Workshop Report

Crab Overfishing Definitions Inter-agency Workshop

February 28-March 1, 2006

Alaska Fisheries Science Center

Seattle, WA

North Pacific Fishery Management Council

Anchorage, AK

March 28, 2006

Contents

Contents 1

Summary from Biology Session 3

1) Measuring female spawning biomass 3
Summary points: 3
Recommendations: 3

2) Defining male spawning biomass 3
Summary points: 3
Red King Crab (Kodiak observations) 3
Tanner Crab (mostly Kodiak observations) 3
Snow Crab (observations from Atlantic Canada) 4
Recommendations: 4

3) Mating ratios 4
Summary points: 4
Recommendations: 4

4) Spawning stock biomass 5
Summary points: 5
Recommendations: 5

5) Stock-Recruitment Relationship 5
Summary points: 5
Recommendations: 5

6) Female natural mortality 6
Summary points: 6
Recommendations: 6

Summary from Modeling/Biological Reference Point/Tier System Session 6

1) Assessment model review 6
Snow crab 6
Red king crab 7

2) Projection modeling: 7
Summary 7

3) Tier System Review: 7

4) Analytical Guidance and Biological Reference Point Analysis 8

Proposed tier system for crab overfishing definitions. 10

Workshop Discussion 11

Attachments:

List of Participants

Workshop Agenda

Powerpoint Presentations

Statement of Work

Progress Report of Workgroup

Summary from Biology Session

Discussions during the Biology Session focused on six main topic areas. Below is a listing of summary points and recommendations for each topic area.

1) Measuring female spawning biomass

a. *Use of ♀ pre- or post-molt size to calculate spawning stock biomass (SSB)*
b. *Effects of senescence*

Summary points:

- Ovary size (potential clutch size) is constrained by volume of body cavity.
- Reproductive potential of females degrades in later years of terminal molt, at least in snow crabs.

Recommendations:

- It is appropriate to adjust female snow and Tanner crab spawning biomass to account for the different size-fecundity relationships among primiparous and multiparous crabs to reflect the relationship between fecundity of primiparous crabs and pre-molt body size (multiparous crabs do not molt).
- No such adjustments are necessary for king crab. It was noted that all female king crabs molt previous to mating and spawning, all fecundity-size relationships have been reported based on post-molt king crab size, and back-calculating pre-molt size would introduce estimation errors.
- Available data should be evaluated to determine the appropriate adjustment. For example, differences in fecundity among primiparous and multiparous crabs of the same size were published by Somerton and Meyers (1983) for Tanner crabs.
- Regarding senescence, spawning biomass calculations should not include "graveyard" females in the estimates. Ideally, an adjustment for this should be based on a data analysis of reduced fecundity with shell age. Failing such data, an option could be to discount the spawning biomass associated with females with the oldest shell condition. If possible, the discounting should be informed with data on fecundity of such graveyard crabs.

2) Defining male spawning biomass

a. *Molt status of mating ♂ king crab*
b. *Shell condition of mating ♂ snow & Tanner crabs*

Summary points:

<u>Red King Crab (Kodiak observations)</u>

- It is unlikely that many king crabs mate within several months of molting.
- It is not known exactly when males molt, however primiparous females molt before multiparous females.
- In January, mates of primiparous females are oldshell males, i.e., male king crabs, which molt at the same time as females, do not participate in mating.
- In April and May (~4 months post-molt) newshell males are able to mate.
- The transferability of Kodiak results to the Bering Sea is unclear.

<u>Tanner Crab (mostly Kodiak observations)</u>

- Primiparous females molt and mate in December – July (most in Feb.) with small mature males.
- Multiparous females mate in mid April – mid May over a 2 week period after egg hatch
- Males average 30 mm carapace width larger than females.
- Males mating with primiparous females are 43% shell condition 2 and 57% shell condition 3 (oldshell).
- Males mating with multiparous females are 10% shell condition 2 and 90% shell condition 3.
- AJ Paul's laboratory studies show that males cannot mate for at least 99 days after molting.

Snow Crab (observations from Atlantic Canada)

- Snow crab males do not molt and mate within a year.
    - Primiparous females molt and mate over a 3 month period (January to March), whereas multiparous females mate over a 2-3 week period after egg hatch (usually in May).
    - Males molt (April-May) and can potentially mate with primiparous females the following winter (about 7-10 months after molting), and with multiparous females in the spring of the following year (about 12-13 months after molting) while their shell is still new. In the wild, however, intermediate-shelled males usually outcompete newshell males for mates.
    - These features are reinforced by geographic distribution as males molt in shallow waters and multiparous females are located at deeper depths.
- Males mating with multiparous females are usually larger than the females.
- Males mating with primiparous females may be smaller than the females.
- Male mortality is observed around mating aggregations, likely due to reproductive exhaustion and fighting. Laboratory studies suggest that fitness of males is reduced by precocious mating (defined as new shell males mating 7-13 months after molting).
- Male preferential selection of larger females for mating.
- Data indicates that, if females are not well mated at the primiparous mating, the chances of successful multiparous reproduction are diminished in some years.

Recommendations:

- Estimates of male spawning biomass should reflect this knowledge. MSE might be used in order to identify which factors have the largest consequences on medium-term management performance.

3) Mating ratios

c. Mating ratio (MR) used to determine effective SSB

d. Applying the MR to determine effective SSB

Summary points:

- Potential for sperm limitation exists in snow, Tanner and king crabs so mating ratios are important.
- Quality of males (mating potential) at size/age can change between years.
- There are many difficulties inherent in calculating mating ratios, including: (1) female mate selection that may vary with stock size and sex ratio, (2) competition among males, and (3) difficulty to extend laboratory results to the field because lab studies do not consider geographic distributions of the sexes, pre-copulatory and post-copulatory embracing periods, and other behaviors.
- Mating ratios dependent upon efficiency in survey estimation, which is not equivalent for males and females. Catchability has a large impact on estimates of mating ratios, so use of them is inherently problematic.

Recommendations:

- Consider exploring existing data on male and female abundance, percent barrenness, and clutch size to determine mating ratios that might best explain the existing data including evaluations within the stock assessment models. Figure 5 of the ADF&G report (eggs vs. CW) could be analyzed spatially with respect to survey estimates of male to female sex ratios. Any exploration of survey data with respect to mating ratios needs to take into account: 1) that shell condition is an unreliable estimator of shell age; 2) survey selectivities are different for males and females of mature size, and 3) seasonal migrations between the survey time and the mating season.

4) Spawning stock biomass

- *Define spawning stock biomass*
- *Define effective ♂ spawning biomass (if necessary)*

Summary points:

- Male spawning biomass is temporally more stable than egg biomass. During low recruitment, females may mature at larger sizes. Female sperm load varies with female recruitment and mating ratio.
- Despite uncertain mating ratios, it is include males in estimates of spawning stock biomass.
- Seasonal movements by males for mating are also uncertain—what fraction of all mature males undertake spawning migrations?
- Methods to study the overall reproductive potential of the stock need to be developed.

Recommendations:

- Males must be included in spawning biomass estimates despite the inherent uncertainty about mating ratios. Some measure of male influence should be incorporated whether by mating ratio, correction for male and female overlap in geographic distribution, or other factors.
- The precise method to incorporate males in SSB should be left to discretion of the stock assessment authors. It is advisable to look at available data (e.g., clutch fullness, spatial distribution, etc.) to investigate the best means of incorporating males (see comments above about mating ratios).

5) Stock-Recruitment Relationship

e. Choice of SSR

f. Other issues (tau range, change in productivity, depensation S-R)

Summary points:

- Discussion ensued on the difficulties related to obtaining precise estimates of tau (steepness parameter) for reference point analysis.
    - In particular, the per recruit reference points were complicated by differing approaches for defining spawning biomass.
- The appropriate choice of productive years (i.e., under the new Tier 5) was discussed. The choice should be up to the assessment authors based on their knowledge of stock. However, the workshop stressed the need for consistency in choices between assessment for OFL and assessment for TAC.
    - There was discussion of the ability to annually review these assessments.
    - A Management Strategy Evaluation (MSE) for evaluating productivity periods was suggested as a useful inclusion in the EA.

Recommendations:

- The form of the stock-recruit model (e.g., Ricker versus Beverton-Holt) must be left to the informed discretion of the stock assessment authors based on an examination of the data.
- Regarding the wide range in steepness parameter fits, examining the pdf of these parameter values may provide guidance on reducing or weighting the range considered.
- If steepness remains poorly defined, then omit consideration of stock-recruit relationships for per recruit reference points and default to mortality-based reference points.
- The stock assessment authors should evaluate data and select most appropriate years for high and low productivity stock-recruitment periods, if possible. This could be a break-point type modeling for detecting productivity changes.

6) Female natural mortality

Summary points:

It appears that the maximum age being used at present is too high. Survey data from the Bering Sea and Atlantic Canada both suggest that females survive 5-6 years after attaining terminal molt. This pattern was repeated three times in survey data for the eastern Bering Sea. Based on assumed age of maturity, average maximum age of snow crab females is more likely to be 12-13 years based on growth data and survival following terminal molt. However, maximum age depends upon the instar at which maturity is attained. This maximum age is for females maturing in instars IX and X (mean size of about 46 and 56 mm CW, respectively, in the Atlantic). Females maturing one or two instars larger (i.e., XI or XII) would live to be about 14-15 years maximum.

- Studies of other crustaceans suggest unmated females may have a higher mortality rate due to predation or ovarian necrosis.
- Discussion of rationale for differential *M* rates based on post-terminal molt age (utilized in model).
    - Investigate data for estimation of differential rates.
    - Potential to over-estimate *M* (e.g. in cases of die-off) when basing on 1st percentile of population (unless truly only natural mortality w/no die-off events).
    - Also include fishing mortality rates on females (handling and discard mortality).
- Importance of estimation of mortality and senescence and their relative impact on contribution to reproductive potential.
- Differential survey selectivity by sex complicates estimation of female mortality.

Recommendations:

- Maximum age of female snow crab is unknown, however average maximum age of snow crab females to be utilized should be 12-13 years or greater.
- Consider using total abundance of multiparous females over time to estimate *M*, however, do not necessarily assume constant M over the life span after the terminal molt. More likely, *M* is lower over first few years and higher over last few years. However, given unknown age of post-terminal molt snow crab (since shell condition is not a reliable estimator of shell age) estimating M from survey data will be problematic. A reliable method of estimating shell age is needed to use the survey data to estimate M.

Summary from Modeling/Biological Reference Point/Tier System Session

1) Assessment model review

Assessment authors presented an overview of the stock assessment approaches used for two species of crabs. These presentations were mainly to familiarize the workshop participants with the approaches used and not a review of the methods. However, some comments from the workshop are summarized here.

Snow crab

- The workshop noted that the model could be used to investigate uncertainty in the relationship between shell condition and time intervals based on uncertainties in shell age determinations (e.g., studies presented from Eastern Canada).
- Survey selectivity estimation evaluations could provide insight on model specification issues.
- The initial stock biomass is estimated to be below B_{msy}. However, the level of historical fishing mortality is given little consideration. For consistency, one should be able to have a clear explanation why the initial stock estimates should start at such low biomass levels. This may indicate an issue with the model assumptions about R_0 or value of pre-specified steepness parameter.

- Sensitivity to the recruitment estimates, particularly the large value estimated from mid 1980s is needed (i.e., is this a single large year class or is it strong recruitment spread over multiple years?). This value influences the rebuilding level and understanding the source of uncertainty would be informative. The model specifications may affect the resultant reference point estimations.

Red king crab

- The workshop discussed how the time-varying specification of natural mortality in the assessment model may reflect a number of factors including discard mortality and bycatch rather than simple changes in predation and other sources of natural mortality.
- The new research model presented appears more flexible in addressing reference point uncertainties and shows potential for dealing with natural mortality rate assumptions and a number of other model specification issues (e.g., including molting probability). The group encouraged continued development of this research model.

2) Projection modeling:

Summary

- The importance using comparable parameters between assessment models and projection models was emphasized. In particular, they should strive to be as consistent as possible, particularly regarding parameters that affect productivity estimates (e.g. recruitment).
- Naming conventions between models (assessment and projection) should be consistent such that parameters are specifically defined (e.g., natural mortality defined to not include discards, handling mortality, etc.).
- Exploration on the impact of environmental variability hypotheses should be incorporated to the extent possible.

3) Tier System Review:

The workshop was presented with a tier system from previous meetings. Based on this, a number of further refinements were recommended including:

- The terms F (exploitation or fishing mortality) and B (biomass) should be left unspecified to give stock assessment analysts the flexibility to use the best measure available to them.
- The term F is not explicitly specified (application and interpretation to be specified by the working group). It should include all sources of fishing mortality (directed removals, discards, and bycatch).
- The draft Tiers 3 and 4 should be combined into a single Tier 3 (see Work Group Progress report for more information on draft Tier System).
- In the new Tier 3, proxy values for F_{msy} and B_{msy} would be determined (e.g., from an SPR calculation). The workshop recommended setting SPR values from 50% to 60% for this tier, corresponding to a range of values that appear appropriate based on previous research by the crab working group. This range should be evaluated to determine to what extent its use is defensible.
- In the new Tier 4 (previously Tier 5), a scalar γ is multiplied by natural mortality. The scalar could be less than or greater than 1 and be more or less conservative than the status quo, depending on stock assessment research for a species. For example, when a change from total mature biomass to some other biomass measure (e.g., based on mature males) is used, the scalar can be applied to account for differences between biomass measures.
- The draft Tier 6 would become Tier 5 (see Work Group Progress report for more information on draft Tier System).

A table showing the formulae to be applied for specifying OFL given these recommendations is provided below. Other comments made by the workshop included:

- Specification of other parameters (e.g., values for alpha, gamma, beta) will be determined by workgroup and will be analyzed for the EA.
- The workshop noted that ABCs should not be included in the tier recommendations (though this does not preclude assessments from providing ABC recommendations).
    - Evaluations of GHL relative to OFL (and status quo OFLs) will need to be analyzed for the EA.
- Catch must include all sources (e.g., bycatch from groundfish fisheries not just catch in directed fisheries).
- The analysis should discuss the risk of overfishing from bycatch in rebuilding plans.

The workshop participants discussed the issue of which specific measures of biomass should be used in overfishing definitions. Some alternatives include: total, male, or female spawning biomass; total, male, or female effective spawning biomass; total, male, or female survey biomass; total or viable egg production. The workshop participants recommended that the choice should be left to the discretion of stock assessment scientists and review process. Given that the choice affects biological reference points, it might be wise to establish a group of scientists assist in producing a document offering technical guidance to stock assessment authors.

4) Analytical Guidance and Biological Reference Point Analysis

The workshop participants discussed ideas for EA problem statement and the suite of alternatives and information to be included in the analysis. The following summarizes the key recommendations from the workshop.

- A problem statement needs to be crafted for consideration by the Council and for use in the EA. It should explicitly address necessary changes from current definitions to be included in revised definition. The problem statement should include the following three elements:
    - The current overfishing definitions have specified and locked-in values for natural mortality (0.2 for king, 0.3 for Tanner and snow crabs). There is no way to change these values without a plan amendment. A framework for these values would facilitate use of the best available scientific information as information improves in the future.
    - The current 3-tier system has flaws. It does not have greater precaution as information becomes less certain. The current system does not take advantage of alternative biological reference points that may be useful. Using natural mortality (M) as a proxy value for F_{msy} may be inappropriate.
    - The current overfishing definition uses total mature biomass of males and females while exploitation occurs only on legal males. There is a need to clearly define the status determination criteria and their application to the exploitable section of the population.

The workshop participants proposed evaluating two alternatives in the EA:

Alternative 1: Status Quo (current OFL definitions and overfished/overfishing determination)
Alternative 2: Revised Tier system

Other suggestions for the analysis included:

- Background information detailing the process of crafting tier system as well as alternative definitions (e.g. fixed rates) will be explicitly contained in EA (alternative considered but not carried forward).

- Initial analyses could focus primarily on tiers where majority of crab species will be initially placed.
- It became clear at the workshop that if Alterative 2 is approved, then some changes will be necessary in the specification process by which stock status in relation to overfishing is determined. Under the status quo, the calculation of OFL is made by a single NOAA Fisheries person as an arithmetic operation. Under the new tier system framework, both the stock assessments and OFL calculations will need to be reviewed more formally through a Council process, because a decision will be necessary to determine which tier is appropriate, which model or data should be used, and whether the calculations are correct. One possible model for this would be similar to the groundfish review system. The Crab Plan Team would meet to review the stock assessments and make recommendations about OFL. The Plan Team recommendations would be reviewed by the industry crab committee, SSC, AP, and Council. Other processes could also be envisioned. The EA should contain a discussion of this issue and proposed process for reviewing OFLs and status determination criteria.

Proposed tier system for crab overfishing definitions.

Information available	Tier	Stock status	F_{OFL}
B, B_{msy}, F_{msy}, and pdf of F_{msy}	1a	$\frac{B}{B_{msy}} > 1$	$F_{OFL} = \mu_A$ =arithmetic mean of the pdf
	1b	$\beta < \frac{B}{B_{msy}} \leq 1$	$F_{OFL} = \mu_A \frac{B/B_{msy} - \alpha}{1-\alpha}$
	1c	$\frac{B}{B_{msy}} \leq \beta$	$F_{OFL} = 0$
B, B_{msy}, F_{msy},	2a	$\frac{B}{B_{msy}} > 1$	$F_{OFL} = F_{msy}$
	2b	$\beta < \frac{B}{B_{msy}} \leq 1$	$F_{OFL} = F_{msy} \frac{B/B_{msy} - \alpha}{1-\alpha}$
	2c	$\frac{B}{B_{msy}} \leq \beta$	$F_{OFL} = 0$
B, F_{msy}, $B_{msy^{prox}}$	3a	$\frac{B}{B_{msy^{prox}}} > 1$	$F_{OFL} = F_{msy}$
	3b	$\beta < \frac{B}{B_{msy^{prox}}} \leq 1$	$F_{OFL} = F_{msy} \frac{B/B_{msy^{prox}} - \alpha}{1-\alpha}$
	3c	$\frac{B}{B_{msy^{prox}}} \leq \beta$	$F_{OFL} = 0$
B, M, $B_{msy^{prox}}$	4a	$\frac{B}{B_{msy^{prox}}} > 1$	$F_{OFL} = \gamma M$
	4b	$\beta < \frac{B}{B_{msy^{prox}}} \leq 1$	$F_{OFL} = \gamma M \frac{B/B_{msy^{prox}} - \alpha}{1-\alpha}$
	4c	$\frac{B}{B_{msy^{prox}}} \leq \beta$	$F_{OFL} = 0$
Reliable catch history from a time period to be determined (groundfish uses 1978 through 1995).	5		OFL = the average catch from a time period to be determined, unless an alternative value is established by the SSC on the basis of the best available scientific information

Workshop Discussion

Introduction

Gordon Kruse welcomed participants to the workshop and requested that everyone introduce themselves (Attachment 1). He then reviewed changes to the agenda since it was first posted and everyone received an updated version of the agenda (Attachment 2). The first two agenda topics are intended to provide the group with an overview of BSAI crab management, the current overfishing definitions, and the National Standard 1 guideline revisions. These topics provide the necessary background of the regional and national context within which revising these definitions is occurring.

History of crab management/charge for workshop participants

Diana Stram provided an overview of the Federal Fishery Management Plan (FMP) for Bering Sea and Aleutian Island (BSAI) crab stocks and the nature of joint State and Federal management (Attachment 3a). Revisions to the current overfishing definitions require a plan amendment to change (as well as the associated NEPA analyses that accompany all plan amendments). The process for an FMP amendment was outlined as well as the charge for workshop participants.

Revisions to national standard one guidelines

Grant Thompson reviewed the status of the current revisions to the National Standard 1 guidelines (Attachment 3b). He noted that the timeline for the revised guidelines has been considerably delayed and it may likely take an additional year before the revisions are finalized. Gordon Kruse commented that the workgroup should continue to proceed with the analysis. However it will be important that the Council does not seek final action on this amendment until after the final revisions to the guidelines are available.

Andre Punt questioned to what extent generation time has been examined by the workgroup in their progress to date and was informed that this has not been evaluated. As this topic was noted to be tied to mating ratios it was determined best to take this up at that point in the discussion in the agenda.

Jie Zheng questioned what the ramifications are if a stock was shown to be overfished in retrospective analysis but is not presently considered overfished. Grant noted that there would be no need to establish a rebuilding plan under those circumstances. Anne Hollowed questioned the situation where a stock currently under a rebuilding plan is now shown not to be considered overfished. Grant noted that while there are considerations given for either grandfathering existing rebuilding plans or allowing for the option to modify those rebuilding plans, there has not yet been a determination of what to do in the circumstance that a stock under a rebuilding plan is now found not to be overfished.

Overview of proposed revisions

This session focused on allowing the workgroup to provide the workshop participants with an overview of their scope of work, their progress to date and the problems they have encountered which have limited their ability to move forward with their analyses.

Lou Rugolo presented an overview of the workgroup's statement of work (Attachment 3d). This document was provided to workshop participants in advance of the meeting and had been previously presented to the Crab Plan Team (CPT) and the Council's Science and Statistical committee (SSC) (Attachment 4). In the interest of time questions were deferred to the discussion portion of the agenda to follow.

Jack Turnock reviewed the draft Tier System developed by the workgroup (Attachment 3d). This tier system was presented to the CPT in September 2004 within the written progress report compiled by the workgroup (Attachment 5). Terry Quinn requested clarification on why the tier system included an ABC given the aforementioned delegation to the State on authority to establish catch levels. Jack Turnock

responded that a buffer between OFL and catch is encouraged. Discussion focused upon the State requirement to stay below the OFL for crab species. However there is no existing mandate for creating a buffer by remaining below an established ABC.

Shareef Siddeek reviewed the parameter inputs to the Spawner Per Recruit (SPR) models utilized in the analysis (Attachment 3e). Gordon Kruse questioned what the uncertainty was in the estimates of male mortality rate. Siddeek responded that he has not yet looked into this, but that female mortality may be higher. Jim Ianelli questioned the benchmarks against which comparisons are being made, i.e. changing the sensitivity parameters and changing the SPR. This topic was deferred to further discussion in the later sessions.

Jack Turnock provided further review of parameter value for SPR models. (Attachment 3f). He commented that in working together for the last 2 years, the workgroup has agreed upon some aspects of the analysis (e.g., base values for natural mortality of Tanner and snow crab = 0.23 yr^{-1}, for king crab = 0.18yr^{-1}, and discard mortality for snow crabs = 50%, for king crabs = 25%) The group has not yet specified a discard mortality rate for Tanner crab. Jack noted that there is a need for consistency between the stock assessment models utilized as outputs and the inputs used in the SPR models. Similar scenarios should be run in the stock assessment models as are being run in the SPR models. He felt that the red king crab models lacked this consistency.

Lou Rugolo provided an overview of the model simplifications (Attachment 3g). He noted some problems inherent with mating assumptions (i.e. assuming that all mature males and females will mate).

Jie Zheng provided an overview of additional considerations in model simplifications (Attachment 3h). Bernard Sainte-Marie questioned why there is an observed peak in the pulse recruitment for newshell females. He noted that if there was a pulse of females entering the population there should have been a subsequent spike in the abundance. Jie answered that this is due to the catchability in the survey whereby the survey does not catch juvenile crab as well as it catches mature crab. Brad Stevens requested clarification on how mature females are defined. Jie commented that they are from the survey data which indicate whether they are immature or mature. Brad noted that the survey is unable to define them without dissection and instead relies on a size cutoff. This cutoff defines crabs as mature and immature but he felt that this is likely inadequate designation for *Chionoecetes* crab. Lou Rugolo noted that he felt that Jie was combining size categories from the NMFS classification (e.g. shell 4 and 5 but counting them all as shell 4). Jie noted that shell 4 and 5 are combined to represent crab two years or longer post terminal molt in the figure.

Shareef Siddeek provided an overview of the model structures utilized (Attachment 3i). Jack Turnock discussed approaches to estimate biological reference points (Attachment 3j). Siddeek questioned the observed discrepancy between Jack's tau values and the values he had calculated. He questioned if this was an artifact of Jack fitting to data from post 1977. Andre Punt questioned to what extent the tau parameter is actually comparable across stock recruitment relationships that differ in relation to the definition of spaening biomass. He noted that it may not be appropriate to estimate tau from various fits and then use a range of taus from one stock recruitment relationship across all stocks. There is the potential here for an inconsistency in logic. Andre questioned the effective biomass calculation in Jack's presentation noting that it seemed to be double-counting males. Jack noted that female spawning biomass is not affected by the fishery. Further discussion on this noted that it is inconsistent to have a definition of spawning biomass that is not affected by the fishery. This discussion will be taken up further in the afternoon sessions.

Andre commented that the scenarios presented by Jack need to be narrowed down if possible. Scenarios should be run which could allow the analysts to begin to reject some hypotheses. Currently there are too many options available. He asked whether Jack had looked at fecundity against those measures in the assessment given that these are all very different and he should be able to evaluate and then reject some of

them. Jack noted that the stock recruitment data for snow crab were not definitive. Jack commented that there are uncertainties in the available data, and better measures are needed of fecundity. Jie noted that there are difficulties with utilizing egg clutch size data (per suggestion to use this data to evaluate the fits with the available data). Andre suggested that the available data should be utilized to resolve these difficulties.

Siddeek presented some additional preliminary results of model runs (Attachment 3k). His results included some changes to the Tier system presented by Jack, reducing the number of Tiers and excluding the alpha parameter included in Jack's overview.

Siddeek provided an overview of the issues which are as yet unresolved by the working group in attempting to move forward with their analysis (Attachment 3l).

Biology Session

Measuring female spawning biomass:

The group discussed the problem noted by the workgroup on how to resolve the use of pre- or post-molt size for the calculation of SSB. Background information was requested on fecundity in relation to internal body size. A paper by Somerton and Myers (1983) that examined the fecundity of primiparous vs. multiparous Tanner crab was referenced in this regard. The apparent shift in fecundity with body size is explained by plotting fecundity of primiparous females against their pre-molt (rather than post-molt) body size.

Brad Stevens commented that king crab studies in Kodiak have been based on post-molt size. He noted that the limit on ovary size is based on pre-molt body size, but the studies themselves have focused on post-molt body size. There is a need for consistency in the choice of body size. Gordon Kruse noted that this is different for king vs. Tanner and snow crab. Brad commented that it is safe to assume that pre-molt and post-molt can be proxies for each other provided there is consistency amongst the choice.

Bernard commented that there is general consensus that this does not matter for king crab, but it does matter for Tanner and snow crab. He commented that it might be possible to use the relationship of pre-molt vs post-molt to scale down primiparous females. He noted that he has some information and data on females for scaling purposes.

Andre commented that either metric is ok provided it is used consistently. Lou noted that he feels that it is important to decide on simple biological first principles. If the workgroup is using female biomass as an index of egg production then they need to establish the appropriate categorization of weight. Doug Pengilly commented that survey data records carapace size and clutch fullness. The largest females might represent a significant part of the reproductive biomass. Siddeek commented that if the growth increment in the model is 40-50% then the model will be prone to larger errors. Andre noted that if the molt probability index included in the model is believable then there should be output from this in the model.

The group discussed the necessity of some form of adjustment but agreed that the data should best inform the measure of the adjustment.

Spawning Stock Biomass

The workshop participants discussed the problems noted by the workgroup in defining what measure should be utilized for spawning stock biomass. Fundamentally the group discussed to what extent this should be established or should analysts be allowed to use their best judgment in making these decisions. There was general agreement that it is necessary to framework OFL definitions.

The use of frameworking is encouraged and it was noted by Anne Hollowed that there is particular need for specificity in direction given that the possibility exists for the State to use a different measurement in

determining harvest rates than NMFS will use in determining OFLs. Some clarity should be provided to the analysts rather than frameworking everything.

Bernard commented that it is simplest to use female mature biomass however this is defined. Brad noted that spawning biomass depends upon the efficiency of the assessment. He does not believe that this is equivalent for males and females and instead it is more likely that the efficiency for females is approximately 50% of males in the survey. Therefore he feels that the use of mating ratios is not valid.

The group discussed the protocol for stock assessment and OFL and ABC deteremination for groundfish and how parameters are specified for each North Pacific groundfish stock. Grant Thompson noted that similar parameters for groundfish are not explicitly specified (e.g., exploitable biomass) in order to allow flexibility to the analysts based upon availability of information.

The group further discussed the inherent problems with the use of mating ratios. Bernard commented that for snow crab and Tanner crab, potential egg production fluctuates more than male sperm biomass. Any measures of spawning biomass that incorporate males will level out the effective biomass over time more than is necessary due to differences in variability. The issue is that males are sperm conservers and large males tend to suboptimally fertilize females.

Different growth rates to maturity are observed, and these signals were noted to be observed in unfished as well as fished populations. Mating ratios are difficult to calculate; dominant males (e.g. large) can also exclude subordinate (e.g. small) males. Also, if a female snow crab is not fully mated, she will attempt to mate with other males. Siddeek commented that calculating a mating ratio is unnecessary if total mature biomass is used. Bernard noted that total mature biomass may be misleading because they are a sexually size-biased species and can still demonstrate sperm limitation.

Given the aforementioned discussion on year to year variability, and the variability in number of males per female depending on prevailing conditions, the discussion concluded that calculating mating ratios may not be recommended. However it was also clear that despite the inherent uncertainty problems there needs to be some means of including males in spawning biomass estimates. Female biomass varies due to recruitment variability and female biomass is inherent linked to male biomass. Female biomass is not being monitored to the extent that male biomass is.

Jim requested clarification about to what extent sufficient data are available to estimate effective mating ratios given the stock recruitment curves. Andre commented that there is a need to predict fertilization at different levels of exploitation. Jie noted that this approach could be used for red king crab where data are available but there is no recruitment information available for Tanner and snow crabs. Bernard showed slides of fecundity data noting that if these data were compared against theoretical expectations, you could characterize each female as more or less stressed, and then calculate where she might have mated and the sex ratio (Attachment 3m).

The group discussed stock migration with respect to the distances over which a crab population can still be considered a single stock. Bernard commented that tag recovery data indicated movement inshore and offshore and generally of the range of 100-150km, with the largest tag recovery distance of ~200km. Anne noted that the analysis needs to discuss a rational pattern of movement.

The group summarized their conclusions from the discussion. Using females alone for spawning stock biomass was rejected as a possibility. One option is to use a female spawning biomass that somehow accounts for the need for males (i.e., some sort of mating ratio included). The relative distribution of males and females geographically is also important. The problems lie in how to incorporate these. Given that data are available for assessment of males and females and clutch fullness data, the advice to the analysts is to look at the data to see what it might reveal for informed decisions about these parameters. Spatial distribution could also be examined. Some sort of correction factor for males appears necessary (i.e., mating ratio, effect of distribution).

Jack further commented that currently there is no accounting for discard mortality. This would impact the viability of remaining males. Lou also commented that assuming the remaining males and their size distribution is sufficient to mate appropriately with females (regardless of size distribution), questions still remain about what is the value of large males to the stock? What is the size dependency relationship between males and females for mating? Bernard questioned the reason for the terminal molt, could it be a density dependent incentive to become larger such that if the population were fished too hard at the tail end it could drive size at maturity down. This would achieve an ecologically viable but commercially extinct population.

Andre commented that there needs to be an analysis of this density component including all available data to see if these data allow us to say anything about these different hypotheses. It seems that these choices should be left to the discretion of the individual assessment author to justify most reasonable and justifiable estimate of reproductive potential.

The analysis should embrace key biological parameters, explore sensitivities to biological parameters but also strive to establish key OFL levels that capture simplicity. Anne noted that for groundfish a means to incorporate uncertainty is to establish a buffer between ABC and OFL, but for crab we cannot do that. Here any buffer would need to be established in the OFL calculation. Gordon suggested the analysts look at GHLs as a proxy for ABC, and evaluate the performance of target control rules under OFLs. The analysis should evaluate different definitions of OFL and see what harvest strategies remain below that.

Further comments on mating ratios reiterated that studies of mating ratios have only been done in tanks where all crabs are counted. If a mating ratio is based on survey data then the implicit assumption is that the survey is estimating males and females with the same efficiencies and this is not true. Brad Stevens noted that the only non-lab study in Chiniak showed a mating ratio of 10:1 from submersible transects. By comparison, the trawl survey showed a sex ratio range of 1:1 to 2:1. Gordon further noted that mating ratio studies also don't include travel time necessary in searching for a mate. Siddeek referenced an AJ Paul paper on mating ratios for Tanner crab, which suggested it to be 1:3 in the laboratory.

The group commented that research is encouraged to explain the inherent variability in parameters for mating ratios.

Stock-Recruitment Relationship:

The group discussed the relationship of the measure of spawning biomass to the parameter tau. Tau values from the survey are not useful. If this parameter proves too difficult to estimate than a simplified solution should be sought. Terry commented that it seems that establishing a per recruit reference point is too difficult at this point and hampered by lack of sufficient information. He suggested that a feasible substitute for this in the tier system would be to use natural mortality. Lou noted that the working group has advanced a similar idea, i.e., adopt Fmsy = M which is an improvement upon the current fixed values. However the application of this would need to be corrected as it has been applied incorrectly in the past in determining overfishing (see discussion pages 7-8 in Attachment 4).

Doug Pengilly commented that this would allow for determination of overfishing but that some measure of spawning stock biomass would be necessary to determine Bmsy and establish an overfished level. Grant noted that while MSST is currently necessary, its inclusion has been argued effectively both ways and under the new guideline revisions it is likely that if it is not possible to establish an MSST for a given stock, it will not be mandated. Lou noted that one problem with the current MSST are the years which were utilized in the calculation. He feels that these years are neither applicable nor sustainable. Andre asked if there is a logical argument for a different set of years that would allow for a proxy for MSY.

The group discussed the need for flexibility in the specific language included in the tier system, and that is should be left to the discretion of the stock assessment author to define a range of years that is most appropriate for future projections and definitions. Depensation could be explored by the working group

in the analysis but should not be hard-wired into the components of the OFL definitions. The analysis should also include an evaluation of conservative OFL levels but these too should not be hard-wired anywhere in the definitions.

Anne discussed the current review process for groundfish whereby assessments and OFLs (and ABCs) are reviewed by the plan teams and then the SSC. A similar process should be employed by the Crab Plan Team whereby an annual review of the assessment (and the OFL calculation) is reviewed by the team with subsequent review and decision-making on appropriate tiers by the SSC. If the annual assessment is used to calculate the GHL/TAC then this should likewise be used for OFL calculations.

Jie Zheng noted the compressed schedule for GHL/TAC calculations by the State. Doug Pengilly clarified that the SSC can review the TACs annually to see if overfishing is occurring, but more extensive review than that would be a matter of interest only. Under the FMP, choosing the stock recruitment curve used to establish the TAC is at the State's discretion provided it does not result in overfishing. Terry noted that a comparison of GHLs to OFLs (historically) should be included in EA.

Female natural mortality

The group discussed the issues of conflict in modeling different mortality rates on males versus females for all crab stocks.

Jie and Siddeek considered that 18-20 years was a sufficient value for maximum age based on the natural mortality values agreed upon by the working group. Bernard noted that 12-13 years may represent a better maximum age for snow crab. He noted that data on the recruitment pulse indicated that a year-class does not last as long as the 18-20 year estimates. These crabs could be alive but do not appear to be contributing to reproduction.

Bernard showed some data on pulses of primiparous and multiparous females, where the pulse then disappears, noting that mortality could possibly be calculated from this (Attachment 3m). Somerton's thesis tracked a pulse of primiparous *Chionoecetes* females in the Bering Sea and results were roughly similar in the timing of the pulse. Female natural mortality also occurs from mating-induced injuries. The possibility that females that go unmated and have a higher natural mortality rate are due to 1) males offer protection to females from predators during molt (large males are more efficient than smaller males at doing this) if the female molts alone it may be injured and killed by predators; 2) it is unknown what happens to the unmated female, some females extrude clutch of unfertilized eggs but some resorb them and may cause higher mortality rate, there are observation of partial necrosis of ovaries which compromises their future reproductive capacity and may also cause higher mortality rate.

The group further discussed episodic recruitment. Lou questioned the expectation of sampling the oldest 1% of population. Andre commented that by depending upon the upper 1st percentile, there is a possibility of overestimating M if there is a die-off. Using this percentile would work if natural mortality was constant over age. Discussion then focused upon the possibility of specifying different M values based upon age. The actual fishing mortality rate on the population however is unknown. Bernard noted similarity in years of high female egg production between the ADF&G data and eastern Canadian stocks. Jack cautioned reliance on the use of 1980s catch data, noting that in those years the catch of males exceeded the estimate from the survey indicating that the survey was underestimating the actual population in those years. Therefore the decline in abundance might not be as valid as the data suggest.

Doug Pengilly noted the necessity of using a different M following terminal molt in the model. Gordon mentioned that senescence must also be accounted for. Jack commented that M is fixed in the snow crab model due to lack of information. He noted that he could try to estimate it within the model to see the model results, but Andre cautioned against the use of the same data to interpret results and within the model. There needs to be consistency in approach.

Lou commented that Bernard's graphs illustrate the problem in using shell condition for age. The assumption is that there are annual steps between shell conditions, but the graphs indicate that this is not necessarily true. Using survey data as an index of abundance can be difficult given the differential survey selectivity by sex. Andre noted that catchability always varies, and questioned if these data are used in the assessment, and if not is it because catchability varies, noting that you cannot argue the data both ways.

In summary for the discussion, females enter a terminal molt then die in approximately 6 years. However, trying to estimate a fixed point on life expectancy is difficult given the stated uncertainty in actual timing. Data could be utilized to generate an estimate of rates. The effect of fishing could be treated through estimating bycatch and handling mortality as well as previously summarized comments on female mortality.

Male spawning biomass

This discussion focused upon the role of shell condition and age of males in participation in breeding, and specifically when molting males mate with females. Males molt late in winter and the question for discussion is can they and do they participate in late spring/early summer mating?

Brad Stevens summarized some studies in the Kodiak region on red king crab, noting that there is no strong understanding of when king crab males molt. Some studies recently in Women's Bay observed that females molt to maturity roughly along the same timing as males. There are observations of females being grasped by oldshell males that had molted previous years (therefore in Kodiak studies they are not observing molting males participating in mating).

