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# North Pacific Fishery Management Council Crab Modeling Workshop

January 9-13, 2012  
Alaska Fisheries Science Center, Seattle WA

## 1 Summary

A technical crab modeling workshop took place from January 9-13, 2012, at the Alaska Fisheries Science Center in Seattle WA. The workshop was chaired by Jim Ianelli (AFSC), and was attended by members of the Crab Plan Team (CPT), the authors of crab and groundfish stock assessment models, outside technical stock assessment expertise, and the general public (see section 4 for list of participants).

The over-arching objectives of the workshop were to review models which are currently under development and provide the assessment authors with feedback and recommendations on model development, with the aim that these models could be used in the future for estimating stock status and biological reference points. One half day of the workshop was devoted to discussions regarding methods for estimating probability distributions for the overfishing limit (OFL). This discussion included biologists working on groundfish stock assessments in addition to the key members of the CPT and SSC (a summary is reported separately for Council presentation).

Assessment models for Aleutian Islands golden king crab and Bering Sea Tanner crab were presented to the workshop. The workshop followed a split-model format to facilitate real-time model development. Model code and documentation were provided to two members of the crab plan team for review two weeks prior to the workshop. Discussions about the data, assumptions, assessment models, and interpretation of the results took place during workshop.

A series of consensus recommendations were identified for both the AIGKC model and the data used by that model, and for the Tanner crab model. The workshop agreed that a meeting dedicated solely to model development for two stocks provided the ability to delve into aspects of models, model fitting, coding and data which would not be possible during a routine meeting of the CPT. It recommended that consideration be given to holding targeted workshops for crab assessment models in the future

### **AIGKC model**

Although much progress has been made in developing the model for this stock, issues mainly related to data processing (prior to inclusion in the model), along with some aspects of the specifications of the model required resolution before this model can be accepted for use in management. The workshop noted that the model equations predict the abundance of new and old shell individuals via a molting probability coupled with a growth transition matrix, but there are no direct observations on new and old shell abundance/composition to reliably estimate parameters that predict molting probabilities. A prior using externally estimated L50 from tagging data was used for molting probability estimation. Moreover, model outcomes are sensitive to assumed values (in the form of a prior) for the relationship between molting probability and size. A workplan to conduct detailed evaluations using general linear models (GLMs) for standardizing the CPUE data was identified as a high priority research topic, and this work will be reviewed at the May 2012 CPT for eventual inclusion in the assessment.

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### **Tanner crab model**

The Tanner crab model was essentially unchanged from that present to the September 2011 meeting of the CPT. Consequently, a relatively large number of model changes and requests for evaluations were done on a compressed schedule during the week. It became apparent that many aspects of the model code are hard-wired often requiring new variable declarations and complex coding. One approach to helping with this would be to write more general code and control model configurations more easily through the use of switches in control files. Also diagnostic display tools could be simplified to aid in evaluating model alternatives. Nonetheless, the authors worked to provide the group with results that could be used for revised rebuilding analyses.

The discussions on this model focused mainly on factors in the survey methods that might be causing poor fits to the survey data if no allowance is made for selectivity and catchability for males to differ markedly between 1982-87 and 1988+. Discussion also focused on whether the Somerton & Otto underbag experiment provided a reliable estimate of survey  $q$  for males for the years 1988+. The workshop generally considered the large change in survey  $q$  implied by the base model (0) was unrealistic. The analysts presented a long list of aspects of the survey that changed over time and could have impacted catchability and selectivity. However, these factors, taken individually and in combination, failed to explain the estimated change in apparent catchability. An alternative explanation, which would also be consistent with observed CPUE from the fishery, was that there was a movement or mortality event during the early 1980s that caused the observed decline in the survey biomass estimates. This possibility led to two sets of model runs: (a) the “Hide’em” scenarios in which the low survey estimates between 1982-87 were due to animals being unavailable to the gear for some reason, and (b) the “Kill’em” scenarios in which these low estimates were due to animals having died. Both scenarios are able to mimic the data better than assuming that catchability was constant from 1982 onwards, but at the same time both rest on assumptions which cannot be validated independently. The workshop noted that the same weight was assigned to each annual length-composition. However, the sample sizes vary markedly among years, sexes, and fisheries. The workshop identified an approach to weight these data based on the number of crabs sized, subject to a maximum weight.

Several modelling issues were identified which require further work. In addition, a number of inconsistencies between how data are treated in the Tanner crab and golden king crab models (e.g., lognormal vs normal errors for the reported catch, multinomial vs. robust normal for size compositions) were noted. Nevertheless, scenarios to employ for projections were identified for moving forward with a Tanner crab rebuilding plan while the model is still under development.

## **2 Aleutian Islands golden king crab model**

The following document was sent for review prior to and during workshop: ([www.tinyurl.com/AIGKC-2011](http://www.tinyurl.com/AIGKC-2011)). During the week a number of updates were distributed.

### **2.1 Summary of discussions**

Siddeek provided an overview of the current status of the AIGKC model and the progress made since it was last reviewed by the CPT (September 2011).

Currently, the stock is split into eastern Aleutian (EAG) and western Aleutian (WAG) components for assessment and management purposes. A number of data-analysis-related issues were noted by the workshop and this was formed the main focus for discussion. Model runs were nonetheless requested to illustrate sensitivity to the different data and assumptions. In particular, the use of the results of analyses of the tagging data results as prior information for the molting probability (with high precision) effectively anchored the magnitude of the population. The discussions on the use of tagging data (for

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population and growth estimates), length compositions as derived by dockside and observers (and weighted by catch), and derivation of CPUE indices (from observers and dockside landings) are presented in the subsequent sections.

### **2.1.1 Tagging data**

The workshop noted that the tagging for the eastern area is used to estimate growth for both areas and to provide independent estimates of exploited legal male biomass for the eastern area. The workshop had concerns about both of these uses of the tagging data. The recovery rate for the tagging data was estimated at approximately 5-8%. The group requested additional information on the tagging data, further documentation on the actual recovery rates, further analysis of the tagging data itself, as well as a sensitivity analysis of model performance with and without the tagging data. Currently, there are no data by shell condition (new-and old-shell) which provide information to estimate the parameters for the molting probability function. Rather, an informative prior for the length-at-50% molting is included in the assessment, and this prior is based on the results of the tagging study. A starting point would be to model the tagged population explicitly. The author should incorporate the tagging data directly into the model and determine its influence on the estimates of molting probability. Alternatively, the author could recode the population dynamics model so that it does not explicitly account for new shell/old shell individuals as it currently does, because the size-composition data used when fitting the model are aggregated over new and old shell crab. Owing to a lack of information on reporting rates and other uncertainties related to the tagging data, the workshop agreed that the tagging data should not be used as the basis for priors on exploited legal male biomass .

