Attachment 2.1:
An exploration of alternative assessment models for Pacific cod in the eastern Bering Sea

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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 on the 2011 assessment of the Pacific cod (*Gadus macrocephalus*) stock in the eastern Bering Sea (EBS, Thompson and Lauth 2011), and to explore additional models.

Comments from the Plan Teams and SSC

Note: Comments directed exclusively at the assessments for Pacific cod in the Aleutian Islands or Gulf of Alaska are not included here.

Joint Plan Team (September, 2011)

JPT1: *"In Model A …, the catchability and selectivity deviations are treated as random effects but they are not properly integrated out. The MLEs are therefore suspect, and the iterative tuning may produce pathological results."* This is correct, and appears to be a problem with all age-structured assessments of BSAI and GOA groundfish. However, there is no reason to believe that a subjectively specified σ, as used in most or all other assessments, is any less suspect or any less likely to produce pathological results. In a univariate linear-normal model, iterative tuning of σ will tend to under-estimate the true variability. Model 5 in this preliminary assessment attempts to address this problem by applying a method that adjusts σ upward to the value that would be correct for a univariate linear-normal model after random effects are properly integrated out (see Annex 2.1.1).

JPT2: *"Allowing survey catchability to vary from year to year, perhaps substantially, achieves a better fit to the data but at the expense of discounting the relative abundance data. Some members felt strongly that this was a mistake."* The reason for allowing survey catchability to vary in last year's Model A was precisely to *avoid* discounting the survey. Either the confidence intervals derived from the survey data are accurate or they are not. Surely it *would* be discounting the survey to claim that there is no need for model estimates to be generally consistent with the survey confidence intervals. If variable catchability is the only way for the model to estimate a time series that is consistent with the survey confidence intervals, then allowing catchability to vary is the only way *not* to discount the survey. Alternatively, if "discounting" means simply that the influence of a given survey datum on model estimates is less than it would have otherwise been, then the Plan Teams' premise is valid, but the same argument could be made for including many other standard parameters or data sets (e.g., allowing selectivity to be less than unity for some range of ages or lengths, allowing recruitment to vary with time, or including size composition data from the fishery would cause the survey abundance data to be "discounted" under this definition). The objective of allowing survey catchability to vary under last year's Model A was to fit the survey

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abundance data in a manner consistent with those data (both the means and the confidence intervals), not to maximize the impact of those data.

JPT3: *"The great variability of survey selectivity estimates from Model A is a clear indication that the model is overfitting the data."* This comment is difficult to interpret for three reasons:

First, comment JPT3 suggests that the problem consists of allowing selectivity to vary *too much*, whereas comment JPT1 (above) suggests just the opposite (because the iterative tuning that was used in last year's Model A tends to *under*estimate the true variability). Because it would be unreasonable to criticize a model for allowing *too little* variability in selectivity and at the same time criticize the same model for allowing *too much* variability in selectivity, comments JPT1 and JPT3 will be reconciled here as follows: Comment JPT1 will be interpreted as implying that the amount of variability allowed in last year's Model A *for any given time-varying selectivity parameter* was too small, while comment JPT3 will be interpreted as implying that the *overall number of time-varying selectivity parameters* in last year's Model A was too large.

Second, comment JPT3 sheds very little light on what constitutes "great" variability. In an effort to address this issue more quantitatively, last year's final assessment introduced a statistic (the selectivity coefficient of variation, SCV) designed to measure the extent to which estimated selectivity varies. In last year's final assessment, the SCV for the accepted model (Model 3b) was 0.208, compared to a value of 0.330 for Model A in last year's preliminary assessment. Given the lack of any Team comment to the contrary, it will be assumed here that the SCV is an appropriate measure of variability in selectivity, and that the break between "great" and "less than great" variability therefore falls somewhere between 0.208 and 0.330. An explicit statement from the Plan Team as to exactly where the break occurs within this range, preferably accompanied by a logical rationale, would be welcome.

Third, comment JPT3 does not mention why great variability between point estimates in a time series constitutes a clear indication of overfitting. A customary goal in statistics is to obtain point estimates that reflect the true variability in the time series, but comment JPT3 suggests that the model should be systematically constrained to *under*estimate the true variability in the time series whenever the latter is "great." Again, an explicit rationale for this claim would be welcome.

JPT4: *"In view of the many new features in Model A and several concerns about it, the Teams do not favor including it … as one of the candidates in November."* In deference to the Teams, Model A was not included in last year's final assessment. However, several features of Model A are considered again in this preliminary assessment.

Joint Plan Team (November, 2011)

JPT5: *"The Teams encouraged the author to try estimating survey catchability internally again. It is possible that with the other improvements made in this assessment, catchability will be estimable, at least in the EBS assessment."* Catchability is estimated internally in Model 1.1 (see "Model Structures" below; also comment JPT9).

BSAI Plan Team (November, 2011)

BPT1: *"The BSAI team recommends that the author check for any poor fits to commercial length frequencies that might indicate a change in selectivity resulting from the implementation of Amendment 80 in 2008 and the creation of longline cooperatives in 2010."* A new fishery selectivity period beginning in 2008 is incorporated in Model 3 (see "Model Structures" below; also comments JPT6 and SSC4).

SSC (December, 2011)

SSC1: *"We agree with a recommendation from the CIE review that the number of explorations and new model configurations for upcoming assessments should be reduced to allow for a thorough evaluation of the performance of the current model over several assessment cycles."* Five primary models are presented in this preliminary assessment, down from six in last year's preliminary assessment. A small subset of results is also presented for nine secondary models (see "Model Structures" below; also comments JPT6, SSC4, and SSC5).

SSC2: *"The SSC notes that weight-at-age in both regions was lowest in May-Aug. or Sept.-Oct. and highest in Jan.-Feb. These patterns seem somewhat counter-intuitive and we encourage the authors to evaluate the biological basis for these patterns."* For the past few years, the parameters of the seasonal weight-length relationships have been estimated independently of one another. Although the resulting estimates gave a better fit to the data than the alternative of assuming no intra-annual variability in weight at length, they did not necessarily follow any explicit phenological process, and counter-intuitive results (such as multiple intra-annual maxima or minima in the seasonal schedule of weight for a given length) could occur. In this preliminary assessment, the inter- and intra-annual weight-length relationship has been completely re-parameterized in a way that follows an explicit phenological process and that prevents such counter-intuitive patterns from arising, while still providing an excellent fit to the data. This re-parameterized relationship is used in Model 1.3, all of the "Pre5" models, and Model 5 (see "Model Structures" and Annex 2.1.2 below; also comments JPT8, SSC4, and SSC5).

SSC3: *"The recommended models for both regions estimate ageing bias as a linear function of age, but the estimated patterns in bias by age differs by region increasing from approximately 0.34 at the youngest age to 0.85 at the oldest age in the BSAI assessment (Model 3b), but decreases from 0.36 to 0 at the oldest age in the GOA assessment (Model 3)."* The effects of these contrasting patterns are examined in Model 1.2 (see "Model Structures" below; also comment JPT7).

Joint Plan Team (May, 2012)

JPT6: *"For the EBS, the Teams recommend that the preliminary assessment include the following four models, which are in addition to any models that the authors wish to propose: Model 1 is last year's final model, Model 2 is last year's final model with re-tuned catchability, Model 3 is last year's final model with a new fishery selectivity period beginning in 2008 or 2010, and Model 4 is last year's final model without age data. For Model 3, the Teams acknowledge that estimating a full set of selectivity parameters with only 2-4 years of data may be challenging."* All four of the Teams' requested models are included in this preliminary assessment (see "Model Structures" below; also comment SSC4).

JPT7: *"For both the EBS and GOA, the Teams recommend that the authors attempt to explore the divergent ageing bias trends in the two regions and the impacts thereof"* (this was a "non-model" proposal, meaning that it *"can be explored sufficiently without developing and presenting a full set of results for an additional model"*). See response to comment SSC3.

JPT8: *"For both the EBS and GOA, the Teams recommend that the authors attempt to evaluate the biological basis for estimated patterns of seasonal weight at length"* (this was a "non-model" proposal, meaning that it *"can be explored sufficiently without developing and presenting a full set of results for an additional model"*). See response to comment SSC2.

JPT9: *"For both the EBS and GOA, the Teams recommend that the authors attempt to estimate catchability internally"* (this was a "non-model" proposal, meaning that it *"can be explored sufficiently*

without developing and presenting a full set of results for an additional model"). See response to comment JPT5.

JPT10: *"The Teams recommend that Stock Synthesis be modified so that a prior distribution can be placed on the average, across the 60-81 cm size range, of the product of catchability and selectivity at age, where the average is weighted by long-term average numbers at length."* This comment has been forwarded to Richard Methot, who develops and maintains the code for Stock Synthesis (SS). He agreed to attempt to make this modification, although it may not be ready in time for this year's assessment.

SSC (June, 2012)

SSC4: *"The SSC agrees with the selection of last year's final model as the baseline and with the proposed suite of alternative models. However, we note that there are limited data to assess any effects resulting from the creation of longline cooperatives in 2010 on fishery selectivity (Model 3).* ***Hence, the SSC recommends evaluation of a change in fishery selectivity in 2008 (in response to Amendment 80), but no change in 2010****"* (emphasis original). See response to comment BPT1.

SSC5: *"In addition, 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. However, given the Plan Team's (and SSC's) reluctance in previous years to consider a new author-recommended model in the fall that incorporates a large number of potentially influential changes in a single model (for example changes in growth, selectivities, and catchability), the SSC encourages the authors to evaluate changes in one or a few structural elements at a time."* Some of the features of last year's Model A are brought forward here in a new model, labeled Model 5. Other features of last year's Model A were not included in the new Model 5 in an attempt to avoid introducing too many changes. Some transitional steps between last year's accepted model and the new Model 5 are provided in Models 1.3 and Pre5.1 through Pre5.6 (see "Model Structures" below; also responses to comments JPT1 through JPT4).

Model Structures

As mentioned above, four primary models and three secondary models were requested by the Plan Team and SSC. A fifth primary model and six more secondary models are also presented here. A brief description of each model is shown below, with more detailed descriptions in the next subsections:

Model	Description
1	Last year's accepted model (same as last year's Model 3b)
1.1	Same as Model 1, except survey catchability estimated internally
1.2	Same as Model 1, except ageing bias parameters fixed at GOA values
1.3	Same as Model 1, except with revised weight-length representation
2	Same as Model 1, except survey catchability re-tuned to match Nichol et al. (2007)
3	Same as Model 1, except new fishery selectivity period beginning in 2008
4	Same as Model 1, except no age data used (same as last year's Model 4)
Pre5.1	Same as Model 1.3, except for three minor changes to the data file
Pre5.2	Same as Model Pre5.1, except ages 1-10 in the initial vector estimated individually
Pre5.3	Same as Model Pre5.2, except Richards growth curve used
Pre5.4	Same as Model Pre5.3, except σ for recruitment *dev*s estimated internally as a free parameter
Pre5.5	Same as Model Pre5.4, except survey selectivity modeled as a function of length
Pre5.6	Same as Model Pre5.5, except fisheries defined by season only (not season-and-gear)
5	Same as Model Pre5.6, except four quantities estimated iteratively

The five primary models are Models 1, 2, 3, 4, and 5. The nine secondary models are Models 1.1-1.3 and Pre5.1-Pre5.6. The purpose of including Models Pre5.1-Pre5.6 is to provide a reasonably smooth transition between Model 1.3 and Model 5. The main differences between primary and secondary models are: 1) full results are presented for primary models, but only a small subset of results is presented for secondary models, and 2) some of the secondary models (specifically, Models Pre5.1-Pre5.6) were subjected to less rigorous tests for convergence than the other models.

Development of the final versions of all primary models and Models 1.1-1.3 included calculation of the Hessian matrix, and—with one exception—all primary models and Models 1.1-1.3 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 0.1. The one exception was that the jitter parameter for Model 5 was reduced to 0.01, because most runs failed if the jitter parameter was set at 0.1. 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.

Development of the final versions of Models Pre5.1-Pre5.6 did not include calculation of the Hessian matrix, and they were not subjected to a jitter test. As a weak test for convergence, each of these models was re-run from its respective ending values (in the control file, not the parameter file), and confirmed to return the same objective function value.

Each model had its own control file, but some groups of models shared a common data file. Specifically, Models 1, 1.1, 1.2, 2, and 3 shared a common data file ("BSbase.dat"); Models Pre5.1-Pre5.5 shared a common data file ("BSmodelPre5.dat"); and Models Pre5.6 and 5 shared a common data file ("BSmodel5.dat"). Models 1.3 and 4 each had their own data file ("BSmodel1_3.dat" and "BSmodel4.dat," respectively).

Except for *dev* parameters, all parameters were estimated with uniform prior distributions. Bounds were non-constraining except in a very few unimportant cases.

All of the models use a double-normal curve to model selectivity. This functional form is constructed from two underlying and linearly rescaled normal distributions, with a horizontal line segment joining the two peaks. As configured in SS, the equation uses the following six parameters:

1. *beginning_of_peak_region* (where the curve first reaches a value of 1.0)
2. *width_of_peak_region* (where the curve first departs from a value of 1.0)
3. *ascending_width* (equal to twice the variance of the underlying normal distribution)
4. *descending_width* (equal to twice the variance of the underlying normal distribution)
5. *initial_selectivity* (at minimum length/age)
6. *final_selectivity* (at maximum length/age)

All but *beginning_of_peak_region* are transformed: The *ascending_width* and *descending_width* are log-transformed and the other three parameters are logit-transformed.

The data used in this preliminary assessment were the same data used in last year's final assessment, except that the weight-length data used in Models 1.3, Pre5.1-Pre5.6, and 5 were updated.

The software used to run all models was SS V3.23b, as compiled on 11/5/2011 (Methot 2005, Methot 2011, Methot and Wetzel *in press*). Stock Synthesis is programmed using the ADMB software package (Fournier et al. 2012).

Model 1

The details of last year's final model (labeled Model 3b in last year's assessment) were described by Thompson and Lauth (2011). That model, in turn, was identical to the final model from the 2010 assessment (Thompson et al. 2010), except for the following features:

- The pre-1982 portion of the AFSC bottom trawl time series was removed from the data file.
- The 1977-1979 and 1980-1984 time blocks for the January-April trawl fishery selectivity parameters were combined. This change was made because the selectivity curve for the 1977-1979 time block tended to have a very difficult-to-rationalize shape (almost constant across length, even at very small sizes), which led to very high and also difficult-to-rationalize initial fishing mortality rates.
- The age corresponding to the *L1* parameter in the length-at-age equation was increased from 0 to 1.4167, to correspond to the age of a 1-year-old fish at the time of the survey, which is when the age data are collected. This change was adopted to prevent mean size at age from going negative (as sometimes happened for age 0 fish in previous assessments, and as happened even for age 1 fish in one of the models from the 2010 assessment), and to facilitate comparison of estimated and observed length at age and variability in length at age.
- A column for age 0 fish was added to the age composition and mean-size-at-age portions of the data file. Even though there are virtually no age 0 fish represented in these two portions of the data file, unless a column for age 0 is included, SS will interpret age 1 fish as being ages 0 and 1 combined, which can bias the estimates of year class strength.
- Ageing bias was estimated internally.
- The parameters governing variability in length (i.e., the distribution of length at age for a given set of von Bertalanffy parameters) were estimated internally.
- All size composition records were included in the log-likelihood function, regardless of whether an age composition record existed for the same year.
- The fit to the mean-size-at-age data was not included in the log likelihood function.

No changes to last year's control file or data file were necessary in order for the code to run under SS V3.23b.

Model 1.1

Model 1.1 is the same as Model 1, except that survey catchability (Q) was estimated internally as a free parameter. In Model 1, Q was fixed at a value of 0.77 (note that SS estimates Q in log space, so this means that $\ln(Q)$ was fixed at a value of -0.261365 in Model 1). The value of Q used in Model 1 was determined iteratively in the 2009 assessment (Thompson et al. 2009) by finding the value that matched the average of the product of catchability and selectivity at age with the value of 0.47 obtained by Nichol et al. (2007). This average was computed across the 60-81 cm size range, weighted by annual numbers at length, and across all years in the post-1981 survey time series. For the 2010 assessment, the Plan Team requested that Q be held constant at the value used in the 2009 assessment. None of the models requested for the 2011 assessment addressed Q, so last year's final model again held Q constant at the value used in the 2009 assessment.

Model 1.2

Model 1.2 was the same as Model 1, except that the ageing bias parameters were hard-wired at the values estimated in last year's assessment of Pacific cod in the Gulf of Alaska (Thompson et al. 2011). As noted by the Plan Teams and SSC, the slopes of the relationships between ageing bias and age in last year's EBS and GOA assessments were of opposite sign. In last year's EBS assessment, ageing bias at age 1 was 0.34, increasing to a value of 0.85 at age 20; whereas in last year's GOA assessment, ageing bias at age 1 was 0.36, decreasing to a value of 0.00 at age 20. The purpose of Model 1.2 was to show how much impact the difference in these two relationships has on other results.

Model 1.3

Model 1.3 was the same as Model 1, except that a new method was used to represent variability in weight at length.

The Pacific cod assessments have always used the traditional functional form $\text{weight}=\alpha\times\text{length}^{\beta}$, where length is measured in cm and weight is measured in kg.

The weight-at-age patterns from last year's assessment are shown for ages 1-16 in Figure 2.1.1. It is important to remember that the weight-at-age patterns shown in this figure result from two processes: 1) weight at length varies (perhaps non-monotonically) throughout the year, and 2) length at age increases throughout the year. Thus, a decrease in weight at age necessarily means that weight at length is decreasing faster than length at age is increasing. However, an increase in weight at age could mean either that weight at length is increasing or that it is decreasing, but more slowly than length at age is increasing.

As shown in Figure 2.1.1, weight at age is minimized in January-February for ages 1-5, in March-April for ages 6-7, and in May-July for ages 8+; while weight at age is maximized in November-December for ages 1-12 and in January-February for ages 13+. Although the SSC found these patterns counter-intuitive, one possible explanation is that weight at length for immature fish remains approximately constant or increases throughout the year, and length at age for these fish increases relatively rapidly; whereas weight at length for mature fish decreases rapidly after spawning but otherwise increases throughout the year, and length at age for these fish increases relatively slowly.

However, even if the seasonal weight-at-age patterns from last year's assessment were determined to be biologically reasonable, it does not necessarily follow that estimates of seasonal weight-length parameters in *future* assessments will also be biologically reasonable, because α and β are estimated independently for each season without regard to any underlying phenological model. For example, it is easy for such parameter estimates to imply intra-annual weight-at-length schedules with multiple maxima or minima (see Annex 2.1.2).

Six models were fit to the 100,641 weight-length measurements that have been collected for Pacific cod in the EBS since 1974 (these include data through the first few months of 2012; note that the data used in last year's assessment included years through 2008 only):

A. Single α and β for the entire time series (no inter- or intra-annual variability)
B. Unique α and β for each season, but no inter-annual variability
C. Unique α and β for each year, but no intra-annual variability
D. Unique α and β for each week, but no inter-annual variability
E. Unconstrained trigonometric functions used to describe intra-annual variability in α and β, with annual means equal to the annual α and β values estimated in Model C (see Annex 2.1.2)
F. Same as Model E, except the trigonometric function for α constrained (conditional on β) such that intra-annual variability in weight at length always has a single maximum and minimum (see Annex 2.1.2)

Note that Model B is the model that has been used in the last few assessments.

Some results related to model selection are shown below (R^2 = coefficient of determination, Δ(lnLike) = difference in log likelihood relative to the maximum, Δ(AIC) = difference in Akaike's Information Criterion relative to the minimum):

Model	R^2	Δ(lnLike)	Δ(AIC)
A	0.916	-4325.963	8447.925
B	0.917	-4204.775	8221.551
C	0.919	-2853.194	5730.388
D	0.923	0	0
E	0.923	-182.964	321.928
F	0.923	-312.984	581.968

Note that all six models give nearly identical R^2 values. However, in terms of either log likelihood or AIC, there are clear differences, with the order of preference the same by either measure: Model D performs the best, followed (in order) by Models E, F, C, B, and A.

Note that Model C, which estimates inter-annual variability only, does much better than Model B, which estimates seasonal variability only. Past assessments of the EBS Pacific cod stock have always assumed no inter-annual variability in weight at length.

The performance of each of the four intra-annually varying models (B, D, E, and F) is illustrated for four example lengths (50, 60, 70, and 80 cm) in Figures 2.1.2a-2.1.2d (one figure per model). In each figure, the blue diamonds represent the mean observed weight for the given length during each week of the year, and the red squares represent the model estimates. Model B estimates much less intra-annual variability at these example lengths than is reflected in the data. Model D appears to do the best job of fitting the data, but much of the week-to-week variability does not appear to follow any discernible pattern. Models E and F do almost as well as Model D, but with a clearly discernible pattern between weeks.

Another perspective on the performance of the four intra-annually varying models is provided in Figures 2.1.3a-2.1.3e. Whereas each figure in Figures 2.1.2 shows four example lengths for a single model, each figure in Figures 2.1.3 compares all four models for each of two example lengths (10 and 20 cm, 30 and 40 cm, 50 and 60 cm, 70 and 80 cm, and 90 and 100 cm, respectively). The extreme week-to-week variability estimated by Model D is even more apparent in Figures 2.1.3 than in Figures 2.1.2, particularly

for small fish (e.g., Figure 2.1.3a). The potential for Model B to produce multiple maxima or minima is also evident in Figures 2.1.3, again especially at smaller lengths. Model E is also capable of exhibiting multiple maxima/minima, although this is illustrated only weakly in the lower panel of Figure 2.1.3a.

Model F was chosen as the basis for the representation of weight at length used in Model 1.3. Summarizing the above, the reasons were as follow:

- Models that incorporate inter-annual variability (C, E, and F) statistically out-performed all models that did not, with the exception of Model D.
- The very complicated week-to-week patterns estimated by Model D are impossible to explain phenologically.
- Of the models that incorporate intra-annual variability (B, D, E, and F), only Models E and F are constrained to exhibit a clear phenological process.
- Of the models that incorporate intra-annual variability (B, D, E, and F), only Model F is constrained to prevent multiple intra-annual maxima/minima.

Given the choice of Model F, the trigonometric functions used to describe the intra-annual variation in α and β were averaged between the endpoints of each season in order to obtain the season-specific values required by SS.

Model 2

Model 2 was the same as Model 1, except that *Q* was re-tuned iteratively by so that the combination of *Q* and the survey selectivity schedule was consistent with the results obtained by Nichol et al. (2007). As described under Model 1.1 above, this involved finding the value of *Q* such that the average product of *Q* and survey selectivity was equal to 0.47. The average was computed across the 60-81 cm size range, weighted by annual numbers at length, and across all years in the post-1981 survey time series. As reported in last year's assessment, Model 3b (the same as Model 1 here) exhibited an average product of 0.51, slightly above the target value of 0.47.

Model 3

Model 3 was the same as Model 1, except that an additional selectivity "time block" was imposed on all fisheries. The new time block began in 2008 and extended through the end of the time series. The purpose of Model 3 was to explore the possibility that selectivity changed as a result of implementing Amendment 80 to the groundfish fishery management plan.

Model 4

Model 4, which was the same as Model 4 in last year's final assessment (Thompson and Lauth 2011), was the same as Model 1, except that ageing bias was not estimated and the fit to the age composition data was not included in the log-likelihood function.

Model 5

For last year's preliminary assessment, the authors were asked by the Plan Teams and SSC to specify their own preferred model, which was labeled Model A. For the reasons listed under "Comments from the Plan Teams and SSC" above (specifically, comments JPT1-JPT4), the Teams then asked the authors not to include Model A in the final assessment.

To avoid a repeat of last year's sequence of events, the SSC has suggested that author-recommended models include fewer new features, and has encouraged the authors to evaluate changes in one or a few structural elements at a time (comment SSC5).

Based on this feedback, the following strategy was used to bring forward an exploratory model (not necessarily the authors' preferred model) in this preliminary assessment, which is labeled Model 5:

- Omit the features of last year's Model A that caused Plan Team concern and that could not be modified so as to eliminate that concern, or that were rendered irrelevant or inappropriate due to the inclusion of other features.
- Retain the features of last year's Model A that already made it into last year's final model.
- Incorporate two new features not included in last year's Model A.
- Incorporate some other features of last year's Model A without modification.
- Incorporate some other features of last year's Model A after modifying them to address Plan Team or other concerns.
- Develop some additional secondary models that provide a reasonably smooth transition from Model 1 to Model 5 by adding one new feature or a few new features at a time.

Here are the features of last year's model A that were omitted:

- In last year's Model A, *Q* was given annual additive *dev*s, with σ_{dev} tuned iteratively to set the root-mean-squared-standardized-residual of the survey abundance estimates equal to 1.0. The Plan Teams felt that this amounted to "discounting" the survey data. By omitting this feature, *Q* is held constant in Model 5. Model 5 is similar to Models 1-4 in this regard.
- In last year's Model A, all estimated fishery selectivity parameters were given annual random walk *dev*s with σ_{dev} tuned iteratively to match the standard deviation of the estimated *dev*s, except that the *dev*s for any selectivity parameter with a tuned σ_{dev} less than 0.005 were removed. The Plan Teams felt that the resulting estimates were suspect because random effects had not been properly integrated out. By omitting this feature, selectivity is held constant for all fisheries in Model 5. This is unlike Models 1-4, where many fishery selectivity parameters are estimated independently in pre-specified blocks of years.
- In last year's Model A, all parameters governing the peak region and descending limb of the survey selectivity function were given annual random walk *dev*s with σ_{dev} tuned iteratively to match the standard deviation of the estimated *dev*s, except that the *dev*s for any selectivity parameter with a tuned σ_{dev} less than 0.005 were removed. The Plan Teams felt that the resulting estimates were suspect because the random effects had not been properly integrated out. By omitting this feature, all parts of the survey selectivity function except the ascending limb are held constant in Model 5. Model 5 is similar to Models 1-4 in this regard.
- In last year's Model A, input sample sizes for size composition data were re-scaled to give a mean of 300 for *each* fishery and the survey. This was done in anticipation of retuning the input sample size for each fishery and the survey in the event that mean effective sample sizes were less than mean input sample sizes. However, this did not turn out to be the case, meaning that the size compositions for each fishery and the survey were weighted equally, even though the true sample sizes were very different. To keep the input sample sizes more proportional to the true sample sizes, Model 5 reverted to the previous practice of scaling the input sample sizes so that the *overall* mean (i.e., across all fisheries and the survey) was 300. Model 5 is similar to Models 1-4 in this regard.
- In last year's Model A, the standard deviation of length at the first reference age was tuned iteratively to match the value from the regression of standard deviation against length at age presented in the 2010 assessment. However, as of last year's final assessment, the parameters

governing variability in length at age (i.e., between-individual variability, conditional on a single set of von Bertalanffy parameter values) are estimated internally, so there is no need to include this feature from last year's Model A. Model 5 is similar to Models 1-4 in this regard.

Here are the features of last year's Model A that already made it into last year's final model:

- All size composition records were activated, regardless of whether an age composition record existed for the same year. Model 5 is similar to Models 1-4 in this regard.
- The first reference age in the mean length-at-age relationship was set at 1.41667, to coincide with age 1 at the time of year when the survey takes place. Model 5 is similar to Models 1-4 in this regard.
- Ageing bias was estimated internally. Model 5 is similar to Models 1-3 in this regard (Model 4 does not need to estimate ageing bias, because it does not use age data).

Here are the two new features not included in last year's Model A that were incorporated:

1. The new weight-length representation developed in Model 1.3 was used.
2. "Tail compression" was turned off. This feature aggregates size composition bins with few or zero data on a record-by-record basis, which improves computational speed, but which also makes some of the graphs in the R4SS package difficult to interpret. In Models 1-4, tail compression is turned on.

Here are the other features of last year's Model A that were incorporated without modification:

3. Fishery CPUE data were omitted. In Models 1-4, fishery CPUE data are included for purposes of comparison, but are not used in estimation.
4. A new population length bin was added for fish in the 0-0.5 cm range, which was used for extrapolating the length-at age curve below the first reference age. In Models 1-4, the lower bound of the first population length bin is 0.5 cm.
5. Mean-size-at-age data were eliminated. In Models 1-4, mean-size-at-age data are included, but not used in estimation.
6. The number of estimated year class strengths in the initial numbers-at-age vector was set at 10. In Models 1-4, only 3 elements of the initial numbers-at-age vector are estimated, which causes an automatic warning in SS.
7. The Richards growth equation (Richards 1959, Schnute 1981, Schnute and Richards 1990) was used, which adds one more parameter. In Models 1-4, the von Bertalanffy equation—a special case of the Richards equation—was used.
8. The log-scale standard deviation of recruitment was estimated internally (i.e., as a free parameter estimated by ADMB). In Models 1-4, this parameter was held constant at the value of 0.57 that was estimated in the final 2009 assessment by matching the standard deviation of the recruitment *dev*s, per Plan Team request.
9. Survey selectivity was modeled as a function of length. In Models 1-4, survey selectivity was modeled as a function of age.
10. Fisheries were defined with respect to each of the five seasons, but not with respect to gear. In Models 1-4, fisheries were defined with respect to both season and gear.
11. Fishery selectivity curves were defined for each of the five seasons, but were not stratified by gear type. In Models 1-4, seasons 1-2 and 4-5 were lumped into a pair of "super" seasons for the purpose of defining fishery selectivity curves, and fishery selectivities were also *gear*-specific (3 super-seasons × 3 gears = 9 selectivity curves).
12. The selectivity curve for the fishery that came closest to being asymptotic on its own (in this case, the season 3 fishery) was forced to be asymptotic by fixing both *width_of_peak_region* and

final_selectivity at a value of 10.0 and *descending_width* at a value of 0.0. In Models 1-4, six of the nine super-season × gear fisheries were forced to exhibit asymptotic selectivity.

13. Survey catchability was tuned iteratively to set the average of the product of catchability and survey selectivity across the 60-81 cm range equal to 0.47, corresponding to the Nichol et al. (2007) estimate. In Models 1-4, *Q* was left at the value of 0.77 estimated by a similar procedure in the final 2009 assessment, per Plan Team request.

Here are the features of last year's Model A that were incorporated after modifying them to address Plan Team or other concerns.

