Tanner Crab Assessment Report for the May 2017 CPT Meeting

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Executive Summary

This report summarizes the results of work since September 2016 to improve the Tanner crab stock assessment, as well as address CPT and SSC comments from previous meetings. Several alternative models to be evaluated for the Fall 2017 assessment are proposed for consideration by the CPT and SSC.

Responses to recent CPT/SSC comments

Jan. 2017 Modeling Workshop

Comment: The CPT recommends that model AMd (based on TCSAM2013) be presented as the base model in May 2017 unless Dr. Stockhausen can identify the reasons for the differences in results between Model AMd and TCSAM02.

Response: The differences between equivalent models based on the new TCSAM02 and old TCSAM2013 model codes have been resolved such that both model codes yield the same answers. Therefore, the TCSAM02 modeling framework was adopted for the base and alternative model scenarios suggested for the Fall 2017 assessment.

Comment: The CPT agreed that these extensions [including likelihood components based on growth data, chela height data] should be considered for inclusion in the set of models presented to the May 2017 meeting.

Response: Models that fit the new EBS growth data for Tanner crab, as well as previously-collected growth data from the GOA, are included in this report (most of the TCSAM02 models considered here include growth data from either the EBS, the GOA, or both). Results are discussed in Section 6. Appropriate chela height data have not yet been collected; consequently, models fitting chela heights are not included here.

Oct. 2016 SSC Meeting

Comment: The SSC supports recommendations by the CPT, including disaggregating bycatch mortality for groundfish fisheries into trawl and pot components.

Response: A model (TCSAM02 model B1) with Tanner bycatch in the groundfish fisheries disaggregated by gear type (fixed, trawl) after 1990 is considered. Results are discussed in Section 6.

Comment: The SSC requested the author look into apparent cycles in the coefficients of variation for an explanation of why they occur.

Response: It is unclear which cycles in cv's are referred to. Presumably this refers to the cv's for trawl survey biomass. This issue remains to be addressed.

Comment: The SSC would like to see Models D and higher brought forward with the additional likelihood component [i.e., for the effort extrapolation].

Response: A TCSAM02 model (AG1e) with additional likelihood components to estimate effort extrapolation parameters for bycatch in the snow crab and BBRKC fisheries is considered here. Results are discussed in Section 6.

Sept. 2016 CPT Meeting

Comment: the CPT found fishing mortality in the early period, which appears to be driven by fitting retained catch, to be unreasonably high. The CPT requested the author look into the M estimates during that period to try to find the specific reason the Fs are so high. Specifically, how do changes in M affect mean recruitment relative to the current model with high fishing mortality? Also, since survey q is hitting the lower bound for 1975-1981, the CPT recommends freeing up q to see if there is a change in F.

Response: This remains to be addressed. A model (AG1b) is considered in this report in which the priors on the survey q's are removed. However, this did eliminate the high F's.

Comment: The total selectivity curves in 1996 shift to the right and left with minor changes to the model likely due to the few data points informing that year. The CPT requests that the author run a scenario with the 1996 data removed from the data used to estimate selectivity in the pre-1991 period to determine how this affects results.

Response: As the CPT noted, the total selectivity curves in 1996 shift to the right and left with minor changes to the model likely due to the few data points informing that year, but also due to the fact that it is unduly influenced by the size-at-50%-selected parameter for the directed total selectivity curve used prior to 1991; the latter is taken as the average of the annual size-at-50%-selected parameters for 1991-1996. The 1996 curve is thus the tail waved by the pre-1991 dog, as it were. The TCSAM2013 models B5 and B6, and all the TCSAM02 models, considered here use the median, rather than the mean, size-at-50%-selected for 1991-1996 as the value for that parameter in the pre-1991 time period.

Comment: The CPT requests that methods used in Model E to reduce penalties on the F-devs be brought forward in future scenarios.

Response: This was addressed using TCSAM02 model AG1d here. Results are discussed in Section 6 in more detail, but this exacerbated problems with unreasonably high F's in some years.

Comment: What is the basis for the female survey q penalty?

Response: The Somerton "underbag experiment" is the basis for the prior on female survey q.

Comment: Are there extra weights set up to help with model convergence that have not been revisited?

Response: Priors are put on survey q parameters, mortality parameters, growth parameters, and recruitment deviations. Penalties are put on F-devs. Smoothing penalties are placed on the probabilities of terminal molt.

Comment: Are the penalties on the F-devs responsible for the total catch mortality in the groundfish fishery not fitting?

Response: My impression is that total catch mortality (or total catch biomass, not discounted for mortality, here) in the groundfish fisheries is fit rather well in the models.

Comment: Why are the retained catch estimates not fitting smaller size classes? The CPT recommends considering if there was a different retention function in those years.

Response: In the assessment, retention was estimated for two time periods: before 1991 and after 1990, the latter period corresponding to when information on total catch (retained + discard) became available. TCSAM02 model AG1c allows the size at 50% retained to vary annually during the 1991/92-

2015/16 time period, and appears to fit retained catch biomass and size compositions more closely, although at the cost of more estimated parameters.

Comment: Why does Model C underestimate small crab and overestimate large crab in the directed fishery size compositions relative to the 2015 model?

Response: Retention in the directed fishery east of 166W shifted to somewhat smaller crab in 2015/16, but this was not reflected in the estimated retention function, which was a single estimated function for 1991/92-2015/16. TCSAM02 model AG1c allows the size at 50% retained to vary annually during this time period, and appears to fit retained catch biomass and size compositions more closely, although at the cost of more estimated parameters.

Comment: Why does the model predict more, larger crab in the past 10 years in the model?

Response: This is probably related to overestimating growth and underestimating the probability of terminal molt in the model.

Comment: The CPT requested the author incorporate available growth data in stages: 1) new EBS data only, 2) old GOA data only, and 3) both datasets to assure there is no difference in the data. The CPT also recommended the author require the size composition data to fit better (less constrained by weighting) now that there is empirical growth data available.

Response: Growth data has been incorporated directly into the assessment model using the TCSAM02 framework. Models AG1, AG2a, AG2b, AG3 and AG4 address these issues.

Comment: The CPT requested in the future the groundfish fisheries be separated by trawl and pot and appropriate handling mortality rates be applied consistent with other EBS crab stocks.

Response: This has been addressed in the TCSAM02 framework. Model B1 provides an example of incorporating Tanner crab bycatch in the groundfish fisheries separately by trawl and fixed (pot and longline) gear after 1990.

Comment: The CPT recommended including the extra component associated with estimating the effort extrapolation parameters in the likelihood function.

Response: This has been addressed in the TCSAM02 modeling framework. Model AG1e provides an example of estimating the effort extrapolation coefficients for bycatch in the snow crab and BBRKC fisheries as model parameters using the extra likelihood component, rather than directly calculating the values for these coefficients. It appears this may introduce some undesired "feedback", though, between the F's supported by observations and the extrapolated F's.

1.0 Introduction

The purpose of this paper is: 1) to report on recent developments in the new Tanner crab stock assessment modeling framework (now "TCSAM02", formerly "TCSAM2015"); 2) to provide direct comparisons between equivalent models based on TCSAM02 and models based on the code used for the 2016 assessment ("TCSAM2013"; Stockhausen, 2016) to allow the CPT and SSC to approve the use of TCSAM02 as the basis for the September 2017 Tanner crab assessment; and 3) to provide a set of alternative model scenarios for the September 2017 Tanner crab assessment based on TCSAM02. Like TCSAM2013, TCSAM02 provides a size-structured integrated assessment environment based on AD Model Builder (Fournier et al., 2012), a suite of C++ libraries for developing models fit to data using automatic differentiation methods. However, TCSAM02, under development for the past two years, provides a much more flexible environment to TCSAM2013 for defining alternative models based on a set of model configuration files. TCSAM02 can fit new data types (e.g., molt increment) and fleets (fixed-gear groundfish) not currently possible in TCSAM2013. It also provides the option to calculate the OFL and associated quantities directly within the model, results thus retain full model uncertainty when calculated using MCMC (using TCSAM2013, the OFL is calculated in a separate projection model and incorporates uncertainty only in recruitment and end-year mature biomass).

A preliminary comparison at the May 2016 CPT Meeting between models using the two frameworks that were configured in similar (but not identical) fashion but fitting identical datasets provided encouragingly-similar, but not identical, results. Due to concerns regarding possible errors in the TCSAM02 code, the CPT suggested that future use of the TCSAM02 framework for the assessment was desirable, but requested additional testing be completed before it could be adopted. The CPT reviewed the results of a second round of comparisons at the January 2017 Modeling Workshop: agreement between supposedly "equivalent" models using the two frameworks was close, but not as close as expected.

Following the Modeling Workshop, I undertook one final effort to achieve "exactly equivalent" models based on the two frameworks that should yield exact agreement (to expected numerical accuracy). This effort was ultimately successful (see Section 4), but in order to achieve exact equivalence it was necessary to modify TCSAM2013 from the version used in the 2016 assessment (Stockhausen, 2016) to incorporate several new TCSAM02-like options, as well as to "retro-fit" TCSAM02 with several TCSAM2013-like options. As shown below, the changes to TCSAM2013 make sense in and of themselves in terms of improving the overall fit of models to the data. In addition, several errors in the input data files for the 2016 assessment have been found and corrected. All changes from the TCSAM2013 2016 assessment model to the base TCSAM02 model are reviewed here in an incremental fashion. The resulting "exactly equivalent" TCSAM2013 model exactly matches the base TCSAM02 model to expected numerical accuracy. This model, using the TCSAM02 framework, is proposed as the "base model" for the Fall 2017 assessment.

In addition to the "base model" for the Fall 2017 assessment, several candidate alternative models are also presented here. The expectation is that the CPT will select a small subset of the most promising alternative models, all based on the TCSAM02 framework, to evaluate as part of the assessment process in September 2017.

In Section 2, I provide an overview of the differences between the TCSAM2013 and TCSAM02 modeling frameworks. A detailed description of the TCSAM02 modeling framework is provided in Appendix A of Stockhausen (2017), while a similarly detailed description of the TCSAM2013 modeling framework is provided in that document's Appendix C. In Section 3, I review several corrections to datasets used in the 2016 assessment that are incorporated in models evaluated here. I also discuss several new datasets that may be included in the assessment using the TCSAM02 framework, including molt increment (growth) data and gear-specific bycatch data from the groundfish fisheries (see Appendices B and C here, as well). In Section 4, I discuss the options incorporated in the TCSAM2013 framework to achieve a model exactly equivalent to a similarly-configured TCSAM02 model and provide results from the series of TCSAM2013 models that document the incremental changes used to obtain the exactly equivalent TCSAM2013 model from the 2016 assessment model. In Section 5, I present results from the "exactly equivalent" TCSAM02 and TCSAM2013 models to document their agreement. In Section 6, I present a preliminary evaluation of several alternative model scenarios that could be selected for use in the Fall 2017 assessment. Finally, in Section 7, I make recommendations for alternative models to be evaluated for the Fall 2017 assessment.

2. An overview of differences between the TCSAM2013 and TCSAM02 modeling frameworks

The term "assessment model" can be used rather loosely, as in reference to 1) a specific computer program; 2) a specific program plus the data to be analyzed; or 3) a specific program plus the data to be analyzed plus the set of program options selected by the assessment author to fit the data, determine stock status, and set catch limits. To try to minimize confusion, then, I refer here to specific computer programs with unspecified data and options as "modeling frameworks" and to a specific program/data/options combination as a “model”. As noted previously, the 2016 Tanner crab assessment used the “TCSAM2013” modeling framework. This framework grew out of the Tanner crab assessment model developed by Turnock and Rugolo (2011), and subsequently modified (Stockhausen et al., 2013; Stockhausen, 2014; Stockhausen, 2015; Stockhausen, 2016). The computer code for the TCSAM2013 modeling framework is available on GitHub: the 2016 assessment model is on the “2016AssessmentModel” branch, while a version which allows direct comparison to the newer “TCSAM02” framework is on the “After201701ModelWkshp” branch. A detailed description of the TCSAM2013 modeling framework is provided in Appendix C of Stockhausen, 2017. While it has been a suitable basis for Tanner crab assessment model development since 2012, the TCSAM2013 framework is substantially limited in future development because, in particular, the number of fleets that can be accommodated in a model is fixed at four (retained catch and bycatch in the directed fishery and bycatch in the snow crab, BBRKC, and groundfish fisheries) while the time periods characterizing different growth, catchability and selectivity regimes are hard-wired in the code.

The TCSAM02 framework incorporates the most important features of the older TCSAM2013 framework, but provides much more flexibility in defining alternative models and accommodating new types of data. This framework also functions as an intermediate stage between TCSAM2013 and future versions of the Tanner crab model based on Gmacs. Key features that make TCSAM02 an improvement on TCSAM2013 are: 1) the ability to specify multiple time blocks for any model parameter in control files; 2) the ability to assign prior probabilities to any model parameter for each associated time block; 3) the ability to define characteristics of multiple fleets and associated data in control files, rather than editing the model framework itself; 4) the ability to specify data likelihood functions in control files, 5) the integration of growth (molt increment) and maturity (chela height) data into the model fitting process; 6) more selectivity function options, as well as the ability to define “availability” functions (ala the snow crab model); 7) numerous prior probability function options, 8) a more numerically-stable approach to growth, and 9) implementation of OFL calculations directly within the model. The TCSAM02 model code is also available on GitHub; the current development version is on the “EffortExtrapolation” branch (committed on April 7, 2017). A detailed description of the model equations is provided in Appendix A of Stockhausen (2017).

It is now possible to configure a TCSAM02 model to reproduce results from a TCSAM2013 model run by using an equivalent model configuration (selectivity functions, prior probability functions, likelihood types, etc.) and judiciously fixing parameter values (see Section 4). However, it appears that differences in the default parameterizations for several model processes result in the convergence of otherwise-equivalent TCSAM02 and TCSAM2013 models to different states (see Section5). As such, I focus here on describing model processes that have different default parameterizations in TCSAM2013 and TCSAM02, including natural mortality, growth, survey catchability, and directed fishery selectivity prior to 1991. In these cases, TCSAM02 has been “retro-fitted” with options to use the default TCSAM2013 parameterization.

2.1 Natural mortality

In TCSAM2013, the natural mortality rate on crab of sex *x* in maturity state *m* in year *y* (? ? ? ? , independent of shell condition and size) is given by:

$$? _{???} \quad ?\begin{cases} ?^{????} \cdot ??_{??} & ??h???\ ?? \\ ?^{????} \cdot ??_{??} \cdot ??^{?}_{????} & È \le ? \le È \end{cases}$$

where ? ???? is the (fixed) base rate (= 0.23), ?? ? ? is a sex- and maturity state-specific multiplier, and ?? ? ? ? ? ? is a sex-specific multiplier on mature crab during the “enhanced mortality” period from 1980 to

1984. In addition, the two values of ?? ? ? for immature crab are constrained to be identical. Priors on the ?? ? ? are applied assuming N(1,0.05) distributions.

In TCSAM02, ln-scale natural mortality rate on crab of sex *x* in maturity state *m* in year *y* (??? ? ? ?) is described by five parameters (the ? 's) using

$$??? \; ? ? ? \quad ?^{?} \quad ?^{?}_{?} \quad ?_{? \; ? ? ?} \cdot ?^{? \; ? ?}_{?} \quad ?_{? ? ? ?} \cdot ?^{? ? ?}_{?} \quad ?_{? ? ? ?} \cdot ?_{? \; ? ? ?} \cdot ?^{? ? ? \; ? ? ?}_{?}$$

where $?^{?}$ is the base (ln-scale) rate for all crab, $?^{?}_{?}$ is a constant offset for all crab for time block *t*, $?^{? \; ? ?}_{?}$ is a constant offset for all mature crab, $?^{? ? ?}_{?}$ is a constant offset for all female crab, and $?^{? \; ? ? \; ? ? ?}_{?}$ is a constant offset for all female crab. Here, *t* may refer to different time blocks for different parameters. Parameterization on the ln-scale was chosen to ensure that the corresponding arithmetic-scale rate was positive. While it is possible to find sets of parameter values that duplicate the natural mortality rates in TCSAM2013 using this parameterization, it does not allow one to specify priors that are exactly equivalent to those used in TCSAM2013.

