Proposed 3-Stage Model
for Assessment of The St Matthew Island Blue King Crab Stock

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A. Introduction

The model presented here was originally proposed at the May 2011 CPT meeting as an assessment tool for the St Matthew Island blue king crab (SMBKC) stock. This document gives an updated description of the model and reports results from representative model scenarios using the 2011/12 assessment data in an effort to respond to standing CPT and SSC recommendations and concerns as summarized in the Fall 2011 CPT and SSC meeting minutes:

> **CPT**: *The team made recommendations to adopt a standardized weighting procedure based on CVs for indices and catch biomass, to provide several model configurations [along with an author-preferred model] for evaluation by the team, and to provide diagnostics to evaluate the choices. The issues of effective sample size and survey representation should be evaluated. The team noted that the report from the team's modeling workshop in 2009 (and annual SAFE guidelines) provide additional guidance for addressing these issues.*
>
> **SSC:** *The way effective sample size is determined differs from what others do, and some explanation would be helpful. Also, the assumption of high mortality in 1998/99, and a rationale for that assumption needs to be provided. Finally, a couple of alternative models would be useful for comparison, including one that does not rely on assumption of high mortality in 1998/99.*

The proposed model is similar in complexity to that described by Collie and Kruse (2005) and a variant of the four-stage catch-survey-analysis (CSA) model previously used to estimate abundance and biomass and prescribe fishery quotas for the SMBKC stock (2010 SAFE; Zheng et al. 1997). The four-stage CSA is related to a full length-based analysis, the major difference being coarser length groups, which are more suited to a small stock with consistently low survey catches. In this approach, the abundance of male crab with a carapace length (CL) of 90 mm or more was modeled in terms of four crab stages: stage 1 (90-104mm CL); stage 2 (105-119 mm CL); stage 3 (newshell 120-133 mm CL); and stage 4 (oldshell ≥ 120 mm CL and newshell ≥ 134 mm CL). Motivation for these stage definitions comes from the fact that for management of the SMBKC fishery male crab measuring at least 105mm CL are considered mature, whereas 120mm CL is considered a proxy for the legal size of 5.5 in carapace width, including spines. Additional motivation for these stage definitions derives from an estimated average growth increment of about 14 mm per molt for SMBKC (Otto and Cummiskey 1990), with the slightly narrower stage-3 size range intended to buttress the model assumption that all stage-3 crab transition to stage 4 after one year (Z. Zheng, ADF&G, pers. comm.).

Like the earlier model, the proposed model considers only male crab at least 90mm in CL, but it combines stages 3 and 4 of the earlier model resulting in just three stages (male size classes) determined by carapace length measurements of (1) 90-104mm, (2) 105-119mm, and (3) 120mm+. This consolidation was heavily driven by concern about the accuracy and consistency of shell-condition information. Frequently in what follows, the three stages will be referred to as "recruits," "sublegal mature," and "legal ." Model code and data for the primary author-recommended scenario described in this document are included in a series of appendices.

B. Model Population Dynamics

Within the model framework, the beginning of the crab year is assumed contemporaneous with the NMFS trawl survey, nominally assigned a date of July 1. With boldface letters indicating vector quantities, let $\boldsymbol{N}_t = [\ N_{1,t},\ N_{2,t},\ N_{3,t}\ ]^{\mathrm{T}}$ designate the vector of stage abundances at the start of year t. Then the basic population dynamics underlying model construction are described by the linear equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-M_t}\boldsymbol{N}_t + \boldsymbol{N}^{new}{}_{t+1}, \qquad [1]$$

where the scalar factor e^{-M_t} accounts for the effect of year-t natural mortality M_t and the hypothesized transition matrix $\boldsymbol{G}$ has the simple structure

$$\boldsymbol{G} = \begin{bmatrix} 1-\pi_{12} & \pi_{12} & 0 \\ 0 & 1-\pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \qquad [2]$$

with π_{jk} equal to the proportion of stage-j crab that molt and grow into stage k from any one year to the next. The vector $\boldsymbol{N}^{new}{}_{t+1} = [\ N^{new}{}_{1,t+1},\ 0\ ,0\ ]^{\mathrm{T}}$ registers the number $N^{new}{}_{1,\ t+1}$ of new crab entering the model in year $t + 1$, all of which are assumed to go into stage 1. Aside from natural mortality and molting and growth, only the directed fishery and some limited bycatch mortality in the groundfish fisheries are assumed to affect the stock. The directed fishery is modeled as a mid-season pulse occurring at time τ_t with full-selection fishing mortality F_t^{df} relative to stage-3 crab. Year-t directed-fishery removals from the stock are computed as

$$\boldsymbol{R}_t^{df} = \boldsymbol{H}^{df}\boldsymbol{S}^{df}(1-e^{-F_t^{df}})e^{-\tau_t M}\boldsymbol{N}_t, \qquad [3]$$

where the diagonal matrices $\boldsymbol{S}^{df} = \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ and $\boldsymbol{H}^{df} = \begin{bmatrix} h^{df} & 0 & 0 \\ 0 & h^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ account for stage selectivities s_1^{df} and s_2^{df} and discard handling mortality h^{df} in the directed fishery, both assumed constant over time. Yearly stage removals resulting from bycatch mortality in the groundfish trawl and fixed-gear fisheries are calculated as Feb 15 (0.63 yr) pulse effects in terms of the respective fishing mortalities F_t^{gt} and F_t^{gf} by

$$\boldsymbol{R}_t^{gt} = \frac{F_t^{gt}}{F_t^{gt}+F_t^{gf}}e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gt} \qquad [4]$$

$$\boldsymbol{R}_t^{gf} = \frac{F_t^{gf}}{F_t^{gt}+F_t^{gf}}e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gf}. \qquad [5]$$

These last two computations assume that the groundfish fisheries affect all stages proportionally, i.e. that all stage selectivities equal one, and that handling mortalities h^{gt} and h^{gf} are constant across both stages and years. My belief is that the available composition data from these fisheries are of such dubious quality as to preclude meaningful use in estimation. Moreover, the impact of these fisheries on the stock is typically very small. These considerations suggest that more elaborate efforts to model that impact are unwarranted. Model population dynamics are thus completely determined by the equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-0.37M_t}(e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df}) - (\boldsymbol{R}_t^{gt} + \boldsymbol{R}_t^{gf})) + \boldsymbol{N}^{new}{}_{t+1}, \qquad [6]$$

for $t \geq 1$ and initial stage abundances $\boldsymbol{N}_1$.

Necessary biomass computations, such as required for management purposes or for integration of groundfish bycatch biomass data into the model, are based on application of the SMBKC length-to-weight relationship of Chilton and Foy (2010) to the stage-1 and stage-2 CL interval midpoints and use fishery reported average retained weights for stage-3 ("legal") crab.

C. Model Data

Data inputs used in model estimation are listed in Table 1. All quantities relate to male SMBKC ≥ 90mm CL.

Table 1. Data inputs used in model estimation.

Data Quantity	Years	Source
Directed pot-fishery retained-catch number	1978/79-1998/99 2009/10-2010/11	Fish tickets (fishery closed 1999/00-2008/09)
NMFS trawl-survey abundance index and estimated CV	1978-2011	NMFS EBS trawl survey
ADFG pot-survey abundance index and estimated CV	Triennial 1995-2010	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2011	NMFS EBS trawl survey
ADFG pot-survey stage proportions and total number of measured crab	Triennial 1995-2010	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2010/11	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2010/11	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2010/11	NMFS groundfish observer program

Extending the previous notation, let Q^{ts} and Q^{ps} denote trawl-survey and pot-survey abundance-index proportionality constants, and let s_j^{ts} and s_j^{ps} denote corresponding stage-j survey selectivities. Model-predicted retained-catch number C_t , trawl and pot-survey abundance indices $A_t^{ts}$and A_t^{ps}, and trawl-survey, pot-survey, and directed-fishery stage proportions $\boldsymbol{P}_t^{ts}$, $\boldsymbol{P}_t^{ps}$, and $\boldsymbol{P}_t^{df}$ are given by

$$C_t = e^{-\tau_t M_t} N_{3,t}(1 - e^{-F^{df}}) \qquad [7]$$

$$A_t^{ts} = Q^{ts}(s_1^{ts}N_{1,t} + s_2^{ts}N_{2,t} + N_{3,t}) \qquad [8]$$

$$A_t^{ps} = Q^{ps}(s_1^{ps}N_{1,t} + s_2^{ps}N_{2,t} + N_{3,t}) \qquad [9]$$

$$\boldsymbol{P}_t^{ts} = \frac{Q^{ts}}{A_t^{ts}}\begin{bmatrix} s_1^{ts} & 0 & 0 \\ 0 & s_2^{ts} & 0 \\ 0 & 0 & 1 \end{bmatrix}\boldsymbol{N}_t \qquad [10]$$

$$\boldsymbol{P}_t^{ps} = \frac{Q^{ps}}{A_t^{ps}} \begin{bmatrix} s_1^{ps} & 0 & 0 \\ 0 & s_2^{ps} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \qquad [11]$$

$$\boldsymbol{P}_t^{df} = \frac{1}{[s_1^{df}, s_2^{df}, 1](e^{-\tau_t M_t}\boldsymbol{N_t} - \frac{1}{2}\boldsymbol{R}_t^{df})} \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix} (e^{-\tau_t M_t}\boldsymbol{N_t} - \tfrac{1}{2}\boldsymbol{R}_t^{df}). \qquad [12]$$