14. The age composition sample size multiplier was tuned iteratively to set the mean of the ratio of effective sample size to input sample size equal to 1.0. In last year's Model A, tuning was done with respect to the *ratio of the means* rather than the *mean of the ratio*, but examination of results from early runs in the present preliminary assessment seemed to suggest that the *mean of the ratio* usually provided a higher standard. In Models 1-4, the variance adjustment was fixed at 1.0.
15. The two parameters governing the ascending limb of the survey selectivity schedule were given annual additive *dev*s with each σ_{dev} tuned to match the estimate that would be appropriate for a univariate linear-normal model with random effects integrated out (see Annex 2.1.1). In the 2009 final assessment (Thompson et al. 2009), σ_{dev} for each of these two parameters was tuned iteratively to match the standard deviation of the corresponding set of *dev*s. Having previously been accepted, this same method was used in last year's Model A. However, the Plan Teams reconsidered their position with respect to this method and determined it to be invalid because the random effects had not been properly integrated out, which is why the method has been modified for use in Model 5. In Models 1-4, no *dev* vector corresponding to the *initial_selectivity* parameter is used, because it was "tuned out" in the 2009 final assessment; and σ_{dev} is set at a value of 0.07 for the *dev* vector corresponding to the *ascending_width* parameter, because current Plan Team policy is to keep this quantity constant at the value estimated (by the now-invalid method) in the 2009 final assessment.

Here are the additional secondary models that were developed in order to provide a reasonably smooth transition from Model 1 to Model 5 by adding one new feature or a few new features at a time:

Pre5.15	Same as Model 1.3, but with the addition of items 2-5 in the above list. All of these items involve minor changes to the data file (half of them simply involve removing data sets that are not used in estimation).
Pre5.16	Same as Model Pre5.1, but with the addition of item 6 in the above list.
Pre5.17	Same as Model Pre5.2, but with the addition of item 7 in the above list.
Pre5.18	Same as Model Pre5.3, but with the addition of item 8 in the above list.
Pre5.19	Same as Model Pre5.4, but with the addition of item 9 in the above list.
Pre5.20	Same as Model Pre5.5, but with the addition of items 10-12 in the above list. All of these items involve switching to fisheries defined by super-season and gear to fisheries defined by season alone.

The full Model 5 is the same as Model Pre5.6, but with the addition of items 13-15 in the above list. These last three items all involve iterative "tuning" adjustments.

Results

Model 1 and the three secondary models based on Model 1

Overview

The following table summarizes the status of the stock as estimated by Model 1 and the three secondary models based on Model 1 ("Est." is the point estimate, "SD" is the standard deviation of the estimate, "SB(2011)" is female spawning biomass in 2011 (t), and "Bratio(2011)" is the ratio of SB(2011) to $B_{100\%}$):

	Model 1		Model 1.1		Model 1.2		Model 1.3	
Quantity	Est.	SD	Est.	SD	Est.	SD	Est.	SD
SB(2011)	323,273	33,721	201,003	31,148	311,441	33,240	315,918	33,047
Bratio(2011)	0.426	0.017	0.306	0.019	0.417	0.017	0.411	0.017

The above results are similar for three of the four models listed, with Model 1.1 being the exception, as it lists both a much small 2011 spawning biomass than the other three models, both in absolute and relative terms. Thus, estimating *Q* internally (Model 1.1) had a major impact on stock status, while use of the GOA ageing bias parameter values (Model 1.2) and adoption of the revised weight-length representation (Model 1.3) had only minor impacts.

Estimates of selected parameters

The following table lists some key parameters estimated by Model 1 or at least one of the three secondary models based on Model 1 (grey shading indicates that the parameter was not estimated in the respective model; "Est." = point estimate, "SD" = standard deviation):

	Model 1		Model 1.1		Model 1.2		Model 1.3	
Quantity	Est.	SD	Est.	SD	Est.	SD	Est.	SD
Length at age 1 (cm)	14.243	0.111	14.265	0.112	14.269	0.111	14.243	0.111
Asymptotic length (cm)	91.021	0.525	94.858	0.800	91.230	0.551	90.982	0.523
Brody growth coefficient	0.248	0.003	0.236	0.003	0.246	0.003	0.248	0.003
SD of length at age 1 (cm)	3.498	0.072	3.610	0.077	3.495	0.072	3.496	0.072
SD of length at age 20 (cm)	10.514	0.172	10.241	0.197	10.573	0.175	10.520	0.172
Ageing bias at age 1 (years)	0.335	0.013	0.323	0.014	0.362	_	0.336	0.013
Ageing bias at age 20 (years)	0.849	0.173	1.143	0.188	0.000	_	0.844	0.173
Trawl survey catchability (*Q*)	0.770	_	1.035	0.034	0.770	_	0.770	_

In general, parameters in the above table that were not forced to be different tended to be estimated at similar values. As suggested by the respective estimates of 2011 spawning biomass presented in the preceding section, Model 1.1 estimated a much higher estimate of *Q* than the value that was hard-wired in the other three models in the group.

Goodness of fit

For Model 1 and the three secondary models based on Model 1, Table 2.1.1 shows the data files used, objective function values, and numbers of parameters. The objective function values are broken down by major component, and the size composition component is broken down further by fleet. Parameter

numbers are expressed as the number of non-*dev* parameters, number of *dev*s, and total number of parameters.

Note that objective functions are comparable only between models that use the same data file. Of the models listed in Table 2.1.1, all but Model 1.3 use the same data file. Model 1.1, by estimating *Q* internally, achieves an improvement of about 30 log-likelihood units relative to Model 1, mostly in the size composition and survey abundance components. Model 1.2, by substituting the values of the ageing bias parameters from last year's GOA Pacific cod assessment, gives a worse objective function value than Model 1 by about 13 log-likelihood points, mostly in the size composition and age composition components.

The number of parameters for the models in this group varies by at most three. Each of these models estimates 65 *dev*s. Models 1 and 1.3 each estimate 117 non-*dev* parameters. Model 1.1 estimates one additional non-*dev* parameter (*Q*), and Model 1.2 estimates two fewer (the two ageing bias parameters).

The Five Primary Models

Overview

The following table summarizes the status of the stock as estimated by the five primary models:

	Model 1		Model 2		Model 3		Model 4		Model 5	
Quantity	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
SB(2011)	323,273	33,721	353,269	36,223	326,272	34,372	336,429	37,182	368,253	44,207
Bratio(2011)	0.426	0.017	0.450	0.018	0.418	0.017	0.440	0.019	0.381	0.033

For the two quantities listed in the above table, Models 2-4 are all within 10% of Model 1. Model 5's estimate of 2011 spawning biomass is 14% higher than Model 1's estimate, and Model 5's estimate of relative 2011 spawning biomass is 11% lower than Model 1's.

Because Model 5 differs from Model 1 in several ways, the material presented in this section will adhere to the SSC's suggestion to provide results for a series of transitional models that span the range of features included in Models 1 and 5. This range begins with Model 1 as one endpoint, followed in order by Models 1.3 and Pre5.1 through Pre5.6, and concluding with Model 5 as the other endpoint. To facilitate navigation of the document, presentation of such transitional results will be shown as indented paragraphs.

Estimates and derived quantities

Tables 2.1.2-2.1.6 show every parameter estimated by at least one of the five primary models, together with standard deviations (except that standard deviations are not shown for fishing mortalities, because SS does not treat these as true parameters and therefore does not produce standard deviations for them).

Table 2.1.2 shows all of the estimated parameters other than recruitment *dev*s, selectivity parameters, and fishing mortality rates estimated by at least one of the five primary models.

Table 2.1.3 shows recruitment *dev*s estimated by each of the five primary models.

Table 2.1.4a shows fishery selectivity parameters estimated by Models 1-4 and Table 2.1.4b shows fishery selectivity parameters estimated by Model 5 (parameter numbering in these tables follows the

order listed in the "Model Structures" section; parameters ending in a 4-digit year correspond to the time block beginning in that year). Fishery selectivity parameters that are not estimated by any of the five primary models are not shown. These consist of *initial_selectivity*, which is set at a very low value for all fisheries in all models, and the parameters governing the descending limb for whatever fisheries are constrained to have asymptotic selectivity. Figures 2.1.4a-e show surface plots of selectivity for each fishery (one figure for each model).

Table 2.1.5 shows survey selectivity parameters estimated by the five primary models (parameter numbering in these tables follows the order listed in the "Model Structures" section; parameters ending in a 4-digit year correspond to the *dev* for that year). Models 1-4 use age-based selectivity while Model 5 uses length-based, and the *dev*s in Models 1-4 are with respect to *ascending_width* while the Model 5 *dev*s are with respect to *initial_selectivity* (the *ascending_width dev*s were initially present in Model 5, but were "tuned out" in the process of developing the model). Figure 2.1.5a shows surface plots of survey selectivity for each model, and Figure 2.1.5b shows contour plots of the same.

Tables 2.1.6a-e show fishing mortality rates by year, gear, and season for the five primary models.

The following table shows *Q* (not estimated internally in any of the primary models), the average product of *Q* and survey selectivity across the 60-81 cm size range, and the survey selectivity coefficient of variation for the five primary models:

Quantity	Model 1	Model 2	Model 3	Model 4	Model 5
Q	0.770	0.730	0.770	0.770	0.723
Mean($Q \times$ selectivity)	0.51	0.47	0.49	0.45	0.47
Survey SCV	0.208	0.198	0.202	0.201	0.242

Models 2 and 5 estimate *Q* iteratively so as to set the average product of *Q* and survey catchability across the 60-81 cm size range equal to the value of 0.47 estimated by Nichol et al. (2007), and they result in *Q* lower than the value of 0.770 that is hard-wired into Models 1, 3, and 4. Models 1 and 3 result in average products slightly higher than the target value, and Model 4 results in an average product slightly lower than the target value.

At last year's September meeting, the Plan Teams concluded that Model A's estimate of survey variability was excessive. Last year's Model A had SCV=0.330, and the model that was ultimately accepted after the final assessment (Model 1 here) had SCV=0.208.

Figures 2.1.6-2.1.8 compare various estimated times series from the five primary models. Figure 2.1.6 shows total (age 0+) biomass, Figure 2.1.7 shows spawning biomass relative to $B_{100\%}$, and Figure 2.1.8 shows age 0 recruits. Qualitatively, the trends for each of these three quantities are similar across all five models. For example, relative estimates of year class strength are very similar for all models and years, with the single exception of Model 5's estimate of the 1978 year class. Quantitatively, the time trends estimated by Model 5 tend to be the most dissimilar, particularly in Figure 2.1.7.

> Transition from Model 1 to Model 5: Table 2.1.7 shows how estimates of selected parameters and results change during the transitional steps. This table is split into two parts: The first shows the estimates themselves ("absolute values"), and the second shows the relative change in the estimates during each transitional step. Grey shading in both parts of the table indicates parameters that were fixed in a particular model. In the second part of the table, green shading indicates a positive change of more than 5% from the previous model, and pink shading indicates a negative change of at least 5% from the previous model. None of the quantities shown change

by more than 5% until the transition from Model Pre5.2 to Model Pre5.3. None of the quantities shown change by more than 10% until the transition from Model Pre5.3 to Model Pre5.4, where internal estimation of σ for the recruitment *dev*s causes that parameter to increase from 0.57 to 0.76 and relative 2011 spawning biomass to decrease from 0.412 to 0.364. No other 10% changes occur until the transition from Model Pre5.5 to Model Pre5.6, where switching from the traditional super-season × gear definition of fisheries to fisheries based only on seasons caused the estimate of the Richards growth parameter to decrease from 0.965 to 0.833 and σ for the recruitment *dev*s to increase from 0.759 to 0.860. Iterative tuning of *Q*, the agecomp sample size multiplier, and σ for the selectivity *dev*s in Model 5 caused four of the listed quantities to change by more than 10% relative to Model Pre5.6: Ageing bias at age 1 decreased from 0.330 to 0.283, ageing bias at age 20 increased from 0.864 to 1.059, σ for the selectivity *dev*s increased from 0.07 to 1.01, and the agecomp sample size multiplier decreased from 1.00 to 0.85.

Goodness of fit

For the five primary models, Table 2.1.8 shows the data files used, objective function values, and numbers of parameters, using the same format as Table 2.1.1. Of the three primary models that use BSbase.dat, Model 2 gives a worse fit than Model 1 by about 10 log-likelihood units, mostly in the survey abundance and size composition components; and Model 3 gives a better fit than Model 1 by about 248 log-likelihood units, mostly in the survey abundance, size composition, and age composition components.

Parameter counts can be difficult to interpret, because *dev*s are constrained and are therefore not comparable to non-*dev* parameters. Models 1 and 2 have the same number of parameters, 117 non-*dev* and 65 *dev*. Model 3 has 17 more non-*dev* parameters than Models 1 and 2, because it adds another time block for each estimated selectivity parameter. Model 4 has two fewer non-*dev* parameters than Models 1 and 2, because it does not estimate ageing bias. Model 5 has 77 fewer non-*dev* parameters than Models 1 and 2, because it does not estimate block-specific fishery selectivity parameters, and it has 7 more *dev*s, because it adds 7 individually estimated age groups to the initial numbers-at-age vector. Note again that SS does not count fishing mortality rates as parameters.

Transition from Model 1 to Model 5: Table 2.1.9 shows objective function values and numbers of parameters for these two models and several transitional models in between, using the same formats as Tables 2.1.1 and 2.1.8, except that data files are listed in the table legend. Models Pre5.1-Pre5.5 all use a common data file, and Models Pre5.6 and 5 use a common data file, while Model 1 and Model 1.3 each use their own unique data file. In the progression from Models Pre5.1-Pre5.5, each successive model gives a better objective function value than its predecessor, with the biggest jump (an improvement of about 55 log-likelihood units) coming when length-based selectivity replaces age-based selectivity for the trawl survey in Model Pre5.5. Although Models Pre5.6 and 5 use the same data file, the objective function values are still not comparable, because the data are weighted differently in these two models.

Figure 2.1.9 shows the fit to the survey abundance time series obtained by the five primary models. None of the fits are particularly good. The estimates from Models 1-3 miss the 95% confidence intervals 30% of the time, and the estimates from Models 4-5 miss the 95% confidence intervals 27% of the time. Table 2.1.10a shows log-scale residuals for the trawl survey index resulting from each of the five primary models. All of the models are biased low, with average residuals ranging from 0.073 (Model 3) to 0.119 (Model 5). Table 2.1.10b shows squared standardized residuals for the trawl survey index resulting from the five primary models. All of the models have root-mean-squared-errors much greater than unity, ranging from 1.987 (Model 3) to 2.460 (Model 5).

Transition from Model 1 to Model 5: Tables 2.1.11a and 2.1.11b show results analogous to Tables 2.1.10a and 2.1.10b.

Table 2.1.12a shows the number of records, input Is, and the mean of the ratio between effective sample size and input sample size for size composition data from each fleet (fisheries and the trawl survey) for the five primary models. All models have ratios of at least 2.0 for every fleet. Table 2.1.12b shows input sample sizes and the ratio between effective sample size and input sample size for each year of age composition data from the survey for the five primary models. Models 1-4 have average ratios ranging from 0.58 (Model 4, which does not attempt to fit the age composition data) to 0.89 (Model 2). Model 5 was tuned so that the average ratio is approximately 1.0; note that one way it does so is by adjusting the sample size multiplier from 1.0 down to 0.85 (i.e., the model multiplies each input sample size by 0.85, so that the average input sample size is 255 rather than 300).

Transition from Model 1 to Model 5: Tables 2.1.13a and 2.1.13b show results analogous to Tables 2.1.12a and 2.1.12b, except using a two-part format similar to Table 2.1.7, with the actual ratios shown in the upper part and the relative changes from each preceding model shown in the lower part. In terms of size composition data (Table 2.1.13a), all models have ratios of at least 2.0 for every fleet, and none of the transitional steps results in a change of more than 5% except for the fit to the August-December trawl fishery going from Model 1.3 to Model Pre5.1 (an improvement of 8.9%), and the fit to the trawl survey going from Model Pre5.4 to Model Pre5.5 (an improvement of 15.6%), Model Pre5.5 to Model Pre5.6 (an improvement of 30.4%), and Model Pre5.6 to Model 5 (an improvement of 19.5%). The fit to the age composition data (Table 2.1.13b) does not proceed monotonically during the transition from Model 1 to Model 5; the average ratio stays approximately constant from Model 1 through Model Pre5.4, then decreases in Model Pre5.5 (-12.8%) and again in Model Pre5.6 (-45.6%), then more than doubles in the transition from Model Pre5.6 to Model 5.

Discussion

Review of models and major issues

This preliminary assessment presents all the models requested by the Plan Team and SSC (four primary models and three secondary models), one additional primary model, and six additional secondary models. The Team/SSC primary models are labeled 1 through 4, the Team/SSC secondary models are labeled 1.1 through 1.3, the additional primary model is labeled 5, and the six additional secondary models are labeled Pre5.1 through Pre5.6. The latter group is used, together with Model 1.3, to illustrate *one possible transition* from Model 1 to Model 5. The phrase "one possible transition" is emphasized because the effects of model features are not necessarily additive, which means that the smoothness (or lack thereof) in the transition presented here may be due in part to the ordering of the secondary models in that transition.

Model 5 was based largely on Model A from last year's preliminary assessment, but with some changes suggested by the Plan Team or SSC. As described more fully in the "Model Structures" section, the following strategy was used to develop Model 5:

- Omit the features of last year's Model A that caused Plan Team concern and that could not be modified so as to eliminate that concern, or that were rendered irrelevant or inappropriate due to the inclusion of other features. The features that were omitted because of Team concern were:
    - Annual *dev*s on survey catchability
    - Annual *dev*s on fishery selectivity parameters
    - Annual *dev*s on survey selectivity parameters other than the ascending limb

- Retain the features of last year's Model A that already made it into last year's final model.
- Incorporate two new features not included in last year's Model A.
- Incorporate some other features of last year's Model A without modification. All of these were items to which neither the Plan Team nor SSC objected after last year's preliminary assessment.
- Incorporate some other features of last year's Model A after modifying them to address Plan Team or other concerns. The feature that was modified because of Team concern was the method used to tune the input σ for each vector of survey selectivity *dev*s. In last year's Model A, the input σ was tuned to match the standard deviation of the estimated *dev*s, but this fails to account for the fact that random effects have not been integrated out. In Model 5, this method was replaced by one that is designed to account for such integration (see Annex 2.1.1).

Comments on any of the models are welcome.

Over the years, the Pacific cod assessment models have been able to track general trends with a fair amount of success, particularly in terms of identifying strong and weak year classes. The models have always succeeded in fitting the size composition data very well. However, fitting *all* of the data sets at levels consistent with best estimates of their associated measurement errors has proven to be an elusive task. Two data sets have been especially problematic in this regard: First, the models have been unable to track the survey abundance data with a level of precision consistent with the observed sampling variance. Second, the models have been unable to track the age composition data with an effective sample size consistent with the input sample size.

The historic difficulty of fitting the survey abundance data continues in this preliminary assessment. However, it is difficult to imagine how any of the fits could be improved very much without allowing *Q* to vary, because the *inter*-annual variability in survey estimates relative to the *intra*-annual variability (standard errors) is so great. For example, the following tables show the relative year-to-year changes in survey estimates of numbers and biomass, together with the coefficients of variation, for every year in which the estimates of numbers or biomass increased by at least 85% over the previous year or decreased by at least 25% from the previous year (tables are sorted in order of increasing relative change):

Numbers				Biomass			
Change	Year	CV(current)	CV(previous)	Change	Year	CV(current)	CV(previous)
-0.43	2002	0.10	0.10	-0.32	1997	0.11	0.10
-0.42	1989	0.07	0.07	-0.27	1995	0.09	0.18
-0.39	1995	0.10	0.12	-0.26	2002	0.11	0.09
-0.35	2008	0.10	0.27	-0.26	1991	0.07	0.07
-0.3	1988	0.07	0.07	0.98	1994	0.18	0.08
0.86	2007	0.27	0.06	1.04	2010	0.12	0.08
1.04	2001	0.10	0.09				

Regarding the fit to the age composition data, it should be noted that some improvement has been achieved in recent years by attempting to estimate the degree of bias in the age data. Nevertheless, the four primary models suggested by the Team/SSC continue to fall short of producing an effective sample size at least as large as the input sample size. Model 5 achieves this goal, in part by reducing the input sample sizes by 15%. Given that the scale of the input sample sizes (average = 300) was chosen subjectively to begin with, it is difficult to argue that the reduction suggested by Model 5 is inappropriate. This raises an important contrast between the two difficult-to-fit data sets: The standard errors of the survey estimates are derived statistically, but the scale of the input sample sizes for the age (or, for that matter, size) composition data is simply assumed.

It may also be noted that Model 5 focuses on achieving an appropriate match to the age composition data while ignoring the better-than-expected fit to the size composition data. This is deliberate, and not inconsistent: The goal of Model 5 is to produce a fit, for each data set, *at least as good* as the typical variance specified for that data set suggests is appropriate. An alternative would be to produce a fit that matches the specified variances exactly, but when this approach has been tried in past Pacific cod assessments, the result has been that the size composition data are so heavily up-weighted that the other data sets contribute very little (or nothing at all), which would run afoul of the Plan Team's desire not to "discount" the survey abundance data.

Over-parameterization has also been a concern regarding the Pacific cod models for many years. As noted in the "Results" section, quantifying the parameterization of these models is challenging, in part because they all use constrained *dev*s, which are not truly free parameters. Model 5 does include seven more *dev*s than Models 1-4 (72 versus 65) because it estimates the abundance of seven more age groups in the initial numbers-at-age vector (10 versus 3). However, it has 75 fewer non-*dev* parameters than Models 1,2, and 4 (40 versus 117); and 94 fewer parameters than Model 3 (40 versus 134). (As noted in the "Results" section, SS does not count fishing mortality rates as parameters.)

Finally, the long-standing issue of catchability has yet to reach an entirely satisfying conclusion. Using the point estimate obtained by Nichol et al. (2007) to tune the model does provide an empirical benchmark, but one that is based on a very small sample (11 fish). The 2009 assessment (Thompson et al. 2009) attempted to calculate the distribution of this point estimate, and obtained a log-scale standard deviation of 0.59, which implies that values fairly far removed from the point estimate are almost as likely to be true. When Q was freed in Model 1.1, the estimate went up from the value of 0.77 used in the last few assessments to 1.035. Moreover, Model 2's estimate was very precise, with a standard deviation of 0.034, implying almost no chance that the true value could be as small as 0.77. However, the extents to which the point estimate from Model 2 and its precision are accurate depend on the extent to which the model is correctly specified. All of the primary models are likely mis-specified to some extent, as evidenced, for example, by their inconsistency with the survey abundance standard errors.

Questions for the Plan Team or SSC

1. For each fishery, Model 5 produces an average value for the ratio between effective sample size and input sample size greater than 2.0, even though this model assumes constant selectivity for each fishery. Is it necessary to incorporate time-varying selectivity under these circumstances?
2. In Model 5, the season 3 fishery was constrained to exhibit asymptotic selectivity, because this fishery came the closest to doing so on its own (i.e., when unconstrained) during early stages of model development. No other Model 5 fisheries were constrained in this manner. However, season 3 has the second smallest average catch of any season and the smallest number of length measurements of any season, so the effect of constraining the selectivity for this fishery may have only a very small impact on model stability. In contrast, six of the nine fisheries defined in Models 1-4 were constrained to exhibit asymptotic selectivity. If Model 5, or something like it, is carried forward into the final assessment, should different criteria be used to specify which fishery or fisheries are constrained to exhibit asymptotic selectivity?
3. Should the Team's preferred model continue to estimate Q (either from a previous assessment or re-tuned in this year's final assessment) by matching the average product of Q and survey selectivity across the 60-81 cm size range to the point estimate from Nichol et al. (2007)?
4. If tuning an input σ by matching the standard deviation of the estimated *dev*s "may produce pathological results" and gives MLEs that are "suspect" (see comment JPT1), what does this imply about the Team's primary models (1-4), given that they all rely on input σ values that were estimated using precisely this method?

5. If forcing *Q* to remain constant makes it impossible for a model to fit the survey abundance time series in a manner consistent with the survey data themselves (point estimates and standard errors), should the Team reconsider what "discounting" the survey means (see comment JPT2)?
6. Regarding the Team's concern over excessive variability in survey selectivity, it may be noted that Models 2-4 all have survey SCV values less than that of Model 1 (0.208). Model 5's SCV (0.242) constitutes a 27% reduction from last year's Model A (0.330), but it is still 16% higher than the SCV from Model 1. Where is the breakpoint between acceptable variability and excessive variability in survey (or other) selectivity (see comment JPT3)?
7. If the Team decides that Model 5 as a whole should not be included in the final assessment, are there any individual features specific to Model 5 that could be carried forward into the final assessment (see comment JPT4)?

References

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Table 2.1.1. Data files, objective function values, and number of parameters for Model 1 and the three secondary models based on Model 1. Note that objective function values are not comparable between models that use different data files.

	Model 1	Model 1.1	Model 1.2	Model 1.3
Data file:	BSbase	BSbase	BSbase	BSmodel1_3

Component	Model 1	Model 1.1	Model 1.2	Model 1.3
Catch	0.00	0.00	0.00	0.00
Equilibrium catch	0.00	0.02	0.00	0.00
Survey CPUE	-4.20	-19.58	-6.79	-5.70
Size composition	4192.75	4170.04	4198.24	4191.29
Age composition	117.70	121.37	126.46	117.60
Recruitment	20.65	24.72	21.08	20.63
"Softbounds"	0.03	0.04	0.03	0.03
Deviations	16.83	17.27	18.14	16.80
Total	4343.76	4313.87	4357.17	4340.65

Sizecomp component	Model 1	Model 1.1	Model 1.2	Model 1.3
Jan-Apr trawl fishery	932.95	934.74	934.61	932.34
May-Jul trawl fishery	181.97	186.22	182.45	181.77
Aug-Dec trawl fishery	221.46	222.73	221.28	221.33
Jan-Apr longline fishery	638.76	650.21	641.44	639.03
May-Jul longline fishery	206.76	194.61	205.71	206.45
Aug-Dec longline fishery	891.28	865.80	890.94	891.32
Jan-Apr pot fishery	112.19	114.21	112.18	112.28
May-Jul pot fishery	70.60	71.05	70.01	70.53
Aug-Dec pot fishery	191.39	187.56	190.66	191.28
Trawl survey	745.40	742.91	748.97	744.95

Parameter count	Model 1	Model 1.1	Model 1.2	Model 1.3
No. non-*dev* parameters	117	118	115	117
No. *dev*s	65	65	65	65
Total no. parameters	182	183	180	182

Table 2.1.2. All of the parameters other than recruitment *dev*s, selectivity parameters, and fishing mortality rates estimated by at least one of the five primary models. Grey shading and a "_" symbol in the St. Dev. column mean that the parameter was fixed in the respective model, and "n/a" means that the parameter was not used in the respective model.

	Model 1		Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Length at age 1 (cm)	14.243	0.111	14.235	0.111	14.254	0.111	14.240	0.112	14.623	0.187
Asymptotic length (cm)	91.021	0.525	90.398	0.508	91.513	0.513	90.379	0.536	89.843	0.892
Brody growth coefficient	0.248	0.003	0.250	0.003	0.247	0.003	0.251	0.003	0.283	0.013
Richards growth coefficient	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.803	0.064
SD of length at age 1 (cm)	3.498	0.072	3.479	0.071	3.546	0.072	3.508	0.072	3.682	0.108
SD of length at age 20 (cm)	10.514	0.172	10.560	0.168	10.269	0.166	10.503	0.170	10.267	0.219
Ageing bias at age 1 (years)	0.335	0.013	0.337	0.013	0.335	0.013	n/a	n/a	0.283	0.018
Ageing bias at age 20 (years)	0.849	0.173	0.814	0.172	0.864	0.175	n/a	n/a	1.059	0.219
ln(mean post-1976 recruitment)	13.224	0.020	13.268	0.021	13.242	0.021	13.241	0.023	13.435	0.080
σ(recruitment)	0.570	_	0.570	_	0.570	_	0.570	_	0.829	0.093
ln(pre-1977 recruitment offset)	-1.159	0.135	-1.101	0.136	-1.248	0.132	-1.086	0.135	-1.412	0.204
Initial F (Jan-Apr trawl fishery)	0.613	0.131	0.533	0.110	0.676	0.147	0.540	0.111	n/a	n/a
Initial F (Jan-Feb fishery)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.813	0.223
Initial age 10 ln(abundance) dev	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.485	0.691
Initial age 9 ln(abundance) dev	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.594	0.669
Initial age 8 ln(abundance) dev	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.688	0.649
Initial age 7 ln(abundance) dev	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.726	0.636
Initial age 6 ln(abundance) dev	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.629	0.631
Initial age 5 ln(abundance) dev	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.374	0.576
Initial age 4 ln(abundance) dev	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.584	0.583
Initial age 3 ln(abundance) dev	1.275	0.195	1.277	0.198	1.268	0.194	1.300	0.197	1.581	0.235
Initial age 2 ln(abundance) dev	-0.684	0.423	-0.687	0.424	-0.662	0.422	-0.662	0.426	-0.351	0.580
Initial age 1 ln(abundance) dev	1.207	0.230	1.212	0.232	1.210	0.227	1.224	0.234	1.680	0.251

Table 2.1.3. Recruitment devs estimated by each of the five primary models.