2.2 Growth

In both TCSAM02 and TCSAM2013, mean post-molt size $\bar{?}_{? \; ? \; ?}$ is modeled as a power function of size *z*, with sex-specific parameters $?_{?}$ and $?_{?}$ using

$$\bar{?}_{? \; ? \; ?} \quad ?^{?_{?}} \cdot ?^{?_{?}}$$

where time blocks can be assigned to $?_{?}$ and $?_{?}$ in TCSAM02 to incorporate time-varying growth. Sex-specific normal priors are defined for the parameters in TCSAM2013; these can be duplicated in TCSAM02.

The sex-specific growth transition matrix, $\Theta_{? \; ? \; ? \; ?^{?}}$, in TCSAM2013 is given by

$\Theta_{? \; ? \; ? \; ?^{?}} \quad ?_{? \; ?} \cdot \Delta_{? \; ?^{?}}{}^{? \; ? \; ? \; ? \; ?} \cdot ?^{?\frac{\Delta_{? \; ?^{?}}}{?_{?}}}$	Sex-specific (*x*) transition matrix for growth from pre-molt *z* to post-molt $?^{?}$, with $?^{?} \geq ?$
$?_{? \; ?} \quad ?? \sum_{?^{?}} \Delta_{? \; ?^{?}}{}^{? \; ? \; ? \; ? \; ?} \cdot ?^{?\frac{\Delta_{? \; ?^{?}}}{?_{?}}} \; ?^{? \; ?}$	Normalization constant so $\grave{E} \quad ? \sum_{?^{?}} \Theta_{? \; ? \; ?^{?}}$
$\Delta_{? \; ?^{?}} \quad ?^{?} - ?$	Actual growth increment
$?_{? \; ?} \quad ??\bar{?}_{? \; ?} - ?? \; ?_{?}$	Mean molt increment, scaled by $?_{?}$

where $?_{?}$ is a fixed (not-estimated) scale factor. TCSAM02 includes this growth model as an option (mainly to match TCSAM2013 for testing), but its preferred growth model is similar to the one used in Gmacs:

$\Theta_{? \; ? \; ? \; ?^{?}} \quad ?_{? \; ? \; ?} \cdot \int_{?^{?} ? ??? \; ?}^{?^{?} ? ??? \; ?} \Gamma ? \frac{?'' - \bar{?}_{? \; ? \; ?}}{?_{? \; ?}} ? \; ??''$	Sex-specific (*x*) transition matrix for growth from pre-molt *z* to post-molt $?^{?}$, with $?^{?} \geq ?$

$?_{? ? ?} \quad ?? \; \Gamma ? \frac{?'' - ?_{? ? ?}}{?_{? ?}} ? ??''?$	Normalization constant so È ? $\Theta_{? ? ? ?}^{?}$ $?^{?}$

where the integral represents the cumulative gamma distribution across the $?^{?}$ size bin. The TCSAM2013 approach was intended as an approximation to the TCSAM02 approach; the latter may be more stable numerically from a convergence perspective.

2.3 Survey catchability

In TCSAM2013, fully-selected survey catchability for the annual NMFS EBS bottom trawl survey is parameterized by sex in two time periods

$$?_{? ?} \quad ? \; \begin{matrix} ?_{?}^{?} & ? & È & É \\ ?_{?}^{??} & È & & É \le ? \end{matrix}$$

Priors are placed on the parameters $?_{?}^{?}$ using normal distributions.

In TCSAM02, fully-selected catchability $?_{? ? ? ?}$ for survey *v* in year $? \in ?$ is parameterized on the ln-scale using

$$?_{? ? ? ? ?} \quad ?????_{?} \quad ??????_{? ?} \quad ?_{? \; ?? ?} \cdot ??????_{? ?} \quad ?_{? ???} \cdot ??????_{? ?} \quad ?_{? ???} \cdot ?_{? \; ?? ?} \cdot ???????_{? ?}?$$

where $????_{?}$ is the baseline ln-scale capture rate (for mature males), $??????_{? ?}$ is an additive modifier for time block *t*, $??????_{? ?}$ is an additive modifier for immature crab, $??????_{? ?}$ is an additive modifier for females, and $???????_{? ?}$ is an additive modifier for immature females. As with natural mortality, the ln-scale was chosen to provide positive-definite estimates of survey catchability. In contrast to natural mortality, however, it is possible to provide priors identical to those used in TCSAM2013 as well as achieve equivalent values.

2.4 Directed fishery selectivity prior to 1991

In TCSAM2013, total catch selectivity for males in the directed fishery is characterized as logistic across three time periods: before 1991, from 1991 to 1996, and after 1996. The logistic functions in each period are defined by two values: 1) β, a parameter characterizing the slope of the function and 2) z_{50}, the size at 50% selected. Two values of β, are estimated: one applying to the fishery before 1997, the other applying to the fishery after 1996. After 1990, z_{50} is estimated annually and is parameterized using

$$?_{???} \quad ?^{????_{??}? ??_{???}}$$

where $????_{??}$ is the ln-scale mean parameter and the $??_{???}$ are annual ln-scale "devs". Prior to 1991, z_{50} is set to the average $?_{???}$ from 1991 to 1996.

In TCSAM02, a similar approach can be taken, except that the value for z_{50} prior to 1991 cannot be calculated as an average over some time period; instead, it must be estimated (or fixed) as a parameter.

2.5 Effort Extrapolation

In both TCSAM2013 and TCSAM02, fishery-specific effort data is used to predict annual fully-selected fishery capture rates for Tanner crab bycatch in the snow crab and Bristol Bay red king crab fisheries in the period before at-sea observer data is available (prior to 1991), based on the assumed relationship

$$?_{? ?} \quad ?_{?} \cdot ?_{? ?}$$

where $?_{? ?}$ is the fully-selected capture rate in fishery f in year y, $?_{?}$ is the estimated catchability in fishery f, and $?_{? ?}$ is the reported annual, fishery-specific effort (in pots). In TCAM2013, the fishery *q*'s are estimated directly from the ratio of fishery mean *F* to mean *E* over the time period (t_f) when at-sea observer data is available from which to estimate the $?_{? ?}$'s as parameters:

$$?_{?} \quad \frac{\sum_{? \in ?_?} ?_{? ?}}{\sum_{? \in ?_?} ?_{? ?}}.$$

Note that, in this formulation, the fishery *q*'s are not parameters (i.e., estimated via maximizing the likelihood) in the model. In TCSAM2013, the time period over which *q* is estimated for each fishery is hard-wired. This approach is also available as an option in TCSAM02, although different time periods can be specified in the model options file.

A second approach to effort extrapolation in which the fishery *q*'s are parameters estimated as part of maximizing the likelihood is provided in TCSAM02 as an option, as well. In this case, the effort data is assumed to have a lognormal error distribution and the following negative log-likelihood components are included in the overall model objective function:

$$?_{?} \quad \sum_{?} \frac{\left[?Ú\,??_{? ?} \quad ?? - Ú\; ?\frac{?_{? ?}}{?_{?}} \quad ??? \right]^{?}}{É \cdot ?_{?}^{?}}$$

where $?_{?}^{?}$ is the assumed ln-scale variance associated with the effort data and $?$ is a small value so that the arguments of the ln functions do not go to zero.

2.6 Fitting Growth Data

Growth (molt increment) data represents a new data source that can be fit as part of a TCSAM02 model. Multiple datasets can be fit at the same time. This capability does not exist in TCSAM2013. The likelihood for each dataset ($_{?}$) is based on the same gamma distribution used in the growth model:

$$_{?} \quad -\sum_{? \in ?} \quad ?? \; ?\Gamma\, ?\frac{?_{?} - ?_{? ? ? ?}}{?_{? ? ?}} ??$$

where $?_{?}$ and $?_{?}$ are the pre-molt and post-molt sizes for individual *i* (of sex x_i collected in year y_i) in dataset *d*, respectively, $?_{? ? ? ?}$ is the predicted mean post-molt size for individual *i*, and $?_{? ? ?}$ is the scale factor for the gamma distribution corresponding to individual *i*.

3. Model data

3.1 Corrections to old datasets

In the course of developing "exactly equivalent" TCSAM2013 and TCSAM02 models, I discovered that the 2015/16 size *frequencies* for retained catch in the directed fishery used in the 2016 assessment (and subsequent models) were incorrect due to a transcription error converting from an Excel pivot table to the input data files for the assessment model. Fortunately, the errors in the resulting size *compositions* (i.e., normalized to sum to 1 over size) that were fit in the assessment model were almost negligible, so the impact on the assessment would have been very small (see Appendix A in the supplemental material).

3.2 New datasets

3.2.1 Growth data

Growth data collected from the EBS and near Kodiak Island were fit in several of the TCSAM02 models discussed below. These data are discussed more fully in Appendix B in the supplemental material. Growth data (molt increments for 2,821 crab) have been collected from Kodiak Island in the Gulf of Alaska over a fairly long time period (primarily in annual collections from 1994-2006). This data formed the basis for the priors placed on growth parameters in TCSAM2013 models (e.g., the 2016 assessment model and all TCSAM2013 models evaluated here). However, it has never been fit within a model before. The data from the EBS, collected during 2015 and 2016, represents the first time molt increment data have been collected there for Tanner crab. Individual crab (125) were collected at sea in the spring of 2015 and again in the spring of 2016. Sex was determined and pre-molt carapace width was measured. Immature females and all males were subsequently held until after molting occurred and the shell hardened. Post-molt carapace width was then recorded for each successfully-molted crab.

Estimated growth (mean post-molt size as a function of pre-molt size) from the 2016 assessment model appears to be reasonably consistent with the Kodiak data for females, particularly at pre-molt sizes larger than 50 mm CW, but overestimates post-molt size for males (Appendix B). It also overestimates post-molt size relative to the EBS data for both sexes (Appendix B).

3.2.2 Groundfish bycatch data

Tanner crab are taken incidentally as bycatch by several gear types in the groundfish fisheries, including trawl, longline, and pot gear. Until now, this bycatch has been fit in TCSAM2013 models based on estimates of annual catch biomass and size compositions from at-sea observer sampling aggregated across all gear types. Handling mortality rates appropriate to trawl-specific bycatch (0.80) have been applied to the gear-aggregated bycatch, although handling mortality rates for fixed gear (longline and pots) are assumed to be somewhat smaller (0.50). Since 1991, when reliable gear-specific bycatch information became available, the trawl-associated fraction of Tanner crab bycatch in the groundfish fisheries has declined substantially (Appendix C in the supplemental material). Consequently, handling mortality on tanner crab bycatch in the groundfish fisheries may be overestimated in recent years. Using information from the NMFS Regional Office's Catch Accounting System (CAS) and Catch-In-Areas databases, I disaggregated the post-1990 Tanner crab bycatch (biomass and size frequencies) into annual trawl gear and fixed (longline and pot) gear biomass and sex-specific size frequency components to be able to apply gear-specific handling mortalities in the assessment (Appendix C). This new dataset can be fit using the TCSAM02 framework, but not within the TCSAM2013 framework, because it adds two new bycatch fisheries to the assessment (post-1990 groundfish trawl- and fixed-gear fisheries), along with additional parameters to describe fishing capture rates and selectivity function and likelihood components to fit the data.

4. Changes to 2016 Assessment Model to achieve exact equivalence with TCSAM02

Changes to the 2016 assessment model that were necessary to achieve exact equivalence with a TCSAM02 model are provided in this section. All models discussed in this section were evaluated using 200 runs with "jittered" parameter values to provide a range of initial starting locations for the objective function minimizing procedure. The run resulting in the smallest objective function value and smallest maximum parameter gradient value was taken to be the global minimum solution. This jittering approach has been found to reduce the possibility that the minimum found by the minimization procedure is a local minimum on the multidimensional surface of the objective function, rather than the global minimum.

The 2016 assessment model is referred to in the discussion below as "AM". The following table (repeated as Table 1) outlines the incremental changes made to AM to achieve a TCSAM2013 model (T13B6) that is directly equivalent to a corresponding TCSAM02 model. Models AM, AMa, AMb, AMc and AMd were compared in detail at the 2017 Crab Modeling Workshop and thus are only discussed briefly below; details are available in the 2017 Modeling Workshop report (Stockhausen, 2017; available as a link from the workshop agenda). The CPT picked AMd as the model to use as the "base" for models presented at the May 2017 CPT meeting. Consequently, AMd was renamed B0 for this report.

Table A. TCSAM2013 model scenarios evaluated since the 2016 assessment. The "incremental change" column describes the changes to the model scenario from the previous model. Results from the first five models (AM-AMd) were discussed in detail at the 2017 Modeling Workshop, at which Model AMd was selected to be the base model for the May 2017 CPT Meeting.

TCSAM2013 Model	Incremental change
AM	2016 assessment model
AMa	AM + removed size-specific "old shell" re-classification for input data
AMb	AMa + fit to total capture (not mortality) size compositions
AMc	AMb + fit to total capture (not mortality) biomass
AMd	AMc + apply seasonal M after molt-to-maturity
B0	same as AMd
B1	B0 + fit to input survey biomass based on 1-mm size bins
B2	B1 + using 2.20462262 to convert from kg to lbs
B3	B2 + capture rates in RKF not explicitly set to 0 for 1984,1985 and 1994, 1995
B4	B3 + corrected retained size comps for 2015/16
B5	B4 + using median size-at-50% selected for TCF males pre1991 (not average)
B6	B5 + using post-1972 median F for GTF before 1973 (not average)
T13B6	same as B6; exactly equivalent to TCSAM02 model T02A

4.1 Model AMa: Fitting to "uncorrected" survey size composition data

Old shell male crab observed in the NMFS trawl survey have been classified as "mature" based on the dual assumptions that: 1) the "old shell" classification indicates that a crab has not molted in the year prior to observation and 2) immature crab molt every year. Thus, old shell male crab must have undergone their terminal molt and can be classified as "mature". However, there is some chance that immature crab that molt annually may be mistakenly classified as "old shell". To address this concern, prior to fitting the survey size compositions, the 2016 assessment model applied a size-specific correction for the fraction of old shell crab (Fig. 1 in Stockhausen, 2017) that were mature vs. immature to observed survey size compositions for male crab classified as mature old shell. This correction was also performed in the 2012-2015 assessments.

The effect of the correction was to increase the number of male crab classified as "immature" relative to those classified as "mature" in any given size bin, but its impact for a size bin depends on both the size-specific correction and the relative number of mature crab classified as new shell vs. old shell. Because most old shell male crab in the survey are larger than 90 mm CW, the effects were rather small (Fig. 2 in Stockhausen, 2017). This correction is not applied in TCSAM02, so the 2016 assessment model ("AM") was re-run without it ("AMa"). Changes relative to the 2016 assessment model were small.

