Review of GMACS Modeling Framework

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Report to Center for Independent Experts

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Executive summary

- This report is a review of the Generalized Model for Alaska Crab Stocks (Gmacs) developed by scientists at the Alaska Fisheries Science Center and the University of Washington. Gmacs is a generalized and flexible size-structured modeling framework, which is being developed to provide standardized assessments that are more transparent than the current approach involving species-specific models and software developed by the scientists involved in the assessment of each stock. Gmacs is at a less advanced stage than was originally anticipated, but the review was sought to consider progress to date and to identify priorities for directions of development.
- Much progress has been made in developing a standardized modeling framework using the AD Model Builder software platform, and with associated packages for producing standardized outputs and simulations. The use of the Github repository for version control and tracking of changes, and associated tools for documentation, has been very successful, and will stand the project in good stead for coherence in its future development. This review endorses the direction that Gmacs is taking and the progress made to date.
- Gmacs is suited to providing required assessment elements to support management of Bering Sea and Aleutian Island crab stocks, in terms of estimates of exploitation rates, effective spawning stock biomass and MSY-related reference points. This will allow measurement of stock status against overfishing limits, setting of acceptable catch limits and application of harvest control rules. Through an associated R package, Gmacs is also well placed to standardize reporting of assessment outcomes, potentially producing plots and tables as required for SAFE guidelines on reporting of crab assessments.
- Data inputs and modeling options, including definition of parameter bounds and priors, are straightforwardly defined in control files for Gmacs, although additional clarification is needed on whether discard mortality is accounted for in the catch data supplied to the model.
- Maturity state, tagging data and fishing effort are not currently included in the implementation of Gmacs, and differences between old and new shell conditions appear not to be accounted for in the modeling of growth. Other issues that should be addressed include estimation of sex-specific recruitment and natural mortality, definition of a stock recruitment relationship, functional forms for selectivity, and the modeling of fishing mortality as either a continuous or a discrete process.
- Simulation capabilities are provided both within Gmacs and using the rsimGmacs R package. The latter will be important in developing simulated data sets for testing of Gmacs. Coordinating the matching of code between Gmacs and rsimGmacs is likely to be challenging, but may well be useful in highlighting major discrepancies.
- The first use of Gmacs is likely to be for Bristol Bay red king crab. Application of Gmacs to assessment of this stock is promising but remains preliminary, and it will be important to match assumptions and model structure between Gmacs and the existing assessment model and to identify the sources of any mismatch in assessment outcomes.
- The priority is to get Gmacs working as a satisfactory framework for Bristol Bay red king crab, but it is already apparent that it should be possible to apply Gmacs to stocks differing in data availability. Extension to snow and Tanner crabs, with different life history characteristics, e.g. relating to terminal molts and maturity stages, is likely to be more challenging to achieve within a single generalized framework, but this is nevertheless attainable.

Recommendations

1. Gmacs should continue to be developed as a flexible size-based modeling framework with the purpose of achieving standardization and transparency across the assessments of Alaskan crab stocks.
2. Use of the Github repository and associated tools should be continued within a community supported modeling approach.
3. Gmacs should be taken forward to allow its first application to Bristol Bay red king crab alongside the current assessment model in 2016, aiming to phase in Gmacs as the main source of information to support management thereafter.
4. Full inclusion of a stock recruitment model should be implemented within Gmacs, using functional forms such as Ricker in addition to Beverton-Holt, accounting for density-dependent feedbacks within stock projections.
5. Development of the gmr R package for producing standardized outputs and diagnostics from Gmacs results should be driven by guidelines on preparation of SAFE report chapters.
6. The stage at which discard mortality is applied to catch data needs to be clarified, and preferably the adjustment should be made within Gmacs for ease of sensitivity analyses.
7. Tagging data should be included as an information source for Gmacs, considering mortality processes as well as movement.
8. Fishing effort should be included as an information source for Gmacs, informing exploitation rates as well as abundance trends through commercial CPUE.
9. Maturity stages should be included in Gmacs, particularly in relation to snow and Tanner crabs.
10. Distinctions between old and new shell condition should be made in modeling of growth processes.
11. Modeling of common recruitment trends between males and females should be considered in Gmacs.
12. Sex-specific natural mortality should be considered in Gmacs.
13. In addition to the gamma distribution, other functional forms for growth transitions should be considered in Gmacs.
14. In common with existing assessment models, Gmacs should include the facility to model fishing mortality as a discrete or pulse process, and should examine timing and sequence in relation to molting, fishing and setting of biological reference points.
15. Coding of model structure should be coordinated between Gmacs and the rsimGmacs simulation package, with the latter used to test the application of Gmacs to particular data and life-history scenarios.
16. Extension of Gmacs to cover data availability and life-history characteristics of different Alaskan crab stocks should be progressed as a second priority behind validation of Gmacs for Bristol Bay red king crab.
17. Model structures within Gmacs should be made as generic as possible, such that simpler life-history characteristics and data availability can be defined as special cases of structurally more complex

models. It should also be possible to define model structures and assumptions associated with existing assessments as special cases of a generic Gmacs model.

18. Bifurcations of code necessary to account for species-specific characteristics should be included within the flow control of a single model framework rather than as separate branches of Gmacs, such that the coherence of a single working version of Gmacs is maintained at each stage of release.
19. Branching should be restricted to research models, with the aim of merging into the working version as appropriate.
20. Design decisions for Gmacs should be driven by the needs of end users (e.g. the Crab Plan Team) for particular assessment outcomes; for example, in relation to evolving definitions of effective spawning biomass.

