"Phase I" Report of the Joint Plan Team Working Group on Assessment/Management Issues Related to Recruitment

May 2012

Introduction

The Groundfish Plan Teams and Crab Plan Team ("GPTs" and "CPT," respectively) have appointed a working group (Robert Foy, James Ianelli, Diana Stram, and Grant Thompson) to list and evaluate alternatives for a number of assessment and management issues related to recruitment. To aid the working group in accomplishing its task, a workshop was held at the AFSC Seattle laboratory during the dates of April 4-5, 2012. The workshop was intended to address a long-standing request from the BSAI GPT for analysis of recruitment-related issues such as: which cohorts to include in estimation of reference points, how to estimate parameters related to recruitment (including parameters of a stock-recruitment relationship), and how to determine the reliability of the F_{MSY} probability density function. The workshop was also intended to satisfy the following SSC request (from the February 2012 minutes):

> *"The SSC supports the previous recommendation of the Groundfish PT ... to hold a workshop to develop guidelines on how to address environmental changes in the SR relationship into biological reference points and how to model environmental forcing in stock projection models.... The SSC believes it would be useful to have members from both the Groundfish and Crab Plan Teams present, because the issues are common to both groups."*

The workshop agenda, a list of modifications to the agenda that occurred during the workshop itself, a list of references, and a list of participants are attached in Appendix A. The workshop initiated discussion of existing and proposed approaches and provided ideas for further analysis.

This "Phase I" working group report is being provided prior to completion of the full working group report because four agenda items from the workshop were deemed critical for consideration at the May 2012 meeting of the CPT. These were:

A. Identification of regime shifts, either for an ecosystem or some subunit thereof
    1. Current policy on identification of regime shifts
    2. Possible improvements to current policy, including consideration of risk

B. Estimation of parameters (average recruitment, stock-recruitment relationships, σ_R)
    1. Establishing criteria for excluding individual within-regime year classes from estimates

C. Forecasting environmental variability

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    2\. How knowledge of environmental forcing changes perceptions of reference points

The full report of the working group will be prepared in time for consideration at the September meetings of the CPT and GPTs. The full report may revisit some or all of the items addressed in this Phase I report, and will address as many of the remaining agenda items as possible within the time available.

Alternatives for items A1, A2, B1, and C2

As noted above, the following description of alternatives, evaluations thereof, and preliminary recommendations (items A2, B1, and C2 only) were developed under extreme time pressure dictated by the needs of the CPT for its May 2012 meeting. All recommendations made here are strictly *provisional*, and are constrained by the fact that any policy that the CPT or SSC might mandate for use in this year's crab stock assessments must, by definition, be implementable by this September.

The material contained in this Phase I report will be re-evaluated during preparation of the final working group report. In this re-evaluation, the working group will consider feedback obtained from the May CPT meeting, the June SSC meeting, individual Team and SSC members, and members of the public.

In the following, "SRR" stands for "stock-recruitment relationship."

A1: Current policy on identification of regime shifts

Alternative A1.1 (status quo):

For groundfish, the status quo approach is contained in a 1999 memorandum from James Balsiger (who was at that time AFSC Director) to the AFSC groundfish stock assessment authors, and consists of the following two sentences: *"Projections of future stock sizes and estimation of reference points should be based only on year classes spawned in 1977 or later, unless a compelling case can be made to begin the time series in some other year. The fact that earlier estimates are available does not in itself constitute a compelling case."*

For crab, the status quo approach is described in various parts of the policy listed in Appendix B. Briefly, this approach calls for identification of potential mechanisms to support regime shifts. Such identification should consider evidence of a change in magnitude and direction of life-history characteristics. Candidate life-history characteristics include natural mortality, growth, maturity, fecundity, recruitment, and recruits per unit of spawning. Candidate ecosystem characteristics include the "Overland method" of regime shift detection, change in production of benthic species in the Eastern Bering Sea, and consumption (from ecosystem model outputs). If stock-recruitment data are available, they are to be examined for evidence of multiple SRRs that are consistent with a proposed regime shift.