4.2 Model AMb: AMa + fitting to fishery size compositions as total capture size compositions
Based on at-sea observer data, TCSAM02 fits fishery *capture* size compositions to the observed *capture* size compositions in the likelihood whereas the 2016 assessment model fit predicted fishery *mortality* size compositions to (supposed) fishery mortality size compositions derived from observed total capture size compositions. These two approaches are equivalent for the bycatch fisheries because the "observed" fishery mortality size compositions are simply scaled (by discard mortality) versions of the capture size compositions. However, this is not the case for male size compositions in the directed fishery because retention mortality is size-specific. In fact, the 2016 assessment model fit predicted size compositions for total male *mortality* in the directed fishery to observed size compositions for total male *capture* because the retained and discarded components of the at-sea observer size composition data can not be disaggregated to apply discard mortality correctly for the directed fishery. This approach was used in previous assessments (2012-2015) as well, but no alternative existed for those assessments because those models directly estimated fishery selectivity functions associated with fishing mortality, whereas the 2016 assessment model estimated fishery selectivity functions associated with total capture and subsequently derived total mortality size compositions based on aggregating size-specific retained and discard mortality predicted separately. In retrospect, this was not the best use of the observed fishery size composition data for the 2016 assessment, because these reflected total capture size compositions. Consequently, an option was added to TCSAM2013 to fit predicted total capture size compositions to observed total capture size compositions—consistent with TCSAM02. Model "AMb" implemented this option, but was otherwise identical to AMa.

The effect of the change from fitting predicted total mortality size comps to observed total catch (i.e., capture) size comps (AMa) to the more consistent practice of fitting predicted total catch size comps to observed total catch size comps (AMb) is to shift the predicted total mortality size comps in AMa slightly toward larger sizes than the predicted total catch size comps in AMb (Fig. 15 in Stockhausen, 2017) while the corresponding predicted total catch size comps in AMa are slightly left-shifted to smaller sizes relative to AMb (Fig. 16 in Stockhausen, 2017). This resulted in large changes in the likelihood components for retained catch and total male catch size compositions in the directed fishery (Table 1 in Stockhausen, 2017). The total objective function was substantially reduced in AMb relative to AMa (151.5 likelihood units), reflecting much better fits to the size compositions for retained males (55.6 units) and captured males (102.1 units) in the directed fishery for AMb. Somewhat offsetting these improvements, AMb exhibited poorer fits to survey size compositions for mature crab (males: -10.2 units, females: -8.4 units).

4.3 Model AMc: AMb + fitting to fishery biomass time series as total capture biomass time series
TCSAM02 fits time series of predicted total capture biomass in the fisheries to time series of observed (based on at-sea and dockside observer data) total capture biomass, whereas the 2016 assessment model fit time series of predicted total biomass mortality in the fisheries to time series of observed (based on at-sea and dockside-based observer data) total biomass mortality. Consequently, an option was added to TCSAM2013 to fit time series of predicted total capture biomass in the fisheries to time series of observed total capture biomass. Model "AMc" implemented this option, but was otherwise identical to AMb.

Estimated natural mortality rates, terminal molt probabilities , and mean growth increments were almost identical for the two models (Fig.s 29-31 in Stockhausen, 2017). Estimated annual recruitment, population abundance trends, mature biomass-at-mating, and predicted survey biomass were also very similar for the two models (Fig.s 32-35). Estimated retained catch biomass was practically identical in the two models prior to 1993, but estimates were slightly higher for AMC relative to AMb from 1993-2010 while they were slightly lower in 2014 and 2015 (Fig. 36 in Stockhausen, 2017). The fishery catch mortality biomass data used to fit AMb was actually better fit by the equivalent estimated time series from AMc, even though AMc was fit using observed total fishery captured biomass (Fig.s 41-44 in Stockhausen, 2017).

4.4 Model AMd: AMc + applying natural mortality after molt-to-maturity

TCSAM02 applies natural mortality rates for mature crab to immature crab immediately following their molt to maturity whereas the 2016 assessment model continued to apply natural mortality rates for previously immature crab after their terminal molt (i.e., crab newly characterized as new shell mature crab) until the end of the year in which the terminal molt occurred. Consequently, an option was added to TCSAM2013 to apply natural mortality rates for mature crab to immature crab immediately following their molt to maturity, consistent with TCSAM02. Model "AMd" implemented this option, but was otherwise identical to AMc.

Estimated natural mortality rates were very slightly lower for immature crab in AMd, compared with AMc, while rates for mature crab were very slightly higher during 1980-1984 (the enhanced mortality period) but otherwise identical (Fig.s 45 and 46 in Stockhausen, 2017). Fits to survey size compositions were better for immature males crab (by 20.3 likelihood units; Table 1 in Stockhausen, 2017), but worse for mature crab (by -20.7 units), for AMd relative to AMc. The fit to mature survey catch biomass was improved in AMd relative to AMc (by 8 likelihood units). Otherwise, results were very similar between the two models.

4.5 Models B0-B6

Following the January Modeling Workshop, the CPT recommended, and the SSC concurred, that AMd be the basis for alternative models considered at the May 2017 CPT Meeting. As such, the TCSAM2013 model AMd has been re-named "B0" for this report, reflecting its use as the basis for the series of incremental TCSAM2013 models B1-B6. This series of models resulted primarily from a series of incremental changes to the TCSAM2013 framework to incorporate options that (if selected) would more closely align a TCSAM2013 model with a corresponding TCSAM02 model. This series also incorporates, however, a couple of corrections to the underlying data that were discovered during this process. As is shown in Section 4, the resulting final TCSAM2013 model considered here (B6) is indeed "exactly equivalent" to the TCSAM02 model T02A.

4.6 Model B1: B0 + fit to input survey biomass based on 1-mm bin sizes

The most precise estimates of annual sex-specific mature biomass from the NMFS bottom trawl survey are based on converting crab size, to 1-mm CW precision, to weight based on established size-weight relationships. This also allows estimation of associated uncertainty in the estimates. In TCSAM2013, however, the annual estimates of sex-specific mature biomass from the NMFS bottom trawl survey that are fit in a model are based on converting the input annual 5-mm bin size frequencies to biomass and summing over shell condition for mature crab by sex. This re-calculation may result in some loss of accuracy due to the wider size bins used in TCSAM2013, while the associated uncertainty in the estimates cannot be calculated within the model (it has been calculated outside the model and provided as an input). TCSAM02, in contrast, uses estimates (and associated uncertainties) of annual biomass based on the original 1-mm CW precision calculated outside the model. To develop an "exactly equivalent" model comparison, I chose to modify TCSAM2013 to include the option to fit input annual sex-specific mature biomass from the NMFS survey based on the same time series for mature survey biomass as would be fit in a TCSAM02 model, rather than recalculating the annual biomass based on the input size compositions. Model B1 uses this option, but is otherwise identical to B0.

4.7 Model B2: B1 + using better conversion from kg to lbs

In the course of developing "exactly equivalent" TCSAM2013 and TCSAM02 models, I discovered that TCSAM2013 used a rather poor approximation (2.2045) to convert input catch biomass data from weight in lbs to kg. I chose to modify TCSAM2013 to include the option to use the conversion factor 2.20462262, as is done in TCSAM02. Model B2 uses this option, but is otherwise identical to B1.

4.8 Model B3: B2 + corrected input bycatch data from the BBRKC fishery

In TCSAM2013, annual effort is used to estimate capture rates for Tanner crab bycatch in BBRKC fishery prior to 1992, based on the ratio of average capture rates to average effort after 1991. Although no Tanner bycatch occurred in the BBRKC fishery during 1994/95 and 1995/96 because it was closed to most fishing, a small amount of effort was recorded for these years, and both the effort and the zero-bycatch values were (mistakenly) included in the input data files. Unfortunately, including values for these years in the input files resulted in estimating ln-scale capture rate "devs" for them, as well—even though capture rates in the BBRKC fishery were explicitly set to zero in the code for 1994/95 and 1995/96. Clearly this is inappropriate and could lead to model instability, so the input data files for bycatch in the BBRKC fishery were modified to effectively set both the bycatch and the effort for these years to zero, which also excluded estimation of associated capture rate devs. Model B3 implements these changes, but is otherwise identical to B2.

4.9 Model B4: B3 + corrected retained size compositions for 2015/16

Model B4 incorporates the corrected retained catch size compositions for 2015/16 (see Section 3 and Appendix A), but is otherwise identical to B3.

4.10 Model B5: B4 + male size-at-50%-selected in directed fishery before 1991 based on median value after 1990

In TCSAM2013, prior to now the size-at-50%-selected for male Tanner crab in the directed fishery before 1991, the first year in which total capture size compositions are available, was set to the mean value over the 1991-1996 time period. It is not possible to do this using TCSAM02, although it is possible to use the median value. As such, I modified TCSAM2013 to include the option to use the median value for male size-at-50%-selected over the 1991-1996 time period, rather than the mean, as the estimated value before 1990. Model B5 uses this option, but is otherwise identical to B4.

4.11 Model B6: B5 + bycatch capture rate in groundfish fisheries before 1973 based on median value after 1972

In the 2016 implementation of TCSAM2013, the pre-1973 capture rate for Tanner crab bycatch in the groundfish fishery was assumed to be equal to its mean value during the data-informed period (i.e., after 1972). This is not possible in TCSAM02, although it is possible to use the median capture rate. Consequently, I modified TCSAM2013 to include the option to use the post-1972 median capture rate for Tanner crab bycatch in the groundfish fisheries as the estimate for the capture rate prior to 1973. Model B6 uses this option, but is otherwise identical to B5.

4.12 Comparisons between models B0 through B6

Appendices D1 and D2 in the accompanying online documents provide detailed comparisons of the results from model B0 through B6, which are summarized here. These results indicate little difference among the models for almost all quantities examined. Of all the models, B5 and B6 tended to exhibit the largest differences with B0, although these were still small. Estimated population processes (natural mortality rates, probabilities of terminal molt, and growth) were nearly identical for all models (Appendix D1, Fig.s 1-9; Appendix D2, Fig.s 1-9). Estimated recruitment, mature biomass, population abundance, and population biomass trends were also nearly identical (Appendix D1, Fig.s 11-26). Recruitment estimates differed from B0 by up to 3% (B6) before 1965, but differed less than 0.5% after 1980 (Appendix D2, Fig. 12). Estimates of population abundance and biomass also differed by up to 3% (B6) before 1970, but differed less than 0.5% after 1985.

As with population-related quantities, survey-related quantities varied little among models (Appendix D1, Fig.s 27-40; Appendix D2, Fig.s 30-52). Estimates of survey catchability varied less than 0.3% (Appendix

D2, Fig. 30), while estimates of survey abundance and biomass differed less than 1% (Appendix D2, Fig.s 37 and 51) , except for mature old shell males in 1980, in which models B5 and B6 were 2% and 3% smaller than B0 for survey abundance and biomass, respectively (Appendix D2, Fig. 51).

Fishery-related quantities also exhibited only small differences, in general (Appendix D1, Fig.s 41-121; Appendix D2, Fig.s 52-148). Estimated fully-selected fishery catchability in the directed fishery for models B5 and B6 was somewhat smaller (5% for males) than the other models in 1979 and somewhat larger (15%) in 1996 (Appendix D1, Fig. 41; Appendix D2, Fig. 53). Differences between models for fishery catchability in the snow crab, BBRKC, and groundfish fisheries were small (<0.03) in absolute scale for all years (Appendix D2, Fig.s 56, 58 and 60). Differences for BBRKC catchability relative to B0 appear large for models B3 and above (±50%) in 1984-1985 and 1994-1995, but these are associated with either capture rates hard-wired to zero in 1984-85 (B0-B2) or input catch data set to zero in 1994-1995 (B3-B6) (Appendix D2, Fig. 59). Catchability in the groundfish fisheries differed by 8% for model B6 relative to B0 prior to 1973, but this was due to using the post-1992 median capture rate, rather than the mean capture rate, as the assumed value before 1973 (Appendix D2, Fig. 57).

Models B5 and B6 exhibited differences in male selectivity in the directed fishery (TCF) prior to 1997 relative to B0 (Appendix D1, Fig.s 45 and 46; Appendix D2, Fig.s 61-64) because B5 and B6 use the estimated median size-at-50%-selected over 1991-1996 rather the mean size for fishery selectivity before 1990. The remaining selectivity curves for the directed fishery, as well those for the bycatch fisheries, were practically identical among the seven models (Appendix D1, Fig.s 47-68; Appendix D2, Fig.s 65-76). The estimated retention functions for the directed fishery were also very similar, although the pre-1990 function rose slightly more slowly for models B5 and B6 relative to model B0 (Appendix D1, Fig. 69; Appendix D2, Fig.s 77-78).

Model-predicted total catch abundance trends in the directed fishery (Appendix D1, Fig. 73; Appendix D2, Fig.s 79 and 80) are very similar for models B0-B4, but differ somewhat these for models B5 and B6, reflecting associated differences in catchability and selectivity. Ignoring model spin-up years (i.e., prior to 1965), predicted female catch abundance was about 5% smaller for models B5 and B6, relative to model B0, except during the 1991-1996 prior to the fishery closure when it was 5% larger. For males, predicted male catch abundance after model spin-up was higher (up to 17% higher for immature males) for models B5 and B6 relative to B0 prior to 1991, the first year total catch data (biomass, size frequencies) were fit in the models. After 1990, relative differences with B0 were substantially reduced, except for immature males in 1995 and 1996, when they dipped to ~5% smaller. In terms of absolute differences, the largest (~46 million mature [new shell + old shell] crab) for B5 and B6 relative to B0 occurs in 1979, the year before retained catch size frequencies are first fit in the models. Model-predicted catch biomass trends in the directed fishery (Appendix D1, Fig. 77; Appendix D2, Fig.s 135 and 136) are similar in nature, although in terms of largest absolute difference for models B5 and B6 relative to B0, the former predict catch biomass ~ 30 thousand t larger than B0 in 1979.

Model-predicted total bycatch abundance and biomass trends in the snow crab fishery (Appendix D1, Fig.s 72 and 76; Appendix D2, Fig.s 81, 82, 137, and 138) are very similar for models B0-B4, but differ somewhat for models B5 and B6, reflecting their associated differences in catchability (see discussion above) almost exactly. Model-predicted total bycatch abundance and biomass trends in the groundfish fisheries (Appendix D1, Fig.s 73 and 77; Appendix D2, Fig.s 83, 84, 139, and 140) are also very similar for models B0-B4, but again differ somewhat for models B5 and B6, closely reflecting their associated differences in catchability (see discussion above). This is also the case for model-predicted total bycatch abundance and biomass trends in the BBRKC fishery (Appendix D1, Fig.s 71 and 75; Appendix D2, Fig.s 86, 142).

Values for the likelihood components in each model's converged objective function are given in Table 2 as absolute values and in Table 3 as differences from the previous model in the incremental series. Although model B1 exhibits a somewhat poorer fit to the data than B0 (~3 likelihood units), with a slightly better fit for the fits to mature male size compositions in the survey but slightly worse fits for survey biomass (~-2 units) and mature female size compositions in the survey (-2.9 units), the survey biomass data being fit is slightly different in the two models (B1converts size compositions to biomass based on 1-mm size bins, whereas B0 used 5-mm size bins), so these differences are not really comparable. It is worth noting, however, that the non-survey-related components do not exhibit any substantial change as a result of changing the survey biomass.