	Model 1		Model 2		Model 3		Model 4		Model 5	
Year	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
1977	1.406	0.109	1.450	0.110	1.347	0.108	1.514	0.112	1.285	0.129
1978	0.518	0.219	0.523	0.227	0.520	0.207	0.564	0.226	1.141	0.161
1979	0.671	0.118	0.668	0.122	0.657	0.114	0.676	0.122	0.386	0.197
1980	-0.385	0.137	-0.395	0.140	-0.377	0.132	-0.365	0.138	-0.252	0.165
1981	-1.047	0.153	-1.045	0.154	-1.051	0.150	-1.040	0.155	-0.802	0.182
1982	0.990	0.042	0.998	0.042	0.966	0.042	1.008	0.043	1.011	0.048
1983	-0.557	0.118	-0.564	0.120	-0.549	0.114	-0.545	0.120	-0.949	0.187
1984	0.777	0.047	0.775	0.048	0.759	0.047	0.789	0.048	0.730	0.052
1985	-0.066	0.073	-0.080	0.074	-0.071	0.071	-0.048	0.074	0.163	0.070
1986	-0.865	0.099	-0.892	0.101	-0.851	0.096	-0.870	0.101	-0.896	0.123
1987	-1.288	0.122	-1.328	0.126	-1.263	0.117	-1.312	0.127	-1.163	0.132
1988	-0.271	0.059	-0.271	0.059	-0.287	0.058	-0.258	0.060	-0.247	0.068
1989	0.526	0.040	0.528	0.041	0.508	0.040	0.547	0.042	0.419	0.048
1990	0.358	0.046	0.347	0.046	0.353	0.045	0.378	0.047	0.346	0.051
1991	-0.349	0.065	-0.359	0.066	-0.341	0.064	-0.328	0.068	-0.453	0.082
1992	0.626	0.033	0.625	0.033	0.628	0.033	0.653	0.036	0.525	0.038
1993	-0.384	0.060	-0.399	0.061	-0.357	0.058	-0.478	0.073	-0.589	0.074
1994	-0.343	0.053	-0.347	0.054	-0.313	0.052	-0.316	0.058	-0.544	0.062
1995	-0.298	0.057	-0.295	0.057	-0.265	0.056	-0.302	0.062	-0.561	0.069
1996	0.713	0.033	0.720	0.033	0.741	0.033	0.733	0.036	0.514	0.041
1997	-0.181	0.053	-0.197	0.054	-0.127	0.052	-0.172	0.059	-0.147	0.066
1998	-0.265	0.053	-0.275	0.054	-0.213	0.052	-0.257	0.058	-0.226	0.071
1999	0.491	0.033	0.491	0.034	0.547	0.034	0.484	0.037	0.591	0.041
2000	0.056	0.039	0.047	0.040	0.099	0.041	0.116	0.044	0.140	0.051
2001	-0.811	0.062	-0.821	0.063	-0.816	0.064	-1.039	0.088	-0.608	0.077
2002	-0.223	0.041	-0.219	0.042	-0.280	0.045	-0.138	0.044	-0.255	0.059
2003	-0.391	0.049	-0.382	0.050	-0.486	0.053	-0.446	0.060	-0.319	0.065
2004	-0.523	0.056	-0.515	0.057	-0.585	0.056	-0.440	0.061	-0.499	0.077
2005	-0.398	0.055	-0.380	0.056	-0.469	0.054	-0.384	0.064	-0.313	0.075
2006	0.896	0.040	0.919	0.040	0.854	0.040	0.919	0.043	0.948	0.048
2007	-0.201	0.076	-0.189	0.076	-0.158	0.078	-0.389	0.094	-0.025	0.093
2008	1.062	0.061	1.081	0.061	1.098	0.063	1.079	0.067	0.967	0.072
2009	-1.027	0.160	-1.016	0.160	-1.015	0.159	-1.123	0.206	-1.091	0.195
2010	0.785	0.130	0.797	0.129	0.795	0.130	0.790	0.135	0.773	0.150

Table 2.1.4a (page 1 of 4). Fishery selectivity parameters estimated by Models 1-4 (Model 5 is shown separately). See text for details.

	Model 1		Model 2		Model 3		Model 4	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
P3_May-Jul_Trawl_Fishery	5.648	0.106	5.628	0.109	5.607	0.110	5.622	0.109
P2_Jan-Apr_Longline_Fishery	-5.158	2.729	-4.938	2.173	-4.848	2.047	-4.770	1.819
P4_Jan-Apr_Longline_Fishery	5.110	0.141	5.098	0.140	5.098	0.140	5.087	0.139
P3_May-Jul_Longline_Fishery	4.999	0.055	4.987	0.055	4.975	0.055	4.984	0.055
P2_Aug-Dec_Longline_Fishery	-2.200	0.237	-2.190	0.237	-2.292	0.196	-2.165	0.236
P4_Aug-Dec_Longline_Fishery	5.241	0.288	5.217	0.288	4.586	0.241	5.209	0.293
P2_Jan-Apr_Pot_Fishery	-8.764	26.446	-8.645	28.262	-8.951	23.418	-8.601	28.892
P3_Jan-Apr_Pot_Fishery	4.994	0.052	4.992	0.053	4.993	0.052	4.994	0.053
P4_Jan-Apr_Pot_Fishery	4.572	0.286	4.573	0.283	4.544	0.269	4.565	0.284
P3_May-Jul_Pot_Fishery	4.918	0.082	4.912	0.082	4.910	0.082	4.910	0.083
P1_Jan-Apr_Trawl_Fishery_1977	68.697	3.055	68.358	3.057	69.039	2.998	68.077	3.024
P1_Jan-Apr_Trawl_Fishery_1985	76.587	1.703	76.277	1.709	76.543	1.699	75.736	1.746
P1_Jan-Apr_Trawl_Fishery_1990	68.186	1.093	67.602	1.122	67.869	1.107	67.609	1.142
P1_Jan-Apr_Trawl_Fishery_1995	73.708	0.926	73.423	0.920	73.482	0.914	73.235	0.930
P1_Jan-Apr_Trawl_Fishery_2000	78.227	1.180	77.974	1.175	77.965	1.176	78.131	1.188
P1_Jan-Apr_Trawl_Fishery_2005	74.221	0.959	74.072	0.957	73.329	1.484	74.064	0.962
P1_Jan-Apr_Trawl_Fishery_2008	n/a	n/a	n/a	n/a	72.682	1.171	n/a	n/a
P3_Jan-Apr_Trawl_Fishery_1977	6.155	0.173	6.151	0.175	6.161	0.169	6.141	0.175
P3_Jan-Apr_Trawl_Fishery_1985	6.642	0.077	6.641	0.078	6.639	0.077	6.625	0.080
P3_Jan-Apr_Trawl_Fishery_1990	6.058	0.059	6.033	0.062	6.043	0.061	6.033	0.062
P3_Jan-Apr_Trawl_Fishery_1995	6.285	0.046	6.279	0.046	6.275	0.046	6.275	0.046
P3_Jan-Apr_Trawl_Fishery_2000	6.300	0.060	6.298	0.060	6.299	0.060	6.304	0.060
P3_Jan-Apr_Trawl_Fishery_2005	6.032	0.058	6.031	0.058	6.153	0.090	6.031	0.059
P3_Jan-Apr_Trawl_Fishery_2008	n/a	n/a	n/a	n/a	5.858	0.077	n/a	n/a
P1_May-Jul_Trawl_Fishery_1977	50.334	1.718	49.937	1.714	50.081	1.716	49.728	1.719
P1_May-Jul_Trawl_Fishery_1985	51.318	1.768	50.913	1.789	50.935	1.777	50.808	1.790
P1_May-Jul_Trawl_Fishery_1990	61.914	1.558	61.504	1.580	61.384	1.577	61.377	1.585
P1_May-Jul_Trawl_Fishery_2000	53.196	1.537	52.864	1.566	52.334	1.566	52.758	1.563
P1_May-Jul_Trawl_Fishery_2005	58.916	1.534	58.587	1.547	57.631	1.616	58.605	1.545
P1_May-Jul_Trawl_Fishery_2008	n/a	n/a	n/a	n/a	57.976	2.088	n/a	n/a

Table 2.1.4a (page 2 of 4). Fishery selectivity parameters estimated by Models 1-4 (Model 5 is shown separately). See text for details.

	Model 1		Model 2		Model 3		Model 4	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
P1_Aug-Dec_Trawl_Fishery_1977	62.324	3.943	62.231	3.918	62.369	3.954	62.316	3.937
P1_Aug-Dec_Trawl_Fishery_1980	81.378	5.431	80.880	5.614	82.305	5.646	80.392	5.641
P1_Aug-Dec_Trawl_Fishery_1985	87.202	5.374	87.147	5.475	87.258	5.446	86.282	5.365
P1_Aug-Dec_Trawl_Fishery_1990	45.799	15.035	46.013	17.091	46.891	18.780	45.891	15.189
P1_Aug-Dec_Trawl_Fishery_1995	102.474	0.827	102.474	0.824	102.474	0.829	102.474	0.810
P1_Aug-Dec_Trawl_Fishery_2000	62.151	2.705	61.720	2.486	73.193	4.732	61.660	2.537
P1_Aug-Dec_Trawl_Fishery_2008	n/a	n/a	n/a	n/a	48.251	2.598	n/a	n/a
P3_Aug-Dec_Trawl_Fishery_1977	5.556	0.326	5.557	0.326	5.552	0.325	5.557	0.326
P3_Aug-Dec_Trawl_Fishery_1980	6.647	0.224	6.639	0.234	6.673	0.226	6.635	0.237
P3_Aug-Dec_Trawl_Fishery_1985	6.637	0.227	6.645	0.231	6.639	0.229	6.618	0.233
P3_Aug-Dec_Trawl_Fishery_1990	3.255	4.249	3.299	4.650	3.482	4.612	3.280	4.245
P3_Aug-Dec_Trawl_Fishery_1995	7.013	0.090	7.020	0.090	7.014	0.090	7.023	0.091
P3_Aug-Dec_Trawl_Fishery_2000	5.631	0.217	5.605	0.205	6.092	0.284	5.607	0.209
P3_Aug-Dec_Trawl_Fishery_2008	n/a	n/a	n/a	n/a	4.611	0.387	n/a	n/a
P1_Jan-Apr_Longline_Fishery_1977	58.582	2.059	58.568	2.050	58.481	2.067	58.539	2.067
P1_Jan-Apr_Longline_Fishery_1980	72.354	2.427	72.152	2.416	72.534	2.502	71.832	2.491
P1_Jan-Apr_Longline_Fishery_1985	75.315	0.909	75.213	0.917	75.222	0.919	74.927	0.918
P1_Jan-Apr_Longline_Fishery_1990	65.935	0.478	65.751	0.475	65.870	0.476	65.754	0.478
P1_Jan-Apr_Longline_Fishery_1995	65.698	0.428	65.601	0.427	65.611	0.426	65.506	0.429
P1_Jan-Apr_Longline_Fishery_2000	63.510	0.448	63.379	0.447	63.368	0.450	63.418	0.450
P1_Jan-Apr_Longline_Fishery_2005	67.471	0.408	67.352	0.407	64.131	0.543	67.301	0.410
P1_Jan-Apr_Longline_Fishery_2008	n/a	n/a	n/a	n/a	69.721	0.507	n/a	n/a
P3_Jan-Apr_Longline_Fishery_1977	5.134	0.208	5.137	0.208	5.119	0.209	5.132	0.209
P3_Jan-Apr_Longline_Fishery_1980	5.912	0.176	5.912	0.177	5.915	0.179	5.906	0.182
P3_Jan-Apr_Longline_Fishery_1985	5.868	0.067	5.870	0.067	5.862	0.067	5.861	0.068
P3_Jan-Apr_Longline_Fishery_1990	5.217	0.047	5.207	0.047	5.213	0.047	5.206	0.047
P3_Jan-Apr_Longline_Fishery_1995	5.299	0.040	5.296	0.040	5.292	0.040	5.291	0.040
P3_Jan-Apr_Longline_Fishery_2000	5.359	0.042	5.353	0.042	5.355	0.042	5.358	0.042
P3_Jan-Apr_Longline_Fishery_2005	5.351	0.036	5.346	0.036	5.240	0.060	5.345	0.036
P3_Jan-Apr_Longline_Fishery_2008	n/a	n/a	n/a	n/a	5.416	0.041	n/a	n/a

Table 2.1.4a (page 3 of 4). Fishery selectivity parameters estimated by Models 1-4 (Model 5 is shown separately). See text for details.

	Model 1		Model 2		Model 3		Model 4	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
P6_Jan-Apr_Longline_Fishery_1977	-1.375	0.792	-1.400	0.787	-1.340	0.791	-1.363	0.785
P6_Jan-Apr_Longline_Fishery_1980	0.284	1.008	0.261	0.982	0.446	1.096	0.334	0.994
P6_Jan-Apr_Longline_Fishery_1985	-1.377	0.481	-1.335	0.472	-1.289	0.468	-1.298	0.455
P6_Jan-Apr_Longline_Fishery_1990	-0.499	0.137	-0.502	0.135	-0.529	0.135	-0.503	0.135
P6_Jan-Apr_Longline_Fishery_1995	-0.747	0.140	-0.762	0.139	-0.760	0.139	-0.755	0.138
P6_Jan-Apr_Longline_Fishery_2000	-1.209	0.147	-1.217	0.145	-1.227	0.145	-1.200	0.145
P6_Jan-Apr_Longline_Fishery_2005	-1.050	0.155	-1.045	0.153	-1.154	0.167	-1.012	0.152
P6_Jan-Apr_Longline_Fishery_2008	n/a	n/a	n/a	n/a	-1.386	0.226	n/a	n/a
P1_May-Jul_Longline_Fishery_1977	63.004	2.224	62.846	2.258	62.851	2.232	62.861	2.252
P1_May-Jul_Longline_Fishery_1980	62.302	1.368	62.026	1.373	62.247	1.358	61.921	1.365
P1_May-Jul_Longline_Fishery_1985	63.188	1.127	62.995	1.127	63.021	1.120	62.852	1.130
P1_May-Jul_Longline_Fishery_1990	63.395	0.544	63.186	0.543	63.149	0.539	63.144	0.545
P1_May-Jul_Longline_Fishery_2000	59.731	0.576	59.559	0.574	59.417	0.571	59.534	0.577
P1_May-Jul_Longline_Fishery_2005	64.076	0.609	63.895	0.610	62.983	0.820	63.851	0.611
P1_May-Jul_Longline_Fishery_2008	n/a	n/a	n/a	n/a	63.800	0.666	n/a	n/a
P1_Aug-Dec_Longline_Fishery_1977	60.183	2.162	60.156	2.148	61.470	2.202	60.153	2.139
P1_Aug-Dec_Longline_Fishery_1980	69.800	1.554	69.691	1.562	69.591	1.696	69.230	1.578
P1_Aug-Dec_Longline_Fishery_1985	64.625	0.751	64.413	0.764	65.336	0.774	64.168	0.775
P1_Aug-Dec_Longline_Fishery_1990	66.975	0.725	66.794	0.729	66.957	0.721	66.773	0.729
P1_Aug-Dec_Longline_Fishery_1995	69.367	0.688	69.142	0.686	69.169	0.681	68.953	0.693
P1_Aug-Dec_Longline_Fishery_2000	63.527	0.426	63.368	0.426	64.008	0.417	63.367	0.436
P1_Aug-Dec_Longline_Fishery_2005	62.342	0.411	62.162	0.408	62.713	0.679	62.235	0.416
P1_Aug-Dec_Longline_Fishery_2008	n/a	n/a	n/a	n/a	61.819	0.462	n/a	n/a
P3_Aug-Dec_Longline_Fishery_1977	4.478	0.327	4.478	0.327	4.623	0.311	4.474	0.325
P3_Aug-Dec_Longline_Fishery_1980	5.416	0.131	5.414	0.132	5.398	0.141	5.388	0.135
P3_Aug-Dec_Longline_Fishery_1985	4.902	0.085	4.887	0.087	4.978	0.084	4.864	0.089
P3_Aug-Dec_Longline_Fishery_1990	5.033	0.077	5.024	0.077	5.030	0.076	5.021	0.077
P3_Aug-Dec_Longline_Fishery_1995	5.499	0.052	5.489	0.053	5.487	0.052	5.477	0.053
P3_Aug-Dec_Longline_Fishery_2000	5.174	0.041	5.165	0.041	5.228	0.039	5.168	0.042
P3_Aug-Dec_Longline_Fishery_2005	4.900	0.043	4.887	0.043	4.990	0.075	4.896	0.044

Table 2.1.4a (page 4 of 4). Fishery selectivity parameters estimated by Models 1-4 (Model 5 is shown separately). See text for details.

	Model 1		Model 2		Model 3		Model 4	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
P3_Aug-Dec_Longline_Fishery_2008	n/a	n/a	n/a	n/a	4.805	0.049	n/a	n/a
P6_Aug-Dec_Longline_Fishery_1977	-2.841	2.526	-2.825	2.445	-1.774	1.241	-2.787	2.425
P6_Aug-Dec_Longline_Fishery_1980	0.164	0.737	0.173	0.722	1.098	0.801	0.241	0.712
P6_Aug-Dec_Longline_Fishery_1985	0.143	0.258	0.181	0.254	0.479	0.228	0.131	0.248
P6_Aug-Dec_Longline_Fishery_1990	2.350	0.853	2.372	0.857	2.207	0.620	2.315	0.817
P6_Aug-Dec_Longline_Fishery_1995	9.379	15.512	9.345	16.203	9.336	16.386	9.335	16.413
P6_Aug-Dec_Longline_Fishery_2000	-0.439	0.195	-0.439	0.191	-0.121	0.136	-0.413	0.191
P6_Aug-Dec_Longline_Fishery_2005	9.772	6.521	9.754	6.973	9.892	3.251	9.783	6.240
P6_Aug-Dec_Longline_Fishery_2008	n/a	n/a	n/a	n/a	-0.068	0.139	n/a	n/a
P1_Jan-Apr_Pot_Fishery_1977	68.513	0.925	68.389	0.924	68.514	0.921	68.434	0.925
P1_Jan-Apr_Pot_Fishery_1995	68.325	0.563	68.250	0.564	68.305	0.559	68.224	0.567
P1_Jan-Apr_Pot_Fishery_2000	67.975	0.535	67.882	0.535	67.919	0.530	67.930	0.538
P1_Jan-Apr_Pot_Fishery_2005	68.103	0.556	68.017	0.558	66.145	0.664	68.014	0.561
P1_Jan-Apr_Pot_Fishery_2008	n/a	n/a	n/a	n/a	69.333	0.650	n/a	n/a
P6_Jan-Apr_Pot_Fishery_1977	0.216	0.563	0.197	0.553	0.167	0.545	0.197	0.553
P6_Jan-Apr_Pot_Fishery_1995	-0.313	0.253	-0.332	0.251	-0.323	0.248	-0.325	0.250
P6_Jan-Apr_Pot_Fishery_2000	-0.620	0.243	-0.631	0.241	-0.629	0.236	-0.622	0.241
P6_Jan-Apr_Pot_Fishery_2005	0.354	0.258	0.340	0.256	0.195	0.292	0.366	0.259
P6_Jan-Apr_Pot_Fishery_2008	n/a	n/a	n/a	n/a	-0.094	0.332	n/a	n/a
P1_May-Jul_Pot_Fishery_1977	67.178	0.852	67.029	0.853	67.065	0.845	67.019	0.857
P1_May-Jul_Pot_Fishery_1995	65.901	0.717	65.772	0.715	65.790	0.711	65.711	0.717
P1_May-Jul_Pot_Fishery_2008	n/a	n/a	n/a	n/a	95.228	67.782	n/a	n/a
P1_Aug-Dec_Pot_Fishery_1977	68.394	1.166	68.225	1.163	68.254	1.158	68.159	1.164
P1_Aug-Dec_Pot_Fishery_2000	62.159	0.775	62.053	0.770	59.945	0.910	62.080	0.774
P1_Aug-Dec_Pot_Fishery_2008	n/a	n/a	n/a	n/a	65.154	1.157	n/a	n/a
P3_Aug-Dec_Pot_Fishery_1977	5.187	0.118	5.180	0.119	5.177	0.118	5.177	0.119
P3_Aug-Dec_Pot_Fishery_2000	4.479	0.121	4.472	0.121	4.284	0.166	4.477	0.121
P3_Aug-Dec_Pot_Fishery_2008	n/a	n/a	n/a	n/a	4.611	0.164	n/a	n/a

Table 2.1.4b. Fishery selectivity parameters estimated by Model 5. See text for details.

	Model 5	
Parameter	Estimate	St. Dev.
P1_Season1_Fishery	69.263	0.569
P2_Season1_Fishery	-8.564	29.566
P3_Season1_Fishery	5.798	0.036
P4_Season1_Fishery	5.191	0.265
P6_Season1_Fishery	-0.038	0.185
P1_Season2_Fishery	69.130	0.587
P2_Season2_Fishery	-8.259	33.647
P3_Season2_Fishery	5.961	0.033
P4_Season2_Fishery	4.840	0.284
P6_Season2_Fishery	0.274	0.159
P1_Season3_Fishery	66.959	0.776
P3_Season3_Fishery	5.760	0.052
P1_Season4_Fishery	65.310	0.463
P2_Season4_Fishery	-1.766	0.401
P3_Season4_Fishery	5.145	0.041
P4_Season4_Fishery	1.268	3.551
P6_Season4_Fishery	2.358	0.425
P1_Season5_Fishery	64.297	0.555
P2_Season5_Fishery	-1.834	0.423
P3_Season5_Fishery	5.190	0.049
P4_Season5_Fishery	4.973	0.697
P6_Season5_Fishery	0.387	0.276

Table 2.1.5. Survey selectivity parameters estimated by the five primary models. Models 1-4 use age-based selectivity while Model 5 uses length-based, and the *dev*s in Models 1-4 are with respect to *ascending_width* while the Model 5 *dev*s are with respect to *initial_selectivity*.

	Model 1		Model 2		Model 3		Model 4			Model 5	
Parameter	Estimate	St. dev.	Estimate	St. dev.	Estimate	St. dev.	Estimate	St. dev.	Parameter	Estimate	St. dev.
P1	1.290	0.065	1.292	0.065	1.292	0.065	1.349	0.095	P1	27.196	1.067
P2	-11.490	107.111	-9.992	122.185	-12.001	101.357	-3.383	0.682	P2	-1.430	0.202
P3	-2.189	0.482	-2.167	0.483	-2.187	0.481	-1.846	0.570	P3	1.748	0.886
P4	3.185	0.175	3.177	0.178	3.106	0.161	1.864	0.438	P4	6.774	0.325
P5	-9.564	1.716	-9.559	1.714	-9.575	1.715	-9.995	0.170	P5	-0.031	0.196
P6	-1.667	0.415	-1.732	0.416	-1.680	0.368	-0.668	0.187	P6	-1.301	0.432
P3_dev_1982	-0.028	0.035	-0.028	0.035	-0.029	0.034	-0.027	0.034	P5_dev_1982	-0.809	0.520
P3_dev_1983	-0.042	0.018	-0.042	0.018	-0.042	0.018	-0.042	0.018	P5_dev_1983	-0.515	0.307
P3_dev_1984	-0.075	0.028	-0.075	0.028	-0.075	0.028	-0.072	0.027	P5_dev_1984	-0.021	0.590
P3_dev_1985	0.003	0.021	0.003	0.021	0.003	0.021	0.004	0.021	P5_dev_1985	0.206	0.361
P3_dev_1986	-0.044	0.023	-0.043	0.023	-0.044	0.023	-0.041	0.022	P5_dev_1986	-0.847	0.370
P3_dev_1987	0.040	0.041	0.044	0.042	0.038	0.040	0.040	0.040	P5_dev_1987	0.756	0.625
P3_dev_1988	-0.062	0.034	-0.058	0.035	-0.064	0.033	-0.057	0.033	P5_dev_1988	-0.549	0.598
P3_dev_1989	-0.110	0.019	-0.110	0.019	-0.109	0.019	-0.105	0.019	P5_dev_1989	-1.726	0.374
P3_dev_1990	-0.028	0.021	-0.028	0.021	-0.027	0.021	-0.028	0.020	P5_dev_1990	-0.242	0.356
P3_dev_1991	-0.041	0.022	-0.041	0.022	-0.041	0.022	-0.040	0.022	P5_dev_1991	-0.542	0.373
P3_dev_1992	0.094	0.041	0.095	0.041	0.092	0.040	0.094	0.040	P5_dev_1992	1.353	0.601
P3_dev_1993	0.047	0.028	0.046	0.028	0.045	0.028	0.046	0.028	P5_dev_1993	0.941	0.488
P3_dev_1994	-0.041	0.021	-0.041	0.022	-0.043	0.021	-0.035	0.027	P5_dev_1994	-0.125	0.397
P3_dev_1995	-0.088	0.020	-0.088	0.020	-0.089	0.020	-0.073	0.024	P5_dev_1995	-0.976	0.393
P3_dev_1996	-0.107	0.019	-0.108	0.019	-0.108	0.018	-0.098	0.022	P5_dev_1996	-1.490	0.355
P3_dev_1997	-0.067	0.016	-0.068	0.016	-0.067	0.016	-0.064	0.018	P5_dev_1997	-0.974	0.268
P3_dev_1998	-0.072	0.019	-0.071	0.019	-0.075	0.019	-0.070	0.022	P5_dev_1998	-1.305	0.334
P3_dev_1999	-0.071	0.018	-0.071	0.018	-0.073	0.018	-0.067	0.021	P5_dev_1999	-1.264	0.316
P3_dev_2000	-0.041	0.016	-0.041	0.016	-0.043	0.016	-0.038	0.018	P5_dev_2000	-0.900	0.258
P3_dev_2001	0.135	0.035	0.137	0.035	0.134	0.035	0.110	0.035	P5_dev_2001	1.476	0.478
P3_dev_2002	-0.012	0.024	-0.011	0.024	-0.006	0.025	0.019	0.035	P5_dev_2002	-0.508	0.352
P3_dev_2003	-0.002	0.019	-0.003	0.019	0.012	0.021	0.001	0.024	P5_dev_2003	0.141	0.326
P3_dev_2004	-0.026	0.019	-0.028	0.019	-0.014	0.020	-0.015	0.024	P5_dev_2004	-0.452	0.307
P3_dev_2005	0.037	0.025	0.036	0.025	0.045	0.026	0.050	0.033	P5_dev_2005	0.620	0.415
P3_dev_2006	0.134	0.036	0.130	0.036	0.144	0.036	0.109	0.037	P5_dev_2006	1.372	0.484
P3_dev_2007	0.197	0.037	0.195	0.037	0.193	0.037	0.150	0.038	P5_dev_2007	2.487	0.536
P3_dev_2008	0.087	0.033	0.088	0.034	0.068	0.030	0.090	0.039	P5_dev_2008	0.550	0.403
P3_dev_2009	0.044	0.022	0.044	0.022	0.033	0.021	0.027	0.022	P5_dev_2009	0.922	0.378

Table 2.1.6a. Fishing mortality rate by year, gear, and season for Model 1. The "total" column weights rates by season length before summing.

	Trawl fishery					Longline fishery					Pot fishery					
Year	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Total
1977	0.080	0.085	0.052	0.046	0.040	0.016	0.016	0.005	0.023	0.030	0	0	0	0	0	0.076
1978	0.092	0.097	0.064	0.053	0.048	0.016	0.017	0.006	0.024	0.033	0	0	0	0	0	0.087
1979	0.067	0.071	0.042	0.038	0.032	0.012	0.013	0.005	0.018	0.024	0	0	0	0	0	0.062
1980	0.060	0.061	0.030	0.039	0.033	0.010	0.010	0.004	0.014	0.017	0	0	0	0	0	0.053
1981	0.032	0.032	0.031	0.060	0.057	0.004	0.004	0.002	0.008	0.010	0	0	0	0	0	0.048
1982	0.033	0.034	0.034	0.042	0.033	0.001	0.001	0.001	0.004	0.005	0	0	0	0	0	0.038
1983	0.051	0.055	0.049	0.050	0.041	0.004	0.005	0.002	0.004	0.005	0	0	0	0	0	0.053
1984	0.058	0.064	0.055	0.053	0.046	0.007	0.008	0.006	0.027	0.037	0	0	0	0	0	0.072
1985	0.074	0.082	0.064	0.064	0.049	0.023	0.026	0.010	0.033	0.045	0	0	0	0	0	0.092
1986	0.083	0.091	0.064	0.064	0.051	0.016	0.018	0.005	0.026	0.037	0	0	0	0	0	0.089
1987	0.091	0.101	0.051	0.052	0.050	0.040	0.045	0.012	0.041	0.058	0	0	0	0	0	0.103
1988	0.184	0.205	0.098	0.110	0.116	0.001	0.001	0.002	0.003	0.003	0	0	0	0	0	0.138
1989	0.195	0.219	0.096	0.057	0.052	0.008	0.009	0.012	0.014	0.013	0.000	0.000	0.000	0.000	0.000	0.127
1990	0.164	0.187	0.090	0.028	0.024	0.030	0.034	0.046	0.050	0.045	0.000	0.000	0.002	0.002	0.001	0.135
1991	0.169	0.371	0.066	0.047	0.000	0.058	0.103	0.085	0.097	0.104	0.000	0.000	0.002	0.010	0.004	0.212
1992	0.139	0.219	0.054	0.032	0.010	0.126	0.236	0.138	0.089	0.000	0.000	0.002	0.030	0.011	0.000	0.211
1993	0.177	0.250	0.027	0.036	0.011	0.213	0.224	0.026	0.000	0.000	0.000	0.011	0.006	0.000	0.000	0.172
1994	0.081	0.286	0.019	0.073	0.014	0.180	0.258	0.029	0.100	0.000	0.000	0.030	0.009	0.015	0.000	0.203
1995	0.200	0.414	0.005	0.188	0.001	0.233	0.304	0.020	0.103	0.055	0.001	0.075	0.038	0.015	0.010	0.307
1996	0.134	0.359	0.036	0.102	0.020	0.226	0.255	0.018	0.114	0.022	0.000	0.123	0.053	0.021	0.005	0.277
1997	0.166	0.386	0.023	0.093	0.023	0.252	0.274	0.041	0.109	0.185	0.000	0.094	0.039	0.020	0.005	0.312
1998	0.115	0.218	0.021	0.132	0.015	0.274	0.203	0.022	0.090	0.111	0.000	0.061	0.033	0.011	0.000	0.243
1999	0.138	0.208	0.015	0.061	0.003	0.314	0.229	0.019	0.116	0.040	0.000	0.060	0.033	0.012	0.000	0.229
2000	0.154	0.207	0.018	0.027	0.003	0.277	0.078	0.008	0.120	0.130	0.124	0.047	0.000	0.000	0.000	0.213
2001	0.063	0.112	0.014	0.035	0.005	0.157	0.143	0.017	0.149	0.142	0.001	0.109	0.003	0.017	0.004	0.181
2002	0.096	0.168	0.029	0.034	0.002	0.290	0.132	0.008	0.174	0.104	0.016	0.083	0.005	0.014	0.005	0.215
2003	0.116	0.129	0.026	0.029	0.000	0.292	0.097	0.000	0.163	0.106	0.126	0.017	0.000	0.022	0.009	0.209
2004	0.153	0.136	0.038	0.036	0.000	0.301	0.148	0.012	0.157	0.151	0.079	0.028	0.005	0.017	0.004	0.233
2005	0.193	0.122	0.033	0.013	0.001	0.412	0.066	0.018	0.173	0.149	0.076	0.030	0.000	0.023	0.003	0.240
2006	0.228	0.128	0.033	0.023	0.000	0.465	0.071	0.011	0.238	0.008	0.103	0.037	0.002	0.022	0.007	0.257
2007	0.142	0.168	0.059	0.019	0.001	0.502	0.025	0.008	0.187	0.007	0.118	0.014	0.003	0.031	0.000	0.240
2008	0.153	0.080	0.023	0.038	0.006	0.533	0.053	0.019	0.220	0.077	0.107	0.027	0.002	0.043	0.001	0.259
2009	0.128	0.113	0.023	0.056	0.003	0.606	0.055	0.016	0.219	0.089	0.124	0.025	0.001	0.009	0.010	0.273
2010	0.154	0.082	0.019	0.047	0.010	0.448	0.023	0.014	0.116	0.086	0.124	0.021	0.002	0.026	0.013	0.216
2011	0.160	0.169	0.026	0.034	0.005	0.242	0.234	0.064	0.127	0.059	0.134	0.022	0.008	0.028	0.006	0.243

Table 2.1.6b. Fishing mortality rate by year, gear, and season for Model 2. The "total" column weights rates by season length before summing.