Jie questioned to what extent the data from the Bering Sea survey in June indicated molted red king crab males participating in mating. He noted that crabs are coded by shell condition and those coded as shell 2 crabs could have molted anytime in the past year and may participate in mating in January/February before they molt in April/May. He indicated a graph from the NMFS issues paper (provided as background material but not part of this report), noting that the shell hardness does not change until 30 days prior to molting.

Brad commented that it is unlikely that king crabs mate within several months of molting. However, it is still possible that crabs 4 months post-molt do participate in mating. Crabs which are molting at the same time as females are not participating in mating.

Doug Pengilly commented that tag recovery data (from both the fishery and survey) from primiparous females in Kodiak shows they are mating with oldshell or very oldshell males. The mating period starts in January and continues into April/May. By that time, 40% have been scored as newshell males. This is not entirely inconsistent with tag return studies, and from this it does not appear impossible that some mating is occurring with males that molted during that season (i.e. by that time they would be ~4 months post-molt). Even if you discount 40% due to possible misclassification, this still leaves 20% newshells involved in mating based on the Kodiak data. To what extent this is applicable to Bristol Bay is unknown.

The discussion summarized the following: that males molt before multiparous females, primiparous females mate first (followed by multiparous), and early mating is dominated by oldshell males. Later on, there are suggestions that newshell crabs begin to participate, however as year moves on it becomes more difficult to accurately classify shell ages

Lou noted that the time for shells to harden after the molt indicates that May is not the prime molting period. Otherwise observations would show much higher incidences of soft-shell crabs in Bristol Bay in June (except in cold years where molt characterization differs).

Fundamentally, the issue is to what extent can red king crab males mate and molt in the same year. Brad commented that there is no data to determine this.

Brad Stevens summarized available information from Kodiak on Tanner crab. Here, there is a similar situation, with a primiparous molt from December-July but the majority of molting occurs in February. Mating occurs with small mature males. Multiparous females mate later (variable from mid April to mid May) within roughly a two week period. Males are not participating in mating in that year. On average they are approximately 30 mm larger than their partners. Shell condition indicates 90% oldshell, 10% shell-2 (for mating with multiparous females) and for mating with primiparous females 57% shell-3 or greater, and 43% shell-2. Some of those shell-2 crabs can mate with primiparous but are excluded from mating with multiparous. If they are molting in that two week period then they are excluded from mating that year.

Bernard summarized snow crab timing for mating. Female crabs molt and mate from the end of December to the end of March, while males molt April-May and sometimes into June. Males mate with primiparous females the following winter but not in the current year. For multiparous they mate the following spring. Males tend to be in shallow waters when molting, and are not physically present at deeper depths. Males can be of equal size or smaller for primiparous mating. In multiparous mating, males are considerably larger than females and typically of intermediate shell condition (SC3). Bernard showed some figures on precocious mating, noting that mating in early May could increase natural mortality (Attachment 3m).

Brad commented that they have also observed increased natural mortality around mating. They have never observed competition amongst males, but do observe mortality presumably due to reproductive exhaustion

Bernard showed a study indicating preferential selection of larger females for mating. For snow crab, if crabs are poorly mated at primiparous mating, then the resulting operational sex ratio is biased to males. There is little chance that at multiparous mating they will then mate successfully. The operational sex ratio is sharply skewed to females, and the sperm reserve aspect to their biology is not as effective if they have not been well mated at the primiparous mating.

Modeling and Biological Reference Point Session

Snow Crab Stock Assessment model

Jack Turnock presented an overview of his snow crab stock assessment model (Attachment 3n). He noted that uncertainty in moving from one shell condition to the next is not explicitly considered, instead it is a deterministic move. Discussion noted that this uncertainty should be investigated particularly in light of the previous conversation on the uncertainty inherent in shell aging.

Other discussions included the growth matrix utilized, noting that the same growth transition matrix is used for both males and females. Jack noted that while mean growth is estimated, the variability in the growth matrix is fixed.

There was discussion of survey selectivity by size, and the potential that the inflection point might be mis-specifed. Jim noted that Q=1 is a very strong assumption. It should instead be estimated to see what it actually is. There appear to be diagnostic problems within the model, as when issues cannot otherwise be accounted for in the model specification, the tendency is for the model to put them into Q. This may therefore be an indication of a larger modeling problem when this is not possible. Andre commented that another problem is the suggestion that the population is not robust to variability.

There was a larger discussion of the characterization of historical fishing. Jim noted that there needs to be a defensible explanation of why the F rate is starting at such a high level. This indicates that there was historical fishing but this is not being backed up with any information. There needs to be additional information or at least a clear hypothesis put forward regarding this starting point.

Technical issues were raised with respect to model specification and this raises concerns regarding reference point estimation.

Red King Crab:

Jie Zheng presented an overview of his red king crab assessment model and an additional research model he has been working on (Attachment 3o).

Jack commented on the inherent assumption in the calculation of M in this model. He noted that the lack of consideration of discard mortality is critical to the establishment of correct OFLs.

Other comments included consideration of the 2001 survey estimate of male abundance which does not fit model trajectories. Jie attributed this to sampling error. Discussion noted this could represent a change in catchability, or possible sampling effects of cold year (i.e., climate-related) effects.

Jie explained his Bristol Bay red king crab research model. This model was developed to address some research issues in 2003/2004 and can be used to address specific criticisms which have been raised by the workgroup previously with the red king crab stock assessment model. The research model is more flexible in treatment of parameters than the assessment model. Here M can be fixed and other parameters added to address things such as handling or discard mortality. There is no documentation at this point on this model but it is anticipated in the future.

Projection models

This discussion focused upon concerns which have been raised regarding the possibility of the workgroup taking assessment results using SRR and M values and evaluating these in the projection model. Concerns were raised regarding a potential disconnect between assessments and projections.

Jack indicated the need for inclusion of appropriate stock assessment information and its equivalent in the projection model. Grant noted that requiring the assessment and projection models to be equivalent is a high standard that would be difficult to obtain (nor is done for groundfish). Some differences are possible and it would be wise not to set impossibly high standards that cannot be met.

Jie commented that the most important input in the projection model is what recruitment is being utilized. Siddeek noted that the projection model parameters may not be the same as for stock assessment parameters. Grant indicated that even if the numbers are directly from the assessment their meaning in the projection model could be different. Jack felt that there was a distinction between the use of the projection model for groundfish versus the use for crab. The crab projection model is to be used for F proxy values and for evaluating different control rules. Grant commented that likewise for groundfish the SPR values reported are from the projection model not from the assessment.

There was a general discussion of the current status determination process. Survey data for each stock are compared with the calculated OFL for that stock. A letter from NMFS (previously from Bob Otto) was submitted indicating the overfished versus overfishing status determination. While this determination has been recently included in the Crab SAFE report, in the last two years no formal letter has been submitted with this determination.

Bernard commented that with a highly variable stock, a definition of overfishing based on biomass value is straying from real overfishing i.e., the impact on females. The definition must be tied to changes in reproductive potential. You could have a stock at high biomass levels in which overfishing is occurring based on reproductive capacity versus a stock at low levels that is achieving its reproductive capacity.

One recommendation regarding the parameterization between stock assessment models and the projection models is that correct naming conventions be utilized in. Equivalent parameterization should be utilized in both the projection model and for assessments.

Climate change should also be considered, with temperature and ice cover considered to the extent possible. Climate effects on populations, particularly king crab need to be included. Recruitment is tied to climate variability. Further exploration of environmental variability to explain the variability in the assessments should be incorporated.

Biological reference points/discussion of tier system

Discussion during this session focused on revising the draft tier system initially put forward by the workgroup in their progress report (Attachment 5). The discussion covered revisions to this draft tier system to craft a workable tier system for the analysis, specific suggestions of what to include in the analysis itself, as well as suggestions for inclusion in a problem statement to be crafted to frame the analysis.

The group discussed the problem statement which will frame the alternatives to be included in the environmental assessment of this amendment analysis. An important aspect of this problem statement is the necessity of a frameworked process (to the extent possible), to avoid having fixed values in the FMP, as with the current system. Fixed values limit flexibility as any change to these values requires an FMP amendment. The problem statement should highlight the need for increased flexibility in crafting new overfishing definitions. The second part of the problem statement should relate to creating a tier system for OFL definitions which relates to the quality of information available on a stock by stock basis. Finally, it was discussed that the problem statement should also clearly relate to the need to appropriate application of status determination criteria utilized in the determination of overfished and overfishing. The process by which this will be determined should be clearly outlined as well as the portion of the stock to which it applies. It has been discussed previously that the process by which overfishing has been determined has not been appropriately applied and one goal of this analysis is to ensure that the process for future application is not ambiguous.

There will be two alternatives analyzed in the environmental assessment for the amendment. These are: Alternative 1, the status quo definitions and method of determination and, Alternative 2, the proposed tier system and method of status determination. Depending upon the specific analytical needs under each tier, there may be options included for analysis under alternative 2. Other alternatives have been discussed during the course of the workgroup's progress on crafting these definitions, such as analyzing different fixed values and other draft tier systems. These alternatives will all be noted as well as the process by which the final tier system was devised in the section of the analysis focusing upon alternatives considered but not carried forward for analysis. This section of the document will note the process by which alternative 2 was crafted. This includes on-going work by the work group, review and recommendations by the plan team and SSC, as well as the workshop itself in providing guidance on refining this alternative

Jie Zheng presented a modified tier system from the one included in the progress report presented earlier in the workshop (Attachment 3p). The group used this draft tier system as a template from which to make modifications to formulate a revised tier system. The final version of the workshop's revised tier system is included in the summary section at the beginning of this document. Many modifications were made both to include aspects of the work group's original tier system as well as aspects from the North Pacific groundfish tier system. The following discussion characterizes the changes that were made in refining the tier system to the final version included in this document.

All reference to an ABC determination by tiers has been excluded in the final tier system version. This is due to the nature of State and Federal management whereby the determination of OFL is made by the Federal government while the determination of harvest levels (formerly GHLs) or TACs are made by the State. There is no mandate to specify an ABC for crab stocks, nor any specification in the State/Federal management system by which an ABC would be utilized. In order to not further complicate the nature of shared management, the group chose to exclude ABC from tier status determination.

One problem that was noted in discussing ABCs, is that in the absence of an ABC there is no specific buffer level between the OFL and the possible harvest strategy. This could pose a conservation concern if OFLs are not properly specified (and hence exceeded by the State in TACs), but can also pose a potential problem with respect to the bycatch of crabs in other Federally-managed groundfish fisheries. In the past the OFL levels for crab fisheries were established at a high enough level that it was highly unlikely that they would be exceeded and therefore shut down groundfish fisheries. The potential exists under new OFLs that this level could be potentially exceeded. Unless specific buffer levels are maintained between OFL and TAC the potential exists for closing down groundfish fisheries which catch crab as bycatch if the combination of the directed fishery and groundfish bycatch of crabs exceeds the crab species OFL. This problem will be noted in the subsequent analysis of this amendment. A State and Federal discussion regarding TACs and OFLs may need to occur to ensure that the bycatch needs of Federal groundfish fisheries are adequately considered in the establishment of TAC levels by the State.

In all tiers referencing a harvest rate, harvest rate (HR) was changed to reference an F rate. How this F rate is to be defined is left to the discretion of the working group. Tier 1 from the workgroup's draft tier system was included in the final tier system version. This tier was modified to exclude the ABC specification as described above. The ability to analyze tier 1 was noted to be difficult given that no crab stocks will currently fall into this tier. Suggestions were made to possibly use the groundfish tier 1 example for discussion purposes in the analysis of how this tier might in the future be utilized. In all tiers, references to effective spawning biomass were changes to B (Biomass) with the definition of this biomass left to the discretion of the stock assessment analysts as information is available.

The group discussed the definition of parameters such as alpha, beta and gamma as referenced in the tier levels. After discussion of the pros and cons of retaining these parameters as well as specifying these with absolute numbers at this point, it was decided to retain the parameters themselves in tier definitions, but left to the discretion of the workgroup to define the actual numbers in their analysis.

The F rates to be analyzed in Tier 3 were a subject of considerable discussion. It was noted that the F rate for this tier must be specified as objective and measurable, thus cannot be frameworked to be simply Fx% as suggested. Given the previous discussions on the complexities in defining spawning biomass, SPR proxies and stock-recruitment relationships it would be difficult to establish an F rate for this tier or define Fmsy. A range of values was chosen for purposes of analysis whereby F50% - F60% will be utilized.

Tier 4 was modified to combine both tiers 4 and 5 from previous versions of the tier system. Tier 5 was included from the work group's draft tier 6. Specific language determining the definition of OFL in tier 5 was modified from the Tier 6 language for the groundfish tier system which establishes OFL as average catch from a time period to be determined or an alternative value for OFL as established by the SSC based on the best scientific information available.

Wrap-up and future directions

Diana Stram provided an overview of the timeline for compiling the workshop report, and presentation to the SSC and Council at the April Council meeting. Eventually the analysis of the proposed overfishing definitions will be included in a larger environmental assessment of the proposed amendment (which analyzes both alternatives as detailed previously) to be presented for initial and subsequently final review by the Council. Anne Hollowed informed the workshop participants of the scheduled CIE review in late April of the proposed overfishing definitions analysis and the intent to present an analysis to the CPT in May and the SSC in June. Further determination of the schedule for preparing the entire analysis for initial review by the SSC and Council is yet to be determined.

The workshop concluded at 5pm on Wednesday, March 1st.

Attachment 1 **List of participants**

Attachment 2 **Agenda**

- Attachment 3a **Overview and purpose of workshop**
- Attachment 3b **National Standard Guidelines Overview**
- Attachment 3c **Statement of work**
- Attachment 3d **Feb WS Tier Proposal**
- Attachment 3e **SPR Input parameters 1**
- Attachment 3f **SPR Parameters 2**
- Attachment 3g **Model Inconsistencies**
- Attachment 3h **Model Simplifications**
- Attachment 3i **Model Structures**
- Attachment 3j **Biological ref. points approaches 1**
- Attachment 3k **Biological ref points 2**
- Attachment 3l **Unresolved model issues**
- Attachment 3m **Biological considerations**
- Attachment 3n **SnowCrab Assessment Overview**
- Attachment 3o **Bering Sea Red King Crab Assessment Overview**
- Attachment 3p **Tier review ppt**

Attachment 4 **Statement of work report**

Attachment 5 **Progress report of workgroup**

Crab Overfishing Definitions Inter-Agency Workshop

List of Participants

Name	Affiliation	email
Bernard Sainte-Marie	DFO Canada	Sainte-MarieB@dfo-mpo.gc.ca
Doug Pengilly	ADF&G	doug_pengilly@fishgame.state.ak.us
Forrest Bowers	ADF&G	forrest_bowers@fishgame.state.ak.us
Doug Woodby	ADF&G	doug_woodby@fishgame.state.ak.us
Gordon Kruse	UAF	Gordon.Kruse@uaf.edu
Terry Quinn	UAF	fftjq@uaf.edu
Ginny Eckert	UAS	ginny.eckert@uas.alaska.edu
Jie Zheng	ADF&G	jie_zheng@fishgame.state.ak.us
Shareef Siddeek	ADF&G	shareef_siddeek@fishgame.state.ak.us
Andre Punt	UW	aepunt@u.washington.edu
Brad Stevens	NMFS	Bradley.G.Stevens@noaa.gov
Gretchen Harrington	NMFS	Gretchen.Harrington@noaa.gov
Diana Stram	NPFMC	Diana.Stram@noaa.gov
Lou Rugolo	NMFS	Lou.Rugolo@noaa.gov
Jack Turnock	NMFS	Jack.Turnock@noaa.gov
Grant Thompson	NMFS	Grant.Thompson@noaa.gov
Jim Ianelli	NMFS	Jim.Ianelli@noaa.gov
Anne Hollowed	NMFS	Anne.Hollowed@noaa.gov
Pat Livingston	NMFS	Pat.Livingston@noaa.gov
Herman Savikko	ADF&G	Herman_savikko@fishgame.state.ak.us
Russ Nelson	NMFS	Russ.nelson@noaa.gov
James Murphy	NMFS/UW	James.T.Murphy@noaa.gov

Attachment 2

Alaska Crab Overfishing Definitions Workshop

February 28 – March 1, 2006

Alaska Fisheries Science Center, Seattle, WA

Feb 22nd 2005 Draft Agenda

Purpose: To solicit expert advice on proposed overfishing definitions for Bering Sea and Aleutian Islands crab stocks. We are requesting a review of issues critical to formulating new overfishing definitions, biological reference points, input parameters, modeling approaches and methods to deal with uncertainty.

DAY 1 (Traynor Room)

8:00 Coffee and informal discussions

8:30 Introduction - Charge for the workshop participants –Kruse or Stram
8:45 History of crab management - current overfishing definitions and need for revision - Stram
9:00 Revisions to NSG 1, rationale for SPR proxies, and techniques for incorporating uncertainty - Thompson
9:30 Overview of proposed revisions - Working group

- Working group Statement of Work
- Tier System review
- Parameters – input to SPR models
- Model simplifications

10:45 Break
11:00 – 12:15 Overview continued – working group

- Model structures
- Approaches to estimate proxy values for biological reference points
- Preliminary results
- Unresolved issues (moderator will direct audience to written comments)

12:15 – 1:15 Break for lunch
1:00-5:00 Biology session – Chair (Bernard St. Marie)

- Measure of effective spawning stock biomass
- Formulation of effective male spawning stock biomass
- Mating ratio to use in calculation of effective spawning biomass
- Applied mating ratio – method of applying the mating ratio for calculation of effective spawning biomass
- Use of pre-molt vs. post-molt female size in spawning stock biomass calculation
- Males participating in reproduction
    - Non-molting males – king crabs
    - Old shell males (1 yr oldshell or 2 yr oldshell) – snow and tanner crabs
- Female natural mortality estimates
- Stock-Recruitment Relationship [SRR]:

(Rapporteur and session lead will prepare summary of findings for afternoon session on Day 2)

DAY 2 (Traynor Room)
8:00 Coffee and informal discussions
8:30 Session on modeling and biological reference points – Chairs (Quinn and Ianelli)

- Description of stock assessment models and the linkage to projection models
  - Snow crab stock assessment model
  - Red king crab stock assessment model
  - Projection models

10:00 Break (*Note: morning session to reconvene in NMML room until lunch)*

- Review of alternative Biological Reference Points
  - Retain Fmsy=M, application of Fmsy to management of stocks
  - Surplus production models
  - SPR proxies for Tier 3 type management
  - Management Strategy Evaluations based on different families of spawner recruit relationships or different productive regimes to evaluate suitability of control rule under different assumptions regarding stock productivity
  - Indicator approaches based on stock condition or other biological factors.
  - Other suggestions

Break for lunch *(Reconvene back in Traynor room following lunch)*

1:00 Proposed Tier system for crab: review and provide comments
2:00 Report from biology session chair + Discussion *(Rapporteur and chair of modeling session break to compile report)*

3:00 Break
3:30 Report from modeling session chairs + Discussion
4:30 Overview of workshop, feedback from workgroup and future directions (Kruse)

Overview of Crab Management and Background on Current Overfishing Definitions

Alaska Crab Overfishing Definitions Workshop
AFSC, Seattle, WA
February 28-March 1, 2006

Diana L. Stram
North Pacific Fishery Management Council

North Pacific Fishery Management Council

Fishery Management Plan (FMP) for the BSAI King and Tanner Crabs

- FMP establishes State/Federal cooperative management regime
  - Crab management deferred to State with Federal oversight
  - 3 categories of management measures defined under the FMP
    - Category 1: Fixed. FMP amendment to change.
    - Category 2: Frameworked. State has flexibility within the criteria specified for frameworked measures.
    - Category 3: Discretionary. State can change through own process.

North Pacific Fishery Management Council

Management measures under FMP

Management measures implemented for the BSAI king and Tanner crab fisheries, as defined by the federal crab FMP, by category.

Category 1 (Fixed in FMP)	Category 2 (Frameworked in FMP)	Category 3 (Discretion of State)
* Legal Gear	* Minimum Size Limits	* Reporting Requirements
* Permit Requirements	* Guideline Harvest Levels	* Gear Placement and Removal
* Federal Observer Requirements	* Inseason Adjustments	* Gear Storage
* Limited Access	* Districts, Subdistricts and Sections	* Gear Modifications
* Norton Sound Superexclusive Registration Area	* Fishing Seasons	* Vessel Tank Inspections
	* Sex Restrictions	* State Observer Requirements
	* Closed Waters	* Bycatch Limits (in crab fisheries)
	* Pot Limits	* Other
	* Registration Areas	

North Pacific Fishery Management Council

Management measures (cont)

- FMP must meet requirements of Federal laws and regulations
  - Compliance with amendments to MSA (e.g. SFA 1996)
- For BSAI Crab FMP Federal requirements are Category 1 measures fixed in the FMP and requiring an FMP amendment to change
- MSA revisions in 1996 (SFA):
  - Defined 'overfished' and 'overfishing'
  - Required all FMPs to specify objective and measurable criteria for ID when fishery is overfished (and if overfished or approaching overfishing, contain mgt measures to prevent and rebuild)
  - Councils must submit amendments by October 11, 1998 to bring FMPs into compliance

North Pacific Fishery Management Council

Amendment 7 to Crab FMP

- Amendment 7 revised definitions of overfishing, MSY and OY (work by members of Crab Plan Team)
- Adopted by NPFMC in June 1998
- Effective date March 3, 1999
- Measures under Amendment 7:
  - Revised OY, MSY, overfishing
  - MSY Control rule = natural mortality rate (M). Fixed values for king crab (M=0.2) and *Chionoecetes* sp (M=0.3)
  - MSY stock size = average mature biomass observed between 1983-1997
  - Overfishing rate = fishing rate >M
  - Minimum Stock Size Threshold (MSST) = ½ MSY stock size
  - Stock is considered overfished if mature biomass below MSST.

North Pacific Fishery Management Council

Overfished and overfishing

- MSA requirement section 304(e) that Secretary report to Congress and Council on status of fisheries and identify fisheries that are overfished or are approaching an overfished condition.
  - Status determination made using criteria specified in FMPs
- If fishery is overfished SoC must notify the Council. Council must take action within 1 year of notification to prepare FMP amendment for purposes of ending overfishing and rebuilding stock.

North Pacific Fishery Management Council

NPFMC's overfished stocks since implementation of Amendment 7

- **BS Tanner** (1998 declaration, 2000 RBP adopted, amd 11). Currently under rebuilding plan. Small harvest in western stock in 2005-2006 (Eastern remains closed).
- **Snow crab** (1999 declaration, 2001 RBP adopted, amd 14). Currently under rebuilding plan. Some harvest under rebuilding plan.
- **St. Matthew BKC** (1999 declaration, 2000 RBP adopted, amd 15). Currently under rebuilding plan. Fishery closed.
- **Pribilof Island BKC** (2002 declaration, 2003 RBP adopted, amd 17). Currently under rebuilding plan. Fishery closed.

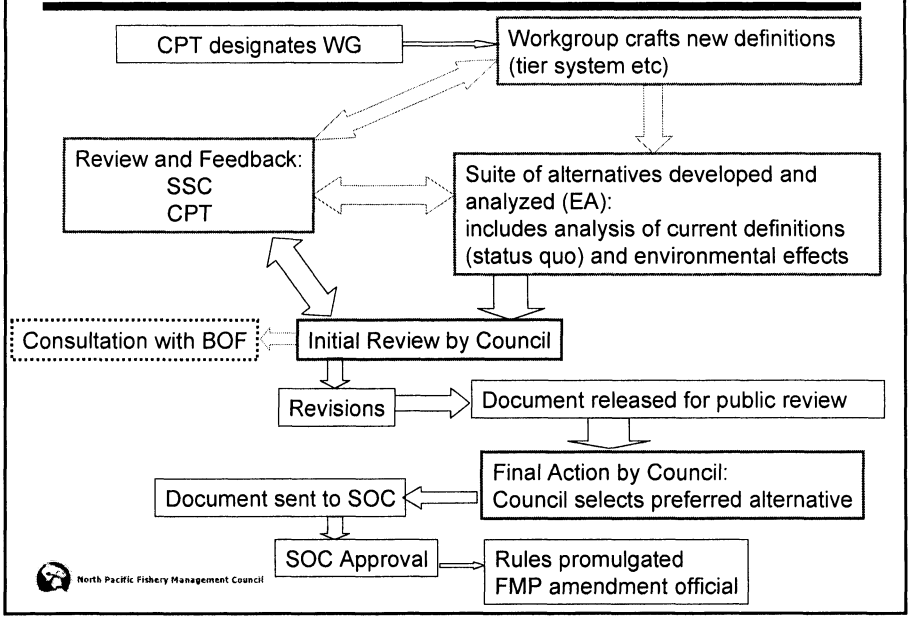
North Pacific Fishery Management Council

Crab Plan Team decision to revise definitions

- In crafting amendment 7 team declared their intent to "review [MSY] estimates on a 5 year review cycle or in the event that environmental conditions signal a regime shift" (EA for Amd 7, 1999)
- 2003 CPT meeting: team reviewed current definitions and decided to revise current defintions.
  - Workgroup created: Lou Rugolo (NMFS), Shareef Siddeek (ADF&G), Jack Turnock (NMFS) and Jie Zheng (ADF&G)
  - Guidance to workgroup and initial timeline for amendment provided in CPT minutes.

North Pacific Fishery Management Council

Process for FMP amendment



Charge for workshop participants

1. Proposed Revisions from workgroup: including statement of work, progress, unresolved issues
   - Review and clarifications from work group
2. Sessions: Biology, Modeling/BRPs (issues per background materials provided)
   - Review unresolved issues
   - Provide expert advice on means to proceed with analysis
3. Reports from session chairs
   - Summarize findings as appr. or summarize discussion where findings N/A
4. Feedback from workgroup
   - Preliminary view of utility of workshop in proceeding with analysis
   - Future directions for analysis

North Pacific Fishery Management Council

National Standard 1 Guidelines, Use of SPR reference points, and Incorporating uncertainty

Grant Thompson

Alaska Fisheries Science Center

Part 1: NS1 Guidelines

- National Standards in MFCMA since 1976
  - In 1996, SFA changed MFCMA to MSFCMA
- NS1: prevent overfishing, achieve OY
- NS guidelines required by M(S)FCMA
- First published in 1977
- Revised in 1983, 1989, and 1998
- New proposed revision published in 2005
- Final rule unlikely this year

What's old: MSY

- Largest long-term average catch possible under prevailing environmental conditions
- MSY control rule
  - Constant catch
  - Constant fishing mortality rate
  - Constant escapement
  - More complicated functional forms
- Must incorporate consideration of risk
- Should be re-estimated when warranted

What's old: OY

- Optimum yield specification
  - Provides greatest overall benefit to Nation
  - Takes protection of ecosystem into account
  - MSY reduced by economic, social, ecological
  - Rebuilds any overfished stocks to MSY level
- "Precautionary approach" urged
  - Targets set safely below limits
  - F should be lowered if B<Bmsy
  - F should vary inversely with uncertainty

What's old: SDC

- Two status determination criteria required
  - If F>MFMT, overfish*ing* is occurring
  - If B<MSST, stock is overfish*ed*
- MFMT must be ≤ MSY control rule
- If possible, MSST should equal greater of:
  - ½ Bmsy
  - Minimum stock size at which stock can be rebuilt to Bmsy in 10 years given F=MFMT

What's old: Rebuilding

- Rebuilding required if F>MFMT, B<MSST
- Rebuilding time period required
  - Tmin = rebuilding time given F=0
  - Tmax = 10 yr if Tmin < 10 yr
  - Tmax = Tmin + 1 generation if Tmin ≥ 10 yr
- Progress monitored at least every 2 years
- No guidance on updating, extending plans

What might be new (1 of 4)

- Nomenclatural changes
  - Thresholds (MFMT, MSST) become limits (Flim, Blim)
  - Overfished becomes depleted
- Specification of core stocks and assemblages
  - Core = principal target stocks; may also include historical targets, bycatch stocks, vulnerable stocks
  - Assemblage = stocks that co-occur with similar productivity, but insufficient data for individual SDC
  - Assemblage should contain at least 1 core stock
  - Manage assemblages more conservatively than cores

What might be new (2 of 4)

- OY control rules required
  - For each core stock (and assemblage?)
  - Must be less than Flim
  - Should quantify social, economic, ecological factors
- Blim definition "simplified"
  - 50% BMSY is new default
  - Range of natural fluctuations can justify other values
- Exceptions to required specification of Blim
  - If OY control rule is as conservative as rebuilding plan
  - If data are insufficient

What might be new (3 of 4)

- New formula for Tmax
  - Tmax = 10 yr if Tmin + 1 gen < 10 yr
  - Tmax = Tmin + 1 gen if Tmin + 1 gen ≥ 10 yr
- Revisions to rebuilding plans
  - Treb can increase to Tmax if F targets met
  - F targets can increase if E(B(Treb))=Bmsy
  - Provision for new estimates of reference points
  - F cannot increase if stock not rebuilt at t=Tmax

What might be new (4 of 4)

- Possible restrictions in present flexibility regarding timing of status determinations
  - Not in proposed NS1 guidelines revision
- "Is overfishing occurring?" may change to "Was overfishing occurring in year X?"
- Possible scenario:
  - Set OFL for Y2 based on assessment in Y1
  - Conduct Y2 fishery so as to achieve catch<OFL
  - Set new Y2 OFL based on Y3 assessment
  - Compare Y2 catch to new Y2 OFL

Part 2: SPR

- %SPR commonly used as MSY proxy
  - S-R data are usually noisy enough to give large errors in Fmsy, Bmsy estimates
  - However, %SPR is independent of S-R curve, because recruits in numerator, denom. cancel
- Proxy values depend on assumptions
  - Clark (1991, 1993) showed F35%-F40% was a safe proxy for MSY in "typical" groundfish
  - Some recent studies of west coast rockfish suggest F50%-F60% better for those stocks

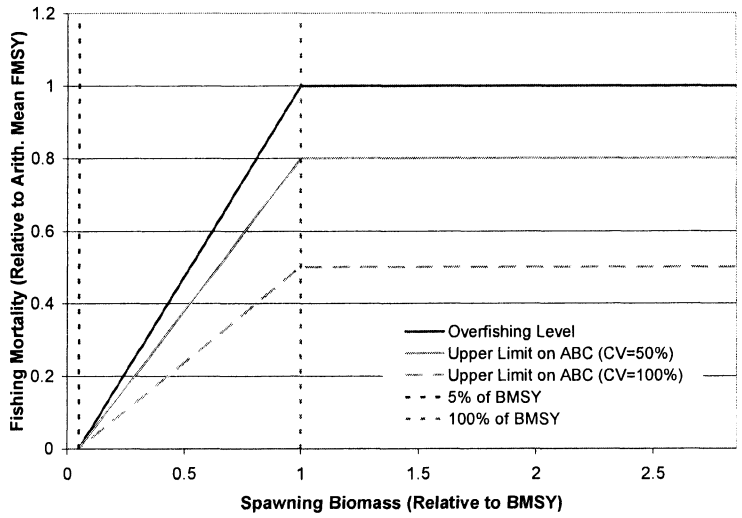
Part 3: Incorporating Uncertainty

- Method 1: Set target so as to achieve constant probability of exceeding limit
  - Implies harvest rate dichotomy, with all F>Fmsy equally bad
  - Target has no optimality properties
- Method 2: Set target so as to maximize expected value of risk-averse utility function
  - Implies harvest rate continuum, with any given overharvest worse than an equivalent underharvest
  - Target has clear optimality properties

Uncertainty: Examples of Method 2

- Alaska groundfish Tier 1
  - Limit F = arithmetic mean Fmsy
  - "Target" F = harmonic mean Fmsy
- Alaska groundfish PSEIS Alternative 3b
  - Reverse engineer SRR from F35%, B35%
  - Closed-form solution exists, assuming linear dynamics, normal process & assessment error

Uncertainty: Alaska groundfish Tier 1



Statement of Work

NPFMC BSAI King & Tanner Crab Working Group

Background:

Establishment:

- Formed by CPT: [Sep., 2003]
- Statement of Work: [Nov., 2003]
- Report to CPT: [Jan., 2005]
- EA SSC Review: [2006]
- EA Final Action: [2006]

Scope & Responsibility:

1. Revise overfishing definitions of FMP
2. Revise poorly defined scientific and technical elements
3. Specify technical elements to:
   - achieve compliance: mandates of MSFCMA and SFA
   - achieve consistency: NS's and Guidelines
   - address stock status & uncertainty
   - bridge gap in Plan specifications & harvest strategies

Categories of Amendments to Plan

Revisions to Plan:

1. Overfishing Definition
2. Overfished Definition
3. MSY Control Rule

Additional Technical Elements:

1. Natural Mortality
2. LRP of Z_{MSY}
3. F and μ
4. Non-Directed Mortalities
5. B_{MSY} and SY
6. Conservation Equivalency
7. Tier System
8. Limit Reference Point System
9. Projection Modeling
10. Sensitivity Analysis

Overfishing Determination

- **Two status determination criteria of SFA:**
  1. Overfishing: if F > MFMT
  2. Overfished: if Total Mature Biomass (TMB) < MSST ⇨ Rebuilding Plan
     [MSST > ½ B_{MSY} or B_{MIN} ⇨ B_{MSY} in 10 y @ F = MFMT]
- **Current Plan [1998]:**
  1. MFMT = F_{MSY} = M = 0.20 [*Lithodes sp.*]; 0.30 [*Chionoecetes sp.*]
  2. MSST = ½ B_{MSY} = 1983-97 Mean NMFS EBS Survey Biomass
- **Statement of Need:**
  1. Plan does not specify how "overfishing" is to be determined
  2. Plan specifies Sustainable Yield (SY) = TMB • F_{MSY}
     TMB = mature ♂ + ♀: all sizes + all shell conditions + all range
  3. Plan does not specify how SY used to determine overfishing
  4. Method for determining overfishing in SAFE is in Plan:
     overfishing if harvest level [*retained male catch*] > SY in one year
     ⇨ inadequate & theoretically inconsistent

Technical Issues *re:* Sustainable Yield

- Total losses unaccounted - i.e., only *retained catch*
- TMB ≠ Exploitable Stock Biomass [ESB]
- SY catch standard as status determination criterion inconsistent w/ overfishing definition F_{MSY}
  i.e., $\mu = 1.0$ allowable on ESB w/o finding overfishing
- Sex differential loss rates [F, F']
- Conceptual flaw in specification of SY
- Equation used to derive SY mis-specified
- $F \neq \mu$: current approach assumes Type I fishery [$\mu=1-e^{-F}$]
  F and M not in competition for deaths
- $F_{MSY}=M$: while M in stock assessment & harvest strategy, modeling allowed to be different, or change w/o effect on F_{MSY}

Example: Plan Overfishing Definition

Sustainable Yield as Overfishing Standard for C. opilio in 2003:

1. TMB in 2003 = **306.2 million pounds**.
2. SY = TMB • F_{MSY} = **92 million pounds**
3. If retained catch < SY, no overfishing by definition
4. The 2003 NMFS survey estimated 65 million male *opilio* ≥ 101 mm cw for SC2 – SC5 combined.
5. At 1.27 lbs/crab (used in GHL calculation), = **82.6 million pounds**.
6. So, this overfishing definition would allow every male ≥ 101 mm cw in population to be removed w/o meeting overfishing threshold in the plan.
7. That's, μ = 100%.

Technical Elements:
Action Item 1: Instantaneous Natural Mortality:

Rationale:

1. M may vary inter-annually or size-variant, but lacking empirical studies.
2. M unknown: [aging limitations in decapods, non-virgin stocks].
3. M in stock assessment & harvest strategy modeling differ from Plan overfishing definitions.
4. For most stocks:
5. M underlying MSY Control Rule decoupled from harvest control rules.
   1. M treated as variable, estimated in external model forms ≈ total stock losses in survey not attributed to retained catch.
   2. M can exceed that specified in overfishing definitions & MSY Control Rule w/o altering target or threshold F rates in Plan.
6. Uncertainty that specified values of M are consistent w/ life-histories.

Technical Elements:
Action Item 1: Instantaneous Natural Mortality:

Actions:

1. Specify method to estimate M for each stock.
2. Describe how M will be applied in overfishing and MSY Control Rules for each stock, and in determining FMSY.
3. Specify relationship between M used in stock assessment modeling and harvest strategy modeling.

- Overall, maintain consistency in M between:
  - overfishing definitions.
  - stock assessment and population dynamic modeling.
  - harvest strategy modeling.

Technical Elements:
Action Item 2: Overfishing Definition Z_{MSY}

Rationale:

1. Limit reference points [e.g., F_{MSY}]: outcome of structured modeling based on input M.
2. Tenet of MSFCMA - define *conservation and management measures* to maintain total annual stock losses $\leq F_{MSY} + M$, i.e., $\leq Z_{MSY}$.
3. Modeled Z_{MSY} ⇨ sustainable yield @ B_{MSY} under F_{MSY}.
4. In harvest control modeling, M estimated annually:
   1. permitted to exceed M specified in Plan overfishing definition
   2. even so, harvest goals set using full F_{MSY}
5. Declines in survey status not accounted for in retained catch, assumed to inter-annual changes in M
6. Whether declines from M, or bycatch / discard losses,
   1. realized Z allowed to > Z_{MSY} w/o meeting overfishing standard
   2. response framework: if M↑, F↓ so that Z_{MSY} not exceeded

Technical Elements:
Action Item 2: Overfishing Definition Z_{MSY}

Actions:

1. Specify how Z_{MSY} will operate as a limit reference point for each stock.
2. Specify how Z_{MSY} will be applied in overfishing definitions and MSY Control Rule for each stock.
3. Specify how Z_{MSY} will be applied in assessing performance of fisheries and the implemented harvest strategies.