Background

Fisheries for ten stocks of Bering Sea and Aleutian Islands (BSAI) crabs are managed by the North Pacific Fishery Management Council, supported by stock assessments undertaken by the Alaska Fisheries Science Center (AFSC) and the Alaska Department of Fish and Game (ADF&G). Recently, scientists at the AFSC and the University of Washington have developed a Generalized Model for Alaska Crab Stocks (Gmacs). Gmacs is a generalized and flexible size-structured modeling framework, the first version of which is being designed to develop stock assessment models for the stocks of red king crab in Bristol Bay and Norton Sound, Alaska. The framework makes use of most of the available data sources for both male and female crabs, including survey and fishery indices of abundance and fishery and survey size-compositions. A workshop held in January 2015 contributed to the implementation of Gmacs to data for red king crab stocks in order to test its efficacy and determine priorities for development for application to other Alaskan crab stocks. A goal of the project is to provide a standardized size structured assessment that is more transparent than the current approach in which assessment scientists have written species-specific software. A generic stock assessment for Alaskan crab stocks was formulated by Maunder (2012) and has since been developed within the AD Model Builder software package (Fournier *et al.*, 2012) in a collaboration between the University of Washington and AFSC (Whitten *et al.*, 2014). A CIE review of the Gmacs modeling framework and issues related to further development and application for stock assessment has been requested.

The CIE review panel members were Nick Caputi (Department of Fisheries, Perth, Western Australia), Malcolm Haddon (University of Tasmania, Hobart, Australia) and the present author (Michael Bell, Heriot-Watt University, Orkney, UK). Terms of Reference agreed at the start of the meeting were:

(a) Evaluation of functional forms, estimation approaches, and diagnostics used in GMACS including uncertainty characterization and satisfying required assessment elements.

(b) Evaluate application of GMACS to the BBRKC stock. Specifically, comment on what important features are missing relative to the current assessment approach?

(c) Evaluation of GMACS as a flexible assessment modeling tool. I.e., potential application to other crab stocks (e.g., Tanner crab, data poor stocks (Tier 4)), and stocks with unique data sets (e.g., snow crab and Bristol Bay red king crab cooperative survey data).

(d) Evaluation of utility of the modeling framework as a community supported modeling approach and practicality for managing into the future.

(e) Recommendations for further improvements and comment on the general applicability to the fishery management questions (risk assessment and MSE options).

These are a slightly rationalized version of the six Terms of Reference listed in the Statement of Work (p.25), covering the same issues. The summary of review findings given below is structured according to these Terms of Reference. This report represents the individual opinion of the present author. No attempt was made to reach a consensus among the three reviewers, but it was apparent during the review meeting that any differences between reviewers are likely to be in emphasis rather than substance.

Description of review activities

Documents and web-based resources relating to the Gmacs modeling framework were made available to reviewers two weeks before the review meeting, through the website www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/draft_assessments.htm. Appendix 1 (p.17) lists the key documents and resources made available through this website. Prior to the meeting it was made clear to the reviewers that Gmacs was currently incomplete, and that an important focus for the review was to gain outside input on the direction of development for the project and to get recommendations on how best to make progress.

A review meeting took place at the Alaska Fisheries Science Center (AFSC), Seattle, 29 June – 1 July 2015 (see Agenda at Appendix 2, p.18), chaired by Martin Dorn of the National Marine Fisheries Service (NMFS). The meeting was introduced by Ron Felthoven, Director of the Resource Ecology and Fisheries Management Division and AFSC. Other attendees at the meeting included:

- CIE reviewers (see p.6)
- Jim Ianelli of NMFS providing the scientific lead on Gmacs development
- Darcy Webber, independent consultant from New Zealand taking forward software development for Gmacs
- Bob Foy, Director of the AFSC Kodiak Laboratory, providing a perspective on management and assessment of Bering Sea and Aleutian Islands (BSAI) crab stocks (by tele-conference)
- Buck Stockhausen of NMFS, describing the rsimGmacs R package and providing a perspective on Tanner crab assessments
- Jie Zheng of the Alaska Department of Fish and Game, presenting information on the Bristol Bay red king crab stock assessment
- Jack Turnock of NMFS, providing a perspective on snow crab assessments
- Scott Goodman and Gary Stauffer of the Bering Sea Fisheries Research Foundation, representing industry interests in the development of Gmacs

Terms of Reference for the review were agreed at the start of the meeting (see p.6). Over the three day meeting there were presentations from Bob Foy, Jim Ianelli, Darcy Webber, Buck Stockhausen and Jie Zheng, covering the background in terms of science needs for support of BSAI crab stock assessment and management (Foy), development of Gmacs and rsimGmacs (Ianelli, Webber, Stockhausen), the community modeling approach (Ianelli, Webber) and current assessment approaches for BSAI stocks (Zheng). Extensive discussions with CIE panel members took place alongside the presentations, and responses to requests for further information and analyses were made by meeting participants (Foy, Webber). Report writing was undertaken by CIE panel members, working independently, during the two weeks following the meeting.

Summary of findings

General

An original intention in seeking a review of Gmacs was to have comparative assessments of BSAI crab stocks using the new framework, as a basis for deciding how to take the assessments forward. Prior to the review it was apparent that this was not possible as Gmacs was at a less advanced stage than originally anticipated. The focus of the review was therefore shifted towards a consideration of progress to date and identifying priorities for directions of development. Although a final endorsement of Gmacs is not sought at this stage, it is worth me stating at the outset that I do endorse both the motivation for Gmacs and the direction it is taking in development:

- the drive towards standardizing models across stocks and increasing transparency for both industry and managers;
- the project being taken forward as a multiple author, multiple agency collaboration;
- the use of AD Model Builder as the software platform;
- the technical details of the implementation so far;
- the development of associated R packages for producing standardized outputs and simulations;
- the use of Github as a code repository for version control, tracking of issues, recording historical development, etc.;
- the approach to documentation; and
- the intention to expand Gmacs to apply to all stocks.