### **2.1.2 Length-composition data**

The workshop discussed the length-composition data used in the model and how these data were weighted. It was suggested that the length-composition data may be over-weighted. The justification of the relative weights used was lacking and should be evaluated through clearer diagnostic tools. The workshop recommended using the length-frequencies collected by the observers while disregarding the dockside [length-frequency]. It was also suggested that the model be fitted to the length-composition for the total (landed and discarded animals) catch and the length-composition from dockside monitoring (as is the case for Tanner crab), and hence use the model to differentiate between landings and discards.

### **2.1.3 CPUE**

The workshop discussed the treatment of CPUE data in the model and the possible confounding of use of both discard and retained CPUE. The dockside (retained) CPUE provides a longer data series (back to 1985) and would be preferable for use in the model. More details regarding the raw catch and effort data were requested such as the number of vessels, number of samples etc. This was central to the runs requested and presented in the next section. There was also some concern in the lack of independence between the retained and discarded catch CPUE, because both of these measures are based on the same effort measure; use of the dockside CPUE would resolve this issue.

### **2.1.4 Model run requests**

The workshop requested several overnight runs during the course of the workshop. These runs were based on a variant of the original model which (a) did not include the estimates of legal male biomass calculated from the tagging data in the assessment, (b) reparameterized how the initial conditions were specified, and (c) omitted the penalty on the change in  $q$  due to rationalization. The runs (which were sequential) were:

**Run 1:** Downweight discard CPUE (longer term remove or have ability to remove)

**Run 2:** Dockside retained CPUE from 1998, then

**Run 3:** Dockside retained CPUE back to 1985.

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Results from these runs indicated (in the first iterations) some counter intuitive changes in the magnitude of the population biomass. These runs were corrected in subsequent evaluations and the results were more consistent (See Tables 1 - 2 and Figures 1-5). But complete runs from both areas required more time than was available during the workshop due to convergence issues.

## **2.2 AIGKC recommendations**

### **2.2.1 Near term (prior to May CPT meeting)**

The following data tasks were identified to be completed prior to the May 2012 CPT:

1. Length data compilations
  - a. Observer versus dockside/landed separately as is the case for Tanner crab (i.e., split the data by dockside landings from those taken at sea by observers).
  - b. Examine issue that the dockside length-frequencies may be difficult to break out by areas for 1996-97 (there was some indication from D. Pengilly that area-specificity might be a problem in those years—need to be checked)
2. Comparative analysis of length frequency data between dockside and observers for consistency (recognizing dockside is legal males only)
3. CPUE modeling (GAM/GLMs) to look at effects of soak time, and other explanatory variables (start with the observer data, which includes more covariates and is shorter)
4. Develop a way to include the tagging data in the assessment as a basis for estimating growth.

### **2.2.2 Longer term work**

1. Provide better documentation, especially on data compilation steps (e.g., the tagging study results)
2. Include clear rationales for selection of data weights
3. Follow SAFE report guidelines
4. Modeling:
  - a. Adopt a more generalized modeling framework (avoid dealing with compile-time changes to model; Siddeek to work with Steve Martell to help on this; a prototype for this has already been started and is hosted on an SVN repository at: <https://code.google.com/p/generic-crab-model/>)
  - b. Compute output diagnostics that provide an easy measure to judge goodness of fit (e.g., standard deviations of normalized residuals (SDNRs) or mean absolute deviations (MADs))
  - c. Consider developing scripts to more easily create model fit figures and diagnostics (R might be preferred over Excel for this task)
  - d. Use a non-robust multinomial likelihood during the early phases of the estimation since robust likelihoods may avoid fitting real signal in the data if used during the early phases of the estimation
5. Examine the feasibility of a single model for both areas as this may help with parameter estimation and better accounting of parameter “sharing” between regions

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## 3 Bering Sea Tanner crab model

### 3.1 Summary of discussions

The following document was sent for review prior to and during workshop: ([www.tinyurl.com/BSAITC-2011](http://www.tinyurl.com/BSAITC-2011)). The model was reviewed by the CPT in September 2011 and the SSC in October. This workshop focused on survey data aspects, and subsequently how other data interacted in the model.

#### 3.1.1 Survey data

The presentation covered the main sources of information for the assessment, with particular focus on the bottom trawl survey and the time series of biomass estimates. In Fig. 3 of the assessment document there appears to be a high abundance of ~61mm crab in 1980 (for males) which fails to show up in subsequent years (females persist over more years). It was noted that the information in this figure is not used directly when fitting the model; rather the values shown are converted to biomass and proportions at length and these are used for fitting. Nonetheless, the anomaly is striking, and alternative causes were discussed. Predation was considered since in some years over 200 thousand t of tanner crab are estimated to have been consumed by Pacific cod. However, the size of crab found in stomachs would be smaller than the crab that were seen in the survey. It was also considered that the high mode in Fig. 3 arose from a random anomaly (or “luck”) of a few high densities in survey trawl stations.

The authors presented information (Table 3) to illustrate all the factors and changes in the survey gear in an effort to find a critical disconnect in survey methods. The effects on catchability suggest that directionality (bias) may be possible, but not in the magnitude or in aggregate that would appear to explain the underestimated biomass i.e., that the catch in some years exceeded the survey biomass. Experimental data indicate that the survey catchability should be on the order of 0.88. However, the base model (Model 0) from the assessment assumes that that catchability for males was about 0.88 only during 1988-2011, and that the effective catchability was much lower (and freely estimated) during 1982-87. The CPT and workshop participants agreed that evidence for such a large change in catchability was difficult to defend given the state of knowledge about Tanner crabs. One suggestion was to analyze the survey data further, but taking into account information that was previously unavailable (e.g., substrate, current direction at time and locale of tow, etc) and see if that provides any further insight. Model alternatives to dealing with this are presented below.