Using a more accurate conversion from kg to lbs in model B2 leads to no appreciable change in the likelihood components relative to B1 (Tables 2, 3). In contrast, not explicitly setting the fishery capture rates for Tanner crab bycatch in the BBRKC fishery to zero in 1984/85 and 1985/86, and setting effort to zero in 1994/95 and 1995/96, in Model B3 lead to a large improvement in the penalty applied to the BBRKC F-devs (11.97 units), but only very small offsetting changes in other components (fits to bycatch biomass in the BBRKC fishery improved by 0.58 units but fits to bycatch size compositions worsened by 0.54 units). Not surprisingly, fitting the correct retained catch size compositions for 2015/16 (B4) changed the value of the corresponding likelihood component (by 9.1 units relative to that for B3), but changes to the other components were small (the fits to male total catch biomass in the directed fishery and survey size compositions for immature males improved 0.7 and 0.6 units, respectively). The change to using the size-at-50% selected for males in the directed fishery before 1991 based on the 1991-1996 median, rather than the average, (B5) improved fits (relative to B4) to size compositions for retained catch (8 units), as well as to fits to size compositions for bycatch in the groundfish fisheries (4.3 units), mature males in the survey (4.7 units), and mature females in the survey (6.7 units). Only the fit to size compositions for immature males in the survey worsened substantially (-7.5 units). Using the median post-1972 fully-selected capture rate for bycatch in the groundfish fisheries prior to 1973, rather than the mean, (B6) resulted in only very small (< 0.3 units), mostly offsetting changes in the fits to data and other likelihood components.

In summary, then, the incremental changes from B0 to B6 are either associated with changes to the data being fit (in which case comparing likelihoods to judge model fit is not really valid; B1-B4) or with, at worst, unimproved fits (B6) or, at best, a much improved fit (B5). As such, TCSAM2013 model B6 seems a reasonable model to adopt as the model which should be matched by an "exactly equivalent" TCSAM02 model.

5. TCSAM02 vs. TCSAM2013: Exactly equivalent model results

Equivalent model options, model processes and time blocks, likelihood components and weighting, and parameter scales and prior distributions were chosen such that the TCSAM02 model "T02A" is an "exactly equivalent" model to TCSAM2013 model B6. As noted above, this required adding several processing options to the TCSAM2013 framework to align possible model configurations with that of the TCSAM02 framework. But it also required adding more processing options than were originally considered necessary (in particular, parameter scaling options) to the TCSAM02 framework. It also required judicious definition of model time blocks (e.g., selectivity periods), likelihood components and weights, and selectivity normalization factors to achieve models that were "exactly equivalent" across the two model frameworks.

However, this effort was successful and the "exact equivalence" between TCSAM2013 model B6 and TCSAM02 model T02A is illustrated in Appendix E in the online supplementary material. For example, differences in estimated population processes such as natural mortality, probabilities of terminal molt, and mean growth differ by less than 5×10^{-4} units (Appendix E, Fig.s 1, 3 and 5). Estimated recruitment differs by less than ~1×10^{-3} percent for almost all years, as do estimated population abundance and population biomass (Appendix E, Fig.s 12, 14, and 28). Similar levels of agreement exist for estimated survey catchability, selectivity, abundance and biomass estimates (Appendix E, Fig.s 30-52) and for fishery catchability, selectivity and retention curves, total catch abundance and biomass, and retained catch abundance and biomass (Appendix E, Fig.s 53-138). It should be noted when reviewing these figures that percent differences can be rather large (> 10%) even when the absolute differences are tiny because the values involved are extremely small. In addition, because TCSAM2013 and TCSAM02 differ on whether selectivity functions are defined (TCSAM2013) or not (TCSAM02) for years when a fishery is closed, the figures comparing selectivity functions may depict differences of 100% during years when a fishery was closed.

The conclusion of "exact equivalence" between B6 and T02A is further reinforced by examining the differences between equivalent likelihood components for the converged models (Tables 4-6). The largest difference between likelihood components related to survey data was 3.4×10^{-4} (relative to 291 units) for the fit to mature male size compositions (Table 4). For fishery data, the largest difference between likelihood components was 9.7×10^{-5} (relative to 35.8 units) for the fit to male bycatch biomass in the BBRKC fishery (Table 5). Finally, the largest difference between likelihood components related to penalties and priors was 1.4×10^{-4} (relative to 26.7 units) for the female survey "q" penalty.

The equivalence between the results from the two model frameworks is rather remarkable because the agreement is based on models in which parameters were estimated, not simply fixed to identical values. This would appear to demonstrate that the TCSAM02 framework can be adopted for use in the September 2017 assessment without fear of a major disconnect with the TCSAM02 framework.

6. Further TCSAM02 model scenarios

6.1 Model scenarios

In addition to demonstrating that T02A was "exactly equivalent" to T13B6, I examined fourteen additional TCSAM02 model scenarios (see Table B, which duplicates Table 7).

Table B. Potential TCSAM02 model scenarios to be considered for the Fall 2017 assessment.

TCSAM02 Model	# of parameters	Description
T02A	332	exactly equivalent to TCSAM2013 model T13B6
AG0	332	T02A + use Gmacs growth function
AG1	332	AG0 + include EBS growth data
AG1a	332	AG1 + eliminate F penalties
AG1b	332	AG1 + eliminate priors on survey q
AG1c	351	AG1 + include annual size-at-50% selected deviations in retention function
AG1d	332	AG1 + estimate M parameters on ln-scale
AG1e	334	AG1 + estimate effort extrapolation parameters using likelihood
AG2a	332	AG0 + include EBS growth data + remove priors on growth parameters
AG2b	332	AG0 + include GOA growth data + remove priors on growth parameters
AG3	332	AG0 + include EBS and GOA growth data + remove priors on growth parameters
AG3a	332	AG3 + reduced weights in likelihood for growth data
AG3b	332	AG3 + reduced weights in likelihood for size compositions
AG4	334	AG3 + estimate scale factor for growth gamma distribution
B1	396	AG4 + AG1c + bycatch data from groundfish fleets separated into trawl and fixed gear components

These scenarios explore the use of different model configurations and different datasets in order to recommend a subset (or combination) to be evaluated as alternative models for the Fall 2017 assessment. The logical relationships between these models is outlined in Figure 1 below. Given time constraints, it was not always possible to develop a series of models based on incremental-changes to compare results between. Thus, for example, the models T02, AG0, AG1, AG2, and AG3 constitute a series of incrementally-changed models, but the models AG1a, AG1b, AG1c, AG1d and AG1e constitute a set of models each related to AG1 by a single incremental change, but the changes are “orthogonal” between models.

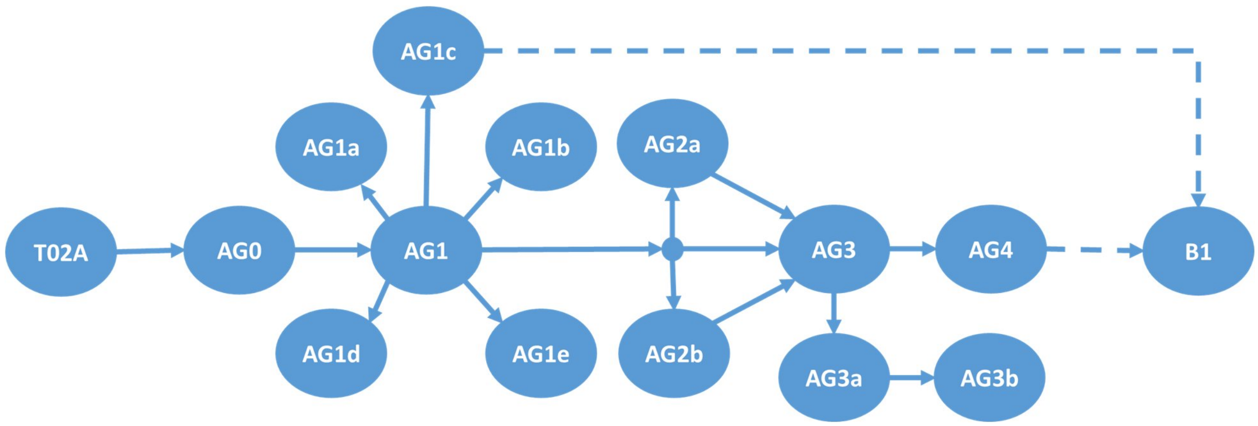

Figure 1. Logical relationships among the alternative TCSAM02 models discussed here. Solid lines denote incremental changes between models, dashed lines indicate multiple changes between models.

6.1.1 AG0 (332 parameters)

The assessment model and subsequent TCSAM2013 models, as well as T02A, represent the annual size transition matrices using an approximation to the cumulative gamma distribution (see Section 2.2 for details). TCSAM02 model AG0 and all subsequent models represent these matrices using ADMB’s cumulative gamma distribution, which should exhibit better numerical stability when estimating parameters. Otherwise, AG0 was identical to T02A.

6.1.2 AG1 (332 parameters)

Model AG1 includes fitting the growth data from the EBS in the likelihood as part of the overall minimization of the model objective function. The likelihood is described in Section 2.6. Otherwise, AG1 is identical to AG0.

6.1.2 AG1a (332 parameters)

Model AG1a eliminates the penalties placed on fishery capture rate deviations by reducing the weights placed on them in the objective function by phase, starting in phase 2 of the minimization process such that the weights are 0 in phase 5 (the final estimation phase). Otherwise, AG1a is identical to AG1.

6.1.3 AG1b (332 parameters)

In AG1 (and AG0, T02A and the TCSAM2013 models), normal priors were applied separately for the male and female survey catchability (q) parameters associated with surveys after 1981. The prior mean and standard deviation for both q’s were taken as 0.88 and 0.05, respectively, based on Somerton’s “underbag” experiment (Somerton, 1999). Model AG1b addresses a CPT/SSC request and removes these priors. Otherwise, AG1b is identical to AG1.

6.1.4 AG1c (351 parameters)

In AG1, retention curves in the directed fishery are estimated for two time periods, pre-1991 and post-1990, but don’t vary within either time period. Since 1991, however, there have been several changes in the size of crab “preferred” by the industry, as well as the prosecution of the fishery itself, and it has been suggested that using a single curve to describe retention in the post-1990 time period may not be ideal. Consequently, Model AG1c estimates annual deviations (for years when the fishery was active) to the size-at-50%-retained parameter used to describe retention in the post-1990 time period. This added 19 parameters to the model. Otherwise AG1c is identical to AG1. This model scenario addresses a CPT/SSC request to consider using multiple retention curves to describe the directed fishery in recent years.

6.1.5 AG1d (332 parameters)

In AG1 (and AG0 and T02A), to match the approach taken in TCSAM2013 models, a natural mortality rate of 0.23 was assumed as a baseline, and multiplicative scaling factors were estimated on the arithmetic scale for immature crab, mature male, and mature female crab, as well as additional multiplicative scaling factors for natural mortality on mature males and mature females in the 1980-1984 time period. Priors were placed on all the multiplicative factors, except on those specific to the 1980-1984 time period. The default parameterization in the TCSAM02 framework for sex/maturity stage- or time period-specific changes to the baseline natural mortality rate is on the ln-scale, not the arithmetic scale. Model AG1c uses this default parameterization, rather than the TCSAM2013 parameterization. Otherwise, it is identical to AG1.

6.1.6 AG1e (334 parameters)

In AG1e, additional likelihood components fitting observed effort (Section 2.5) were included in the model objective function to estimate fishery-specific *q*'s as model parameters to extrapolate annual effort data to Tanner crab bycatch rates for the snow crab and BBRKC fisheries prior to 1991. This added 2 parameters to the model, one for each fishery in which effort was extrapolated. Otherwise, AG1e was identical to AG1.

6.1.7 AG2a (332 parameters)

Model AG2a was identical to AG1, except that it eliminated the priors, developed from the Kodiak growth data, placed on the growth-related parameters. Another way of describing AG2a would be to say it was identical to AG0, except that it fit the EBS data and eliminated the priors on the growth-related parameters.

6.1.8 AG2b (332 parameters)

Model AG2b is identical to AG0, except that it fits the Kodiak growth data and eliminates the priors on the growth-related parameters. Thus, it is also related to AG2a by a single incremental change (i.e., the Kodiak growth data substituted for the EBS growth data).

6.1.9 AG3 (332 parameters)

Model AG3 fits both the EBS and Kodiak growth datasets and eliminates the priors on the growth-related parameters. Models AG2a, AG2b, and AG3 together address a request by the CPT/SSC.

6.1.10 AG3a (332 parameters)

Model AG3a reduced the weights placed on the growth data likelihoods from 10 to 1 for the EBS data and from 1 to 0.01 for the Kodiak data. Otherwise it was identical to AG3.

6.1.11 AG3b (332 parameters)

Model AG3b reduced weights placed on all size composition data likelihoods from 1 to 0.1. Otherwise it was identical to AG3a.

6.1.12 AG4 (334 parameters)

Model AG4 estimated the sex-specific shape parameters for the gamma distributions used to describe growth. These were fixed in all previous models. This added two parameters to the model. Otherwise it was identical to AG3.

6.1.13 B1 (396 parameters)

The TCSAM02 model B1 incorporates and fits growth data in the same manner as AG4 (adding 2 parameters relative to T02A). It estimates annual deviations in size-at-50%-retained for retention curves in the directed fishery after 1991 in the same manner AG1c (adding 19 more parameters relative to T02A). It also fits to different bycatch biomass and size composition data from the groundfish fisheries than was fit in any previous model. B1 fits to gear-aggregated ("all gear") bycatch biomass and size compositions in the groundfish fisheries prior to 1991, as in previous models, but to gear-disaggregated ("fixed" and "trawl") bycatch biomass and size compositions after 1990 (see Appendix C). Sex-specific selectivity curves are estimated for the "all-gear" bycatch in two time periods: pre-1987 and 1987-1990. They are estimated separately for the "fixed gear" and "trawl gear" bycatch in two time periods as well: 1991-1996 and post-1996. These time periods were chosen to based on those used for previous models, which estimated sex-specific "all gear" selectivity curves in three time periods: pre-1987, 1987-1996, and post-1996. In previous models, the selectivity curves in all time periods were assumed to be ascending logistic functions of crab size. In B1, the selectivity curves for the "all gear" and "fixed gear" bycatch are assumed to be logistic, as well. However, the selectivity curves for the "trawl gear" bycatch are assumed to be dome-shaped (see discussion in Appendix C). Consequently, 32 parameters related to bycatch selectivity in the groundfish fisheries are estimated in model B1, whereas only 12 parameters were estimated in previous models.

6.2 Model Comparisons

Values of data-related and non-data-related (i.e., penalties and priors on parameters) components from the converged objective function for each TCSAM02 model are listed in Tables 8 and9. Not all of these are directly comparable, some because of differences in the data being fit and others because of differences in the weights applied to the components.

6.2.1 Comparisons between models T02A, AG0, AG1, AG2a, AG2b, and AG3

This series of models addresses the effects of an incremental series of changes in estimation of growth. T02A is "exactly equivalent" to TCSAM2013 model B6, so it provides the link to prior TCSAM2013 models. As described above, AG0 is almost identical to T02A, but uses ADMB's cumulative gamma distributions, rather than approximations based on its gamma distribution, to describe the sex-specific growth (size transition) matrices. AG1 is almost identical to AG0, but also includes the growth data from the EBS when estimating model parameters. AG2a is almost identical to AG1, but removes the priors on the growth parameters. AG2b is almost identical to AG2a, but includes the Kodiak growth data, rather than the EBS data, in the model fit. AG3 is almost identical to both AG2a and AG2b, but includes the growth data from both the EBS and Kodiak, rather than from a single source.

An exhaustive comparison of the results from models T02A, AG0, AG1, AG2a, AG2b, and AG3 is provided in the "F" Appendices available as part of the online supplemental material and summarized here. Because of the number of models and the scale of differences in model results for some quantities, comparison plots between models are provided in the online supplemental material for T02A vs. AG0 (Appendices F1a and F1b), AG1 vs. AG0 (Appendices F2a and F2b), and AG1 vs. AG2a, AG2b, and AG3 (Appendix F3a and F3b).

6.2.1.1 Comparison between models T02A and AG0

Models T02A and AG0 give very similar results, with differences between estimated model quantities such as annual recruitment, population abundance and population biomass < 0.2%; (see Appendix F1b)—suggesting these models are essentially indistinguishable. The differences between negative log-likelihood values associated the data-related components in the converged objective functions (Table 10) suggest that T02A provides a slightly better fit to the survey size compositions for immature crab. From a practical standpoint, however, the cumulative gamma function seems to be much more stable in terms of model convergence than the approach used in T02A, so AG0 is to be favored here given the closeness between the models' results.