It is already clear that impressive progress has been made in relation to all of these aspects. In terms of developing a framework for length-based assessment approaches, the Gmacs project is potentially world-leading, likely to be applied or adapted for crustacean assessments extending well beyond Alaskan crab stocks. It is likely unrealistic to expect greater progress by this stage; careful development of this generic framework is likely to be a time-consuming process, but time well spent in terms of delivering a hugely valuable resource to support effective management of the BSAI crab fisheries. The set up and management of the Gmacs project is also well suited for ongoing development to improve the framework and to adapt it for future management needs and inclusion of further sources of information.

Based on what was shown at the review meeting, it looks realistic to expect a Gmacs assessment to be undertaken in parallel with the Bristol Bay red king crab assessment in 2016, with this being phased in as the main source of information to support the harvest strategy thereafter. Phasing in of Gmacs assessments for other stocks, or more particularly for other Alaskan crab species, will depend on incorporating the necessary flexibility to deal with the complexities of differences in life-history and differences in the level and types of information available. This flexibility is central to the concept and motivation of Gmacs; it is perhaps the least developed aspect of the framework at present, but it is natural that the current priority is to develop and test the framework for application to Tier 3 stocks, representing the greatest amount of information available and greatest scope for modeling of population dynamic processes.

The main point of this review document is to express endorsement for the direction that Gmacs is taking and for the progress made to date. This judgment is made following a review meeting that was very successful in communicating the essentials of the framework and how it is being developed. The review comments that follow will necessarily be brief, concentrating on identifying priorities for further development.

ToR(a) Evaluation of functional forms, estimation approaches, and diagnostics used in GMACS including uncertainty characterization and satisfying required assessment elements

Required assessment elements are those used to measure stock status in relation to the overfishing limits (OFL), to define acceptable biological catch (ABC) and set acceptable catch levels (ACL). This includes definition of harvest control rules at the state level and the overarching OFL at the federal level. These elements are primarily biological reference points relating to MSY, estimates of exploitation rates and estimates of effective spawning biomass (ESB) in the required currency for the OFL and harvest strategies. Additionally, measurement of uncertainty around assessment outcomes and stock projection capability are required elements of an effective stock assessment. There are some differences of detail in what is required between the tiers of the current crab management system (the ten stocks being currently distributed between Tiers 3 to 5), but effectively the needs for capability within Gmacs are the same. Not all of these elements were explicitly demonstrated at the meeting, but given the definition of population dynamics processes within the model, and the link with observations, it is clear that all likely requirements are met, in relation both to the current management system and likely future developments. Reference point calculations are specified in the control file for running the model, including the target spawner per recruit (SPR) ratio for the B_{MSY} proxy, use of the directed fishery in SPR calculations, definition of years to include in average recruitment and definition of the proportion of mature male biomass to include. Evolution in requirements for reference points, e.g. in relation to the method of calculating ESB for the OFL definition, is likely to be possible using the existing controls, or would be readily developed by a trivial extension of these. Uncertainty in parameters or derived quantities should be readily addressed within the existing MCMC capabilities of the tried and tested AD Model Builder (ADMB) platform. Likewise, efficiency of parameter estimation, given structural definition of the assessment model, is well established within ADMB.

An element that is currently missing in Gmacs is the definition of a stock recruitment relationship (SRR). The SRR is specified in the control file, the options being Beverton-Holt or none; this presumably relates only to steepness included in the likelihood calculations, as the SRR is not used to provide recruitment estimates (currently parameterized as average and deviations). Estimation of the SRR would likely be a requirement for application of Gmacs to stocks in Tiers 1 and 2 of the current crab management system (no stocks at present), and it would be useful to consider alternative functional forms to Beverton-Holt, such as Ricker, for accounting for density-dependent feedbacks in stock projections. At the meeting, Malcom Haddon emphasized the importance of accounting for the time lag between egg production and recruitment to the modeled population; projection from settlement in Gmacs would circumvent this problem, and getting round the mixing of cohorts in individual size-classes caused by growth variability.

Aside from providing the elements needed by assessors to provide inputs to the management process, Gmacs also seems well placed to ease and standardize reporting of assessment outcomes, particularly through the gmr package. This is an R package that deals with Gmacs objects, providing plotting routines for model diagnostics, summarization of data and model fits. The meeting was shown the simple, one-line commands that can be used in R to produce, for example plots of spawning stock biomass (with confidence regions) and fits to size composition data. Undoubtedly, there is a great deal more that could be added to the current capability, driven for example by the requirements for preparation of BSAI crab SAFE report chapters (Crab Plan Team, 2015). This might include all standard tables and plots of input data as well as model outputs, as well as outputs of diagnostics of value in refining models for individual stocks, and will be of considerable value in standardizing the presentation of agreed assessment elements, as well as streamlining the assessment and reporting process.

Additional diagnostics that could be incorporated in processing of outputs in gmr include retrospective analyses and plots and residual plots (c.f. Figures 25-29 in Zheng & Sideek, 2015).

Input to Gmacs, defining input data, assessment options, parameter bounds and priors, is simple and intuitive, as shown in the presentation by Jim Ianelli on day 1 of the meeting (http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/PRESENTATIONS/Ianelli_June_2015_CIE.pdf). Inputs include model dimensions, length-based parameters (size bins, length-weight, maturity, etc.), catch data, survey indices, size composition data, molt increment data, 'leading' parameters (natural mortality and recruitment parameters, with bounds and priors), selectivity controls and controls relating to the estimation of biological reference points. Retrospective analyses and data simulations are already provided as command line options. Input to Gmacs is, in principle (i.e. given adequate documentation of required formats), admirably clear and well suited to extension alongside the capabilities of the package. One aspect, however, which does need clarification, and on which there appeared to be some uncertainty at the meeting, was the inclusion of discard mortality in the catch data – discard mortality rates are specified, but it is unclear whether the catch data input to the model was already adjusted for discard mortality or whether this was calculated within Gmacs. Principally, this is a matter of clarity of documentation for those preparing input data; given the specification of discard mortality rates it seems likely that the adjustment is made within Gmacs, and this would certainly make sense for ease of analyzing sensitivity of assessment outcomes to assumptions about discard mortality (possibly coded as an option within Gmacs?). It should also be clarified that fishing mortality is specified by fleet in the catch equations (subscripting F by k), distinguishing landings from discards.