Note that the model analogue of retained catch is assumed to be precisely those stage-3 crab captured in the directed fishery. With $\boldsymbol{wt}_t = [wt_{1,t}, wt_{2,t}, wt_{3,t}]^T$ an estimate of stage mean weights in year t as described above, model predicted groundfish bycatch mortality biomasses in the trawl and fixed-gear fisheries are given by

$$B_t^{gt} = \boldsymbol{wt}_t{}^T \boldsymbol{R}_t^{gt} \text{ and } B_t^{gf} = \boldsymbol{wt}_t{}^T \boldsymbol{R}_t^{gf}. \qquad [13]$$

D. Model Objective Function

The objective function consists of a sum of eight "negative loglikelihood" terms characterizing the hypothesized error structure of the principal data inputs with respect to their true, i.e. model-predicted, values, and four "penalty" terms associated with year-to-year variation in model recruit abundance and fishing mortality in the directed fishery and groundfish trawl and fixed-gear fisheries. Sample sizes n_t (observed number of male SMBKC $\geq$ 90mm CL) and estimated coefficients of variation $\widehat{cv}_t$ were used to develop appropriate variances for stage-proportion and abundance-index components. Table 2 lists all components of the objective function. Upper and lower case letters designate model predicted and data computed quantities, respectively. As above, boldface letters indicate vector quantities. The weights w_j appearing in the objective function component expressions in Table 2 play the role of "tuning" parameters in the modeling procedure. Determination of the weighting scheme involved a great deal of trial and error with respect to graphical and other diagnostic tools; however, the author's basic strategy was to begin with a baseline weighting scheme that was either unity or otherwise defensible in terms of plausible variances and then experiment with various modifications.

The weighting scheme used for the author-recommended primary scenario is given in Table 3. The weight of 1,500 used for the lognormal fishery catch number component (w_1) corresponds to a coefficient of variation of approximately 2.6%, whereas the weight of 1.25 applied to the quadratic/normal recruit-deviation penalty (w_9) is approximately the inverse of the sample variance of trawl-survey time-series estimates of 90-104mm male crab ("recruit") abundance. By contrast, there is no similar obvious *a priori* interpretation of the weights 5.0 and 0.1 (w_2 and w_3) applied to the lognormal trawl-survey and pot-survey abundance index components, the individual terms of which in any case already incorporate year-specific conventional survey-based variance estimates, i.e. $\log(1+ CV^2)$. Rather these weights presumably reflect relative differences in how informative are the corresponding data sources about the "true" underlying stock. The default 1.0 weights on the lognormal groundfish bycatch mortality biomass components (w_7 and w_8) correspond to implied CVs of about 130%, which this author judges probably appropriate given the nature of the data.

The factors denoted by neff_t appearing in the multinomial loglikelihood expressions of the objective function represent effective sample sizes describing observed survey and fishery stage-proportion error structure with respect to model predicted values. Each set is determined by a single set-specific parameter N_{max} such that the effective sample size in any given year $neff_t$ is equal to the observed number of crab n_t if $n_t < N_{max}$ and otherwise equal to N_{max}. With this approach, the choice of the N_{max} can largely account for any choice of the multinomial component weights, which may thus be set to unity. Alternatively, for the primary author-recommended scenario, the effective sample size was set equal to the square root of the actual observed number of crab, with component weights w_4, w_5, and w_6 again set at unity. This more elegant strategy gave results similar to those obtained with the maximum effective sample size N_{max} set equal to 20 for the NMFS trawl-survey composition data and to 50 for both the ADFG pot-survey and fishery observer composition data.

Table 2. Loglikelihood and penalty components of model objective function. The w_k are weights, described in text; the $neff_t$ are effective sample sizes, also described in text. All summations are with respect to years over each data series.

Component		Form
Legal retained-catch number	Lognormal	$w_1 \sum [\log(c_t + 0.001) - \log(C_t + 0.001)]^2$
Trawl-survey abundance index	Lognormal	$w_2 \sum [\frac{\ln(a_t^{ts}) - \ln(A_t^{ts})}{\ln(1 + \widehat{cv_t^{ts}}^2)}]^2$
Pot-survey abundance index	Lognormal	$w_3 \sum [\frac{\ln(a_t^{ps}) - \ln(A_t^{ps})}{\ln(1 + \widehat{cv_t^{ps}}^2)}]^2$
Trawl-survey stage proportions	Multinomial	$w_4 \sum neff_t^{ts} (\boldsymbol{p}_t^{ts})^T \ln(\boldsymbol{P}_t^{ts} + 0.01)$
Pot-survey stage proportions	Multinomial	$w_5 \sum neff_t^{ps} (\boldsymbol{p}_t^{ps})^T \ln(\boldsymbol{P}_t^{ps} + 0.01)$
Directed-fishery stage proportions	Multinomial	$w_6 \sum neff_t^{df} (\boldsymbol{p}_t^{df})^T \ln(\boldsymbol{P}_t^{df} + 0.01)$
Groundfish trawl mortality biomass	Lognormal	$w_7 \sum [\ln(b_t^{gt}) - \ln(B_t^{gt})]^2$
Groundfish fixed-gear mortality biomass	Lognormal	$w_8 \sum [\ln(b_t^{gf}) - \ln(B_t^{gf})]^2$
$\ln(N_{1,t}^{new})$ deviations	Quadratic/Normal	$w_9 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{df})$ deviations	Quadratic/Normal	$w_{10} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gft})$ deviations	Quadratic/Normal	$w_{11} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gff})$ deviations	Quadratic/Normal	$w_{12} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$

Table 3. Objective-function weighting scheme generating primary scenario results. For stage proportion data, the effective sample size $neff_t$ was set equal to the square root of the observed sample size (number of measured crab).

Objective-Function Component	Weight w_j
Legal retained-catch number	1500
Trawl-survey abundance index	5.0
Pot-survey abundance index	0.1
Trawl-survey stage proportions	$1.0\ (neff_t = \sqrt{n_t})$
Pot-survey stage proportions	$1.0\ (neff_t = \sqrt{n_t})$
Directed-fishery stage proportions	$1.0\ (neff_t = \sqrt{n_t})$
Groundfish trawl mortality biomass	1.0
Groundfish fixed-gear mortality biomass	1.0
Log model recruit-abundance deviations	1.25
Log directed fishing mortality deviations	0.001
Log groundfish trawl fishing mortality deviations	1.0
Log groundfish fixed-gear fishing mortality deviations	1.0

E. Model Parameters

Primary scenario model estimated parameters are listed in Table 4 and include an estimated parameter for natural mortality in 1998/99 on the assumption of an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002). In any year with no directed fishery, and hence zero retained catch, F_t^{df} is set to zero rather than model estimated. Similarly, for years in which no groundfish bycatch data are available, F_t^{gf} and F_t^{gt} are imputed to be the geometric means of the estimates from years for which there are data. Table 5 lists additional externally determined parameters used in model computations. Note, in particular, that under the primary scenario stage 1 to 2 and stage 2 to 3 transition probabilities are assumed equal to 1.0, consistent with Otto and Commiskey (2009).

Table 4. Primary scenario model estimated parameters.

Parameter	Number
Log initial stage abundances	3
1998/99 natural mortality	1
Pot-survey "catchability"	1
Stage 1 and 2 Trawl-survey selectivities	2
Stage 1 and 2 Pot-survey selectivities	2
Stage 1 and 2 Directed-fishery selectivities	2
Mean log recruit abundance	1
Log recruit abundance deviations	33[a]
Mean log directed-fishery mortality	1
Log directed-fishery mortality deviations	23[a]
Mean log groundfish trawl fishery mortality	1
Log groundfish trawl fishery mortality deviations	19[a]
Mean log groundfish fixed-gear fishery mortality	1
Log groundfish fixed-gear fishery mortality deviations	19[a]
Total	109

[a] Subject to zero-sum constraint.

Table 5. Fixed parameters used in model computations based on the primary scenario.

Parameter	Value	Source/Rationale
Trawl-survey "catchability", i.e. abundance-index proportionality constant	1.0	Conventional calibration strategy
Natural mortality (except 1998/99)	0.18 yr^{-1}	Zheng 2005
Stage 1 and 2 transition probabilities	1.0, 1.0	Otto and Commiskey 2009
Stage-1 and 2 mean weights	1.65, 2.57 lb	Chilton and Foy (2010) length-weight equation applied to stage mid-lengths.
Stage-3 mean weights	depend on year	Fishery-reported average retained weight from fish tickets.
Directed-fishery handling mortality	0.20	2011 Crab SAFE (?)
Groundfish trawl handling mortality	0.80	2011 Crab SAFE (?)
Groundfish fixed-gear handling mortality	0.50	2011 Crab SAFE (?)

F. Estimation

The model was implemented using the software AD Model Builder (ADMB Project 2009), with parameter estimation via minimization of the model objective function by automatic differentiation. Standard errors provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.

G. Primary Scenario Results

Results for the author-recommended primary scenario with 109 estimated parameters (Table 4) are based on the fixed parameters in Table 5 and the weighting scheme in Table 3. AD Model Builder parameter estimates and reported standard errors are given in Table 6; objective function component contributions are listed in Table 7; selected graphical displays of model results are presented in Figures 1, 2, and 3. Parameter estimates are mostly sensible and reasonably well estimated, as measured by their standard errors, and all estimates lie within the interior of the parameter space. Overall model fit to the data is fair, though there remains clear evidence of serial correlation in the trawl-survey composition data residuals (e.g. Figure 2).