Growth was also considered as a potential source of difference in biomass trends. The growth rate data are from the Gulf of Alaska. Rugolo and Turnock (2010) derived the growth relationships for male and female Tanner crab using data collected in the Gulf of Alaska near Kodiak (Munk pers. comm., Donaldson et al. 1981), and examined growth relationships developed by Zheng and Kruse (1999). The participants indicated that there were likely more important issues behind the discrepancies in estimated catchability.

#### 3.1.2 Modeling

The workshop was presented with an overview of the Tanner crab model and had a number of questions for clarification including some related to inconsistencies in the pre-1991 selectivity parameters (appeared to be missing for the 1989-90 period in Table 8 of SAFE report).

Prior to the workshop participants had requested:

1. Profiles in M (mature male) and Q (male)
2. A display of the information from Somerton (1981a) east-west of 177 to better judge differences
3. Historical F for king and snow crab predicted from effort not catch

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4. Male lengths (survey) fitted for combined shell condition prior to the availability of chela data.
  5. An evaluation and discussion of the rationale for  $q$  estimated during the middle period
  6. Consider estimating the beta parameters.
  7. Replace the weights by CVs

During the week, the most recent time series of  $F_s$  from the RKC fishery was provided to address item 3. Most of the other analyses were focused on item 5 and in developing alternative models which fit the 1980s survey data but do not imply a very large change in survey catchability.

The workshop directed that focus should be on the primary effects (such as  $q$  or external mortality sources) first and that secondary factors such as input sample sizes second. As such, several model issues were identified. One was to assume that catchability was constant after 1982 but there was an “extra mortality” event in the early 1980s. Others included changing the year that the survey catchabilities were assumed to be the same (in the three-period model) and examining different prior distributions on catchability and evaluate which likelihood components were most affected. The following runs were thus requested:

1. For model 1 (and 0) remove penalty on survey  $q$
2. Increment year of change in middle selectivity period (change to 1988, 89, 90, 91, 92, 93; but start with 93 and perhaps 1990)
3. Kill-em-off scenario (add in mortality event...) from Model 1
4. Try profile on  $q$  for period 3—conduct runs with different prior means on survey  $q$  for period 3 (means less than 0.88).
5. Total catch length frequencies—examine right hand side of length compositions from observer and dockside data.
6. Look at dropping the 1980 survey length frequency (Model 0 or “best”)
7. Evaluate sensitivity to the early groundfish discard catch data—maybe by setting 1<sup>st</sup> two years of data to the 3<sup>rd</sup> year of data...

Related to these model changes were the following requested outputs for evaluation purposes:

1. Report  $q$  for a standard length by sex (for comparison purposes only)—include in table for comparisons
2. Overlay different model  $q$ 's over time, separate panels for males and females
3. Show diagnostics on residuals of observed vs predicted catches
4. Check assumption for directed fishery prior to 1991 for selectivity parameters (perhaps mislabeled)
5. Check on bycatch estimates prior to real data and how bycatches are extrapolated to earlier years (pre 1991).

After the first 6 model alternatives were examined, the group focused on factors that appeared to be driving some of the results. For example, the length frequency of the Tanner crab bycatch in the red king crab fishery had the largest likelihood component and appeared to have a large influence on the results (Table 4). The fit to survey data was better when the bycatch length-frequency information was downweighted, suggesting a conflict between these data sources (Table 5).

It was apparent after the first iteration of model evaluations that input sample size specifications (where all gears had an input multinomial sample size of 200 in each year) played a role. This was clearly a strong assumption for Tanner crab catch in other fisheries where there were many years of data but relatively few animals were measured for size. During the meeting, runs were made in which the assumed multinomial sample sizes were markedly downweighted (a value of 1), which led to better fits to the survey data.

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Consequently, the participants discussed the desire to have sample sizes specified by year. As a first pass the authors normalized all sample sizes to have a mean value of 200. However, the differences in sampling intensity were high between the different gear types so the workshop requested that they be normalized and scaled relative to each other with the most intensively sampled gear (the directed fishery) set to have a mean value of 200 (although any resulting annual sample sizes were constrained not to exceed 400). The results of this work are presented in Tables 6 and 7.

For better evaluation of input sample sizes, the spatial coverage of length measures should be examined and the number of units (tow or pot) sampled should be evaluated relative to the number of animals measured.

### **3.1.3 Coding issues**

The following summarizes discussion from the workshop and also findings during and after the workshop (in preparing the report) from examining the Tanner crab model code in more detail. The chair of the workshop chose to include these issues here since they need further clarification/investigations going forward in an effort to improve model stability.

It was noted that the selectivity in the snow crab fishery was specified as a double-logistic, dome-shaped and that pre -and post-rationalization discard selectivity estimates were separate. The model also uses the “max()” function which may create differentiability issues. One resolution would be to examine normalizing selectivity to a specific length bin. Another area where non-differentiability may arise was in the following statement: `if(fmordt_rk(i)< 0.01) fmordt_rk(i)= 0.01;` which could cause estimation issues. Using the derivative checker in ADMB (the `-dd` option) and examining the corresponding “ders.dat” should be used as a diagnostic tool to ensure the objective function is continuous and differentiable.

On examination there were 22 components to the objective function that is being minimized. Each of these also contain one or more components, for example, `penalrec` is the penalty on the recruitment that contains two components, a quadratic penalty on the annual recruitment deviations with a user specified weight like `wghtrecf`, and a quadratic penalty on the first differences of the early recruitment anomalies that are used to initialize the model with a weight of 1. A table that summarizes these weights in terms of the corresponding variance components is needed to clearly understand aspects of model tuning (i.e., variances should be specified as the appropriate combination of weights and input variances). Some of these weights are for likelihood components and others are prior distributions, whereas other components of the objective function are applied to input variances corresponding to specific data components.

### **3.1.4 Catch and fishing mortality penalties**

The Tanner crab model is specified to fit catches from all fisheries (directed and bycatch) under the assumption that the catches are normally distributed (i.e. a penalty is included in the objective function based on the sums of squared differences between observed and model catches). The weight assigned to this penalty (10.0) implies a constant standard deviation of 223 t which causes the model to fit low catch years with less precision than large catches (i.e., the CV varies as a function of catch). Previous versions of the model used to assume lognormal errors in the measured catch; this is probably a more sensible and would increase the precision in fitting small catches relative to large catches.