Some elements were flagged up as missing from the current implementation of Gmacs, notably inclusion of maturity state, tagging information and fishing effort. Distinction between new and old shell states is identified as included in the model, but the extent to which this has been applied in model runs so far is unclear (see below). Inclusion of those elements required to match model structures applied for different BSAI crab stocks should define the priorities for inclusion of these elements. This might not include fishing effort or tagging information at present, but both of these elements would represent a significant enhancement to Gmacs. Given that model fitting attempts to achieve internal consistency between the different modeled elements, any additional data that are highly informative about particular fishery or population processes would be beneficial to the assessment process, potentially reducing uncertainty. For fishing effort, this would apply both to exploitation rates and to commercial CPUE as an abundance index. Tagging information, depending on the nature of tagging studies undertaken, would provide information on growth and mortality. It is recommended that both these aspects be explored. Tagging also provides data on movement; incorporation of spatial processes in Gmacs is probably a step too far, and a full spatial model would require a great deal of movement data. However, issues of stock definition and shifts in distribution, e.g. in relation to environmental temperature (noted in Bristol Bay red king crab), are relevant to interpretation of model diagnostics (alongside spatial survey data), and it could be explored whether there are systematic ways of accounting for such processes without a fully spatially-explicit model. The same might apply to accounting for seasonal movement patterns, such as seen in Tanner crabs.

A fairly long wish-list could probably be written for elements to be included in Gmacs in the long-term. Catchability related to temperature (or other environmental variables) would likely be high on this list. Priorities should be determined by the likely influence of the elements on reducing bias and uncertainty in assessment outcomes. Issues than can be addressed without significant increases in model complexity, or even with reductions in model complexity, should probably be priorities in this regard. For example, it was questioned whether it was necessary to model recruitment separately for males and females. Whether real differences in recruitment are likely depends on the size at which crabs enter the model – discarding of females and sexual differences in growth have a bearing here, on recruit quantities by sex and the mix of cohorts within size classes, but it is relevant to consider whether the patterns are likely to be distinct enough to make it worthwhile to model two sets of recruitment deviations. Survey data on Bristol Bay red king crabs, provided to the meeting by Bob Foy, showed variation around a sex ratio of 0.5 for the smallest size classes, the variation likely being due to sampling rather than process variability. Darcy Webber suggested that the dimensionality of the estimation problem could be addressed by using the same recruitment deviations for both sexes, using a time-varying sex ratio with a strong prior of 0.5. This seems a sensible approach, and simply setting male and female recruitment to be equal should also be considered. Recruitment estimates for Bristol Bay red king crab appear to be similar between males and females, except at the start of the time series.

By contrast, there seems only to be one prior for natural mortality, not specific to sexes although there does appear to be the facility for *M* to be sex-specific. Four options for modeling time-varying natural mortality otherwise provides a great deal of flexibility.

Choice of functional forms in Gmacs seems sensible, but some further development in structure and functional forms is desirable. Use of the gamma distribution for growth transitions is the most obvious choice; Malcolm Haddon suggested also to consider the normal distribution (as applied in some other models for crabs), and also empirical distributions. Similarly, dome-shaped selectivity (e.g. double normal) should be allowed for in Gmacs – at the meeting it was suggested that this might apply for bycatch fisheries where the target species is smaller than the bycatch species.

Molting probabilities are currently defined as being independent of shell condition, but this aspect would benefit from further elaboration, e.g. by accounting shell age in the molting process. As it stands, molting probabilities being modeled as independent of shall age is an approximation that is unlikely to matter for population dynamics whilst the stock is relatively stable, but could introduce biases and lags in tracking strong trends of increase or decrease in stock abundance. Certainly, the sensitivity of model outcomes to this approximation should be explored, and unless there are good reasons (precision, bias, correct specification of model structure in relation to population processes) Gmacs should at least follow the practice for modeling old and new shell conditions applied in existing assessment models, e.g. that for Bristol Bay red king crab.

Timing and sequence in the modeling is an issue that needs careful examination in Gmacs, and certainly there should at least be the facility for the way in which these are modeled to be aligned between Gmacs and existing assessment models. This applies particularly to the modeling of fishing mortality as either a continuous or a pulse process. Gmacs currently applies continuous fishing mortality, whereas at least the Bristol Bay king crab model applies pulse fishing (also in the rsimGmacs simulation package). Possibly this is not a critical assumption either way for the purposes of estimation, but there should consistency in what is applied, or the facility to apply consistency, and it should be considered whether there are any implications for estimation of equilibrium SPR. The ordering of molting, surveys and fishery is relevant to the setting of reference points – the biomass reference point is set for mid-February, after fishing and before growth. Modeling of this sequence should have no overhead in terms of parameters to estimate, and should be a design decision driven principally by the requirements of the Crab Plan Team in setting management criteria, which potentially could differ between stocks.