Table 6. Primary scenario model-based parameter estimates and standard errors.

Parameter	Value	Standard Error
Log initial stage abundances	7.756, 7.449, 7.323	0.294, 0.401, 0.462
Pot-survey abundance index proportionality constant	3.902	0.553
1998/99 natural mortality	1.618	0.217
Trawl-survey selectivities	0.86, 1.24	0.09, 0.12
Pot-survey selectivities	0.32, 0.75	0.07, 0.12
Directed-fishery selectivities	0.36, 0.73	0.06, 0.08
Mean log recruit abundance	6.828	0.048
Log recruit abundance deviations	[-1.876, 0.968]	[0.125, 0.483]
Mean log directed fishing mortality	-1.189	0.090
Log directed fishing mortality deviations	[-3.435, 1.909]	[0.106, 0.526]
Mean log groundfish trawl fishing mortality	-10.479	0.249
Log groundfish trawl fishing deviations	[-1.399, 1.490]	[0.696, 0.737]
Mean log grounfish fixed-gear fishing mortality	-8.864	0.233
Log groundfish fixed-gear fishing mortality deviations	[-2.163, 2.323]	[0.689, 0.699]

Table 7. Primary scenario component contributions to the optimized objective function value. Listed values include weights.

Component	Value	Percent
Retained catch	< 0.1	< 0.1
Trawl-survey abundance index	43.8	2.8
Pot-survey abundance index	7.4	0.5
Trawl-survey stage proportions	443.2	28.7
Pot-survey stage proportions	297.3	19.2
Directed-fishery stage proportions	686.7	44.4
Groundfish trawl bycatch mortality biomass	17.7	1.1
Groundfish fixed-gear bycatch mortality biomass	19.0	1.2
Log recruit deviations penalty	11.1	0.7
Log directed fishing morality deviations	< 0.1	< 0.1
Log groundfish trawl fishing mortality deviations	8.5	0.6
Log groundfish fixed-gear fishing mortality deviations	10.1	0.7
Total	1,545	100

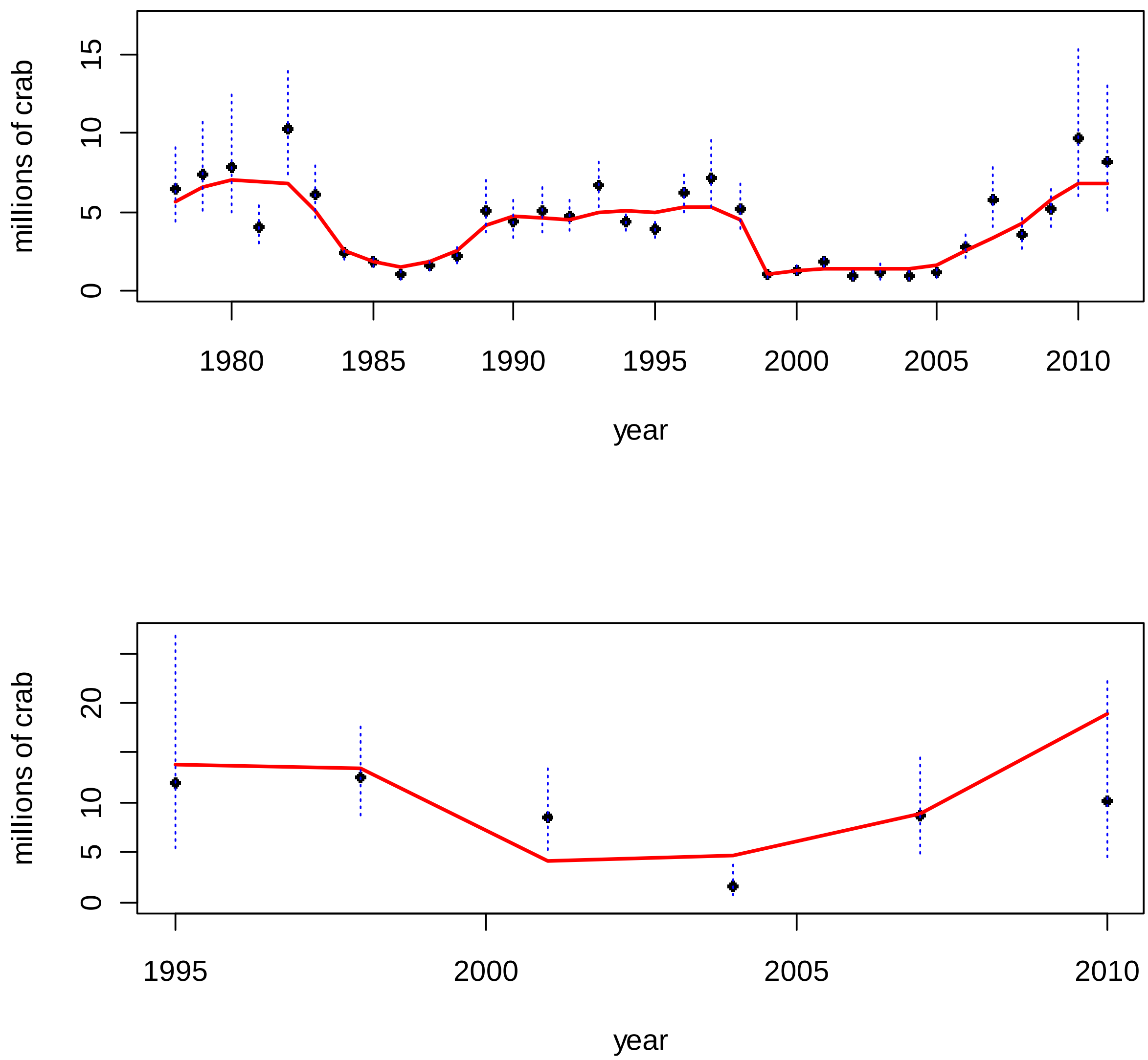


Figure 1. Primary-scenario model-predicted trawl-survey (top) and pot-survey (bottom) abundance indicies. Points are observed survey estimates with approximate 95% confidence intervals consistent with hypothesized error structure and objective function weighting scheme.

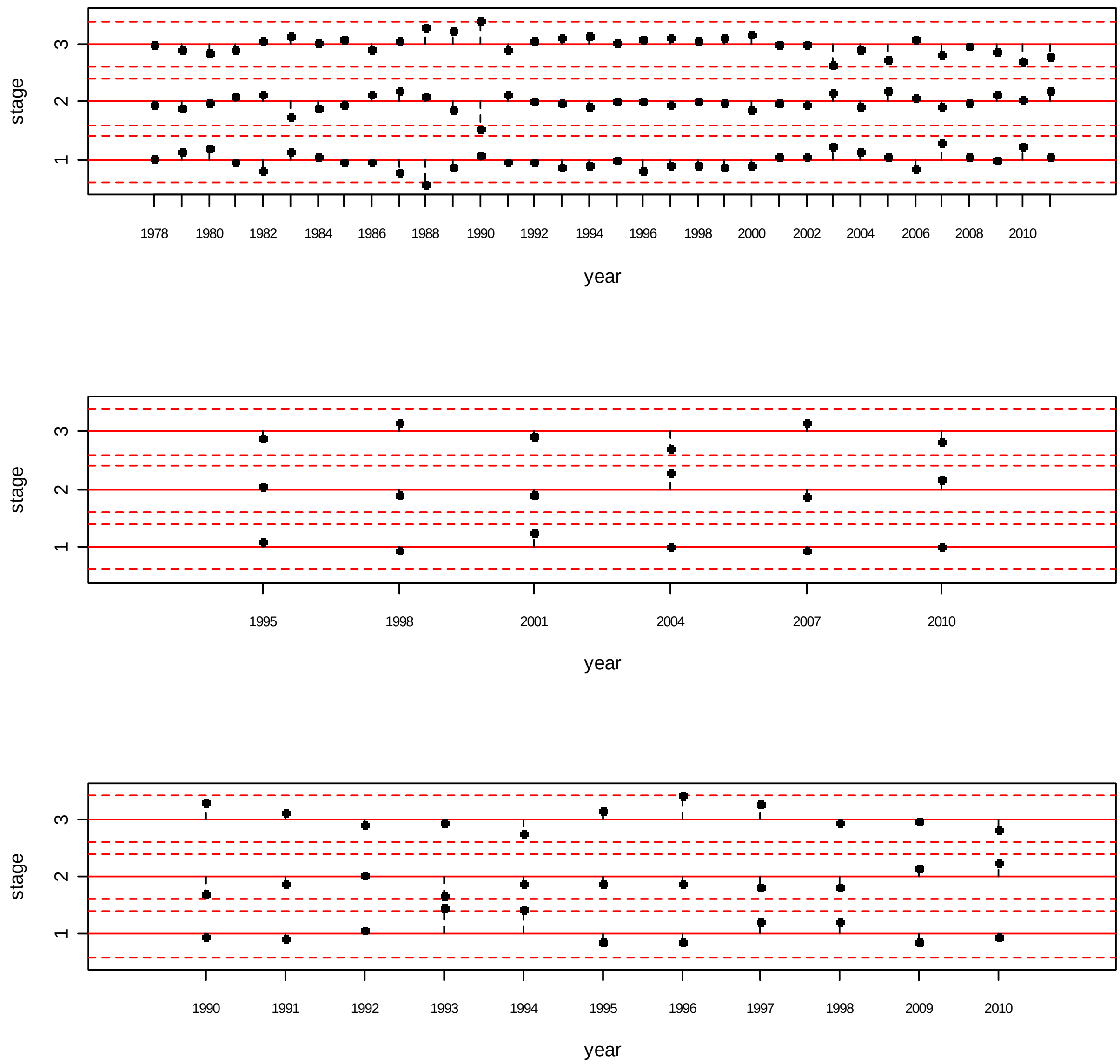
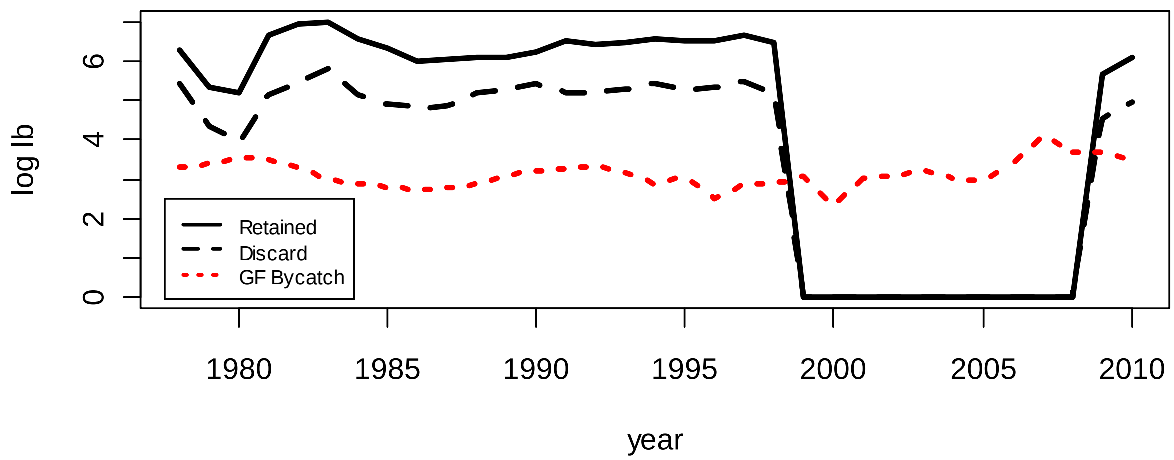