Because item A1 is restricted to the status quo by definition, no other alternatives are presented for this item. Also, because the status quo is a matter of fact, no recommendation is made for this item.

A2: Possible improvements to current policy, including consideration of risk

Alternative A2.1: Do not consider effects of regime shifts.

Pro: 1) Extremely easy to implement. 2) Minimizes chance of a "false positive" regime shift identification. 3) If the regimes that occurred during the period spanned by the full time series of data constitute a random sample from the distribution of regimes that will occur in the long-term future, this method would give an unbiased estimate of future conditions over the long term.

Con: 1) Maximizes chance of a "false negative" regime shift (non)identification. 2) Given that regimes (almost by definition) persist for a period of at least several years, this method is likely to give a biased estimate of future conditions over the short term. 3) Because environmental regimes typically appear to persist over approximately decadal time scales and because most datasets for BSAI and GOA groundfish and crab typically extend back only a few decades, it is unlikely that the set of regimes that occurred during the period spanned by the data constitutes a random sample from the distribution of regimes that will occur in the long-term future; in which case this method is also likely to give a biased estimate of future conditions over the long term.

Alternative A2.2: Estimate breakpoints in the time series of recruits using an appropriate statistical test such as AIC or likelihood ratio, and possibly employing additional constraints such as a minimum length for the current regime or a maximum permissible CV for parameter estimates.

Pro: 1) Basing the analysis on the time series of recruits, without considering recruits per unit of spawning or a curvilinear SRR, is similar to existing practice for Tier 3 groundfish. 2) If the true SRR is of Beverton-Holt (or similar, asymptotic) form and spawning biomass has been sufficiently high throughout the time series (such that the recruitment predicted by the curve is almost independent of spawning biomass), this method will likely produce results similar to those that would be produced by the more complicated alternative of considering a fully parameterized SRR.

Con: 1) If spawning biomass has been sufficiently low for the most recent part of the time series, low recruitments from those recent years will be mistaken for a new regime even though the true SRR has not changed. 2) Because this method implicitly assumes that the true SRR is approximately horizontal across the observed range of spawning biomasses, productivity will be overestimated if the assumption is extrapolated all the way down to the origin.

Alternative A2.3: Estimate breakpoints in the time series of recruits per unit of spawning using an appropriate statistical test such as AIC or likelihood ratio, and possibly employing additional constraints such as a minimum length for the current regime or a maximum permissible CV for parameter estimates.

Pro: 1) Avoids the problem identified under "Con" for Alternative A2.2. 2) If spawning biomass has been severely depleted throughout the time series (such that spawning biomass is always close to zero), this method will likely produce results similar to those that would be produced by the more complicated alternative of considering a fully parameterized SRR.

Con: 1) If the true SRR is of Beverton-Holt (or similar, asymptotic) form and spawning biomass has been sufficiently high throughout the time series (such that the recruitment predicted by the curve is almost independent of spawning biomass) but spawning biomass has declined significantly during the most recent part of the time series, recent decreases in recruits per unit of spawning will be mistaken for a new regime even though the true SRR has not changed. 2) Because this method implicitly assumes that the true relationship between recruits and spawning is proportional across the observed range of spawning biomasses, productivity will be underestimated if the assumption is extrapolated far beyond the range of the data.

Alternative A2.4: Estimate breakpoints in the time series of an environmental time series such as the Pacific Decadal Oscillation (PDO) using an appropriate statistical test such as AIC or likelihood ratio, and possibly employing additional constraints such as a minimum length for the current regime or a maximum permissible CV for parameter estimates.

Pro: 1) The necessary data may be available even when recruitment data are not. 2) Breakpoints in environmental time series such as the PDO have already been well studied and shown to be significant predictors of many things. 3) This approach would eliminate the need to conduct a separate analysis for every stock.

Con: 1) If the productivity of a particular stock is not linked, directly or indirectly, to the environmental variable(s) used in the analysis, a "false positive" regime shift identification will result. 2) If the productivity of a stock changes only in response to some variable *not* used in the analysis, a "false negative" regime shift (non)identification will result.