Two simulation facilities for Gmacs were described at the meeting. Within Gmacs itself, and requiring an ADMB .pin file for parameter values, there is the facility to simulate a stock with random recruitment deviations and observation errors on catch and stock indices, which can be used to explore how aspects of variation propagate through to assessment outcomes. This is an extremely powerful tool that will no doubt find much use in risk assessment in relation to using assessment outcomes for management purposes. The other tool is an R package, rsimGmacs, developed by Buck Stockhausen as an independent testing platform for Gmacs (Buckhausen, 2015). Currently it is coded only for red king crab, but will be developed for Tanner crab and other species, allowing implementations of Gmacs for these species to be tested. The purpose of rsimGmacs is to provide an independent check on code specification, and to provide data sets for Gmacs to test that it can recover the same parameters. Current versions of rsimGmacs and Gmacs differ in significant ways, e.g. in the specification of fishing in continuous (Gmacs) or pulse forms (rsimGmacs), and in the separation of growth processes between old and new shell crabs. A major challenge will be to coordinate the two sets of code – in a sense, Gmacs would ideally need to be 'finished' before rsimGmacs can properly be defined, but in practice there is likely to be parallel development that will have virtue in identifying major discrepancies. It is recommended that rsimGmacs and Gmacs are brought into line for versions used to test application to species other than red king crab. rsimGmacs is potentially an extremely valuable tool to generate data sets for testing, and could also be used to address effects of model mis-specification.

(b) Evaluate application of GMACS to the BBRKC stock. Specifically, comment on what important features are missing relative to the current assessment approach?

The first use of Gmacs is likely to be for Bristol Bay red king crab (BBRKC), one of the two stocks currently in Tier 3 of the crab management system. The most recent assessment for BBRKC (Zheng &Siddeek, 2015) was summarized at the meeting by Jie Zheng, and preliminary runs of a comparative assessment in Gmacs were presented by Darcy Webber (GMACS Development Team, 2015b). At the time of the meeting the Gmacs implementation for BBRKC was still at an early stage, such that it is difficult to comment in detail on its performance relative to the Zheng model. Obvious differences in model formulation, principally the treatment of new and old shell conditions and the modeling of pulse (Zheng model) versus continuous fishing (Gmacs) noted above, will need to be accounted for (preferably by including these facilities in Gmacs) before a fair comparison is possible.

Two versions of the Gmac model were run, one applied to both males and females ('TwoSex') and one applied to males only ('OneSex'). The OneSex model was used as the basis for comparison with the Zheng model, for reasons of structural differences relating to sex-specific natural mortality and recruitment in the TwoSex model. Early runs of OneSex showed big differences from the Zheng model in terms of the trend in survey biomass, the latter model providing a much closer fit. This appeared not to be represented in uncertainties round biomass estimates, suggesting that this did not result simply from different feasible solutions within a delicately balancing set of parameter covariances. In the version presented at the meeting ((GMACS Development Team, 2015b, draft at 30 June) the correspondence between OneSex and Zheng survey biomass trends was much closer, largely as a result of increasing the weight applied to the survey likelihood component. Fits to catches by gear type were good (with some uncertainty about inclusion of discard mortality, which needs clarification – see above), to length-frequencies in the retained and discarded portions of the directed catch and in trawl bycatches were mostly reasonable, albeit with some obvious discrepancies.

For now, it is worth stating that the successful implementation of the BBRKC assessment model is a major achievement in itself, but it is too early to identify obvious advantages or shortcomings of the new approach. A proper comparison will need to ensure that the Gmacs model does not differ structurally from the Zheng model without good reasons intrinsic to the adoption of the new framework, i.e.

features that are essential for standardization, transparency and proper specification of population processes. There is no obvious rationale at present for dropping any of the features of the Zheng model, whilst the development of Gmacs may well include additional functionality that will go beyond what is currently possible in the Zheng model. Both modeling approaches are capable of producing descriptions of BBRKC stock dynamics that are consistent with the available data; any departure of assessment outcomes from the current assessment model which has implications for management (e.g. the lower mature male biomass estimates from OneSex) should be examined carefully, as changes in management should be based on clear signals from stock indicators rather than simply a change in modeling framework. Once structural differences have been eliminated or justified, any remaining differences in model outcomes should be carefully examined, using parameter constraints and sensitivity analyses, to determine whether the source is a difference in emphasis within the overall likelihood, differences in the way that likelihoods are formulated, differences in functional forms, correlations causing difficulty in separate identification of parameters (and hence real uncertainty in outcomes) or some other facet of the difference in modeling framework. Only when differences can be ascribed to modeling choices or assumptions that are clearly 'better', justified for taking forward future assessments, should any changes in assessment outcome associated with the adoption of Gmacs be adopted for management. It is recommended as an urgent priority that Gmacs be developed to match the essential elements of the Zheng model for BBRKC before being run in parallel with the assessment in 2016 with the kind of sensitivity analyses suggested above. Once complete comparability is achieved, or assessment changes are justified and rationalized, Gmacs could then be phased in as the principle assessment model for BBRKC.

(c) Evaluation of GMACS as a flexible assessment modeling tool. I.e., potential application to other crab stocks e.g., Tanner crab, data poor stocks (Tier 4), and stocks with unique data sets (e.g., snow crab and Bristol Bay red king crab cooperative survey data)

Ten different BSAI crab stocks are distributed between Tiers 3 to 5 of the crab management system which defines OFL and associated biological reference points. A sloping control rule relating F_{OFL} to effective spawning biomass expressed as a fraction of B_{MSY} (or proxy) is defined for stocks in Tiers 1-4. This covers seven stocks, of which two are in the Tier 3, representing the 'best' information currently available in terms of catch information and biomass estimates. The remaining three stocks are in Tier 5, with OFL defined by average catch. The generic model needs to consider all levels of data availability for stocks in Tiers 1-4, as well as the complexity represented in differences in life-history between the species.