Figure 2. Primary-scenario model stage-proportion standardized residuals (observed minus predicted) for trawl-survey (top), pot-survey (middle), and fishery-observer (bottom) composition data. Dotted red lines indicate approximate 95% confidence intervals consistent with hypothesized multinomial effective sample sizes.



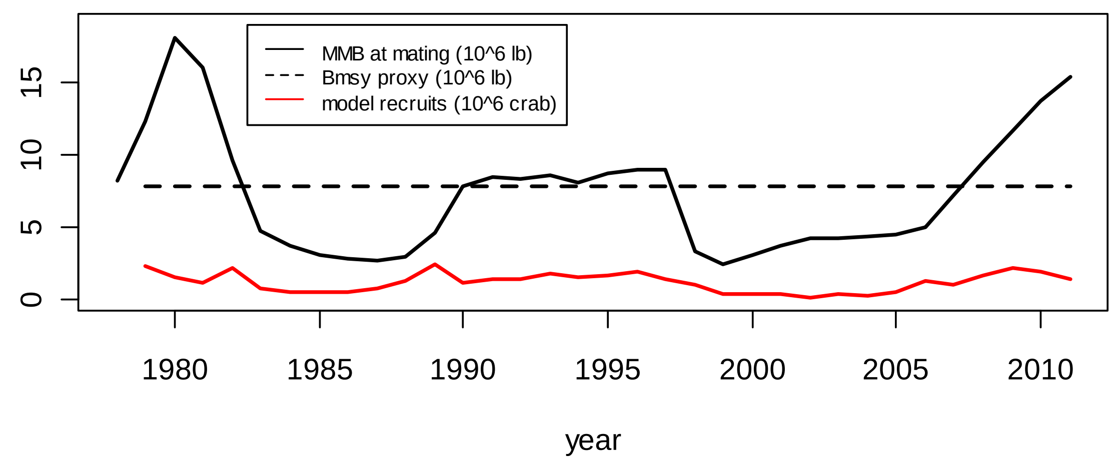


Figure 3. Primary-scenario fishing-mortality biomass (top) and recruit (= stage 1 under this scenario) abundance and mature male biomass at time of mating (bottom). Retained fishing mortality is the directed fishery reported value, whereas all other quantities are model-predicted values. The *Bmsy* proxy is the model-estimated $F_{35\%}$ value, as detailed in the description of OFL determination (§I).

H. Alternative Scenarios

1. Survey-Index Component Weights: The weighting scheme used under the author-recommended primary scenario deviates from what can be considered a baseline variance-motivated scheme by virtue of weights of 5.0 and 0.1 applied to the trawl-survey and pot-survey abundance index components, respectively. (See Table 3.) This choice, as opposed to the baseline choice (1.0, 1.0), was heavily guided by examination of the residuals shown in Figures 1 and 2. The author found model results to be moderately sensitive to the choice of these weights and, in particular, to their ratio, with discrepancies increasing over the last few years of the assessment period, as evident in Figure 4. That sensitivity is likely driven by the somewhat different trends exhibited by the two indices, which could in turn be linked to substantial differences in the spatial distribution of the two surveys (Figure 5).

2. Use of Maximum Effective Multinomial Sample Sizes: As previously noted, for the primary author-recommended scenario, the effective sample size for composition data was set equal to the square root of the actual observed number of crab, with objective function multinomial component weights w_4, w_5, and w_6 set at unity. By comparison, setting the maximum effective sample size N_{max} at 20 for the NMFS trawl-survey composition data and at 50 for both the ADFG pot-survey and fishery observer composition data, again with component weights put at unity, yielded very similar results (not included in this document).

3. Constant Natural Mortality: Under the author-recommended primary scenario, 1998/99 natural mortality is model estimated to account for an hypothesized anomalous stock mortality event (Zheng and Kruse 2005). By comparison with the scenario under which 1998/99 natural mortality is fixed at the 0.18 yr^{-1} value assumed in other years, estimation of this one additional parameter reduces the minimized value of the objective function from 1,578 to 1,545, suggesting that its inclusion significantly improves model fit. Moreover, comparison of the other mutual parameter estimates and of graphical displays of the two sets of results (not provided in this document) gives little if any reason to prefer the constant natural mortality alternative.

The author also explored the alternative of allowing natural mortality to deviate by year around an assumed geometric mean value of 0.18 yr^{-1} under a range of penalty weights but found no reason to prefer that alternative to the recommended scenario. However, results of that exercise were in line with the hypothesis of an anomalous high mortality event in 1998/99.

4. Model-Estimated Stage Transition Probabilities: Under the primary scenario stage 1 to 2 and stage 2 to 3 transition probabilities are set equal to unity in keeping with the assumption that in each year all recruit males molt and grow into sublegal males, which in turn all molt and grow into legal males. Logit-space model estimation of these parameters yields values very near unity, though with extremely large standard errors, and hence overall results essentially indistinguishable from those obtained under the primary scenario.