	Trawl fishery					Longline fishery					Pot fishery					
Year	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Total
1977	0.070	0.074	0.046	0.040	0.035	0.014	0.014	0.005	0.020	0.026	0	0	0	0	0	0.067
1978	0.080	0.086	0.056	0.047	0.042	0.014	0.015	0.005	0.022	0.030	0	0	0	0	0	0.077
1979	0.059	0.063	0.037	0.034	0.029	0.011	0.012	0.004	0.016	0.022	0	0	0	0	0	0.055
1980	0.053	0.054	0.026	0.034	0.029	0.009	0.009	0.003	0.012	0.015	0	0	0	0	0	0.047
1981	0.029	0.029	0.028	0.054	0.051	0.003	0.003	0.002	0.008	0.009	0	0	0	0	0	0.043
1982	0.030	0.031	0.031	0.038	0.030	0.001	0.001	0.001	0.003	0.004	0	0	0	0	0	0.034
1983	0.047	0.050	0.045	0.046	0.038	0.004	0.004	0.002	0.004	0.005	0	0	0	0	0	0.049
1984	0.054	0.059	0.051	0.049	0.042	0.007	0.007	0.005	0.025	0.034	0	0	0	0	0	0.066
1985	0.068	0.076	0.060	0.059	0.046	0.021	0.024	0.009	0.031	0.042	0	0	0	0	0	0.086
1986	0.077	0.085	0.060	0.059	0.047	0.015	0.017	0.005	0.024	0.034	0	0	0	0	0	0.083
1987	0.085	0.094	0.048	0.049	0.047	0.038	0.041	0.011	0.038	0.054	0	0	0	0	0	0.096
1988	0.172	0.191	0.092	0.103	0.108	0.001	0.001	0.001	0.003	0.003	0	0	0	0	0	0.129
1989	0.182	0.205	0.090	0.054	0.049	0.007	0.008	0.011	0.013	0.012	0.000	0.000	0.000	0.000	0.000	0.119
1990	0.154	0.175	0.085	0.027	0.023	0.028	0.032	0.043	0.047	0.042	0.000	0.000	0.002	0.002	0.001	0.127
1991	0.159	0.348	0.062	0.044	0.000	0.055	0.097	0.080	0.090	0.097	0.000	0.000	0.002	0.010	0.004	0.198
1992	0.130	0.205	0.051	0.030	0.009	0.119	0.222	0.129	0.083	0.000	0.000	0.001	0.028	0.010	0.000	0.197
1993	0.165	0.233	0.025	0.034	0.010	0.200	0.210	0.024	0.000	0.000	0.000	0.010	0.006	0.000	0.000	0.160
1994	0.076	0.268	0.017	0.069	0.013	0.170	0.243	0.027	0.094	0.000	0.000	0.028	0.009	0.014	0.000	0.190
1995	0.188	0.387	0.005	0.175	0.001	0.221	0.287	0.019	0.097	0.052	0.001	0.071	0.035	0.014	0.009	0.289
1996	0.126	0.336	0.033	0.095	0.019	0.213	0.241	0.016	0.107	0.021	0.000	0.115	0.050	0.020	0.005	0.259
1997	0.156	0.361	0.022	0.087	0.021	0.238	0.258	0.038	0.102	0.172	0.000	0.089	0.037	0.018	0.005	0.292
1998	0.108	0.203	0.019	0.122	0.014	0.257	0.190	0.020	0.083	0.103	0.000	0.057	0.031	0.010	0.000	0.227
1999	0.128	0.193	0.014	0.056	0.003	0.294	0.214	0.017	0.108	0.037	0.000	0.056	0.031	0.011	0.000	0.213
2000	0.143	0.192	0.017	0.025	0.003	0.259	0.073	0.007	0.112	0.122	0.116	0.044	0.000	0.000	0.000	0.199
2001	0.059	0.104	0.013	0.033	0.004	0.148	0.135	0.016	0.140	0.134	0.001	0.102	0.003	0.016	0.003	0.170
2002	0.089	0.156	0.027	0.032	0.001	0.274	0.124	0.007	0.164	0.098	0.015	0.078	0.005	0.013	0.005	0.202
2003	0.108	0.120	0.024	0.028	0.000	0.276	0.091	0.000	0.153	0.100	0.119	0.016	0.000	0.021	0.008	0.196
2004	0.143	0.127	0.036	0.034	0.000	0.284	0.139	0.012	0.148	0.142	0.075	0.026	0.004	0.016	0.004	0.219
2005	0.181	0.114	0.031	0.013	0.001	0.387	0.062	0.017	0.162	0.139	0.071	0.028	0.000	0.021	0.003	0.225
2006	0.213	0.119	0.031	0.021	0.000	0.435	0.066	0.010	0.221	0.008	0.096	0.035	0.002	0.021	0.006	0.240
2007	0.132	0.156	0.054	0.017	0.001	0.467	0.024	0.007	0.173	0.006	0.110	0.013	0.003	0.029	0.000	0.222
2008	0.141	0.074	0.022	0.035	0.005	0.493	0.049	0.017	0.203	0.071	0.099	0.025	0.002	0.040	0.001	0.239
2009	0.117	0.103	0.021	0.051	0.003	0.558	0.051	0.015	0.200	0.081	0.114	0.023	0.001	0.008	0.009	0.251
2010	0.141	0.075	0.017	0.043	0.009	0.412	0.021	0.013	0.107	0.079	0.113	0.019	0.002	0.024	0.012	0.198
2011	0.147	0.154	0.024	0.031	0.004	0.223	0.215	0.059	0.117	0.054	0.123	0.020	0.007	0.025	0.006	0.223

Table 2.1.6c. Fishing mortality rate by year, gear, and season for Model 3. The "total" column weights rates by season length before summing.

	Trawl fishery					Longline fishery					Pot fishery					
Year	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Total
1977	0.087	0.093	0.057	0.050	0.043	0.017	0.017	0.006	0.026	0.034	0	0	0	0	0	0.083
1978	0.100	0.107	0.069	0.058	0.052	0.017	0.018	0.007	0.028	0.038	0	0	0	0	0	0.096
1979	0.073	0.078	0.045	0.041	0.035	0.013	0.014	0.005	0.021	0.028	0	0	0	0	0	0.068
1980	0.066	0.066	0.031	0.043	0.035	0.011	0.011	0.004	0.014	0.018	0	0	0	0	0	0.057
1981	0.034	0.034	0.032	0.065	0.061	0.004	0.004	0.002	0.009	0.011	0	0	0	0	0	0.052
1982	0.034	0.035	0.035	0.044	0.035	0.001	0.001	0.001	0.004	0.005	0	0	0	0	0	0.040
1983	0.053	0.056	0.050	0.052	0.043	0.004	0.005	0.003	0.004	0.005	0	0	0	0	0	0.055
1984	0.059	0.065	0.056	0.055	0.047	0.007	0.008	0.006	0.027	0.036	0	0	0	0	0	0.073
1985	0.075	0.083	0.065	0.064	0.050	0.023	0.026	0.010	0.034	0.046	0	0	0	0	0	0.093
1986	0.083	0.092	0.065	0.064	0.051	0.016	0.018	0.005	0.026	0.037	0	0	0	0	0	0.090
1987	0.091	0.101	0.051	0.052	0.050	0.040	0.044	0.012	0.041	0.058	0	0	0	0	0	0.103
1988	0.183	0.204	0.097	0.110	0.115	0.001	0.001	0.002	0.003	0.003	0	0	0	0	0	0.138
1989	0.193	0.217	0.095	0.057	0.052	0.008	0.009	0.012	0.014	0.012	0.000	0.000	0.000	0.000	0.000	0.126
1990	0.162	0.184	0.089	0.028	0.024	0.029	0.033	0.045	0.050	0.045	0.000	0.000	0.002	0.002	0.001	0.134
1991	0.166	0.365	0.065	0.046	0.000	0.058	0.102	0.084	0.096	0.103	0.000	0.000	0.002	0.010	0.004	0.209
1992	0.136	0.215	0.053	0.032	0.010	0.125	0.233	0.135	0.088	0.000	0.000	0.002	0.029	0.010	0.000	0.207
1993	0.173	0.244	0.026	0.036	0.011	0.210	0.221	0.026	0.000	0.000	0.000	0.011	0.006	0.000	0.000	0.168
1994	0.079	0.279	0.018	0.072	0.014	0.177	0.253	0.028	0.098	0.000	0.000	0.029	0.009	0.015	0.000	0.198
1995	0.194	0.401	0.005	0.181	0.001	0.228	0.296	0.019	0.100	0.053	0.001	0.073	0.037	0.014	0.010	0.299
1996	0.130	0.346	0.034	0.098	0.019	0.219	0.248	0.017	0.109	0.021	0.000	0.119	0.051	0.021	0.005	0.267
1997	0.159	0.369	0.022	0.089	0.021	0.243	0.263	0.039	0.104	0.175	0.000	0.091	0.037	0.019	0.005	0.299
1998	0.109	0.206	0.020	0.124	0.014	0.261	0.193	0.021	0.085	0.104	0.000	0.058	0.031	0.010	0.000	0.230
1999	0.130	0.195	0.014	0.056	0.003	0.296	0.216	0.017	0.108	0.037	0.000	0.056	0.031	0.011	0.000	0.215
2000	0.142	0.191	0.017	0.030	0.004	0.259	0.073	0.007	0.114	0.123	0.116	0.044	0.000	0.000	0.000	0.201
2001	0.058	0.102	0.013	0.038	0.005	0.146	0.133	0.016	0.141	0.134	0.001	0.101	0.003	0.015	0.003	0.170
2002	0.087	0.152	0.026	0.037	0.002	0.268	0.121	0.007	0.163	0.097	0.015	0.077	0.005	0.012	0.005	0.200
2003	0.104	0.116	0.023	0.031	0.000	0.267	0.088	0.000	0.151	0.098	0.115	0.015	0.000	0.019	0.008	0.191
2004	0.136	0.121	0.034	0.037	0.000	0.272	0.133	0.011	0.145	0.139	0.072	0.025	0.004	0.015	0.003	0.212
2005	0.166	0.104	0.030	0.013	0.001	0.383	0.061	0.016	0.154	0.133	0.068	0.027	0.000	0.020	0.003	0.216
2006	0.196	0.110	0.030	0.023	0.000	0.442	0.067	0.010	0.215	0.008	0.093	0.033	0.002	0.020	0.006	0.234
2007	0.124	0.147	0.054	0.020	0.001	0.488	0.025	0.007	0.174	0.006	0.109	0.013	0.003	0.028	0.000	0.224
2008	0.141	0.074	0.022	0.032	0.005	0.520	0.052	0.018	0.270	0.095	0.109	0.027	0.006	0.043	0.001	0.269
2009	0.122	0.108	0.022	0.045	0.002	0.617	0.057	0.016	0.263	0.106	0.130	0.027	0.003	0.009	0.011	0.286
2010	0.151	0.080	0.018	0.040	0.008	0.483	0.025	0.014	0.133	0.098	0.135	0.023	0.011	0.029	0.014	0.231
2011	0.158	0.167	0.025	0.028	0.004	0.258	0.250	0.063	0.143	0.066	0.145	0.023	0.055	0.030	0.007	0.266

Table 2.1.6d. Fishing mortality rate by year, gear, and season for Model 4. The "total" column weights rates by season length before summing.

	Trawl fishery					Longline fishery					Pot fishery					
Year	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Total
1977	0.070	0.075	0.046	0.041	0.035	0.014	0.014	0.005	0.020	0.026	0	0	0	0	0	0.067
1978	0.081	0.086	0.056	0.047	0.042	0.014	0.015	0.005	0.022	0.029	0	0	0	0	0	0.077
1979	0.059	0.062	0.037	0.034	0.028	0.011	0.011	0.004	0.016	0.021	0	0	0	0	0	0.055
1980	0.053	0.053	0.026	0.033	0.028	0.009	0.009	0.003	0.012	0.015	0	0	0	0	0	0.046
1981	0.028	0.028	0.027	0.052	0.049	0.003	0.003	0.002	0.007	0.009	0	0	0	0	0	0.042
1982	0.029	0.030	0.031	0.037	0.029	0.001	0.001	0.001	0.003	0.004	0	0	0	0	0	0.033
1983	0.046	0.049	0.044	0.044	0.037	0.004	0.004	0.002	0.004	0.004	0	0	0	0	0	0.048
1984	0.052	0.058	0.050	0.048	0.041	0.006	0.007	0.005	0.024	0.033	0	0	0	0	0	0.065
1985	0.067	0.074	0.059	0.057	0.044	0.021	0.023	0.009	0.030	0.042	0	0	0	0	0	0.084
1986	0.076	0.083	0.060	0.058	0.046	0.015	0.017	0.005	0.024	0.034	0	0	0	0	0	0.082
1987	0.084	0.093	0.048	0.048	0.046	0.037	0.041	0.011	0.038	0.054	0	0	0	0	0	0.095
1988	0.170	0.190	0.092	0.101	0.106	0.001	0.001	0.001	0.003	0.003	0	0	0	0	0	0.128
1989	0.182	0.204	0.091	0.053	0.048	0.007	0.008	0.011	0.013	0.012	0.000	0.000	0.000	0.000	0.000	0.119
1990	0.154	0.176	0.085	0.027	0.023	0.028	0.032	0.043	0.047	0.042	0.000	0.000	0.002	0.002	0.001	0.128
1991	0.159	0.350	0.062	0.044	0.000	0.055	0.098	0.080	0.091	0.098	0.000	0.000	0.002	0.010	0.004	0.200
1992	0.131	0.206	0.051	0.030	0.009	0.120	0.223	0.130	0.084	0.000	0.000	0.001	0.028	0.010	0.000	0.198
1993	0.166	0.235	0.025	0.034	0.010	0.201	0.212	0.025	0.000	0.000	0.000	0.010	0.006	0.000	0.000	0.162
1994	0.076	0.269	0.017	0.069	0.013	0.171	0.244	0.027	0.094	0.000	0.000	0.028	0.009	0.014	0.000	0.191
1995	0.188	0.387	0.005	0.176	0.001	0.221	0.287	0.019	0.097	0.052	0.001	0.071	0.036	0.014	0.009	0.289
1996	0.126	0.336	0.033	0.095	0.019	0.213	0.241	0.017	0.107	0.021	0.000	0.115	0.050	0.020	0.005	0.260
1997	0.156	0.363	0.022	0.087	0.021	0.239	0.260	0.038	0.103	0.174	0.000	0.089	0.037	0.019	0.005	0.294
1998	0.109	0.206	0.020	0.124	0.014	0.262	0.194	0.021	0.085	0.105	0.000	0.058	0.031	0.010	0.000	0.231
1999	0.131	0.196	0.014	0.057	0.003	0.301	0.220	0.018	0.110	0.038	0.000	0.057	0.031	0.011	0.000	0.218
2000	0.146	0.197	0.017	0.026	0.003	0.265	0.075	0.007	0.114	0.124	0.118	0.045	0.000	0.000	0.000	0.203
2001	0.060	0.107	0.013	0.033	0.004	0.150	0.137	0.017	0.143	0.136	0.001	0.105	0.003	0.016	0.003	0.174
2002	0.091	0.160	0.028	0.033	0.001	0.278	0.126	0.008	0.167	0.100	0.016	0.080	0.005	0.013	0.005	0.206
2003	0.111	0.123	0.025	0.028	0.000	0.281	0.093	0.000	0.156	0.102	0.121	0.016	0.000	0.021	0.009	0.200
2004	0.146	0.130	0.037	0.035	0.000	0.289	0.142	0.012	0.151	0.145	0.076	0.027	0.004	0.016	0.004	0.224
2005	0.185	0.117	0.032	0.013	0.001	0.395	0.063	0.017	0.167	0.143	0.073	0.029	0.000	0.022	0.003	0.231
2006	0.219	0.123	0.032	0.022	0.000	0.447	0.068	0.011	0.229	0.008	0.099	0.036	0.002	0.022	0.006	0.247
2007	0.136	0.161	0.056	0.018	0.001	0.481	0.024	0.008	0.180	0.007	0.113	0.014	0.003	0.030	0.000	0.230
2008	0.146	0.077	0.022	0.036	0.005	0.508	0.050	0.018	0.210	0.073	0.102	0.026	0.002	0.041	0.001	0.247
2009	0.121	0.106	0.022	0.053	0.003	0.572	0.052	0.015	0.207	0.084	0.117	0.024	0.001	0.008	0.009	0.258
2010	0.145	0.077	0.018	0.045	0.009	0.422	0.022	0.014	0.111	0.082	0.116	0.020	0.002	0.025	0.012	0.205
2011	0.153	0.162	0.025	0.033	0.004	0.233	0.226	0.062	0.124	0.057	0.128	0.021	0.007	0.027	0.006	0.234

Table 2.1.6e. Fishing mortality rate by year and season for Model 5. The "total" column weights rates by season length before summing.

Year	Sea1	Sea2	Sea3	Sea4	Sea5	Total
1977	0.248	0.237	0.148	0.143	0.133	0.176
1978	0.226	0.211	0.136	0.125	0.119	0.158
1979	0.131	0.124	0.083	0.077	0.071	0.094
1980	0.105	0.094	0.060	0.054	0.047	0.070
1981	0.046	0.041	0.047	0.060	0.055	0.050
1982	0.036	0.034	0.039	0.034	0.028	0.035
1983	0.054	0.055	0.049	0.041	0.036	0.047
1984	0.072	0.076	0.062	0.071	0.078	0.071
1985	0.092	0.097	0.070	0.069	0.073	0.078
1986	0.097	0.101	0.066	0.062	0.067	0.076
1987	0.128	0.133	0.062	0.069	0.087	0.091
1988	0.187	0.195	0.094	0.075	0.086	0.120
1989	0.198	0.209	0.094	0.048	0.047	0.111
1990	0.198	0.212	0.115	0.068	0.066	0.125
1991	0.241	0.479	0.133	0.140	0.104	0.206
1992	0.270	0.426	0.196	0.126	0.013	0.199
1993	0.357	0.422	0.050	0.041	0.013	0.155
1994	0.248	0.540	0.051	0.185	0.017	0.193
1995	0.411	0.712	0.054	0.193	0.062	0.259
1996	0.351	0.682	0.101	0.178	0.038	0.248
1997	0.445	0.779	0.108	0.187	0.229	0.316
1998	0.433	0.529	0.085	0.196	0.148	0.255
1999	0.514	0.548	0.075	0.186	0.050	0.250
2000	0.582	0.341	0.035	0.166	0.147	0.228
2001	0.244	0.364	0.044	0.227	0.166	0.197
2002	0.416	0.374	0.054	0.238	0.114	0.224
2003	0.509	0.228	0.033	0.213	0.111	0.203
2004	0.483	0.270	0.060	0.195	0.139	0.212
2005	0.595	0.189	0.049	0.202	0.154	0.219
2006	0.680	0.202	0.044	0.272	0.015	0.228
2007	0.612	0.183	0.065	0.219	0.007	0.205
2008	0.649	0.132	0.040	0.286	0.084	0.226
2009	0.656	0.151	0.038	0.271	0.096	0.228
2010	0.571	0.098	0.033	0.184	0.103	0.183
2011	0.438	0.331	0.088	0.185	0.068	0.208

Table 2.1.7. Selected parameter estimates and results from Models 1 and 5 and the secondary models that constitute a transition between those two primary models. Grey shading indicates parameters that were fixed, green shading indicates a positive change of more than 5% from the previous model, and pink shading indicates a negative change of at least 5% from the previous model.

Absolute values:

Quantity	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
Length at age 1 (cm)	14.243	14.243	14.245	14.246	14.365	14.369	13.622	14.622	14.623
Asymptotic length (cm)	91.021	90.982	90.986	91.059	90.114	90.164	89.235	91.394	89.843
Brody growth coefficient	0.248	0.248	0.248	0.248	0.263	0.263	0.267	0.270	0.283
Richards growth coefficient	1.000	1.000	1.000	1.000	0.926	0.926	0.965	0.833	0.803
SD of length at age 1 (cm)	3.498	3.496	3.497	3.498	3.489	3.491	3.333	3.669	3.682
SD of length at age 20 (cm)	10.514	10.520	10.509	10.503	10.525	10.543	10.641	10.480	10.267
Ageing bias at age 1 (years)	0.335	0.336	0.336	0.335	0.334	0.334	0.340	0.330	0.283
Ageing bias at age 20 (years)	0.849	0.844	0.844	0.844	0.863	0.858	0.830	0.864	1.059
σ(recruitment *dev* s)	0.570	0.570	0.570	0.570	0.570	0.760	0.759	0.860	0.829
Trawl survey catchability (*Q*)	0.770	0.770	0.770	0.770	0.770	0.770	0.770	0.770	0.723
σ(selectivity *dev* s)	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	1.010
Agecomp sample size multiplier	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.850
Spawning biomass 2011 (t)	323,273	315,918	316,030	316,938	316,271	316,713	343,693	341,604	368,253
SB(2011)/B100%	0.426	0.411	0.411	0.411	0.412	0.364	0.383	0.372	0.381

Relative changes from previous model:

Quantity	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
Length at age 1 (cm)	n/a	0.000	0.000	0.000	0.008	0.000	-0.052	0.073	0.000
Asymptotic length (cm)	n/a	0.000	0.000	0.001	-0.010	0.001	-0.010	0.024	-0.017
Brody growth coefficient	n/a	0.000	0.000	-0.001	0.061	-0.001	0.016	0.014	0.047
Richards growth coefficient	n/a	0.000	0.000	0.000	-0.074	0.000	0.042	-0.137	-0.035
SD of length at age 1 (cm)	n/a	0.000	0.000	0.000	-0.003	0.000	-0.045	0.101	0.004
SD of length at age 20 (cm)	n/a	0.001	-0.001	-0.001	0.002	0.002	0.009	-0.015	-0.020
Ageing bias at age 1 (years)	n/a	0.000	0.000	0.000	-0.004	0.001	0.017	-0.030	-0.143
Ageing bias at age 20 (years)	n/a	-0.006	0.001	0.000	0.022	-0.006	-0.032	0.041	0.226
σ(recruitment *dev* s)	n/a	0.000	0.000	0.000	0.000	0.334	-0.001	0.132	-0.036
Trawl survey catchability (*Q*)	n/a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.061
σ(selectivity *dev* s)	n/a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.429
Agecomp sample size multiplier	n/a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.150
Spawning biomass 2011 (t)	n/a	-0.023	0.000	0.003	-0.002	0.001	0.085	-0.006	0.078
SB(2011)/B100%	n/a	-0.036	0.000	0.002	0.001	-0.115	0.052	-0.030	0.024

Table 2.1.8. Data files, objective function values, and number of parameters for the five primary models. Note that objective function values are not comparable between models that use different data files.

	Model 1	Model 2	Model 3	Model 4	Model 5
Data file:	BSbase	BSbase	BSbase	BSmodel4	BSmodel5
Component	Model 1	Model 2	Model 3	Model 4	Model 5
Catch	0.00	0.00	0.00	0.00	0.00
Equilibrium catch	0.00	0.00	0.00	0.00	0.00
Survey CPUE	-4.20	-0.72	-9.50	-7.13	22.01
Size composition	4192.75	4199.40	3951.66	4177.78	2590.40
Age composition	117.70	118.06	114.64	n/a	118.15
Recruitment	20.65	20.10	22.36	21.34	17.38
"Softbounds"	0.03	0.03	0.04	0.04	0.01
Deviations	16.83	16.76	16.68	13.08	14.27
Total	4343.76	4353.63	4095.87	4205.10	2762.21
Sizecomp component	Model 1	Model 2	Model 3	Model 4	Model 5
Jan-Apr trawl fishery	932.95	932.85	935.05	924.36	n/a
May-Jul trawl fishery	181.97	181.47	181.15	181.14	n/a
Aug-Dec trawl fishery	221.46	221.29	185.99	222.34	n/a
Jan-Apr longline fishery	638.76	637.23	547.57	636.52	n/a
May-Jul longline fishery	206.76	209.12	210.30	206.22	n/a
Aug-Dec longline fishery	891.28	896.13	783.03	883.24	n/a
Jan-Apr pot fishery	112.19	111.98	103.18	111.04	n/a
May-Jul pot fishery	70.60	70.63	72.06	71.63	n/a
Aug-Dec pot fishery	191.39	192.09	184.89	190.84	n/a
Trawl survey	745.40	746.62	748.44	750.45	406.62
Jan-Feb fishery	n/a	n/a	n/a	n/a	610.40
Mar-Apr fishery	n/a	n/a	n/a	n/a	397.71
May-Jul fishery	n/a	n/a	n/a	n/a	482.94
Aug-Oct fishery	n/a	n/a	n/a	n/a	403.70
Nov-Dec fishery	n/a	n/a	n/a	n/a	289.04
Parameter count	Model 1	Model 2	Model 3	Model 4	Model 5
No. non-*dev* parameters	117	117	134	115	40
No. *dev*s	65	65	65	65	72
Total no. parameters	182	182	199	180	112

Table 2.1.9. Objective function values, and number of parameters for the transition from Model 1 to Model 5. Note that objective function values are not comparable between models that use different data files. Model 1 uses "BSbase.dat," Model 1.3 uses "BSmodel1_3.dat," Models Pre5.1-Pre5.5 use "BSmodelPre5.dat," and Models Pre5.6 and 5 use "BSmodel5.dat."

Component	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
Catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equilibrium catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Survey CPUE	-4.20	-5.70	-5.74	-5.47	-4.99	-4.79	0.27	32.36	22.01
Size composition	4192.75	4191.29	4208.94	4207.79	4206.15	4201.95	4089.57	2645.18	2590.40
Age composition	117.70	117.60	117.78	117.65	117.27	117.47	140.17	214.09	118.15
Recruitment	20.65	20.63	20.62	12.11	12.08	12.40	12.11	19.85	17.38
"Softbounds"	0.03	0.03	0.04	0.04	0.04	0.04	0.03	0.01	0.01
Deviations	16.83	16.80	16.81	16.77	16.65	16.58	46.20	12.62	14.27
Total	4343.76	4340.65	4358.45	4348.89	4347.20	4343.64	4288.36	2924.12	2762.21

Sizecomp component	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
Jan-Apr trawl fishery	932.95	932.34	934.50	934.15	935.67	935.38	944.19	n/a	n/a
May-Jul trawl fishery	181.97	181.77	183.39	183.85	183.77	184.06	184.94	n/a	n/a
Aug-Dec trawl fishery	221.46	221.33	223.30	223.58	224.40	223.59	224.62	n/a	n/a
Jan-Apr longline fishery	638.76	639.03	640.98	640.98	644.16	644.00	643.53	n/a	n/a
May-Jul longline fishery	206.76	206.45	207.64	207.23	208.23	207.16	207.88	n/a	n/a
Aug-Dec longline fishery	891.28	891.32	892.67	891.98	889.77	888.69	884.63	n/a	n/a
Jan-Apr pot fishery	112.19	112.28	113.82	113.80	114.07	114.09	114.38	n/a	n/a
May-Jul pot fishery	70.60	70.53	71.08	71.10	71.73	71.75	72.43	n/a	n/a
Aug-Dec pot fishery	191.39	191.28	192.83	192.70	193.20	192.98	193.61	n/a	n/a
Trawl survey	745.40	744.95	748.73	748.43	741.15	740.27	619.36	619.99	406.62
Jan-Feb fishery	n/a	n/a	n/a	n/a	n/a	n/a	n/a	403.34	610.40
Mar-Apr fishery	n/a	n/a	n/a	n/a	n/a	n/a	n/a	469.74	397.71
May-Jul fishery	n/a	n/a	n/a	n/a	n/a	n/a	n/a	391.39	482.94
Aug-Oct fishery	n/a	n/a	n/a	n/a	n/a	n/a	n/a	288.93	403.70
Nov-Dec fishery	n/a	n/a	n/a	n/a	n/a	n/a	n/a	471.80	289.04

Parameter count	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
No. non-*dev* parameters	117	117	117	117	118	119	119	40	40
No. *dev* s	65	65	65	72	72	72	100	100	72
Total no. parameters	182	182	182	189	190	191	219	140	112

Table 2.1.10a. Residuals for the trawl survey index resulting from the five primary models. For each year, residual = ln(observed/expected). The bottom row shows the mean for each column. Ideally, this value should be close to zero. A positive mean implies that the model tends to be biased low.