Technical Elements:
Action Item 3: Fishing Mortality [F] and Exploitation [μ] Rates

Rationale:

1. Plan lacks specification on correct use F and μ in deriving harvest strategies consistent w/ overfishing definitions.
2. In practice, F and μ used interchangeably in formulae to estimate harvest goals.
3. Where M and F compete for deaths, ⇨ overestimate both μ @ F, and harvest quotas.
4. Incorrect specification of "*Utilization Rate*" [V] in place of μ as Plan status determination criterion for overfishing.
   1. V does not consider indirect losses [bycatch, discards].
   2. exploitation rate is based on fully-recruited F, fishery selectivities and M.
   3. V underestimates μ given any non-directed stock losses.
- *risk prone* status determination criterion.

Technical Elements:
Action Item 3: Fishing Mortality [F] and Exploitation [μ] Rates

Actions:

1. Specify exploitable stock component of each stock subject to the target or threshold F definitions in Plan:
   1. exploitable stock biomass [ESB]
   2. *exploitable stock abundance [ESA]*, since
   3. ESB = ESA when size frequency pop=catch
2. Specify how full-selection F & fishery selectivity used to derive the exploitation rate [μ] corresponding to the target or threshold F definitions.
3. Specify method to estimate F_{MSY}, or its proxy, without specifying fixed values in the Plan.

Technical Elements:
Action Item 4: Non-Directed Mortalities

Rationale:

1. Plan inadequately specifies operational use of discard and bycatch mortalities in:
   1. deriving target or threshold F [or μ] rates.
   2. estimating preseason harvest goals.
2. Lack inclusion non-directed mortalities *operationally* results in F rates and harvest goals that exceed the overfishing definitions.

Actions:

1. Specify how non-directed mortalities will be used to derive exploitation rate [μ], and target / threshold F rates.
2. Describe approach to estimate *discard loss rates* from the directed fishery for each stock, or values of those rates.
3. Describe approach to estimate *bycatch loss rates* from non-directed fisheries for each stock, or values of those rates.

Technical Elements:
Action Item 5: Biomass B_{MSY} and Sustainable Yield [SY]

Rationale:

1. Plan inadequately specifies equilibrium biomass B_{MSY} that produces MSY from each stock.
2. B_{MSY} definitions *may be* underestimated:
   1. *risk prone:* judging stock health, recovery, assessing if overfished.
   2. violates NSGs in establishing explicitly *risk averse* reference values.
3. Plan B_{MSY} values = mean survey $TMB_{83\text{-}97}$; values fixed.
4. B_{MSY} not defined for stock w/o annual surveys.
5. Plan MSST = ½ B_{MSY}.
6. ESB crab stocks not in equilibrium during this 15 y period:
   1. significantly varying trends in abundance; systematic declining.
   2. @ levels biomass not produce MSY on "*continuing basis*" by definition.
7. Using these 15 y data to estimate B_{MSY} ⇨ underestimate overfished definitions, specify biomass test standards that are artificially low.

Technical Elements:

Action Item 5: Biomass B_{MSY} and Sustainable Yield [SY]

Rationale:

1. NSGs: MSST greater of ½ B_{MSY} or stock size @ rebuilding to B_{MSY} in 10 y fishing @ MFMT
2. Plan MSY Control Rule: MFMT = F_{MSY} = M.
   1. Amendment #7: MSY is "*mature biomass ... exploited at a F rate equal to conservative estimate of M*"
   2. EA of A#7: overfishing is "*expected utilization rate as the projected ghl divided by the estimated legal male abundance*"
   3. As noted, V ≠ μ:
      1. "*expected* " not realized
      2. "*projected ghl*" not realized catch
3. Plan no requirement to compare V to MFMT or to any retrospective estimate of ful-selection F
4. SAFE: defines <u>catch standard</u> called SY; states "*overfishing occurs if the harvest level exceeds SY in one year*"
   1. this overfishing definition not in Plan
   2. wholly lacking and theoretically inconsistent
   3. *C. opilio* in 2003: μ=1.0 on every ♂ ≥ 101 mm cw in EBS

Technical Elements:

Action Item 5: Biomass B_{MSY} and Sustainable Yield [SY]

Rationale:

1. SY as derived = F_{MSY} • TMB:
   1. not computed on exploitable stock abundance.
   2. TMB = $\Sigma\ [♀_{MAT} + ♂_{MAT,\ <4"cw,\ SC0+} + ♂_{MAT,\ \geq 4"cw,\ SC3+}]$.
   3. TMB also Σ [geographically unfished components].
2. SY theory: yield in excess for stock replacement.
3. EBS stocks not demonstrated ability to:
   1. replace total annual losses.
   2. maintain themselves in equilibrium.
4. Conceptual mismatch in Plan: stock component used to estimate harvest quotas ↔ exploited by fishery.
5. In practice, led to exceedingly high μ born by segments of the stock ⇨ localized depletions.
6. Plans allows removal @ F=∞ of entire stock components [e.g., unmated male *C. opilio*, ≥ 78 mm cw] w/o finding of overfishing.

Technical Elements:
Action Item 5: Biomass B_{MSY} and Sustainable Yield [SY]

Actions:

1. Describe approach to estimate B_{MSY} and MSST or their proxies.
2. Prescribe the exploitable stock biomass component of each stock used to estimate harvest goals.
3. Describe the approach to estimate catch standards from ESA using μ corresponding to target or threshold F.

Technical Elements:
Action Item 6: Conservation Equivalency

Rationale:

1. MSY Control Rule not attentive exceeding overfishing definitions, or harvest quotas.
2. Plan lacks framework to consider effects on biomass, or safeguarding long-term reproductive potential.
3. No explicit control feedback to insure stabilities in stock or fishery metrics
4. Harvest goals must account for total direct + indirect losses, and relate to F limits in Plan.
5. Customarily, harvest quotas are exceeded: F rates on which quotas based are exceeded.
6. Routinely exceeding threshold fishing mortality rates:
    1. erosion stock biomass.
    2. declines long-term productivity.
    3. lower standing or spawning stock biomass.
    4. inconsistent w/ intent of NSGs in establishing biological reference points: explicitly *risk averse*.

Technical Elements:
Action Item 6: Conservation Equivalency

Rationale:

1. Conservation Equivalency: mechanism to account for the result of exceeding specified Fs:
   1. provides maintenance of reproductive potential and stock biomass standards set in Plan.
   2. control feedback to MSY Control Rule to establish stock status resulting from over-achieving target F rates or harvest goals.
2. Current Plan fails to specify target < threshold limit reference points consistent w/ precautionary approach.
3. NSGs recommend buffer between MFMT and target F such that probability of exceeding MFMT is low.

Technical Elements:
Action Item 6: Conservation Equivalency

Actions:

1. Specify Conservation Equivalency approach to maintain stock biomass standards.
2. Describe currency of measure for determining equivalent conservation value for MSY Control Rule in response to exceeding overfishing definitions.
3. Describe analytical framework to be applied to target setting to achieve equivalent stock conservation standards.
4. Describe the harvest control rule for the MFMT and for the *target* F lower than *threshold* MFMT.

Technical Elements:

Action Item 7: Tier System for Overfishing Definitions

Rationale:

1. NPFMC's groundfish plans, F_{OFL} prescribed through tiers based on information availability on the stocks.
2. BSAI crab plan: reduced tier system not fully implemented
   1. F_{OFL} definitions: lower tier standards for groundfish.
   2. incomplete information & understanding stocks and fisheries.
3. In contrast, crab harvest strategy modeling rely on fully parameterized models to estimate:
   1. stock abundance.
   2. guideline harvest levels.
   3. μ rates.
   4. Fs ⇨ overfishing thresholds.
4. Tier System needed to prescribe MFMTs as per groundfish.
5. Modified Crab Plan Tier System:
   1. status of knowledge - per groundfish.
   2. status of stocks - understanding & uncertainty.

Technical Elements:

Action Item 7: Tier System for Overfishing Definitions

Rationale:

- Current Plan Tier System: 3 tiers based on level of survey information & survey-based biomass standards:

1. Annually surveyed stocks: B_{MSY}, MSST, F_{MSY} defined
2. Periodically surveyed stocks: F_{MSY}, proxy for MSY
3. Non-surveyed stocks: F_{MSY}, proxy for MSY

Technical Elements:
Action Item 7: Tier System for Overfishing Definitions

Actions:

1. Define Tier System for prescribing threshold overfishing definitions for each stock.
2. Describe methods for determining B_{MSY}, MSST and F_{MSY} [or proxies], and harvest control rules for each tier.
3. Formulate system for setting F_{OFL} considering status of knowledge, status of stocks and their uncertainties.
4. Specify approach for integrating Tier System and Limit Reference Point System for prescribing threshold or target F rates for each stock.

Technical Elements:
Action Item 8: Limit Reference Point System

Rationale:

1. Caddy proposed Limit Reference Point [LRP] system for gauging health and status of stocks.
2. LRPs = meaningful and measurable indices.
3. LRPs evaluated to derive aggregate index of sos, and implemented in a Limit Reference Point System.
4. LRP System: for stocks difficult to quantify reference points, used to:
   1. assess stock status by suite non- or semi-quantitative multiple criteria
   2. guidance in applying precautionary approach
   3. assessment of LRPs indicate management response to achieve Plan goals
   4. responses are formulated in MSY Control Rule for setting F_{OFL}, or target Fs
5. LRPs:
   1. values of A, B, F, Z, R
   2. trajectories in A, B and R
   3. uncertainties in A, B, F, Z, R
   4. fishery metrics [non-directed, % soft-shell ...]
   5. ecosystem-based [multi-species or technical
   6. interactions, refugia ...

Technical Elements:
Action Item 8: Limit Reference Point System

Actions:

1. Identify suite of LRPs to gauging stock and fishery status.
2. Define LRP System System for status of stock and fishery assessment integrated in MSY Control Rule.
3. Define method for enumerating annual SOS to replace current determination of stock biomass relative to threshold.
4. Define LRP System and use in rules for specifying: F Buffer Zone, F Target Zone and F Overfishing Zone.
5. Define method to link the Limit Reference Point System and the Tier System.
6. Prescribe how combined TS/LRP system used to set F_{OFL} values consistent with current status of stocks.

Technical Elements:
Action Item 9: Projection Modeling Framework

Rationale:

1. Plan lacks model framework to evaluate alternative management strategies on stock health.
2. Need projection modeling framework to:
   1. assess stock + fishery performance.
   2. evaluate overfishing effects.
   3. provide quantified & reliable measures of achieving specified outcomes by management action.
3. Restrepo [1998] and NRC: harvest strategy + decision rules must be evaluated to determine ability to sustain stocks.
4. NSGs: need to determine if stock ⇨ overfished condition defined as, B falling < MSST in 2 years.
5. NSG-1 describes remedial action to rebuild stock once B < MSST.
6. Intent of FCMA that overfished stocks rebuilt *quickly*.

Technical Elements:
Action Item 9: Projection Modeling Framework

Rationale:

1. For stocks under Rebuilding Plan, evaluate rebuilding trajectories under current model scenario to gauge success of management measures.
2. For stocks not under Rebuilding Plans, it's desirable that MSY Control Rule leads to returning stock to B_{MSY}.
3. To guard against declines in abundance, desirable that overfishing rules afford ***built-in*** rebuilding as stock falls < MSY stock size.
4. Both rules intended to ⇨ greater & more stable yields; stability conferred to reproductive potential.
5. MSY Control Rule of crab plan does not provide required measures of protection to stocks or to fisheries.

Technical Elements:
Action Item 9: Projection Modeling Framework

Actions:

1. Define analytical framework for examining consequences of alternative management strategies on stock status.
2. Specify performance criteria for process of evaluating harvest strategies and decision rules.
3. Define simulation framework for rebuilding plans to achieve stock recovery, specifying both *rebuilding period* and *rebuilding trajectory.*
4. Define simulation framework to specify rebuilding control rules for each stock under Rebuilding Plan.
5. Define analytical framework to prescribe overfishing control rules for each stock.

Technical Elements:
Action Item 10: Sensitivity Analysis

Rationale:

1. Amendment will revise overfishing, overfished and MSY Control Rule definitions, specify status determination criteria to evaluate performance of management system, to:
   1. meet conservation requirements of Acts: long-term stock productivity.
   2. formulate rules & strategies ⇨ precautionary approach.
2. LRPs often from structured models where data allow.
3. Utility is dependent on input parameters of essential processes.
4. Parameters:
   1. species: [biological, life-history, population dynamic].
   2. fishery: [F, non-directed losses, partial recruitment].
   3. survey: [net selectivity, protocols].
5. Value of sensitivity analysis:
   1. Where low confidence in a parameter value, restricted range estimates to evaluate effects on model performance.
   2. Examine model structure & parameter space: relative contribution to model performance.
   3. Insight to model dependencies for research planning of information needs.

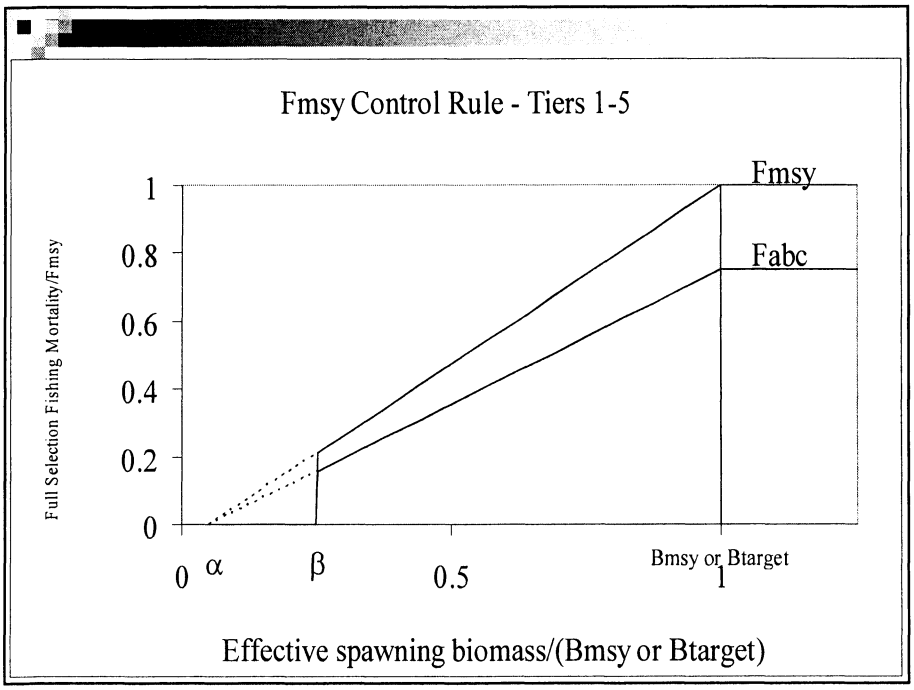
Technical Elements:
Action Item 10: Sensitivity Analysis

Actions:

1. Identify fishery and stock parameters whose variation effect threshold definitions and control rules.
2. Define analytical framework to conduct sensitivity analyses of reference points for each stock.
3. Define analytical framework to select robust overfishing and overfished values based on sensitivity analyses.
4. Identify critical information needs for management which would guide research planning.

Proposed tier system

- Based on the North Pacific groundfish 6 tier system
- The tiers correspond to information availability on the stocks, reliability of survey data, and the stock assessment model used.
- Agreed upon by working group and presented to SSC June 2004



Tier 1) Information available: *Reliable point estimates of B and BMSY and reliable pdf of FMSY .*

1a) Stock status: *B/BMSY > 1*

FOFL = μ_A *, the arithmetic mean of the pdf*

FABC <= μ_H*, the harmonic mean of the pdf*

1b) Stock status: β *< B/BMSY <= 1*

FOFL = μ_A *x (B/BMSY -* α*)/(1 -* α*)*

FABC <= μ_H *x (B/BMSY -* α*)/(1 -* α*)*

1c) Stock status: *B/BMSY <=* β

FOFL = 0

FABC = 0

Tier 2) Information available: Reliable point estimates of B, BMSY , FMSY , Flimit (proxy for Fmsy), and FTarget . The F% proxies for Fmsy and Ftarget need to be determined for crab stocks.

2a) Stock status: B/BMSY > 1

FOFL = FMSY

FABC <= FMSY x (FTarget /Flimit)

2b) Stock status: β < B/BMSY <= 1

FOFL = FMSY x (B/BMSY - α)/(1 - α)

FABC <= FMSY x (FTarget /Flimit) x (B/BMSY - α)/(1 - α)

2c) Stock status: B/BMSY <= β

FOFL = 0

FABC = 0

Tier 3) Information available: *Reliable point estimates of B, BTarget, Flimit, and FTarget. The F% and B% proxies for Fmsy, Ftarget and Btarget need to be determined for crab stocks.*

3a) Stock status: B/BTarget > 1
FOFL = Flimit
FABC <= FTarget

3b) Stock status: β < B/BTarget <= 1
FOFL = Flimit x (B/BTarget - α)/(1 - α)
FABC <= FTarget x (B/BTarget - α)/(1 - α)

3c) Stock status: B/BTarget <= β
FOFL = 0
FABC = 0

- 4) Information available: *Reliable point estimates of B, Flimit, and FTarget. No stock assessment model, but reliable estimate of a proxy for BTarget% based on survey data. The F% and B% proxies for Fmsy, Ftarget and Btarget need to be determined for crab stocks.*

4a) Stock status: B/BTarget > 1
FOFL = Flimit
FABC <= FTarget

4b) Stock status: β < B/BTarget <= 1
FOFL = Flimit x (B/BTarget - α)/(1 - α)
FABC <= FTarget x (B/BTarget - α)/(1 - α)

4c) Stock status: B/BTarget <= β
FOFL = 0
FABC = 0

5) Information available: *Reliable point estimates of B and natural mortality rate M. No stock assessment model, but reliable estimate of a proxy for BTarget (B% needs to be determined for crab stocks) based on survey data. Could have a multiplier on natural mortality (γ) to get FOFL if M is determined not to be a good proxy for the FOFL for crab stocks.*

5a) Stock status: B/BTarget > 1

FOFL = γ x M

FABC <= 0.75 x FOFL

5b) Stock status: β < B/BTarget <= 1

FOFL = γ x M x (B/BTarget - α)/(1 - α)

FABC <= 0.75 x FOFL x (B/BTarget - α)/(1 - α)

5c) Stock status: B/BTarget <= β

FOFL = 0

FABC = 0

Tier 6) Information available: *Reliable catch history from a time period to be determined (groundfish uses 1978 through 1995).*

OFL = the average catch from a time period to be determined, unless an alternative value is established by the SSC on the basis of the best available scientific information.

ABC <= 0.75 x OFL

Values to be determined

- α and β parameters
- (α = 0.05 for groundfish control rule)
- F proxy for Fmsy and maximum Ftarget
- Maximum Ftarget/Fmsy proxy will determine size of buffer (groundfish uses F40%/F35%)
- Proxy for Bmsy for tiers 4 and 5 where F control rule declines with declining biomass (different from groundfish rule)

Parameters-input to SPR Models

- Base values of input biological and fishery parameters
- Variations in input parameter values
- Additional input parameter values for stochastic simulations

Red King Crab

Parameter	Male	Female	Remarks
Size range (mm CL)	65-200	65-165	
Instantaneous M	0.18	0.18	Based on 25-year longevity with 1% survival at maximum age
Pot fishery handling mortality rate (h)	0.2	0.2	[a]Kruse et al., 2000. Model estimate of discard selectivity with M=0.18 using 1985-2004 data
Trawl fishery bycatch death proportion	0.8	0.8	Model estimate of trawl selectivity with M=0.18 using 1985-2004 data
Mean fishing period (yr)	0.0112	0.0112	Mean fishing time during 1996-2004
Lapsed time (yr)	0.542	0.542	Molt time (Apr 1) to start of fishery (Oct 15)
Growth increment: a, b	17.542, -0.016	16.7, -0.098	Zheng (unpublished data)
Maturity Probability: a, b	0.5, 120.0	0.287, 89.0	Estimates from Otto's unpublished data
Molt Probability: a, b	0.115, 134.113[a]	100% molt[b]	[a]Model estimates with M=0.18 using 1985-2004 data; [b]Zheng et al., 1995a
Recruit distribution			Model estimates with M=0.18 using 1985-2004 data
Pot selectivity	Retained, Discard	Discard	Model estimates with M=0.18 using 1985-2004 data
Weight length model: a, b	0.0003614, 3.16[a]	0.02286, 2.234[b]	[a]Belsiger, 1974; [b]Zheng et al., 1995a

Snow Crab

Parameter	Male	Female	Remarks
Size range (mm CW)	25-135	25-135	
Instantaneous M	0.23	0.23	Based on 20-year longevity with 1% survival at maximum age
Pot fishery handling mortality rate (h)	0.5	0.5	Model estimate of discard selectivity, Turnock and Rugolo, 2005
Trawl fishery bycatch death proportion	0.8	0.8	Model estimate of trawl selectivity, Turnock and Rugolo, 2005
Mean fishing period (yr)	0.096	0.096	Mean fishing time during 1995-2004
Lapsed time (yr)	0.792	0.792	Molt time (Apr 1) to start of fishery (Jan 15)
Growth increment: a, b	8.47, 0.19	12.29, 0.05	Growth Gamma distribution, β=0.75; Turnock and Rugolo, 2005
Maturity Probability: a, b	0.12, 88.	0.16, 49.0	Turnock, unpublished
Molt Probability: Immature Mature	100% molt 0%	100% molt 0%	Turnock and Rugolo, 2005
Recruit Distribution	mean 32.5 mm, β_r = 1.5	mean 32.5 mm, β_r = 1.5	Recruit proportion Gamma distribution, β_r from Turnock and Rugolo, 2005
Pot selectivity	Retained new-, old-shell. Discard new-, old-shell	Discard	Retained and discard selectivity curves estimated from Turnock, unpublished data
Weight length model: a, b	0.00023, 3.12948	0.00253, 2.56427	Somerton, 1981

Tanner Crab

Parameter	Male	Female	Remarks
Size range (mm CW)	60-180	50-120	
Instantaneous M	0.23	0.23	Based on 20-year longevity with 1% survival at maximum age
Pot fishery handling mortality rate (h)	0.5	0.5	Applicable to sub-legal
Instantaneous bycatch mortality in the trawl fishery	0.02	0.02	Applicable to all sizes, Siddeek, 2002
Mean fishing period (yr)	0.0425	0.0425	Mean fishing time during 1996- to closure year, Siddeek, 2002
Lapsed time (yr)	0.542	0.542	Molt time (Apr 1) to start of fishery (Oct 15)
Growth increment: a, b	15.75, 0.07	25.6, -0.1337	Zheng and Kruse, 1999
Maturity Probability: a, b	0.12, 115. 0	0.129, 78.24595	Estimates from Otto's unpublished data
Molt Probability: Immature Mature	100% molt 0%	100% molt 0%	Assumed similar to snow crab
Recruit Distribution	mean 72.5 mm, β_r = 1.023	mean 62.5 mm, β_r = 0.955	Recruit proportion Gamma distribution, β_r from Zheng et al., 1999
Pot Selectivity:	New-shell, Old-shell	Combined New-&old-shell	Size-specific selectivity values from Zheng and Kruse, 1999
Weight length model: a, b	0.00019, 3.00894	0.00182, 2.70462	Somerton, 1981

Pribilof Blue King Crab

Parameter	Male	Female	Remarks
Size range (mm CL)	75-170	85-145	
Instantaneous M	0.18	0.18	Based on 25-year longevity with 1% survival at maximum age
Pot fishery handling mortality rate (h)	0.2	0.2	Applicable to sub-legal. Siddeek, 2003b
Instantaneous bycatch mortality in the trawl fishery	0.02	0.02	Applicable to all sizes. Siddeek, 2003b
Mean fishing period (yr)	0.0308	0.0308	Mean fishing time during 1996 to closure year
Lapsed time (yr)	0.542	0.542	Molt time (Apr 1) to start of fishery (Oct 15)
Growth increment distribution normal with	14.1, 3.1[1]	5.2, 1.04[2]	[1]Otto and Cummiskey, 1990; [2]Somerton and MacIntosh, 1985
Maturity Probability: a, b	0%, if CL<120; 100%, if CL>120	0.283515,93.79601[3]	[3]Somerton and MacIntosh, 1983
Molt Probability: Immature Mature, a, b	0.000002,0.0914[4] 0.000002,0.0914[4]	100% Newshell 0%, Oldshell 100%	[4]Otto and Cummiskey, 1990
Recruit distribution: mean, std. dev	97.5, 7.5	90.0, 1.6667	Recruit proportion normal distribution
Pot selectivity	0.080993,114.0782	0.080993,114.0782	Siddeek, 2003b
Weight length model a, b	0.00047, 3.103	0.02065, 2.27	Otto, personal communication, AFSC, Kodiak

St. Mathew Blue King Crab

Parameter	Male	Female	Remarks
Size range (mm CL)	60-155	60-155	
Instantaneous M	0.18	0.18	Based on 25-year longevity with 1% survival at maximum age
Pot fishery handling mortality rate (h)	0.2	0.2	Applicable to sub-legal. Siddeek, 2002
Instantaneous bycatch mortality in the trawl fishery	0.02	0.02	Applicable to all sizes. Siddeek, 2002
Mean fishing period (yr)	0.026	0.026	Mean fishing time during 1996 to closure year
Lapsed time (yr)	0.542	0.542	Molt time (Apr 1) to start of fishery (Oct 15)
Growth increment distribution, normal with mean, standard	14.1, 3.1[1]	5.2, 1.04[2]	[1]Otto and Cummiskey, 1990; [2]Somerton and MacIntosh, 1985
Maturity Probability: a, b	0.299876,103.9999	0.266642,89.24575	Estimates from Otto's unpublished data
Molt Probability: Immature Mature a, b	0.097,133.8334 0.097,133.8334	100% Newshell 0%, Oldshell 100%	[3]Otto and Cummiskey, 1990
Recruit distribution: mean, std.dev	80.0, 6.6667	65.0, 5.0	Recruit proportion normal distribution
Pot selectivity	0.080993,114.0782	0.080993,114.0782	Siddeek, 2003b
Weight length model a, b	0.0004, 3.139	0.02065, 2.27	

Input Parameter Variation for Sensitivity Analysis using BB Red King Crab

- Minimum Legal Size: 125, 135 (current), 145
- M : male=0.18, female=0.18; male=0.18, female=0.22 (~25% higher)
- Fishing period: 4-7days (before rationalization); Oct 15-Jan 15
- ESB : female, total
- Handling mortality: 0%, 20%, 50%
- Fishery Start date: Oct 15, Dec 15
- Trawl bycatch mortality: 80%, 100%
- Female spawning biomass calculation: pre-molt, post-molt

Additional Parameters for Stochastic Simulations

- Overall recruitment variability: $\sigma = 0.7$
- Autocorrelation: $\rho = 0.5$
- (σ and ρ were also varied to 0.9 for sensitivity analysis)
- For F variability a σ value of 0.2 was considered in one set of simulations

Stochastic simulations considered 100-year fishery

Input values to SPR models

Estimated from Stock assessment models

Fixed parameters

Assumptions

Estimated in stock assessment models

- Fishery selectivity curves for retained and discarded crab by sex and shell condition
- Trawl bycatch selectivity and F
- Growth transition matrix by sex
- Molting probability by size – male king crabs

Fixed and assumed parameters

- Natural mortality – agreed upon by workgroup as 0.23 for snow and Tanner crabs and 0.18 for King crabs.
- Maturity curves by size for males and females – estimated from survey data
- Mean weight by size and sex – estimated from survey data

Assumed parameters

- Mating Ratio – number of females one male will mate with
- Mortality of discarded crab in directed pot fisheries (agreed upon as 50% for base runs)
- Groundfish trawl discard mortality (80%).
- Form (Beverton and Holt or Ricker) and steepness of the SR curves

- Tanner and snow crab males and females have terminal molt at maturity.
- Both males and females have only one year of their mature life when they should be new shell (if new shell was equivalent to shell age < 1 year)

Snow Crab
Calculation of effective female spawning biomass

$$efspbio = fspbio \frac{male\ oldshell\ sp\ numbers * mating\ ratio}{female\ sp\ numbers}$$

- Total effective sp biomass = efspbio + old shell male sp biomass

Estimation of effective male spawning biomass using mating ratio

- If an assumed mating ratio is used then emspbio is,

$$emspbio = mspbio * \frac{NMF}{NMM_O * MR}$$

- , if NMM0 > (NMF/MR).
- This is applied only if there are more males than are needed to fertilize the females, that is if NMM0 > (NMF/MR). The use of the mating ratio reduces the male spawning biomass at F=0, to only the biomass that is needed to fertilize the mature females (at F=0).

Spawning biomass per recruit model results for snow crab. Mating ratio = 1.7 (sex ratio at F=0). Total effective spawning biomass is female effective spawning biomass plus effective male spawning biomass (no mating ratio).

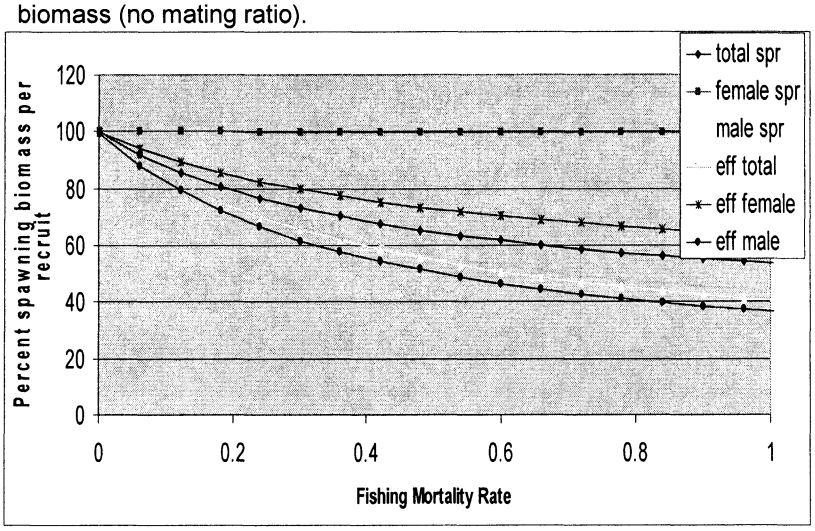
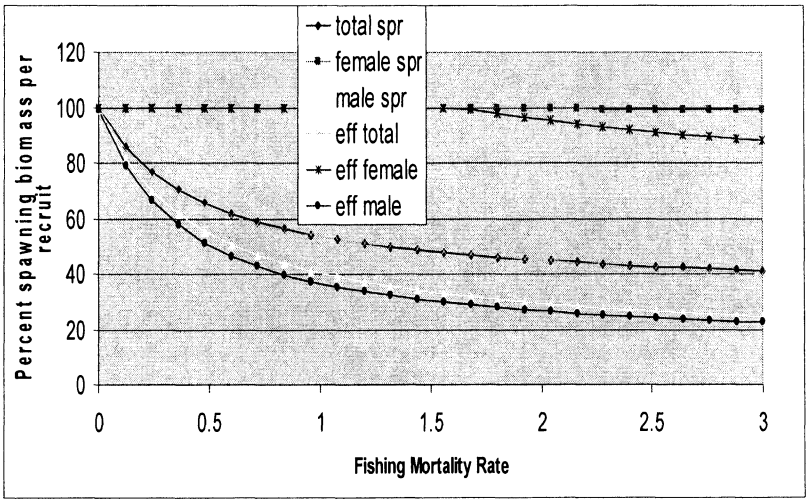
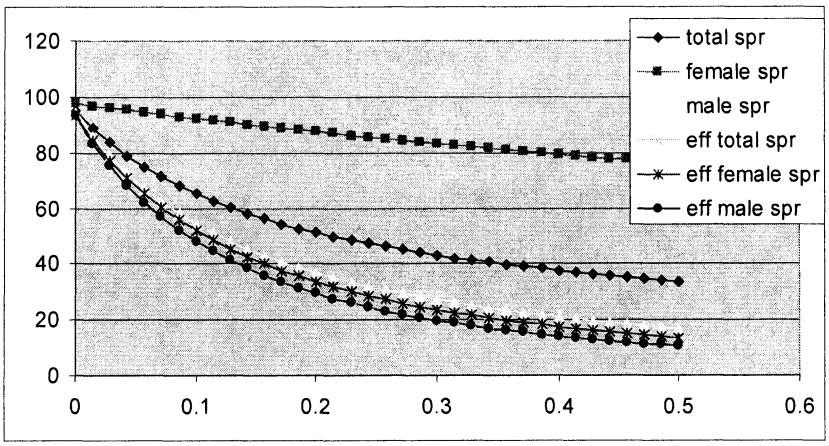
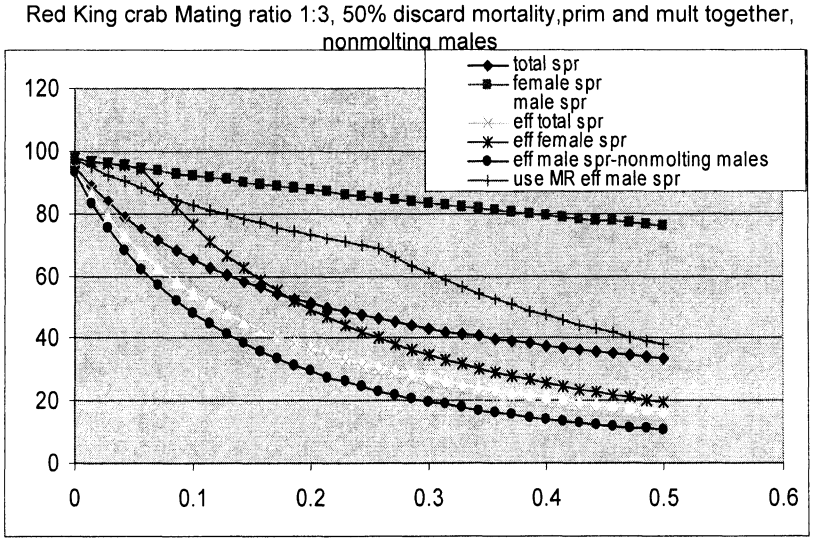


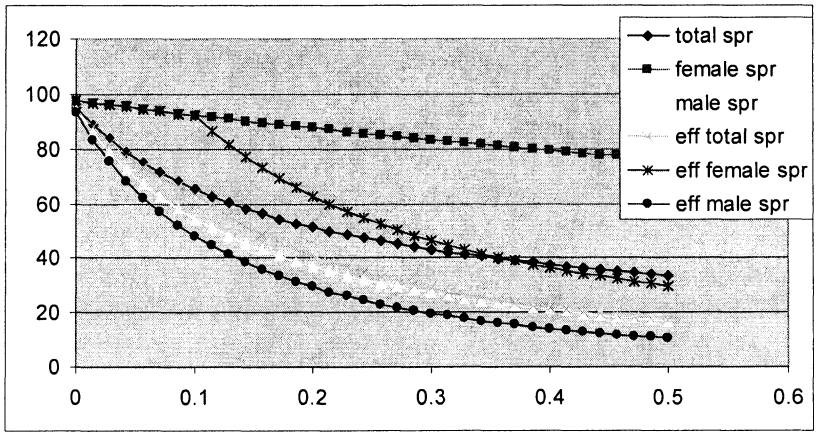
Figure 3. Mating ratio = 3.0. Primiparous and mulitparous separate. Total effective spawning biomass is female effective spawning biomass plus old shell male spawning biomass(no Mating ratio).