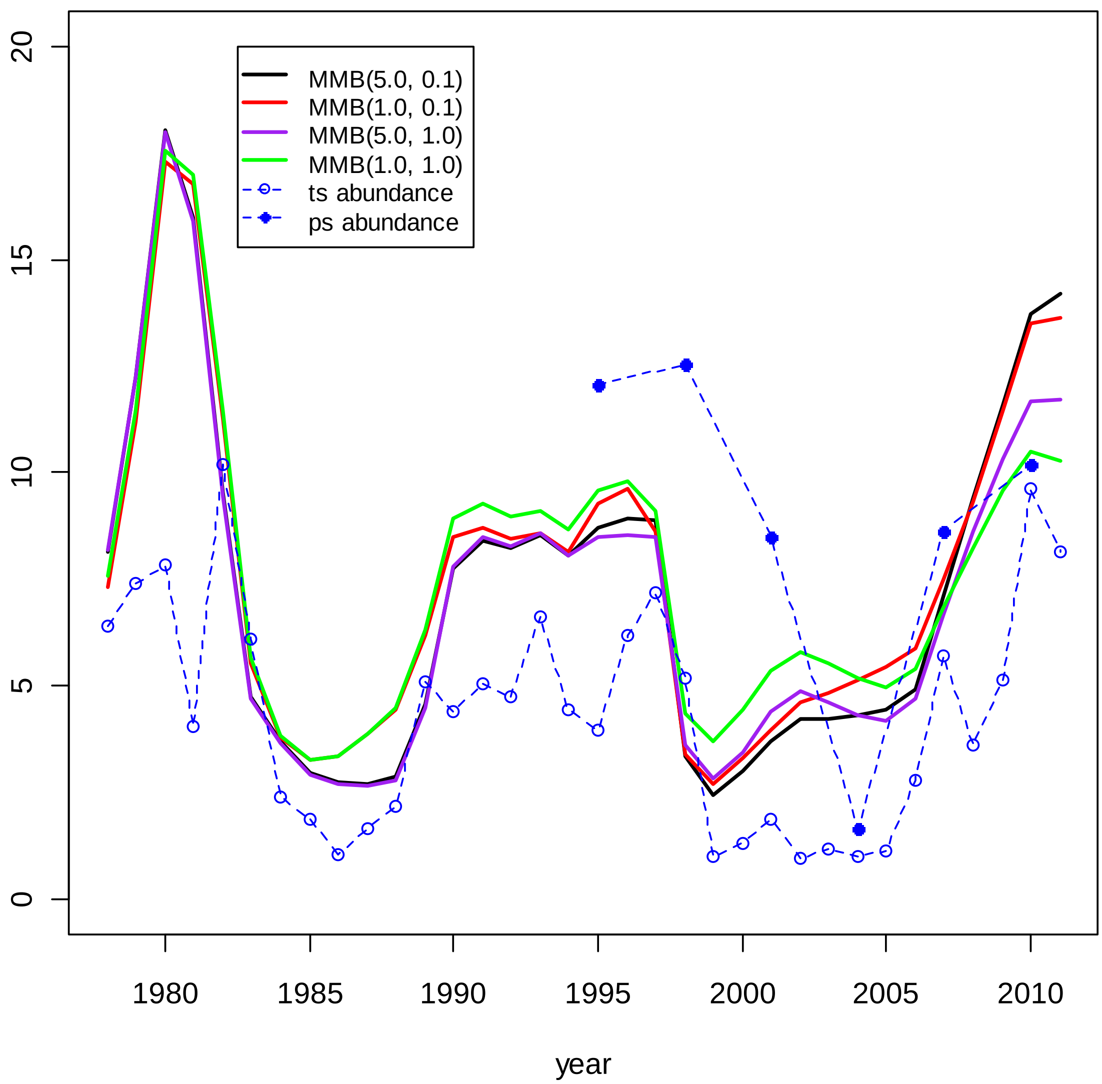


Figure 4. Model-predicted mature male biomass at time of mating (10^6 lb) for selected weight combinations applied to the trawl-survey and pot-survey abundance index (10^6 crab) components. The choice (5.0, 1.0) is the author-recommended setting, whereas the choice (1.0, 1.0) represents the baseline setting with individual terms of each component weighted by the inverse of its "natural" survey-based variance estimate. Biomass estimates for 2011 are the OFL projected values, as described in §I.

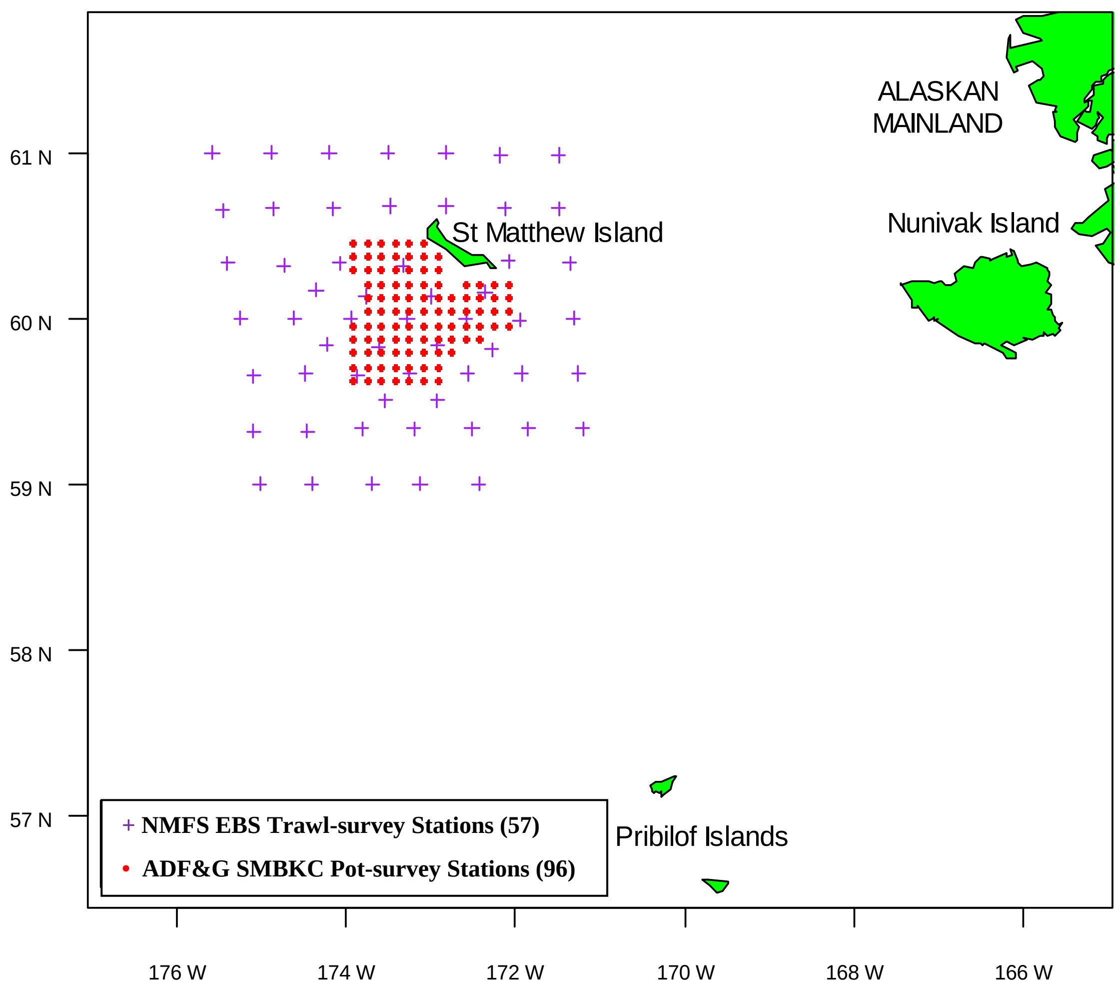


Figure 5. Spatial distribution of trawl-survey and pot-survey stations. As well as the much larger area associated with the trawl survey, of particular note is the greater proximity of the pot-survey to St Matthew Island.

I. Model Determination of The OFL

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock has been managed in recent years as a Tier 4 stock. Thus given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

$$a) \quad F_{OFL} = F_{MSY}, \; when \;\; B / B_{MSY} > 1;$$

$$b) \quad F_{OFL} = F_{MSY}\,(B / B_{MSY} - \alpha)/(1-\alpha), \; when \;\; \beta < B / B_{MSY} \le 1;$$

$$c) \quad F_{OFL} < F_{MSY} \;\; with \; directed \;\; fishery \; F = 0, \; when \;\; B / B_{MSY} \le \beta\,,$$

where B is specified to be mature-male biomass at time of mating MMB_{mating}. Note that since B is itself a function of fishing mortality and hence of F_{OFL}, in case b) numerical approximation of F_{OFL} is required. Previous recommendations for the SMBKC stock are to use the period 1989/90-2009/10 to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ in setting the F_{MSY} proxy value γM. The parameters α and β are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$.

In the approach used here, motivated by Turnock and Rugolo (2008) as described in Appendix G of NPFMC 2009, the F_{MSY} proxy is taken to be $F_{35\%}$, the fishing mortality that would result in a stable per-recruit mature-male biomass $SBPR_{35\%}$ equal to 35% of its pristine or unfished value $SBPR_0$ under model dynamics. A corresponding alternative *Bmsy* proxy is then the product of $SBPR_{35\%}$ and mean, i.e. average estimated, recruit abundance. In all of this, it is full-selection fishing mortality F^{df} in the directed fishery that is treated as the control variable in determining F_{OFL}, with fishing mortality in the groundfish fisheries assumed constant and equal to the geometric means exp$(mean_ln_F^{gt})$ and exp$(mean_ln_F^{gf})$ of the yearly model-estimated values. Assessment-year OFL is then projected as the sum of 1) directed- fishery retained-catch biomass B_{ret}, 2) directed-fishery discard-mortality biomass B_{dis}, and 3) groundfish bycatch-mortality biomasses $B_{GFTmort}$ and $B_{GFFmort}$ assuming full-selection fishing mortality F_{OFL} in the directed fishery, so that

$$OFL = B_{ret} + B_{dis} + B_{GFTmort} + B_{GFFmort}\;,$$

with B_{ret} constituting the retained-catch portion of the OFL.

Under the author-recommended primary scenario presented here for the 2011/12 assessment data, this approach leads to a B_{MSY} proxy of 7.74 million pounds, an OFL of 4.75 million pounds, 4.53 million pounds of which is allotted to retained catch, and an OFL-projected MMB_{mating} equal to 14.20 million pounds. Alternatively, for this same scenario the B_{MSY} proxy determined as average estimated MMB_{mating} over the author's current recommended reference period 1978/79-1998/99 is 7.58 million pounds, which leads to the same OFL determination. By comparison, the *Bmsy* proxy and OFL determined under the 2011/12 survey-based assessment were respectively 6.85 and 3.74 million pounds.