6.2.1.1 Comparison between models AG0 and AG1

In contrast to the difference between T02A and AGO, fitting the EBS growth data in AG1 leads to non-negligible differences between the two models for a host of estimated quantities (Appendices F2a and F2b). Natural mortality rates for mature females in AG1 are slightly (~0.03) lower in all years, while those for mature males are 0.12 yr^{-1} higher during the "enhanced mortality" period (1980-1984; Appendix F2a, Fig. 1). Probabilities of terminal molt in AG1 are right-shifted to larger sizes relative to AG0, while the slope of the mean growth curves are shallower and the growth distributions are left-shifted to smaller sizes (Appendix F2a, Fig.s 2-9). This implies that the size and age at which an average crab matures in AG1 is both larger and older than in AG0.

Estimated recruitment time series for both models exhibit the same temporal patterns, for the most part, but AG1 exhibits substantially (~20%) higher peaks in recruitment than AG0 and appears to average about 10% higher overall (Appendix F2a, Fig.s 10-14; Appendix F2b, Fig. 12). After model startup perturbations fade (~early 1970s), population abundance and biomass trends in the two models are similar, but population abundance in AG1 tends to be ~10% higher at all life stages than in AG0, while population biomass in AG1 tends to be ~15% higher than in AG0 for immature crab, but this difference decreases to less than 10% for mature, old shell males (Appendix F2b, Fig.s 14 and 28).

Estimated survey catchabilities are identical between the two models before 1982, but AG1 estimates survey *q* for females almost 10% smaller than AG0, and 5% smaller for males, after 1981 (Appendix F2b, Fig. 30). Survey selectivity functions estimated in AG1 exhibit smaller slopes than those in AG0 for females prior to 1982 and in all years for males, such that the smaller females in AG1 are less likely to be caught in the survey before 1982 and all small males are less likely to be caught (Appendix F2a, Fig. 28). However, the estimated trends in total survey abundance and biomass, particularly the latter, are very similar (Appendix F2a, Fig.s 29, 30)—with predicted survey biomass for immature crab biased somewhat (~5%) higher in AG1 relative to AG0, but somewhat lower (~-2%) for mature new shell crab, and unbiased for old shell crab (Appendix F2b, Fig.s.37, 51).

Estimated fully-selected capture rates in the directed fishery, the snow crab fishery, the BBRKC fishery, and the groundfish fisheries tend to be smaller for AG1 than for AG0. In the directed fishery, annual capture rates are about 5% smaller in AG1 than AG0 for almost all model years (1980 and 1981 being the exceptions when catchability in AG1 is higher; Appendix F2a, Fig. 40; Appendix F2b, Fig. 53). Estimated capture rates in the snow crab fishery are about 6% smaller for AG1 after 1991, compared to AG0, whereas they are about 10% smaller in the groundfish fisheries for females and 7% smaller for males across the model time range (Appendix F2a, Fig.s 39 and 37; Appendix F2b, Fig. 55). In the BBRKC fishery, AG1 estimates of annual capture rates are 2-7%smaller than those in AG0.

Estimated capture selectivity curves in the directed fishery are similar for the two models, as are estimated retention curves (Appendix F2a, Fig.s 58-62). This is also true for selectivity curves in the snow crab fishery, while curves in the groundfish and BBRKC fisheries are somewhat right-shifted to larger sizes during some time periods in AG1, relative to AG0 (Appendix F2a, Fig.s 41-57).

The results summarized in Table 10 suggest that adding the EBS growth data resulted in particularly poorer fits to bycatch size compositions from the groundfish fisheries (a change for the worse of 18 likelihood units), survey mature biomass (~47 units), and survey size compositions for mature crab (~131 units). However, fits to survey size compositions for immature crab did improve by 114 likelihood units.

6.2.1.1 Comparison between models AG1, AG2a, AG2b, and AG3

Removing the priors on the growth parameters now that growth data is being fit in the model (AG2a) has little effect on results, as judged by comparing the likelihoods between AG1 and AG2a (Table 11). somewhat better fits to female and mature male size compositions in the survey are offset by a poorer fit to the survey size compositions for immature males. This is also born out by the graphs in Appendices F3a and F3b in the supplemental material.

Including the Kodiak growth data in the model fitting process (AG2b, AG3) has a slightly larger effect on the model estimates and likelihood components relative to AG1 (Appendices F3a, F3b; Table 11). Adding the EBS growth data to the model (AG1) led to decreased estimated growth rates and probabilities of making the terminal molt to maturity. Adding the Kodiak growth data (AG3), or simply substituting it for the EBS data (AG2b), enhances these changes, leading to even slower growth and smaller probabilities of terminal molt.

The results for AG2b and AG3 are more similar to one another than they are to AG1 or AG2a for all model quantities. This is reflected in very similar changes in the data-related likelihood components for AG2a and AG3 relative to AG1 (Table 11). In fact, including the Kodiak data results in a slightly worse fit to the EBS data (4.4 likelihood units) in AG3 relative to AG1 (Table 9). These observations suggest that the Kodiak data is more influential on the model results than the EBS data. This is not surprising, given the much larger number of observations included in the Kodiak dataset. However, the likelihood associated with the Kodiak data was already down-weighted in the model objective function by a factor of 10 already to reduce its influence relative to the EBS data. Whether this is the correct relative scaling, or not, is an issue.

The EBS growth data appear to give adequate information on growth to the model, whether or not priors are placed on the growth parameters. The differences in model results when the Kodiak data is or is not included seem to suggest growth and maturity in the EBS is somewhat different from that at Kodiak. Because the EBS data appear to be adequate to strongly inform the model on growth, including the Kodiak data appears to be an unnecessary complication because it requires the issue of the relative scaling of the two growth-related likelihood components to be resolved.

6.2.2 Comparisons between models AG1, AG1a, AG1b, and AG1d

Results from models AG1, AG1a, AG1b, and AG1d are compared in detail in Appendices G1 and G2 in the online supplemental material and summarized here. Taking AG1 as the base model for comparison, eliminating the penalties on F-devs (AG1a) has no effect on estimated M for immature crab relative to AG1, but leads to substantially smaller (0.08-0.17 yr^{-1}) estimates for mature crab during the hypothesized "enhanced mortality" period (1980-1984), particularly males (0.68 vs. 0.85 yr^{-1}; Appendix G1, Fig. 1; Appendix G2, Fig. 1). Estimating parameters related to M on the ln-scale (AG1d) results in substantially larger (by 0.05-0.1 yr^{-1}) estimates of M outside the enhanced mortality period, but good agreement during that period. In contrast, differences in the estimated probability of terminal molt and mean growth are small (Appendix G1, Fig.s 2, 3; Appendix G2, Fig.s 2-5), although differences in mean post-molt sizes (smaller post-molt size for AG1b, larger for AG1d) are somewhat amplified such that growth into a post-molt size bin may still differ by 0.1 between models (Appendix G2, Fig.s 8, 9).

Estimated recruitment trends among the four models are quite similar in the timing of highs and lows after 1970 (i.e., essentially after model startup) but the scale differs somewhat (Appendix G1, Fig.s 11-14; Appendix G2, Fig.s 12, 13). After 1980, estimated recruitment is ~10% larger in AG1d and AG1b, while AG1a is ~3% smaller, relative to AG1. In terms of population abundance and biomass trends (Appendix G1, Fig.s 15-26; Appendix G2, Fig.s 14, 15, 18 and 29), AG1a is always ~2-3% smaller than AG1 after 1980, AG1b is always 10% higher, and AG1d is ~5% higher for immature and mature new shell crab, but ~1% smaller than AG1 for mature old shell crab.

Estimated survey *q*'s for all models are similar prior to 1982 (~0.5 for both males and females; Appendix G2, Fig. 27; Appendix G2, Fig.s 30, 31). AG1 estimated smaller values of *q* for females after 1981 (~0.33), but larger values (~0.6) for males. Eliminating the priors on the *q*'s (AG1b) reduces the estimated values for both males and females for the period after 1981, while estimating parameters related to M on the ln-scale (AG1d) increases the estimated values. Eliminating the F penalties (AG1a) shifted estimated pre-1982 survey selectivity curves toward smaller sizes, but had no effect on survey selectivity after 1981, while estimating M on the ln-scale shifted selectivity curves toward larger sizes after 1981, but had no effect before 1982. Removing the priors on survey catchability had negligible effect on estimated survey selectivities (Appendix G1, Fig. 28; Appendix G2, Fig. 36). Although the models exhibited differences primarily in scale for trends in population abundance and biomass, these differences were not evident in the predicted trends for survey abundance and biomass (Appendix G1, Fig.s 29, 30; Appendix G2, Fig.s 37, 38, 51 and 52).

Eliminating the penalties on F-devs (AG1a) had a major impact on model-predicted capture rates and selectivity in 1995 in the directed fishery relative to AG1, with smaller changes occurring in selectivity in other years prior to the fishery closure in 1997. Selectivities for the two models were similar after 2004, as were retention functions (Appendix G1, Fig.s 40, 59-62). Removing the penalties on the F-devs allowed the model to create large spikes in capture rates for males in the directed fishery in 1971, 1979, 1980, and 1995. A large spike in male capture rate was also created in the BBRKC fishery in 1993, while the associated selectivity curve used for the 1988-1996 time period was shifted to larger sizes (Appendix G1, Fig. 38). Similar phenomena did not occur for the groundfish fisheries or the snow crab fishery, where agreement was reasonably good between the two models in terms of trends and levels for capture rates and shapes and locations for selectivity curves (Appendix G1, Fig.s 37, 39, 41-46, 52-57). Predicted catch abundance and biomass in the fisheries generally agreed well when observations were available to constrain the related predictions, but substantial (relative) differences when observations were not available followed the patterns seen for capture rates (Apendix G1, Fig.s 67-70; Appendix G2, Fig.s 79-86).

Removing the priors on survey *q*'s (AG1b) resulted in ~10% higher predicted capture rates relative to AG1 in all the fisheries (Appendix G1, Fig.s 37-49; Appendix G2, Fig.s 53-60). Associated changes in fishery selectivity curves were small, except for males in the snow crab fishery in the pre-1997 and 1997-2004 time blocks. Predicted total catch abundance and biomass agreed within about 5% for most of the 4 fisheries for most of the time (Appendix G1, Fig.s 63-70; Appendix G2, Fig.s 79-86, 135-142).

Estimating M on the ln-scale (AG1d) had little effect on capture rates in any of the fisheries, relative to AG1 (Appendix G1, Fig.s 37-49; Appendix G2, Fig.s 53-60). Relative to AG1, selectivity curves were in good agreement for both sexes in the directed fishery, as were retention curves for males. Selectivity curves for males in the groundfish fisheries were right-shifted to larger sizes by ~10 mm in the 1997-2015 period (Appendix G1, Fig. 46). Selectivity curves for females were shifted to smaller sizes in the BBRKC fishery in the post-2005 period (Appendix G1, Fig.s 49-51), and the dome-shaped selectivity curves for males before 1997 in the snow crab fishery descended more rapidly (Appendix G1, Fig.s 52, 53). Results for predicted total catch abundance and biomass were reasonably similar between AG1d and AG1 (Appendix G2, Fig.s 79-84, 135-140), except for predicted female catch abundance in the BBRKC fishery which did, however, exhibit a decrease by about 20 percentage points between 2004 to 2005 (Appendix G2, Fig.s 85, 141).

Regarding the data-related likelihood components (Table 10), eliminating the penalties on the F-devs (AG1a) dramatically improved the fit to survey size compositions for immature males (55 likelihood units), but decreased the fits to survey size compositions for mature males (35 units), mature male survey biomass (9 units), and retained catch size compositions (10 units). Removing the priors on survey q's (AG1b) resulted in improved fits to mature male survey size compositions (43 units), immature female survey size compositions (11 units), male size compositions in the groundfish fisheries (7 units), and retained catch size compositions (6 units), but led to worse fits to mature female survey size compositions (11 units) and mature biomass in the survey (17 units). Estimating M on the ln-scale (AG1d) led to better fits to immature male survey size compositions (62 units) and mature male survey biomass (11 units), but worse fits to survey size compositions for immature females (36 units) and mature males (21 units).

6.2.3 Comparisons between models AG1 and AG1c

Exhaustive comparisons between the results from models AG1 and AG1c are provided in Appendices H1 and H2 in the online supplemental material and summarized here. Estimating annual deviations to size-at-50% retention during the period since 1990 leads to dramatically better fits to (not surprisingly) retained catch size compositions (188 likelihood units), but also to size compositions for total male catch in the directed fishery (22 units) and mature male survey size compositions (22 units), without substantially worsening the fits to any other data components. This change also eliminates the tendency of previous models to simultaneously over-predict recent total male catch biomass in the directed fishery while under-predicting retained catch biomass (Appendix H1, Fig.s 136, 168).

6.2.4 Comparisons between models AG1 and AG1e

Results from models AG1 and AG1e are compared in detail in Appendices I1 and I2 in the online supplemental material and summarized here. Estimating the effort extrapolation parameters for fishery capture rates in the snow crab and BBRKC fisheries (AG1e) using an additional component in the objective function leads to better fits relative to AG1 for mature male survey biomass (14 likelihood units) and survey size compositions for immature males (19 units), but worse fits for survey size compositions for mature males (30 units) and immature females (23 units).

Estimated natural mortality is somewhat higher for males in AG1e (Appendix I1, Fig. 1), but other population processes (terminal molt probabilities, mean growth, growth distributions) are almost identical to those in AG1 (Appendix I1, Fig.s 2-9), while population quantities and trends (recruitment, abundance, biomass) are also very similar (differences typically less than 5%), although mature male abundance and biomass is slightly smaller in AG1e (Appendix I1, Fig.s 11-26). Estimated survey q for males after 1981 is 3% higher for AG1e, but this is offset by selectivity curves that rise slightly less rapidly with size after 1981 (Appendix I1, Fig. 28) such that the agreement in estimated survey biomass typically varies less than 4% between the models (Appendix I2, Fig. 51).

Estimated fishery capture rates in the directed fishery are in pretty good agreement between the two models (Appendix I1, Fig. 40; Appendix I2, Fig.s 53, 54), while capture rates for males in the groundfish fisheries are elevated on the order of 5% in AG1e relative to AG1 (AppendixI1, Fig. 37; Appendix I2, Fig. 57). The discrepancies are larger for the snow crab and BBRKC fisheries (Appendix I1, Fig.s 38, 39; Appendix I2, Fig.s 55, 59), surprisingly on the order of 20% for the snow crab fishery and 10% for the BBRKC fishery during the post-1990 period when observer data is available to inform and constrain capture rates. This suggests that estimating the effort extrapolation parameters assuming a linear relationship between effort and capture rate during the post-1991 period may be problematic in terms of creating undesired feedback between the pre-1992 and post-1991 time periods in these fisheries. Related effects are the changes to the estimated selectivity functions in the BBRKC fishery before 1997 and in the snow crab fishery during 1997-2004 between the two models (Appendix I1, Fig.s 47, 54). Consequently, estimated total catch abundance and biomass can be substantially higher in AG1e than AG1 for the BBRKC and snow crab fisheries when the model is not informed by data (Appendix I1, Fig.s 64, 65, 135, 139).