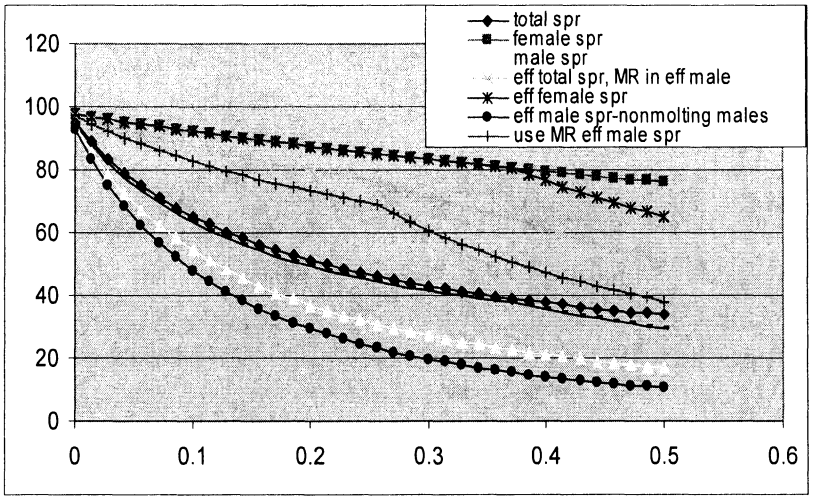
Red King Crab mating ratio 1:2(sex ratio at F=0), discard mortality 50%, all females together in effective spawning biomass calculation, nonmolting males



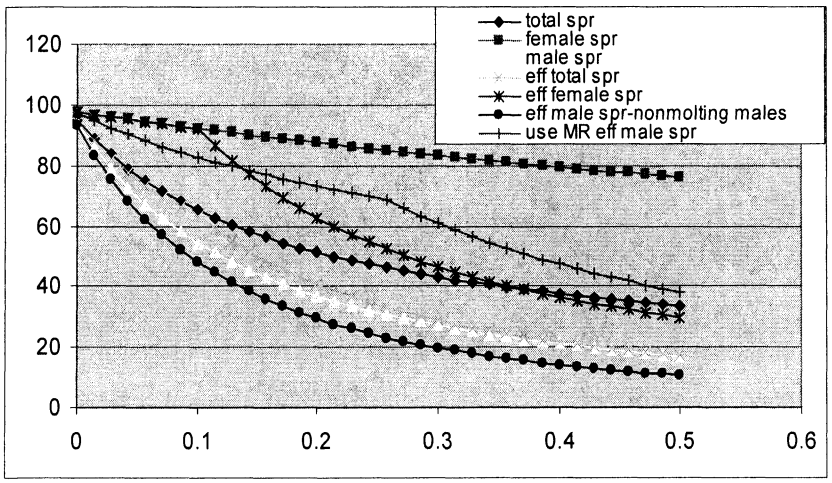

Red King crab Mating ratio 1:3, 50% discard mortality,prim and mult together, nonmolting males
total spr
female spr
male spr
eff total spr
eff female spr
eff male spr-nonmolting males
use MR eff male spr
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6

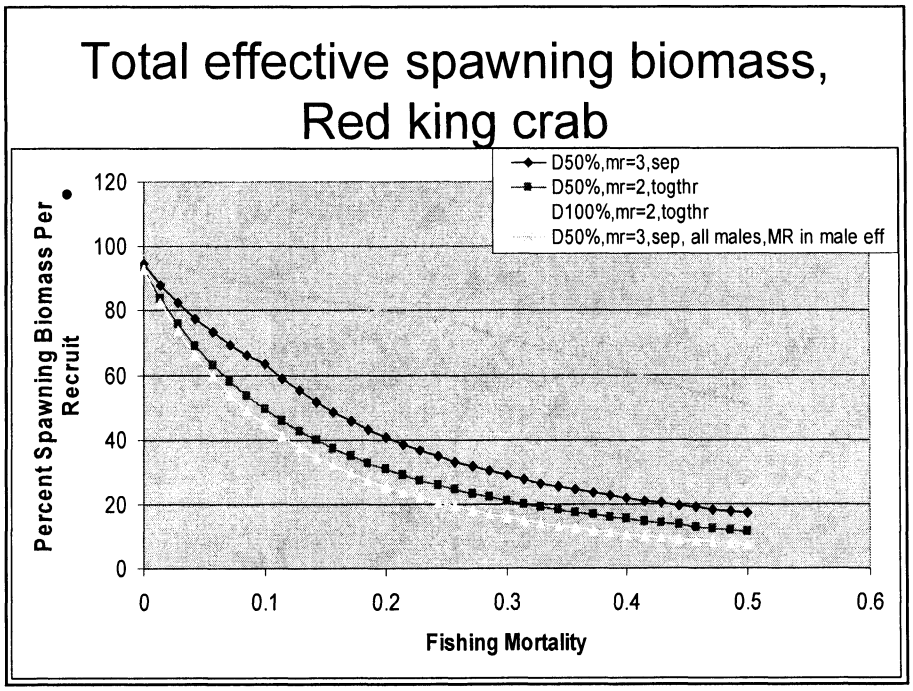

Red King Crab mating ratio 1:3, discard mortality 50%, MR applied separately to primiparous and multiparous in effective spawning biomass calculation, nonmolting males(each male can potentially mate with 6 females)
total spr
female spr
male spr
eff total spr
eff female spr
eff male spr
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6

Red King crab Mating ratio 1:3, 50% discard mortality,prim and mult separate, all males (2005 F for red king crab = 0.31, max target F=0.76)



Red King crab Mating ratio 1:3, 50% discard mortality,prim and mult separate, nonmolting males




Total effective spawning biomass, Red king crab
D50%,mr=3,sep
D50%,mr=2,togthr
D100%,mr=2,togthr
D50%,mr=3,sep, all males,MR in male eff
Percent Spawning Biomass Per Recruit
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Fishing Mortality

Simplifications in Population + Fishery Dynamic Modeling Approaches

NPFMC BSAI King & Tanner Crab Working Group

Model Inconsistencies:

- **Model Framework:** non-equilibrium spawning biomass-per-recruit.
- **Goal**: simulate essential life-history, reproductive + fishery dynamics suitable to amending technical components of FMP.
- It incompletely captures current understanding of key dynamical features.
- **Result:** fundamental inconsistencies between *natural ecosystem* + *electronic ecosystem* we've constructed.
- **Effect is Caution:**
  1. Degree of resource conservation inherent in model outcomes.
  2. Suitability of threshold definitions to MSFCMA.

Inconsistencies: Natural *v* Model Ecosystems

- **Action:** No resolution required by Workshop.
  Not Items lacking consensus agreement by the Work Group.

- **Require Understanding:**
  1. In considering suitability of model output for the Environmental Assessment.
  2. Regarding decisions on "unresolved issues" in terms of degree of *built-in* risk in model outcomes.

Inconsistencies: Natural *v* Model Ecosystems

a. Spatial Segregation of Males + Females

As seen in NMFS EBS trawl survey data:

1. Segregation of large mature males + females.
2. Segregation of ♂ + ♀ in different reproductive and shell class condition states (e.g., primiparous-multiparous, SC2-SC5).
   e.g., *C. opilio* in north + west.

- No large-scale annual spawning migrations to central area as teleosts.

Inconsistency:

- Model ecosystem makes no distinctions.
- Assumes all mature ♂ + ♀ are associated, so to say:

A mature ♂ or ♀ anywhere = a mature ♂ or ♀ everywhere.

Inconsistencies: Natural *v* Model Ecosystems

b. *Size Dependent Requirements in Mating*

- Model ecosystem assumes none.
- Treats crabs as teleosts that broadcast spawn.
- In mating pairs of crabs, ♂ > ♀ for successful copulation (+40%)
- Not of equal size or, particularly, where ♂ < ♀.

Inconsistency:

- In model accounting, accumulate mature ♂ + ♀ biomass, then
- Imposes successful mating solely from count of ♂ + ♀ & MR, so to say:

A mature ♂ of any size = mature ♂ of all sizes.

[e.g., 45 mm ♂ *C. opilio* can successfully mate a 90 mm ♀]

- Q: What value do large males play ecologically in population regulation and stability?

Inconsistencies: Natural *v* Model Ecosystems

c. *Differential Sex Ratios in Stock Components*

- Principal feature of these fisheries = differential exploitation of stocks spatially [logistics to port, ice cover].
- Results in differential sex ratio and size distributions over range.
  1. e.g., *C. opilio* catch primarily S. of 58.5°N causing unequal sex ratios
  2. Larval drift northward > shifting distribution of stock

Inconsistency:

- Model ecosystem assumes sex ratio U[0,1] across range in applying mating ratio to derive metrics of reproduction
- Assumes entire reproductive stock aggregated *en masse.*
  1. Would allow, e.g, complete removal of mature ♂ from large area w/o consequence since,
  2. Applies credits ♂ from other, even geographically isolated parts of range, to mate ♀.

Inconsistencies: Natural *v* Model Ecosystems

d. *Annual v Biennial Reproduction in C. opilio*

- In eastern Canada, exhibit both annual + biennial reproductive cycles fn: ambient water temperature.
- Recent research study found expressed in EBS snow crab as well.
- Persistent cold water (<1.5°C) tongue [NW to SE] St. Matthew.
- Occupies notable portion of geographic range of ♀ stock. Some years, extends though Bristol Bay.
- Biennial ♀ have ½ lifetime reproductive output as annual ♀.

Inconsistency:

- Model ecosystem makes no distinction; assumes all ♀ annual cycle
- That population fecundity is keyed to mature biomass w/o regard to distribution of annual-biennial cycles in ♀ stock
- Since no large-scale spawning aggregations, "cold water" males unavailable to mate annual females elsewhere.

Inconsistencies: Natural *v* Model Ecosystems

e. *Biomass as a Proxy for Fecundity*

- Status of reproductive stock gauged by index of mature biomass.
- More meaningful as expected population fecundity; ultimate expression of reproductive stock health.
- Suitable to teleost given relationship of gonad volume and mass

Inconsistency:

- Model ecosystem assumes:
  1. All ♀ brooding a full clutch: untrue (e.g., primipera vs multipera, plus variation due to demographics and senescence)
  2. All clutches fully fertilized
  3. All ♀ in annual spawning cycle (*C. opilio*)
- Use of such index of biomass in SRR engine to generate new recruits is flawed.

Inconsistencies: Natural *v* Model Ecosystems

f. *Bareness in Mature Females*

- Key assumption in management: stock protected against risks recruitment over fishing (ROF) since only ♂ are exploited.
- Also, since *Chionoecetes* exhibit polygany + polyandry, and ♀ use spermathecae, may tolerate Fs o.w. *risk prone* in teleosts.
- In male only fisheries, assess effects of ROF by changes in reproductive condition of mature ♀ stock.
- We find barren mature ♀ at rates inconsistent with no-ROF model
- In *C. opilio* in ♀ stock associated with fishery (S. of 58.5°N)

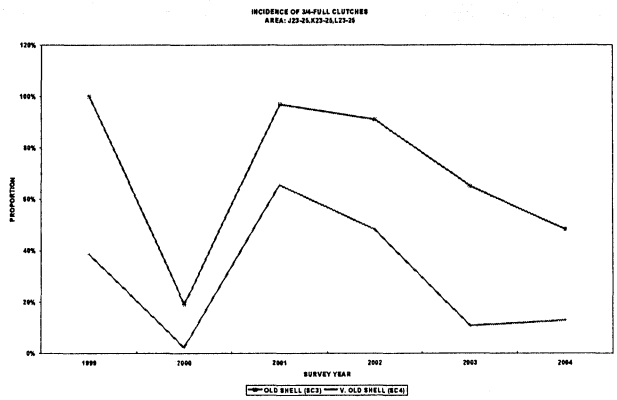
Inconsistency:

- Model ecosystem accounting of mature ♀ biomass as index of
  1. Overall reproductive stock health
  2. As input to SRR engine to generate new recruits

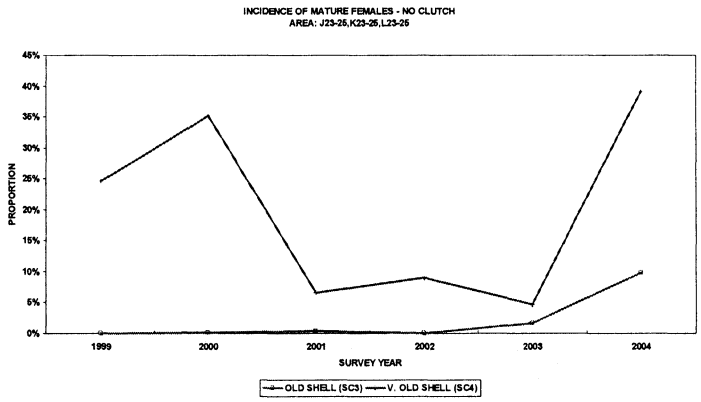
Assumes all ♀ of all shell condition classes are mated and brooding full clutches.

Percentage of C. opilio Females Brooding 75% to Full Clutches

(3600 nm² Area Central to Fishery)



Percentage of Barren C. opilio Females
(3600 nm^2 Area Central to Fishery)



Inconsistencies: Natural *v* Model Ecosystems

g. *Spawning Aggregation Behavior & Applied Mating Ratio*

- Observed mating feature: dense local aggregations of reproductive crabs w/ sex ratio skewed to females.
- Also, mature ♂ @ distances from aggregations precluding participation.
- While may be possible that MM ♂ mate w/ more than # ♀ in MR, the number of ♀ mated by each male, on average, is unknown.

Inconsistency:

- In applying MR (e.g., 1:3) in assessing reproductive success, modeling assumes that:
  1. Every ♂ <u>will</u> mate that # ♀ throughout the geographic range of the stock.
     Recall: *A mature ♂ or ♀ anywhere = a mature ♂ or ♀ everywhere.*
     A mature ♂ of any size = mature ♂ of all sizes.
  2. Primiparous mating earlier than multiparous. In applying MR, each ♂ allowed to mate 3 primiparous ♀, and 3 multiparous ♀ w/o regard to spatial distribution of these classes of reproductive females.
     This applied MR is twice that of input mating ratio.

Inconsistencies: Natural *v* Model Ecosystems

h. *Polygany v Polyandry & Mating Ratio*

- *Chionoecetes* exhibits both polygnic + polyandrous mating
- Females store sperm in discrete packets in spermathecae to mobilize for self-fertilization in absence of males.
- In applying MR (e.g., 1:3), each male <u>will</u> mate with 3 different ♀.
- However, if any, or all, of ♀ will mate with > 1 ♂ in season, the 2nd+ copulation on a ♀ comes at expense of the implied # of ♀s that 2nd ♂ can mate.
- Polyandry counteracts polygany arithmetically as modeled by the MR.

Inconsistency:

- Model ecosystem fails to account for ♂ that contribute to ♀ polyandry.
- Attempts to account for ♂ polygany, but the computation of effective spawning stock biomass from MR is incorrect if polyandry a principal feature depending on ♂:♀ ratios.

Inconsistencies: Natural *v* Model Ecosystems

h. *Polygany v Polyandry & Mating Ratio*

- Sainte-Marie and Sainte-Marie (1998):
- 47 inseminated multiparous & primiparous ♀ in Gulf of Saint Lawrence.
- For morphological comparisons, 3 arbitrary groups on spermathecal load:
  1. "almost empty to containing only small loads" (0.001 – 0.10 g)
  2. "moderate loading" (0.2 – 0.5 g)
  3. "heavy loading" (1.0 – 1.8 g)
- In our recent *opilio* research study, 1859 multiparous & primiparous, annual & biennial ♀ in 6 bimonthly sampling cruises: 28 cruise-area x shell condition class combinations):
  1. Overall mean spermathecal load = 0.051 g.
  2. Maximum # sperm packets = 6 (biennial, SC3 and SC4 multiparous ♀)
  3. Maximum spermathecal load in: SC3 (0.55 g) and SC4 (0.51 g) in JUN03 collection from cold water realm (i.e., biennial ♀).
- More thorough comparative analysis under development before drawing conclusions on health of reproductive stock or *re:* male limitation.

Inconsistencies: Natural *v* Model Ecosystems

i. *Complete Egg Fertilization*

- NMFS EBS trawl survey, score clutch size ranging from barren to full.
- If ♀ brooding new clutch of orange eggs, we assume are fertilized.
- In seasonal research study, from MAR03 collection, held ~ 60 SC3 + SC4 multiparous ♀ in laboratory through hatching and extrusion of new clutch in absence of males.
- Sacrificed in August (+5 mo). All ♀ brooding clutch of orange eggs, examined for fertilization and stage of embryonic development.
- Approximately 20-25% of clutches bearing unfertilized embryos.
- Thus, when sampled on NMFS survey in May/June, females may be observed with clutches of unfertilized eggs; cast off later in year.
- Incidence not included in percent bareness figures.

Inconsistency:

- Model ecosystem assumes all clutches are fertilized.
- Female biomass as index of reproductive condition, or in SRR engine to generate new recruits.

Conclusion: Natural *v* Model Ecosystems Inconsistencies

		Direction of Contribution to Conservation	
Inconsistency:		Risk Prone	Risk Aversion
a.	Spatial Segregation:	✓	
b.	Size Dependencies:	✓	
c.	Differential Sex Ratios:	✓	
d.	Annual v Biennial:	✓	
e.	Biomass as Proxy:	✓	
f.	Bareness in Females:	✓	
g.	Spawning Aggregation:	✓	
h.	Polygany v Polyandry:	✓	
i.	Complete Egg Fertilization:	✓	

- Individual or collective effect on overfishing definitions: Unknown.

Model Simplifications/assumptions

1. Spatial dynamics
   - Snow and red king crab distributions shifted to north after 1976/77.
   - Snow crab migrated to southwest, deep waters when they grow older; males go to deeper waters than females:

     Good: few females and juvenile males on fishing ground.

     Bad: not sure these older males move back to mate with females or not.
   - Males and females may spatially distribute unevenly during mating time.

Only spatial consideration in the model is bipartite mating, so this model simplification could be biased toward higher harvest rates

Model Simplifications/assumptions

2. No male/female size difference consideration for snow crab:
   - All other crab stocks modeled by ADF&G have cut-off size for mature males.
   - Median mature males are 38 mm larger than median mature females for snow crab, so the issue may not matter much.

This model simplification could slightly be biased toward higher harvest rates

Model Simplifications/assumptions

3. No stored sperm for Tanner and snow females (-).
4. No biennial spawning of female snow crab (in terms of need of males for mating each year) (-).
5. Extremely low natural mortality (-).
6. Assuming low productivity (higher Tau values) of S-R curves (-).
7. No consideration of mating competition for males (or only strong males can mate) (-).
8. High handling mortality rate for snow crab (-).
9. Much lower mating ratios than observed in labs (-).

Above model simplifications/assumptions could be biased toward lower (conservative) harvest rates

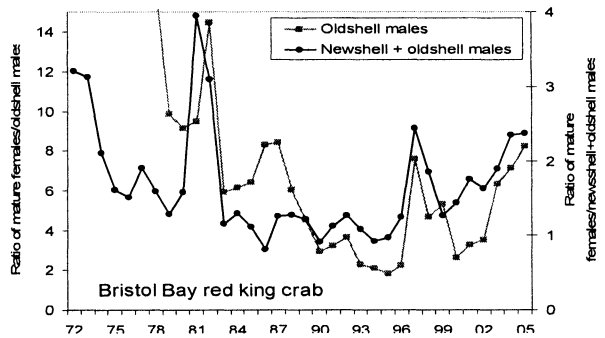
What do egg clutch data mean?

For red king crab:

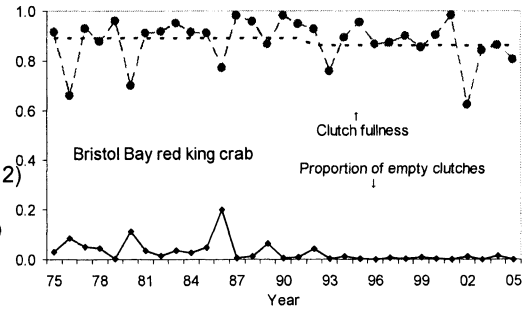
- Females need mating for extruding eggs (McMullen 1969, per. comm. with Drs. Brad Stevens and Tom Shirley).
- Some females may extrude unfertilized egg clutches without mating if there are mature males near them, but when males:females ratio is very high, up to 72% of mature females without egg clutches (McMullen and Yoshihara 1969).

So, some egg clutches may not be 100% fertilized, and % of barren females may be an indicator of lack of males for mating.

Bristol Bay
Red king crab



Mature harvest rates
At survey time:
75-81: 0.24
82-84: 0.05
85-93: 0.16 (mostly 0.2)
94-95: 0.00
96-04: 0.13 (0.1-0.15)



What do egg clutch data mean?

For Bristol Bay red king crab:

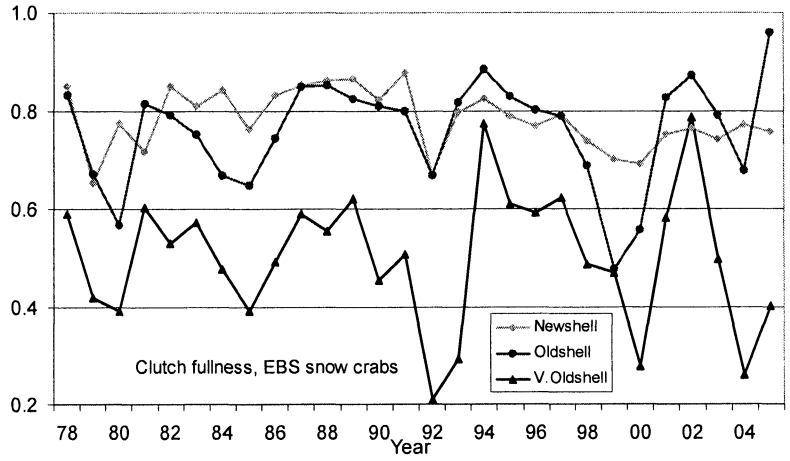
- About 0-20% of newshell mature females were barren before 1994, and few barren females occurred under the current harvest rates.
- The current mature male harvest rates for retained crab are 10%-15% at the survey time, or 11%-16% at the beginning of the fishing season. With a 20% bycatch mortality rate, total mature male harvest rates range from 13% to 19% at the beginning of the fishing season.
- Legal male harvest rates are about 50% to 100% higher than mature male harvest rate, or about 38% or lower based on the current mature harvest rates.

What do egg clutch data mean?

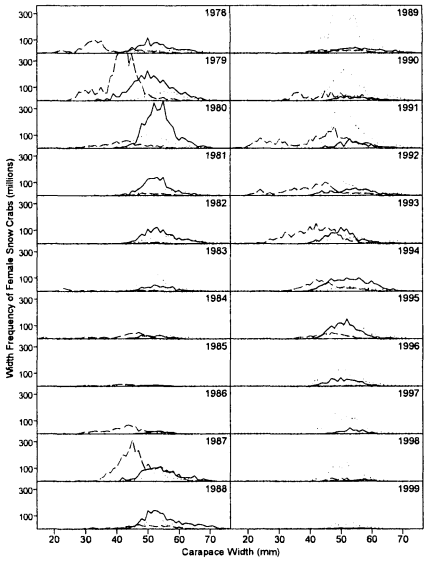
For EBS snow crab:

- All females can extrude egg clutches and hold them for at least 5 months in the absence of males, and about 20% of the females have full clutches of unfertilized eggs (Rugolo's lab study).
- Are barren females due to lack of males or their own problems? Logically, it may be their own problems.
- Senescence may be the cause (Ernst, Orensanz & Armstrong 2005)
- Snow crab egg clutch data may not be very useful to answer the question: lack or not lack of males for mating.

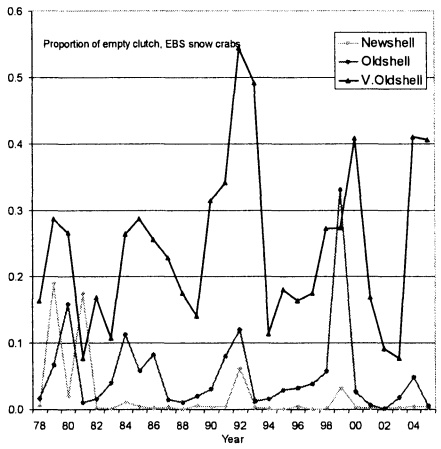
EBS snow crab:
Reduced fecundity occurred primarily to very old mature females



EBS snow crab: post-terminal molt vs barren females

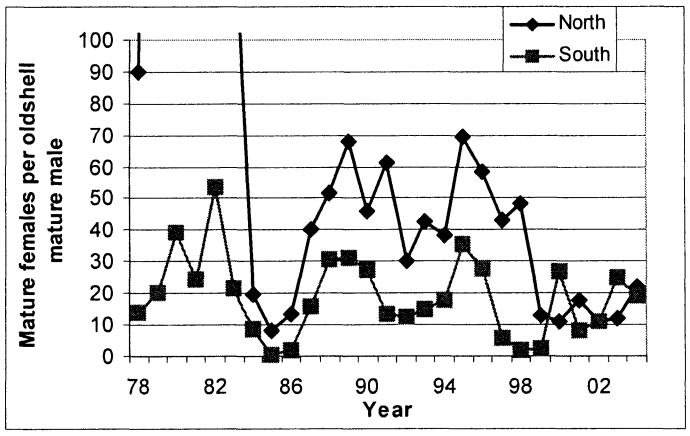


Periods with high proportions of barren females correspond to the periods with very old mature females



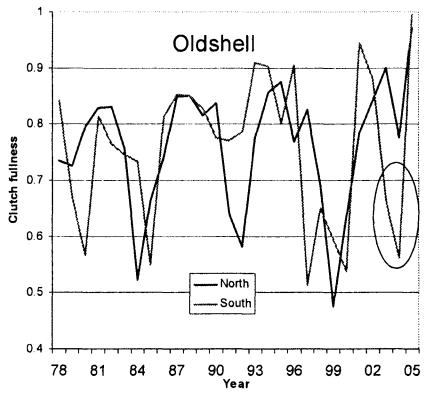
One hypothesis is that because fishing occurred primarily in the south (south of 58.5 degree N), barren females in the south is due to lack of males caused by fishing. This hypothesis contradicts with the available data:

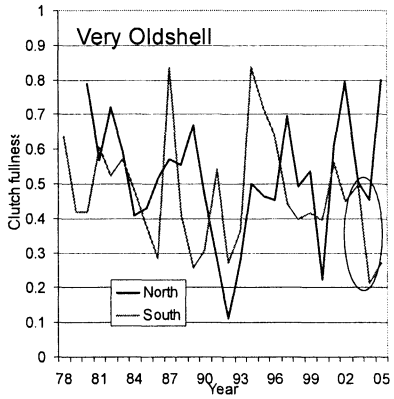
1. There were a lot more of old shell mature males to mate with females in the south than in the north (58.5-61.2 degree N).



One hypothesis is that because fishing occurred primarily in the south (south of 58.5 degree N), barren females in the south is due to lack of males caused by fishing. This hypothesis contradicts with the available data:

2. There are no consistent difference of egg clutch fullness between north and south. The hypothesis was generated by using two years (2003-04) of data.

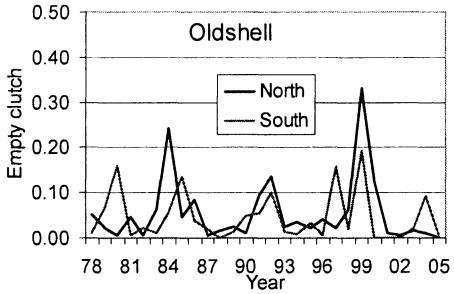


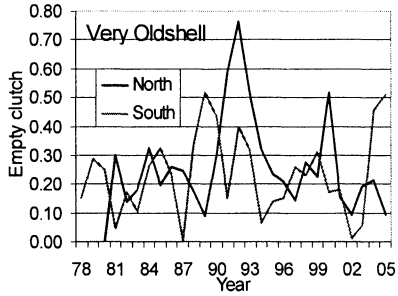


There were very small sample sizes for newshell females in the south for some years, so the data are not shown here.

One hypothesis is that because fishing occurred primarily in the south (south of 58.5 degree N), barren females in the south is due to lack of males caused by fishing. This hypothesis contradicts with the available data:

3. Highest proportions of barren females occurred in the north, not south.

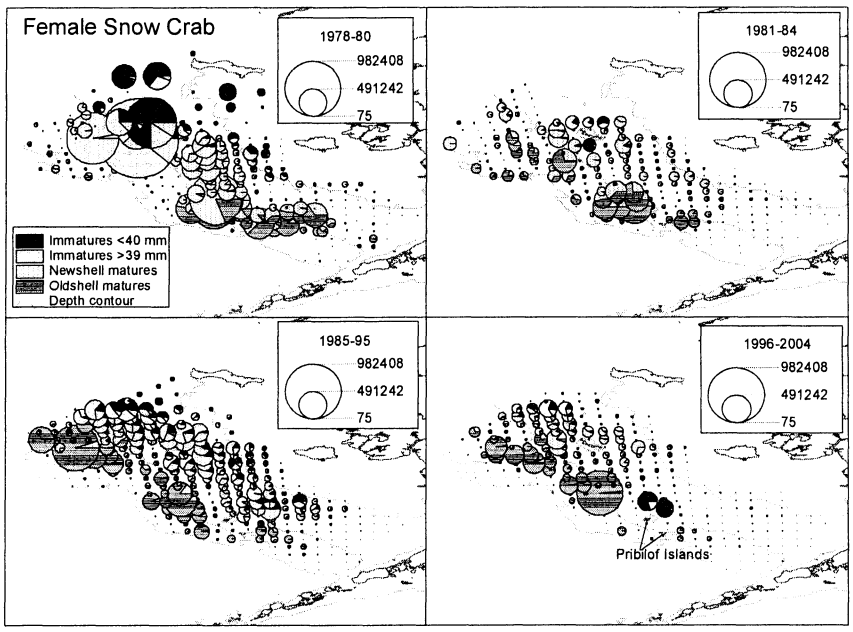




There were very small sample sizes for newshell females in the south for some years, so the data are not shown here.

Summary of snow crab egg clutch

- Egg clutch data may be difficult to interpret
- Reduced fecundity/barren females are highly correlated to senescence
- There are no supports for the hypothesis that reduced fecundity/barren females in the south were caused by lack of males due to fishing
- Preliminary results of egg fertilization study: 52 out of 54 mature females sampled during 2005 summer survey carried fertilized eggs, and remaining two cannot be decided (Kirsten Gravel)
- ADF&G will continue to study egg fertilization rates, hopefully working with U.of AK and NMFS

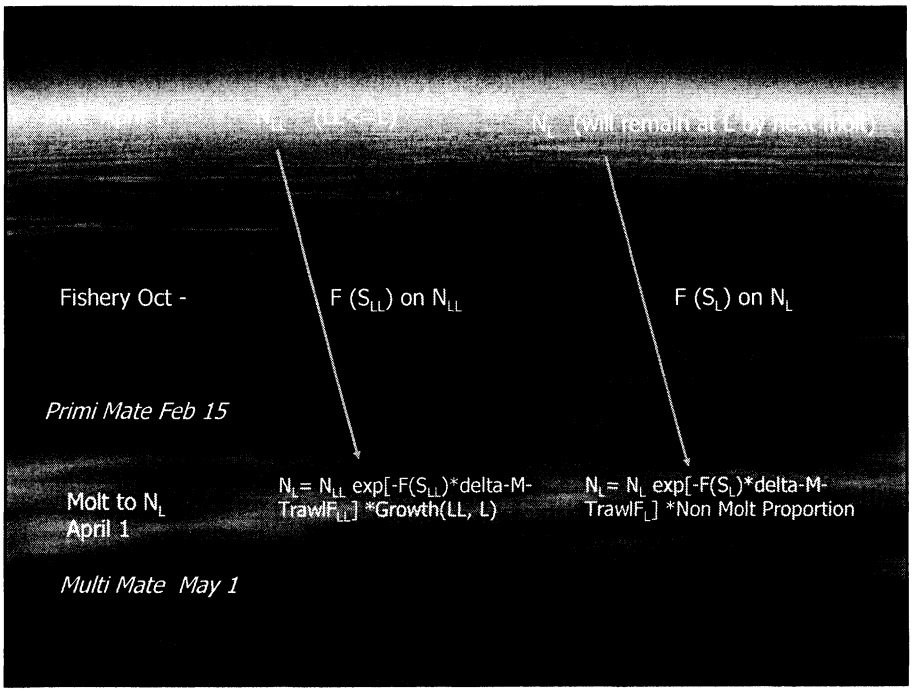


Model Structures

"All models are wrong; some are useful " --- George Box

Cohort progress for modeling

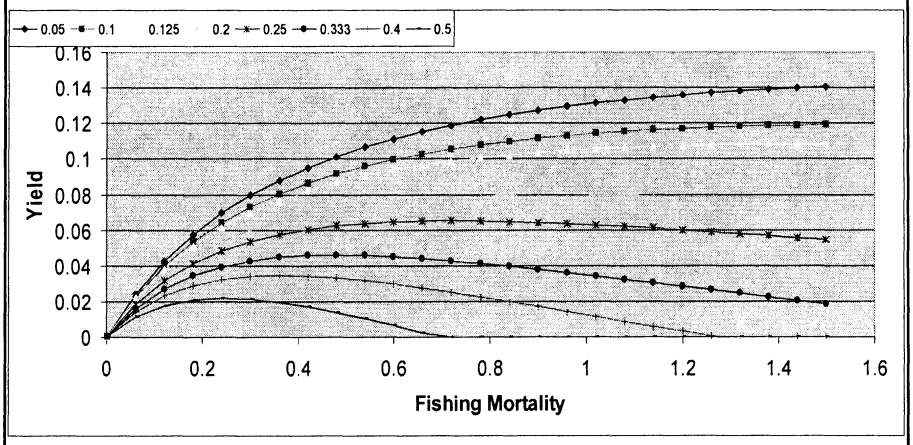
- Red king crab cohort progress – EXCEL
- Snow crab cohort progress – EXCEL
- Tanner crab – similar to snow crab
- Blue king crab – similar to red king crab with an important exception - biennial spawning (so mated females molt once in two years)


Molt April 1
N_{LL} (LL<=L)
N_L (will remain at L by next molt)
Fishery Oct -
F (S_{LL}) on N_{LL}
F (S_L) on N_L
Primi Mate Feb 15
Molt to N_L
April 1
N_L= N_{LL} exp[-F(S_{LL})*delta-M-$TrawlF_{LL}$] *Growth(LL, L)
N_L= N_L exp[-F(S_L)*delta-M-$TrawlF_L$] *Non Molt Proportion
Multi Mate May 1

Clark's Method for Estimating F% proxy for Fmsy

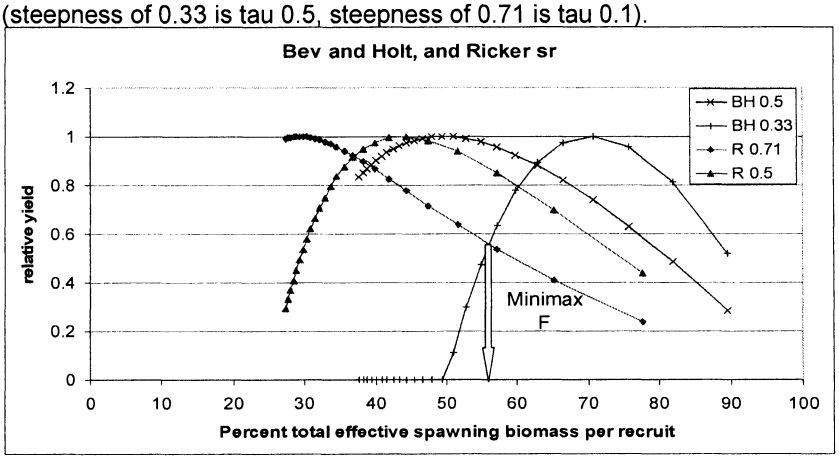
- Clark's maximin method of estimating F% is determined by the intersection of the least productive and most productive sr curves used in the analysis
- Clark's method of selecting the range of sr curves was somewhat subjective – He reasoned that the range of F that fish stocks can sustain before collapse was F=M up to F=5M
- However, Clark's generalized groundfish stock used fishery selectivity equal to maturity
- For crab stocks fishery selectivity is at larger sizes than maturity and the majority of the catch is male crab

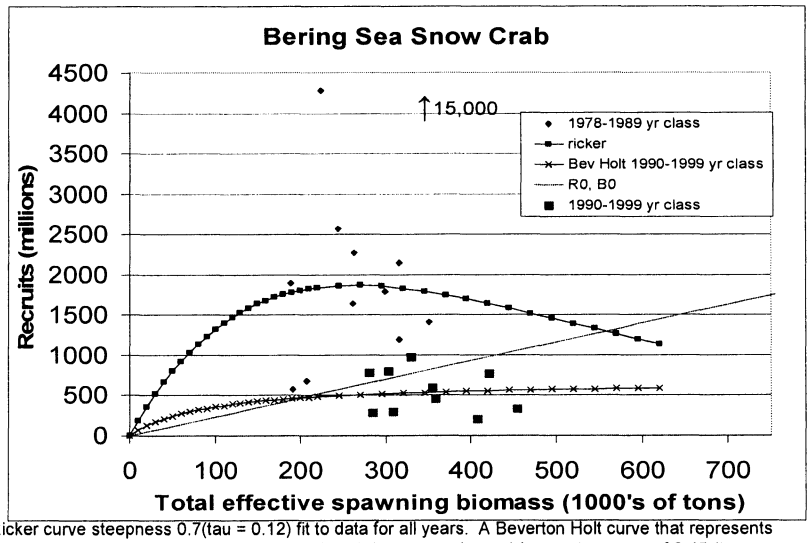
Snow crab yield, Beverton Holt SR



- F target pre-2000 was F=1.1. Tau 0.33=steepness 0.43, Tau 0.5 = steepness 0.33

Figure 1. Example of Clark minimax method to determine F% proxy for Fmsy. Numbers are for steepness parameter of the SR curve (steepness of 0.33 is tau 0.5, steepness of 0.71 is tau 0.1).





Ricker curve steepness 0.7(tau = 0.12) fit to data for all years. A Beverton Holt curve that represents the most current period of low recruitment (1990-1999 year classes) has a steepness of 0.45 (tau = 0.36). The steepness for the Beverton Holt curve was estimated from the slope of the line connecting (0,0) with the point for the lowest spawning biomass with the highest recruitment (280,784).

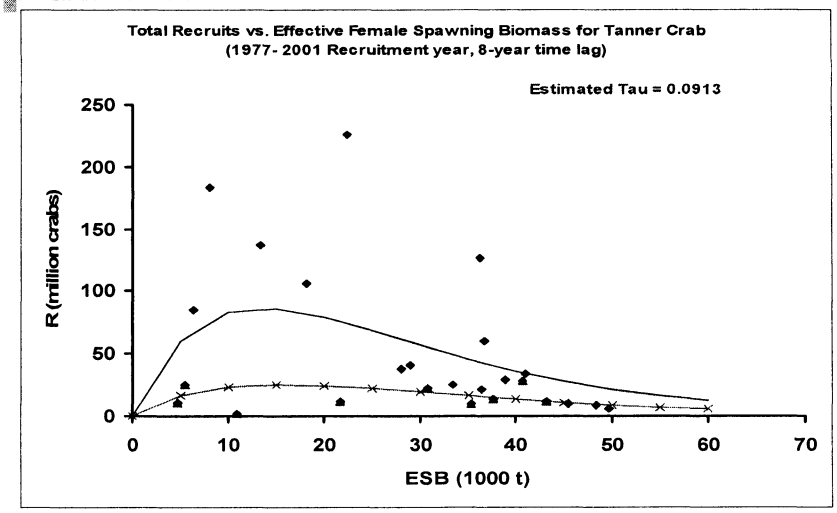
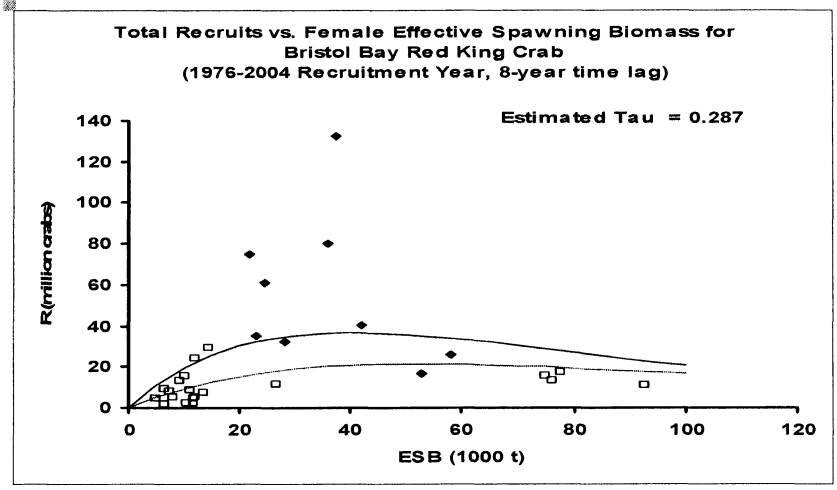
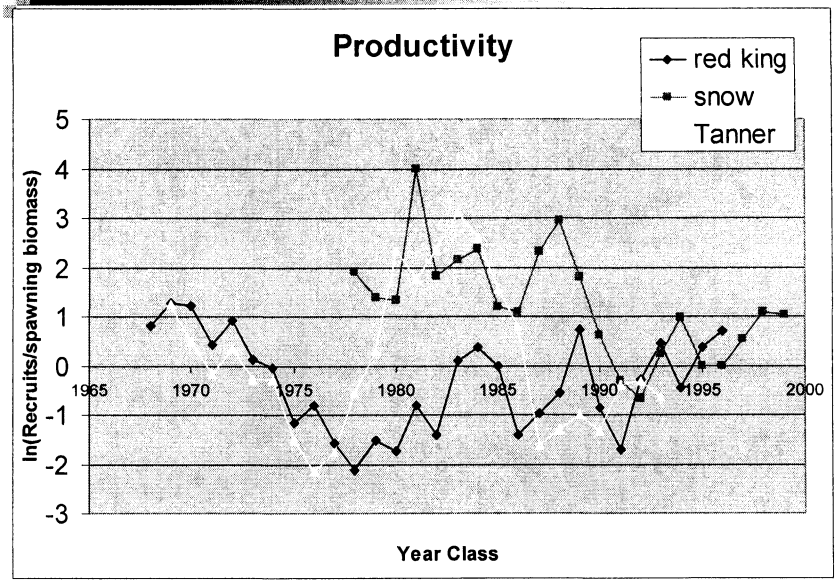


Figure 11. Spawner recruit estimates from the Tanner crab stock assessment model. Ricker curves are fit to all years (steepness 0.73, tau 0.09) and fit to the most recent low recruitments from the 1985-1993 year classes (shown in red) (steepness 0.52, tau 0.24). A ricker curve with steepness = 0.65 (tau = 0.13) was used to develop the current harvest strategy for Tanner crab.