Clearly, it is relevant to ask whether the Gmacs framework can cover all the possible options, or should the framework be bifurcated, and should particular classes of stocks be identified? Considering the first issue, that of different levels of data availability, the answer probably is that Gmacs should cover these options, and the application of Gmacs to data poor stocks using stock reduction analysis indicates that this approach will be successful (Martell *et al.*, 2015); provided there is sufficient flexibility defined to constrain and fix parameters, and apply stronger assumptions when necessary, the task of finding internal consistency within the available data sets should be similar at all levels of data availability down to and including Tier 4.

Less certain is the capability of generalizing Gmacs to cover different life histories. For snow crabs, this means accounting for a terminal molt, likely to be relatively straightforward, and keeping track of maturity stages (also for Tanner crabs), which may be less straightforward. My own recommendations would be: (i) to make model structures – stages between which transition probabilities are defined – as generic as possible, so that models not requiring stage separations, can be defined as special cases with just one stage for a particular process and an identity matrix for the transition probability; and (ii) to keep any bifurcations as flow control within an overall set of code that covers all possibilities, sharing code blocks as far as possible for particular model constructions. This approach should compensate for unwieldiness of code (and possible inefficiency?) by coherence of the framework; otherwise branches should be defined for research models rather than overall Gmacs releases to be applied as working stock assessment models. Aligned with this approach is the need to be able to define existing models as special cases of the generic model. Ultimately, design decisions should be driven by the needs of the Crab Plan Team, e.g. the need for estimating effective spawning biomass, the definition of which (currently mature male biomass) may evolve over time.

Priority at present is to get Gmacs working as a satisfactory framework for BBRKC as a Tier 3 stock; generalization for other species (also within rsimGmacs) is the task to follow.

(d) Evaluation of utility of the modeling framework as a community supported modeling approach and practicality for managing into the future

All members of the review team were very impressed by the demonstrations of the use of the Github repository and associated tools, e.g. for self documentation, as a community modeling approach. Given the complexity of the coding task and the number of collaborators, this seems to be the only practical way of managing the project, the principal advantages being in version control, keeping track of changes and facilitating documentation. Tagging is used to freeze a version, e.g. an assessment that has been performed. The users have already demonstrated the practicality of the approach for managing into the future. To this endorsement there is very little to add, except to re-iterate the comments about bifurcation of Gmacs made above: coherence of a single working version of Gmacs is important, managed as a series of releases which are enhanced in capabilities and efficiency, with branching restricted to research models that are merged into new releases of the working assessment model as appropriate.

The utility of Gmacs itself as a community supported approach is a slightly separate question to the utility of the approach to managing the project, but again I can only state that the team have already demonstrated the value of pooled expertise, and this approach is likely to be a pre-requisite for the development of a truly generic framework covering cases that have previously been developed separately (GMACS Development Team, 2015a).

(e) Recommendations for further improvements and comment on the general applicability to the fishery management questions (risk assessment and MSE options)

Recommendations for further improvements are scattered through the previous sections, and collected together on p.4. As already stated, the current priority should be to address issues relating to the application of Gmacs to BBRKC before considering the complexities of different life histories and other aspects of model flexibility. Here, the outstanding issues relate to continuous versus pulse fishery dynamics, sex-specific processes, old and new shell conditions, data weighting, etc. Technical issues relating to the application of MCMC within ADMB should also be addressed at this early stage. With regards to model diagnostics and automated generation of plots and tables, the SAFE guidelines effectively provide a template for what is needed (Crab Plan Team, 2015). In the longer term, in addition to considering technical issues such as the specification of selectivity, attention is needed to the use of Gmacs to evaluate simpler management strategy options that do not use all of the complexity within the framework.

Conclusions

The final conclusions of this review are quite simple:

- the development of a generic framework for assessment of Alaskan crab stocks to achieve standardization and transparency is worthwhile and attainable;
- whilst being at an early stage of development, Gmacs represents a significant step in this direction;
- Gmacs has the potential for sufficient flexibility to account for differences in data availability between stocks and in the biology of the different species;
- management of the project, version control and documentation are demonstrably working, and probably represent the only practicable approach for a community-based modeling development of this type; and
- Gmacs and supporting applications (gmr and rsimGmacs) should be able to deliver all required assessment elements to support management of BSAI crab stocks.

Application of Gmacs is likely to extend well beyond assessment of Alaskan crab species, having the potential to be a modeling tool for length-based assessments of crustaceans world-wide.

Acknowledgments

I would like to thank Jim Ianelli for being a good host and directing the review, Martin Dorn for good chairmanship, Bob Foy, Buck Stockhausen, Darcy Webber and Jie Zheng for effective and interesting presentations on Gmacs and its context, and all participants for discussions during the meeting. Roberto Koeneke and Manoj Shivlani, Coordinators for CIE with NVTI Communications Inc., provided excellent arrangements for setting up and attending the meeting. I am also grateful to my fellow reviewers Nick Caputi and Malcolm Haddon for stimulating discussions and good companionship.

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Zheng, J. &Siddeek, M.S.M., 2015. *Bristol Bay Red King Crab Stock Assessment in Spring 2015*. Alaska Department of Fish and Game, 130 pp. http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/rkc-safe15s.pdf

APPENDIX 1: Bibliography of materials provided during the review meeting

Documents:

Crab Plan Team, 2015. *A Guide to the Preparation of Bering Sea and Aleutian Islands Crab SAFE Report Chapters.* Draft, 13 pp. http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/guideline for crab assessments.pdf

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Zheng, J. & Siddeek, M.S.M.,2015.*Bristol Bay Red King Crab Stock Assessment in Spring 2015*. Alaska Department of Fish and Game, 130pp. http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/rkc-safe15s.pdf

Web-based resources:

2015 GMACS Review Documents:
http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/draft_assessments.htm

GMACS Wiki:
https://github.com/seacode/gmacs/wiki

GMACS API:
http://seacode.github.io/gmacs/

BSAI Crab Plan Team:
http://www.npfmc.org/fishery-management-plan-team/bsai-crab-plan-team/