Alternative A2.5: Estimate both parameters of a two-parameter SRR for every age- or length-structured stock assessment, with breakpoints estimated using an appropriate statistical test such as AIC or likelihood ratio, and possibly employing additional constraints such as a minimum length for the current regime or a maximum permissible CV for parameter estimates.

Pro: 1) Eliminates the need to use proxy reference points. 2) Does not imply functional forms for the SRR (e.g., horizontal or linear through the origin) that are almost certain to be implausible if extrapolated across the entire range of possible spawning biomasses.

Con: 1) Reliably estimating both parameters of a two-parameter SRR has proven to be very difficult for the vast majority of BSAI and GOA groundfish and crab stocks.

Alternative A2.6 (*provisional recommendation*): Condition the productivity parameter of a two-parameter SRR on one or more F_{MSY} proxies specified or implied by the harvest control rules in the respective FMP, then estimate the scale parameter of the SRR for every age- or length-structured stock assessment, with breakpoints estimated using an appropriate statistical test such as AIC or likelihood ratio, and possibly employing additional constraints such as a minimum length for the current regime or a maximum permissible CV for parameter estimates.

Pro: 1) Results in management recommendations that are consistent with existing F_{MSY} proxies. 2) Does not imply functional forms for the SRR (e.g., horizontal or linear through the origin) that are almost certain to be implausible if extrapolated across the entire range of possible spawning biomasses. 3) Eliminates the need to estimate the more difficult-to-estimate of the two SRR parameters, instead requiring estimation of only the scale parameter, which is analogous to the "average recruitment" currently estimated in all Tier 3 groundfish assessments. 4) This approach has been tested on 11 BSAI and GOA groundfish stocks using a very simple model, and the results appear to be reasonable wherever the assumptions are not violated too severely (6 of the 11 stocks were shown to have breakpoints that passed five statistical tests of significance, with the starting years of the current regimes for these 6 stocks ranging from 1968 to 1990).

Con: 1) Requires use of F_{MSY} proxies. 2) Estimates of derived quantities such as B_{MSY} can be implausible if the F_{MSY} proxies are inconsistent with the data (however, this approach is intended only to estimate the *breakpoints*; estimates of other quantities obtained in the process of determining the breakpoints do not have to be used for management purposes).

Option for any of the above except A2.1: Use a decision-theoretic approach to compute the optimal breakpoints, possibly employing additional constraints such as a minimum length for the current regime or a maximum permissible CV for parameter estimates.

Pro: 1) Costs of mis-estimating a breakpoint are weighted appropriately.

Con: 1) Requires specification of a loss (cost) function. 2) More complicated than an approach that does not weight the costs of mis-estimating a breakpoint appropriately.

B1: Establishing criteria for excluding individual within-regime year classes from estimates

A simple but quantitative evaluation of the alternatives listed here is contained in Appendix C.

Alternative B1.1: Do not exclude any individual within-regime year classes from estimates.

Pro: 1) Eliminates the need to specify quantitative criteria for excluding individual year classes.

Con: 1) May include poorly estimated year classes (e.g., will stock assessment authors be required to estimate strengths of *all* year classes in the current regime, even age 0 in the current year?).

Alternative B1.2 (*provisional recommendation*): Exclude all year classes within the last *X* years (*provisional recommendation*: *X*=3, where year 1 is defined as the first age with a survey selectivity of at least 10%).

Pro: 1) Extremely easy to implement. 2) Always feasible, unless *X* is set higher than the largest age in the model.

Con: 2) No necessary relationship to precision of estimated year class strengths.

Alternative B1.3: Exclude all year classes with model-estimated CVs greater than *X*.

Pro: 1) Very easy to implement, where feasible. 2) Clear relationship to precision of estimated year class strengths.

Con: 1) May not be feasible, because model-estimated CVs vary greatly across assessments (for example, looking at the CVs of estimated year class strengths from 1977-2009 in the sablefish and EBS Pacific cod assessments, sablefish had only 3 year classes with a CV of less than 10% compared to 25 year classes for Pacific cod, while sablefish had 25 year classes with a CV of greater than 20% compared to 1 year class for Pacific cod).