Fishing mortality rates were fixed for the RKC fishery (not estimated), and the impact of this was unclear. The document (Fig. 12) shows that the peak predicted catches (all fisheries combined) was almost double the landed catch (35.52 thousand t; Table 1 of SAFE report).

The impact of appropriately scaling the sampling effort (instead of assuming 200 for all fleets and all years of data) may apparently have allowed the 3-period selectivity for RKC behave poorly by fitting the absolute catches only by changing selectivity (as opposed to changing the fishing mortality). On examining the code and results in more detail after the workshop, it appears that the last fishing mortality is ignored and hence the estimate is only based on the *fmort-dev* calculations - the reason for this is unclear.

## 3.2 Recommendations

### 3.2.1 General

The following summarizes the key recommendations arising from the workshop:

- Better documentation (with subscripts for year etc) of the model code and data inputs,
- Clearer accounting of relative variances among gear types (i.e., likelihood weights and variance combinations make tracking the assumed standard error or standard deviations unclear). For example the fit to the “observed” catches had a sums-of-squares penalty of 10.0 which implies a standard deviation of 223 t regardless of fishery.
- Diagnostic tools need to be improved. They are incomplete and comparisons between different model configurations were difficult to interpret and see.
- Develop the model to be more generally applicable. Presently, most model specifications are implemented by recoding and recompiling the model. Input control switches should help clean the presentation and improve the ability to evaluate alternatives in a timely and efficient manner.
- Consider alternative logistic selectivity parameterizations based on the difference between the lengths at 50% and 95% selectivity since the scale of these parameters are in millimeters and can provide more intuitive prior distribution specifications (if needed).
- The spatial coverage of length measures should be examined to better evaluate assumptions related to input sample sizes. The number of units (tow or pot) sampled should be evaluated relative to the number of animals measured. This might be preferred given the contagious nature of sampling process.
- Conduct a GLM for survey biomass estimates to evaluate factors that are presently ignored (e.g., currents speed relative to tow direction, substrate type (given that tanner crab appear to “hunker down” in mud), gear temperature etc.
- Others?

### 3.2.2 Rebuilding requirements

The workshop noted that there is an urgent need for some models to carry forward for projections and rebuilding analyses. Specifically, a bookend of two model configurations was recommended to go forward for projection purposes for the rebuilding analysis: these model configurations were those based on the early 1980s additional mortality scenario with and without priors on survey catchability for the 2<sup>nd</sup> period (1982-2011). Both of these model configurations should use the sample sizes recommended by the workshop. A second set of bookends to be used in conjunction with these model configurations involves two sets of implied recruitment scenarios for estimation of the  $B_{MSY}$  proxy (and hence rebuilding target): one using the recruits which gave rise to the biomass estimated during 1974-80 and a second using recruits from 1982-2011. The full set of rebuilding scenarios (RBS) are as follows:

Rebuilding scenario	Survey catchability prior 1982-2011	Recruitment/biomass period
RBS 1	LN(0.88, 0.05 <sup>2</sup> )	1974-1980
RBS 2	LN(0.88, 0.05 <sup>2</sup> )	1982-2011
RBS 3	Freely estimated	1974-1980
RBS 4	Freely estimated	1982-2011

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Each of these scenarios should be reported for projections under the following fishing mortalities:

Projection case	Description
PC 0	F=0 all fisheries
PC 1	F=recent 3-year average F from groundfish fishery, F=0 for all other fisheries
PC 2	As in PC 1, but also with 3-year average F from RKC fishery
PC 3	As in PC 2, but also F= projected snow crab catches
PC 4	As in PC 3, but with reduced snow crab catch
PC 5	As in PC 4, but with combinations of directed Tanner fishing and snow crab to contrast rebuilding times

The workshop noted that the Council be clear that selection of these model runs does not preclude nor presuppose the direction of the final Tanner model specification accepted by the CPT and SSC. These options are selected in hopes that they bracket the likely range of results to facilitate Council analysts in drafting the appropriate NEPA document for Council consideration.

## 4 Workshop participants and attendees

Jim Ianelli	AFSC Seattle (Chair)	Scott Goodman
Diana Stram	NPFMC	Steve Hughes
Robert Foy	AFSC Kodiak	Dick Powell
Ginny Eckert	UAF Juneau	Denby Lloyd
Siddeek Shareef	ADFG Juneau	Dave Somerton
Paul Starr	New Zealand	Linda Kozak
André Punt	UW	Tom Casey
Jason Gasper	NMFS RO Juneau	Hamachan Hamazaki
Lou Rugolo	AFSC Seattle	Edward Poulson
Jack Turnock	AFSC Seattle	Dick Tremaine
Doug Pengilly	ADFG Kodiak	Rip Carlton
Jack Tagart	BSFRF	Buck Stockhausen
Doug Woodby	ADFG Juneau (SSC member)	Bing Hinckle
Anne Hollowed	AFSC Seattle (SSC member)	
Pat Livingston	AFSC Seattle (SSC chair)	
Jie Zheng	ADFG Juneau	
Steve Martell	UBC	

## 5 Tables

Table 1. Likelihood values for base scenario (Scenario 1) and three runs with different sets of conditions (see figure captions for detail) for EAG.