May 2014 Crab Plan Team documents:
http://legistar2.granicus.com/npfmc/meetings/2015/5/924_A_Crab_Plan_Team_15-05-04_Meeting_Agenda.pdf

APPENDIX 2: Agenda for the review meeting

Draft Agenda

Review of GMACS Modeling Framework

Alaska Fisheries Science Center, Seattle, WA

June 29 – July 1, 2015

For security and check-in: Anne Hollowed, Martin Dorn and William Stockhausen

Adjourn each day at about 5pm

Monday, June 29:

9:00 AM Welcome (AFSC Leadership) and introductions (Martin Dorn, Chair), Review/adopt agenda/schedule and Terms of reference, meeting protocols.
9:15 AM NPFMC Crab Plan Team and Council cycle (Foy/Turnock)
10:30 AM – Break
10:45 AM Overview of GMACS modeling framework. (Jim Ianelli)
12:00 PM – Lunch
1:00 PM Current BBRKC Assessment (Jie Zheng)
3:00 PM – Break
3:15 PM Comparisons of GMACS and current BBRKC assessment (Webber/Ianelli)
4:00 PM Discussions, model run requests

Tuesday, June 30

9:00 AM Results and requests from previous days' discussions
9:30 AM Comparisons of GMACS and current BBRKC (continued)
10:30 AM – Break
10:45 AM External simulation package and tests (Stockhausen)
12:00 PM – Lunch
1:00 PM Within-GMACssimulation-testing options
3:00 PM – Break
3:15 PM Discussions, model run requests

Wednesday, July 1

9:00 AM Results and requests from previous days' discussions
9:15 AM Data poor and alternative model configurations for other stocks
10:30 AM – Break
10:45 AM API and wiki (user manual) overview
12:00 PM – Lunch
1:00 PM git development cycle demo
3:00 PM – Break
3:15 PM Discussions, model run requests

APPENDIX 3: Statement of Work

Statement of Work
External Independent Peer Review by the Center for Independent Experts

Review of GMACS Modeling Framework

Scope of Work and CIE Process: The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Representative (COR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

Project Description: The Alaska Fisheries Science Center (AFSC) is responsible for assessments of 5 Bering Sea crab stocks. Collectively these crab stocks support valuable commercial fisheries. Recently, scientists at the AFSC and the University of Washington have developed a **Generalized Model for Alaska of Crab Stocks (GMACS).** GMACS is a generalized and flexible size-structured modeling framework. The first version has been designed to develop stock assessment models for the stocks of red king crab in Bristol Bay and Norton Sound, Alaska. The framework makes use of most of the available data sources for both male and female crabs, including survey and fishery indices of abundance and fishery and survey size-compositions. A workshop held in January 2015 contributed to the implementation of GMACS to data for red king crab stocks in order to test its efficacy and determine priorities for development for application to other Alaskan crab stocks. A goal of the project is to provide a standardized size structured assessment that is more transparent than the current approach in which assessment scientists have written species-specific software. A CIE review of the GMACS modeling framework and issues related to further development and application for stock assessment is requested.

The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**. The tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements for CIE Reviewers:Three CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. Each CIE reviewer's duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review described herein. CIE reviewers shall have the expertise, background, and experience to complete an independent peer review in accordance with the SoW and ToRs herein. CIE reviewers shall have expertise and work experience in analytical stock assessment, including population dynamics, age/length based stock assessment models, data-poor stocks, survey design, and population structure and spatial management.

Location of Peer Review: Each CIE reviewer shall conduct an independent peer review during the panel review meeting scheduled during the week of July 29^{th}, 2015 at the Alaska Fisheries Science Center in Seattle, Washington.

Statement of Tasks: Each CIE reviewers shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

Prior to the Peer Review: Upon completion of the CIE reviewer selection by the CIE Steering committee, the CIE shall provide the CIE reviewer information (name, affiliation, and contact details) to the Contract Officer Representative (COR), who forwards this information to the NMFS Project Contact no later the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers with the background documents, reports, foreign national security clearance, and information concerning other pertinent meeting arrangements. The NMFS Project Contact is also responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COR prior to the commencement of the peer review.

Foreign National Security Clearance: When CIE reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for CIE reviewers who are non-US citizens. For this reason, the CIE reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national-registration-system.html

Pre-review Background Documents: Two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the CIE reviewers the necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE Lead Coordinator on where to send documents. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for the peer review.

AFSC will provide copies of the statement of work, stock assessment documents, prior CIE review documents, and other background materials to include both primary and grey literature.

This list of pre-review documents may be updated up to two weeks before the peer review. Any delays in submission of pre-review documents for the CIE peer review will result in delays with the CIE peer review process, including a SoW modification to the schedule of milestones and deliverables. Furthermore, the CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein.

Panel Review Meeting: Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs shall not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COR and CIE Lead Coordinator.** Each CIE reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the ToRs as specified herein. The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The NMFS Project Contact is responsible for ensuring that the Chair understands the contractual role of the CIE reviewers as specified herein. The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

Contract Deliverables - Independent CIE Peer Review Reports: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Other Tasks – Contribution to Summary Report: Each CIE reviewer may assist the Chair of the panel review meeting with contributions to the Summary Report, based on the terms of reference of the review. Each CIE reviewer is not required to reach a consensus, and should provide a brief summary of the reviewer's views on the summary of findings and conclusions reached by the review panel in accordance with the ToRs.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review;
2) Participate during the panel review meeting at the **Alaska Fisheries Science Center** in **Seattle, Washington** during **June 29th - July 1st 2015** as called for in the SoW, and conduct an independent peer review in accordance with the ToRs (Annex 2);
3) In Seattle, Washington during June 29th - July 1st 2015 as specified herein, conduct an independent peer review in accordance with the ToRs (**Annex 2**).
4) No later than **July 15, 2015**, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Dr. Manoj Shivlani, CIE Lead Coordinator, via email to mshivlani@ntvifederal.com, and Dr. David Die, CIE Regional Coordinator, via email to ddie@rsmas.miami.edu. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in Annex 2;