Red king crab recruitment and female effective spawning biomass. A Ricker curve was fit to all years estimated steepness at 0.47 (tau = 0.287). A Ricker curve fit to year classes after 1976 regime shift onward estimated steepness at 0.36 (tau=0.45).
Clear squares – 1982-1996 yr class
solid – 1968- 1981 yr class



Meta- analysis

- Specify prior distribution for steepness of the spawner recruit curve that does not include SR data used in the analysis
- Assemble spawner recruit data for appropriate crab stocks – Red king, Tanner, Snow crab
- Estimate posterior distribution of steepness using sr data and prior
- Use estimated steepness to determine F% proxy for Fmsy in spawning biomass per recruit model

Management Strategy Evaluation

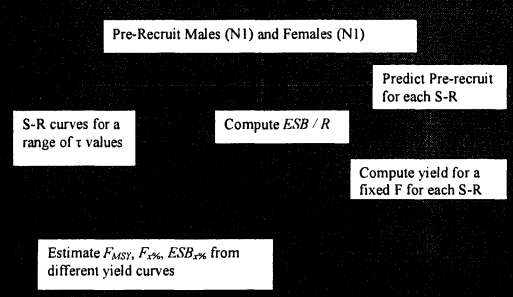
Future work

Red king crab pre-crash F ranged from about 0.45 to 0.88 (discard included in M). Recent F(since 1996) ranged from 0.15 to 0.35. 2005 F was 0.31

Approaches to estimate proxy BRP values

- Estimate equilibrium yield by a deterministic method, identify $F_{x\%}$ and related BRPs, perform sensitivity analysis of various input parameter values
- Estimate average yields from 100-year fishery by projection modeling with stochastic S-R, identify $F_{x\%}$ and related BRPs
- Perform various diagnostic tests on selected $F_{x\%}$ by projection modeling with stochastic S-R: (a) rebuilding possibility of a severely depleted stock under the chosen $F_{x\%}$ with a less productive S-R curve (B-H with Tau=0.3), (b) distribution of relative mean ESB for a range of $F_{x\%}$ values, (c) CV of yield for a range of $F_{x\%}$ values, and (d) extinction probability of the stock for a range of $F_{x\%}$ values

Equilibrium Approach – Deterministic Simulation



Stochastic Approach – Projection Modeling

Full age structure of males ($N1_n$) and females ($N2_n$) in year n

Predict pre-recruit for each S-R, add a random error

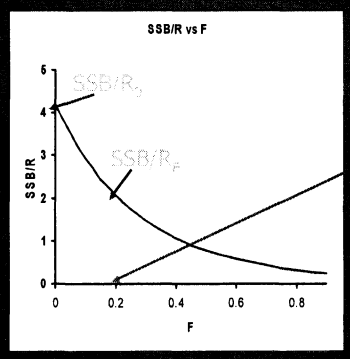
Compute ESB_n / R

S-R curves for a range of τ values

Compute yield for a fixed F for each year; estimate mean yield from 100-year fishery for the fixed F and each S-R

Estimate F_{MSY}, $F_{20\%}$, $ESB_{20\%}$ from different mean-yield curves

What is F%?



e.g. $F_{20\%}$ is an F which produces a SSB/R_F equivalent to 20% SSB/R_0

Identification of $F_{X\%}$

- Red king crab example - EXCEL

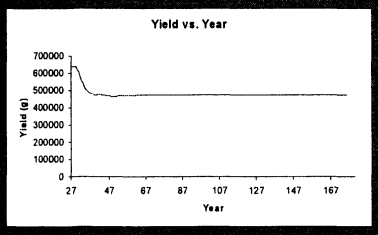
Year class development for stochastic simulation – stock projection modeling

Year	1	2	3	4	5	6	7	8	9	10	11	12
Age 1	R1,1	R2,1	R3,1	R4,1	R5,1	R6,1	R7,1	R8,1	R9,1			
2		R1,2	R2,2	R3,2	R4,2	R5,2	R6,2	R7,2	R8,2			
3			R1,3	R2,3	R3,3	R4,3	R5,3	R6,3	R7,3			
4				R1,4	R2,4	R3,4	R4,4	R5,4	R6,4			
5					R1,5	R2,5	R3,5	R4,5	R5,5			
6						R1,6	R2,6	R3,6	R4,6			

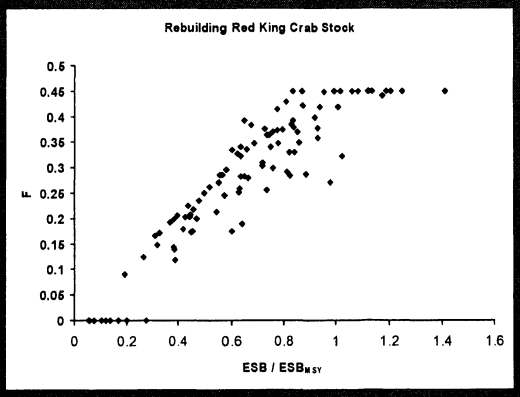
Testing the Stochastic Program

- Stochastic program produced results coinciding with the deterministic estimates.

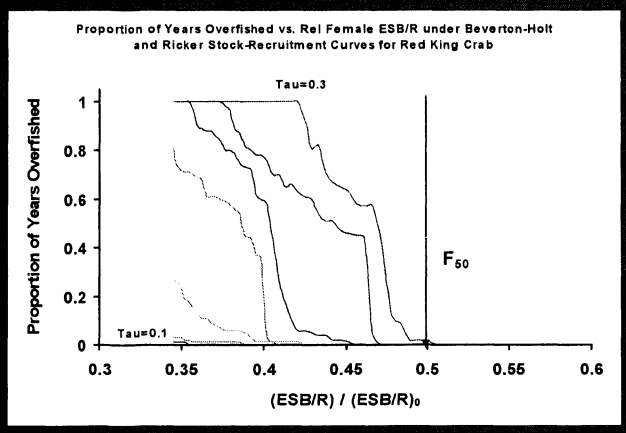
e.g., R and Y predictions



Rebuilding red king crab stock from a 20%ESB_{MSY} to MSY level under proposed harvest control rule with F_{50}. The data points correspond to 100-year fishery simulation under stochastic Beverton-Holt S-R model with female ESB, overall recruitment variability, σ =0.7, serial correlation, ρ= .5, M = 0.18, h = 0.2, mating ratio=1:3, and τ =0.3



Proportion of years *ESB* has depleted to < 25%ESB_{MSY} vs. relative *ESB/R* from 100-year fishery for the red king crab stock. The estimates are made under stochastic Beverton and Holt and Ricker stock-recruitment models with female *ESB*, M = 0.18, h = 0.2, mating ratio = 1:3, overall recruitment variability, σ = 0.7, serial correlation, ρ = 0.5, and τ = 0.1-0.3. The proportion of years *ESB* has depleted below 25%ESB_{MSY} is < 0.02 at F_{50} for all τ values up to 0.3.



CPT Overfishing Working Group

Crab Plan Team Presentation,
September 2005

Introduction

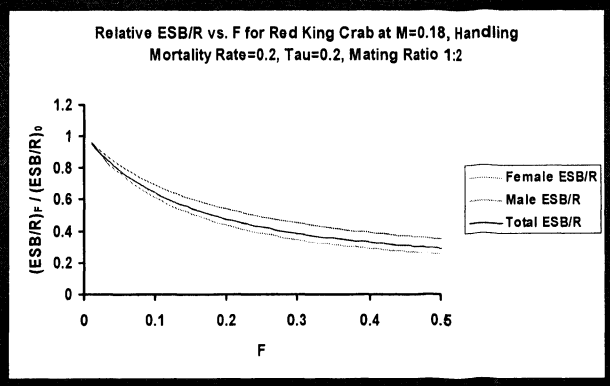
- Over the time period the CPT overfishing working group has progressed in defining the important input parameters and modeling approaches to determine limit and target reference points. This is a part of the major undertakings to revise the crab FMP.
- The models developed to address the issues should not be categorized as EXCEL, FORTRAN, and ADMB models. Those are just the vehicles to process the mathematical computations or parameter estimation in the simulation models. So, there are two types of simulation models followed by the working group, which are not redundant, but complementary.
- Recently the working group has confronted with different points of view on some of the input parameters and computation procedures. The subsequent slides list the issues and we seek your guidance to resolve them.

Note: In the following slides the text in yellow are definitions of the issues or justifications for positions taken by members.

Crab Modeling Issues

A. Measure of spawning biomass: *This is the spawning biomass that will be considered for the stock-recruitment relationship*

- Total male and female effective mature biomass at time of mating (2).
  Pros: more conservative; cons: primiparous and multiparous females mate at different times, a snow and Tanner crab male weighs much heavier than a female, and males are used twice for effective spawning biomass calculation.
- Fully mated female mature biomass at the hatching time (1). *Support: larvae come from these females, a better measure of larvae abundance. Mature males have been used to derive mated female mature biomass.*
- Do both to explore the results and choose plausible one (1). *The reason for the positions taken by the two single votes is that the sensitivity of female effective spawning biomass per recruit (ESB/R) against fishing mortality behaves differently for different species. For example, in the September 05 CPT meeting, one working group member showed that the behavior of female ESB/R for snow crab was insensitive to low F values. On the other hand, it is sensitive or behave similarly to male or total ESB/R for red king crab (Figure in the next slide).*



Crab Modeling Issues

B. Formulation of effective male spawning biomass: *This is required if total effective spawning biomass calculation is needed.*

- Use total male mature biomass as effective male spawning biomass (2)
- Use the mating ratio on males to estimate the effective male spawning biomass (2). *The reason for this position is that if some mature males are not considered for effective female spawning biomass calculation, then they should not be considered for the effective mature male biomass calculation.*

Crab Modeling Issues

C. Mating ratio in effective spawning biomass calculation: *Male to female mating ratio is used to determine the effective female spawners for spawning biomass calculation.*

- Use 1:3 (1). *Support for this position comes from literature (many with a mating ratio of 1:4, 1:7 or 1:9) and egg clutch fullness data and survey sex ratios.*
- Use the sex ratio at F=0 as the mating ratio (2). *This position assumes every male is needed for mating even without any fishing. It is a conservative assumption.*
- Run different mating ratios and choose the plausible one based on results and other factors (1). *The basis for this is that this parameter is uncertain, and we need to consider their impacts to the results.*

Crab Modeling Issues

D. Application of mating ratio in the effective spawning biomass calculation: *How should we use the mating ratio to calculate the effective spawning biomass?*

- Put all mature female crabs (primiparous and multiparous) together for effective female spawning biomass calculation, despite their different mating times (2). *This position assumes a male can mate with either primiparous or multiparous, but not both in a mating season.*
- For snow crab, put all mature female crabs together for effective spawning biomass calculation. But for red king crab, keep separate the primiparous and multiparous female abundance for effective female spawning biomass calculation (2). *The reason for this position is that the primiparous and multiparous female and the male mating abundances are calculated at quite different mating time periods in an year. A male red king crab is assumed to be able to mate with both primiparous and multiparous females, but a snow crab male cannot due to larger space separation.*

Crab Modeling Issues

E. Time course of events: *Time sequence of molting and mating in an year.*

primiparous mating Feb 15, crab molting April 1, multiparous mating May 1 - No conflict. *No conflicts on this issue.*

Crab Modeling Issues

F. Pre- or post-molt size in female spawning biomass calculation: *Whether pre-molt or post-molt carapace size of females should be used to calculate spawning biomass of females.*

- Use pre-molt size (2). *This assumption can reduce effective female spawning biomass, thus maybe more conservative, but no data or literature to support this.*
- For all king crabs use post-molt size, for snow and Tanner crabs ok to use lower weight, but not more than 10-30% reduction from post-molt size (1). *This position is derived from literature and published data.*
- No decision (1).

For red king crab estimation of spawning biomass by the two methods do not appreciably change the outcome, but it only complicates the estimation procedure.

Crab Modeling Issues

G. Use non-molting males for red king crab effective male spawning numbers and biomass calculation as considered for snow crab: *Do not consider those male red king crabs, which are destined to molt in the next molting season, in the spawning abundance calculation.*

- Use non-molting males (2)
- For red king crab, consider all mature males for primiparous mating, but for multiparous mating, consider only old-shell males (2). *The mature males considered for mating with primiparous females are at least 10.5 months older from last molting and mature males considered for mating with multiparous females are at least 13 months from last molting.*

Crab Modeling Issues

H. Survey selectivity for red king crab: Request to one member

(a) Estimate the red king crab parameters with the Weinberg selectivity curve.

(b) Estimate survey selectivity separately for a handling mortality 20% and 50% with an M of 0.18 and keeping the same molting probability model.

(c) Fit the model for the time series 1985-2005. *Not an issue, but a request.*

Crab Modeling Issues

I. Shell condition of males in effective spawning biomass calculation: *How old is old to qualify for mating?*

- Old-shell males two years from molting can mate with multiparous females, and old-shell males one year from molting can mate with primiparous females (2). *Because of different mating and molting timings, this means a male needs to wait for at least 22.5 months from last molt to mate with primiparous females and 25 months from last molt to mate with multiparous females.*
- Old-shell males one year from molting can mate during next mating season with primiparous and multiparous females (2). *The reason for this position is that there are conflicting views on this issue. Some crab biologists consider 6-15 months are sufficient to harden the shells and ready for mating. Oldshell males considered for mating are at least 13 months older from last molting to oldshell.*

Crab Modeling Issues

J. S-R relationship:

Use Beverton-Holt model unless data strongly suggest Ricker (2). *Use a conservative stock-recruitment model for reference points estimation.*

- Look at both Beverton-Holt and Ricker (2). *The reason for this is that simulation studies have shown that reference point harvest rates from Beverton-Holt are lower than that from Ricker model. With a number of precautionary restrictions already taken on various input parameter values the harvest rate may become extremely low to have any meaningful application. So, it is better to explore the outcomes of different stock-recruitment relationships to decide on plausible choices of models and values.*

Crab Modeling Issues

K. Steepness parameter range for S-R curves: *The parameter related to the steepness near the origin of the stock-recruitment curve.*

- Decide on a particular S-R (form and steepness) and use that to get F%. Look at S-R data and make judgment about steepness (1).
- Clark's method is one tool to look at approximate value, need to consider current S-R data and steepness low as 0.4 to 0.45. If have confidence on a S-R fit, it can be used to derive F%. Meta analysis can also be used (1).
- Clark and Bayesian approaches are ok, Tau range of 0.1-0.3 can be used. If have confidence, use a particular S-R fit to derive reference points (1).
- If have confidence on a particular S-R curve, use that to get reference points. A tau range of 0.1-0.3 and a range of 0.3-0.5 can be used as scenarios for high and low productive periods for reference estimation (1).

  Tau range is a major issue. Tau range of 0.1-0.3 is for groundfish with maximum ages of 20-30 years and is supported by the current three crab stocks with S-R data available. A tau range of 0.4-0.5 is more for a rock fish stock with maximum ages of over 40 years, but it is more conservative.

Crab Modeling Issues

L. Change in productivity periods: *Low and high productivity periods due to different regime of environment.*

- Use most current information on S-R curve if confident in S-R data for reference points (1).
- Difficult to come up with switching productivity periods – but I am open to switching (1).
- Agree with the above two opinions (1).
- If can get range of Tau values for low and high productivity periods, use that for reference points estimation for different productivity periods. There is no clear cut answer (1). *No major conflicts, but the group is still trying to figure out how to tackle this issue.*

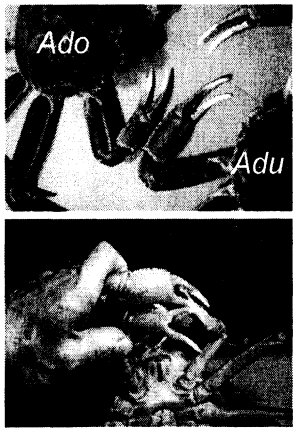
Crab Modeling Issues

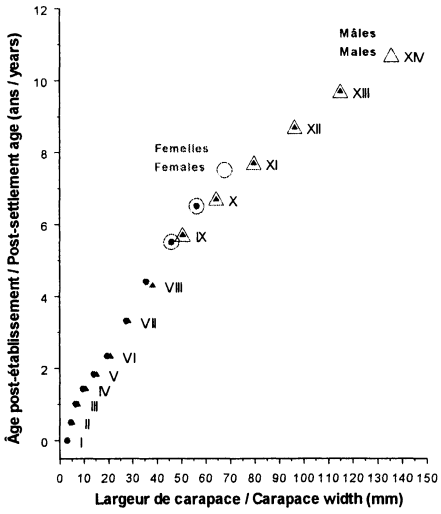
M. Depensation S-R model:

- Depensatory S-R model can be used to select the inflection point as an approximate threshold point and increment/decrement near that point to get rebuilding within 10 years under F=0 (1).
- Use depensation models in simulations- needs to see the effect, may be that reference points are the same as non-depensatory curves, but that need different slope or biomass at F=0 in control rule (1).
- Agree with the above two opinions. Need to model with depensation for beta parameter determination, rebuilding schedules and harvest control rule (1).
- Depensation depends on environmental conditions, use for when to close the fishery in harvest control rule (1). *There is no major conflicts on this.*

Croissance / Growth

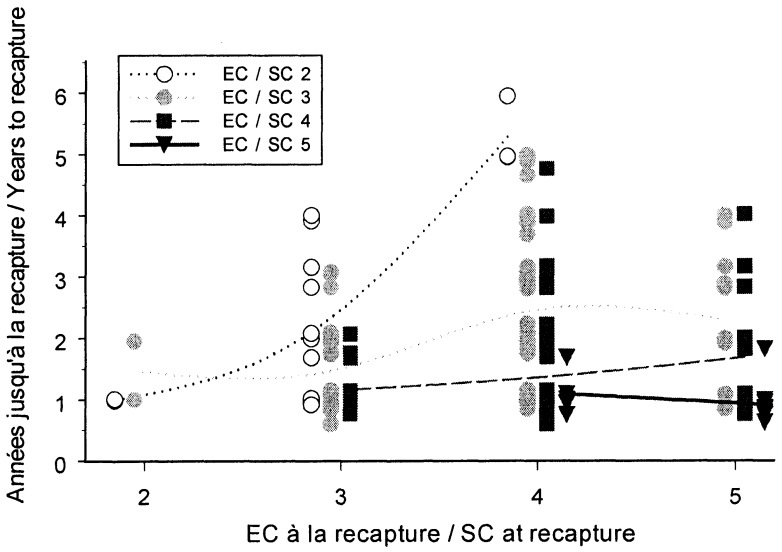
- Mue terminale / Terminal molt
- Saut-de-mue / Skip-molting
- Dimorphisme sexuel de taille et d'âge / Sexual dimorphism by size and age





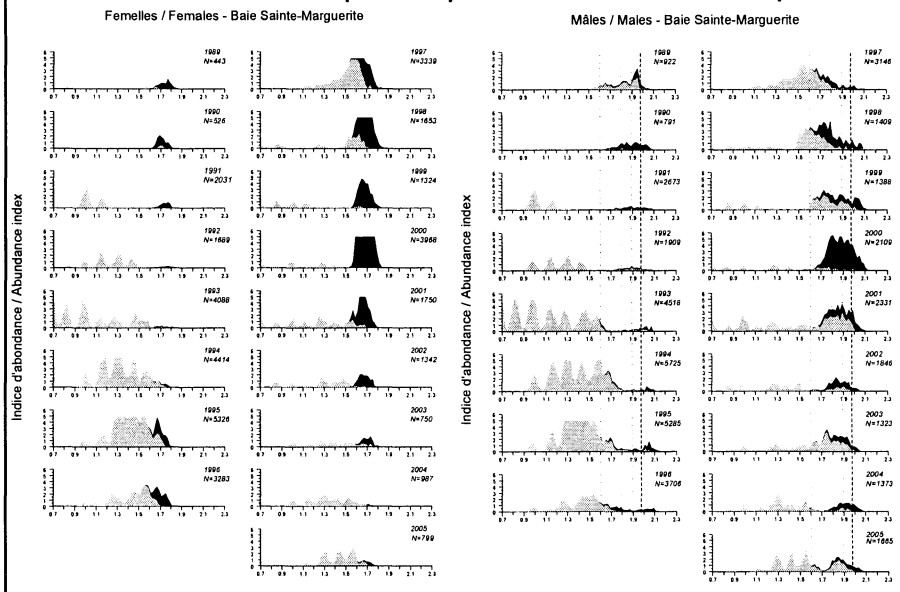
Draft Materials *Please do no cite without permission from author*

Changement EC / Change in SC



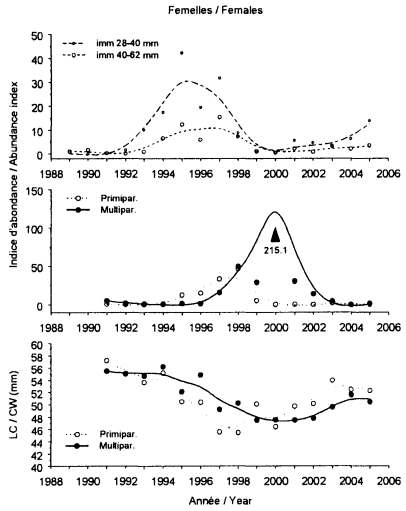
Draft Materials *Please do no cite without permission from author*

Le recrutement est épisodique / Recruitment is episodic



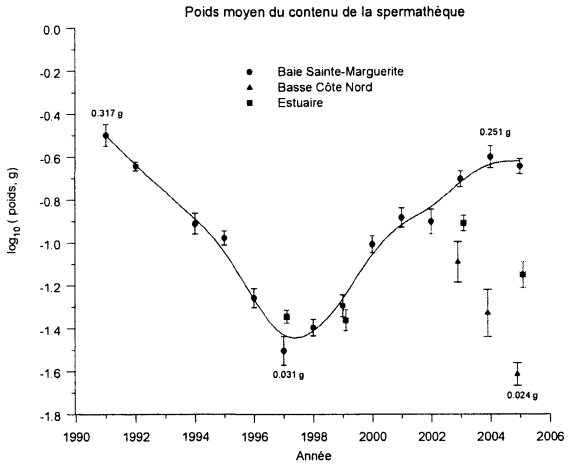
Draft Materials *Please do no cite without permission from author*

Female population dynamics in Baie Sainte-Marguerite



Draft Materials *Please do no cite without permission from author*

Spermathecal load (g content) by year for primiparous females at 3 GSL sites

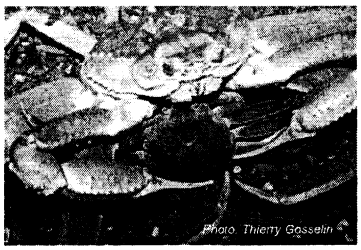


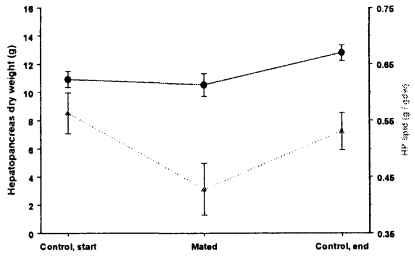
Sources of variability:

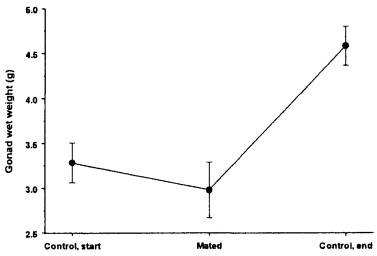
- Mating ratio
- Polyandry
- ♂ sperm repletion

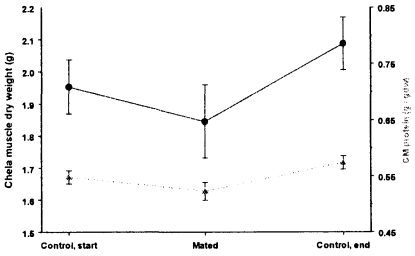
Draft Materials *Please do no cite without permission from author*

Impact de l'accouplement précoce
Impact of precocious mating



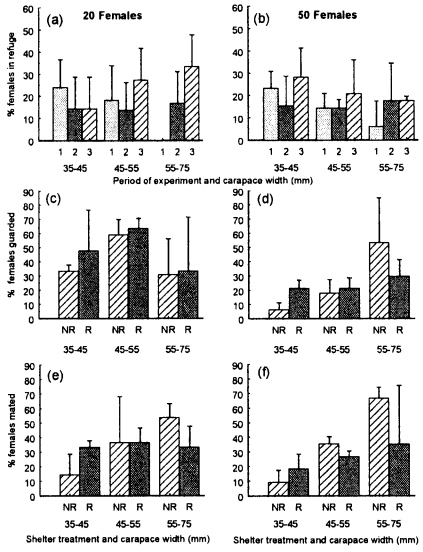






Draft Materials *Please do no cite without permission from author*

Multiparous mating at 3♂:20♀ and 3:50



Draft Materials *Please do no cite without permission from author*

Snow crab stock assessment

•Changes to model

•New data – 2005 survey abundance and size frequency, 2005 fishery catch and size frequency

•Natural Mortality 0.23

•Two scenarios – 50% and 100% fishery discard mortality

•

•Rebuilding evaluated under various harvest control rules

•Total effective spawning biomass at mating time used in spawner recruit curve and harvest strategy

•Mating ratio 1.7:1 (the sex ratio at F=0)

•Old shell males only in effective male spawning biomass(no use of MR)

Assumptions cont.

- Terminal molt for females and males at maturity (morphometric maturity for males)
- Shell condition may not be accurate measure of shell age
- Model fits survey length frequency of new and old shell combined
- Survey selectivity estimated the same for new and old shell

Data

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1978-2005 (Year when fishery actually occurred)
Discarded male and female crab pot fishery size frequency	1992-2005
Trawl fishery bycatch size frequencies by sex	1990-2003
Survey size frequencies by sex and shell condition	1978-2005
Retained catch estimates	1978-2005
Discard catch estimates from snow crab pot fishery	1992-2004 from observer data
Trawl bycatch estimates	1973-2003
Total survey biomass estimates and coefficients of variation	1978-2005

Figure 1. Catch (1,000s lbs) from the directed snow crab pot fishery and groundfish trawl bycatch. P.37. 2005 GHL 20.9, catch 24.6 – 20% above

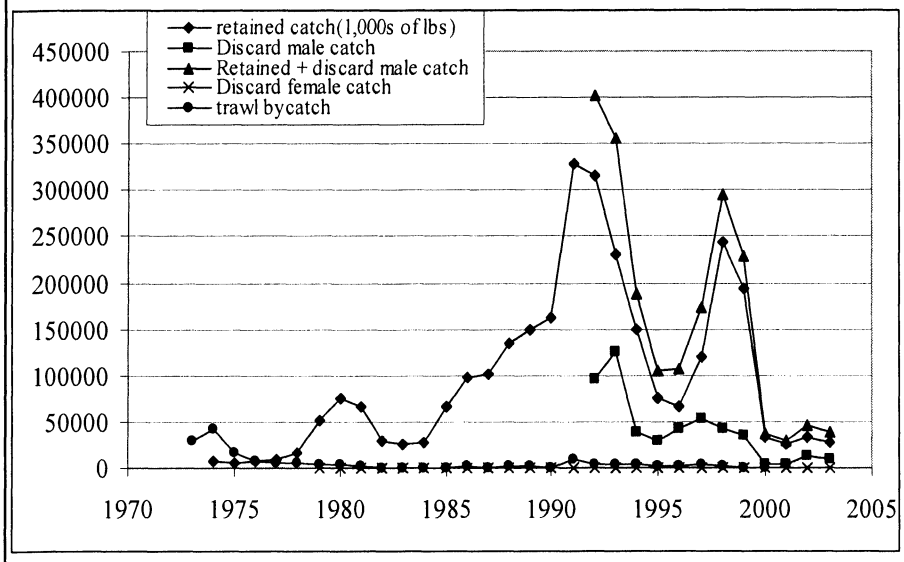


Figure 2. Total mature biomass (million lbs).p.38

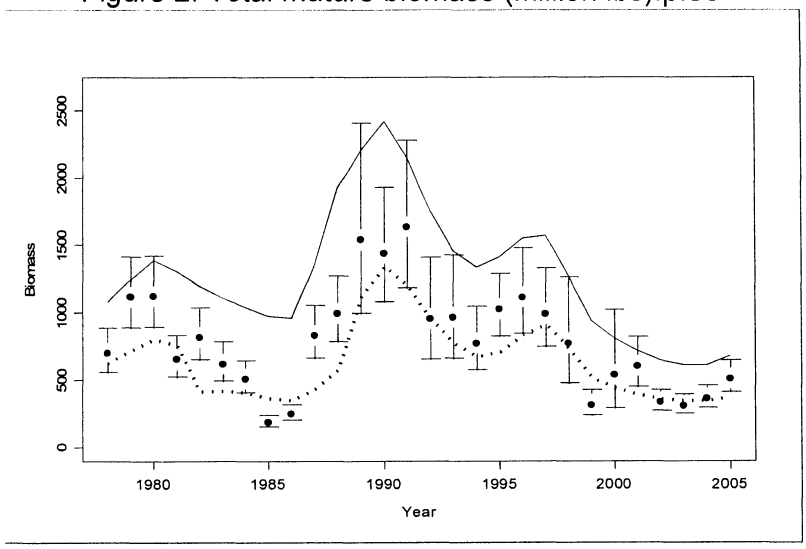
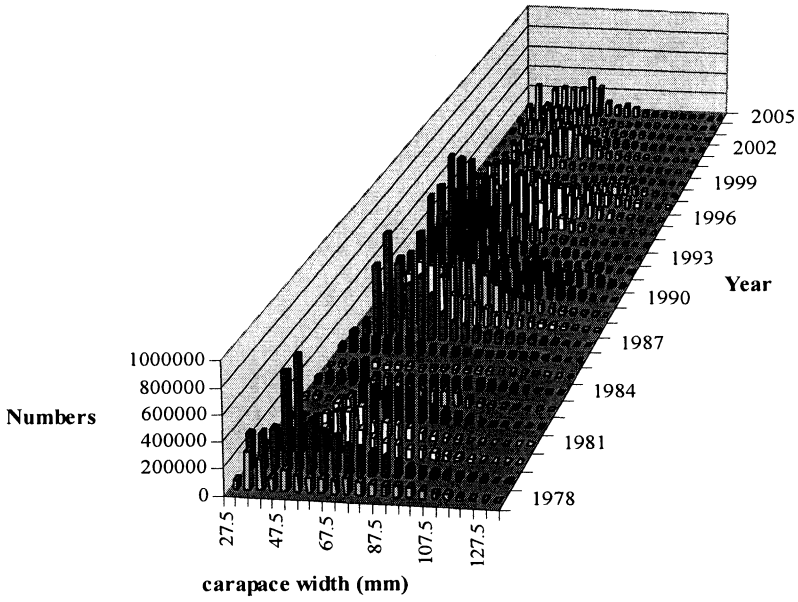
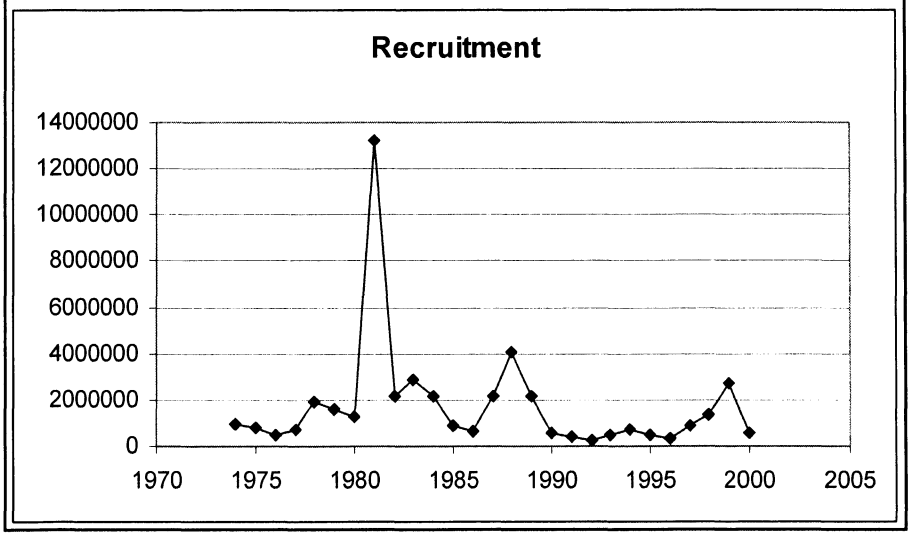


Figure 5. p.41. survey male



- Recruitment by year class (5 year lag to fertilization year)



- Prior on steepness (0.52 red king), R0 prior 2.0
- Steepness estimated at 0.54 and R0= 3.0 bill.
- Bmsy for Total effective spawning biomass at mating time was estimated at 856 million lbs (TMB Bmsy 1600 mill lbs).
- Spawning biomass per recruit analysis with a SR curve steepness of 0.54 results in a proxy Bmsy value of 827 million lbs using spr at maximum yield and average recruitment(1.9 bill.).

Figure 49.p. 82. steepness 0.54, R0 3.0

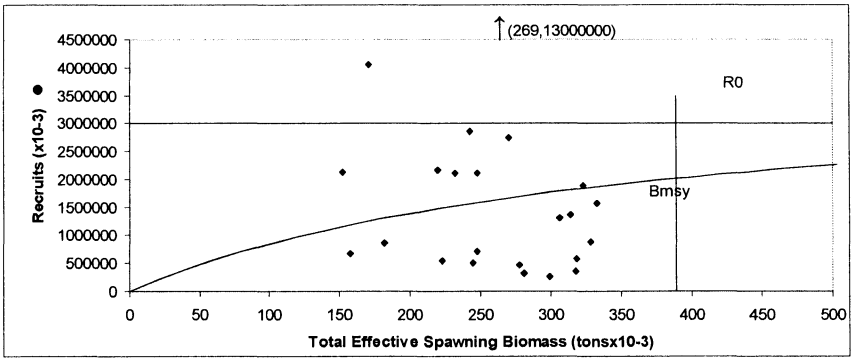


Figure 50. p. 82.

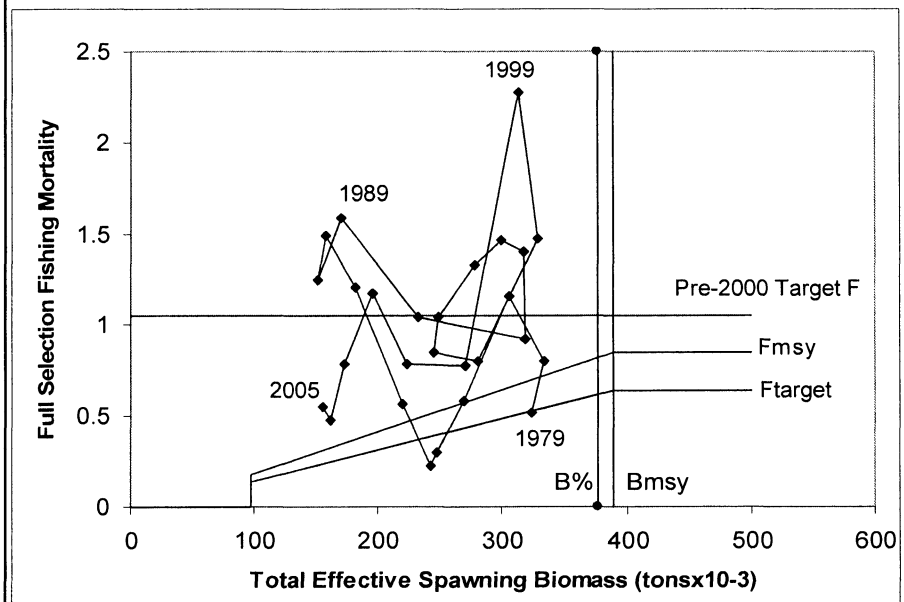


Figure 51. Ftarget control rule. P. 84

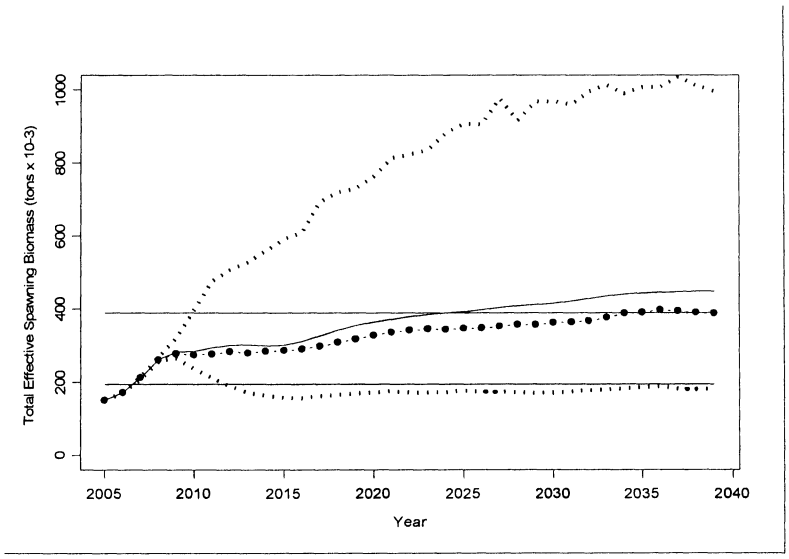


Figure 57. 0.4*Fmsy control rule. P. 90.