EAG	Scenario 1	Run 1	Run 2	Run 3
		Ignore Penalty	DocksideRetCPUE 1998-2010	DocksideRetCPUE 1985-2010
like_retlencomp	-1560.530	-1570.830	-1574.650	-1541.370
like_discdlencomp	-1020.510	-1021.670	-1025.710	-1021.420
like_gdiscdlencomp	-450.298	-481.088	-485.574	-475.814
like_survcpuelen	-184.681	-204.428	-209.295	-206.630
like_retcpue	-91.785	-176.098	-213.320	-317.770
like_discdcpue	-302.501	-1.161	-0.436	-0.198
like_survcpue	-39.026	67.311	51.343	56.138
like_retdcatchB	12.658	9.551	7.675	8.077
like_discdcatchB	20.838	3.803	4.231	5.092
like_gdiscdcatchB	7.622	7.180	6.821	6.757
like_rec_dev	22.156	8.683	5.279	6.063
like_Pot_F	0.0011	0.0006	0.0009	0.0009
like_GroundFish_F	93.581	87.445	83.649	83.131
like_Legal_Discd_QQ	1.326	0.486	0.671	0.749
like_ExpolitedLegal97	13.921	0	0	0
like_ExploitedLegal00	29.921	0	0	0
like_ExploitedLegal03	1.924	0	0	0
like_ExploitedLegal06	7.469	0	0	0
like_moltL50	47.078	0.711	3.878	4.071
like_Growth_beta	6.640	3.203	2.210	3.153
like_q_ratio	0.003	0	0	0
Total negative log likelihood	-3384.190	-3266.900	-3343.230	-3389.98

Table 2. Likelihood values for base scenario (Scenario 1) and three runs with different sets of conditions (see figure captions for detail) for WAG.

WAG	Scenario 1	Run 1	Run 2	Run 3
		Ignore Penalty	DocksideRetCPUE 1998-2010	DocksideRetCPUE 1985-2010
like_retlencomp	-1577.530	-1577.260	-1577.790	-1562.580
like_discdlencomp	-739.823	-739.611	-739.788	-738.876
like_gdiscdlencomp	-409.590	-410.075	-409.913	-410.918
like_retcpue	-3.139	-2.324	-11.873	-15.183
like_discdcpue	-1.998	0.089	-0.109	0.137
like_retdcatchB	3.711	3.634	4.379	4.998
like_discdcatchB	7.121	7.579	8.419	8.400
like_gdiscdcatchB	1.952	1.818	1.915	1.898
like_rec_dev	6.857	6.857	6.606	12.886
like_Pot_F	0.0691	0.0821	0.0728	0.0945
like_GroundFish_F	24.234	22.594	23.776	23.599
like_Legal_Discd_QQ	0.002	0.002	0.002	0.005
like_moltL50	1.452	1.087	1.300	0.533
like_Growth_beta	0.057	0.061	0.059	0.666
like_q_ratio	0.082	0	0	0
Total negative log likelihood	-2686.550	-2685.470	-2692.950	-2674.34

Table 3. Description of NMFS summer EBS bottom trawl survey changes over time.

Year	Description of change
1982	1st year of new net (83-112)
1982-1988	Focused examination on net configurations, protocols (e.g., warp lengths, tow speeds)
1982	Combinations of 6 vessels; one of principals underpowered / single screw / 3.0 kts
1982	distance traveled est. via Loran C and chart dividers
1982	time fished from brake-set to haul-back; data show 30.0 min & 2.778 km > implies input
1986	vessel non-standard trawl doors > net spread
1980s	evolving net mensuration & methods to est. spread (no electronics)
1986	SCANMAR 1st tested 1986 & implemented in 1988
1988	began use Loran C Burroughs program to calculate distance fished
1989	began use of standard scope table
1989	Rose and Walters (1990) mean net width-inverse scope to calculate net spread all tows pre-1988
1990	P: increase quantification net performance and data quality – scope table used to today when net width values not recorded
1992	Branker depth/temperature logger for ‘on-bottom’ evidence
1993	West coast ‘trawlgate’ marked start critical examination & standardizing survey protocols
1993	Trident ‘A-boats’ > well powered and standard design
1994	standard setting & retrieval protocol
1995	distance fished via GPS stream data
1995	begin on-bottom / off-bottom w/ bottom contact sensor

Table 4. Likelihood values for some Tanner crab initial model runs.

	Model 0			Model 1			
	priors	no priors	no 1980lf	priors 2 sel	no priors	Kill em off 83	Kill em off 83
	V25	25a	25b	V26	26a	26b	no priors
recruitment deviations	1.6	1.8	1.8	1.3	1.2	1.3	1.4
Maturity smoothness constraint	2.0	2.0	1.9	1.9	2.0	1.9	2.0
Survey q penalty	12.0	0.0	22.9	32.9	0.0	30.9	0.0
F penalty	30.6	29.8	30.8	29.2	30.1	29.1	28.5
retained length	106.6	96.3	97.8	126.7	119.5	125.7	112.9
total directed length	67.6	60.1	61.1	69.4	61.1	68.0	58.4
female directed length	63.6	61.4	62.6	61.6	58.6	61.7	58.9
survey length	320.2	310.4	298.0	378.5	361.4	388.3	373.6
groundfish fishery length	271.8	276.7	274.1	287.0	275.7	287.2	279.0
snow fishery length	572.5	575.4	571.6	597.2	596.9	596.4	589.7
red king fishery length	1268	1255	1257	1314	1312	1315	1287
survey biomass	201.1	208.8	199.8	245.6	262.8	227.7	277.9
fishery cpue	-	-	-	-	-	-	-
directed fishery male discard catch	4.7	5.4	5.0	4.3	5.3	4.4	5.8
directed fishery male retained catch	11.6	11.7	12.6	13.1	12.2	12.8	13.1
directed fishery female discard catch	11.6	12.2	11.7	11.7	11.2	11.8	11.8
grndfish fishery male + female catch	3.1	2.3	2.9	1.8	1.4	1.8	1.4
snow fishery male + female catch	16.7	13.8	16.4	16.5	13.2	16.3	12.7
red king fishery male + female catch	19.3	16.7	18.4	18.7	14.8	18.8	14.0
natural mortality penalty	37.1	30.6	39.1	34.7	24.8	34.2	24.4

Table 5. Likelihood values for Tanner crab model runs with red-king crab sample size set to 1 (middle column) and all bycatch fisheries set to 1 (last column).