Year	Model 1	Model 2	Model 3	Model 4	Model 5
1982	-0.151	-0.157	-0.136	-0.175	-0.172
1983	0.138	0.136	0.155	0.153	0.070
1984	-0.058	-0.057	-0.046	-0.059	-0.075
1985	0.093	0.096	0.101	0.076	0.094
1986	0.128	0.135	0.134	0.104	0.181
1987	0.148	0.159	0.151	0.129	0.126
1988	0.169	0.183	0.172	0.162	0.125
1989	-0.042	-0.025	-0.041	-0.022	-0.101
1990	-0.002	0.008	-0.001	0.007	-0.026
1991	-0.099	-0.091	-0.098	-0.121	-0.047
1992	-0.022	-0.009	-0.029	-0.059	0.038
1993	0.220	0.231	0.211	0.187	0.262
1994	0.720	0.730	0.707	0.698	0.828
1995	0.471	0.482	0.452	0.462	0.600
1996	0.437	0.446	0.410	0.436	0.619
1997	0.087	0.092	0.053	0.094	0.306
1998	-0.045	-0.043	-0.086	-0.057	0.218
1999	0.001	0.008	-0.049	-0.021	0.181
2000	-0.087	-0.078	-0.140	-0.096	0.035
2001	0.348	0.359	0.286	0.348	0.354
2002	0.085	0.097	0.022	0.069	0.087
2003	0.117	0.128	0.063	0.119	0.069
2004	0.081	0.088	0.061	0.074	0.074
2005	0.168	0.171	0.186	0.148	0.138
2006	-0.002	-0.003	0.035	-0.007	-0.020
2007	-0.026	-0.036	0.010	-0.017	-0.077
2008	-0.362	-0.373	-0.335	-0.358	-0.367
2009	-0.211	-0.223	-0.205	-0.173	-0.250
2010	0.108	0.096	0.079	0.107	0.181
2011	0.085	0.073	0.057	0.094	0.131
Mean	0.083	0.087	0.073	0.077	0.119

Table 2.1.10b. Squared standardized residuals (SSR) for the trawl survey index resulting from the five primary models. For each year, SSR = $(\ln(\text{observed}/\text{expected})/\sigma)^2$. The bottom row shows the root mean squared error. Ideally, this value should be close to unity.

Year	Model 1	Model 2	Model 3	Model 4	Model 5
1982	5.415	5.795	4.373	7.237	6.972
1983	1.681	1.633	2.093	2.060	0.433
1984	0.627	0.615	0.389	0.644	1.053
1985	0.483	0.516	0.567	0.323	0.492
1986	1.643	1.821	1.807	1.092	3.307
1987	4.989	5.758	5.184	3.784	3.583
1988	5.861	6.833	6.052	5.381	3.225
1989	0.381	0.133	0.363	0.102	2.198
1990	0.001	0.008	0.000	0.006	0.093
1991	0.909	0.767	0.890	1.336	0.202
1992	0.036	0.006	0.060	0.259	0.103
1993	3.087	3.409	2.864	2.230	4.413
1994	34.098	35.092	32.881	32.109	45.095
1995	22.483	23.537	20.681	21.589	36.476
1996	9.169	9.582	8.076	9.133	18.429
1997	0.357	0.405	0.132	0.419	4.447
1998	0.249	0.225	0.906	0.400	5.886
1999	0.000	0.007	0.278	0.052	3.818
2000	0.921	0.733	2.345	1.111	0.146
2001	13.133	13.928	8.835	13.103	13.569
2002	0.708	0.903	0.048	0.458	0.729
2003	0.885	1.060	0.258	0.912	0.309
2004	0.905	1.069	0.523	0.763	0.756
2005	1.444	1.491	1.773	1.128	0.970
2006	0.001	0.003	0.343	0.015	0.111
2007	0.010	0.019	0.001	0.004	0.086
2008	12.230	13.044	10.496	11.979	12.571
2009	5.864	6.499	5.530	3.914	8.195
2010	0.679	0.537	0.362	0.666	1.893
2011	0.814	0.596	0.368	0.993	1.935
RMSE	2.074	2.129	1.987	2.027	2.460

Table 2.1.11a. Residuals for the trawl survey index resulting from Models 1 and 5 and the secondary models that constitute a transition between those two primary models. For each year, residual = ln(observed/expected). The bottom row shows the mean for each column. Ideally, this value should be close to zero. A positive mean implies that the model tends to be biased low.

Year	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
1982	-0.151	-0.143	-0.143	-0.140	-0.145	-0.143	-0.133	-0.106	-0.172
1983	0.138	0.146	0.145	0.147	0.144	0.147	0.160	0.050	0.070
1984	-0.058	-0.047	-0.047	-0.045	-0.044	-0.044	-0.057	-0.008	-0.075
1985	0.093	0.104	0.104	0.106	0.106	0.108	0.165	0.173	0.094
1986	0.128	0.137	0.138	0.139	0.138	0.138	0.123	0.153	0.181
1987	0.148	0.156	0.156	0.157	0.155	0.155	0.161	0.190	0.126
1988	0.169	0.173	0.173	0.174	0.172	0.173	0.177	0.119	0.125
1989	-0.042	-0.045	-0.045	-0.045	-0.045	-0.043	-0.041	-0.239	-0.101
1990	-0.002	-0.007	-0.008	-0.007	-0.003	-0.002	-0.002	-0.037	-0.026
1991	-0.099	-0.105	-0.105	-0.103	-0.096	-0.095	-0.115	-0.080	-0.047
1992	-0.022	-0.028	-0.028	-0.026	-0.021	-0.020	-0.006	0.157	0.038
1993	0.220	0.211	0.211	0.212	0.216	0.217	0.245	0.414	0.262
1994	0.720	0.707	0.706	0.708	0.714	0.715	0.721	0.835	0.828
1995	0.471	0.456	0.456	0.457	0.461	0.462	0.463	0.546	0.600
1996	0.437	0.422	0.421	0.422	0.428	0.429	0.442	0.528	0.619
1997	0.087	0.079	0.079	0.080	0.087	0.089	0.097	0.171	0.306
1998	-0.045	-0.045	-0.045	-0.043	-0.035	-0.034	-0.029	0.163	0.218
1999	0.001	0.002	0.002	0.003	0.008	0.009	0.006	0.145	0.181
2000	-0.087	-0.088	-0.088	-0.088	-0.085	-0.084	-0.064	-0.030	0.035
2001	0.348	0.347	0.347	0.347	0.350	0.350	0.385	0.526	0.354
2002	0.085	0.084	0.084	0.084	0.085	0.084	0.080	0.095	0.087
2003	0.117	0.116	0.116	0.115	0.115	0.114	0.139	0.106	0.069
2004	0.081	0.080	0.080	0.080	0.082	0.081	0.083	0.058	0.074
2005	0.168	0.168	0.168	0.167	0.171	0.170	0.201	0.217	0.138
2006	-0.002	-0.002	-0.002	-0.003	0.000	-0.001	-0.016	0.097	-0.020
2007	-0.026	-0.026	-0.026	-0.028	-0.025	-0.028	-0.065	0.177	-0.077
2008	-0.362	-0.362	-0.361	-0.364	-0.362	-0.364	-0.384	-0.402	-0.367
2009	-0.211	-0.211	-0.211	-0.214	-0.214	-0.216	-0.237	-0.261	-0.250
2010	0.108	0.109	0.109	0.106	0.103	0.099	0.112	0.010	0.181
2011	0.085	0.088	0.088	0.084	0.081	0.074	0.082	-0.029	0.131
Mean	0.083	0.082	0.082	0.083	0.085	0.085	0.090	0.125	0.119

Table 2.1.11b. Squared standardized residuals (SSR) for the trawl survey index resulting from Models 1 and 5 and the secondary models that constitute a transition between those two primary models. For each year, SSR = $(\ln(\text{observed}/\text{expected})/\sigma)^2$. The bottom row shows the root mean squared error. Ideally, this value should be close to unity.

Year	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
1982	5.415	4.824	4.848	4.630	4.981	4.855	4.203	2.630	6.972
1983	1.681	1.865	1.856	1.906	1.807	1.907	2.249	0.221	0.433
1984	0.627	0.410	0.412	0.370	0.357	0.355	0.615	0.013	1.053
1985	0.483	0.605	0.604	0.625	0.619	0.643	1.502	1.659	0.492
1986	1.643	1.896	1.900	1.951	1.899	1.901	1.531	2.344	3.307
1987	4.989	5.503	5.500	5.599	5.436	5.467	5.904	8.202	3.583
1988	5.861	6.115	6.108	6.179	6.080	6.104	6.405	2.902	3.225
1989	0.381	0.433	0.438	0.436	0.440	0.399	0.360	12.206	2.198
1990	0.001	0.007	0.008	0.007	0.001	0.001	0.000	0.187	0.093
1991	0.909	1.010	1.014	0.981	0.855	0.827	1.214	0.588	0.202
1992	0.036	0.056	0.057	0.050	0.033	0.028	0.003	1.799	0.103
1993	3.087	2.850	2.841	2.880	2.975	3.016	3.853	10.977	4.413
1994	34.098	32.865	32.839	33.003	33.562	33.651	34.270	45.950	45.095
1995	22.483	21.071	21.044	21.176	21.507	21.633	21.716	30.192	36.476
1996	9.169	8.549	8.535	8.586	8.797	8.842	9.397	13.428	18.429
1997	0.357	0.297	0.294	0.302	0.364	0.376	0.450	1.384	4.447
1998	0.249	0.252	0.254	0.233	0.151	0.141	0.107	3.278	5.886
1999	0.000	0.000	0.000	0.001	0.007	0.009	0.005	2.448	3.818
2000	0.921	0.934	0.939	0.924	0.864	0.852	0.500	0.111	0.146
2001	13.133	12.990	12.987	13.037	13.222	13.226	16.053	29.946	13.569
2002	0.708	0.678	0.678	0.684	0.694	0.689	0.614	0.880	0.729
2003	0.885	0.865	0.864	0.861	0.850	0.847	1.256	0.726	0.309
2004	0.905	0.896	0.895	0.882	0.928	0.911	0.949	0.472	0.756
2005	1.444	1.440	1.437	1.421	1.493	1.480	2.067	2.399	0.970
2006	0.001	0.001	0.001	0.003	0.000	0.000	0.068	2.599	0.111
2007	0.010	0.010	0.010	0.011	0.009	0.011	0.062	0.454	0.086
2008	12.230	12.230	12.225	12.364	12.229	12.401	13.828	15.132	12.571
2009	5.864	5.855	5.852	5.982	5.991	6.140	7.339	8.961	8.195
2010	0.679	0.695	0.694	0.651	0.619	0.564	0.732	0.006	1.893
2011	0.814	0.863	0.865	0.785	0.730	0.608	0.760	0.095	1.935
RMSE	2.074	2.050	2.049	2.054	2.062	2.065	2.145	2.596	2.460

Table 2.1.12a. Number of records, input sample sizes, and mean of the ratio between effective sample size and input sample size for size composition data from each fleet for the five primary models.

Fleet	Nrec	Input N	Model 1	Model 2	Model 3	Model 4	Model 5
Jan-Apr trawl fishery	60	327	5.702	5.704	5.462	5.725	n/a
May-Jul trawl fishery	31	67	9.305	9.287	9.247	9.264	n/a
Aug-Dec trawl fishery	34	42	13.205	13.230	13.819	13.186	n/a
Jan-Apr longline fishery	64	466	9.021	9.020	8.760	9.060	n/a
May-Jul longline fishery	31	211	9.511	9.441	9.127	9.458	n/a
Aug-Dec longline fishery	59	673	6.886	6.916	6.811	7.005	n/a
Jan-Apr pot fishery	32	143	12.998	13.023	14.203	13.147	n/a
May-Jul pot fishery	16	141	17.940	17.995	17.601	17.810	n/a
Aug-Dec pot fishery	33	76	10.942	10.942	11.321	10.982	n/a
Trawl survey	30	281	2.114	2.108	2.072	2.127	3.862
Jan-Feb fishery	33	334	n/a	n/a	n/a	n/a	6.149
Mar-Apr fishery	33	399	n/a	n/a	n/a	n/a	6.340
May-Jul fishery	34	138	n/a	n/a	n/a	n/a	7.474
Aug-Oct fishery	33	430	n/a	n/a	n/a	n/a	8.101
Nov-Dec fishery	30	338	n/a	n/a	n/a	n/a	7.916

Table 2.1.12b. Input sample size and the ratio between effective sample size and input sample size for each year of age composition data from the survey for the five primary models. The last row in the top half of the table is the mean of the ratio of effective N to input N.

Year	Input N	Model 1	Model 2	Model 3	Model 4	Model 5
1994	210	2.242	2.298	1.974	0.610	2.279
1995	176	0.169	0.169	0.175	0.132	0.142
1996	209	1.051	1.070	1.019	1.841	0.798
1997	212	1.027	0.991	0.962	1.508	1.005
1998	187	3.723	3.649	3.227	0.829	3.926
1999	253	0.770	0.746	0.744	0.453	0.427
2000	254	0.556	0.591	0.502	0.715	0.259
2001	280	0.466	0.453	0.438	1.439	0.261
2002	279	0.330	0.337	0.345	0.450	0.314
2003	400	0.599	0.580	0.515	0.261	0.950
2004	306	0.113	0.111	0.118	0.130	0.140
2005	377	1.676	1.764	1.077	0.284	1.289
2006	383	0.409	0.410	0.474	0.322	0.461
2007	424	0.178	0.180	0.205	0.195	0.164
2008	357	0.582	0.566	0.622	0.162	0.644
2009	416	0.199	0.198	0.235	0.096	0.261
2010	378	0.894	0.943	0.623	0.495	0.986
All	300	0.881	0.886	0.780	0.584	0.990

Table 2.1.13a. Number of records, input sample sizes, and mean of the ratio between effective sample size and input sample size for size composition data from each fleet for Models 1 and 5 and the secondary models that constitute a transition between those two primary models. Green shading indicates a positive change of more than 5% from the previous model (there were no instances of a negative change of at least 5% from the previous model).

Absolute values:

Fleet	Nrec	Input N	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
Jan-Apr trawl fishery	60	327	5.702	5.703	5.755	5.780	5.767	5.779	5.764	n/a	n/a
May-Jul trawl fishery	31	67	9.305	9.313	9.456	9.430	9.400	9.364	9.397	n/a	n/a
Aug-Dec trawl fishery	34	42	13.205	13.226	14.405	14.398	14.402	14.419	14.313	n/a	n/a
Jan-Apr longline fishery	64	466	9.021	9.024	9.255	9.260	9.215	9.233	9.237	n/a	n/a
May-Jul longline fishery	31	211	9.511	9.504	9.595	9.624	9.583	9.595	9.636	n/a	n/a
Aug-Dec longline fishery	59	673	6.886	6.886	7.052	7.143	7.190	7.270	7.480	n/a	n/a
Jan-Apr pot fishery	32	143	12.998	12.988	13.047	13.046	13.012	13.012	12.968	n/a	n/a
May-Jul pot fishery	16	141	17.940	17.954	18.798	18.812	18.802	18.822	18.693	n/a	n/a
Aug-Dec pot fishery	33	76	10.942	10.953	11.430	11.436	11.388	11.399	11.335	n/a	n/a
Trawl survey	30	281	2.114	2.116	2.132	2.132	2.144	2.144	2.480	3.233	3.862
Jan-Feb fishery	33	334	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6.201	6.149
Mar-Apr fishery	33	399	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6.247	6.340
May-Jul fishery	34	138	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7.346	7.474
Aug-Oct fishery	33	430	n/a	n/a	n/a	n/a	n/a	n/a	n/a	8.368	8.101
Nov-Dec fishery	30	338	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7.839	7.916

Relative changes from previous model:

Fleet	Nrec	Input N	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
Jan-Apr trawl fishery	60	327	n/a	0.000	0.009	0.004	-0.002	0.002	-0.003	n/a	n/a
May-Jul trawl fishery	31	67	n/a	0.001	0.015	-0.003	-0.003	-0.004	0.003	n/a	n/a
Aug-Dec trawl fishery	34	42	n/a	0.002	0.089	0.000	0.000	0.001	-0.007	n/a	n/a
Jan-Apr longline fishery	64	466	n/a	0.000	0.026	0.001	-0.005	0.002	0.000	n/a	n/a
May-Jul longline fishery	31	211	n/a	-0.001	0.010	0.003	-0.004	0.001	0.004	n/a	n/a
Aug-Dec longline fishery	59	673	n/a	0.000	0.024	0.013	0.007	0.011	0.029	n/a	n/a
Jan-Apr pot fishery	32	143	n/a	-0.001	0.005	0.000	-0.003	0.000	-0.003	n/a	n/a
May-Jul pot fishery	16	141	n/a	0.001	0.047	0.001	-0.001	0.001	-0.007	n/a	n/a
Aug-Dec pot fishery	33	76	n/a	0.001	0.044	0.000	-0.004	0.001	-0.006	n/a	n/a
Trawl survey	30	281	n/a	0.001	0.007	0.000	0.005	0.000	0.156	0.304	0.195
Jan-Feb fishery	33	334	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.008
Mar-Apr fishery	33	399	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.015
May-Jul fishery	34	138	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.017
Aug-Oct fishery	33	430	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-0.032
Nov-Dec fishery	30	338	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.010

Table 2.1.13b. Input sample size and the ratio between effective sample size and input sample size for each year of age composition data from the survey for Models 1 and 5 and the secondary models that constitute a transition between those two primary models. The last row in the top half of the table is the mean of the ratio of effective N to input N. Green shading indicates a positive change of more than 5% from the previous model, and pink indicates a negative change of at least 5% from the previous model.

Absolute values:

Year	Input N	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
1994	210	2.242	2.229	2.228	2.228	2.223	2.231	1.687	1.690	2.279
1995	176	0.169	0.169	0.169	0.169	0.169	0.168	0.175	0.108	0.142
1996	209	1.051	1.070	1.069	1.069	1.082	1.087	0.908	0.242	0.798
1997	212	1.027	1.067	1.066	1.068	1.108	1.117	0.941	0.159	1.005
1998	187	3.723	3.847	3.859	3.908	4.000	4.013	2.885	0.302	3.926
1999	253	0.770	0.764	0.766	0.768	0.771	0.767	0.644	0.218	0.427
2000	254	0.556	0.553	0.553	0.550	0.546	0.548	0.476	0.161	0.259
2001	280	0.466	0.463	0.464	0.465	0.468	0.467	0.322	0.212	0.261
2002	279	0.330	0.331	0.331	0.330	0.329	0.330	0.262	0.207	0.314
2003	400	0.599	0.596	0.597	0.600	0.606	0.599	0.864	1.020	0.950
2004	306	0.113	0.113	0.113	0.113	0.114	0.113	0.108	0.120	0.140
2005	377	1.676	1.678	1.677	1.675	1.648	1.643	2.197	0.968	1.289
2006	383	0.409	0.408	0.408	0.407	0.414	0.414	0.296	0.183	0.461
2007	424	0.178	0.178	0.177	0.177	0.180	0.181	0.188	0.045	0.164
2008	357	0.582	0.583	0.583	0.584	0.591	0.587	0.441	0.362	0.644
2009	416	0.199	0.199	0.199	0.199	0.198	0.197	0.214	0.142	0.261
2010	378	0.894	0.904	0.902	0.901	0.881	0.857	0.744	1.128	0.986
All	300	0.881	0.891	0.892	0.895	0.902	0.901	0.785	0.427	0.990

Relative changes from previous model:

Year	Input N	1	1.3	Pre5.1	Pre5.2	Pre5.3	Pre5.4	Pre5.5	Pre5.6	5
1994	210	n/a	-0.006	-0.001	0.000	-0.002	0.004	-0.244	0.002	0.349
1995	176	n/a	0.003	0.000	0.000	-0.003	-0.001	0.040	-0.386	0.323
1996	209	n/a	0.018	-0.001	0.000	0.013	0.005	-0.165	-0.734	2.303
1997	212	n/a	0.039	0.000	0.002	0.037	0.008	-0.157	-0.831	5.330
1998	187	n/a	0.033	0.003	0.013	0.024	0.003	-0.281	-0.895	12.016
1999	253	n/a	-0.007	0.002	0.003	0.004	-0.006	-0.160	-0.662	0.958
2000	254	n/a	-0.006	-0.001	-0.005	-0.008	0.005	-0.131	-0.663	0.614
2001	280	n/a	-0.008	0.002	0.004	0.007	-0.003	-0.310	-0.344	0.235
2002	279	n/a	0.004	-0.001	-0.003	-0.004	0.002	-0.206	-0.209	0.518
2003	400	n/a	-0.006	0.002	0.005	0.010	-0.011	0.443	0.180	-0.069
2004	306	n/a	-0.001	0.000	0.001	0.009	-0.003	-0.046	0.107	0.165
2005	377	n/a	0.001	-0.001	-0.001	-0.016	-0.003	0.337	-0.559	0.332
2006	383	n/a	-0.001	-0.001	-0.001	0.017	0.001	-0.285	-0.384	1.523
2007	424	n/a	-0.002	-0.001	-0.001	0.014	0.007	0.039	-0.763	2.687
2008	357	n/a	0.001	0.001	0.002	0.011	-0.005	-0.249	-0.180	0.780
2009	416	n/a	0.001	0.000	0.002	-0.007	-0.003	0.085	-0.335	0.835
2010	378	n/a	0.012	-0.002	-0.001	-0.023	-0.027	-0.133	0.517	-0.125
All	300	n/a	0.011	0.001	0.003	0.008	0.000	-0.128	-0.456	1.317

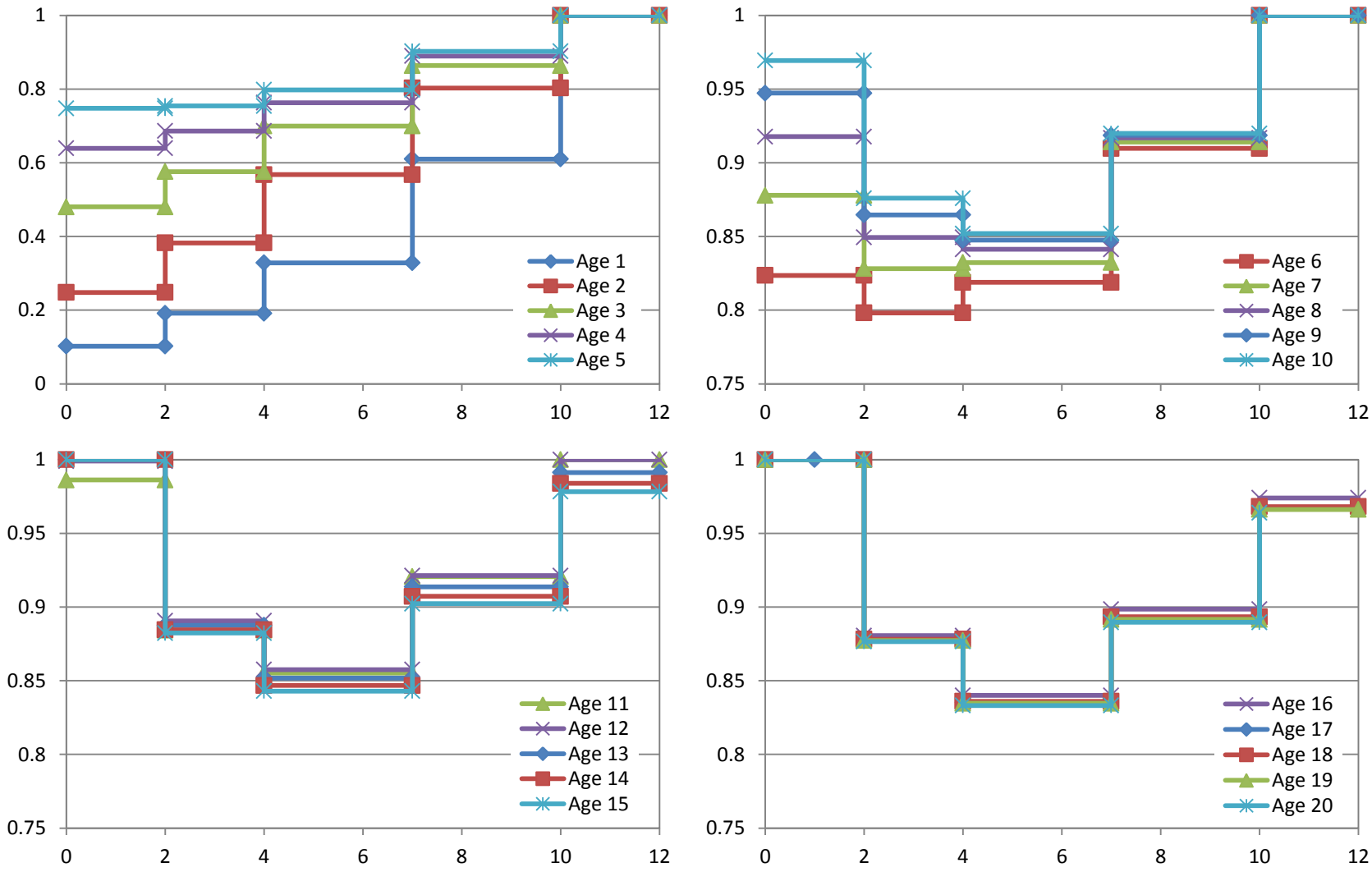


Figure 2.1.1. Relative mean weight at age by time within year for Model 1. Horizontal axis represents months elapsed within the year; vertical axis is mean weight relative to intra-annual maximum mean weight.

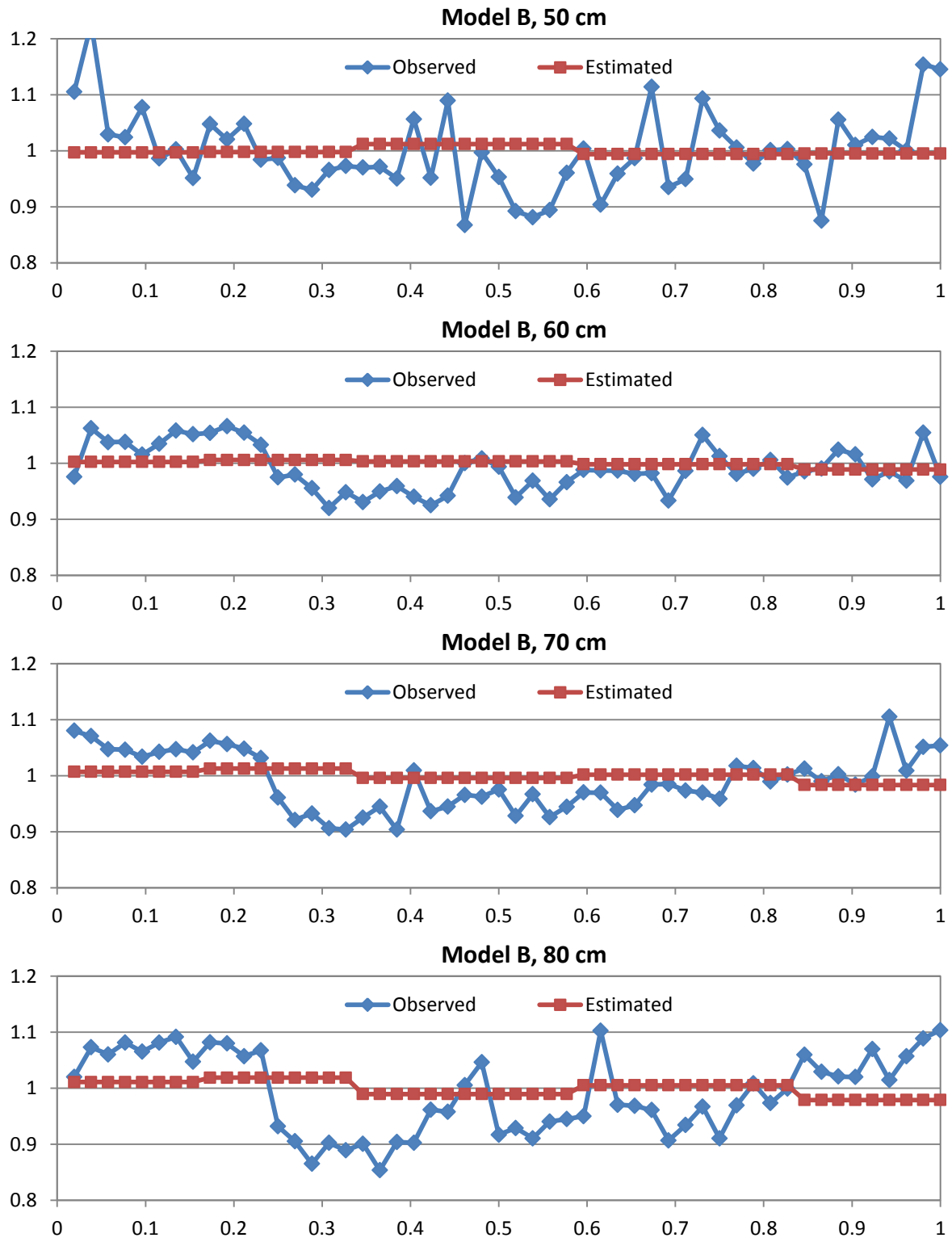


Figure 2.1.2a. Fit of weight-length Model B to weekly relative mean weight-at-length data for four example lengths. Horizontal axis is relative time within the year; vertical axis is mean weekly weight scaled relative to average weight (at that length) for the year.