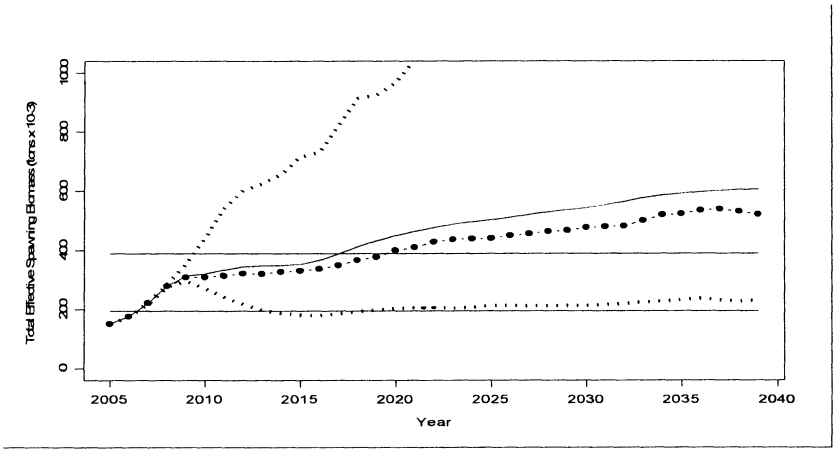
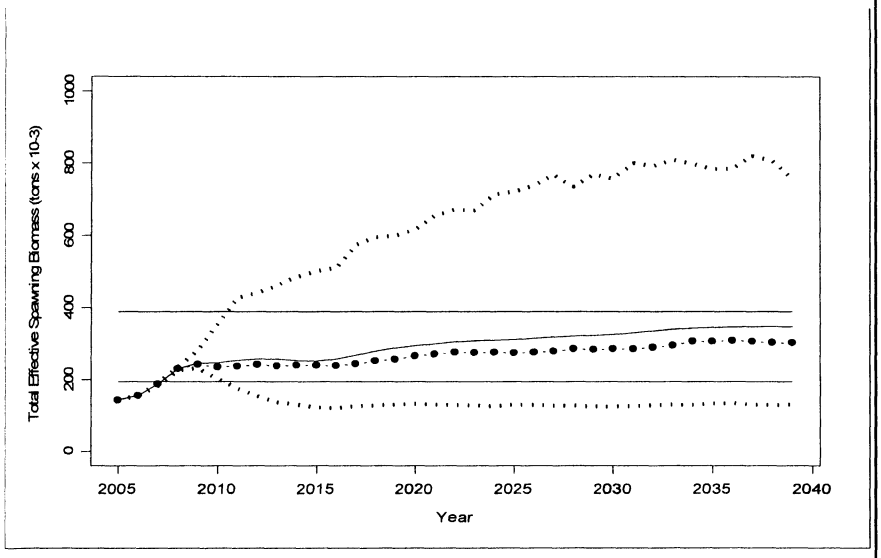


Figure 53. Current Harvest Strategy. P. 86

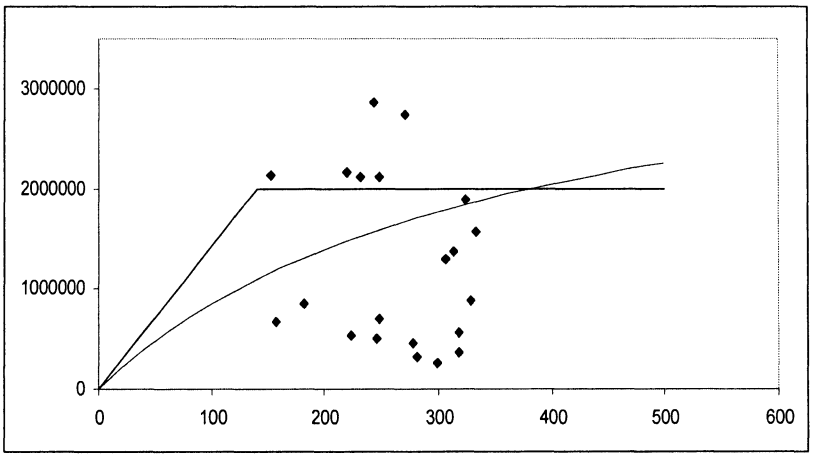


Total effective spawning biomass. P.20.

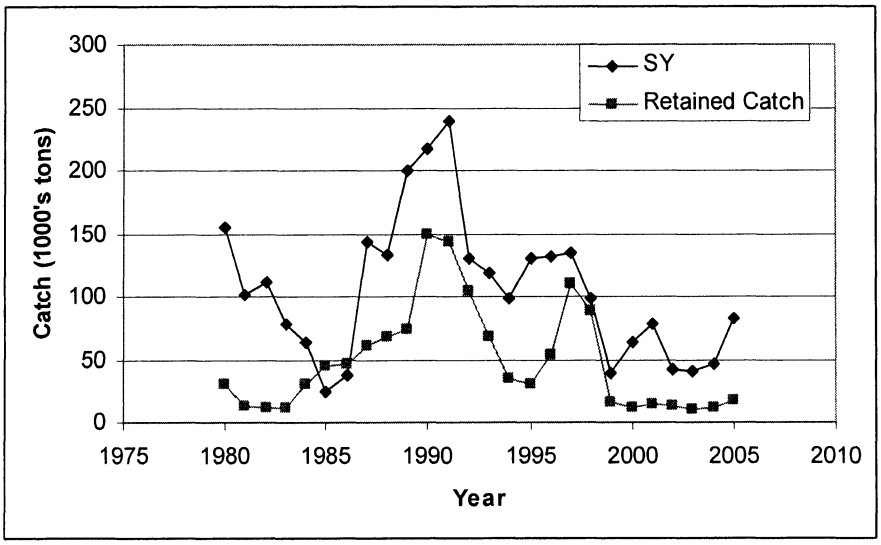
$$efspbio = fspbio \frac{male\ oldshell\ sp\ numbers * mating\ ratio}{female\ sp\ numbers}$$

- Total eff sp biomass = efspbio+old shell male sp bio
-

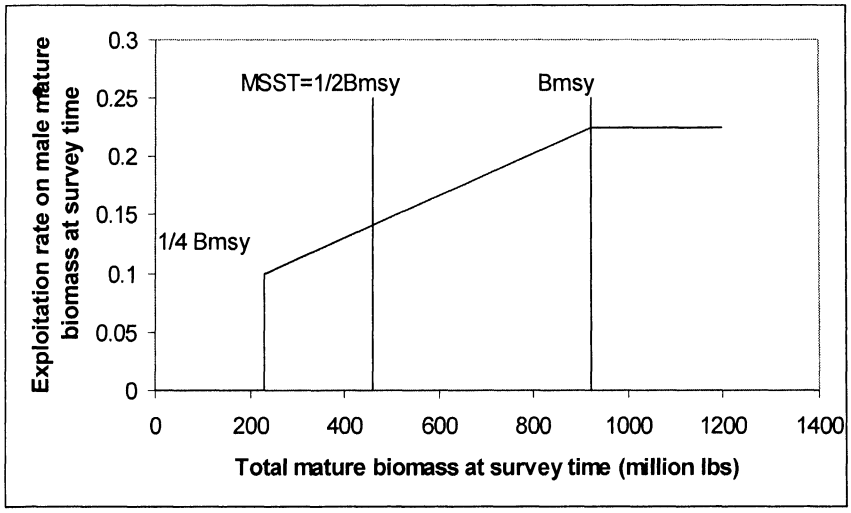
Current harvest strategy SR curve and Estimated SR curve



Current OFL definition



Current harvest strategy control rule



- 2006 retained catch estimated using the current harvest strategy is 31 million lbs (F=0.77).
- 2006 retained catch using the Ftarget control rule is 10 million lbs (50% discard mortality, F=0.225) and 6.7 million lbs(100% discard mort).

Table 7. Projected biomass and catch (p.35)

Control Rule	Biomass or Catch (million lbs)	2006	2007	2008	2009	2010
F target	TESB	330	378.4	466.4	572	609.4
	RC	10	22.7	46.6	81	58
F msy	TESB	327.8	371.8	453.2	547.8	574.2
	RC	12.7	28.3	56.7	95.5	64.2
F = 0	TESB	338.8	400.4	521.4	686.4	809.6
	RC	0	0	0	0	0
Current HS	TESB	314.6	343.2	413.6	508.2	530.2
	RC	31	45.3	70	87.7	75.6
F rebuild	TESB	334.4	387.2	488.4	613.8	679.8
	RC	6.4	13.4	28.7	53	42.1

- Under the revised NSG1, the maximum time to rebuild is Tmin (F=0) plus one mean generation time.
- Tmax = 5 yr + 9.7 yr = 15 yr.
- Rebuilding in 15 yr would result from a control rule using 0.4*Fmsy as the maximum target F.

- Clutch fullness and percent barren females shows effects during periods of high catch
- Higher percent barren and lower clutch fullness in south vs north in 2003 and 2004 (most fishery removals in south)
- Females in colder northern waters shift to biennial spawning
- Exploitation rates are computed on the entire stock, however, most catch is removed from the southern part of the snow crab range
- Spatial sex ratios may effect egg production differentially by area
- Polygamy and polyandry
- All eggs may not be fertilized

Figure 25. Clutch fullness for Bering sea snow crab survey data by shell condition for 1978 to 2004.
p.61.

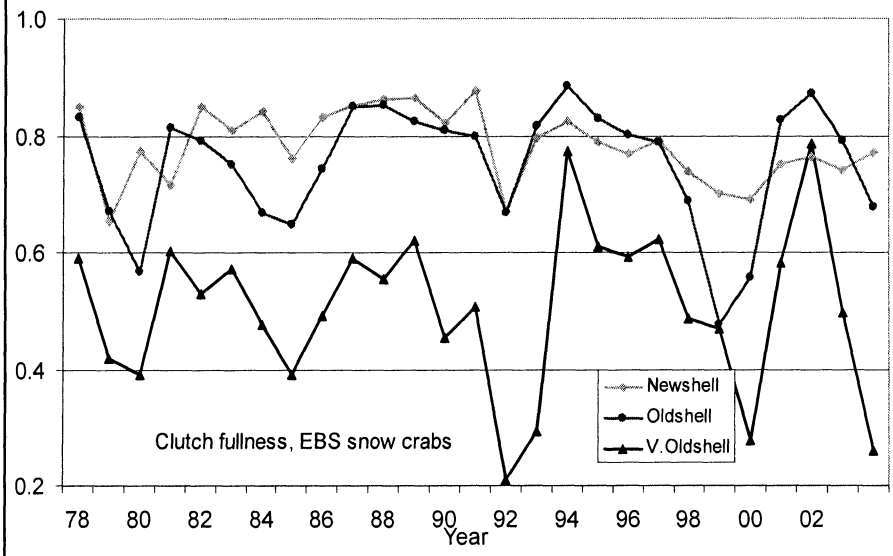
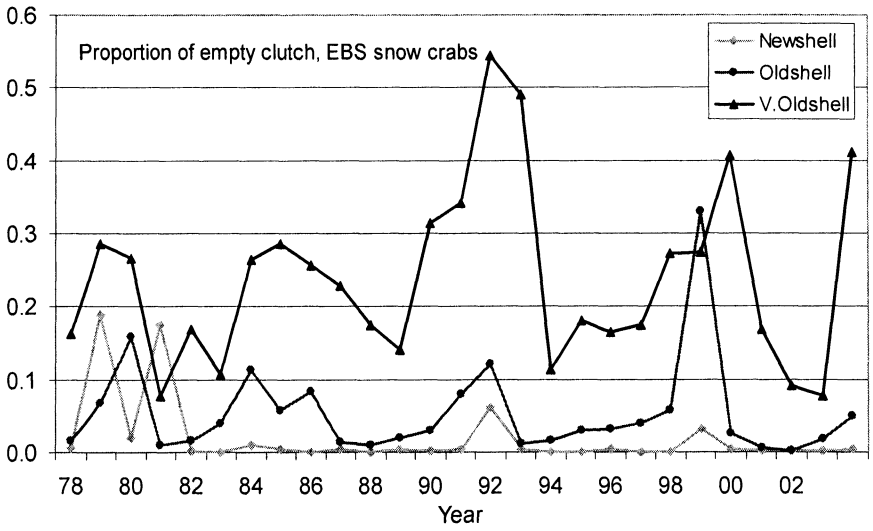
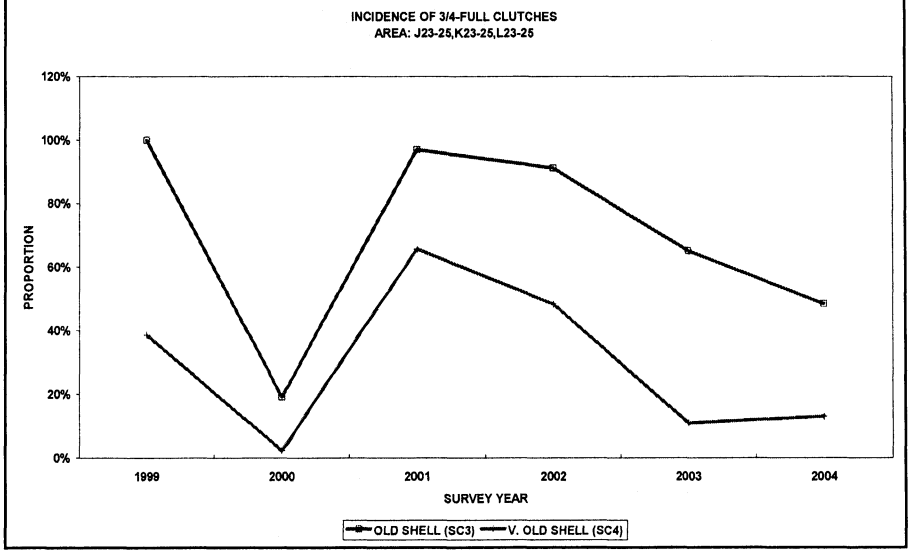


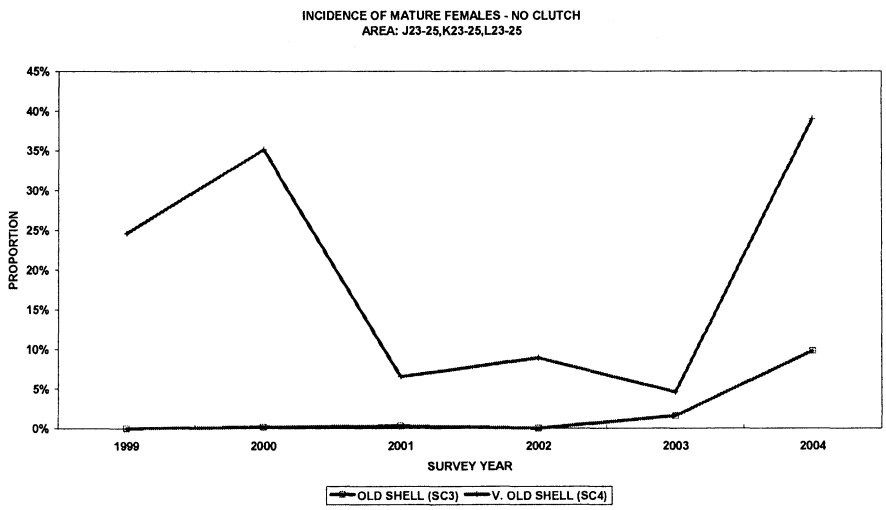
Figure 26. Proportion of barren females by shell condition from survey data 1978 to 2004. 61.p.



- Survey biomass increased in 2005 due to possible moderate recruitment – indicated in 2004 and 2005 female survey size data.
- Model estimate of total biomass increased in 2005, however, the projected (2006) total effective spawning biomass was similar to 2005 (at mating time).

Survey data percent of females with >= 3/4 full clutch





Total effective spawning biomass(million lbs) at mating time

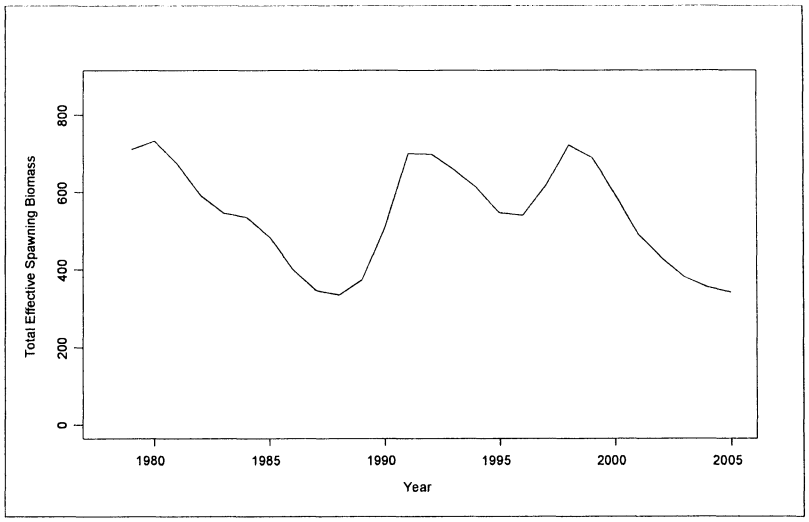
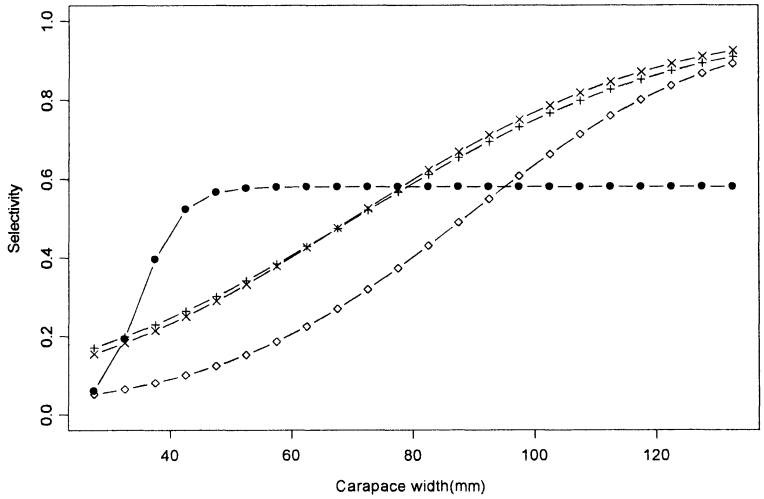
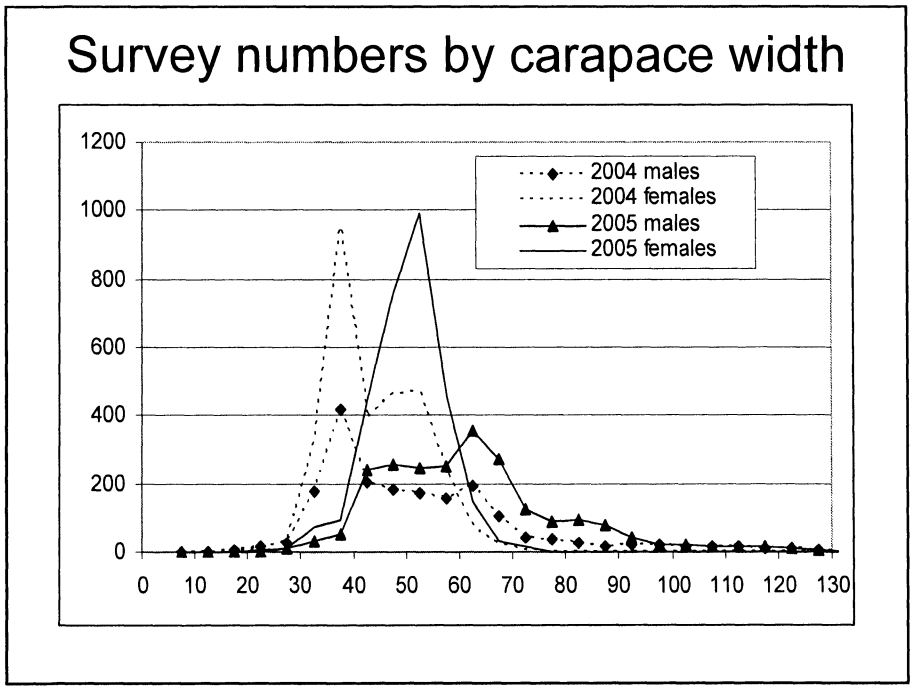


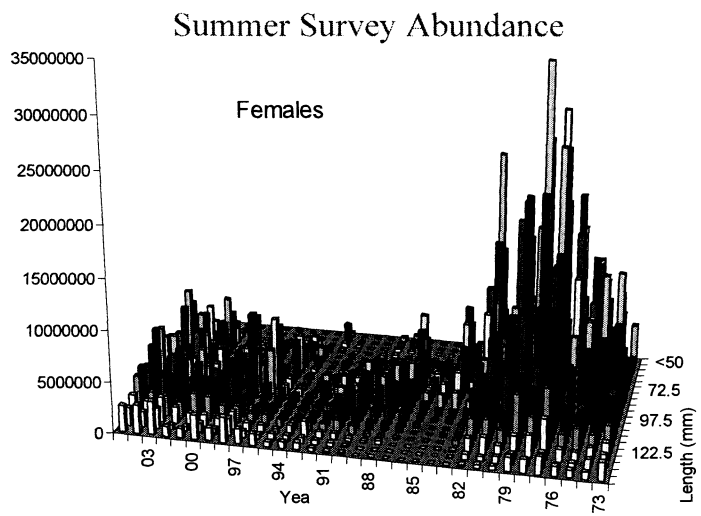
Figure 22. Survey selectivity curves. P. 57.

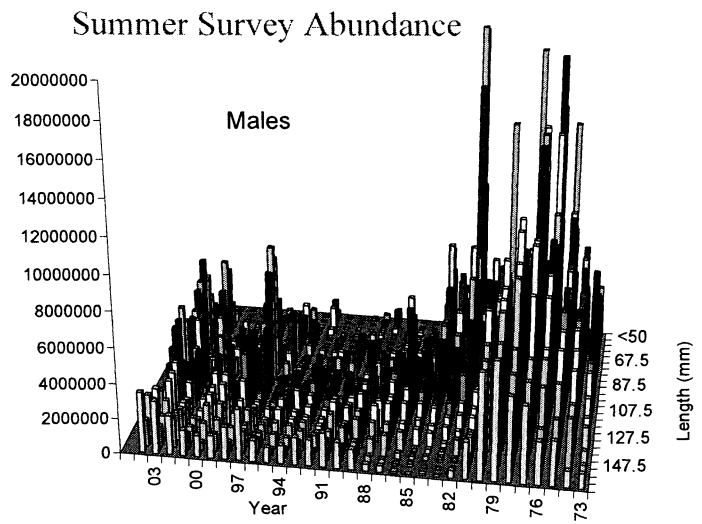



Survey numbers by carapace width
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
2004 males
2004 females
2005 males
2005 females

Population Dynamics and Stock Assessment of Red King Crab in Bristol Bay, Alaska

Jie Zheng
Alaska Department of Fish and Game
Juneau, Alaska, USA





What occurred during early 80s?

Speculation:

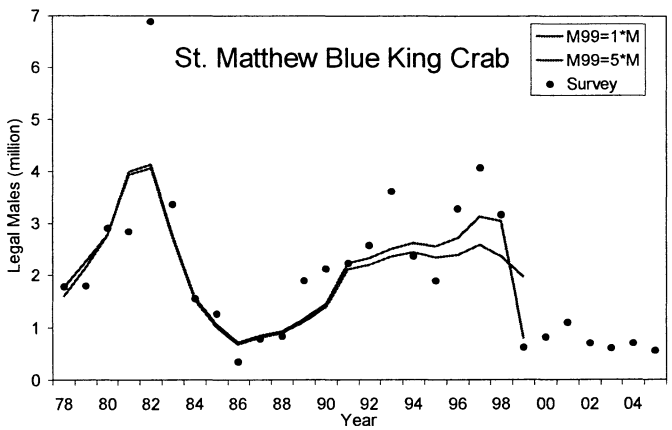
1) Completely wiped out by fishing:
   - ✓ Directed pot fishery
   - ✓ Indirected pot fishery (Tanner crab fishery)
   - ✓ Trawl (esp. "red bag" hypothesis)
2) High fishing and natural mortality

Summary of early 1980s

- High fishing mortality in 1980 and 1981
- Bycatch from the Tanner crab fishery
- Trawl observed and unobserved bycatch
- Older crabs due to slow growth in late 60s and early 1970s
- Disease could be an issue with record population density
- Main predator biomass increased 10 times within a few years and highly concentrated in Bristol Bay

High fishing and natural mortality

- Natural mortality estimated by LBA was much higher in the early 1980s than the other periods
- My position: "***In summary, our results indicate that high natural mortality coupled with high harvest rates may have contributed to and hastened the collapse of the Bristol Bay RKC population. Low spawning biomass in the early 1980s appears to be responsible for its continued lack of recovery." → from Zheng, Murphy & Kruse (1995)***



If actual M increases greatly and the model uses a fixed M, the model will greatly over-estimate population abundance at critical times

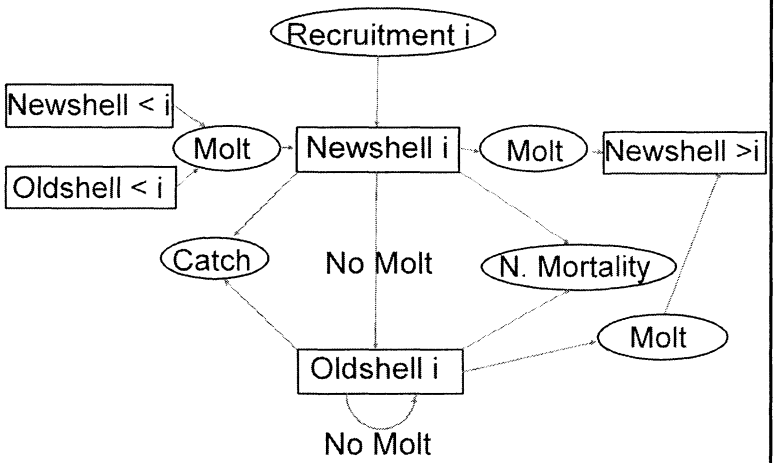
Bristol Bay Red King Crab Models

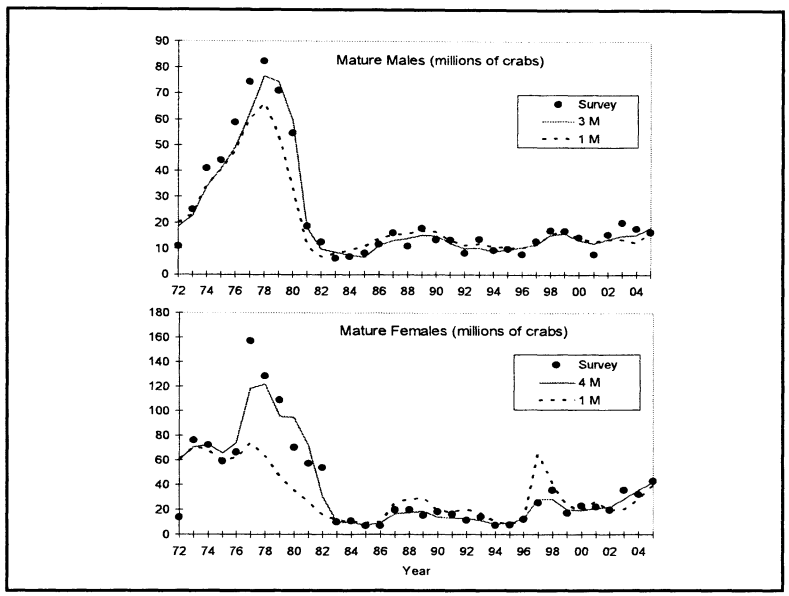
1. Stock assessment model used since 1994 (Zheng et al. 1995a, 1995b, Zheng and Kruse 2002)
2. Research model developed in 2003 and presented for Red King Crab Stock Assessment Workshop in 2004.
3. Catch-length model and catch-survey model (Zheng et al. 1996a, Zheng et al. 1996b)

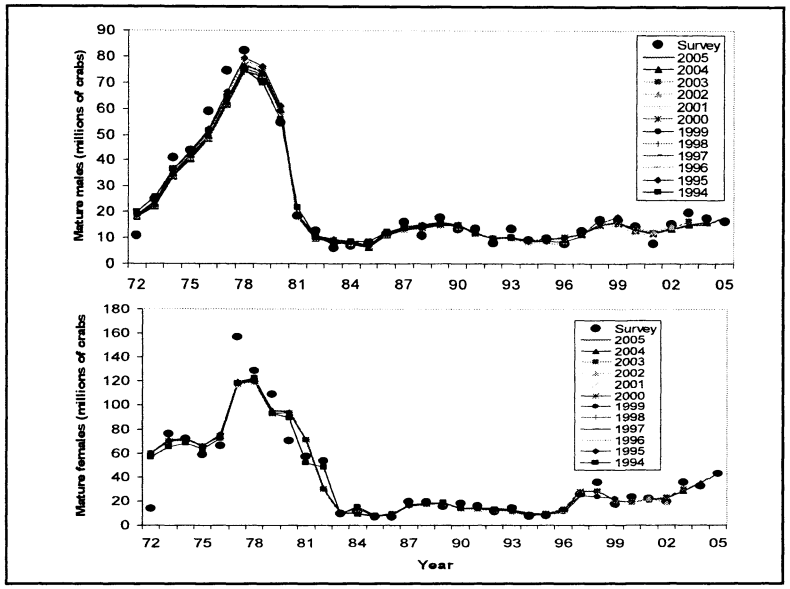
Stock Assessment Model Since 1994

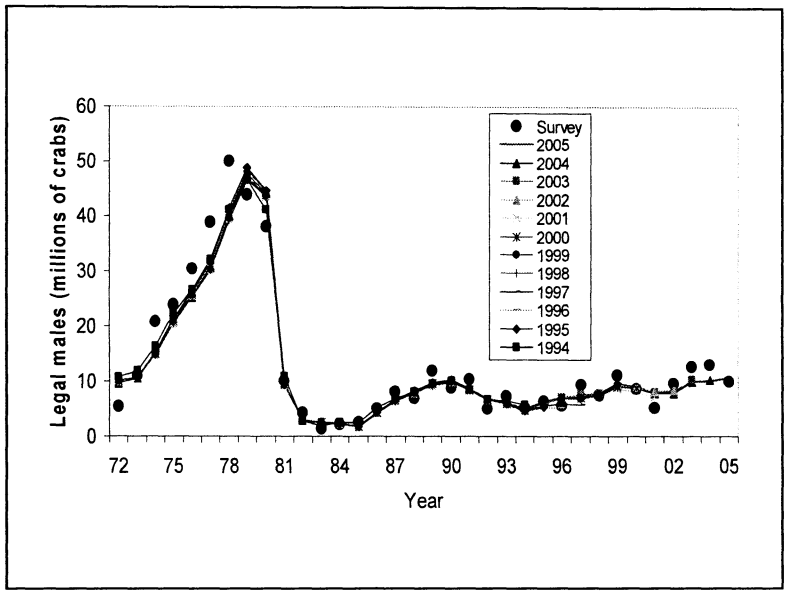
- **Parameters Estimated Independently:**
  - *Length-weight relationship: Personal comm. from Stevens*
  - *Growth increment per Molt: tagging data*
  - *Mean length of recruits: 95 mm for females, 102 mm for males*
- **Parameters Estimated Conditionally:**
  - *Recruits for each year except the first*
  - *Total abundance in the first year (1972)*
  - *Parameters β (growth variation) & β_r (R variation)*
  - *M_f: 4 levels for females & 3 levels for males*
  - *Molting probability parameters α_1, α_2, α_3, β_1, β_2, and β_3 for males*
- **Parameters assumed:**
  - *Survey catchability for mature crabs to be 1.*

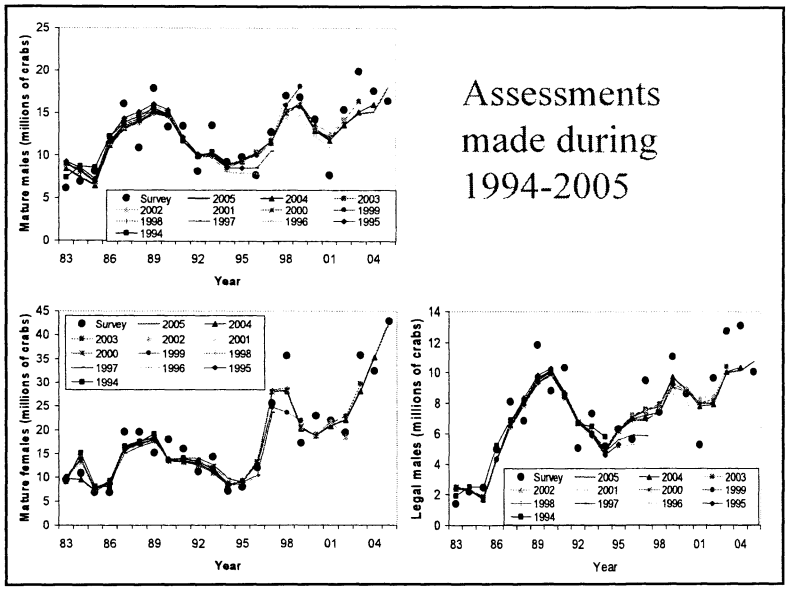
Length-based Analysis (LBA)



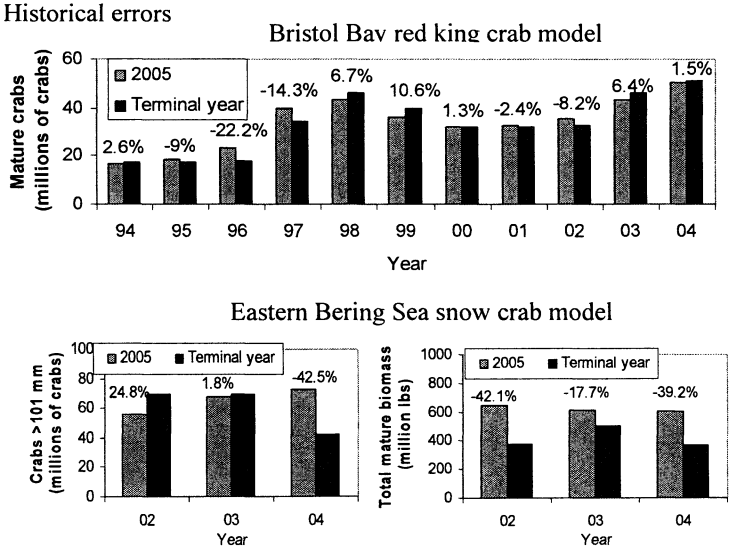

Mature Males (millions of crabs)
Survey
3 M
1 M
Mature Females (millions of crabs)
Survey
4 M
1 M
Year


Mature males (millions of crabs)
Survey
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
Mature females (millions of crabs)
Year


Legal males (millions of crabs)
Year
Survey
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994


Assessments made during 1994-2005
Mature males (millions of crabs)
Mature females (millions of crabs)
Legal males (millions of crabs)
Year

Historical errors



Bristol Bay Research Model

- Original intent was to use it to study survey catchability, bycatch and "red bag" issues.
- More complex and less stable results
- Used to estimate parameters with a constant M and male molting probability for the work group for data 1985-2005.

Male model:

$$N_{l+1,t+1} = \sum_{l'=1}^{l'=l+1} \{ P_{l',l+1} [(N_{l',t} + O_{l',t}) e^{-M_t} - C_{l',t} e^{(y-1)M_t}] m_{l',t} \} + R_{l+1,t+1},$$

$$O_{l+1,t+1} = [(N_{l+1,t} + O_{l+1,t}) e^{-M_t} - C_{l+1,t} e^{(y_t-1)M_t}] (1 - m_{l+1,t}),$$

$N_{l,t}$ and $O_{l,t}$ are newshell and oldshell crab abundances in length class l and year t,

M_t is instantaneous natural mortality in year t,

$m_{l,t}$ is molting probability for length class l in year t,

$R_{l,t}$ is recruitment into length class l in year t,

y_t is lag in years between assessment survey and the fishery in year t,

$P_{l',l}$ is proportion of molting crabs growing from length class l' to l after one molt, and

$C_{l,t}$ is catch of length class l in year t.

Mean growth increment per molt is assumed to be a linear function of pre-molt length:

$G_l = a + b\,\iota$, a and b are constants, & ι is mid-length of a length group.

Growth increment per molt is assumed to follow a gamma distribution:

$$g(x \mid \alpha_l, \beta) = x^{\alpha_l - 1} e^{-x/\beta} / [\beta^{\alpha_l} \Gamma(\alpha_l)],$$

The expected proportion of molting individuals growing from length class $l1$ to length class $l2$ after one molt is equal to the sum of probabilities with length range $[i1, i2)$ of the receiving length class $l2$ at the beginning of next year; i.e.,

$$P_{m,l_1,l_2} = \int_{\iota_1-\iota}^{\iota_2-\iota} g(x \mid \alpha_l, \beta) dx,$$

For the last length class L, $P_{L,L} = 1$.