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Appendix A: AD Model Builder Model Code

```
//Basic 3-stage catch-survey-analysis (CSA) model for St Matthew Island blue king crab
// Constructed by Bill Gaeuman April 2011

// Data used in estimation
//  1) trawl survey sample size, composition, total abundance, and CV
//  2) pot survey sample size, composition, total abundance, and CV
//  3) fishery retained catch number
//  4) crab observer sample size and composition data
//  5) groundfish trawl and fixed gear bycatch biomass data

// Directed fishery assumed to occur as pulse at midpoint of season.
// Groundfish fishery assumed to occur as a Feb 15 pulse.
// Abundances in 1000s of crab (crab per 1000 pot lifts for pot survey estimate).
// Biomasses in 1000s of lb (lb per 1000 pot lifts for pot survey estimate).
// Effort in 1000s of pot lifts (NOT USED).
//+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
DATA_SECTION
 init_int start_yr                      // Beginning year, e.g. 1978
 init_int nyrs                          // Model time frame in years, e.g. 33 [years through last trawl survey]
 init_vector wt(1,3)                    // Stage mean weights for necessary biomass computations
 init_vector hm(1,3)                    // Directed and groundfish fixed-gear and trawl fishery handling mortalities

 init_int nyrs_ts                       // Number of years of trawl survey data
 init_ivector yid_ts(1,nyrs_ts)         // Trawl survey data year indices
 init_matrix ts_data(1,nyrs_ts,1,6)     // Sample size, stage abundance indices, total abundance, CV

 init_int nyrs_ps                       // Number of years of pot survey data
 init_ivector yid_ps(1,nyrs_ps)         // Pot survey data year indices
 init_matrix ps_data(1,nyrs_ps,1,6)     // Sample size, stage abundance indices, total abundance, CV

 init_int nyrs_pf                       // Number of years of directed pot fishery data (other than zero catch)
 init_ivector yid_pf(1,nyrs_pf)         // Fishery data year indices
 init_matrix pf_data(1,nyrs_pf,1,4)     // Catch number, time to midpoint of fishery, effort (not used), catch weight

 init_int nyrs_ob                       // Number of years of observer data
 init_ivector yid_ob(1,nyrs_ob)         // Observer data year indices
 init_matrix ob_data(1,nyrs_ob,1,3)     // Observed stage counts

 init_int nyrs_gf                       // Number of years of groundfish bycatch biomass data
 init_vector yid_gf(1,nyrs_gf)          // Groundfish data year indices
 init_matrix gf_data(1,nyrs_gf,1,2)     // Trawl and fixed-gear male bycatch biomass [NOT mortality]

 //Error trap to ensure data properly digested
 init_int eof;
 !! if(eof != 999){cout<<"DATA READING ERROR"<<endl; exit(1);};

 ivector yrs(1,nyrs)                    // Model years, e.g. 1978, 1979,..., 2010

 vector n_ts(1,nyrs_ts)                 // Survey and observer data sample sizes [number of male crab >= 90mm CL]
 vector n_ps(1,nyrs_ps)
 vector n_ob(1,nyrs_ob)

 vector x_ts(1,nyrs_ts)                 // Survey estimated total abundances and ret catch number
 vector x_ps(1,nyrs_ps)
 vector x_ret(1,nyrs_pf)

 vector eff(1,nyrs_pf)                  // Directed fishery effort
 vector lag_pf(1,nyrs)                  // Time to pot fishery [= zero if no fishery]
 !!lag_pf.initialize();
 vector ret_wt(1,nyrs)                  // Retained catch weight [considered known; =0 if no fishery]
 !!ret_wt.initialize();
 vector avg_ret_wt(1,nyrs);             // Avg retained weight for biomass computations [obvious quotients or their average]

 vector cv_ts(1,nyrs_ts)                // Survey estimated CVs
 vector cv_ps(1,nyrs_ps)

 matrix p_ts(1,nyrs_ts,1,3)             // Survey and fishery (from observer data) stage proportions
```

```
 matrix p_ps(1,nyrs_ps,1,3)
 matrix p_ob(1,nyrs_ob,1,3)

 vector gft_mort(1,nyrs_gf)                    // Groundfish bycatch mortality (from NMFS groundfish obs data)
 vector gff_mort(1,nyrs_gf)

 // Between-year relative variances for ts and ps abundance likelihood components
 vector sig_ts(1,nyrs_ts);
 vector sig_ps(1,nyrs_ps);

 // Effective sample sizes for composition data
 vector effn_ts(1,nyrs_ts);
 vector effn_ps(1,nyrs_ps);
 vector effn_ob(1,nyrs_ob);

// Switch to control file
!! ad_comm::change_datafile_name("smbkc11.ctl");
 // Phases
 init_int ph_M
 init_int ph_M98
 init_int ph_Qts
 init_int ph_Qps
 init_int ph_logN1o
 init_int ph_logN2o
 init_int ph_logN3o
 init_int ph_logit_p12
 init_int ph_logit_p23
 init_int ph_s_ts
 init_int ph_s_ps
 init_int ph_s_pf
 init_int ph_mean_log_Fpf
 init_int ph_log_Fpf_dev
 init_int ph_mean_log_New
 init_int ph_log_New_dev

 // Objective function likelihood and penalty weights
 init_vector Lw(1,8)
 init_vector Pw(1,4)

 // Starting values
 init_number M_start
 init_number M98_start
 init_number Qts_start
 init_number Qps_start
 init_number logN1o_start
 init_number logN2o_start
 init_number logN3o_start
 init_number logit_p12_start
 init_number logit_p23_start
 init_number s_ts_start
 init_number s_ps_start
 init_number s_pf_start
 init_number mean_log_Fpf_start
 init_number mean_log_New_start

//Max effective sample sizes for composition data
init_number Nmax_ts
init_number Nmax_ps
init_number Nmax_ob

 //Error trap to ensure data properly digested
 init_int eof_ctl;
 !! if(eof_ctl != 999){cout<<"CTL DATA READING ERROR"<<endl; exit(1);};
//+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
PARAMETER_SECTION

 // Natural mortality [allows distinct value for 1998/99]
 init_number M(ph_M)
 init_number M98(ph_M98)
```

```
// Trawl survey "catchability"
init_number Qts(ph_Qts)

 // Pot survey proportionality constant
init_bounded_number Qps(0.5,10.0,ph_Qps)

// Trawl-survey stage 1 and 2 selectivies
init_bounded_vector s_ts(1,2,0.2,2.0,ph_s_ts)

// Pot-survey stage 1 and 2 selectivities
init_bounded_vector s_ps(1,2,0.2,1.5,ph_s_ps)

// Pot_fishery stage 1 and 2 slectivities
init_bounded_vector s_pf(1,2,0.2,1.5,ph_s_pf)

// Log initial stage abundances
init_bounded_number logN1o(5.0,10.0,ph_logN1o)
init_bounded_number logN2o(5.0,10.0,ph_logN2o)
init_bounded_number logN3o(5.0,10.0,ph_logN3o)

// Logit p12 and p23 transition probabilities
init_number logit_p12(ph_logit_p12)
init_number logit_p23(ph_logit_p23)

// Mean log fishing mortality and deviations
init_bounded_number mean_log_Fpf(-3.0,0.0,ph_mean_log_Fpf)
init_bounded_dev_vector log_Fpf_dev(1,nyrs_pf,-10.0,10.0,ph_log_Fpf_dev)

// Mean log recruitment and deviations
init_bounded_number mean_log_New(5.0,10.0,ph_mean_log_New)
init_bounded_dev_vector log_New_dev(2,nyrs,-5.0,3.0,ph_log_New_dev)

// Mean log groundfish fishing mortalities and deviations
init_bounded_number mean_log_Fgft(-12.0,4.0,4)
init_bounded_number mean_log_Fgff(-12.0,-4.0,4)
init_bounded_dev_vector log_Fgft_dev(1,nyrs_gf,-5.0,5.0,5)
init_bounded_dev_vector log_Fgff_dev(1,nyrs_gf,-5.0,5.0,5)

// Yearly natural mortality [= M98 in year 21 and otherwise = M]
vector MM(1,nyrs)

// Row-stage-to-column-stage transition matrix (molting + growth)
matrix TM(1,3,1,3)

// Fishing mortalitites [= 0 in years with no fishery]
vector Fpf(1,nyrs)
!! Fpf.initialize();

// Groundfish fishing mortalities [= geometric mean in years with no data]
vector Fgft(1,nyrs);
vector Fgff(1,nyrs);

// Model recruitment [note: New(t) contributes to N1(t)]
vector New(2,nyrs)

// Yearly stage abundances at beginning of year [survey time]
matrix N(1,nyrs,1,3)

// Model predicted fishery stage removal (mortality) numbers [= 0 in years with no fishery]
matrix R_pf(1,nyrs,1,3)
!! R_pf.initialize();

// Model predicted groundfish bycatch removal (mortality) numbers and biomasses
matrix R_gft(1,nyrs,1,3)
matrix R_gff(1,nyrs,1,3)
vector B_gft(1,nyrs) // Only years nyrs_gf used in likelihood; based on mean_log_Fgf otherwise
vector B_gff(1,nyrs)

// Directed fishery discard mortality [= 0 in years with no fishery; function of df fishing mort otherwise]
vector Dis_mort(1,nyrs);
```

```
!! Dis_mort.initialize();

 // Model predicted abundance indices and ret catch
 vector X_ts(1,nyrs_ts)
 vector X_ps(1,nyrs_ps)
 vector X_ret(1,nyrs_pf)

 // Model predicted composition measures
 matrix P_ts(1,nyrs_ts,1,3)
 matrix P_ps(1,nyrs_ps,1,3)
 matrix P_ob(1,nyrs_ob,1,3)

 // Model predicted Feb 15 mature male biomass
 vector MMB215(1,nyrs)

 objective_function_value f

 // Components of objective function for model diagnostics
 vector LogLike(1,8)
 vector Pen(1,4)
//+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
INITIALIZATION_SECTION
 M M_start
 M98 M98_start
 Qts Qts_start
 Qps Qps_start
 logN1o logN1o_start
 logN2o logN2o_start
 logN3o logN3o_start
 logit_p12 logit_p12_start
 logit_p23 logit_p23_start
 s_ts s_ts_start
 s_ps s_ps_start
 s_pf s_pf_start
 mean_log_Fpf mean_log_New_start
 mean_log_New mean_log_New_start
//+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
PRELIMINARY_CALCS_SECTION
 int k;

 // Vector of years
 yrs.fill_seqadd(start_yr,1);

 //Extract data
 // Trawl Survey Data
 n_ts=column(ts_data,1);
 x_ts=column(ts_data,5);
 cv_ts=column(ts_data,6);
 for(k=1;k<=nyrs_ts;k++)
   p_ts(k)=--ts_data(k)(2,4)/sum(ts_data(k)(2,4));

 // Pot Survey Data
 n_ps=column(ps_data,1);
 x_ps=column(ps_data,5);
 cv_ps=column(ps_data,6);
 for(k=1;k<=nyrs_ps;k++)
   p_ps(k)=--ps_data(k)(2,4)/sum(ps_data(k)(2,4));

 // Pot Fishery Data
 x_ret = column(pf_data,1);
 eff = column(pf_data,3);
 for(k=1;k<=nyrs_pf;k++)
 {
   lag_pf(yid_pf(k)) = pf_data(k,2);         // = 0 in years with no fishery
   ret_wt(yid_pf(k)) = pf_data(k,4);    // = 0 in years with no fishery
 }

 // Observer Data
 n_ob=rowsum(ob_data);
 for(k=1;k<=nyrs_ob;k++)
```

```
  p_ob(k)=ob_data(k)/n_ob(k);

 // Avg retained weights for biomass computations [=obvious quotients or their average]
 avg_ret_wt = sum(elem_div(ret_wt(yid_pf),x_ret))/double(nyrs_pf);
 for(k=1;k<=nyrs_pf;k++)
  avg_ret_wt(yid_pf(k)) = ret_wt(yid_pf(k))/x_ret(k);

 // Groundfish bycatch mortality after adjusting for handling mortalities [= geometric mean in years with no data]
 gft_mort = column(gf_data,1)*hm(3);
 gff_mort = column(gf_data,2)*hm(2);

 // Between-year relative variances for ts and ps abundance likelihood components
 sig_ts = sqrt( log(square(cv_ts) + 1.0) );
 sig_ps = sqrt( log(square(cv_ps) + 1.0) );

 // Effective sample sizes for composition data
  for(k=1;k<=nyrs_ts;k++)
  //if(n_ts(k)>Nmax_ts) effn_ts(k) = Nmax_ts; else effn_ts(k) = n_ts(k);
  effn_ts(k)=sqrt(n_ts(k));
 for(k=1;k<=nyrs_ps;k++)
  //if(n_ps(k)>Nmax_ps) effn_ps(k) = Nmax_ps; else effn_ps(k) = n_ps(k);
  effn_ps(k)=sqrt(n_ps(k));
 for(k=1;k<=nyrs_ob;k++)
  //if(n_ob(k)>Nmax_ob) effn_ob(k) = Nmax_ob; else effn_ob(k) = n_ob(k);
  effn_ob(k)=sqrt(n_ob(k));
//+++++++++++++++++++++++++++++++++++++++++++++++++++
PROCEDURE_SECTION
 get_numbers();
 run_pop_dynamics();
 predict_data();
 calculate_obj_function();
//+++++++++++++++++++++++++++++++++++++++++++++++++++
 FUNCTION get_numbers
 int j;

 // Natural mortality for years 1 to nyrs
 MM = M; MM(21) = M98;

 //Transition matrix depends on 2 estimated parameters logit_p12, logit_p23
 dvariable p12, p23;
 //p12 = 1.0/( 1.0+mfexp(-logit_p12) );
 //p23 = 1.0/( 1.0+mfexp(-logit_p23) );
 p12 = 1.0; p23 = 1.0;
 TM(1,1)=1.0-p12; TM(1,2)=p12;     TM(1,3)=0.0;
 TM(2,1)=0.0;     TM(2,2)=1.0-p23; TM(2,3)=p23;
 TM(3,1)=0.0;     TM(3,2)=0.0;     TM(3,3)=1.0;

 // Directed fishing mortalities [= 0 in years with no fishery]
 for(j=1;j<=nyrs_pf;j++)
  Fpf(yid_pf(j)) = mfexp(mean_log_Fpf+log_Fpf_dev(j));

 // Estimated model recruitment [New(t) contributes to (and is, if p12=1) N(t,1)]
 for(j=2;j<=nyrs;j++)
  New(j) = mfexp(mean_log_New+log_New_dev(j));

 // Initial stage abundances
 N(1,1)=mfexp(logN1o); N(1,2)=mfexp(logN2o); N(1,3)=mfexp(logN3o);

 // Directed fishery discard mortality weight for output
 Dis_mort = column(R_pf,1)*wt(1)+column(R_pf,2)*wt(2);

 // Groundfish killing constants same for all stages [= geometric mean in years with no data]
 Fgft = exp(mean_log_Fgft);
 Fgff = exp(mean_log_Fgff);
 for(j=1;j<=nyrs_gf;j++)
 {
  Fgft(yid_gf(j)) = mfexp(mean_log_Fgft + log_Fgft_dev(j));
  Fgff(yid_gf(j)) = mfexp(mean_log_Fgff + log_Fgff_dev(j));
 }
 //++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
FUNCTION run_pop_dynamics
 int t;
 dvar_vector NN(1,3);
 dvariable S,D;

 for(t=1;t<=nyrs;t++)
 {
   // Survival to directed pot fishery, df full-selection exploitation rate
   S=mfexp(-lag_pf(t)*MM(t));
   D=(1.0-mfexp(-Fpf(t)));

   // Calculate fishery removals
   R_pf(t,1)=N(t,1)*S*D*s_pf(1)*hm(1);
   R_pf(t,2)=N(t,2)*S*D*s_pf(2)*hm(1);
   R_pf(t,3)=N(t,3)*S*D;

   // Take out fishery removals and discount to Feb 15
   NN = (N(t)*S-R_pf(t))*mfexp(-(0.63-lag_pf(t))*MM(t));

   // Calculate and take out groundfish removals wrt Feb 15 a la Baranof
   R_gft(t) = Fgft(t)/(Fgft(t)+Fgff(t))*NN*(1.0-mfexp(-(Fgft(t)+Fgff(t))));
   R_gff(t) = Fgff(t)/(Fgft(t)+Fgff(t))*NN*(1.0-mfexp(-(Fgft(t)+Fgff(t))));
   NN = NN-R_gft(t)-R_gff(t);

   // Calculate Feb 15 mature male biomass
   MMB215(t) = NN(2)*wt(2)+NN(3)*avg_ret_wt(t);

   // Discount who's lef to end of year
   NN = NN*mfexp(-(0.37*MM(t)));

   // Calculate next year's abundances only thru assessment year t+1 = nyrs
   if(t<nyrs)
   {
     N(t+1,1)=TM(1,1)*NN(1)+New(t+1);
     N(t+1,2)=TM(1,2)*NN(1)+TM(2,2)*NN(2);
     N(t+1,3)=TM(2,3)*NN(2)+NN(3);
   }
 }
//+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
FUNCTION predict_data
 int j;

 // Predicted retained catch number (of "legals")
 for(j=1;j<=nyrs_pf;j++)
   X_ret(j) = R_pf(yid_pf(j),3);

 // Predicted trawl survey total abundance and proportions
 for(j=1;j<=nyrs_ts;j++)
 {
   X_ts(j) = N(yid_ts(j),1)*s_ts(1) + N(yid_ts(j),2)*s_ts(2) + N(yid_ts(j),3);
   P_ts(j,1)= N(yid_ts(j),1)*s_ts(1)/X_ts(j);
   P_ts(j,2)= N(yid_ts(j),2)*s_ts(2)/X_ts(j);
   P_ts(j,3)= N(yid_ts(j),3)/X_ts(j);
 }
 X_ts = Qts*X_ts;

 // Predicted pot-survey total abundance and proportions
 for(j=1;j<=nyrs_ps;j++)
 {
   X_ps(j) = N(yid_ps(j),1)*s_ps(1) + N(yid_ps(j),2)*s_ps(2) + N(yid_ps(j),3);
   P_ps(j,1)= N(yid_ps(j),1)*s_ps(1)/X_ps(j);
   P_ps(j,2)= N(yid_ps(j),2)*s_ps(2)/X_ps(j);
   P_ps(j,3)= N(yid_ps(j),3)/X_ps(j);
 }
 X_ps = Qps*X_ps;

 // Predicted observer proportions using stage removals [after accounting for handling mortality]
 for(j=1;j<=nyrs_ob;j++)
 {
   P_ob(j,1) = s_pf(1)*(N(yid_ob(j),1)*mfexp(-lag_pf(yid_ob(j))*MM(yid_ob(j)))-0.5*R_pf(yid_ob(j),1));
```

```
  P_ob(j,2) = s_pf(2)*(N(yid_ob(j),2)*mfexp(-lag_pf(yid_ob(j))*MM(yid_ob(j)))-0.5*R_pf(yid_ob(j),2));
  P_ob(j,3) = N(yid_ob(j),3)*mfexp(-lag_pf(yid_ob(j))*MM(yid_ob(j)))-0.5*R_pf(yid_ob(j),3);
  P_ob(j) = P_ob(j) / sum(P_ob(j));
 }

 // Groundfish mortality biomass (1000 lb) from predicted removals and stage weights [assume equal stage selectivities]
 for(j=1;j<=nyrs;j++)
 {
  B_gft(j) = R_gft(j)(1,2)*wt(1,2)+R_gft(j,3)*avg_ret_wt(j);
  B_gff(j) = R_gff(j)(1,2)*wt(1,2)+R_gff(j,3)*avg_ret_wt(j);
 }
//++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
FUNCTION calculate_obj_function
 int j;
 dvariable pop_bound;

 // Loglikelihoods (less additive constants)

 // 1. Retained catch number of "legals"
 LogLike(1) = -0.5*norm2(log(x_ret + 0.001) - log(X_ret + 0.001));

 // 2. Trawl suvey abundance lognormally distributed about predicted value
 LogLike(2) = -0.5*norm2(elem_div(log(x_ts)-log(X_ts),sig_ts));

 // 3. Pot survey abundance lognormally distributed about predicted value
 LogLike(3) = -0.5*norm2(elem_div(log(x_ps)-log(X_ps),sig_ps));

 // 4. Trawl survey proportions are multinomial wrt predicted proportions
 LogLike(4) = effn_ts*rowsum(elem_prod(p_ts,log(P_ts+0.01)));

 // 5. Pot survey proportions are multinomial wrt predicted proportions
 LogLike(5) = effn_ps*rowsum(elem_prod(p_ps,log(P_ps+0.01)));

 // 6. Observer proportions are multinomial wrt predicted proportions
 LogLike(6) = effn_ob*rowsum(elem_prod(p_ob,log(P_ob+0.01)));

 // 7. + 8. Groundfish trawl and fixed-gear mortality biomass
 LogLike(7) = 0.0; LogLike(8) = 0.0;
 for(j=0;j<=nyrs_gf;j++)
 {
  LogLike(7) += -0.5*square(log(gft_mort(j)+0.01) - log(B_gft(yid_gf(j))+0.01));
  LogLike(8) += -0.5*square(log(gff_mort(j)+0.01) - log(B_gff(yid_gf(j))+0.01));
 }

 // Quadratic (normal) penalties

 // 1. Model recruit deviations
 Pen(1) = 0.5*norm2(log_New_dev);

 // 2. Directed fishery log fishing mortality deviations
 Pen(2) = 0.5*norm2(log_Fpf_dev);

 // 3. + 4. Gft and Gff log fishing mortality deviations
 Pen(3) = 0.5*norm2(log_Fgft_dev);
 Pen(4) = 0.5*norm2(log_Fgff_dev);

 // Full objective function
 f = Pw*Pen - Lw*LogLike;
//+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
GLOBALS_SECTION
 #include <math.h>
 #include <admodel.h>
//+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
REPORT_SECTION
 //Write to report file whatever's wanted for playing with.
```