	Model 1		
	No priors		
	Kill em off 83		
	N=200	RKC_N=1	AllByc_N=1
Recruitment deviations	1.4	1.3	1.4
Maturity smoothness constraint	2.0	2.0	1.7
Survey q penalty	0.0	0.0	0.0
F penalty	28.5	29.8	19.8
Retained length	112.9	118.5	114.2
Total directed length	58.4	57.9	58.0
Female directed length	58.9	57.5	61.5
Survey length	373.6	345.9	263.0
Groundfish fishery length	279.0	268.9	5.4
Snow fishery length	589.7	601.7	8.9
Red king fishery length	1286.9	8.6	8.8
Survey biomass	277.9	251.7	215.3
Fishery cpue	-	-	-
Directed fishery male discard catch	5.8	5.6	6.2
Directed fishery male retained catch	13.1	11.6	13.5
Directed fishery female discard catch	11.8	11.2	10.7
Groundfish fishery male + female catch	1.4	1.4	1.5
Snow fishery male + female catch	12.7	13.4	8.8
Red king fishery male + female catch	14.0	11.4	12.9
Natural mortality penalty	24.4	17.7	16.8

Table 6. Actual number of Tanner crab measured.

Directed retained		Directed total			SnowCrab		
New+Old Shell		Male	Female	Year	Females	Males	
1980	13,310	1991	13,386	2,984	1991	14,031	478
1981	11,311	1992	15,007	1,374	1992	11,708	686
1982	13,519	1993	13,511	2,871	1993	6,280	859
1983	1,675	1994	5,792	2,132	1994	6,969	1,542
1984	2,542	1995	5,589	3,119	1995	2,982	1,523
1988	12,380	1996	352	168	1996	1,898	428
1989	4,123	2005	15,459	879	1997	3,265	662
1990	120,676	2006	24,226	4,432	1998	2,747	515
1991	126,299	2007	26,091	1,577	1999	870	271
1992	125,193	2008	19,797	294	2000	103	22
1993	71,622	2009	16,229	147	2001	892	38
1994	27,658				2002	2,086	140
1995	1,525				2003	565	49
1996	4,430				2004	162	21
2005	705				2005	686	692
2006	2,940				2006	9,212	368
2007	5,827				2007	9,468	1,256
2008	3,490				2008	13,113	728
2009	14,315				2009	8,435	722
					2010	11,014	474
					2011	12,073	250

Bristol Bay RKC Fishery - Discard Catch			Groundfish			Surveys	
Year	Females	Males	Year	Females	Males	Year	Both sexes
1989	642	193	1973	1,604	1,212	1974	200
1990	1,580	43	1974	4,155	2,789	1975	200
1991	2,273	89	1975	16	24	1976	200
1992	2,056	105	1976	2,928	2,526	1977	200
1993	2,647	1,196	1977	10,873	9,803	1978	200
1996	15	5	1978	11,724	8,105	1979	200
1997	1,030	41	1979	24,924	16,953	1980	200
1998	335	18	1980	10,424	5,598	1981	200
1999	130	10	1981	12,956	6,817	1982	200
2000	605	36	1982	7,690	5,694	1983	200
2001	372	26	1983	14,112	7,983	1984	200
2002	555	43	1984	24,303	10,589	1985	200
2003	440	40	1985	26,334	12,765	1986	200
2004	412	41	1986	3,224	1,776	1987	200
2005	980	70	1987	3,310	1,690	1988	200
2006	691	68	1988	3,082	1,918	1989	200
2007	1,123	89	1989	2,812	2,188	1990	200
2008	2,574	98	1990	3,015	1,985	1991	200
2009	2,611	70	1991	14,432	6,155	1992	200
2010	581	28	1992	4,903	1,749	1993	200
			1993	1,148	279	1994	200
			1994	854	328	1995	200
			1995	4,404	2,248	1996	200
			1996	3,458	2,364	1997	200
			1997	12,176	5,314	1998	200
			1998	10,139	4,282	1999	200
			1999	12,037	4,399	2000	200
			2000	12,391	3,701	2001	200
			2001	12,910	2,485	2002	200
			2002	15,498	3,232	2003	200
			2003	13,542	3,292	2004	200
			2004	11,110	2,788	2005	200
			2005	13,424	4,097	2006	200
			2006	17,129	3,498	2007	200
			2007	17,513	3,150	2008	200
			2008	10,658	2,832	2009	200
			2009	6,435	1,973	2010	200
			2010	5,952	2,096	2011	200
			2011	2,055	697		

Table 7. Revised input sample sizes for Tanner crab model (see text for details).

Directed retained		Directed total			SnowCrab		
New+Old Shell		Male	Female	Year	Females	Males	
1980	89.75	1991	20.12	90.26	1992	4.63	78.95
1981	76.27	1992	9.27	101.19	1993	5.79	42.35
1982	91.16	1993	19.36	91.11	1994	10.4	46.99
1983	11.29	1994	14.38	39.06	1995	10.27	20.11
1984	17.14	1995	21.03	37.69	1996	2.89	12.8
1988	83.48	1996	1.13	2.37	1997	4.46	22.02
1989	27.8	2005	5.93	104.24	1998	3.47	18.52
1990	400	2006	29.89	163.36	1999	1.83	5.87
1991	400	2007	10.63	175.93	2000	0.15	0.69
1992	400	2008	1.98	133.49	2001	0.26	6.01
1993	400	2009	0.99	109.43	2002	0.94	14.07
1994	186.5				2003	0.33	3.81
1995	10.28				2004	0.14	1.09
1996	29.87				2005	4.67	4.63
2005	4.75				2006	2.48	62.12
2006	19.82				2007	8.47	63.84
2007	39.29				2008	4.91	88.42
2008	23.53				2009	4.87	56.88
2009	96.53				2010	3.2	74.27