The molting probability for a given length class is modeled by an inverse logistic function:

$$m_l = 1 - \frac{1}{1 + a\ e^{-b\ i}},$$

a and b are parameters, and i is the mean length of length class l.

Recruitment is separated into a time-dependent variable, Rt, and size-dependent variables, Ul, representing the proportion of recruits belonging to each length class.

$$R_{l,t} = R_t U_l,$$

U_l is described by a gamma distribution.

Retained selectivities, pot female bycatch selectivities, trawl male and females bycatch selectivities

$$s_{l,t} = \frac{1}{1 + e^{-\beta\ (i - L_{50,t})}},$$

$$L_{50,t} = \overline{L}_{50} e^{\delta_t}, \quad \delta_t - \delta_{t+1} \sim N(0, \sigma_\delta^2)$$

i.e., annual lengths at 50% selectivity follow a random walk process

Different sets of parameters (β, $L_{50,t}$) are estimated for retained males, pot female bycatch, trawl male bycatch, and trawl female bycatch

Survey selectivities/catchabilities,

$$s_l = \frac{A}{1 + e^{-\beta\,(l - L_{50})}},$$

Different sets of parameters (β, L_{50}) are estimated for males and females.

A is set to be 0.774 for females and 0.896 for males based on Weinberg et al. (2004).

Robust likelihood function

For length compositions ($p_{l,t,s,sh}$):

$$Rf = \prod_{l=1}^{L}\prod_{t=1}^{T}\prod_{s=1}^{2}\prod_{sh=1}^{2}\frac{\left\{\exp\left[-\frac{(p_{l,t,s,sh} - \hat{p}_{l,t,s,sh})^2}{2\sigma^2}\right] + 0.01\right\}}{\sqrt{2\pi\sigma^2}},$$

$$\sigma^2 = \left[\hat{p}_{l,t,s,sh}(1 - \hat{p}_{l,t,s,sh}) + 0.1/L\right]/n,$$

where L is the number of length groups, T is the number of years, and n is sample size.

Objective function

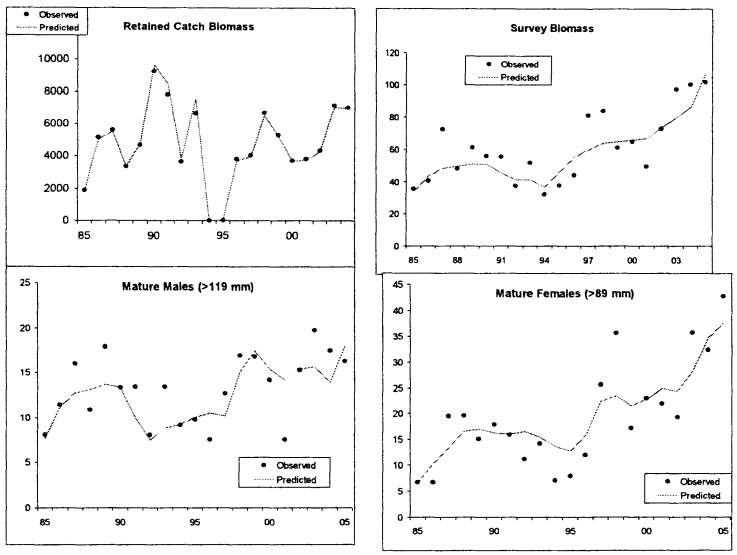
Weighted log-likelihood functions:

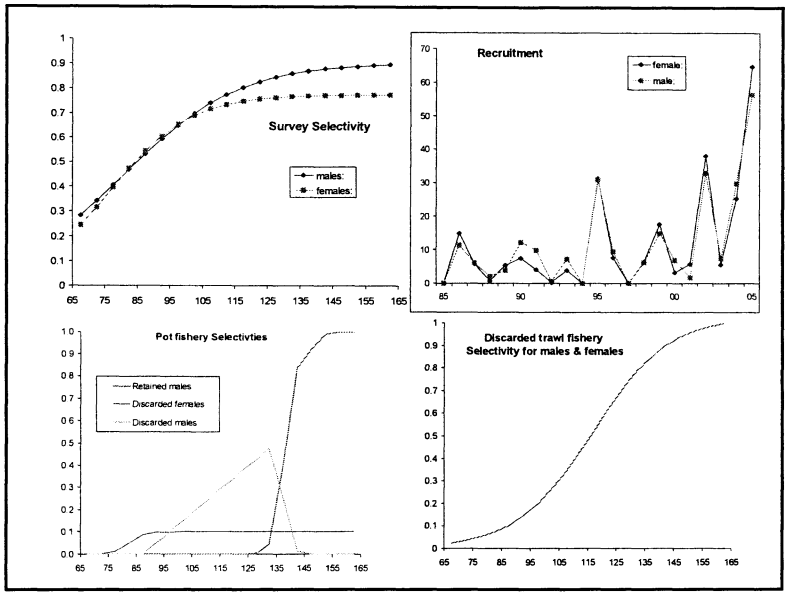
Length compositions: $-\lambda_i \sum \log(Rf_i)$

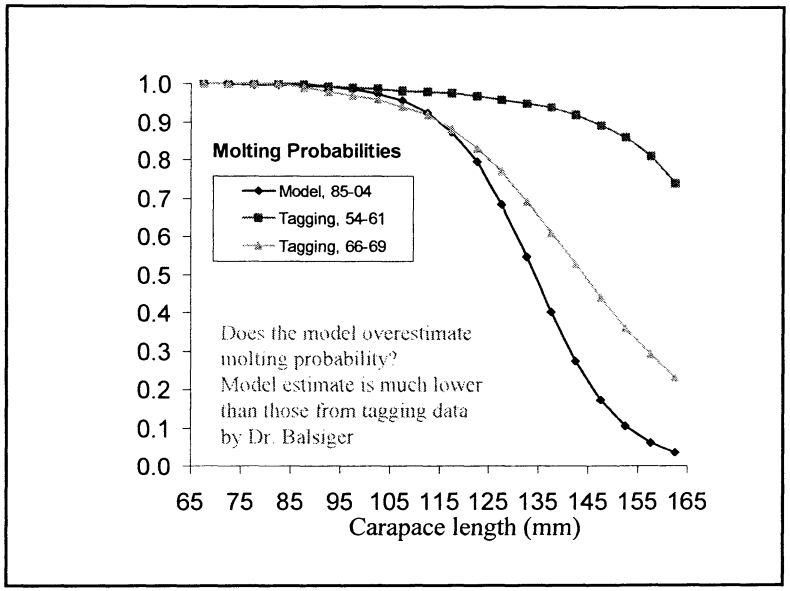
Biomasses: $\lambda_j \sum \left[\log(B_t / \hat{B}_t)^2\right]$

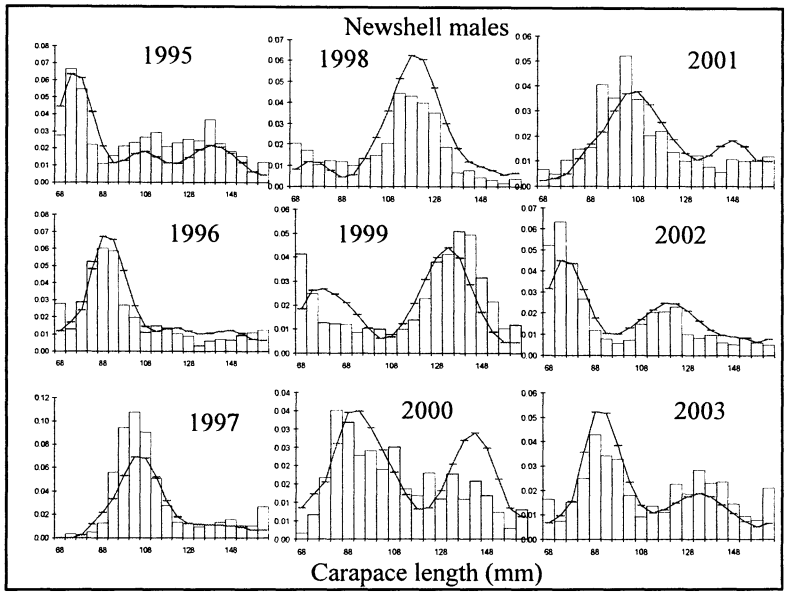
Other components: *R variation, R sex ratio, 50% length variations*

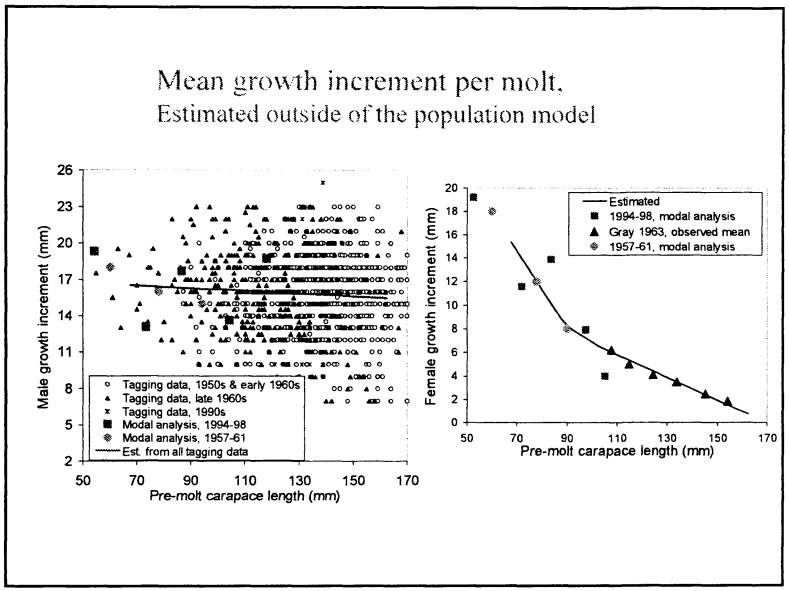
Weighted λs are assumed to be 6 for retained length compositions, 2 for Trawl survey length compositions, 1 for all other length compositions, 3000 for retained catch biomass, 1000 for survey biomass, and 200 for all other biomasses, 0 for recruitment variation, 1 for recruitment sex ratio, and 0.25 for all annual changes in length of 50% selectivity.




Survey Selectivity
males:
females:
Recruitment
female
male
Pot fishery Selectivties
Retained males
Discarded females
Discarded males
Discarded trawl fishery
Selectivity for males & females


Molting Probabilities
Model, 85-04
Tagging, 54-61
Tagging, 66-69
Does the model overestimate molting probability?
Model estimate is much lower than those from tagging data by Dr. Balsiger
Carapace length (mm)


Newshell males
1995
1998
2001
1996
1999
2002
1997
2000
2003
Carapace length (mm)


Mean growth increment per molt,
Estimated outside of the population model
Male growth increment (mm)
Pre-molt carapace length (mm)
Tagging data, 1950s & early 1960s
Tagging data, late 1960s
Tagging data, 1990s
Modal analysis, 1994-98
Modal analysis, 1957-61
Est. from all tagging data
Female growth increment (mm)
Pre-molt carapace length (mm)
Estimated
1994-98, modal analysis
Gray 1963, observed mean
1957-61, modal analysis

Thanks

Tier system

- Issue 1: State of Alaska or the Fed determines ABC?
  - ABC is part of the discussion of Guideline Harvest Level under section 8.2.2 of the Crab FMP. This is a category 2 measure which is delegated to the State of Alaska
  - If the Fed wants to revise this section of the FMP to determine ABC, the State will not need any state harvest strategies and may set TAC to be ABC unless there are conservation concerns. In this case, the State will change its current duties of developing harvest strategies, setting ABC/TAC, and executing fisheries to executing fisheries only
  - If this section of the FMP is not revised, the state harvest strategies will set ABC (always below the overfishing levels), and the new tier system (like the current one) will not contain ABC determination

Tier system

- Issue 2: Should the tier system cover all crab stocks?
  - Among 22 crab stocks, many have little data to fall into any tier of the discussed tier system.

New tier system

- A new tier system for discussion:
  - Simplification so that the Fed can carry its duties without much dispute with the State
  - No ABC determination like the current tier system; the state harvest strategies determine ABC/TAC that will be always less than the overfishing levels
  - Cover all crab stocks

A new tier system for discussion

Tier 1) *Information available: Reliable point estimates of ESB, ESB_{MSY}, and HR_{MSY}. Stock assessment model exists.*

1.a) Stock status:

$$\frac{ESB}{ESB_{MSY}} > 1$$

$$HR_{OFL} = HR_{MSY}$$

1.b) Stock status:

$$\beta < \frac{ESB}{ESB_{MSY}} \leq 1$$

$$HR_{OFL} = HR_{MSY} \times \frac{ESB}{ESB_{MSY}}$$

1.c) Stock status:

$$\frac{ESB}{ESB_{MSY}} \leq \beta$$

$$HR_{OFL} = 0$$

HR---legal harvest rate
β set to be 0.25

No stocks are currently assigned to this tier

A new tier system for discussion

Tier 2) *Information available: Reliable point estimates of ESB, ESB_{TARG} from survey or model, and proxy HR_{LIMIT}.*

2.a) Stock status:

$$\frac{ESB}{ESB_{TARG}} > 1$$

$$HR_{OFL} = proxy\ HR_{LIMIT}$$

2.b) Stock status:

$$\beta < \frac{ESB}{ESB_{TARG}} \leq 1$$

$$HR_{OFL} = proxy\ HR_{LIMIT} \times \frac{ESB}{ESB_{MSY}}$$

2.c) Stock status:

$$\frac{ESB}{ESB_{TARG}} \leq \beta$$

$$HR_{OFL} = 0$$

Stocks assigned to this tier:

1. Bristol Bay red king crab
2. Eastern Bering Sea Tanner crab
3. Eastern Bering Sea snow crab

A new tier system for discussion

3) *Information available: Reliable point estimates of ESB, M, ESB_{TARG} from survey data or model. Because mature male crab abundance is normally 150% or higher than legal abundance, multiplier γ is set to be 1.5. If female data are not available, mature male biomass will be used as a proxy of ESB.*

3.a) Stock status:

$$\frac{ESB}{ESB_{TARG}} > 1$$

$$HR_{OFL} = \gamma \times (1 - \exp(-M))$$

3.b) Stock status:

$$\beta < \frac{ESB}{ESB_{TARG}} \leq 1$$

$$HR_{OFL} = \gamma \times (1 - \exp(-M)) \times \frac{ESB}{ESB_{MSY}}$$

3.c) Stock status:

$$\frac{ESB}{ESB_{TARG}} \leq \beta$$

$$HR_{OFL} = 0$$

Stocks assigned to this tier:

4. Pribilof Islands red king crab
5. Pribilof Islands blue king crab
6. Saint Matthew Island blue king crab
7. Dutch Harbor red king crab
8. Norton Sound red king crab
9. Eastern Aleutian Islands Tanner crab

A new tier system for discussion

Tier 4*) Information available: Reliable catch history from a sufficiently long time period to be determined by the stock assessment analyst in concurrent with CPT and SSC. Insufficient biological information to estimate any stock assessment parameters.*

OFL = the average catch for a selected time period.

Stocks assigned to this tier:
10. Adak red king crab, 11. Pribilof Islands golden king crab
12. Saint Matthew golden king crab, 13. Aleutian Islands golden king crab

Tier 5*) Information available: Insufficient biological information or catch history is available to estimate any stock assessment parameters and mean catch. This tier is for unexploited crab stocks or stocks with only exploratory fisheries.*

No OFL is defined, but biological indicators such as female reproductive condition, proportions of recruits and post-recruits, and catch per potlift should be monitored from observer's data for stocks with exploratory fisheries.

Stocks assigned to this tier:
14. Western Aleutian Tanner crab, 15. Saint Lawrence Island blue king crab,
16. Aleutian Islands scarlet king crab, 17. Eastern Bering Sea scarlet king crab,
18. Bering Sea triangle Tanner crab, 19. Eastern Aleutian Islands triangle Tanner crab,
20. Eastern Aleutian Islands grooved Tanner crab, 21. Western Aleutian Islands grooved Tanner crab,
22. Eastern Bering Sea grooved Tanner crab

Attachment 4

North Pacific Fisheries Management Council
Bering Sea / Aleutian Islands King and Tanner Crab Working Group

Working Group Membership:
NMFS: L. Rugolo [Co-Chair], J. Turnock
ADFG: S. Shareef [Co-Chair], J. Zheng

Draft Statement of Work

I. **Scope of Responsibility of Working Group:**

To revise and amend the Bering Sea / Aleutian Islands King and Tanner Crab Fishery Management Plan [FMP or Plan] of the NPFMC insuring that:

1. The revised Plan is in compliance with the Federal laws governing the management of these stocks - the Magnuson-Stevens Fishery Conservation and Management Act [MSFCMA], and the Sustainable Fisheries Act [SFA].
2. The underlying fisheries scientific and technical frameworks are consistent with the National Standards [NS] established by these Acts.
3. The specified conservation and management measures conform to the National Standard Guidelines [NSGs] - notably, to NSG1 and the adoption of precautionary management practices.
4. The fisheries scientific and technical frameworks that serve as the biological underpinning of management, represents the best scientific information available as required by NS2.

Revisions and amendments to the Plan are specified in two sections: **II. Revisions to the Plan**, and **III. Additional Technical Components to Implement in the Plan**. In each section, specific **Action Items** are identified for implementation. A brief overview precedes each item which provides the rationale for amending that Plan element. The value of each Action Item to the conservation and utilization of these stocks will be shown in the Environmental Assessment for the Plan amendment.

II. **Revisions to the Plan:**

Statement of Need:
For each stock under this Plan, the threshold definition of overfishing, the definition as to whether the stock is overfished, and the overfishing control rule require revision.

The SFA requires that status of overfishing determination criteria specify both a maximum fishing mortality threshold [MFMT], and a minimum stock size threshold [MSST] or reasonable proxies thereof. Stocks must be assessed according to whether the maximum fishing mortality threshold is exceeded, and whether the stock is below the minimum stock size threshold.

The NSGs require NOAA Fisheries to determine if the fishing mortality rate threshold is being exceeded and if the biomass is below the established threshold for each stock under the Plan. If the fishing mortality rate is above threshold, then overfishing is occurring. If the stock size is below the minimum threshold, then the stock is overfished. Remedial management action is required if either occurs. Where overfishing is occurring, fishing mortality must be reduced so that stocks can produce maximum sustainable yield [MSY] on a continuing basis. For stocks that are overfished, rebuilding plans with an acceptable likelihood of success must be implemented to rebuild stocks to the MSY level within an appropriate time frame.

The MSFCMA defines ten National Standards for fishery conservation and management. NS1 requires the adoption of conservation and management measures that prevent overfishing while providing optimum yield [OY] on a continuing basis from each stock. The advisory guidelines for NS1 state that the Councils should adopt a precautionary approach to specifying OY. The precautionary approach guidelines identify MSY as the minimum standard for defining management limits. The MSFCMA adopts this concept and constrains OY to be no greater than MSY.

A principle feature of the precautionary approach to management is the definition of ***limits*** to safeguard the long-term productivity of the stock. The NSGs define two limits for management that are required to insure stock conservation and yields close to MSY. These are the MFMT and MSST intended as benchmarks to gauge if a stock is being overfished or if it's in an overfished state. Another important feature of applying the precautionary approach is the specification of ***targets*** that are set safely below these limits. Target setting considers uncertainty and other management objectives. Criteria used to set limit and target levels should be explicitly ***risk averse***. Status determination criteria are used to evaluate the performance of limit and target reference point systems.

Pertinent Definitions:

I. ***Fishing Mortality Rate [F]*** refers to the full-selection instantaneous rate of fishing mortality that applies to fish of fully selected, or recruited sizes or ages. The terms *'full-selection F'* and *'fully-recruited F'* are synonymous.

ii. ***Overfishing*** is determined to be occurring when the fishing mortality rate F exceeds the MFMT rate required to produce the maximum sustainable yield on a continuing basis. It is defined in NS1 as *"a rate or level of fishing mortality that jeopardizes the capacity of a stock ... to produce the maximum sustainable yield on a continuing basis"*. The status determination of overfishing is based on the overfishing threshold [MFMT] specified in a Plan. Exceeding this threshold for a period of 1 year or more constitutes overfishing.

iii. ***Overfished*** stocks are those whose biomass is below the minimum stock size threshold expressed in terms of spawning biomass or other measures of reproductive capacity. The MSST should be set at the greater of one-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock were exploited at the full MFMT.

Should the stock size in a year fall below this threshold, the stock is considered overfished. The MSFCMA also uses "*overfished*" to describe a stock that is subject to an F in excess of the MFMT.

iv. The NS1 defines the following MSY-related concepts:

[a]. **MSY** is the largest long-term average catch or yield that can be taken from a stock under prevailing ecological and environmental conditions.

[b] **MSY Control Rule** is the harvest strategy which, if implemented, would be expected to result in a long-term average catch approximating MSY.

[c] **MSY Stock Size** is the equilibrium stock size under a constant fishing mortality MSY control rule - i.e., the long-term average stock size that would be achieved under an MSY control rule in which the fishing mortality rate was constant.

The Working Group will devise overfishing and overfished definitions, and MSY Control Rules for the stocks that are in compliance with governing Acts. The Amendment will specify thresholds to serve as standards for determining if a stock is being overfished or if it's in an overfished state. It will specify the MSY control rule that intrinsically links these threshold definitions for each stock.

☞ ***Action Item II.1.*** ***Overfishing Definition***:

1. A maximum fishing mortality rate [F] threshold [MFMT], or reasonable proxy thereof. Such a limit reference point, or F_{OFL}, will:
   a. Represent the 'full-selection F' or the 'fully-recruited F' rate.
   b. Encompass indirect losses to the stock as discards, and non-directed losses as bycatch from non-target fisheries.
   c. Prescribe the F-based overfishing definition for the stock component exploited by the fishery - i.e., the exploitable stock biomass or its corollary, exploitable stock abundance.
   d. Prescribe proxy overfishing definitions if required. Proxy definitions will be needed when the F_{MSY} cannot be estimated or when the estimated value is deemed unreliable [e.g., extremely low precision, insufficient contrast in the data, or inadequate models]. The choice among proxy measures must conform to the conservation requirements of the Acts in defining limits intended to safeguard the long-term productivity of the stock.

☞ ***Action Item II.2.*** ***Overfished Definition:***

2. A minimum stock size threshold MSST, or reasonable proxy thereof, expressed in terms of spawning biomass or other measures of reproductive capacity. The MSST should be the greater of either one-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock were exploited at the full MFMT. Formulation of this definition should satisfy:
   a. The Act's conservation requirement of safeguarding the long-term productivity of the stock.

b. Where data allow, it would be derived in a structured modeling framework that reflects the species' essential biological and life-history characteristics, as well as its population and fishery dynamics.

c. Proxy overfished definitions should be scientifically defensible and supported by empirical evidence. Proxy definitions will be needed when the MSST cannot be estimated or when the estimated value is deemed unreliable [e.g., extremely low precision, insufficient contrast in the data, or inadequate models]. The choice among proxy measures must conform to the conservation requirements of the Acts in defining limits intended to safeguard the long-term productivity of the stock

☞ ***Action Item II.3. MSY Control Rule:***

3. In the National Standard Guidelines, the above two limit definitions are intrinsically linked through an MSY Control Rule that specifies how the F threshold should vary as a function of stock biomass in order to achieve yields close to MSY on a continuing basis. Control rules are pre-established plans for implementing management decisions without delay in response to changing status of the stock. The NSG1 states that the choice of a control rule should be guided by the characteristics of the fishery, the FMP's objectives and the best scientific information available. To minimize the occurrence of stock sizes for which rebuilding plans are required, the MSY Control Rule should afford *"built-in"* rebuilding as stock size declines below the MSY Stock Size.

Item III.7 and III.8 describes a method to intrinsically link the Plan's MSY Control Rule to an integrated *Tier System* and *Limit Reference Point System*. Item III.9 discusses desirable properties of control rules to achieve in this amendment.

III. Additional Technical Components to Implement in the Plan:

In addition to revising inadequately defined fisheries scientific and technical elements of the Plan, this Amendment will specify additional technical elements that are required to meet the responsibilities described in Items I.1 - I.4. The following is a list of key fisheries scientific and technical components of the Plan that require amending. Most have been described in the *Addendum to the Crab Plan Team Meeting Minutes of 22-24 September 2003* [Rugolo] submitted to the NPFMC in October 2003. Additional elements may be included in order to achieve compliance with the governing Acts, and with their attendant Standards and Guidelines.

1. <u>Instantaneous Natural Mortality Rate [M]</u>:
The rates of natural mortality used in stock assessment and harvest strategy modeling differ from those specified in the overfishing definitions of the Plan. For most stocks, the instantaneous rate of natural mortality [M] underlying the MSY Control Rule is decoupled from the applied harvest control rules. This results because the harvest strategy and population dynamic modeling frameworks are not analytically linked. In some cases, M is treated as a variable that is estimated annually in external model formulations whose

value represents total stock losses not attributed to direct fishery removals. As practiced, annual estimates of M can exceed that specified in the overfishing definition or MSY Control Rule without modification to the target or threshold fishing mortality rate definitions in the Plan.

There is a high degree of uncertainty whether the values of M specified in the Plan are consistent with the life-histories of the subject species. Current estimates are based on a method for estimating Z for lightly exploited stocks using observed oldest age [t_{MAX}] in the stock [Hoenig 1983]. Its formulation neither considered crustaceans nor virgin populations. Application of Hoenig [1983] is functionally equivalent to assuming that the 99th percentile of longevity [i.e, maximum attainable age in a virgin population] is known, and that this percentile is t_{MAX}. This is a risk-negative assumption, particularly in cases where age data are derived from exploited populations, and ages are inferred from indirect methods as for these crab species. By comparison, if the observed oldest ages [t_{MAX}] represent the 95th percentile, the Hoenig method provides M estimates that are approximately 40% higher across the range of modeled ages. When used to derive overfishing definitions, this difference provides substantially more risk-prone outcomes in terms of target or threshold F rates. This violates the intent of the NSGs in establishing target and limit reference points that are explicitly *risk averse* if the input value t_{MAX} is less than the 99th percentile of longevity.

Where empirically derived estimates of M are available for a stock, the Working Group may choose to co-opt these estimates for use in the amendment. Such estimates should preferably be the outcome of a directed research investigation designed to estimate M, in contrast to indirect methods using survey data in which the effects of indirect losses to the stock are not properly quantified. In such approaches, the instantaneous rate of total annual mortality Z is the quantity estimated, and M inferred by subtraction of an imposed F. The value of M specified in the Plan for any stock must be scientifically defensible. At a minimum, it must be consistent with the life-history of the species.

☞ ***Action Item III.1. Instantaneous Natural Mortality [M]:***

The Amendment will:

a. Describe the method that will be used to estimate M for each crab species subject to this Plan.

b. Describe how the rate M will be applied in the overfishing definition and in the MSY Control Rule for each stock.

2. <u>Plan Overfishing Definition and Z_{MSY}</u>:

The instantaneous rate of total annual mortality [Z] is defined as M + F. Most derived limit reference points [e.g., F_{MSY}] are outcomes of structured modeling frameworks whose value depends on the specified input M. While M may change inter-annually, or may be age or size-variant, empirical studies are commonly lacking to provide such understanding. The principle in the MSFCMA of fishing at F_{MSY} is that, given a specified value of M, the Plan will define conservation and management measures to maintain total annual losses from the stock at or below the sum of $F_{MSY} + M$. Hence, at or below $Z_{MSY} = F_{MSY} + M$. It's the

modeled Z_{MSY}, not F_{MSY}, that produces the measure of interest - the production of sustainable yields at the maximum [MSY], from a stock maintained at B_{MSY}, under and applied fishing rate F_{MSY}.

Heretofore in crab stock assessment and harvest strategy modeling, M has been estimated annually in excess of that specified in the overfishing threshold definitions for the stocks. Even in such instances, harvest goals are derived using the full value of F_{MSY}. Declines in abundance seen in the survey and not attributed to the retained catch, are assumed to result from inter-annual changes in natural mortality. Whether such declines result from true changes in M or from background bycatch or discard losses, the realized Z on exploited stocks has been allowed to exceed Z_{MSY} in practice without meeting the overfishing test standard of the Plan. Hence, without conforming to the intent of fishing below an overfishing threshold definition deemed appropriate for each stock.

☞ ***Action Item III.2. Plan Overfishing Definition and Z_{MSY}:***

The Amendment will:

a. Describe how Z_{MSY} will operate as a limit reference point for each stock.
b. Describe how Z_{MSY} will be applied in the overfishing definition and the MSY Control Rule for each stock.
c. Describe how Z_{MSY} will be applied in assessing the performance of the fisheries and the adopted conservation and management measures.

3. Instantaneous Fishing Mortality Rate F and Annual Exploitation Rate [u]:

The Plan fails to specify the proper use of F and u in devising conservation and management measures consistent with adopted overfishing definitions. In practice, F and u have been incorrectly used interchangeably in computational formulae that estimate preseason harvest levels. Where M and F compete for deaths during a fishery, or where losses from M occur between the time of the survey and the fishery opening, using the numerical value of F in place of the proper value of u results in overestimating the exploitation rate corresponding to that F. It also results in overestimating preseason harvest quotas.

The Plan also incorrectly uses the *"rate of utilization"* in place of exploitation rate as a status determination criterion for determining if overfishing is occurring. The utilization rate refers only to the retained catch and does not consider indirect losses from the stock from bycatch or discards. Exploitation rate is based on the fully-recruited F, fishery selectivities and natural mortality. Utilization rate underestimates exploitation rate if any indirect losses occur in the stock. If used as a status determination criterion, it provides more risk prone assessment outcomes.

☞ ***Action Item III.3. Instantaneous Fishing Mortality [F] and Exploitation Rate [u]:***

The Amendment will:

a. Describe how the fully-recruited F rate and fishery selectivity will be employed to derive the exploitation rate corresponding to the target or threshold F definitions in the Plan.

b. Prescribe what is the exploited component of each stock that is subject to the target or threshold Fs in the Plan.

4. Non-Directed Mortalities and Overfishing Definitions:
The Plan inadequately specifies the operational use of discard and bycatch mortalities in the formulation of target or threshold F rates, and in the estimation of preseason harvest goals. The lack of incorporation of these mortalities in the operational framework of the Plan results in estimating and applying F [or u] rates and catch quotas that exceed the overfishing definitions of the Plan.

☞ ***Action Item III.4. Non-Directed Mortalities and Overfishing Definitions:***
The Amendment will:

a. Describe how discard mortalities will be employed to derive the exploitation rate corresponding to the target and threshold F rates specified in the Plan.
b. Describe the approach to estimate the discard loss rates from the directed fishery for each stock, or the values of those rates.
c. Describes the approach to estimate the bycatch loss rates from the non-directed fisheries for each stock, or the values of those rates.

5. Biomass B_{MSY} and Sustainable Yield [SY]:
The Plan inadequately defines the equilibrium stock biomass [B_{MSY}] that will produce the maximum sustainable yield from each stock. The definitions of B_{MSY} may be underestimated for some stocks which would result in risk-prone outcomes in terms of judging stock health or stock recovery, or for assessing if the stock is overfished. This violates the intent of the NSGs in establishing reference values that are explicitly risk averse.

The Plan's B_{MSY} values for each stock are defined by the average survey estimate of total mature biomass [TMB] for the 15-years from 1983-97. The BS crab stocks were not in equilibrium during this period. Instead, they illustrated significantly varying trends in overall abundance. They were at levels of stock biomass that would not produce MSY on a continuing basis by definition. Computing B_{MSY} and MSST using data from this 15-year period may underestimate overfished definitions thereby specifying biomass standards that are artificially low.

The MSY Control Rule of the Plan specifies that the MFMT = F_{MSY} = M, where for *Chionoecetes* sp., M = 0.30, and for *Lithodes* sp., M = 0.20. Overfishing would occur if fishing mortality [F] exceeded the MFMT, F_{MSY}, in any year. Amendment #7 of the Plan defines MSY as *"the mature biomass of the stock ... exploited at a fishing mortality rate equal to a conservative estimate of natural mortality"*. While the Environmental Assessment [EA] of Amendment #7 defines a status determination criterion for overfishing as the *"expected utilization rate as the projected guideline harvest level divided by the estimated legal male abundance"*. Utilization rate is not equivalent to exploitation rate since it does not account for indirect losses due to bycatch or discards. Utilization rate underestimates

exploitation rate in such instances. This criterion is further lacking since it uses "*expected*", not "realized" utilization rate, based on "*projected guideline harvest level*", not the "realized catch". In practice, stock losses due to natural mortality from the time of the survey to the fishery have also been unaccounted for in harvest setting.

The status determination framework in the Plan does not require that this "*utilization rate*" be compared to the MFMTs based on the F_{MSY} specified in the MSY Control Rule or to any retrospectively derived estimate of fully-recruited F. A further complication is a description in the Executive Summary of the SAFE Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions and in Amendment #7 which defines a catch standard called sustainable yield [SY] = TMB*F_{MSY}. The SAFE report states that "*overfishing occurs if the harvest level exceeds the SY in one year*" - a definition that is not contained in Amendment #7. This latter definition is wholly lacking and theoretically inconsistent. For *C. opilio* in 2003, this definition would allow the removal of every male ≥ 4" cw, of every shell condition throughout the entire BS geographic range [i.e., u = 100%, F = ∞] without meeting the overfishing threshold standard. [see Item 13., p.5 of *Addendum to the Crab Plan Team Meeting Minutes of 22-24 September 2003* for the numerical illustration].

Sustainable yield as derived by TMB*F_{MSY} is not computed on the exploited portion of the stock. TMB includes mature female biomass which is not a component of landings. TMB also includes mature males of smaller size than the minimum size limits, and males of shell condition which are not targeted by the fishery or main component of yield. For some stocks, TMB includes components of the stock which are geographically not fished. The stock of *C. opilio* is noteworthy in this regard.

The sustainable yield that can be taken from a stock is meant to represent a measure of production which can be removed in excess of that necessary to provide stock replacement. It is often based on long-term dynamic equilibrium theory and results from a stock's inherent production characteristics. The Bering Sea crab stocks under this Plan have neither demonstrated the ability to replace total annual losses, nor the ability to maintain themselves in dynamic equilibrium. They have instead fallen and remained at exceedingly low levels of biomass. The inability of these stocks to respond to declines in abundance suggests that they have fallen to levels below their compensatory reserve.

A conceptual mismatch exists in the Plan concerning the stock component used to estimate harvest goals by the MSY Control Rule and the component of the stock exploited by the fishery. This application has led to exceedingly high rates of exploitation born by specific segments of the stock, and to localized depletions as exemplified by changes in the spatial distribution of *C. opilio* over time.

☞ ***Action Item III.5. Biomass B_{MSY} and Sustainable Yield [SY]:***

The Amendment will:

a. Describe the approach to estimate B_{MSY} or a proxy thereof.
b. Prescribe the exploitable abundance component of the stock to be used to estimate harvest goals.

c. Describe the approach to estimate catch standards using the exploitation rate corollary to the target F on the exploitable component of the stock.

6. Conservation Equivalency:

The MSY Control Rule of the Plan is not attentive to exceeding annual target F rates or specified overfishing definitions. No framework exists in the Plan for considering the consequences of such outcomes on stock biomass, or for safeguarding the long-term reproductive potential of the stock. The operational framework of the Plan provides no explicit control feedback to safeguard long-term stock productivity, or to insure stabilities in stock abundance or yield.

Harvest goals estimated for exploited stocks should include all direct and indirect stock removals, and relate directly to target or threshold fishing mortality rates specified in the Plan. The current crab Plan does not specify target fishing rates lower than the threshold limit reference points [F_{MSY}] as recommended by NSG 1. For these stocks, harvest control analyses estimate preseason harvest goals from survey-based estimates of stock biomass. Customarily, preseason harvest goals are exceeded by the fisheries - hence, the F rates on which the goals were based are also customarily exceeded.

Routinely exceeding threshold fishing mortality rates for most exploited fishery resources often leads to the erosion of stock biomass and to declines in the long-term productivity. The rates of such declines vary proportionally to the level of fully-recruited F in excess of threshold. Exceeding a target F rate would minimally result in a lower standing or spawning stock biomass in any year vs not having exceeded those rates. This practice is inconsistent with the intent of the NSGs in establishing biological reference points that are explicitly risk averse.

The concept of Conservation Equivalency as practiced or implemented in inter-jurisdictional State or Federal fishery management plans accounts for the outcome of exceeding target or threshold F rates. It provides for the maintenance of reproductive potential and stock biomass standards specified in the Plan. Requisite adjustments are made in the MSY Control Rule to reconstitute stock status resulting from over-achieving target fishing rates or harvest goals.

☞ ***Action Item III.6. Conservation Equivalency:***

The Amendment will:

a. Specify the approach of Conservation Equivalency which will serve to maintain stock biomass standards established in the Plan.
b. Identify the currency of measure for determining the equivalent conservation value used to adjust the MSY Control Rule in response to exceeding overfishing definitions in the Plan.
c. Describe the analytical framework to be applied in the Plan's MSY Control Rule for target rate setting that would achieve stock conservation equivalency and the specified stock biomass standards.

7. Tier System for Defining Overfishing Definitions:
Under the MSFCMA and the SFA, overfishing is defined as any amount of fishing in excess of the maximum fishing mortality threshold [MFMT]. In the NPFMC's BSAI and GOA Groundfish Fishery Management Plans, the MFMT or F_{OFL} is prescribed through a set of six tiers based on the level of information availability on the stocks. The BSAI King and Tanner Crab FMP contains a reduced tier system that is not fully implemented.

In the crab Plan, overfishing definitions for all stocks are derived under what would be lower tier standards for groundfish. Such overfishing definitions acknowledge incomplete or unreliable information and understanding of the stocks and the fisheries. In contrast, the current stock assessment and harvest strategy modeling rely on fully parameterized population dynamic models, such as stock-recruitment, to estimate stock abundance, guideline harvest levels, and target exploitation rates, or their corollary fishing mortality rates, corresponding to the overfishing thresholds [F_{OFL}]. Whether the available information and understanding for these stocks is sufficient for these purposes is at question.