Alternative B1.4: Exclude all year classes with model-estimated CVs greater than a fraction *X* (<1) of the CV at the first age included in the model.

Pro: 1) Very easy to implement, where feasible. 2) Clear relationship to precision of estimated year class strengths. 3) May be more feasible than B1.3, because the *relative* CV (rather than the *absolute* CV) is the criterion.

Con: 1) May still be infeasible (i.e., if *X* is set too low).

Alternative B1.5: Exclude all year classes with model-estimated CVs greater than a fraction *X* (>1) of the asymptotic CV (i.e., the limiting CV that is approached as the number of times a year class is observed becomes large).

Pro: 1) Clear relationship to precision of estimated year class strengths. 2) Where feasible, may be more intuitive than the other approaches, because this approach explicitly focuses on using only those year classes where the estimates have truly stabilized.

Con: 1) May be infeasible, because an asymptotic CV does not always exist. 2) The most difficult alternative to implement, because the asymptotic CV may vary from year class to year class.

C2: How knowledge of environmental forcing changes perceptions of reference points

Alternative C2.1 *(provisional recommendation)*: Acknowledge that current knowledge of environmental forcing is insufficient to alter perceptions of reference points quantitatively.

Pro: 1) Extremely easy to implement. 2) Probably an accurate description of the current state of knowledge for the vast majority (if not all) BSAI and GOA groundfish and crab stocks.

Con: 1) Does not advance the state of the art.

Alternative C2.2: Use knowledge of environmental forcing to compare past, present, and projected stock sizes with past, present, and future values of environmentally forced reference points.

Pro: 1) Keeps BSAI and GOA groundfish and crab on the cutting edge of fishery science and management. 2) Avoids comparing apples and oranges in terms of stock status and reference points (i.e., for any year, stock size would be compared to the reference point applicable to that year, as determined by the relevant past, present, or future values of the relevant environmental variables).

Con: 1) Extremely difficult to implement anytime in the near future, and almost certainly impossible to implement for the crab assessments that are due this September. 2) Criteria used to make status determinations and to measure rebuilding will be moving targets, even for a fixed set of biological data.

Appendix A: The April 2012 Workshop on Assessment/Management Issues Related to Recruitment

Agenda

	Wednesday, April 4	Speakers
0900	Welcome, purpose of workshop, introductions, appointment of rapporteurs	
	A. Identification of regime shifts, either for an ecosystem or some subunit thereof	
	1. Current policy on identification of regime shifts*	
0920	Estimating B_{MSY} for Tier 4 crab stocks and recruitment for Tier 3 crab stocks: Which years are representative?	B. Foy, D. Stram
0945	Jim Balsiger's memo of September 1999	Grant Thompson
0950	Discussion	
1010	- Break -	
	2. Possible improvements to current policy, including consideration of risk*	
1020	A null hypothesis to explain regime-like transitions in ecosystem time series	Emanuele Di Lorenzo
1045	Considerations of biological factors affecting potential crab production regimes	L. Rugolo, J. Turnoc
1110	Identification and management of stocks with regime-based recruitment	Cody Szuwalski
1135	Risk-based selection of regime boundaries for a stock managed under a sloping, SPR-based control rule	Grant Thompson
1200	Discussion	
1220	- Lunch -	
	B. Estimation of parameters (average recruitment, stock-recruitment relationships, σ_R)	
	1. Establishing criteria for excluding individual within-regime year classes from estimates*	
1320	Criteria for excluding individual within-regime year classes from estimates: current practice for EBS pollock	Jim Ianelli
1345	Accounting for uncertainty in estimated recruitment when computing stock status reference points: an example from the 2010 BSAI blackspotted/rougheye rockfish assessment	Paul Spencer
1410	Choice of recruitment periods for OFL determination and its impacts on Bristol Bay red king crab	Jie Zheng
1435	Discussion	
1455	Break	
	2. Use of "conditioned" stock-recruitment parameters (e.g., FMSY=F35%, BMSY=B35%)	
1505	Deriving steepness from F_{MSY} or F_{spr}	Steve Martell
1530	Discussion	
	3. Specification of priors, including hierarchical Bayes and other meta-analytic approaches	
1550	Use of stock-recruit steepness priors based on meta-analysis in West Coast rockfish assessments	Martin Dorn
1615	Preliminary results for developing Bayesian priors for relative cohort strength of groundfishes off the U.S. West Coast using multi-species Stock Synthesis models	Jim Thorson
1640	Discussion	
1700	- Adjourn for the day -	