Appendix B: 2011 Assessment Year Model Data File

```
# Start year and number of years
1978
34

# Stage mean weights. First two from new allometry applied to midpoint; for stage-3 use some estimate wrt anticipated fishery.
1.65 2.57 4.5

# DF, GFP, GFT handling mortalities
0.2 0.5 0.8

# Trawl survey data years and year indices
34
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34

# Trawl survey sample size (# crab >= 90mm CL), stage abundance indices (1000 crab), total abundance (1000 crab), CV
163  2383.953  2267.881  1763.845  6415.679  0.46
187  2939.465  2225.224  2223.035  7387.724  0.44
188  2538.596  2455.871  2866.546  7861.013  0.57
140  476.513  1232.574  2346.203  4055.29  0.36
269  1712.626  2495.21  5986.638  10194.474  0.38
231  1077.954  1663.271  3363.261  6104.486  0.34
104  409.983  499.327  1477.702  2387.012  0.24
93  380.799  376.362  1123.509  1880.67  0.22
46  205.746  456.502  376.719  1038.967  0.44
71  324.853  631.447  714.729  1671.029  0.32
81  410.042  815.615  956.848  2182.505  0.30
211  2163.89  1158.441  1792.259  5114.59  0.37
170  1052.505  1031.312  2338.24  4422.057  0.32
198  1135.368  1679.787  2236.354  5051.509  0.36
220  1073.975  1381.761  2290.595  4746.331  0.25
324  1521.091  1827.941  3276.482  6625.514  0.26
211  882.631  1298.458  2256.571  4437.66  0.18
178  1024.932  1187.954  1740.559  3953.445  0.19
285  1237.52  1891.225  3064.331  6193.076  0.25
296  1165.177  2228.021  3788.648  7181.846  0.35
243  659.734  1660.708  2849.292  5169.734  0.34
52  223.11  222.054  557.883  1003.047  0.24
61  281.517  284.922  740.249  1306.688  0.30
91  418.787  501.603  938.334  1858.724  0.28
38  110.517  230.059  639.942  980.518  0.30
65  449.169  280.004  464.91  1194.083  0.56
48  247.092  183.531  562.339  992.962  0.45
42  319.33  310.2  500.942  1130.472  0.41
126  916.712  641.737  1239.883  2798.332  0.36
250  2517.558  2019.884  1192.533  5729.975  0.40
167  1351.674  800.761  1456.517  3608.952  0.36
251  1572.586  2161.295  1410.063  5143.944  0.27
385  3927.464  3252.942  2458.051  9638.457  0.58
315  1692.685  3215.090  3251.827  8159.602 0.59

# Pot survey data years and year indices
6
18 21 24 27 30 33

# Pot survey sample size (# crab >= 90mm CL), stage abundance indices (crab per 1000 pot lifts),
# total abundance (crab per 1000 pot lifts), CV
4624 1919 3198 6925 12042 0.13
4812 964 2763 8804 12531 0.06
3255 1266 1737 5474 8477 0.08
640 112 414 1141 1667 0.15
3319 1086 2721 4836 8643 0.09
3920 1326 3276 5607 10209 0.13

# Fishery data years and year indices
23
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 32 33
```