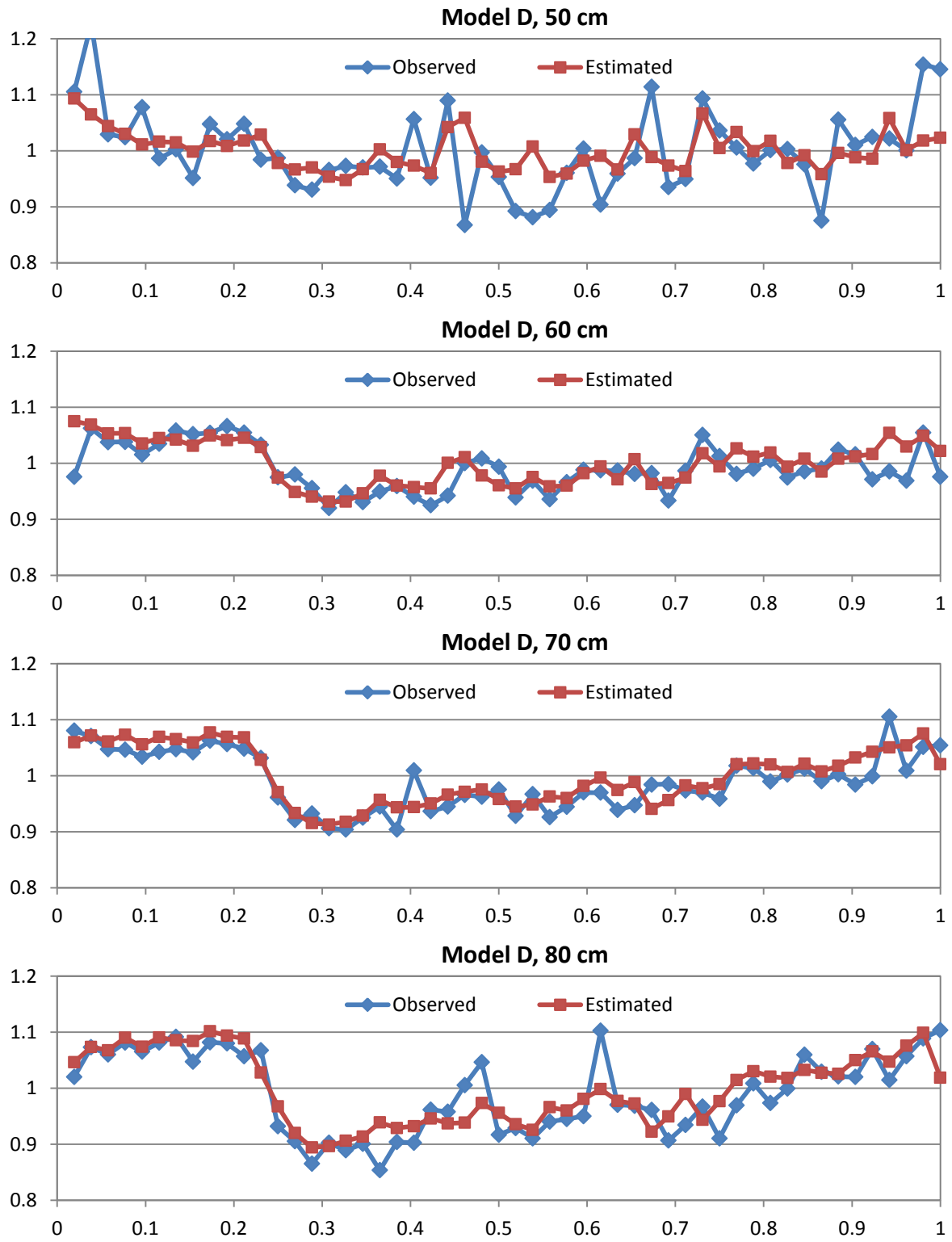


Figure 2.1.2b. Fit of weight-length Model D to weekly mean relative weight-at-length data for four example lengths. Horizontal axis is relative time within the year; vertical axis is mean weekly weight scaled relative to average weight (at that length) for the year.

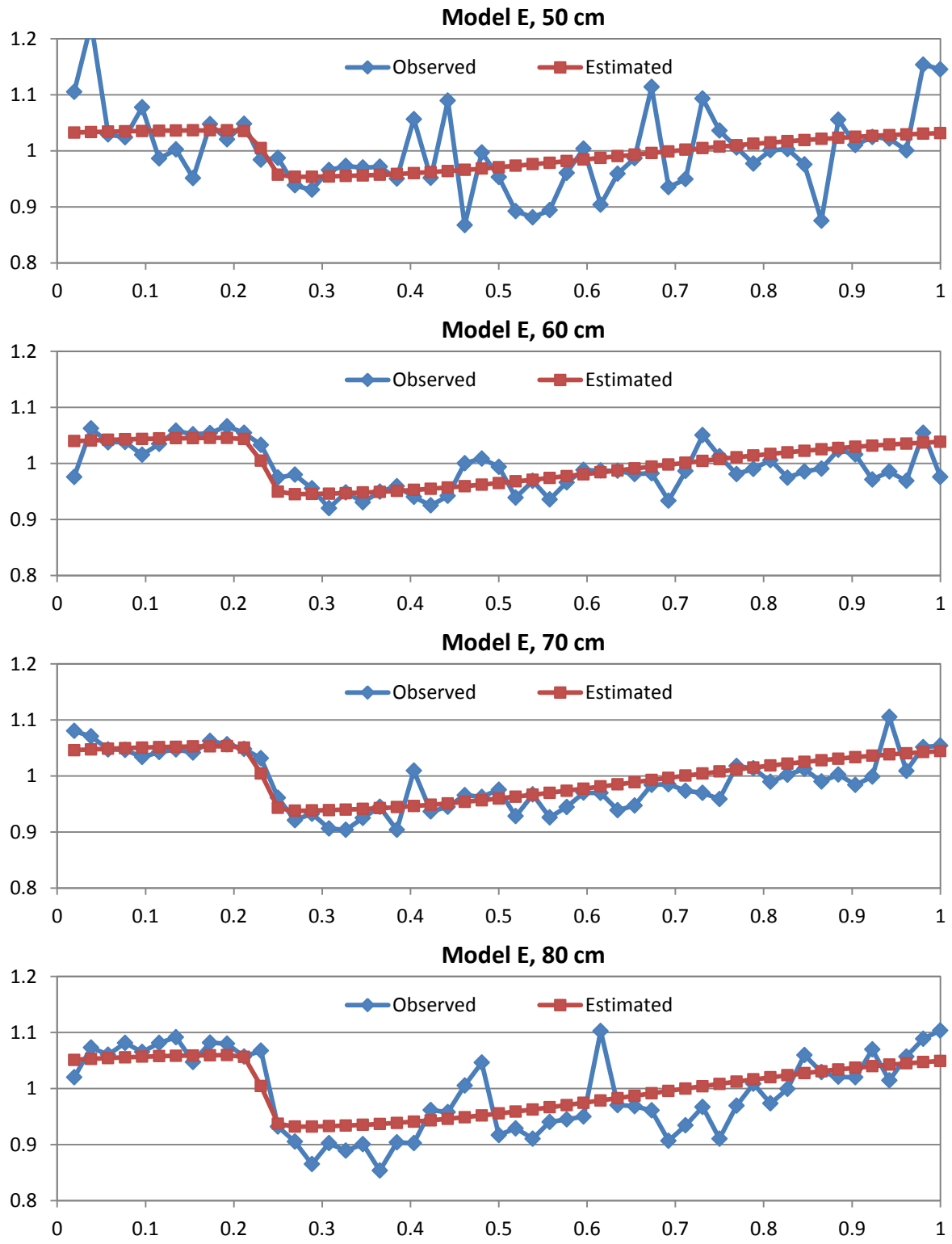


Figure 2.1.2c. Fit of weight-length Model E to weekly mean relative weight-at-length data for four example lengths. Horizontal axis is relative time within the year; vertical axis is mean weekly weight scaled relative to average weight (at that length) for the year.

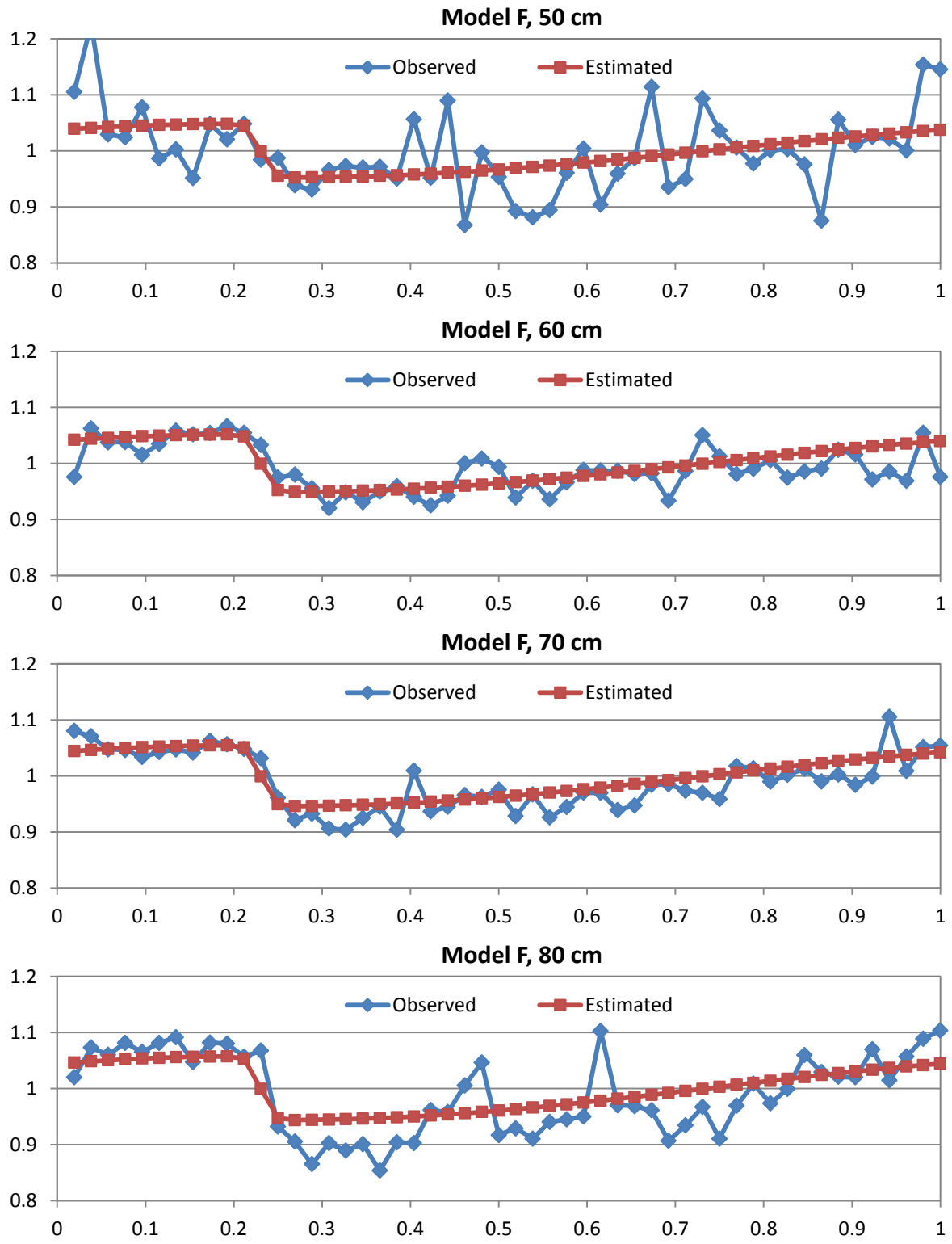


Figure 2.1.2d. Fit of weight-length Model F to weekly relative mean weight-at-length data for four example lengths. Horizontal axis is relative time within the year; vertical axis is mean weekly weight scaled relative to average weight (at that length) for the year.

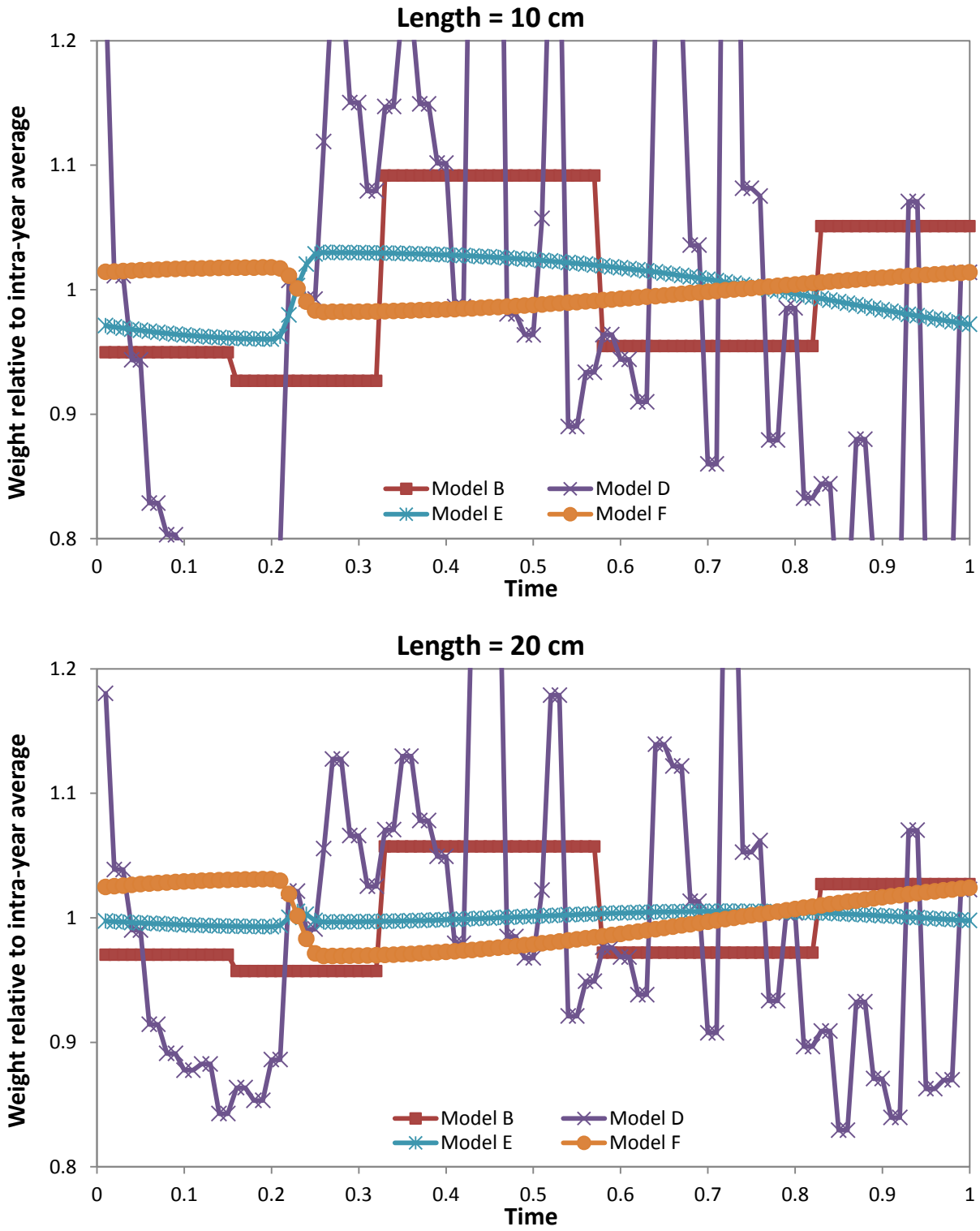


Figure 2.1.3a. Relative intra-annual weight at lengths 10 and 20 cm as estimated by four models.

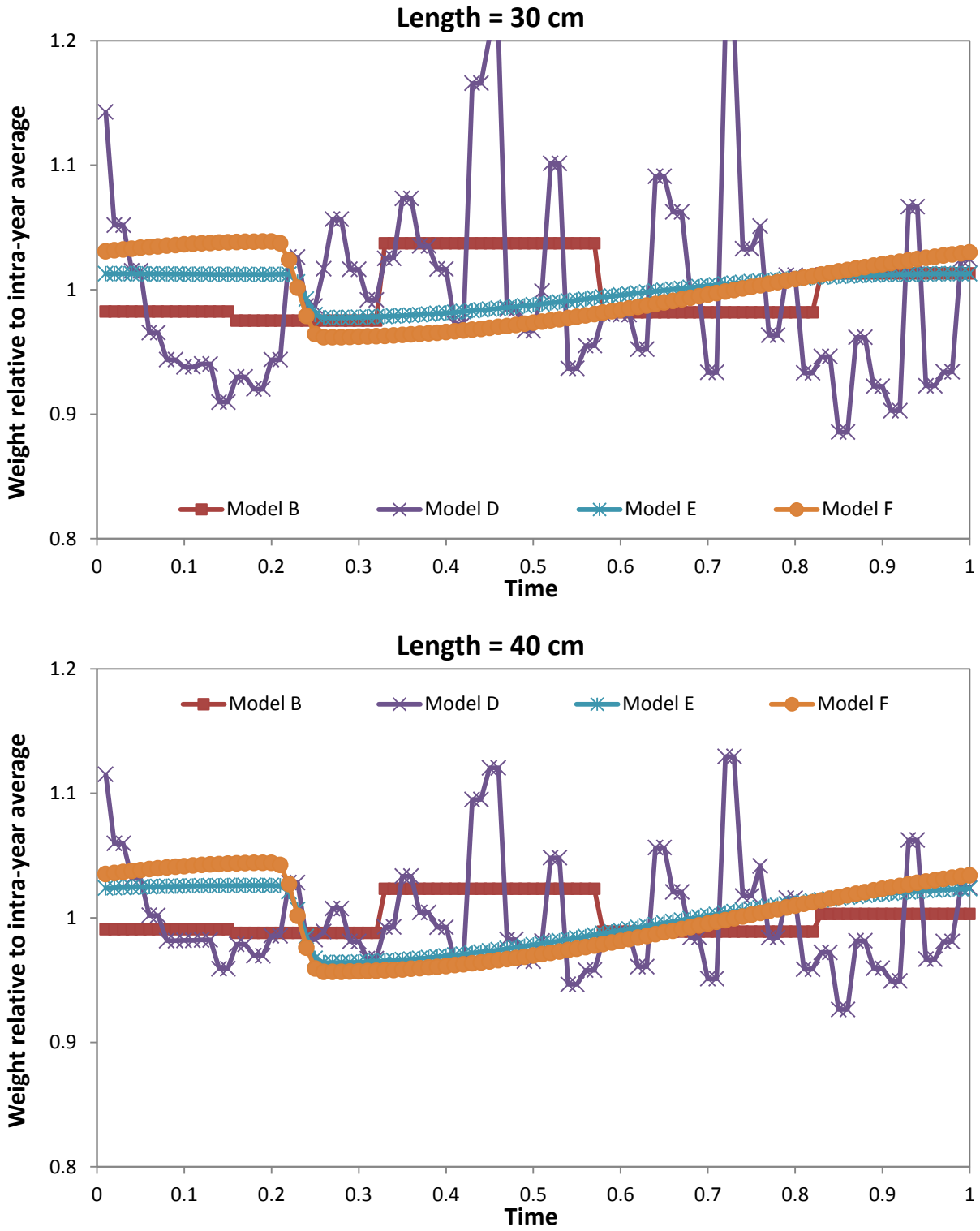
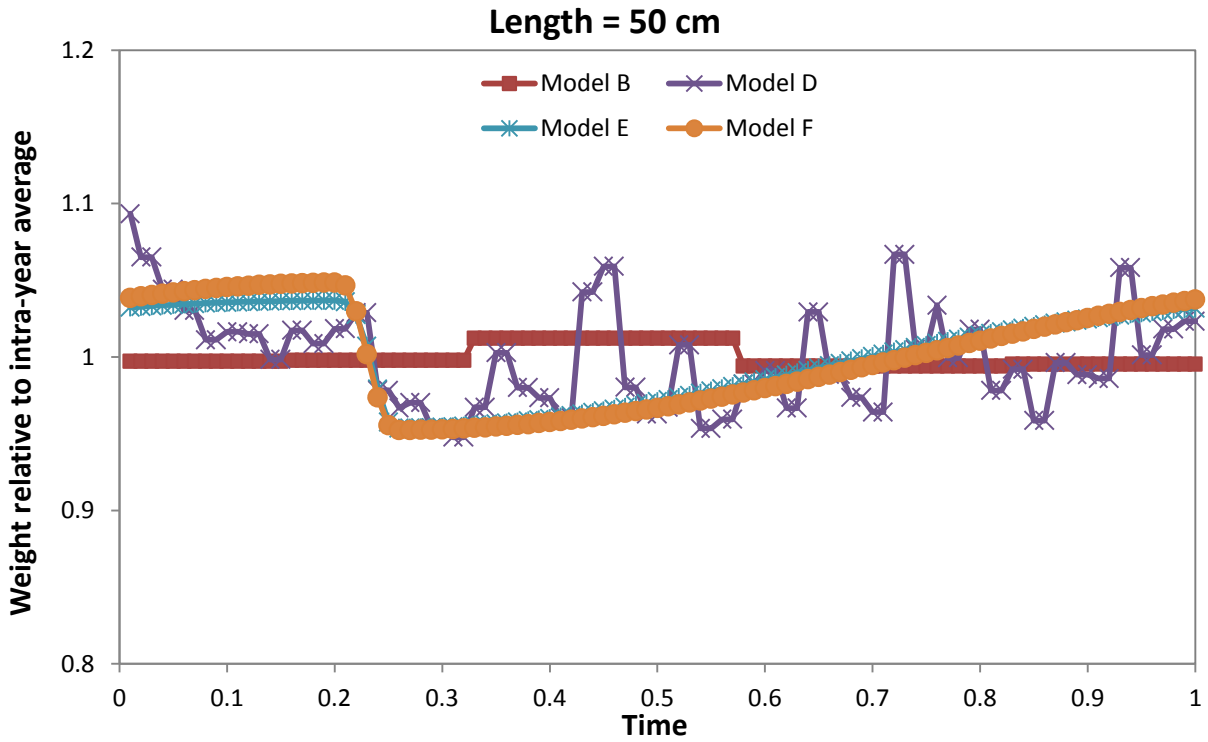


Figure 2.1.3b. Relative intra-annual weight at lengths 30 and 40 cm as estimated by four models.



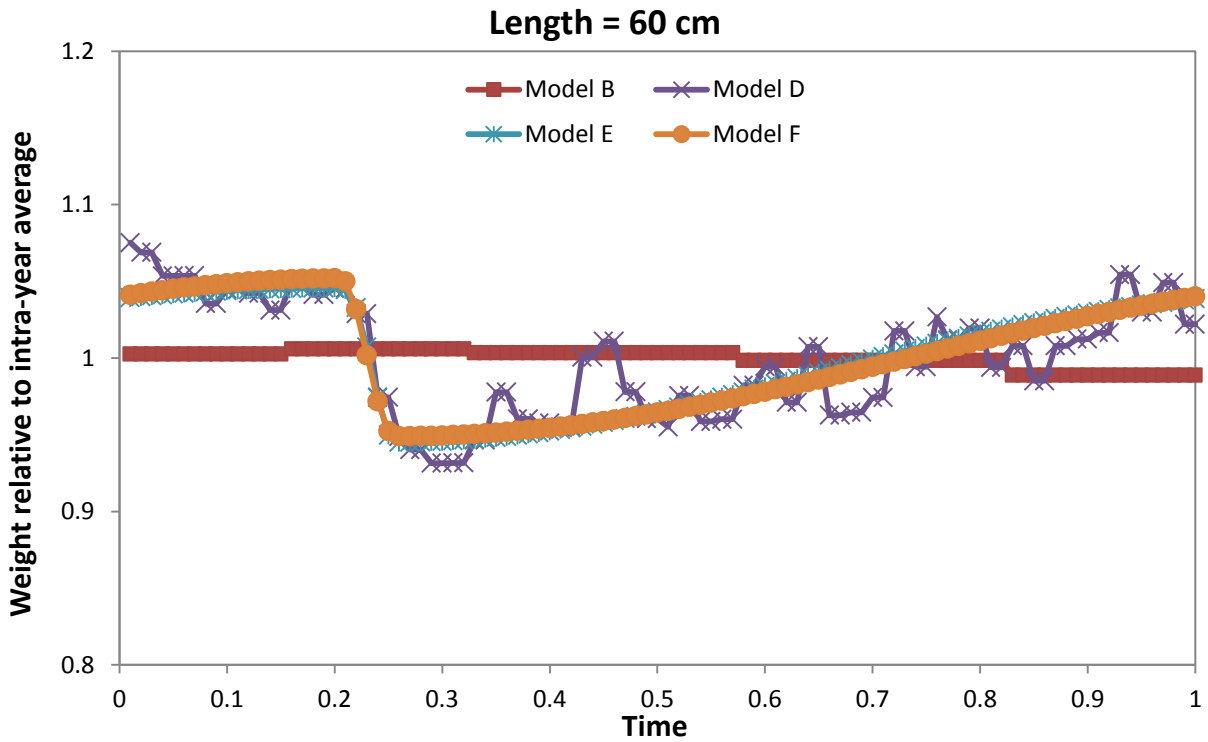


Figure 2.1.3c. Relative intra-annual weight at lengths 50 and 60 cm as estimated by four models.

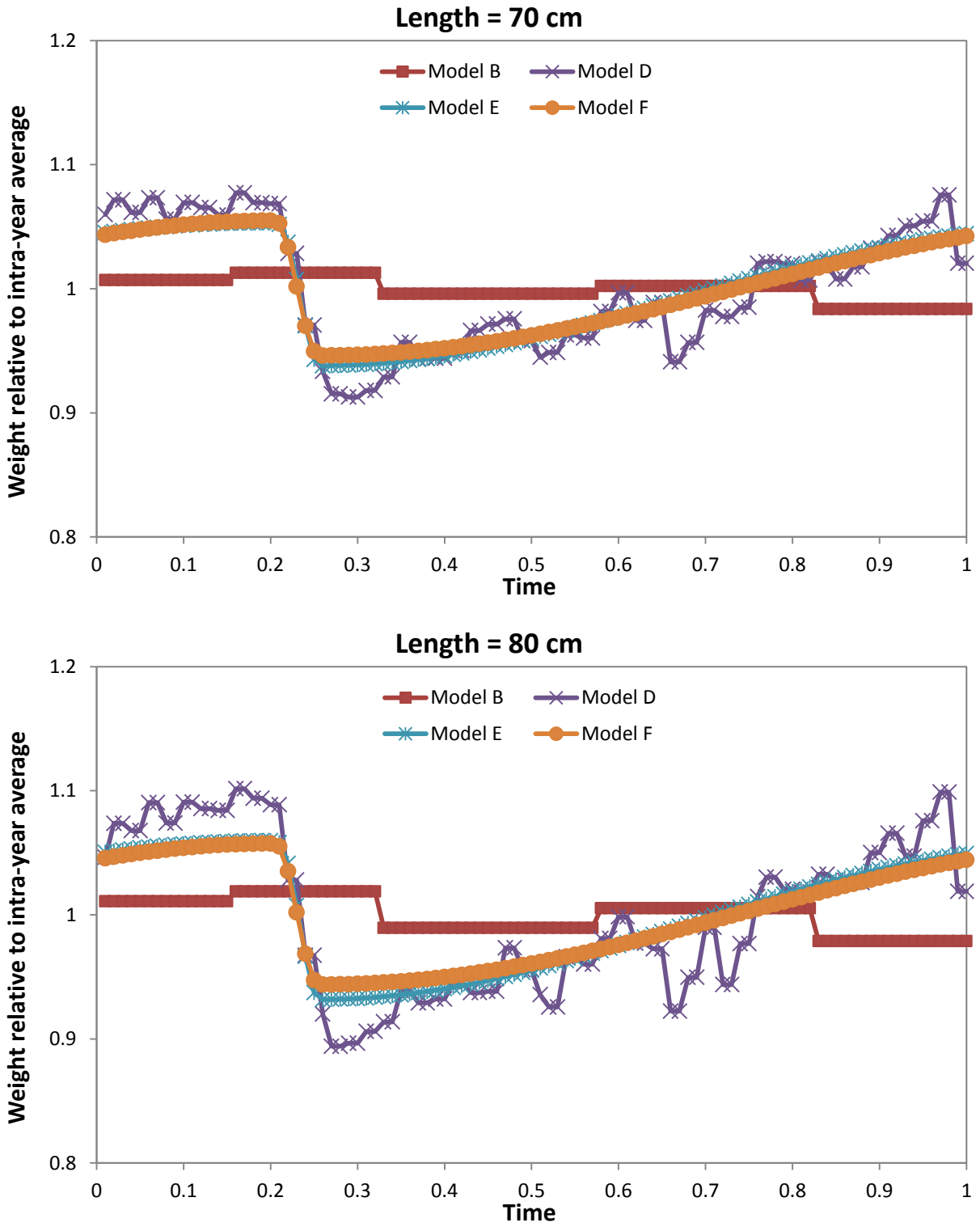
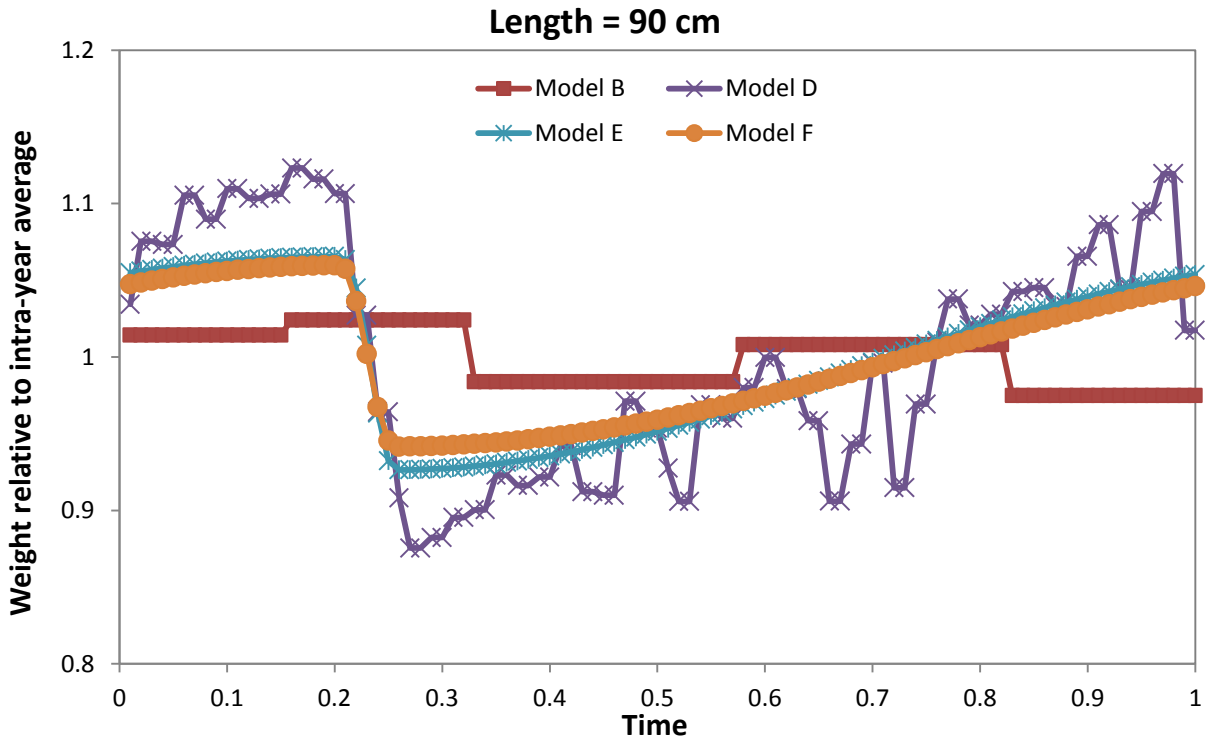


Figure 2.1.3d. Relative intra-annual weight at lengths 70 and 80 cm as estimated by four models.



