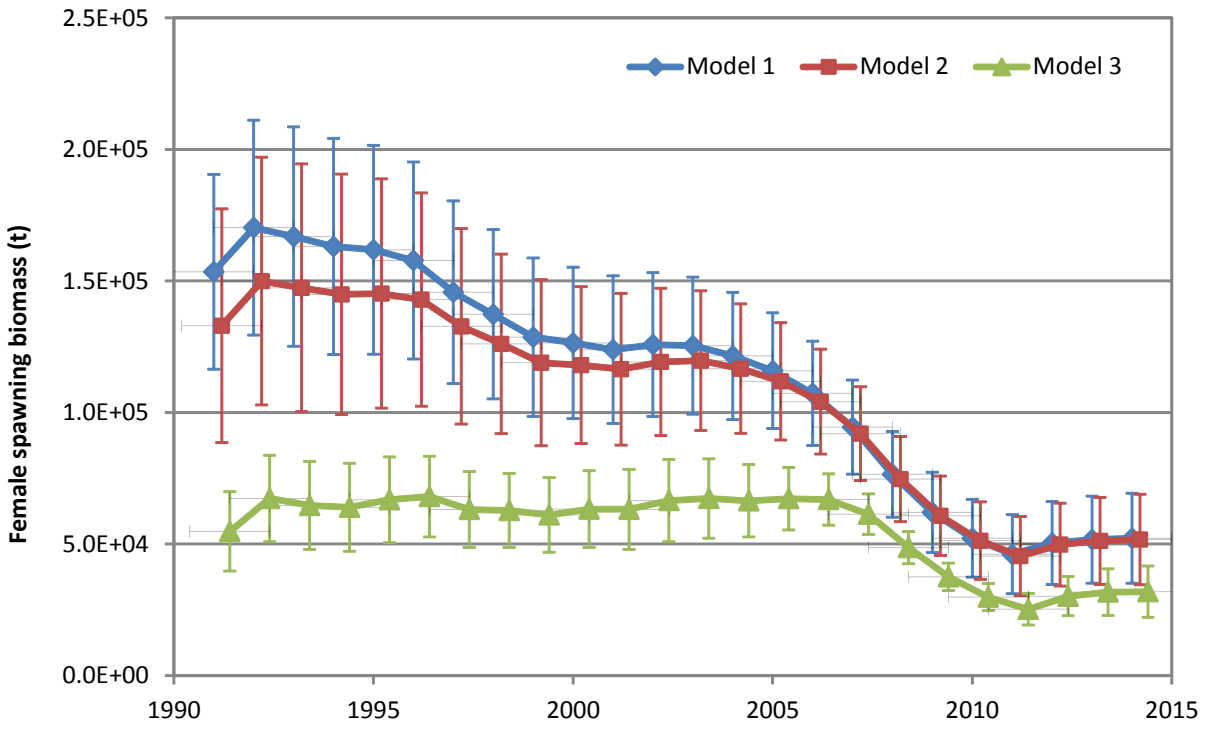


Figure 2A.1.6—Model estimates of the female spawning biomass time series.