6.2.5 Comparisons between models AG3, AG3a, AG3b, and AG4

Exhaustive comparisons between the results from models AG3, AG3a, AG3b, and AG4 are provided in Appendices J1 and J2 in the online supplemental material and summarized here. Reducing the weights placed on the likelihood components related to growth (AG3a) improved fits to all survey data components except survey compositions for immature males while (not surprisingly) decreasing the fits to the growth data, particularly to the Kodiak male growth data (Table 11). This suggests that the growth data and the survey data are in conflict with one another, and perhaps that the immature male and mature male survey size compositions are in conflict with one another. A potential source for this conflict would be inconsistencies between the growth data and the maturity ogive used to assign maturity status to male crab outside the model. Appropriately-collected chela height data for male crab might help to resolve this issue. Along these lines, it is interesting to note that reducing the weight placed on size compositions in the model (AG3b) led to worse fits to survey size compositions for immature crab, but better fits for mature crab. It also led to worse fits to the growth data (again, particularly the Kodiak data for males).

Estimating sex-specific scale parameters for the gamma distribution growth model (AG4) had offsetting effects on likelihood components associated with the survey (Table 11). Fits to size compositions for immature crab were improved (16 likelihood units), while fits to size compositions for mature crab worsened (20 units). The fit to mature male biomass in the survey also degraded (7 units). The estimated scale values were 0.386 ± 0.01 for males and 0.326 ± 0.01 for females, compared with the assumed value 0.75 used previously. These values lead to a narrower distribution around the mean for growth. However, this change did not substantially alter any other model results, such that comparisons of model quantities between AG3 and AG4 exhibit only very small differences (see figures in Appendix J1, Appendix J2).

6.2.6 Comparisons between models B1, AG4, and AG1c

Results from models B1, AG4, and AG1c are compared in detail in Appendices K1 and K2 in the online supplemental material and summarized here. Model B1 combines the features of models AG4 (gamma growth scale parameter estimated) and AG1c (annual deviations for size-at-50%-retained estimated post-1990). It also fits the Tanner crab bycatch in the groundfish fisheries differently than in previous models. The bycatch is divided into two time periods: pre-1991 and post-1990. The "all gear" bycatch time series (biomass and size compositions) in the pre-1991 period is identical to that fit in previous models. The post-1990 bycatch is disaggregated into two gear types: fixed gear (longline and pot) and trawl gear (see Appendix C for details). Sex-specific logistic selectivity curves are used to fit the "all gear" and "fixed gear" data, but dome-shaped double-logistic curves are used to fit to the "trawl gear" data.

Model B1's fits to catch biomass in the "all gear" groundfish fishery (1973-1990), the "fixed gear" fishery (1991-2015), and the "trawl gear" fishery (1991-2015) are shown in Fig.s 2-4 below. The mean size compositions predicted by the model are compared with the mean observed size compositions in Fig. 5. More comprehensive results are given in Appendices K1 and K2.

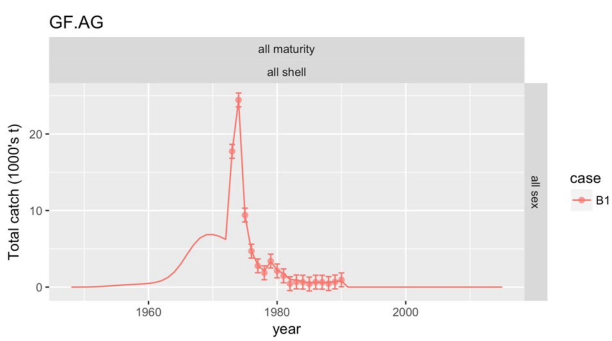

Figure 2. Model B1 fit to Tanner crab bycatch in the "all gear" groundfish fisheries. Bycatch data after 1990 is disaggregated into trawl and fixed gear fleets and fit separately.

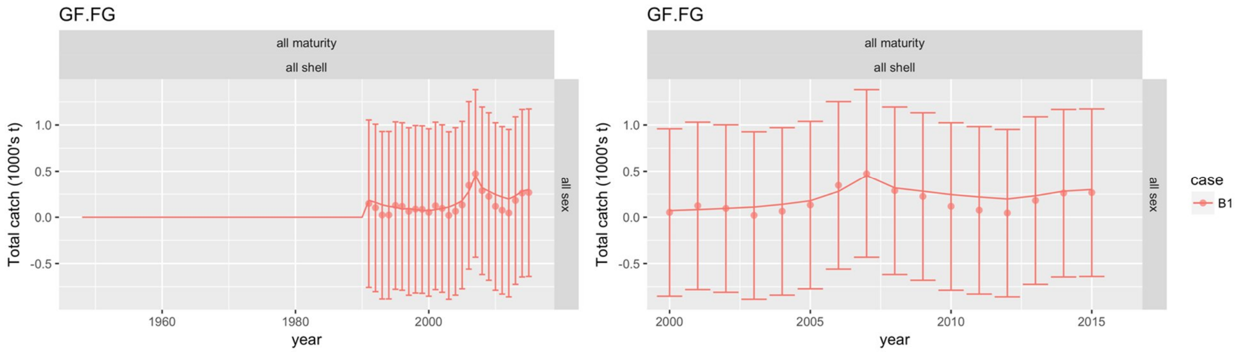

Figure 3. Model B1 fit to Tanner crab bycatch in the "fixed gear" groundfish fisheries (1991-present). The righthand graph shows the trend since 2000.

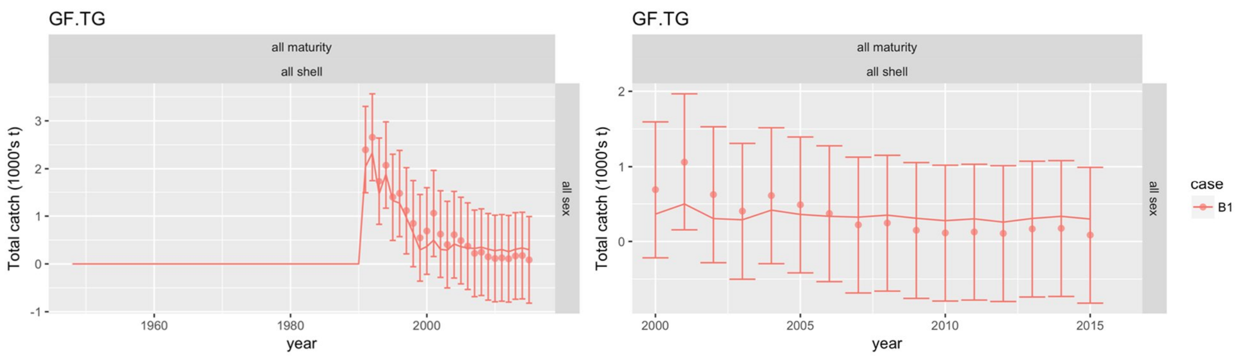

Figure 4. Model B1 fit to Tanner crab bycatch in the "trawl gear" groundfish fisheries (1991-present). The righthand graph shows the trend since 2000.

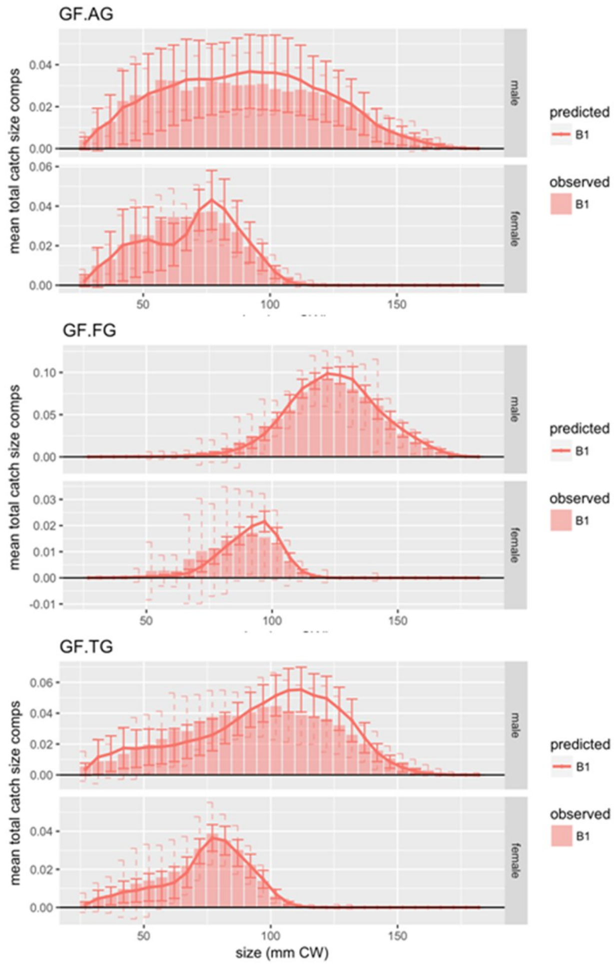

Figure 5. Comparison of mean predicted size compositions from B1 to observed mean Tanner crab bycatch size compositions in: 1) the "all gear" groundfish fisheries (1973-1990; top), 2) the "fixed gear" groundfish fisheries (1991-present; center), 3) the "trawl gear" groundfish fisheries (1991-present; bottom).

Compared with AG4, B1 fits the retained and total catch size compositions in the directed fishery much more closely (Table 11) because it estimates annual retention curves. However, the fits are also improved to the growth data (but by only 6 likelihood units for the EBS data), mature male survey biomass (27 units), and mature crab survey size compositions (86 units). In contrast, only the fit to mature female survey biomass appears to be substantially (10 units) degraded. Although not fully explored here, this model seems a worthwhile candidate for further exploration. In particular, fits to the size compositions may be improved using a different set of selectivity curves.

7. Recommendations for Fall 2017 Alternative Models

Based on the results presented here, I recommend adopting the TCSAM02 model framework for all models evaluated for the Fall 2017 assessment. I further recommend not including the Kodiak growth data when fitting the assessment model because the EBS growth data appears to be adequate to inform the model as to growth. I also recommend that the apparent conflict between the growth data and the size composition data be investigated more fully, particularly with regard to assigning maturity state to male crab outside the model. Finally, I recommend the following model configurations, all based on the TCSAM02 framework, be evaluated for the Fall 2017 assessment:

- B0: use TCSAM02 Model T02A here as the base model for the assessment
- B1: B0 + Gmacs growth function + EBS growth data + no priors on growth + estimate gamma distribution (growth model) scale parameter (TCSAM02 Model AG4 here, but without the Kodiak growth data)
- B2: B1 + include annual deviations after 1990 on size-at-50% retained in the directed fishery retention function (ala TCSAM02 Model AG1c here)
- B3: B2 + bycatch data from groundfish fleets separated into trawl and fixed gear components (TCSAM02 Model B1 here)

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Accompanying Supplemental Material (available online)

Appendix A: AppendixA_RetainedCatchSizeComps.DirectedFisheries.pdf

Appendix B: AppendixB_GrowthData.pdf

Appendix C: AppendixC_TannerCrabBycatchFromGFs.pdf

Appendix D1: AppendixD1_ModelComparisons.B0-B1-B2-B3-B4-B5-B6.pdf

Appendix D2: AppendixD2_ModelDifferences.B0-B1-B2-B3-B4-B5-B6.pdf

Appendix E: AppendixE_ModelDifferences.T13B6-T02A.pdf

Appendix F1a: AppendixF1a_ModelComparisons.T02A-AG0.pdf

Appendix F1b: AppendixF1b_ModelDifferences.T02A-AG0.pdf

Appendix F2a: AppendixF1a_ModelComparisons.AG1-AG0.pdf

Appendix F2b: AppendixF1b_ModelDifferences.AG1-AG0.pdf

Appendix F3a: AppendixF1a_ModelComparisons. AG1-AG2a-AG2b-AG3.pdf

Appendix F3b: AppendixF1b_ModelDifferences. AG1-AG2a-AG2b-AG3.pdf

Appendix G1: AppendixG1_ModelComparisons.AG1-AG1a-AG1b-AG1d.pdf

Appendix G2: AppendixG2_ModelDifferences.AG1-AG1a-AG1b-AG1d.pdf

Appendix H1: AppendixH1_ModelComparisons.AG1-AG1c.pdf

Appendix H2: AppendixH2_ModelDifferences.AG1-AG1c.pdf

Appendix I1: AppendixI1_ModelComparisons.AG1-AG1e.pdf

Appendix I2: AppendixI2_ModelDifferences.AG1-AG1e.pdf

Appendix J1: AppendixJ1_ModelComparisons.AG3-AG3a-AG3b-AG4.pdf

Appendix J2: AppendixJ2_ModelDifferences.AG3-AG3a-AG3b-AG4.pdf

Appendix K1: AppendixK1_ModelComparisons.B1-AG4-AG1c.pdf

Appendix K2: AppendixK2_ModelDifferences.B1-AG4-AG1c.pdf

Tables

Table 1. TCSAM2013 model scenarios evaluated since the 2016 assessment. The "incremental change" column describes the changes to the model scenario from the previous model. Results from the first five models (AM-AMd) were discussed in detail at the 2017 Modeling Workshop, at which Model AMd was selected to be the base model for the May 2017 CPT Meeting.

TCSAM2013 Model	Incremental change
AM	2016 assessment model
AMa	AM + removed size-specific "old shell" re-classification for input data
AMb	AMa + fit to total capture (not mortality) size compositions
AMc	AMb + fit to total capture (not mortality) biomass
AMd	AMc + apply seasonal M after molt-to-maturity
B0	same as AMd
B1	B0 + fit to input survey biomass based on 1-mm size bins
B2	B1 + using 2.20462262 to convert from kg to lbs
B3	B2 + capture rates in RKF not explicitly set to 0 for 1984,1985 and 1994, 1995
B4	B3 + corrected retained size comps for 2015/16
B5	B4 + using median size-at-50% selected for TCF males pre1991 (not average)
B6	B5 + using post-1972 median F for GTF before 1973 (not average)
T13B6	same as B6; exactly equivalent to TCSAM02 model T02A

Table 2. Comparison of objective function components for the TCSAM2013 models B0-B6.