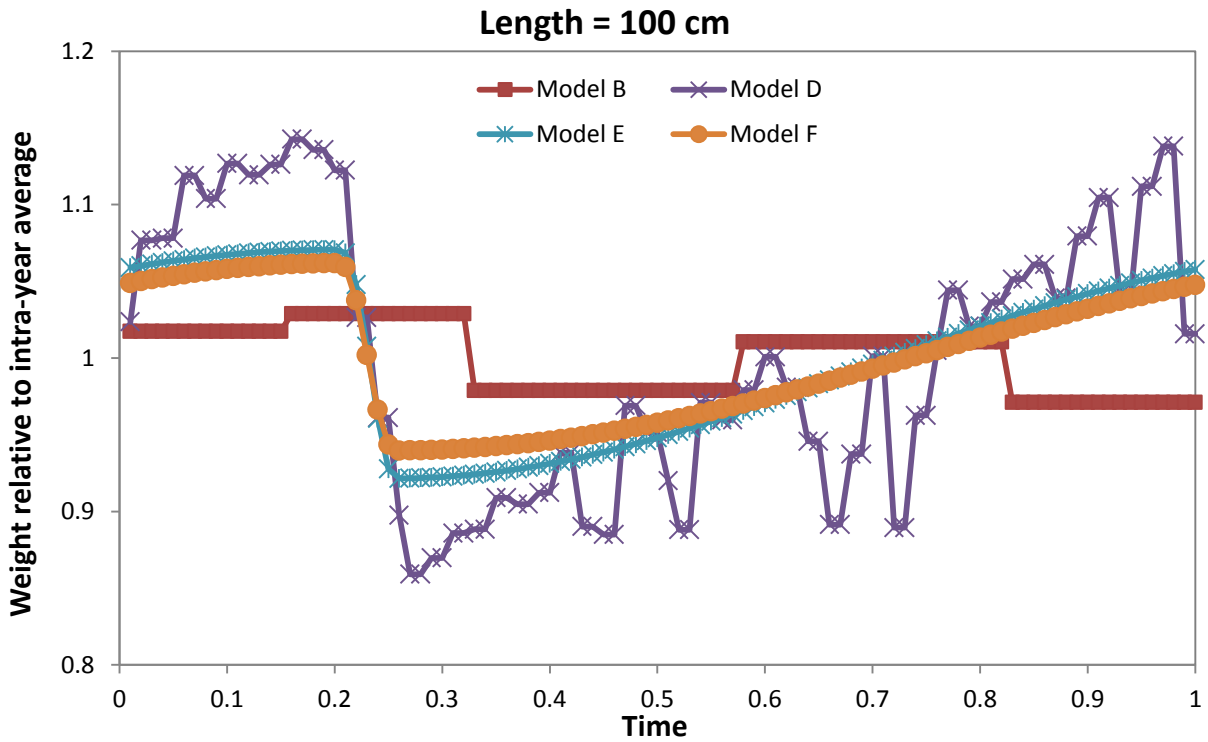


Figure 2.1.3e. Relative intra-annual weight at lengths 90 and 100 cm as estimated by four models.

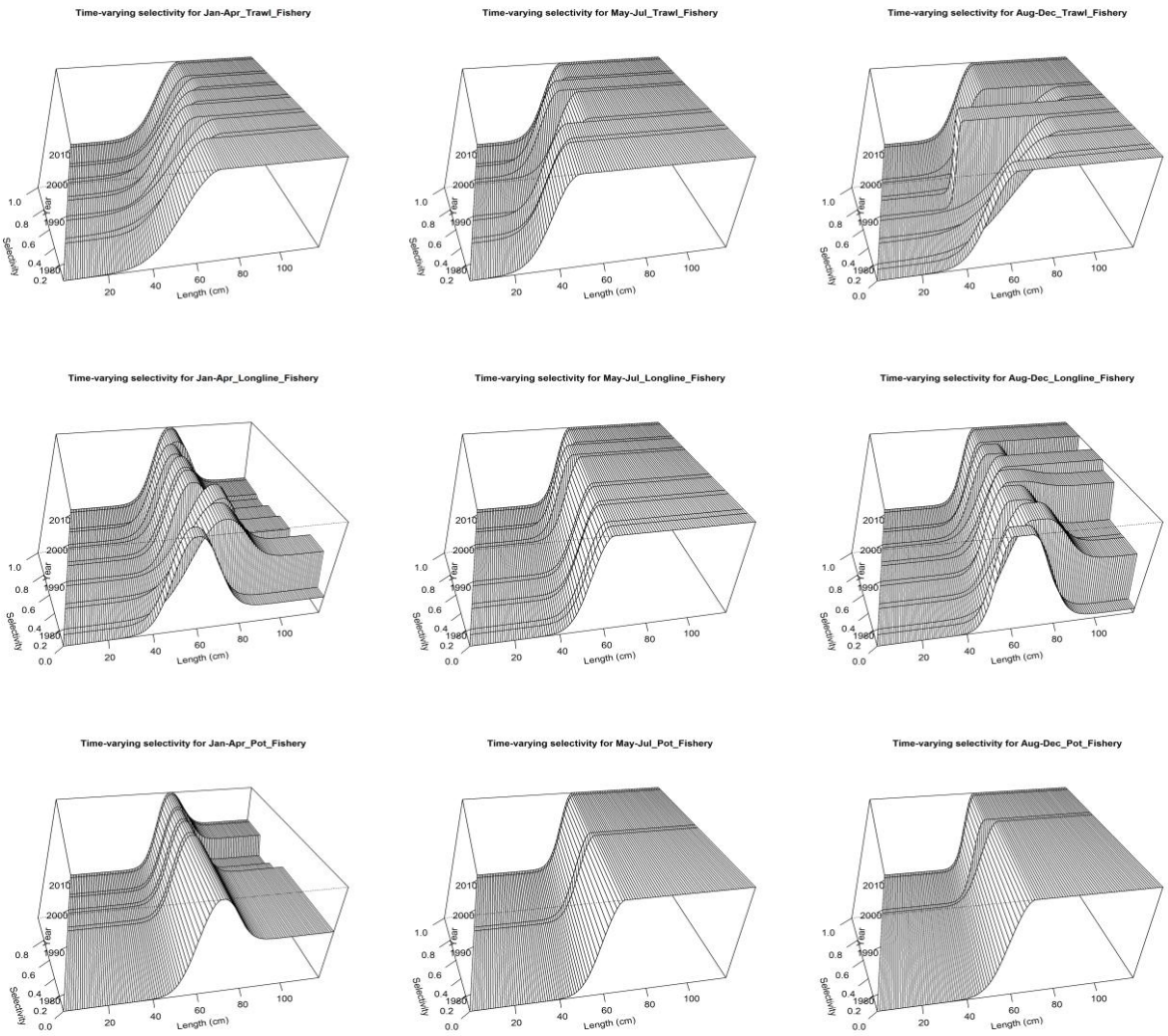


Figure 2.1.4a. Fishery selectivity as estimated by Model 1.

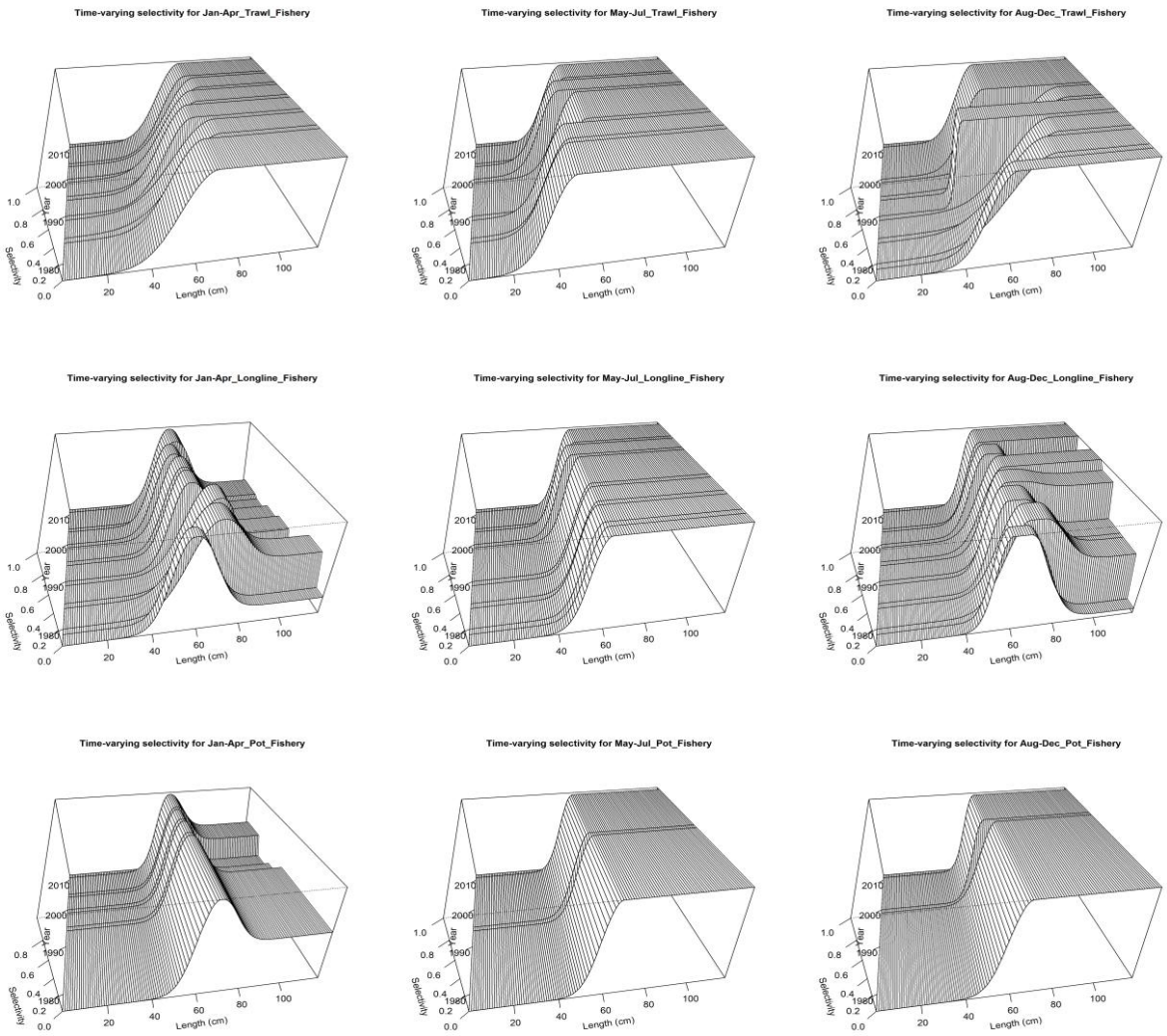


Figure 2.1.4b. Fishery selectivity as estimated by Model 2.

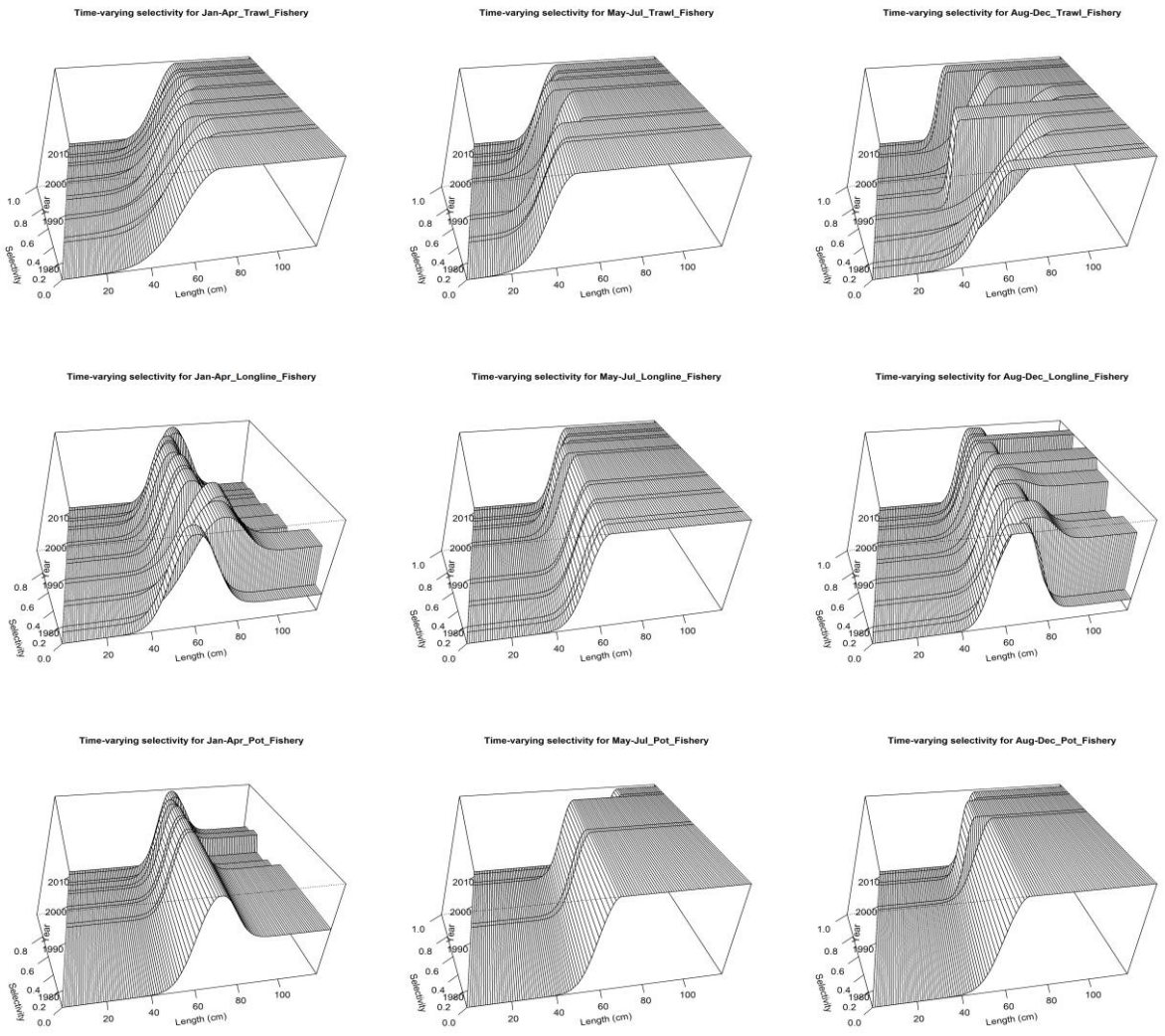


Figure 2.1.4c. Fishery selectivity as estimated by Model 3.

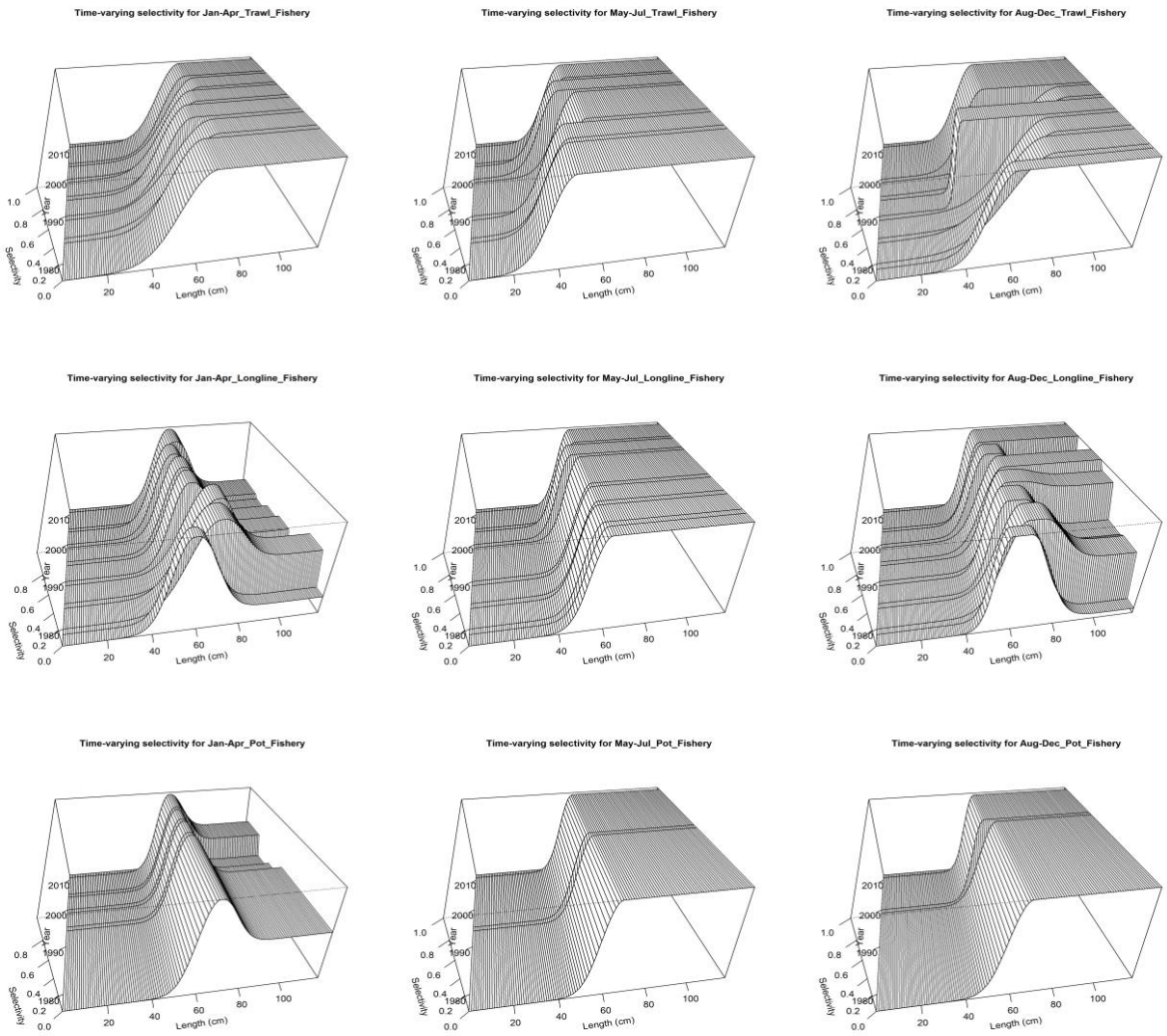


Figure 2.1.4d. Fishery selectivity as estimated by Model 4.

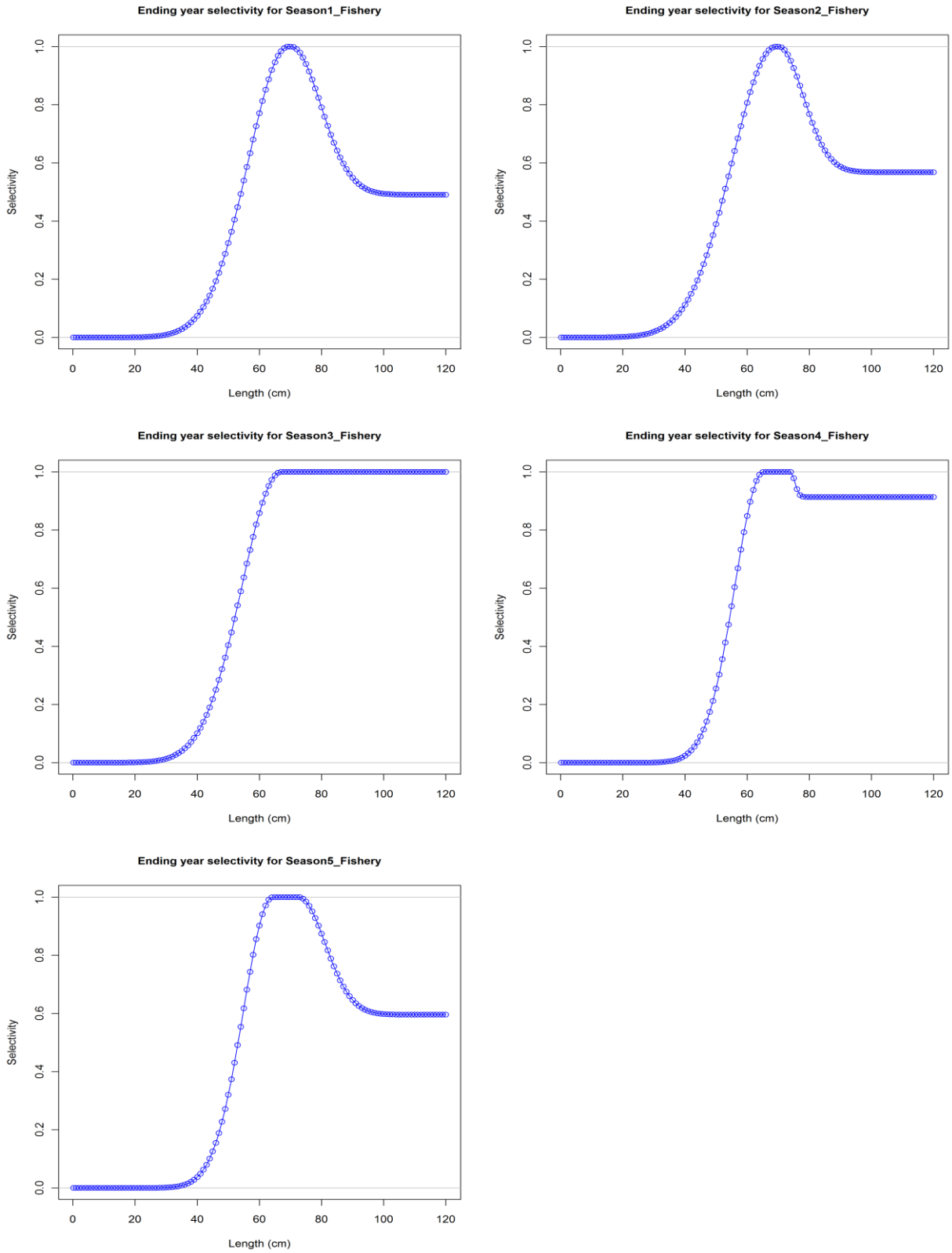


Figure 2.1.4e. Fishery selectivity as estimated by Model 5.

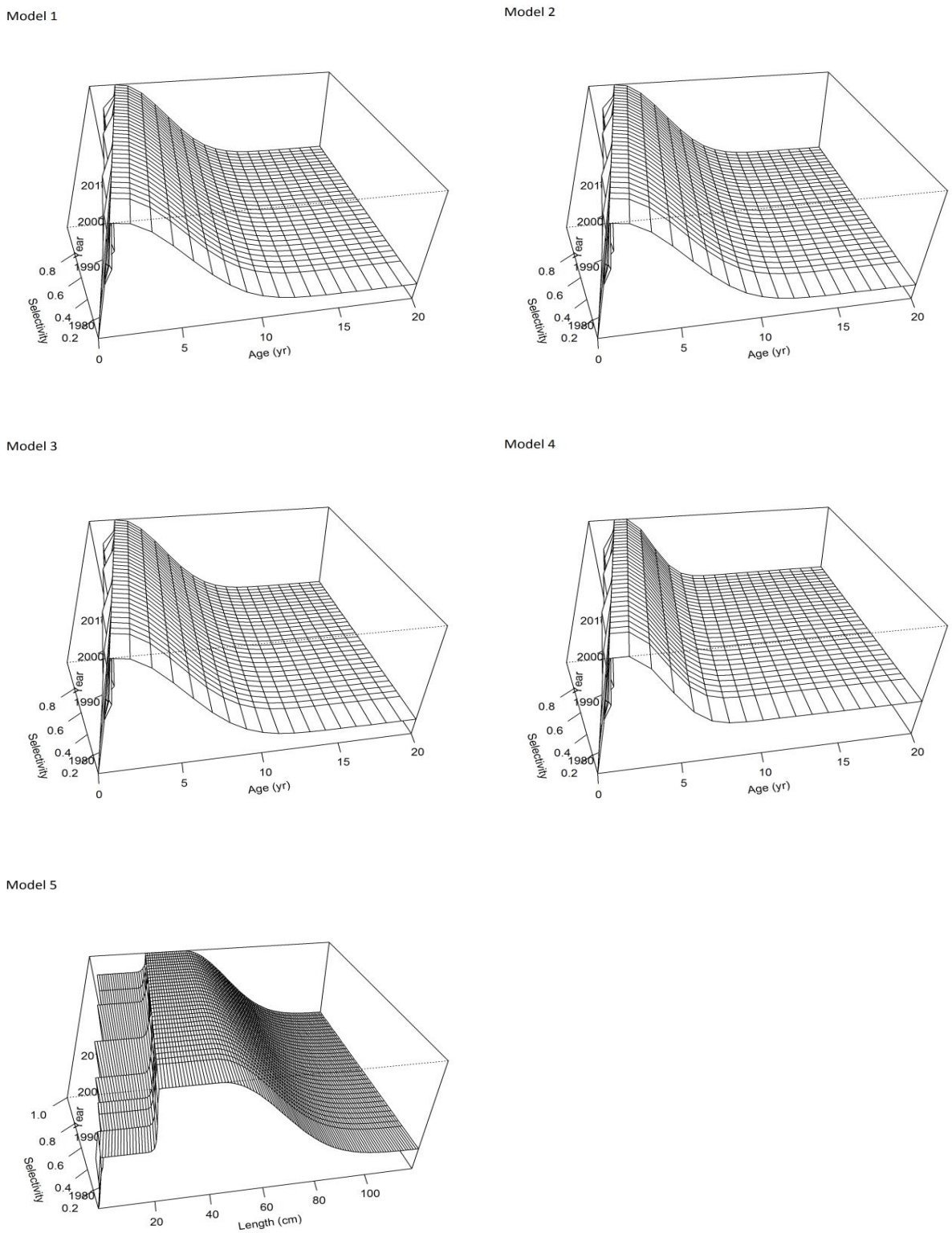


Figure 2.1.5a. Surface plots of time-varying survey selectivity as estimated by five primary models. Note that Models 1-4 use age-based selectivity, while Model 5 uses length-based.

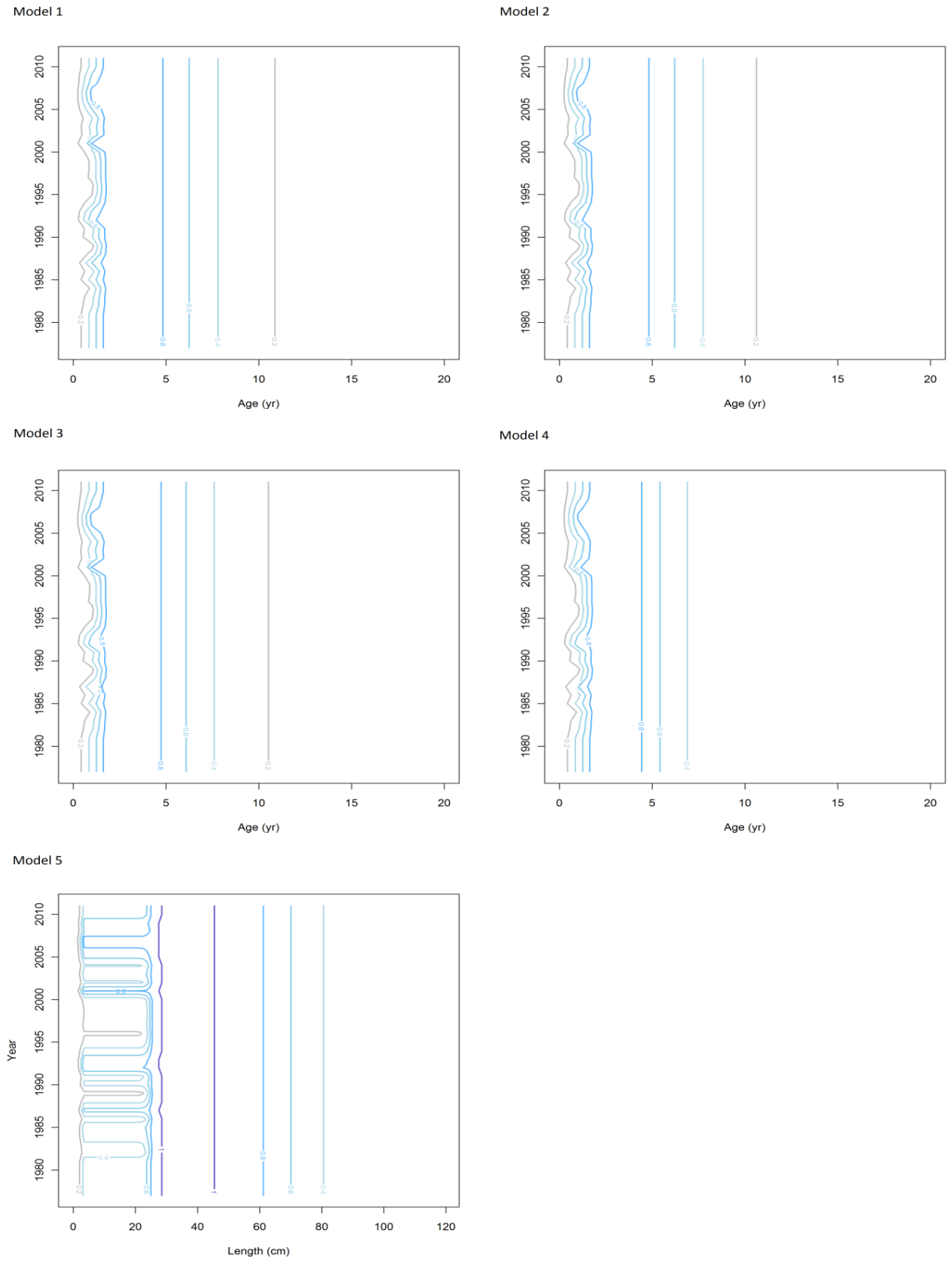


Figure 2.1.5b. Contour plots of time-varying survey selectivity as estimated by five primary models. Note that Models 1-4 use age-based selectivity, while Model 5 uses length-based.