 # Catch number (1000s), time to midpoint of fishery (yr), pot lifts (1000s), retained weight (1000 lb)
436.126 0.07 43.754 1984.251
052.966 0.06 9.877 210.819
033.162 0.07 1.651 150.232
1045.619 0.05 58.550 4627.761
1935.886 0.07 165.618 8844.789
1931.990 0.12 133.944 9454.323
841.017 0.10 73.320 3764.592
436.021 0.14 46.988 2175.087
219.548 0.14 22.073 1003.162
227.447 0.14 28.230 1039.779
280.401 0.14 21.678 1236.462
247.641 0.14 30.803 1166.258
391.405 0.14 26.264 1725.349
726.519 0.18 37.104 3372.066
545.222 0.14 56.630 2475.916
630.353 0.18 58.647 3003.089
827.015 0.18 60.860 3764.262
666.905 0.18 48.560 3166.093
660.665 0.18 91.085 3078.959
939.822 0.18 81.117 4649.660
635.370 0.18 91.826 2968.573
103.376 0.44 10.697 460.859
298.669 0.44 29.346 1263.982

 # Observer data years and year indices
11
13 14 15 16 17 18 19 20 21 32 33

 # Onboard observer stage counts (actual counts)
17 59 74
451 600 2342
306 430 870
629 470 1142
1393 1285 2057
98 141 424
78 109 302
581 656 1958
255 286 782
2798 6405 10599
5974 14331 25161

 # Groundfish bycatch biomass years and year indices
19
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33

 # Trawl and fixed-gear MALE (0.5*reported totals) bycatch biomasses (1000 lb)
0.993 5.355
5.232 0.283
0.808 0.199
2.191 0.446
0.064 0.030
0.018 0.769
0.0 2.566
0.024 6.922
0.046 0.091
0.070 4.380
3.157 2.154
3.510 4.914
0.394 3.087
0.0 2.845
5.962 6.783
0.286 299.895
0.705 25.797
1.722 18.280
0.075 7.471

#eof
999

Appendix C: Model Control File

```
#phases:
#M
-1
#M98
1
#Qts
-1
#Qps
1
#logNo
1 1 1
#logitp
-6 -6
#TS selectivities
2
#PS selectivities
2
#PF selectivities
2
#Fpf and dev
1 3
#New and dev
1 3

#weights
#like weights:
#catch, ts abund, ps abund, ts comp, ps comp, obs comp, gft biomass, gff biomass
1500    5.0     0.1     1.0     1.0     1.0     1.0     1.0
#dev pen weights:
# recruit,  df F,   gft F,   gff F
1.25    0.001    1.0    1.0

#starting values:
#M
0.18
#M98
1.0
#Qts
1.0
#Qps
4.0
#logNo
7.8 7.7 7.5 #from initial ts numbers
#logitp
2.5 2.5
#TS selectivities
0.8
#PS selectivities
0.5
#PF selectivities
0.5
#logMeanF
-1.5
#logMeanNew
6.7

# Max effective sample sizes for ts, ps, and obs composition data
20 50 50

#eof
999
```