category	Objective Function Values							description
	B0	B1	B2	B3	B4	B5	B6	
likelihood: catch biomass	189.68	191.65	191.65	191.72	191.88	190.83	190.80	survey: mature crab
	41.47	41.44	41.44	41.44	41.61	44.04	44.04	fishery: TCF retained males
	14.25	14.23	14.23	14.24	14.43	15.21	15.22	fishery: TCF male total catch biomass
	34.16	34.14	34.14	34.25	34.03	31.83	31.84	fishery: TCF female catch biomass
	25.04	25.05	25.05	25.06	25.07	25.41	25.41	fishery: SCF total catch biomass
	7.19	7.18	7.18	6.60	6.60	6.84	6.83	fishery: RKF total catch biomass
	1.84	1.85	1.85	1.85	1.85	1.86	1.86	fishery: GTF total catch biomass
likelihood: size comps	260.87	260.97	260.97	260.89	270.02	262.02	262.00	fishery: TCF retained males
	91.83	91.92	91.92	91.93	91.21	91.90	91.91	fishery: TCF total males
	9.51	9.51	9.51	9.51	9.51	9.48	9.48	fishery: TCF discarded females
	53.31	53.34	53.34	53.32	53.30	53.43	53.43	fishery: SCF males
	12.44	12.44	12.44	12.45	12.44	12.36	12.37	fishery: SCF females
	34.57	34.56	34.56	35.10	35.19	35.83	35.83	fishery: RKC males
	2.01	2.02	2.02	2.02	2.02	2.01	2.01	fishery: RKC females
	474.19	474.05	474.05	473.98	473.79	469.53	469.66	fishery: GTF males+females
	220.21	219.39	219.39	219.32	218.67	226.17	226.08	survey: immature males
	297.87	295.61	295.61	295.48	295.74	291.05	290.89	survey: mature males
	286.55	286.96	286.96	287.01	286.96	288.16	288.06	survey: immature females
	149.05	151.97	151.97	152.03	152.37	145.72	146.01	survey: mature females
penalty	0.12	0.12	0.12	0.12	0.12	0.12	0.12	recruitment penalty
	48.47	48.47	48.47	48.47	48.47	48.46	48.46	historic recruitment penalty
	-2.05	-2.06	-2.06	-2.06	-2.06	-2.03	-2.03	natural mortality penalty (immatures)
	3.46	3.33	3.33	3.36	3.37	1.85	1.89	natural mortality penalty (mature males)
	36.07	36.39	36.39	36.42	36.40	36.93	36.86	natural mortality penalty (mature females)
	2.18	2.18	2.18	2.18	2.18	2.17	2.17	maturity curve smoothness (females)
	0.81	0.81	0.81	0.81	0.81	0.78	0.78	maturity curve smoothness (males)
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	z50 devs for male selectivity in TCF (AR1)
	127.89	127.97	127.97	127.83	128.05	127.95	127.95	penalty on F-devs in directed fishery
	32.06	32.06	32.06	32.05	32.05	32.18	32.19	penalty on F-devs in snow crab fishery
	147.29	147.30	147.30	135.32	135.30	136.04	136.04	penalty on F-devs in BBRKC fishery
	53.34	53.38	53.38	53.36	53.36	53.41	53.39	penalty on F-devs in groundfish fishery
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	z50 devs for male selectivity in TCF (norm2)
priors	3.07	3.14	3.14	3.16	3.16	3.25	3.27	survey q penalty
	27.51	27.78	27.78	27.82	27.86	26.57	26.65	female survey q penalty
	-0.48	-0.48	-0.48	-0.48	-0.48	-0.48	-0.48	female growth parameter a
	-2.12	-2.12	-2.12	-2.12	-2.12	-2.12	-2.12	female growth parameter b
	-2.24	-2.24	-2.24	-2.24	-2.26	-2.26	-2.26	male growth parameter a
	-1.35	-1.35	-1.35	-1.35	-1.35	-1.35	-1.35	male growth parameter b
total	2,680.05	2,682.98	2,682.96	2,670.85	2,679.54	2,665.17	2,665.27	

Table 3. Comparison of incremental differences in objective function components for TCSAM2013 models B1-B6, relative to the previous model. Positive values indicate smaller component values (i.e., better fits) for the incrementally-changed model relative to the previous model.

category	Objective Function Differences						description
	B0-B1	B1-B2	B2-B3	B3-B4	B4-B5	B5-B6	
likelihood: catch biomass	-1.97	0.00	-0.07	-0.16	1.05	0.03	survey: mature crab
	0.02	0.00	0.01	-0.18	-2.43	0.00	fishery: TCF retained males
	0.02	0.00	-0.01	-0.19	-0.79	0.00	fishery: TCF male total catch biomass
	0.02	0.00	-0.11	0.22	2.20	-0.01	fishery: TCF female catch biomass
	-0.01	0.00	-0.01	0.00	-0.35	0.01	fishery: SCF total catch biomass
	0.00	0.00	0.58	0.00	-0.24	0.00	fishery: RKF total catch biomass
	-0.01	0.00	0.00	0.00	-0.01	-0.01	fishery: GTF total catch biomass
likelihood: size comps	-0.10	0.00	0.08	-9.13	8.00	0.02	fishery: TCF retained males
	-0.09	0.00	-0.02	0.72	-0.69	-0.01	fishery: TCF total males
	0.00	0.00	-0.01	0.00	0.03	0.00	fishery: TCF discarded females
	-0.03	0.00	0.02	0.01	-0.12	0.00	fishery: SCF males
	0.00	0.00	0.00	0.00	0.08	0.00	fishery: SCF females
	0.00	0.00	-0.54	-0.09	-0.64	0.00	fishery: RKC males
	0.00	0.00	0.00	0.00	0.00	0.00	fishery: RKC females
	0.14	0.00	0.06	0.19	4.27	-0.14	fishery: GTF males+females
	0.82	0.00	0.08	0.64	-7.50	0.10	survey: immature males
	2.25	0.00	0.13	-0.26	4.69	0.15	survey: mature males
	-0.41	0.00	-0.05	0.05	-1.20	0.10	survey: immature females
	-2.92	0.00	-0.07	-0.33	6.65	-0.30	survey: mature females
penalty	0.00	0.00	0.00	0.00	0.00	0.00	recruitment penalty
	0.00	0.00	0.00	0.00	0.01	0.00	historic recruitment penalty
	0.00	0.00	0.00	0.00	-0.02	0.00	natural mortality penalty (immatures)
	0.13	0.00	-0.03	-0.01	1.52	-0.04	natural mortality penalty (mature males)
	-0.33	0.00	-0.02	0.02	-0.53	0.07	natural mortality penalty (mature females)
	0.00	0.00	0.00	0.00	0.01	0.00	maturity curve smoothness (females)
	0.00	0.00	0.00	0.00	0.02	0.00	maturity curve smoothness (males)
	0.00	0.00	0.00	0.00	0.00	0.00	z50 devs for male selectivity in TCF (AR1)
	-0.09	0.00	0.14	-0.21	0.09	0.00	penalty on F-devs in directed fishery
	0.00	0.00	0.01	0.00	-0.13	0.00	penalty on F-devs in snow crab fishery
	-0.01	0.00	11.97	0.02	-0.74	0.01	penalty on F-devs in BBRKC fishery
	-0.04	0.00	0.02	0.01	-0.05	0.02	penalty on F-devs in groundfish fishery
	0.00	0.00	0.00	0.00	0.00	0.00	z50 devs for male selectivity in TCF (norm2)
priors	-0.08	0.00	-0.02	0.00	-0.09	-0.01	survey q penalty
	-0.27	0.00	-0.04	-0.04	1.28	-0.08	female survey q penalty
	0.00	0.00	0.00	0.00	0.00	0.00	female growth parameter a
	0.00	0.00	0.00	0.00	0.00	0.00	female growth parameter b
	0.00	0.00	0.00	0.02	0.00	0.00	male growth parameter a
	0.00	0.00	0.00	0.00	0.00	0.00	male growth parameter b
total	-2.93	0.02	12.11	-8.69	14.37	-0.10	total

Table 4. Comparison of differences in survey data-related objective function components for the "exactly equivalent" TCSAM2013 and TCSAM02 models (i.e., T13B6 and T02A).

data type	sex	maturity	T13B6	T02A	T13B6-T02A
mature biomass	all	mature	190.801	190.801	5.37E-05
size compositions	females	immature	288.060	288.060	6.06E-05
		mature	146.015	146.015	1.30E-04
	males	immature	226.077	226.078	-2.78E-04
		mature	290.894	290.894	3.41E-04

Table 5. Comparison of differences in fishery data-related objective function components for the "exactly equivalent" TCSAM2013 and TCSAM02 models (i.e., T13B6 and T02A).

catch type	data type	fleet	sex	T13B6	T02A	T13B6-T02A
retained	biomass	TCF	males	44.044	44.044	1.87E-05
	size compositions		males	261.998	261.998	1.41E-05
total catch	biomass	GTF	all	1.864	1.864	1.69E-06
		RKF	all	6.834	6.834	-2.12E-05
		SCF	all	25.405	25.405	-2.11E-06
		TCF	all	31.840	31.840	1.45E-05
	size compositions	GTF	all	469.663	469.662	4.94E-05
		RKF	females	2.013	2.013	1.67E-08
			males	35.830	35.830	9.70E-05
		SCF	females	12.366	12.366	2.35E-07
			males	53.427	53.427	-2.10E-05
		TCF	females	9.481	9.481	5.25E-07
			males	91.910	91.910	-7.35E-05

Table 6. Comparison of differences in non data-related objective function components for the "exactly equivalent" TCSAM2013 and TCSAM02 models (i.e., T13B6 and T02A).

T02A (TCSAM02)			T13B6 (TCSAM2013)			T13B6-T02A			category	description
wgt	nll	objfun	wgt	nll	objfun	wgt	nll	objfun		
1	0.78	0.78	1	0.78	0.78	0	1.35E-06	1.35E-06	maturity	maturity curve smoothness (males)
2	1.08	2.17	2	1.08	2.17	0	-6.54E-07	-1.31E-06		maturity curve smoothness (females)
2	24.23	48.46	2	24.23	48.46	0	-9.60E-07	-1.92E-06	recruitment	historic recruitment penalty
0.002	58.15	0.12	0.002	58.15	0.12	0	-6.31E-06	-1.26E-08		recruitment penalty
1	-2.03	-2.03	1	-2.03	-2.03	0	1.23E-06	1.23E-06	natural mortality	natural mortality penalty (immatures)
1	1.89	1.89	1	1.89	1.89	0	9.53E-05	9.53E-05		natural mortality penalty (mature males)
1	36.86	36.86	1	36.86	36.86	0	8.34E-06	8.34E-06		natural mortality penalty (mature females)
1	-2.26	-2.26	1	-2.26	-2.26	0	7.30E-06	7.30E-06	growth	male growth parameter a
1	-0.48	-0.48	1	-0.48	-0.48	0	-4.31E-10	-4.31E-10		female growth parameter a
1	-1.35	-1.35	1	-1.35	-1.35	0	-1.00E-08	-1.00E-08		male growth parameter b
1	-2.12	-2.12	1	-2.12	-2.12	0	6.74E-07	6.74E-07		female growth parameter b
0	12.08	0.00	0	12.08	0.00	0	-3.33E-08	0.00E+00	selectivity functions	z50 devs for male selectivity in TCF (AR1)
2	63.98	127.95	2	63.98	127.95	0	-2.00E-05	-4.00E-05	fisheries	penalty on F-devs in directed fishery
1	32.19	32.19	1	32.19	32.19	0	-6.49E-06	-6.49E-06		penalty on F-devs in snow crab fishery
1	53.39	53.39	1	53.39	53.39	0	-4.10E-06	-4.10E-06		penalty on F-devs in groundfish fishery
6	22.67	136.04	6	22.67	136.04	0	-9.86E-06	-5.91E-05		penalty on F-devs in BBRKC fishery
1	3.27	3.27	1	3.27	3.27	0	-3.26E-05	-3.26E-05	surveys	survey q penalty
1	26.65	26.65	1	26.65	26.65	0	1.41E-04	1.41E-04		female survey q penalty

Table 7. Potential TCSAM02 model scenarios to be considered for the Fall 2017 assessment.

TCSAM02 Model	# of parameters	Description
T02A	332	exactly equivalent to TCSAM2013 model T13B6
AG0	332	T02A + use Gmacs growth function
AG1	332	AG0 + include EBS growth data
AG1a	332	AG1 + eliminate F penalties
AG1b	332	AG1 + eliminate priors on survey q
AG1c	351	AG1 + include annual size-at-50% selected deviations in retention function
AG1d	332	AG1 + estimate M parameters on ln-scale
AG1e	334	AG1 + estimate effort extrapolation parameters using likelihood
AG2a	332	AG0 + include EBS growth data + remove priors on growth parameters
AG2b	332	AG0 + include GOA growth data + remove priors on growth parameters
AG3	332	AG0 + include EBS and GOA growth data + remove priors on growth parameters
AG3a	332	AG3 + reduced weights in likelihood for growth data
AG3b	332	AG3 + reduced weights in likelihood for size compositions
AG4	334	AG3 + estimate scale factor for growth gamma distribution
B1	396	AG4 + AG1c + bycatch data from groundfish fleets separated into trawl and fixed gear components

Table 8. Data-related objective function components for the TCSAM02 models. Abbreviations: GF.AG = groundfish fleets, all gear; GF.FG = groundfish fleets, fixed gear; GF.TG = groundfish fleets, trawl gear; GTF = groundfish fleet; RKF = BBRKC fleet; SCF = snow crab fleet; TCF = directed Tanner crab fishery.

category	fleet	catch type	data type	sex	maturity	shell condition	T02A	AG0	AG1	AG1a	AG1b	AG1c	AG1d	AG1e	AG2a	AG2b	AG3	AG3a	AG3b	AG4	B1
							TCSAM02 Model														
effort data	RKF			male	immature	new shell	--	--	--	--	--	--	--	0.3	--	--	--	--	--	--	467.6
				male	immature	old shell	--	--	--	--	--	--	--	0.3	--	--	--	--	--	--	467.6
				male	mature	new shell	--	--	--	--	--	--	--	0.3	--	--	--	--	--	--	467.6
				male	mature	old shell	--	--	--	--	--	--	--	0.3	--	--	--	--	--	--	467.6
				female	immature	new shell	--	--	--	--	--	--	--	0.0	--	--	--	--	--	--	467.6
				female	immature	old shell	--	--	--	--	--	--	--	0.0	--	--	--	--	--	--	467.6
				female	mature	new shell	--	--	--	--	--	--	--	0.0	--	--	--	--	--	--	467.6
				female	mature	old shell	--	--	--	--	--	--	--	0.0	--	--	--	--	--	--	467.6
	SCF			male	immature	new shell	--	--	--	--	--	--	--	11.0	--	--	--	--	--	--	1,007.4
				male	immature	old shell	--	--	--	--	--	--	--	11.0	--	--	--	--	--	--	1,007.4
				male	mature	new shell	--	--	--	--	--	--	--	11.0	--	--	--	--	--	--	1,007.4
				male	mature	old shell	--	--	--	--	--	--	--	11.0	--	--	--	--	--	--	1,007.4
				female	immature	new shell	--	--	--	--	--	--	--	0.0	--	--	--	--	--	--	1,007.4
				female	immature	old shell	--	--	--	--	--	--	--	0.0	--	--	--	--	--	--	1,007.4
				female	mature	new shell	--	--	--	--	--	--	--	0.0	--	--	--	--	--	--	1,007.4
				female	mature	old shell	--	--	--	--	--	--	--	0.0	--	--	--	--	--	--	1,007.4
fisheries data	GF.AG	total catch	biomass	all sexes	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.3
			n.at.z	female	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	17.1
			n.at.z	male	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	23.0
	GF.FG	total catch	abundance	all sexes	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.4
			biomass	all sexes	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.3
			n.at.z	female	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.7
			n.at.z	male	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.5
	GF.TG	total catch	abundance	all sexes	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.6
			biomass	all sexes	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.3
			n.at.z	female	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	10.9
			n.at.z	male	all	all	--	--	--	--	--	--	--	--	--	--	--	--	--	--	13.2
	GTF	total catch	biomass	all sexes	all	all	1.9	1.9	1.8	0.5	1.6	1.7	1.7	2.7	1.8	1.7	1.8	1.8	1.5	1.8	0.0
			n.at.z	female	all	all	203.9	203.8	209.6	206.5	212.1	211.1	209.5	214.5	210.2	200.7	202.9	206.9	23.1	206.0	0.0
			n.at.z	male	all	all	265.7	266.2	278.5	279.3	271.8	272.3	280.9	274.8	278.3	287.5	286.3	271.4	46.9	289.9	0.0
	RKF	total catch	biomass	female	all	all	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			biomass	male	all	all	6.8	6.8	7.0	0.3	6.6	7.3	6.4	24.9	7.0	7.0	7.1	6.9	3.1	7.1	7.3
			n.at.z	female	all	all	2.0	2.0	2.0	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	0.2	2.0	1.9
			n.at.z	male	all	all	35.8	35.8	38.4	35.5	36.4	37.7	37.0	46.8	38.5	37.8	37.8	37.7	8.6	37.6	36.1
	SCF	total catch	biomass	female	all	all	23.8	23.8	26.0	26.2	25.9	25.5	26.3	26.5	26.1	27.1	27.7	24.8	12.7	27.7	26.1
			biomass	male	all	all	1.6	1.6	1.6	0.5	1.5	1.5	1.5	114.3	1.6	1.5	1.5	1.6	1.5	1.5	1.5
			n.at.z	female	all	all	12.4	12.4	12.0	12.0	11.9	11.6	11.6	12.5	12.0	12.0	12.4	12.1	1.8	12.4	11.4
			n.at.z	male	all	all	53.4	53.4	50.4	51.3	45.9	47.4	47.6	53.8	50.2	45.9	49.3	51.3	13.5	49.1	45.1
	TCF	retained catch	biomass	male	all	all	44.0	44.1	48.5	56.7	48.8	8.8	49.6	49.5	48.4	49.9	49.6	46.0	12.1	49.9	8.5
			n.at.z	male	all	all	262.0	262.3	259.6	269.6	253.3	71.4	258.7	255.2	259.9	257.6	253.5	264.3	39.1	250.3	63.2
		total catch	biomass	female	all	all	31.8	31.8	34.4	2.7	36.6	39.5	37.7	38.1	34.4	35.8	35.4	33.0	4.8	35.6	39.2
			biomass	male	all	all	15.2	15.2	16.8	19.5	17.1	3.1	17.3	16.0	16.7	16.9	16.9	15.9	1.8	16.9	2.9
			n.at.z	female	all	all	9.5	9.5	9.8	9.6	9.8	9.6	10.4	10.1	9.9	9.2	9.4	9.8	0.9	9.6	9.3
			n.at.z	male	all	all	91.9	91.6	84.7	90.8	84.5	62.3	84.5	86.8	84.8	85.6	85.7	89.4	14.9	86.2	63.4
growth data			EBS	female	immature	new shell	0.0	0.0	1,227.5	1,227.5	1,227.2	1,227.5	1,228.9	1,227.7	1,227.2	0.0	1,256.3	125.4	124.1	1,200.5	1,198.5
			EBS	male	immature	new shell	0.0	0.0	1,630.0	1,633.8	1,628.0	1,629.8	1,635.6	1,634.0	1,627.5	0.0	1,645.4	184.6	168.9	1,626.1	1,628.8
			Kodiak	female	immature	new shell	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,239.5	2,251.9	23.8	23.2	2,083.1	2,085.3
			Kodiak	male	immature	new shell	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3,504.8	3,522.6	46.0	41.1	3,317.8	3,313.5
surveys data	NMFS trawl survey	index catch	biomass	female	mature	all	104.3	104.2	118.3	121.3	124.5	117.9	115.1	117.9	117.9	124.3	123.1	113.2	80.6	124.8	134.0
			biomass	male	mature	all	86.5	86.4	119.2	128.7	130.1	119.7	105.6	105.4	117.8	145.8	141.0	101.9	46.2	148.0	113.6
			n.at.z	female	immature	all	288.1	289.2	232.3	227.5	220.9	234.3	268.6	255.5	230.0	274.7	262.4	249.2	68.2	251.9	266.1
			n.at.z	female	mature	all	146.0	145.5	221.2	224.1	232.3	214.9	226.0	221.5	219.8	225.5	226.8	188.9	15.8	239.9	185.4
			n.at.z	male	immature	all	226.1	227.1	169.7	115.1	169.4	168.9	107.6	151.0	176.7	111.0	121.7	168.3	24.3	116.6	124.5
			n.at.z	male	mature	all	290.9	290.5	345.1	379.9	302.0	323.4	366.5	375.4	341.2	380.3	376.1	335.9	32.1	383.3	331.7