* Critical items for May 2012 Crab Plan Team meeting

Thursday April 5th		

B. Estimation of parameters, continued

4. Alternatives for setting/estimating σ_R

0900	Problems associated with estimating recruitment and σ_R in a random effects model	G. Thompson
0925	Discussion	
	5. Determining "reliability" of the F_{MSY} pdf	
0945	Environmental factors affecting EBS pollock S-R relationships	Jim Ianelli
1010	Discussion	
1030	- Break -	
	6. Other issues involving the stock-recruitment relationship	
1040	Improving ecological validity and linkage among spawner recruitment, mortality, age structure, and harvesting models: An example from western rock lobster fishery neutrality harvesting model	Yuk W. Cheng
1105	Comprehensive analysis of the stock-recruitment relationship and reference points	Mark Maunder
1130	A new paradigm for stock-recruitment relationships: Viewing the stock-recruitment relationship as density dependent survival invalidates the Beverton-Holt and Ricker models	Mark Maunder
1155	Discussion	
1215	- Lunch -	

C. Forecasting environmental variability

1. Best practices for incorporating environmental forcing in stock assessments

1315	Advice for estimating fishery management reference points given low frequency between-year environmental variability	Melissa Haltuch
1340	Multispecies modeling, including projections and effects of temperature variability and predators on mortality estimates	Kirstin Holsman
1405	Environmental forcing of recruitment in the Bering Sea and Gulf of Alaska and its use in stock assessments and stock projections	Franz Mueter
1430	Recruitment products and indices from FOCI and BASIS – new proposed products for the Plan Teams and SSC	Jeff Napp
1455	Discussion	
1515	- Break -	
	2. How knowledge of environmental forcing changes perceptions of reference points*	
1525	F_{msy} and B_{msy} proxies by regime	Jim Ianelli
1550	Discussion	
1610	Wrap-up	
1630	- Adjourn -	

* Critical items for May 2012 Crab Plan Team meeting

Modifications to the Agenda

1. Lou Rugulo and Jack Turnock’s presentation under item A2 was withdrawn.
2. Unscheduled presentation by Andre Punt on use of surplus production models to estimate B_{MSY} in crab stocks was added in place of Rugulo and Turnock’s presentation under A2.
3. Martin Dorn’s presentation under item B3 was withdrawn.
4. Unscheduled presentation by Kerim Aydin on a multispecies model with an “emergent” stock-recruitment relationship was added under item C1.
5. Jim Ianelli’s presentation under item C2 was withdrawn.

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Appendix B: Establishing Criteria in Estimating B_{MSY}

CPT (May 2011) with SSC revision (June 2011)

These criteria to select the time period to represent B_{MSY} or B_{MSYproxy} should be included in the analysis in each SAFE.

The time period should be representative of the stock fluctuating around B_{MSY}. The time period should be representative of the stock being fished at an average rate near F_{MSY}. For Tier 3 we are looking for an average recruitment and not an average biomass (B_{MSYproxy} formally only applies to Tier 4).

1. Provide an estimate of the production potential of the stock over the full time period of the assessment.
    a. Identify if the stock below a threshold for responding to increase production.
    b. For Tier-3 stocks, provide the time series of ln(R/S) and recruitment (R). For crab stocks, S is mature male biomass at the time of mating, and R is model estimate of recruitment.
    c. For Tier-4 stocks, provide a surplus production analysis using biomass and catch to evaluate the production potential over time. Give the formula for surplus production (units of MMB). Annual surplus production (ASP_t) is equivalent to the amount of yield that could have been taken in a given year that would have left the stock at equilibrium,

        $ASP_t = B_{t+1} - B_t + C_t$

        B_{t+1} = biomass in year t+1

        B_t = biomass in year t

        C_t = catch in year t

        Also, evaluate the time series of survey recruiting size class as a recruitment index. If it looks consistent look at time series of survey R/S.
    d. Identify potential mechanisms that should be considered to support production changes (i.e. Regime Shifts) based on a. and b. above. Consider evidence of a change in magnitude and direction of life-history characteristics that support a proposed change in production.