Year	Bristol Bay RKC Fishery - Discard Catch		Year	Groundfish		Year	Surveys
	Females	Males		Females	Males		Both sexes
1992	1.30	13.86	1973	10.82	8.17	1974	200
1993	0.29	17.85	1974	28.02	18.81	1975	200
1996	0.60	0.1	1975	0.11	0.16	1976	200
1997	0.71	6.95	1976	19.74	17.03	1977	200
1998	8.06	2.26	1977	73.32	66.1	1978	200
1999	0.03	0.88	1978	79.06	54.65	1979	200
2000	0.28	4.08	1979	168.06	114.32	1980	200
2001	0.12	2.51	1980	70.29	37.75	1981	200
2002	0.07	3.74	1981	87.36	45.97	1982	200
2003	0.24	2.97	1982	51.85	38.4	1983	200
2004	0.18	2.78	1983	95.16	53.83	1984	200
2005	0.29	6.61	1984	163.88	71.4	1985	200
2006	0.27	4.66	1985	177.57	86.08	1986	200
2007	0.28	7.57	1986	21.74	11.98	1987	200
2008	0.47	17.36	1987	22.32	11.4	1988	200
2009	0.46	17.61	1988	20.78	12.94	1989	200
2010	0.60	3.92	1989	18.96	14.75	1990	200
			1990	20.33	13.38	1991	200
			1991	97.32	41.5	1992	200
			1992	33.06	11.79	1993	200
			1993	7.74	1.88	1994	200
			1994	5.76	2.21	1995	200
			1995	29.7	15.16	1996	200
			1996	23.32	15.94	1997	200
			1997	82.1	35.83	1998	200
			1998	68.37	28.87	1999	200
			1999	81.17	29.66	2000	200
			2000	83.55	24.96	2001	200
			2001	87.05	16.76	2002	200
			2002	104.5	21.79	2003	200
			2003	91.31	22.2	2004	200
			2004	74.92	18.8	2005	200
			2005	90.52	27.63	2006	200
			2006	115.5	23.59	2007	200
			2007	118.09	21.24	2008	200
			2008	71.87	19.1	2009	200
			2009	43.39	13.3	2010	200
			2010	40.13	14.13	2011	200
			2011	13.86	4.7		

## 6 Figures

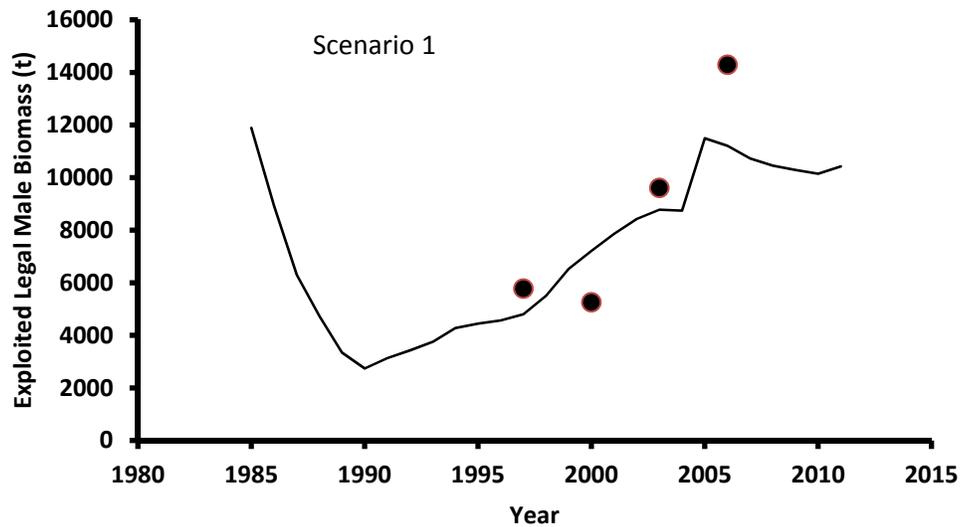


Figure 1. Tagging data estimated exploited legal male biomass (filled circle) superimposed on predicted exploited legal male biomass (solid line). Tagging data estimated biomass values were used as penalty in the model fit under Scenario 1 for EAG.

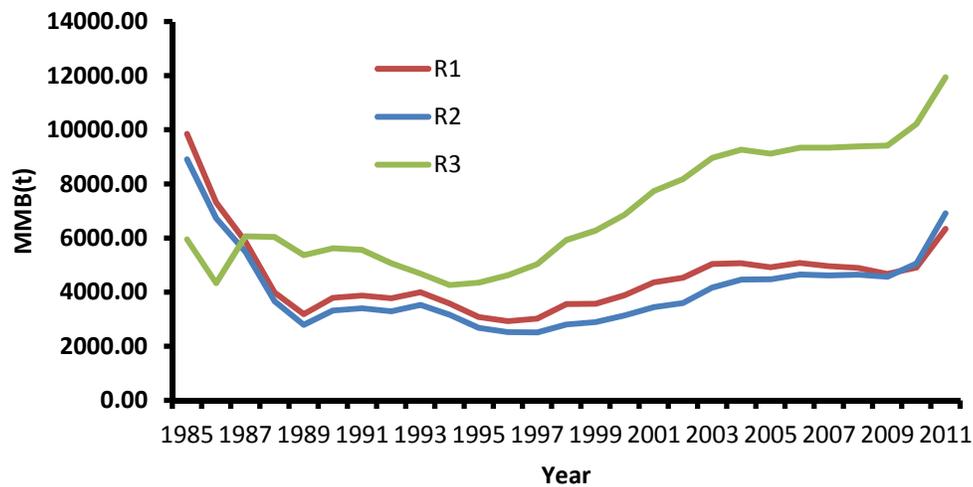


Figure 2. EAG mature male biomass (MMB) time series for R1: Run 1 – set first five initial population generation parameters ( $\alpha_N$ ) to 0; omit all LMB priors (tagging related biomass estimates), omit  $q_{ratio}$  penalty, include molt probability and growth function beta penalty, down weight (0.25) discard CPUE; and consider the 1998-2010 CPUE time series as used in the report; R2: Run 2 – Same condition as R1, but observer retained CPUE is replaced by dockside CPUE; and R3: Run 3 – Same conditions as in R2, but dockside retained CPUE is extended back to 1985.