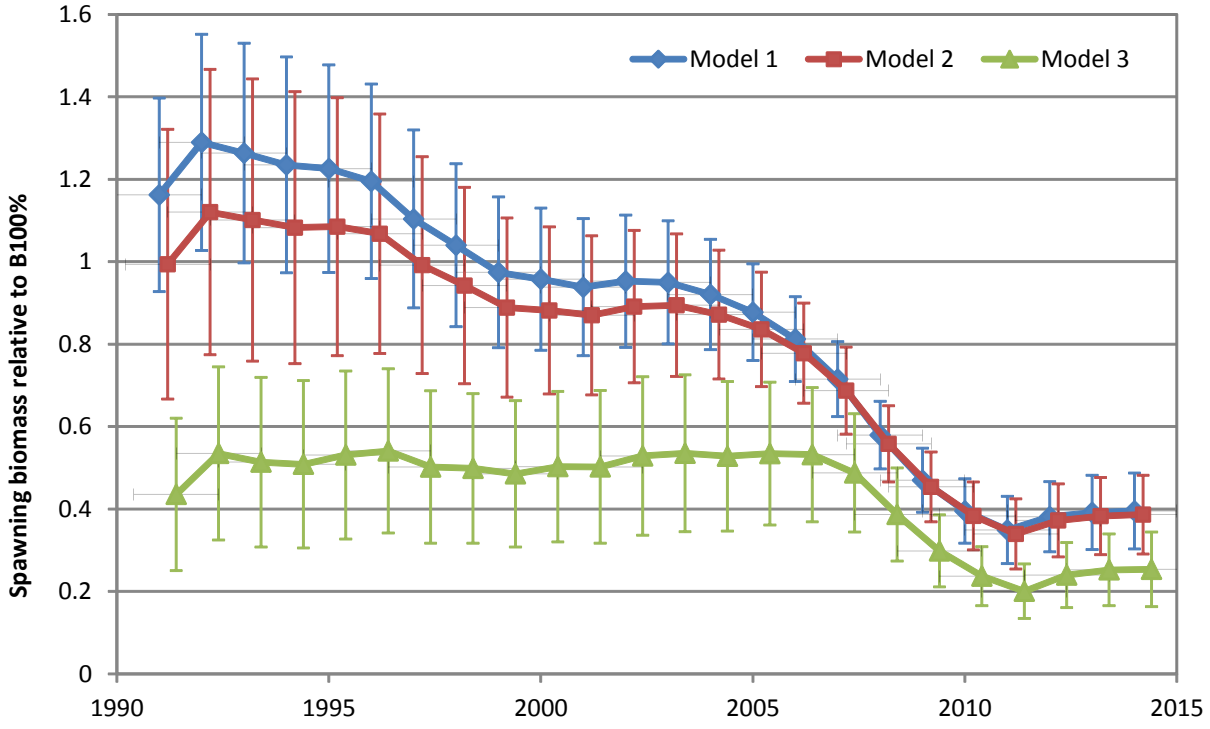


Figure 2A.1.7—Model estimates of the relative female spawning biomass time series.

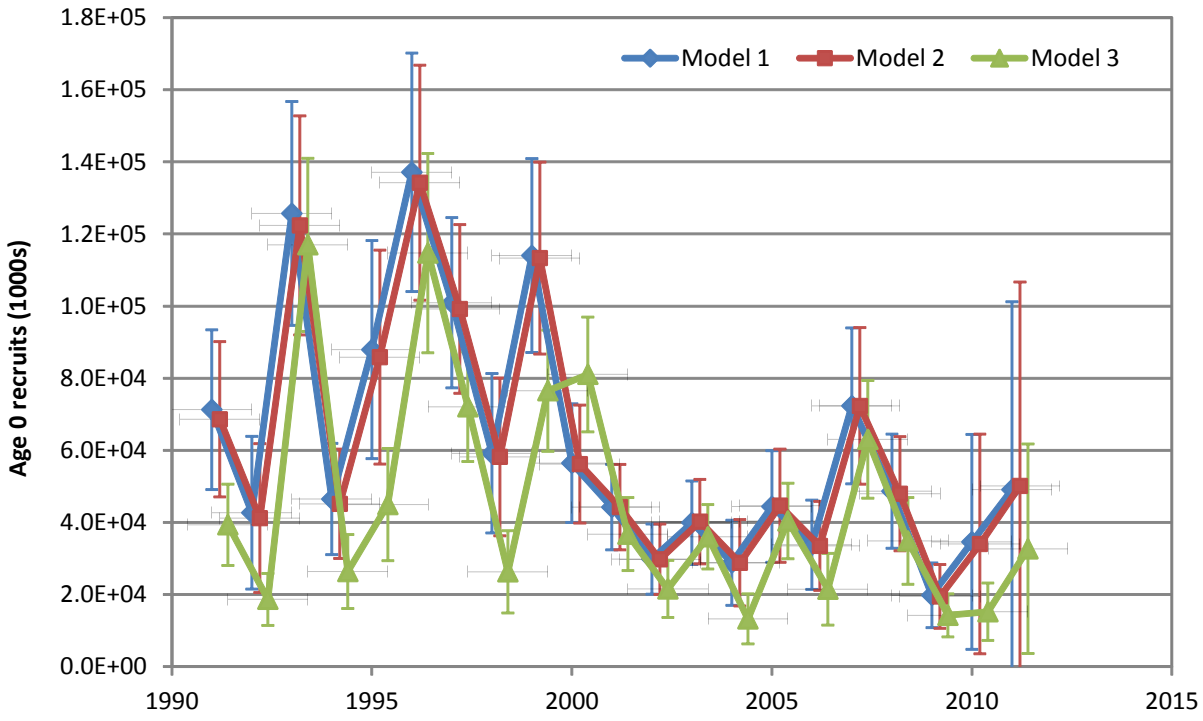


Figure 2A.1.8—Model estimates of the age 0 recruitment time series.