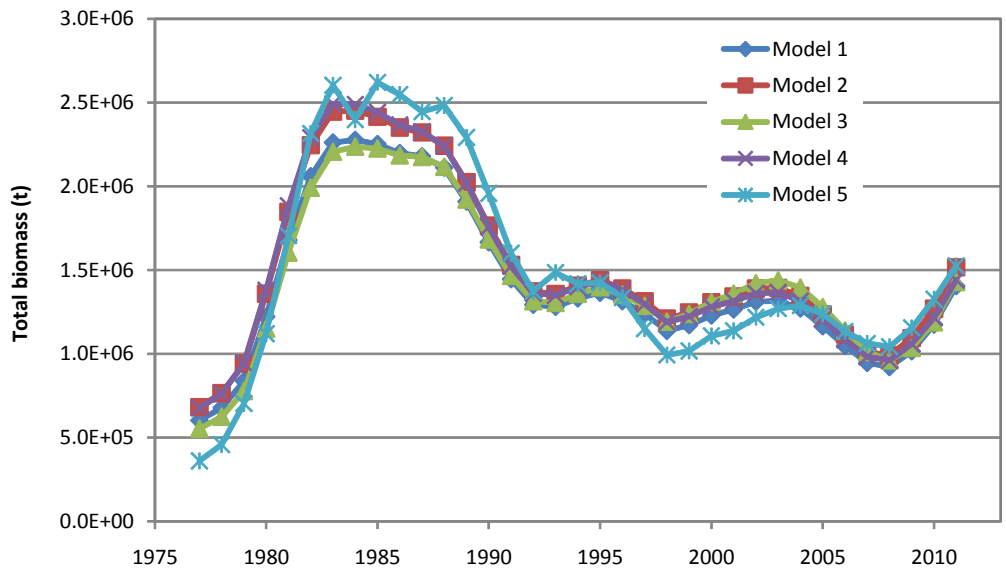


Figure 2.1.6. Time series of total (age 0+) biomass (t) as estimated by the five primary models.

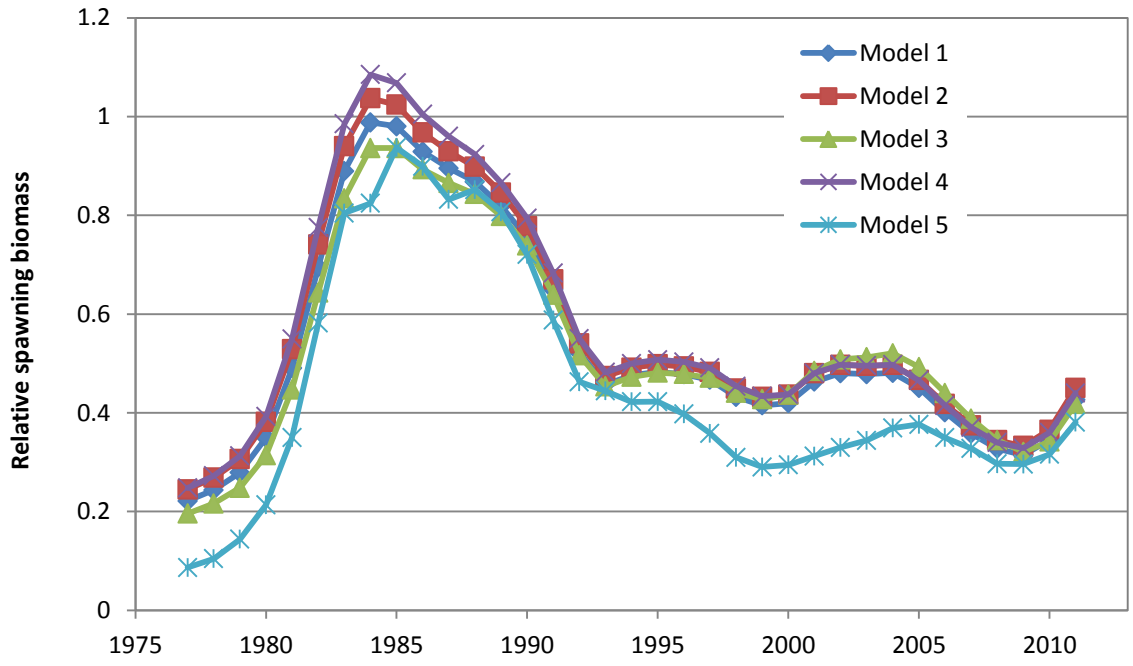


Figure 2.1.7. Time series of spawning biomass relative to $B_{100\%}$ as estimated by the five primary models.

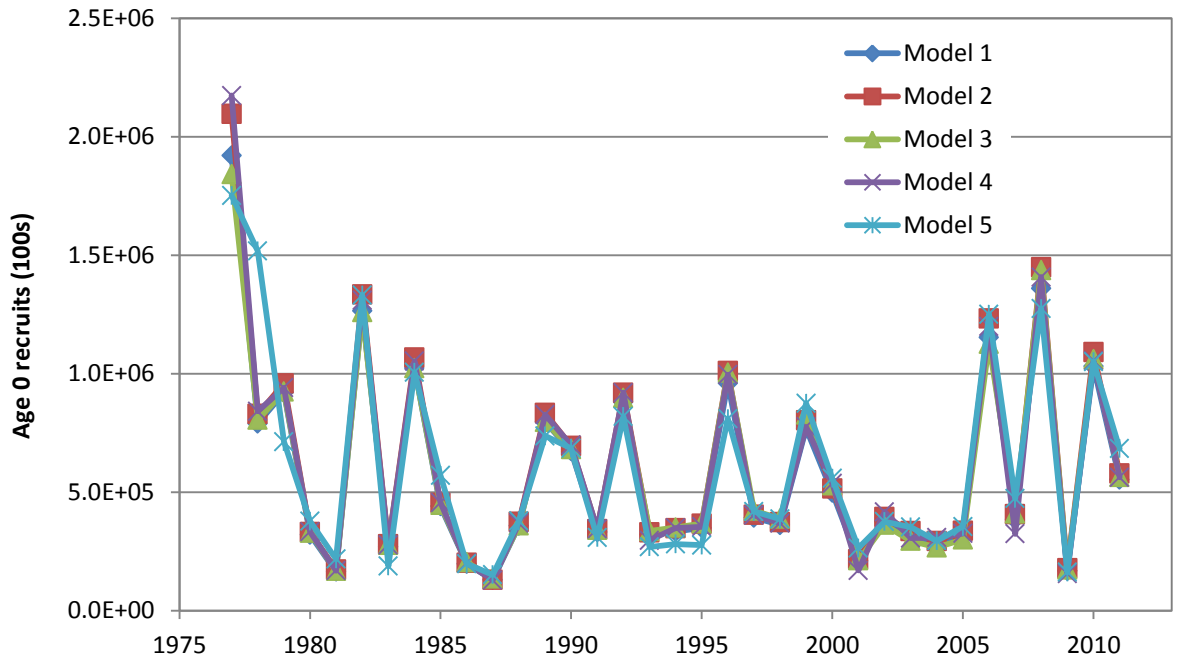


Figure 2.1.8. Time series of age 0 recruits (1000s) as estimated by the five primary models.

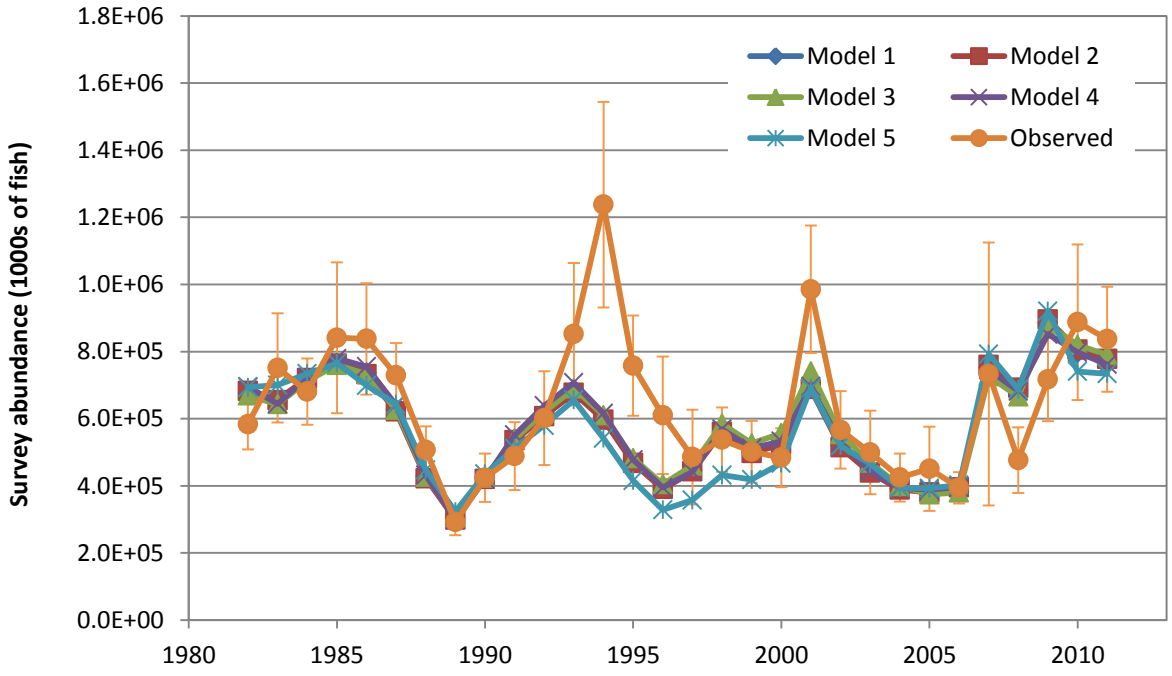


Figure 2.1.9. Estimates of survey abundance (1000s of fish) obtained by the five primary models, with point estimates and 95% confidence intervals from the survey ("Observed").

Annex 2.1.1: Estimating the standard deviation in a random effects model

Background

To develop the idea of a random effects model, consider first the following univariate, linear-normal, *fixed effects* model:

- $\mathbf{x}$ is an $m\times1$ variable with *known* realizations at times j=1,2,…,n
- α is a constant scalar
- $\boldsymbol{\beta}$ is an $m\times1$ constant vector
- $ytru_j$ is a scalar related to $\mathbf{x}_j$ by $ytru_j = \alpha+\boldsymbol{\beta}'\mathbf{x}_j$
- $yobs_j$ is related to $ytru_j$ by $yobs_j = ytru_j+\varepsilon_j$, where $\varepsilon_j \sim N(0,\sigma\varepsilon^2)$

Now, suppose that the value of each $\mathbf{x}_j$ is unknown or, worse, that the identities of the m scalar variables comprising the vector $\mathbf{x}$ are unknown. In both of these cases, the fixed effects model is often replaced by a *random effects* model. Two of the assumptions are the same as in the fixed effects model:

- $ytru_j$ is a scalar related to $\mathbf{x}_j$ by $ytru_j = \alpha+\boldsymbol{\beta}'\mathbf{x}_j$
- $yobs_j$ is related to $ytru_j$ by $yobs_j = ytru_j+\varepsilon_j$, where $\varepsilon_j \sim N(0,\sigma\varepsilon^2)$

However, in the random effects model, $\mathbf{x}$ is replaced by a multivariate normal random variable with mean vector $\boldsymbol{\mu}\mathbf{x}$, covariance matrix $\boldsymbol{\Sigma}\mathbf{x}$, and unknown realizations at times j=1,2,…,n. Then the following conditions will hold:

- $ytru$ is normally distributed with mean $\mu y = \alpha+\boldsymbol{\beta}'\boldsymbol{\mu}\mathbf{x}$ and variance $\sigma y = \boldsymbol{\beta}'\boldsymbol{\Sigma}\mathbf{x}\,\boldsymbol{\beta}$
- $yobs$ is normally distributed with the same mean as $ytru$, but variance $\sigma y_{obs}^2 = \sigma y^2 + \sigma\varepsilon^2$

The full log likelihood in the random effects model consists of two parts. One is the distribution of the observed values:

$$lnLik_1 = -\left(\frac{n}{2}\right)\cdot\ln(2\pi) - n\cdot\ln(\sigma\varepsilon) - \left(\frac{1}{2}\right)\cdot\sum_{j=1}^{n}\left(\frac{yobs_j - ytru_j}{\sigma\varepsilon}\right)^2 \quad .$$

The other is the distribution of the true values:

$$lnLik_2 = -\left(\frac{n}{2}\right)\cdot\ln(2\pi) - n\cdot\ln(\sigma y) - \left(\frac{1}{2}\right)\cdot\sum_{j=1}^{n}\left(\frac{ytru_j - \mu y}{\sigma y}\right)^2 \quad .$$

As an aside, the designation of the above as a "likelihood" is somewhat problematic, because the above equation does not contain any data *per se*. Alternatively, it might be referred to as a joint prior distribution, but this is not completely satisfactory either, because σy is a "real" parameter of the model that gives rise to the true states, independent of any modeler's prior beliefs about the distribution of those states. Although these are interesting philosophical issues, the method developed here does not particularly depend on what the above equation is called. Because it is widely referred to as a "likelihood," this term will be used here, too.

In many applications, this model is reparameterized by defining $\boldsymbol{\delta} \equiv \mathbf{ytru} - \mu y$ and substituting into the above two equations. Then, after summing, the full log likelihood can be written as:

$$lnLik_{full} = -\left(\frac{n}{2}\right)\cdot\ln(2\pi) - n\cdot\ln(\sigma\varepsilon) - \left(\frac{1}{2}\right)\cdot\sum_{j=1}^{n}\left(\frac{yobs_j - (\mu y + \delta_j)}{\sigma\varepsilon}\right)^2$$
$$-\left(\frac{n}{2}\right)\cdot\ln(2\pi) - n\cdot\ln(\sigma y) - \left(\frac{1}{2}\right)\cdot\sum_{j=1}^{n}\left(\frac{\delta_j}{\sigma y}\right)^2 \quad .$$

The MLE of μy is $\mu yest$ = mean(**yobs**). Note that $\mu yest$ is independent of any estimate of σy.

Given an estimate of σy ($\sigma yest$) the MLE of **ytru** is

$$\mathbf{yest} = \frac{\sigma yest^2\cdot\mathbf{yobs} + \sigma\varepsilon^2\cdot mean(\mathbf{yobs})}{\sigma yest^2 + \sigma\varepsilon^2} \quad . \qquad (2.1.1.1)$$

Note that **yest** is dependent on $\sigma yest$, except for two extreme cases:

- If $\sigma yest$=0, **yest**=mean(**yobs**)
- If $\sigma yest$=∞, **yest**=**yobs**

Differentiating the full log likelihood profile (i.e., the log of the full likelihood with μy and either **ytru** or δ set at their MLEs conditional on σy) with respect to σy shows that the partial derivative is zero whenever the following quadratic is zero:

$$sy^2 - \sqrt{\mathrm{var}(\mathbf{yobs})}\cdot sy + s\varepsilon^2 = 0 \quad ,$$

where sy is a surrogate for σy.

The above quadratic has the following roots:

$$sy = \begin{pmatrix} \dfrac{\sqrt{\mathrm{var}(\mathbf{yobs})} - \sqrt{\mathrm{var}(\mathbf{yobs}) - 4\sigma\varepsilon^2}}{2} \\ \dfrac{\sqrt{\mathrm{var}(\mathbf{yobs})} + \sqrt{\mathrm{var}(\mathbf{yobs}) - 4\sigma\varepsilon^2}}{2} \end{pmatrix} \quad . \qquad (2.1.1.2)$$

If var(**yobs**)>$\sigma\varepsilon^2$, the full likelihood profile has a global maximum at 0, a local minimum at sy_1, and a local maximum at sy_2. The latter will be taken to be the MLE for the full likelihood profile, σy_{full}.

The full log likelihood can be written as the sum of a conditional log likelihood and a marginal log likelihood:

$$lnLik_{cond} = -\left(\frac{n}{2}\right)\cdot\ln(2\pi) - n\cdot\ln\left(\frac{\sigma y\cdot\sigma\varepsilon}{\sqrt{\sigma y^2 + \sigma\varepsilon^2}}\right) - \left(\frac{1}{2}\right)\cdot\sum_{j=1}^{n}\left(\frac{\delta_j - \dfrac{\sigma y^2\cdot(yobs_j - \mu y)}{\sigma y^2 + \sigma\varepsilon^2}}{\dfrac{\sigma y\cdot\sigma\varepsilon}{\sqrt{\sigma y^2 + \sigma\varepsilon^2}}}\right)^2 \quad ,$$

and

$$lnLik_{marg} = -\left(\frac{n}{2}\right)\cdot\ln(2\pi) - n\cdot\ln\left(\sqrt{\sigma y^2 + \sigma\varepsilon^2}\right) - \left(\frac{1}{2}\right)\cdot\sum_{j=1}^{n}\left(\frac{yobs_j - \mu y}{\sqrt{\sigma y^2 + \sigma\varepsilon^2}}\right)^2 \quad .$$

Because δ appears only as the argument of the conditional log likelihood, integrating it out (i.e., integrating out the random effects) leaves the marginal posterior.

The marginal likelihood profile has a single maximum at

$$\sigma y_{marg} = \sqrt{\mathrm{var}(\mathbf{yobs}) - \sigma\varepsilon^2} \quad . \qquad (2.1.1.3)$$

The above is a much more obvious estimator than σy_{full}, because it simply says that the variance of the observed values is equal to the sum of the variance of the true values plus the variance of the observation error.

It can be shown that σy_{marg} is always greater than σy_{full}.

Estimating σy for a vector of *dev*s in Stock Synthesis

Some quantities, such as population density, lend themselves to measurement by statistically designed field experiments from which estimates of precision (e.g., $\sigma\varepsilon$) can be obtained. Others, such as *dev*s associated with a selectivity parameter, do not.

First, note that Equation 2.1.1.2 can be solved for $\sigma\varepsilon$ as follows:

$$\sigma\varepsilon = \sqrt{\sigma y_{full}\cdot\left(\sqrt{\mathrm{var}(\mathbf{yobs})} - \sigma y_{full}\right)} \quad .$$

Substituting the above into Equation 2.1.1.3 gives

$$\sigma y_{marg} = \sqrt{\mathrm{var}(\mathbf{yobs}) - \sigma y_{full}\cdot\left(\sqrt{\mathrm{var}(\mathbf{yobs})} - \sigma y_{full}\right)} \quad . \qquad (2.1.1.4)$$

The above shows that σy_{marg} can be computed just from **yobs** and σy_{full}. However, σy_{full} cannot be computed from Equation 2.1.1.2 if $\sigma\varepsilon$ is unknown. Moreover, in cases such as the *dev*s associated with a selectivity parameter, not only will $\sigma\varepsilon$ be unknown, but **yobs** will not even exist (i.e., there are never any direct observations of the *dev*s associated with a selectivity parameter). In other words, in such cases it is necessary to estimate both **yobs** and σy_{full} without knowledge of $\sigma\varepsilon$. This can be accomplished as follows:

1. Recall from Equation 2.1.1.1 that **yest**=**yobs** if $\sigma y=\infty$. Therefore, fix σy initially at a very large value and run SS. The resulting estimated *dev*s should be the equivalent of **yobs**. It may take several tries to find a value of σy sufficiently high that it does not constrain the *dev*s. To avoid getting trapped in a local minimum, it is probably best to start with a reasonably low value of σy and then increase it gradually. It is also possible that one or more *dev*s (particularly *dev*s on selectivity parameters) may want to go to +/– ∞, in which case the assumption of normality is not

reasonable. In such cases, the "outlier" *dev*s should not be considered when making the determination that σy is no longer constraining the *dev*s.

2. Estimate σy iteratively by choosing an initial value, running SS, computing the standard deviations of the estimated *dev*s, re-setting σy at that value, and repeating until σy equals the standard deviations of the estimated *dev*s. Because SS uses the full likelihood, the resulting estimate of σy should be the equivalent of σy_{full}. As in Step 1, if one or more *dev*s tends toward +/– ∞, those *dev*s should not be included when computing the standard deviation of the *dev*s.
3. Given the estimate of **yobs** from Step 1 and the estimate of σy_{full} from Step 2, estimate σy_{full} by Equation 2.1.1.4.

Because Equation 2.1.1.2 will result in the estimate of σy_{full} being real only when var(**yobs**)>$\sigma\varepsilon^2$, it is possible that Step 2 in the above algorithm will fail, even when the "true" value of σy is positive. The algorithm should therefore be conservative in the sense of tending to err toward underestimating σy.

It should also be noted that, while the above algorithm is appropriate (given var(**yobs**)>$\sigma\varepsilon^2$) for a univariate linear-normal model, when used in a multivariate nonlinear model such as SS, the properties of the estimator are presently unknown.

Annex 2.1.2: A trigonometric model of seasonally varying weight at length

Trigonometric functions such as sine or cosine are natural choices for describing processes that vary on a cyclical basis. For example, the α and β parameters of the standard weight-length equation $W=\alpha L^{\beta}$ might reasonably be assumed to vary on an annual cycle. However, there are two problems with fitting each of these two parameters to a sine or cosine function as usually formulated.

The first problem is that, while it is reasonable to assume that α and β vary on an annual cycle, it is much less reasonable to assume that the cycle is symmetric (e.g., that the rate of approach *to* the maximum is equal to the rate of descent *from* the maximum). This problem can be overcome by linearly rescaling time between the points corresponding to the minimum and maximum. This can be accomplished by means of the following two functions:

$$a(t,t1,t2)=\left\{\begin{array}{ll} \dfrac{1}{2\left(1-\left|t2-t1\right|\right)} & \text{if} \quad t<\min\left(t1,t2\right) \\ \dfrac{1}{2\left|t2-t1\right|} & \text{if} \quad \min\left(t1,t2\right)\le t\le \max\left(t1,t2\right) \\ \dfrac{1}{2\left(1-\left|t2-t1\right|\right)} & \text{if} \quad t>\max\left(t1,t2\right) \end{array}\right\} \quad ,$$

and

$$b(t,t1,t2)=\left\{\begin{array}{ll} \dfrac{\min\left(t1,t2\right)}{2\left(1-\left|t2-t1\right|\right)}-\dfrac{1}{2}-\dfrac{1}{2}(t1\ge t2) & \text{if} \quad t<\min\left(t1,t2\right) \\ \dfrac{\min\left(t1,t2\right)}{2\left|t2-t1\right|}-\dfrac{1}{2}(t2\ge t1) & \text{if} \quad \min\left(t1,t2\right)\le t\le \max\left(t1,t2\right) \\ \dfrac{\max\left(t1,t2\right)}{2\left(1-\left|t2-t1\right|\right)}-\dfrac{1}{2}(t1\ge t2) & \text{if} \quad t>\max\left(t1,t2\right) \end{array}\right\} \quad ,$$

where notation of the form "($x\le y$)" denotes a Boolean operator that returns 1 if true and 0 if false.

With the above linear rescalings of time, a reasonable formula for intra-annual variation of α or β is:

$$p(t,t1,t2,pmid,prat)=pmid\cdot\left(1+(1-prat)\cdot\cos\left(2\pi\cdot\left(a(t,t1,t2)\cdot t-b(t,t1,t2)\right)\right)\right) \quad ,$$

where time is measured on an annual scale, *pmid* is the midpoint between the minimum and maximum of the curve, and *prat* is the ratio between the minimum and *pmid*. A hypothetical example is shown in Figure 2.1.2.1.

To keep things simple, it may be assumed that *t1* and *t2* for β equal *t2* and *t1* for α, respectively. This causes β to be minimized when α is maximized, and vice-versa.

The second problem is that, if the values of the parameters are left unconstrained (except for the obvious natural boundaries $0\le t1\le 1$, $0\le t2\le 1$, $pmid>0$, and $0\le prat\le 1$), the functions can imply very complicated patterns of intra-annual variability in weight at length that would be difficult to justify biologically. A hypothetical example is shown in Figure 2.1.2.2.

One way to address this problem is to constrain the *prat* parameter for α (αrat) conditionally on the *pmid* and *prat* parameters for β (βmid and βrat, respectively) to be greater than:

$$\alpha rat_{min}(\beta mid, \beta rat) = \frac{1}{1 + \beta mid \cdot (1 - \beta rat) \cdot \ln(Lmin)} \quad ,$$

where *Lmin* is the minimum length being modeled. When this constraint is satisfied, the resulting intra-annual pattern of weight at length is assured to have only one minimum and one maximum for all modeled lengths.

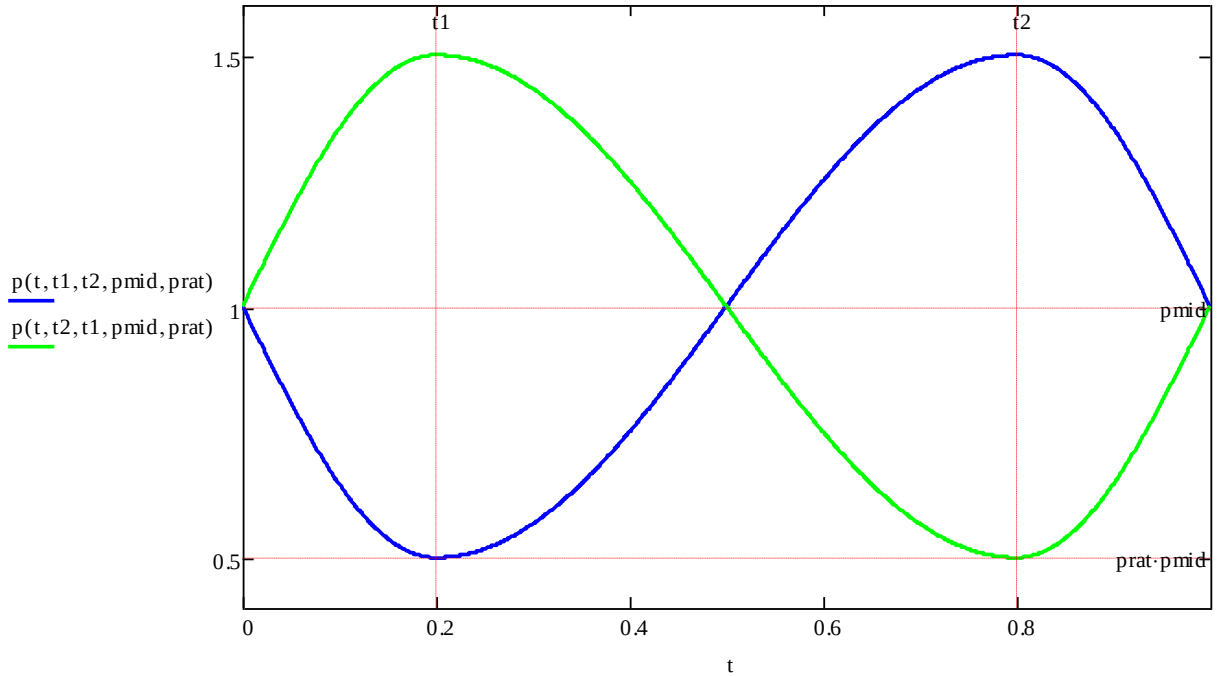


Figure 2.1.2.1. Hypothetical illustration of the trigonometric function with linearly rescaled time used to represent intra-annual variability in weight-length parameters, showing how the curve is flipped about the vertical midpoint when the time parameters are switched. Time is measured in years.

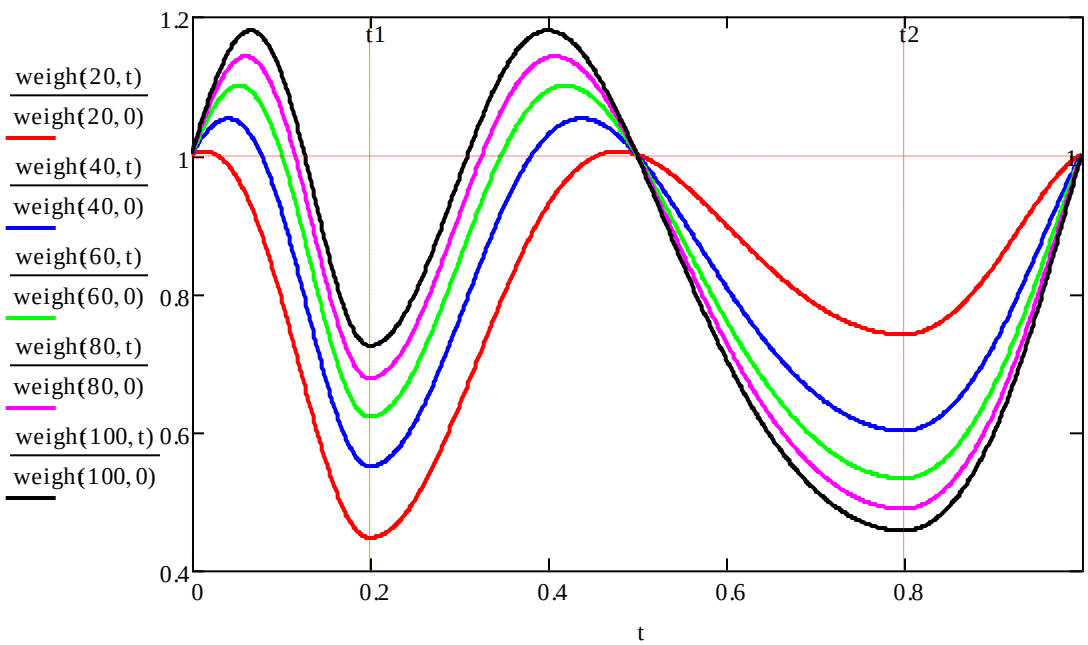


Figure 2.1.2.2. Hypothetical illustration showing how allowing the parameters of the weight-length model to be unconstrained can lead to very complicated intra-annual dynamics. Five example lengths are shown (20,40,60,80,100). Weights for each length are scaled relative to weight at *t*=0.