        Candidate life-history characteristics (empirical data) include:
        i. Natural Mortality (M)
        ii. Growth
        iii. Maturity (maturity schedule)

    iv. Fecundity
    v. Recruitment & recruits/spawner
    vi. Candidate ecosystem characteristics (empirical data) include:
        1. Overland method of Regime Shift detection
        2. Change in production of benthic spp. in EBS.
        3. Consumption (ecosystem model output).

2. Provide a plot of the history of the exploitation rate on MMB at the time of the fishery relative to F_{MSY} (Tier-3) or relative to the F_{MSY}=M proxy (Tier-4).
3. Provide a plot of the history of the exploitation rate on MMB at the time of the fishery relative to ln(R/S) (Tier-3) or relative to ln(R_{OBS}/MMB_{OBS}) (Tier-4) where R_{OBS} is observed survey recruitment and MMB_{OBS} is observed survey MMB at the time of mating.
4. Examine the stock-recruitment relationship (SRR) for evidence of:
    a. Depensation in the SRR.
    b. Multiple SRRs consistent with a proposed regime shift paradigm.

The following methods were discussed by the CPT and SSC but considered not to be viable (see June 2011 SSC minutes). They are left in this version so that authors may comment on/ or consider their use.

5. For many crab stocks, historical rates of exploitation were higher or lower than current estimates of maximum rates fishing at F_{MSY}. The resultant B_{MSY} would be a biased (low or high) measure of reproductive potential since MMB at mating is tabulated after the extraction of the catch. If recruitment was maintained despite the difference, the extent of this bias is proportional to the magnitude of the catch above or below fishing at F_{MSY}. The recalculated B_{MSY} should be a better reference biomass estimate regardless of whether catches were larger or smaller than F_{MSY} catch.

6. For Tier-4 stocks, an alternative $B_{MSYproxy}$ can be estimated that adjusts for stock losses in excess of F_{MSY}. The analyst should estimate $B_{MSYproxy}$ based on the following approach:
    a. Using observed survey mature male biomass, estimate mature male biomass at the time of the fishery.
    b. Using the F_{MSY} proxy, estimate the catch using the biomass from (a).
    c. In years where exploitation rates exceeded those at F_{MSY}, replace the observed catch with that from (b) and recalculate MMB at mating.

d. Produce a new time series of MMB at mating replacing those years where MMB was recalculated in (c).
e. Recalculate B_{MSYproxy} over the reference time period with the new time series of MMB at mating derived in (d).

Appendix C: A simple analysis of the B1 alternatives

Assumptions common to all examples discussed here:

A. The observational data consist of a survey time series (of length *n*) of numbers at age, which, when log-transformed, are distributed normally about the true log numbers at age.
B. The time series of *Q*, selectivity at age, and *Z* at age are known.

   Given the above assumptions, after *n* observations, the CV of a cohort's estimated initial abundance (i.e., the abundance at some age prior to the age at the first observation) is equal to sqrt(*h*(*n*)/*n*), where *h*(*n*) is the harmonic mean of the time series of the log-scale observation error variances. To make things even simpler, an additional assumption will be used:

C. The log-scale observation error variance is equal to the following constant function of age (*t*): sigma^2 = exp(*a* + *b***t* + *c***t*^2).
   a. In the special case where *b*=*c*=0, the CV of the estimated initial abundance after *n* years is CV(n)=sqrt(exp(*a*)/*n*). Note that this value equals zero in the limit as *n* approaches infinity.
   b. In the special case where *b*≠0 and *c*=0, the CV of the estimated initial abundance after *n* years is CV(*n*)=sqrt(exp(*a*)*(exp(*b*)-1)/(1-exp(-*b***n*))). Note that this value equals zero in the limit as *n* approaches infinity, as in the *b*=*c*=0 case.
   c. In the general case where *b*≠0 and *c*≠0, there is no short-hand formula for the CV of the estimated initial abundance after *n* years . In contrast to the two previous cases, CV(*n*) reaches a positive asymptote (the "asymptotic CV") in the limit as *n* approaches infinity.