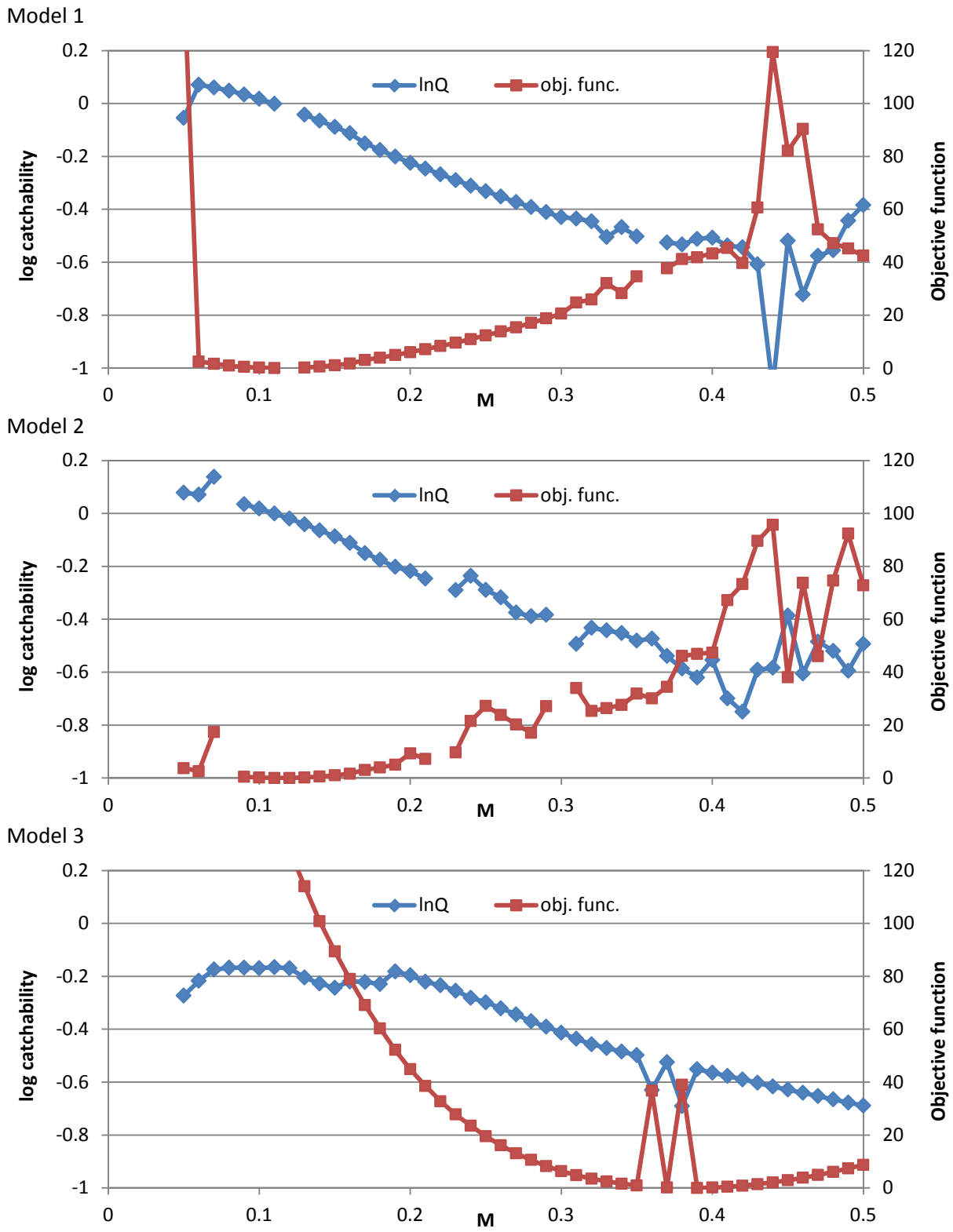


Figure 2A.1.9—Likelihood profiles with respect to the natural mortality rate. Objective function minima occur at *M*=0.11 (Model 1 and Model 2), and *M*=0.39 (Model 3). The relationship between *M* and log catchability is also shown for each model. Jaggedness indicates lack of convergence in some runs.