Table 9. Non-data-related objective function components for the TCSAM02 models. Abbreviations: GF.AG = groundfish fleets, all gear; GF.FG = groundfish fleets, fixed gear; GF.TG = groundfish fleets, trawl gear; GTF = groundfish fleet; RKF = BBRKC fleet; SCF = snow crab fleet; TCF = directed Tanner crab fishery.

type	element	level	Model														
			T02A	AG0	AG1	AG1a	AG1b	AG1c	AG1d	AG1e	AG2a	AG2b	AG3	AG3a	AG3b	AG4	B1
maturity	smoothness	males	0.8	0.9	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.7	1.5	1.2	0.4	1.2	1.0
		females	2.2	2.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.1	1.9	1.7	0.7	1.6	1.7
fisheries	F devs	TCF	128.0	128.1	123.8	--	130.4	127.9	122.4	118.9	123.9	123.4	123.3	127.0	109.0	123.2	121.6
		SCF	32.2	32.2	31.8	--	32.3	33.4	33.1	29.2	31.7	33.5	31.7	32.0	31.8	31.8	33.1
		GTF	53.4	53.4	53.2	--	53.3	53.1	52.9	53.8	53.2	53.2	53.3	53.3	53.7	53.3	--
		RKF	136.0	136.0	137.4	--	135.8	137.8	136.0	137.5	137.4	138.0	138.1	136.9	127.0	138.2	138.1
		GF.AG	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.7
		GF.FG	--	--	--	--	--	--	--	--	--	--	--	--	--	--	23.3
		GF.TG	--	--	--	--	--	--	--	--	--	--	--	--	--	--	28.7
growth	prior on a	males	-2.3	-2.3	5.3	6.3	4.5	4.9	6.4	6.1	--	--	--	--	--	--	--
		females	-0.5	-0.5	-0.9	-0.9	-0.8	-0.9	-1.1	-0.9	--	--	--	--	--	--	--
	prior on b	males	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	--	--	--	--	--	--	--
		females	-2.1	-2.1	-2.1	-2.2	-2.0	-2.1	-2.4	-2.2	--	--	--	--	--	--	--
natural mortality	C1		--	--	--	--	--	--	6.2	--	--	--	--	--	--	--	--
	C2		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	C3		1.9	2.0	1.2	-1.7	4.7	2.0	7.9	15.0	1.7	-1.9	-1.7	0.9	-2.0	-1.9	-1.0
	C4		36.9	37.1	17.7	17.7	9.8	17.1	--	23.3	17.4	20.6	19.4	26.6	7.2	17.0	14.9
	C5		--	--	--	--	--	--	3.7	--	--	--	--	--	--	--	--
	C6		-2.0	-2.0	-2.1	-2.0	-1.9	-2.1	0.0	-2.0	-2.1	-1.7	-1.9	-2.1	-2.0	-1.8	-1.7
recruitment	rec devs	pre-1975	48.5	48.5	48.1	47.4	48.0	48.0	48.1	48.1	48.1	48.0	48.0	48.3	48.7	48.0	48.3
		post-1974	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
surveys	catchability	males, post 1981	3.3	3.3	14.3	9.7	--	22.4	12.7	6.7	13.6	20.0	18.8	6.0	-1.0	20.1	20.5
		females, post 1981	26.7	26.6	55.2	43.4	--	65.0	22.9	54.7	56.1	56.6	55.8	35.2	-0.5	58.4	71.7

Table 10. Comparison of data-related negative log-likelihood (NLL) components to the objective function for the TCSAM02 models T02A, AG0, AG1, AG1a, AG1b, AG1c, AG1d, AG1e, and AG2a. Abbreviations: GTF = groundfish fleet, RKF = BBRKC fleet, SCF = snow crab fleet, TCF = directed Tanner crab fishery. Green cells highlight changes in NLL components between models > 2 likelihood units that may indicate a better fit to the data by the new model, orange cells highlight changes in NLL components between models < -2 likelihood units that may indicate a poorer fit to the data by the new model. '—' indicates the comparison is not valid.

category	fleet	catch type	data type	sex	maturity	shell condition	T02A-AG0	AG0-AG1	AG1-AG1a	AG1-AG1b	AG1-AG1c	AG1-AG1d	AG1-AG1e	AG1-AG2a
fisheries data	GTF	total catch	biomass	all sexes	all	all	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
			n.at.z	female	all	all	0.1	-5.7	3.0	-2.5	-1.6	0.0	-5.0	-0.6
			n.at.z	male	all	all	-0.5	-12.3	-0.8	6.7	6.1	-2.4	3.7	0.2
	RKF	total catch	biomass	female	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			biomass	male	all	all	0.0	0.0	0.3	0.0	0.0	0.0	-0.9	0.0
			n.at.z	female	all	all	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
			n.at.z	male	all	all	0.0	-2.6	2.8	2.0	0.6	1.4	-8.5	-0.1
	SCF	total catch	biomass	female	all	all	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
			biomass	male	all	all	0.0	0.0	0.1	0.0	0.0	0.0	-5.6	0.0
			n.at.z	female	all	all	0.0	0.4	0.0	0.1	0.4	0.4	-0.5	0.0
			n.at.z	male	all	all	0.0	3.0	-0.9	4.4	3.0	2.8	-3.4	0.2
	TCF	retained catch	abundance	female	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			abundance	male	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			biomass	female	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			biomass	male	all	all	0.0	-0.2	-0.4	0.0	2.0	-0.1	-0.1	0.0
			n.at.z	male	all	all	-0.3	2.7	-10.0	6.3	188.2	0.9	4.4	-0.3
		total catch	biomass	female	all	all	0.0	-0.1	1.6	-0.1	-0.3	-0.2	-0.2	0.0
			biomass	male	all	all	0.0	-0.1	-0.1	0.0	0.7	0.0	0.0	0.0
			n.at.z	female	all	all	0.0	-0.3	0.2	0.1	0.2	-0.6	-0.3	0.0
			n.at.z	male	all	all	0.3	7.0	-6.1	0.2	22.3	0.1	-2.2	-0.1
growth data			EBS	female	immature	new shell	--	--	0.0	0.0	0.0	-0.1	0.0	0.0
			EBS	male	immature	new shell	--	--	-0.4	0.2	0.0	-0.6	-0.4	0.3
surveys data	NMFS trawl survey	index catch	biomass	female	mature	all	0.0	-14.1	-3.0	-6.2	0.4	3.2	0.4	0.4
			biomass	male	mature	all	0.1	-32.7	-9.5	-11.0	-0.6	13.6	13.8	1.4
			n.at.z	female	immature	all	-1.1	56.9	4.7	11.3	-2.0	-36.3	-23.2	2.3
			n.at.z	female	mature	all	0.5	-75.7	-2.9	-11.2	6.3	-4.8	-0.3	1.4
			n.at.z	male	immature	all	-1.0	57.4	54.6	0.3	0.8	62.1	18.7	-7.0
			n.at.z	male	mature	all	0.4	-54.6	-34.8	43.1	21.7	-21.4	-30.3	3.9

Table 11. Comparison of data-related negative log-likelihood (NLL) components to the objective function for the TCSAM02 models AG1, AG2a, AG2b, AG3, AG3a, AG3b, and B1. Abbreviations: GTF = groundfish fleet, RKF = BBRKC fleet, SCF = snow crab fleet, TCF = directed Tanner crab fishery. Green cells highlight changes in NLL components between models > 2 likelihood units that may indicate a better fit to the data by the new model, orange cells highlight changes in NLL components between models < -2 likelihood units that may indicate a poorer fit to the data by the new model. '—' indicates the comparison is not valid.

category	fleet	catch type	data type	sex	maturity	shell condition	AG1-AG2a	AG1-AG2b	AG1-AG3	AG3-AG3a	AG3-AG3b	AG3-AG4	AG4-B1
fisheries data	GTF	total catch	biomass	all sexes	all	all	0.0	0.0	0.0	0.0	0.0	0.0	--
			n.at.z	female	all	all	-0.6	8.8	6.7	-4.1	-28.0	-3.2	--
			n.at.z	male	all	all	0.2	-9.0	-7.8	14.9	-183.1	-3.7	---
	RKF	total catch	biomass	female	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			biomass	male	all	all	0.0	0.0	0.0	0.0	0.2	0.0	0.0
			n.at.z	female	all	all	0.0	0.0	0.0	0.0	0.1	0.0	0.1
			n.at.z	male	all	all	-0.1	0.6	0.6	0.0	-48.2	0.2	1.7
	SCF	total catch	biomass	female	all	all	0.0	-0.1	-0.1	0.1	0.8	0.0	0.1
			biomass	male	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			n.at.z	female	all	all	0.0	0.0	-0.4	0.2	-5.4	-0.1	0.9
			n.at.z	male	all	all	0.2	4.5	1.1	-2.0	-86.1	0.2	4.2
	TCF	retained catch	abundance	female	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			abundance	male	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			biomass	female	all	all	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			biomass	male	all	all	0.0	-0.1	-0.1	0.2	1.9	0.0	2.1
			n.at.z	male	all	all	-0.3	2.0	6.1	-10.8	-137.5	3.2	190.3
		total catch	biomass	female	all	all	0.0	-0.1	-0.1	0.1	1.5	0.0	-0.2
			biomass	male	all	all	0.0	0.0	0.0	0.0	0.8	0.0	0.7
			n.at.z	female	all	all	0.0	0.7	0.5	-0.5	0.5	-0.3	0.1
			n.at.z	male	all	all	-0.1	-1.0	-1.0	-3.7	-63.3	-0.5	22.3
growth data			EBS	female	immature	new shell	0.0	--	-2.9	0.2	1.6	5.6	5.8
			EBS	male	immature	new shell	0.3	--	-1.5	-20.1	-4.3	1.9	1.7
			Kodiak	female	immature	new shell	0.0	--	--	-123.8	-69.3	168.7	166.6
			Kodiak	male	immature	new shell	0.0	--	--	-1,079.7	-583.2	204.9	209.1
surveys data	NMFS trawl survey	index catch	biomass	female	mature	all	0.4	-6.1	-4.9	9.9	42.6	-1.7	-10.9
			biomass	male	mature	all	1.4	-26.6	-21.8	39.1	94.8	-7.0	27.4
			n.at.z	female	immature	all	2.3	-42.5	-30.1	13.2	-419.8	10.5	-3.7
			n.at.z	female	mature	all	1.4	-4.3	-5.7	38.0	69.3	-13.1	41.5
			n.at.z	male	immature	all	-7.0	58.7	48.0	-46.6	-121.6	5.1	-2.8
			n.at.z	male	mature	all	3.9	-35.2	-31.0	40.2	54.9	-7.2	44.4

Table 12.Comparison of OFL-related quantities from all TCSAM02 models (except B1).

case	OFL (1000's t)	Fofl	projected B (1000's t)	currrent B (1000's t)	Fmsy	Bmsy (1000's t)	MSY (1000's t)	B100 (1000's t)	avg male recruitment (millions)	avg female recruitment (millions)
T02A	27.38	0.93	45.47	85.19	0.93	26.54	11.21	75.83	87.97	87.97
AG0	27.38	0.93	45.45	85.19	0.93	26.54	11.22	75.83	88.01	88.01
AG1	42.60	1.20	60.58	119.79	1.20	31.39	12.97	89.68	130.73	130.73
AG1a	37.54	0.99	61.47	113.99	0.99	30.46	11.67	87.04	112.22	112.22
AG1b	74.29	1.53	89.51	191.45	1.53	43.19	18.81	123.41	192.70	192.70
AG1c	47.07	0.91	68.85	134.75	0.91	34.48	14.35	98.50	148.72	148.72
AG1d	48.41	1.84	49.42	118.75	1.84	28.40	14.84	81.15	207.33	207.33
AG1e	42.07	1.38	52.24	111.87	1.38	28.36	13.22	81.02	136.62	136.62
AG2a	42.32	1.21	59.86	118.89	1.21	31.11	12.99	88.88	131.59	131.59
AG2b	45.93	1.16	68.77	130.32	1.16	33.76	12.78	96.45	132.04	132.04
AG3	45.40	1.16	67.67	128.96	1.16	33.48	12.85	95.65	133.04	133.04
AG3a	31.21	0.96	50.77	95.55	0.96	27.84	11.54	79.54	100.28	100.28
AG3b	21.62	1.41	35.79	65.74	1.41	24.73	9.45	70.64	86.78	86.78