Schedule of Milestones and Deliverables: CIE shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

One month prior	CIE sends reviewer contact information to the COR, who then sends this to the NMFS Project Contact
Two weeks prior	NMFS Project Contact sends the CIE Reviewers the pre-review documents
June 29th - July 1st 2015	Each reviewer participates and conducts an independent peer review during the panel review meeting
July 15, 2015	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
July 29, 2015	CIE submits CIE independent peer review reports to the COR
August 7, 2015	The COR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be made through the COR who submits the modification for approval to the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the CIE within 10 working days after receipt of all required information of the decision on substitutions. The COR can approve changes to the milestone dates, list of pre-review documents, and Terms of Reference (ToR) of the SoW as long as the role and ability of the CIE reviewers to complete the SoW deliverable in accordance with the ToRs and deliverable schedule are not adversely impacted. The SoW and ToRs cannot be changed once the peer review has begun.

Acceptance of Deliverables: Upon review and acceptance of the CIE independent peer review reports by the CIE Lead Coordinator, Regional Coordinator, and Steering Committee, these reports shall be sent to the COR for final approval as contract deliverables based on compliance with the SoW. As specified in the Schedule of Milestones and Deliverables, the CIE shall send via e-mail the contract deliverables (the CIE independent peer review reports) to the COR (William Michaels, via William.Michaels@noaa.gov).

Applicable Performance Standards: The contract is successfully completed when the COR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards: (1) each CIE report shall have the format and content in accordance with Annex 1, (2) each CIE report shall address each ToR as specified in Annex 2, (3) the CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Distribution of Approved Deliverables: Upon notification of acceptance by the COR, the CIE Lead Coordinator shall send via e-mail the final CIE reports in *.PDF format to the COR. The COR will distribute the approved CIE reports to the NMFS Project Contact and regional Center Director.

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Annex 1: Format and Contents of CIE Independent Peer Review Report

1. The CIE independent report shall be prefaced with an Executive Summary providing a concise summary of the findings and recommendations.

2. The main body of the reviewer report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Summary of Findings for each ToR, and Conclusions and Recommendations in accordance with the ToRs.

   a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including providing a detailed summary of findings, conclusions, and recommendations.

   b. Reviewers should discuss their independent views on each ToR even if these were consistent with those of other panelists, and especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the Summary Report that they feel might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The CIE independent report shall be a stand-alone document for others to understand the proceedings and findings of the meeting, regardless of whether or not they read the summary report. The CIE independent report shall be an independent peer review of each ToRs, and shall not simply repeat the contents of the summary report.

3. The reviewer report shall include as separate appendices as follows:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of the CIE Statement of Work
   Appendix 3: Panel Membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference for the Peer Review

Review of GMACS Modeling Framework

CIE reviewers shall address the following Terms of Reference during the peer review and in the CIE reports.

a. Evaluation of modeling framework as a flexible assessment modeling tool.
b. Evaluation of functional forms and estimation frameworks, used in GMACS.
c. Evaluation, of the diagnostic products of GMACS. and the ability to compile assessment documents
d. Evaluation of utility of the modeling framework as a community supported modeling approach and practicality for managing into the future.
e. Evaluation, of the flexibility of the model to address the stock specific characteristics of assessed species including: spatial management (e.g., Tanner crab), data poor (Tier 4 assessments), and stocks with unique data sets (e.g., snow crab and Bristol Bay red king crab cooperative survey data).
f. Recommendations for further improvements and comment on the general applicability to the fishery management questions (risk assessment and MSE options).

Annex 3: Tentative Agenda

Review of GMACS Modeling Framework

Alaska Fisheries Science Center, Seattle, WA
June 29 – July 1, 2015

Contact for security and check-in: Anne Hollowed, Martin Dorn and William Stockhausen
Contacts for additional documents: James Ianelli, Darcy Webber

Monday, June 29:
9:00 AM – 10:30 AM: **Introduction**
Topics: *Introductions, agenda, Overview, GMACS modeling framework. (Ianelli, Webber)*
10:30 AM – Break
10:45 AM – Current Bristol Bay red king crab (BBRKC) models used (*Zheng)*
12:00 PM – Lunch
1:00 PM -3:00 PM: **Input data**
Topics: *Model structure, likelihood formulations, data weighting, output diagnostics*
3:00 PM – Break
3:15 PM – **Discussions**
5:00 PM – Adjourn for day

Tuesday, June 30:
9:00 AM – 10:30 AM: **Assessment model**
Topics: *Community model development environment*
10:30 AM – Break
10:45 AM – **Discussions**
12:00 PM – Lunch
1:00 PM -3:00 PM: **Demonstration runs BBRKC and NSRKC**
Topics: *Applications to Bristol Bay Red King Crab and Norton Sound Red King Crab; Issues and concerns for implementation for other crab stocks*
3:00 PM – Break
3:15 PM – Discussions
5:00 PM – Adjourn for day

Wednesday, July 1:
9:00 AM – 10:30 AM: Open Discussions
Topics: *Open discussion with analysts as needed*
10:30 AM – Break
10:45 AM – Discussions
12:00 PM – Lunch
1:00 PM -3:00 PM: **Alternative model runs, further discussion as needed**
Topics: *TBA*
3:00 PM – Break
3:15 PM – Further discussions and summarize
5:00 PM – Adjourn meeting