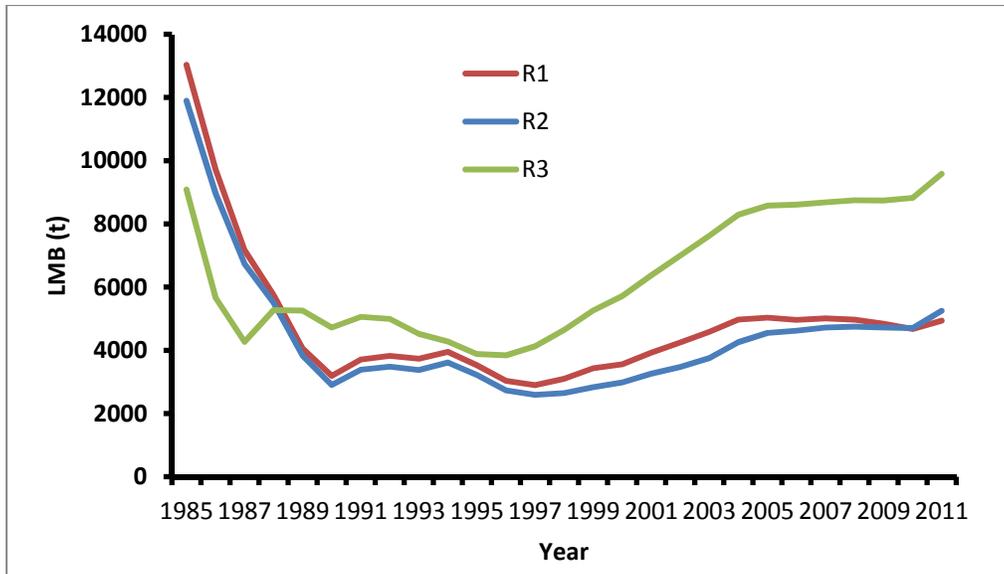


Figure 3. EAG legal male biomass (LMB) time series for R1: Run 1 – set first five initial population generation parameters ( $\alpha_N$ ) to 0; omit all LMB priors (tagging related exploited biomass estimates), omit  $q_{ratio}$  penalty, include molt probability and growth function beta penalty, down weight (0.25) discard CPUE; and consider the 1998-2010 CPUE time series as used in the report; R2: Run2 – Same condition as R1, but observer retained CPUE is replaced by dockside CPUE; and R3: Run 3 – Same conditions as in R2, but dockside retained CPUE is extended back to 1985.

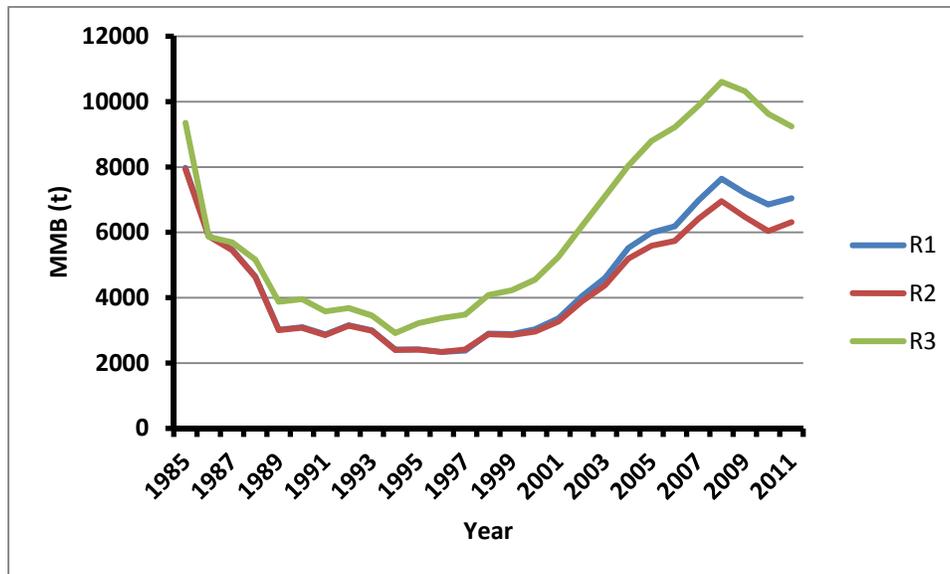


Figure 4. WAG mature male biomass (MMB) time series for R1: Run 1 – set first five initial population generation parameters ( $\alpha_N$ ) to 0; omit  $q_{ratio}$  penalty, include molt probability and growth function beta penalty, down weight (0.25) discard CPUE; and consider the 1998-2010 CPUE time series as used in the report; R2: Run 2 – Same condition as R1, but observer retained CPUE is replaced by dockside CPUE; and R3: Run 3 – Same conditions as in R2, but dockside retained CPUE is extended back to 1985.

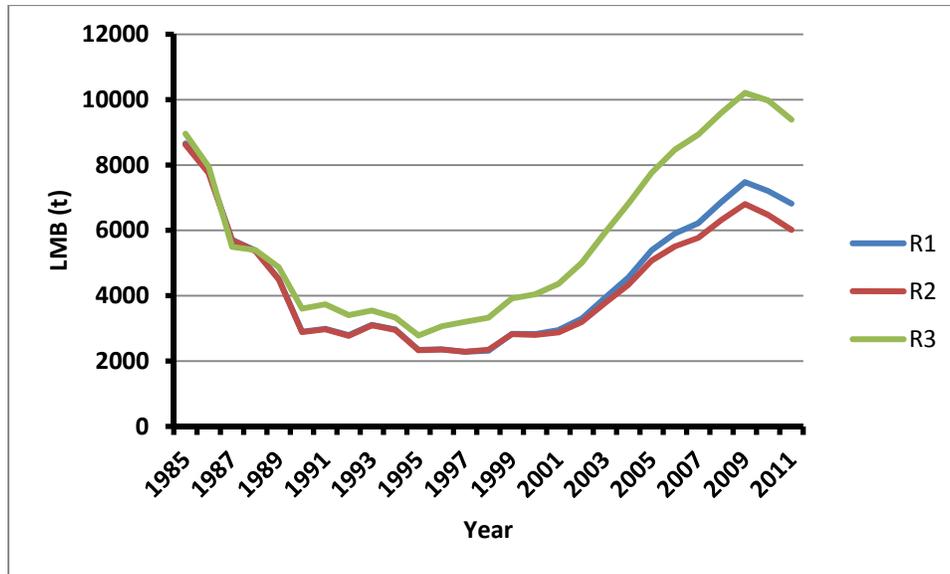


Figure 5. WAG legal male biomass (LMB) time series for R1: Run 1 – set first five initial population generation parameters ( $\alpha_N$ ) to 0; omit  $q\_ratio$  penalty, include molt probability and growth function beta penalty, down weight (0.25) discard CPUE; and consider the 1998-2010 CPUE time series as used in the report; R2: Run2 – Same condition as R1, but observer retained CPUE is replaced by dockside CPUE; and R3: Run 3 – Same conditions as in R2, but dockside retained CPUE is extended back to 1985.