Alternatives for criteria pertaining to exclusion of the most recent within-regime year classes:

1. Exclude no year classes.
2. Exclude all year classes within the last *X* years.
   a. In the special case where *b*=*c*=0, the *proportional reduction* in CV relative to CV(1) will depend only on *X*, but the *absolute* CV will also depend on *a*.
   b. In the special case where *b*≠0 and *c*=0, the *proportional reduction* in CV relative to CV(1) will depend only on *X* and *b*, but the *absolute* CV will also depend on *a*.
   c. In the case where *b*≠0 and *c*≠0, both the *proportional reduction* in CV relative to CV(1) will depend only on *X*, *b*, and *c*; but the *absolute* CV will also depend on *a*.
3. Exclude all year classes with model-estimated CVs greater than *X*.
   a. In the special case where *b*=*c*=0, the number of years needed to achieve CV(*n*)=*X* and the *proportional reduction* in CV relative to CV(1) will both depend on *X* and *a*.
   b. In the special case where *b*≠0 and *c*=0, the number of years needed to achieve CV(*n*)=*X* and the *proportional reduction* in CV relative to CV(1) will both depend on *X*, *a*, and *b*.
   c. In the case where *b*≠0 and *c*≠0, it will be impossible to achieve CV(*n*)=*X* if *X* is set too low. If *X* is set sufficiently high, the number of years needed to achieve CV(*n*)=*X* and the *proportional reduction* in CV relative to CV(1) will both depend on *X*, *a*, *b*, and *c*.
4. Exclude all year classes with model-estimated CVs greater than a fraction *X* (<1) of the CV at the first age included in the model.

a. In the special case where $b=c=0$, the number of years needed to achieve CV(n)=X*CV(1) will depend only on X, but the *absolute* CV will also depend on a.
b. In the special case where $b\neq 0$ and $c=0$, the number of years needed to achieve CV(n)=X*CV(1) will depend only on X and b, but the *absolute* CV will also depend on a.
c. In the case where $b\neq 0$ and $c\neq 0$, it will be impossible to achieve CV(n)=X*CV(1) if X is set too low. If X is set sufficiently high, the number of years needed to achieve CV(n)=X*CV(1) will depend only on X, b, and c; but the *absolute* CV will also depend on a.

5. Exclude all year classes with model-estimated CVs greater than a fraction X (>1) of the asymptotic CV.
    a. In the special case where $b=c=0$, the asymptotic CV is zero, so the number of years needed to achieve CV(n)=X*CV(∞) will always be infinite.
    b. In the special case where $b\neq 0$ and $c=0$, the asymptotic CV is zero, so the number of years needed to achieve CV(n)=X*CV(∞) will always be infinite.
    c. In the case where $b\neq 0$ and $c\neq 0$, the number of years needed to achieve CV(n)=X*CV(∞) will depend only on X, b, and c; but the *absolute* CV will also depend on a.

Note that Alternative #1 is the only one that works regardless of the values of the parameters. However, this begs the question of what to count as the “first observation.” Here are some alternatives:

I. The first observation is the first age in the model. This definition could be problematic, because some models start at an age prior to the first age with data (e.g., SS always starts at age zero); conversely, an author might start the model well past the first age with data.

II. The first observation is the first age with relative abundance data for the cohort in question. This definition could be problematic if only a trivial amount of abundance data exist at the first age thus defined.

III. The first observation is the first age with *significant* relative abundance data for the cohort in question. This begs the question of what constitutes “significant.” Some sub-alternatives:
    i. “Significant” means an observation error CV of less than X. This definition could be problematic if X is set so low that the definition cannot be satisfied at any reasonably low age (or, worse, not at all).
    ii. “Significant” means estimated survey selectivity greater than X in the respective age and year.