A Tier System is needed in the crab Plan for prescribing the maximum fishing mortality threshold [MFMT] rates analogous to the groundfish Plans, with modification. The tiers would similarly correspond to orders of information availability on the stocks, and further explicitly address uncertainty in that information. The Tier System would reflect the annual status of stocks [SOS] - its understanding and uncertainty - as well the status of knowledge [SOK] per the groundfish Plans. This modified system would reflect the challenges faced in conducting analytical stock assessments on invertebrate fishery resources, and in formulating population dynamic models that provide meaningful output, such as target or limit biological reference points.

☞ ***Action Item III.7. Tier System for Defining Overfishing Definitions:***
The Amendment will:

a. Define a Tier System for prescribing the threshold overfishing definitions for each stock.
b. Formulate the system for setting F_{OFLs} that considers both the status of knowledge and its uncertainty, and the status of the stocks.
c. Describe the approach for formally integrating the Tier System and the Limit Reference Point System [see Item II.8] for prescribing target or threshold fishing mortality rates for each stock.

8. Limit Reference Point [LRP] System:
Caddy [1998] proposed a limit reference point system for gauging the annual health and status of the stocks. Limit reference points represent meaningful and measurable indices of stock health and status. These reference points are evaluated and used to derive an aggregate index of stock health that is implemented in a *"Traffic Light System"*.

Caddy's diagnostic Traffic Light System is suitable to stocks for which uncertainty exists in quantifying reference points due to the lack of information or to low confidence in that information. The approach assesses stock and fishery status by a suite of non or semi-

quantitative multiple criteria. Its provides guidance as to the emphasis to be placed in applying the precautionary approach. Using a set of limit reference points to gauge the status of the stocks and the fisheries, the results indicate the management response requisite to achieving Plan goals. These responses are formulated in the MSY Control Rule for setting F_{OFLs} or target fishing mortality rates.

Several candidate LRPs are suitable to stocks under this Plan. These would include biomass [B], fishing rate [F], total annual mortality rate [Z], recruitment [R], trajectories in both stock biomass [B_T] and recruitment [R_T], and uncertainty in the estimates of any of these metrics [e.g., B_U, F_U, $Z_{U\ldots}$]. Other LRPs may also be suitable.

☞ ***Action Item III.8. Limit Reference Point System:***

The Amendment will:

a. Identify the suite of LRPs essential to gauging stock and fishery status.
b. Define a Traffic Light System for the status of stock and fishery assessment that is integrated in the MSY Control Rule.
c. Describe the method of enumerating annual SOS that would replace the current determination of stock biomass relative to threshold.
d. Define the limit reference point system and its use in a control rule that specifies the F Buffer Zone, F Target Zone and F Overfishing Zone.
e. Define the method to link the Limit Reference Point System and the Tier System for prescribing the maximum fishing mortality threshold or target F rates for each stock.
f. Prescribe how these combined systems would be used to set F_{OFL} values appropriate to the current status of the stock and fisheries.

9. Projection Modeling Framework:

The Plan lacks a suitably rigorous and informative modeling framework for evaluating the consequences of alternative fishery conservation and management measures on stock health. A general simulation framework is required for assessing how the stocks and fisheries would perform if fished at target or threshold Fs. Where specific outcomes are desired by a proposed management control [e.g., increase in stock biomass], this framework should provide quantified and reliable measures of achieving that outcome.

Restrepo et. al [1998] describe a fishery management strategy as *"the combination of data collection, stock assessment, control rules, and technical measures for implementing the harvest controls"*. In their review of stock assessment methods, the National Research Council stated *"Both harvesting strategies and decision rules for regulatory actions have to be evaluated simultaneously to determine their combined ability to sustain stocks"* [1998]. A flexible, generalized simulation modeling framework is required for evaluating management strategies for the BS crab stocks under this Plan. This includes specifying the performance criteria that will be examined in the evaluation process.

The NSG 1 describes the remedial action required to rebuild stocks once biomass has fallen below the MSST. The time frame for rebuilding depressed stocks is 10 years where

stock productivity characteristics allow, or some function of generation time when the expected time to rebuild under zero fishing is greater than 10 years. The intent of the MSFCMA is that overfished stocks be rebuilt quickly.

Where a stock is under a rebuilding plan, rebuilding trajectories of stock biomass given current population dynamic model formulations need to be compared to the rebuilding plan trajectories of stock biomass to evaluate the success of implemented management measures. In the current crab rebuilding plans, trajectories in expected stock biomass are not specified for the various management alternatives modeled. Restrepo et. al [1998] characterize a rebuilding plan as a strategy for selecting fishing mortality rates to achieve stock recovery within a specified time frame. Components of such plans include a *"rebuilding period"* and a *"rebuilding trajectory"* among others. A rebuilding Control Rule is specified that incorporates these components.

Even where stocks are not under rebuilding plans, a desirable property of any MSY control rule is that its application should always lead toward returning the stock to B_{MSY}. To guard against dramatic declines in stock biomass and the need to implement rebuilding plans, a desired property of an overfishing control rule would be to afford *"built-in"* rebuilding as stock size declines below the *MSY Stock Size*. In this manner, greater and more stable yields to the fisheries could be realized, as well as conferring stability to the reproductive potential of the stock. The MSY Control Rule of this Plan does not to provide these measures of protection to the stocks or to the fisheries.

☞ ***Action Item III.9. Projection Modeling Framework:***

The Amendment will:

a. Define a suitable analytical framework for examining the consequences of alternative conservation and management measures on stock status.
b. Specify the performance criteria that will be examined in the process of evaluating harvest strategies and decision rules.
c. Define a general simulation framework for developing rebuilding plans that achieve stock recovery in the requisite time frame. Plan components will specify both the rebuilding period and rebuilding trajectory.
d. Define a general simulation framework that would specify the rebuilding control rule for to each stock under a rebuilding plan.
e. Define an analytical framework that would prescribe the overfishing control rules for each stock.

10. <u>Sensitivity Analysis</u>:

As described under Action Items II.1 and II.2, this amendment will revise the overfishing and overfished definitions in the Plan, and specify status determination criteria for evaluating the performance of each fishery management system. These definitions will meet the conservation requirements of the Acts in safeguarding long-term stock productivity. They will also address the essential goal of formulating strategies and decision rules that are consistent with precautionary management practices.

Where data and understanding allow, limit reference points will be estimated within structured models that reflect the species essential biological and life-history characteristics, as well as their population and fishery dynamics. The suitability of such parameterized model structures for this purpose will depend on the validity of the input parameter values chosen to represent these essential processes.

For crab stocks under this Plan, key parameters belong to one of two main categories: [1] those related to the species itself [i.e., biological, life-history and population dynamics], and [2] those related to the fishery, and a lesser category related to the survey. Species-specific parameters include natural mortality, molt probability, growth increment, mating ratio, schedules of maturity and fecundity, weight @ size, longevity and recruitment. Fishery-specific parameters include the fishing season [duration and timing], discard mortality, bycatch mortality and the partial recruitment pattern. The latter reflects both crab *availability* [temporal and spatial distribution relative to the fishery] and the *selectivity* of crabs of different ages or sizes by the gears. Net selectivity is a key survey-specific parameter. Changes in these parameters due to natural variability or to changes in the fishery management system will affect estimates of reference points. To assess these affects and derive robust reference point values, sensitivity analyses will be performed.

Sensitivity analysis is of value in two broad respects. First, in instances where there is low confidence or poor understanding of a parameter value, the analysis can be configured with a restricted range of reasonable estimates of this parameter so as to examine the effects on model outcomes. Secondly, sensitivity analyses can be performed on the entire model structure and parameter space in order to provide understanding the relative contribution of parameters to model performance. The latter would be insightful in terms of identifying critical model dependencies which are important considerations in research planning aimed at meeting the essential information needs of the stocks. The formulation of effective fisheries conservation and management measures for these stocks indeed depends on such understanding. Sensitivity analyses conducted by the Working Group as part of this amendment will address both of these objectives.

☞ ***Action Item III.10. Sensitivity Analysis:***

The Amendment will:

a. Identify the important fishery and stock parameters whose variation would affect the overfishing and overfished threshold definitions.
b. Define an analytical framework that would be used to conduct sensitivity analyses of these reference points for each stock.
c. Define an analytical framework that would be used to select robust overfishing and overfished values based on sensitivity analyses.
d. Identify the critical information needs for management which would guide research planning for these stocks.

Attachment 5

North Pacific Fisheries Management Council
Bering Sea / Aleutian Islands King and Tanner Crab Working Group

Progress Report to the Crab Plan Team
22 September 2004

L. Rugolo, S. Shareef, J. Turnock and J. Zheng

I. Overview of the Statement of Work of the Working Group:

The Statement of Work [or Work Plan] of the Working Group defines the scope of responsibilities of the Group, and specifies proposed technical revisions to the Bering Sea / Aleutian Islands King and Tanner Crab Fishery Management Plan. A total of thirteen technical features of the FMP are identified as in need of revision to achieve Plan compliance with governing Federal laws, National Standards and Guidelines. Amendments to the Plan are presented in two sections of the Statement of Work: Revisions to the Plan [Section II], and Additional Technical Components to Implement in the Plan [Section III]. In each section, specific Action Items are identified for implementation. An overview precedes each item which provides the rationale for amending that element of the FMP. The value of each Action Item to the conservation and utilization of these stocks will be specified in the Environmental Assessment of the Plan amendment.

The following is excerpted from the Statement of Work [1.15.04]. The reader is referred to the full version of the Work Plan for a more complete description of the Action Items and the rationale for their inclusion in the Plan amendment. For consistency with the Statement of Work, we maintain here the numbering scheme of the thirteen Action Items per the Statement of Work. This scheme is: Action Items II.1 to II.3, and Action Items III.1 to III.10.

Section II: Revisions to the Plan

For stocks subject to this FMP, the threshold definition of overfishing, the definition as to whether the stock is overfished, and the overfishing control rule require revision. The SFA requires that status determination criteria specify both a maximum fishing mortality threshold [MFMT], and a minimum stock size threshold [MSST]. Stocks are assessed according to whether the maximum fishing mortality threshold is exceeded, and whether the stock is below the minimum stock size threshold. If the fishing mortality rate is above threshold, then overfishing is occurring. If the stock size is below the minimum threshold, then the stock is overfished. If overfishing is occurring, fishing mortality must be reduced so that stocks can produce maximum sustainable yield [MSY] on a continuing basis. For stocks that are overfished, rebuilding plans with an acceptable likelihood of success must be implemented to rebuild stocks to the MSY level within an appropriate time frame.

The National Standard 1 requires the adoption of conservation and management measures that prevent overfishing while providing optimum yield [OY] on a continuing basis. The advisory guidelines for NS1 recommend a precautionary approach to specifying OY. The precautionary approach guidelines identify MSY as the minimum standard for defining management limits. A principle feature of the precautionary

approach to management is the definition of *limits* to safeguard long-term stock productivity. The NSGs define two limits for management that are required to insure stock conservation and yields close to MSY. These are the MFMT and MSST intended as benchmarks to gauge overfishing and overfished status criteria. The precautionary approach specifies *targets* that are set safely below these limits. Target setting considers uncertainty and other management objectives. Criteria used to set limit and target levels should be explicitly *risk averse*. Status determination criteria are used to evaluate limit and target reference point systems.

The Working Group will devise overfishing and overfished definitions, and MSY Control Rules for the stocks that are in compliance with governing Acts, and with their attendant Standards and Guidelines. The Amendment will specify thresholds to serve in determining if a stock is being overfished or if it's in an overfished state. It will specify the MSY control rule that intrinsically links these definitions for each stock.

Action Item II.1. Overfishing Definition:
A maximum fishing mortality rate [F] threshold [MFMT], or reasonable proxy thereof. Such a limit reference point, or F_{OFL}, will:

a. Represent the 'full-selection F' or the 'fully-recruited F' rate.
b. Encompass indirect losses to the stock as discards, and non-directed losses as bycatch from non-target fisheries.
c. Prescribe the F-based overfishing definition for the stock component exploited by the fishery - i.e., the exploitable stock biomass or its corollary, exploitable stock abundance.
d. Prescribe proxy overfishing definitions if required. Proxy definitions will be needed when the F_{MSY} cannot be estimated or when the estimated value is deemed unreliable [e.g., extremely low precision, insufficient contrast in the data, or inadequate models]. The choice among proxy measures must conform to the conservation requirements of the Acts in defining limits intended to safeguard the long-term productivity of the stock.

Action Item II.2. Overfished Definition:
A minimum stock size threshold MSST, or reasonable proxy thereof, expressed in terms of spawning biomass or other measures of reproductive capacity. The MSST should be the greater of either one-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock were exploited at the full MFMT. Formulation of this definition should satisfy:

a. The Act's conservation requirement of safeguarding the long-term productivity of the stock.
b. Where data allow, it would be derived in a structured modeling framework that reflects the species' essential biological and life-history characteristics, as well as its population and fishery dynamics.
c. Proxy overfished definitions should be scientifically defensible and supported by empirical evidence. Proxy definitions will be needed when the MSST cannot be estimated or when the estimated value is deemed unreliable [e.g., extremely low precision, insufficient contrast in the data,

or inadequate models]. The choice among proxy measures must conform to the conservation requirements of the Acts in defining limits intended to safeguard the long-term productivity of the stock.

Action Item II.3. MSY Control Rule:
In the National Standard Guidelines, the two limit definitions are intrinsically linked through an MSY Control Rule that specifies how the F threshold varies as a function of stock biomass to achieve continuing yields close to MSY. Control rules are pre-established plans for implementing management decisions without delay in response to changing status of the stock. The NSG1 states that the choice of a control rule should be guided by the characteristics of the fishery, the FMP's objectives and the best scientific information available. To minimize the occurrence of stock sizes for which rebuilding plans are required, the MSY Control Rule should afford *"built-in"* rebuilding as stock size declines below the MSY Stock Size.

Action Items Item III.7 and III.8 describes a method to link the Plan's MSY Control Rule to an integrated *Tier System* and *Limit Reference Point System*. Action Item III.9 discusses desirable properties of control rules to achieve in this amendment.

Section III. Additional Technical Components to Implement in the Plan
The Statement of Work specifies additional technical elements to implement in a Plan amendment required to meet Federal fisheries management responsibilities. Ten key fisheries scientific and technical components of the current FMP require amending. The Working Group acknowledges that additional elements may be included in order to achieve compliance of the FMP with the governing Acts, and with their attendant Standards and Guidelines.

Action Item III.1. Instantaneous Natural Mortality [M]:
The Amendment will:

a. Describe the method that will be used to estimate M for each crab species subject to this Plan.
b. Describe how the rate M will be applied in the overfishing definition and in the MSY Control Rule for each stock.

Action Item III.2. Plan Overfishing Definition and Z_{MSY}:
The Amendment will:

a. Describe how Z_{MSY} will operate as a limit reference point for each stock.
b. Describe how Z_{MSY} will be applied in the overfishing definition and the MSY Control Rule for each stock.
c. Describe how Z_{MSY} will be applied in assessing the performance of the fisheries and the adopted conservation and management measures.

Action Item III.3. Instantaneous Fishing Mortality [F] and Exploitation Rate [u]:

The Amendment will:

a. Describe how the fully-recruited F rate and fishery selectivity will be employed to derive the exploitation rate corresponding to the target or threshold F definitions in the Plan.

b. Prescribe what is the exploited component of each stock that is subject to the target or threshold Fs in the Plan.

Action Item III.4. Non-Directed Mortalities and Overfishing Definitions:

The Amendment will:

a. Describe how discard mortalities will be employed to derive the exploitation rate corresponding to the target and threshold F rates specified in the Plan.

b. Describe the approach to estimate the discard loss rates from the directed fishery for each stock, or the values of those rates.

c. Describes the approach to estimate the bycatch loss rates from the non-directed fisheries for each stock, or the values of those rates.

Action Item III.5. Biomass B_{MSY} and Sustainable Yield [SY]:

The Amendment will:

a. Describe the approach to estimate B_{MSY} or a proxy thereof.

b. Prescribe the exploitable abundance component of the stock to be used to estimate harvest goals.

c. Describe the approach to estimate catch standards using the exploitation rate corollary to the target F on the exploitable component of the stock.

Action Item III.6. Conservation Equivalency:

The Amendment will:

a. Specify the approach of Conservation Equivalency which will serve to maintain stock biomass standards established in the Plan.

b. Identify the currency of measure for determining the equivalent conservation value used to adjust the MSY Control Rule in response to exceeding overfishing definitions in the Plan.

c. Describe the analytical framework to be applied in the Plan's MSY Control Rule for target rate setting that would achieve stock conservation equivalency and the specified stock biomass standards.

Action Item III.7. Tier System for Defining Overfishing Definitions:

The Amendment will:

a. Define a Tier System for prescribing the threshold overfishing definitions for each stock.

b. Formulate the system for setting F_{OFLs} that considers both the status of knowledge and its uncertainty, and the status of the stocks.

c. Describe the approach for formally integrating the Tier System and the

Limit Reference Point System [see Item II.8] for prescribing target or threshold fishing mortality rates for each stock.

Action Item III.8. Limit Reference Point System:

The Amendment will:

a. Identify the suite of LRPs essential to gauging stock and fishery status.
b. Define a Traffic Light System for the status of stock and fishery assessment that is integrated in the MSY Control Rule.
c. Describe the method of enumerating annual SOS that would replace the current determination of stock biomass relative to threshold.
d. Define the limit reference point system and its use in a control rule that specifies the F Buffer Zone, F Target Zone and F Overfishing Zone.
e. Define the method to link the Limit Reference Point System and the Tier System for prescribing the maximum fishing mortality threshold or target F rates for each stock.
f. Prescribe how these combined systems would be used to set F_{OFL} values appropriate to the current status of the stock and fisheries.

Action Item III.9. Projection Modeling Framework:

The Amendment will:

a. Define a suitable analytical framework for examining the consequences of alternative conservation and management measures on stock status.
b. Specify the performance criteria that will be examined in the process of evaluating harvest strategies and decision rules.
c. Define a general simulation framework for developing rebuilding plans that achieve stock recovery in the requisite time frame. Plan components will specify both the rebuilding period and rebuilding trajectory.
d. Define a general simulation framework that would specify the rebuilding control rule for each stock under a rebuilding plan.
e. Define an analytical framework that would prescribe the overfishing control rules for each stock.

Action Item III.10. Sensitivity Analysis:

The Amendment will:

a. Identify the important fishery and stock parameters whose variation would affect the overfishing and overfished threshold definitions.
b. Define an analytical framework that would be used to conduct sensitivity analyses of these reference points for each stock.
c. Define an analytical framework that would be used to select robust overfishing and overfished values based on sensitivity analyses.
d. Identify the critical information needs for management which would guide research planning for these stocks.

II. Work Plan Presentation to SSC:

In February 2004, Lou Rugolo and Shareef Siddeek presented the Working Group Statement of Work to the Scientific and Statistical Committee of the North Pacific Fishery Management Council. The following are the SSC's comments on the Work Plan as extracted from the NPFMC's Minutes of the February 2004 SSC meeting:

> Lou Rugolo (NMFS) and Shareef Siddeek (ADF&G) presented an overview of the progress of their working group to revise the overfishing definitions in the crab FMP. Public comment was provided by Arni Thomson of the Alaska Crab Coalition.
>
> The crab working group is comprised of four members, two from NMFS and two from ADF&G. When the overfishing definitions were originally developed by the crab plan team, they had intended that they be revisited in a period of 5 years or so. Now, 5 years later, this working group is embarking on this task. In its September 2003 meeting minutes, the crab plan team specified that the charge of the working group is to "lead the analysis of a new FMP amendment to revise overfished/overfishing definitions."
>
> The SSC believes that it is appropriate to undertake a review of these crab plan definitions. A number of inconsistencies and unnecessary complexities have been uncovered, and improvements can be made.
>
> Top priority should be given toward a careful examination and revision of the definitions of overfishing and overfished, as indicated by the crab plan team. In the course of embarking on this priority task, other closely related issues must be reevaluated, such as B_{MSY}, natural mortality rate (M), MSST, and MFMT. There is a linkage among all these parameters, so population simulation modeling, biomass dynamic modeling, and yield-per- recruit analyses would inform this analysis. For instance, MFMT should be considered under alternative definitions of MSST in the context of stock rebuilding and attainment of other management objectives. Effects of natural variation in recruitment and uncertainty in stock assessments and mortality on these estimates should be considered.
>
> The SSC notes that the estimation of M and B_{MSY} is difficult for these crab species. For instance, estimates of B_{MSY} depend upon the period over which data are used, and the choice of the appropriate time period may be subjective. The current FMP defines overfishing using explicit values of M for king and Tanner crab stocks that were developed based on estimates of longevity. As new estimates of M are developed, the SSC recommends frame working these definitions in the FMP so that future plan amendments are unnecessary when new data and analyses result in new estimates of M.
>
> The working group discussed an intention to explicitly link M estimates in population models with M estimates used in harvest control rules. The SSC supports this goal, but also notes that there could be reasons for these two sets of estimates to differ. First, M used to define harvest control rules may be based

on life history considerations, whereas M may be estimated internal to the population dynamic model such that best fits are attained. However, survey catchability and selectivity are confounded with M in population models, so neither one of these parameters may be estimated with much confidence. It may be possible to craft a stock assessment scenario, in which M is fixed at the same level as in the harvest control rule, allowing catchability and/or selectivities to be estimated. Second, to the extent that some crab stocks apparently experience large, short-term increases in M perhaps due to disease or environmental causes, it may be undesirable to trigger commensurate increases in F at a time of population crash. Presumably, this would be the outcome if population model estimates of M were directly translated into harvest policy. Instead, simulation modeling can be used to develop long-term harvest policies that are more risk averse to these and other uncertainties in stock dynamics.

The SSC recommends that the working group consider one additional facet in their work plan. Typically, crab abundance is estimated by summer crab surveys or population models that incorporate summer survey data. To estimate the overfishing level, MFMT should be applied to estimated crab abundance at the time of the fishery. As crab fisheries occur in fall or winter, summer crab abundance should be discounted for the natural mortality that occurs between the time of the survey and the time of the fishery. Failure to do so results in misapplication of the overfishing definition.

Since the analysis has not yet been conducted, statements made during the presentation suggested that a plan amendment could include higher estimates of B_{MSY}, higher MSSTs, lower estimates of M, lower MFMTs, and perhaps lower target harvest rates to stay safely below MFMT. Such statements should be avoided until the analyses are completed and reviewed.

As a plan amendment is developed, it should be brought forward to the NPFMC and Alaska Board of Fisheries on parallel tracks. This should be workable, as the Board of Fisheries is scheduled to address BSAI crabs in March 2005.

For its next meeting, the SSC asks the working group to present an outline of the new draft control rule system that might be applied to BSAI crabs. A more formalized procedure for setting overfishing levels, such as the tier system for groundfish, is preferred. Like the groundfish tier system, rather than a constant F limit reference point, the working group should consider scaled-down reductions in F_{OFL} as the stock declines to low levels.

III. Working Group Meetings:

To date, the WG has met on four occasions [11/03, 03/04/ 06/04 and 09/04]. The next meeting is tentatively scheduled for November 2004. Work progresses on many fronts and notable progress has been made on key components of the Work Plan. The agendas for each of the meetings are appended to this Progress Report to provide context and understanding of our work and considerations during this time.

IV. **Alternatives to the Environmental Assessment:**
The Working Group is proposing three alternatives to the Environmental Assessment Amendment to the BSAI King and Tanner Crab Fishery Management Plan. The analysis will evaluate the consequences of each alternative to formulating conservation and utilization decisions concerning the stocks. These are:

1. Status Quo

   Maintain the current overfishing and overfished definitions in the FMP.

2. Specify numerical values of the biological reference points in the plan. Specify formal review process by assessment team of estimated threshold stock and fishing rate values [F_{OFL} and B], full-selection F and current stock biomass.

   a. Assessment team review will determine status criteria of overfishing and overfished.

   b. Assessment team will conduct annual assessment of the status of the stocks using the limit reference point system specified in the plan.

3. Framework biological reference points in fishery management plan. Specify formal review and approval process by assessment team of annual stock assessment estimation of threshold stock and fishing mortality rate values [F_{OFL} and B], full-selection F and current stock biomass.

   a. Assessment team review will determine status criteria of overfishing and overfished.

   b. Assessment team will conduct annual assessment of the status of the stocks using the limit reference point system specified in the plan.

V. Approach to Estimate Biological Reference Points for Bering Sea and Aleutian Island Crab Stocks: Preliminary Deterministic Calculations Using Bristol Bay Red King Crab Stock Information

Introduction

The proposed new tier system for BSAI crab stocks identifies F_{MSY} and B_{MSY} as limit reference points for data rich stocks (Tiers 1&2) and it prescribes F% and corresponding spawning biomass ratio (B%) as limit reference points for data poor stocks (Tiers 3 to 5). We are currently looking into Clark's (1991, 1993, 2002) approach and modifying his method to suit crab biological characteristics and estimate F% and B% for data poor stocks. Our approach is as follows:

1. Estimate F% for the Bering Sea and Aleutian Islands (BSAI) crab stocks with standard deterministic stock-recruitment (S-R) relationships (Beverton-Holt (1957) and Ricker (1954)). We used the Bristol Bay red king crab (a data rich stock) population dynamics parameters to test whether Clark's (1991) method of F% estimation is suitable for crab stocks. Preliminary estimate of F% under one scenario, sensitivity of that F% value to equilibrium recruitment and biomass are reported here.

2. Estimate the same biological reference points following a stochastic approach using the same two S-R models, adding variability to the recruitment generated by the two deterministic S-R models and fishing mortality (which takes account of abundance variability). Perform sensitivity analysis of important parameters (different M levels, high and low molt probability, high and low handling mortality) on the biological reference points. Assess the mean yield, variability of yield (e.g., CV of yield), and probability of stock collapse in a time horizon under a given F%.

3. Repeat Task #2 under a completely random recruitment scenario (i.e., no S-R relationship exists, see Booth (2004)).

4. Repeat Task #2 with a Beverton-Holt S-R depensation model (Myers et al. 1995).

Method 1. Estimation of F% Using Bristol Bay Red King Crab Stock Parameters

The Bristol Bay red king crab stock parameters (Zheng unpublished), except a lower M and a lower productive stock-recruitment curves, were used to test Clark's (1991) deterministic per-recruit analysis approach in determining F%. Clark determined F% (his estimate for the typical groundfish based on deterministic S-R relationship was F35%) by identifying a relative spawning biomass-per-recruit (SSB/R) value that corresponds to the **maximum of minimum** relative yields (yield / MSY) for a range of relative SSB/R values. Once the F% is determined, the exact full-recruitment fishing mortality (in Clark's notation F_{MMY}) can be estimated using the relative SSB/R vs. F curve.

We first identified the probable range of steepness parameter values (Tau) of the standard S-R curves based on the assumption that high Tau values, which lead to the stock collapse at F < 2M and low Tau values that do not cause the stock collapse at F > 7M, were improbable. Clark (1991) used the similar criteria to select his D range (which is equivalent to 1/Tau). The difference between our approach and Clark's approach is that Clark assumed recruitment and maturity at the same age to select his Tau range whereas we assumed maturity at younger age than recruitment. Our approach results in lower productive stock-recruitment curves than Clark's approach. Then we estimated various yield and biomass quantities using the base parameter values, S-R relationship, and the selected range of Tau values – yield (Y), equilibrium relative yield (Y/MSY), equilibrium relative spawning biomass (SSB/SSB_0), equilibrium relative recruitment (R/R_0), and equilibrium relative spawning biomass-per-recruit [$(SSB/R)/(SSB/R)_0$] where the subscript 0 represents virgin levels. We plotted these values to identify F% and investigate its effect on relative recruitment and relative spawning stock biomass.

Only a constant M scenario, medium molt probability, 20% handling mortality, retained selectivity, discard selectivity, maturity probability, gamma growth increment probability, and a fixed medium mating ratio (1:2) were used in the deterministic simulation model (Table 1). The reference points were estimated under two scenarios: (1) using an effective spawning biomass-per-recruit, which incorporates a mating ratio (say ESB), and (2) using a total mature biomass-per-recruit, which disregards the mating ratio and assumes all mature crabs participate in spawning (say SSB). In this report, we present only those results for the second scenario (i.e., for SSB). We caution the readers that the results presented in this report are very preliminary and the simulation models are still being improved.

Results

Choosing a Tau range:

Figure 1(a) provides equilibrium yield against full-recruitment fishing mortality (F) under scenario 2 (SSB) for the Beverton-Holt S-R model. A Tau (Mace 1994) range of 0.35 – 0.5 was selected as appropriate for this scenario. Tau values above 0.5 suggest that the stock is not sustainable with an F < 2M (very unlikely) and Tau values below 0.35 suggest that the stock can sustain long term F above 7M without collapse (another unlikely scenario).

Spawning stock biomass range to produce above 75% MSY:

For the Tau range 0.35 – 0.5, the spawning stock biomass within an approximate range of 20-60% of virgin spawning biomass produces above 75% of MSY under deterministic Beverton-Holt S-R relationship and scenario 2 (Figure 1(b)). Thus, as long as the spawning biomass is kept within this range of the virgin biomass, a larger portion of MSY can be harvested. This is a biomass-based harvest strategy. But difficulty arises when estimating the biomass ratio because virgin biomass is largely unknown.

F%:

Figures 1(c) and (d) depict the relative Y against the relative SSB/R (Scenario 2) for the deterministic Beverton-Holt S-R model. The maximum of the minimum yield at each relative SSB/R for selected range of Tau values (Clark named it as 'maximinyield') was identified in

Figure 1(c). The F% was F66% corresponding to an F_{MSY} of 0.14 (Figure 1(d)), which is equal to a legal harvest rate of approximately 13% for Bristol Bay red king crabs.

Effect of F% on equilibrium recruitment:
Figure 1(e) shows the relative recruitment vs. relative SSB/R (Scenario 2) for the deterministic Beverton-Holt S-R model. The fishing mortality equal to or lower than F66% level maintains the equilibrium recruitment above 50% of the maximum recruitment under a favorable environmental condition. In the literature (e.g., Myers et al. 1994), the F that produces 50% of the maximum R has been identified as a limit reference point.

Effect of F% on equilibrium biomass:
Figure 1(f) depicts the relative SSB vs. relative SSB/R (Scenario 2) for the deterministic Beverton-Holt S-R model. The fishing mortality equal to or lower than F66% level maintains the equilibrium spawning biomass well above 20% of the virgin spawning biomass. In the literature (e.g., Beddington and Cooke 1983), the 20% of the virgin spawning biomass level has arbitrarily been set as a lower limit below which stock might collapse.

Summary

1. Under deterministic population dynamics scenario, it appears that F66% full-recruitment fishing mortality on Bristol Bay legal male red king crabs at the time of the fishery would produce a long term harvest above 75% MSY, maintain above 50% recruitment (under a favorable environmental condition), and maintain above 20% of virgin spawning stock biomass. However, the results should not to be treated as conclusive because of a number of restrictive assumptions (e.g., low S-R productivity due to selection of a particular Tau range) made in the preliminary analysis at the model developmental stage. We will further investigate the appropriateness of the Tau range in light of disjoint selectivity and maturity schedules for crab species (which is different from what Clark has assumed in his groundfish analysis).

2. Further refinement of simulation models, including stochastic simulation models, sensitivity analyses of key parameters on biological reference points, and estimation of stock productivity under various scenarios, are in progress.

3. The refined simulation models will be applied to five major BSAI crab stocks: Bristol Bay red king crab, Bering Sea snow crab, Bering Sea Tanner crab, St. Mathew Island blue king crab, and Aleutian Islands golden king crab. General conclusions on F% and corresponding B% values will be made for other data-poor crab stocks based on results of those five stocks.

References

Beddington, J.R. and J.G. Cooke. 1983. The potential yield of fish stocks. FAO Fisheries Technical Paper 242, FIRM/T242. FAO, Rome.

Beverton, R.J.H. and S.J. Holt 1957. On the dynamics of exploited fish populations. Fish. Invest. Series 2, volume 19. U.K. Ministry of Agriculture and Fisheries, London.

Booth, A.J. 2004. Determination of cichlid-specific biological reference points. Fish. Res. 67:307-316.

Clark, W.G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci.48:734-750.

Clark, W.G. 1993. The effect of recruitment variability on the choice of a target level of spawning biomass per recruit. Alaska Sea Grant 1993:233-246.

Clark, W.G. 2002. F35% revisited ten years later. North American Journal of Fisheries Management 22: 251–257.

Mace, P.M. 1994. Relationships between common biological reference points used as thresholds and targets for of fisheries management studies. Can. J. Fish. Aquat. Sci. 51:110-122.

Myers, R.A., A.A. Rosenberg, P.M. Mace, N.J. Barrowman, and V.R. Restrepo. 1994. In search of thresholds for recruitment overfishing. ICES Journal of Marine Science 51:191-205.

Myers, R.A., N.J. Barrowman, J.A. Hutchings, A.A. Rosenberg. 1995. Population dynamics of exploited fish stocks at low population levels. Science, 269: 11061108.

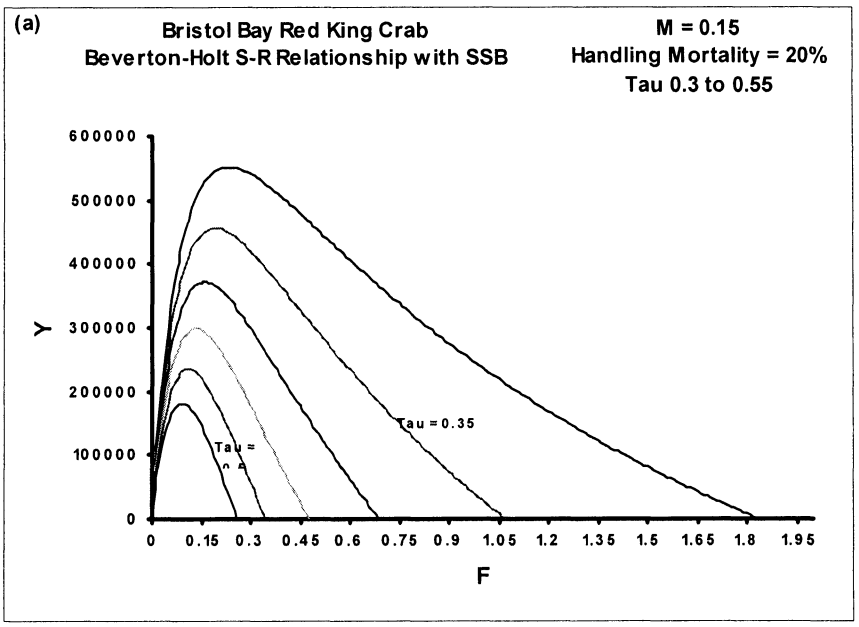
Ricker, W. E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559–623.

Table 1. Input parameters (base values) for Bristol Bay red king crab for reference point estimation. CL = carapace length.

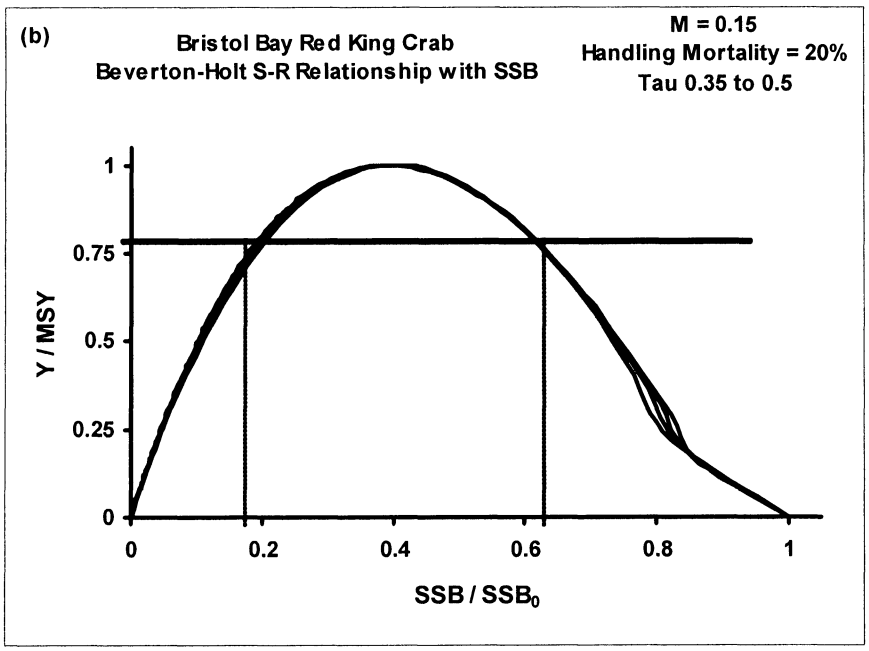
Parameter	Male		Female	
	PreRecruit 1	Recruit & PostRecruit	Class 1	Class 2
Size Range (mm CL)	95-129	135-169	90-119	120-139
Natural Mortality (M)	0.15	0.15	0.15	0.15
Handling Mortality	0.20		0.20	0.20
Mean Fishing Period, 1966-03 (yr^{-1}), δ		0.01136		
Mean Lapsed Time Between Mid-Molt and Start of Fishing Period (yr^{-1}), T		0.625		
Growth Increment Linear Model: a, b	17.54158	-0.01558	16.7	-0.09846
Growth Increment Gamma Probability: beta	Male: 0.653		Female: 1.018	
Recruitment Gamma Probability: mean, beta	107	1.252	97	0.456
Maturity Probability: Logistic *a, b*	$5.734\ 10^{13}$	-0.264	$1.262\ 10^{11}$	-0.2872
Molt Probability: Reverse Logistic *a, b*	Intermediate: 3.53885.31, 0.09		Probability = 1.0	
Pot Selectivity Probability, Retained: Single Logistic *a, b*	0.66438, 137.50334 (Retained)		Constant Selectivity = 0.255	
Discards: Double Logistic *a, b, c, d*	0.07456, 113.30948, 0.59615, 137.18722			
Mating Ratio (Male:Female)	1:2		1:2	
Weight-Length Model (g-mm): *a, b*	0.0003614, 3.16		0.02286, 2.234	

Figures 1(a) through 1(f):

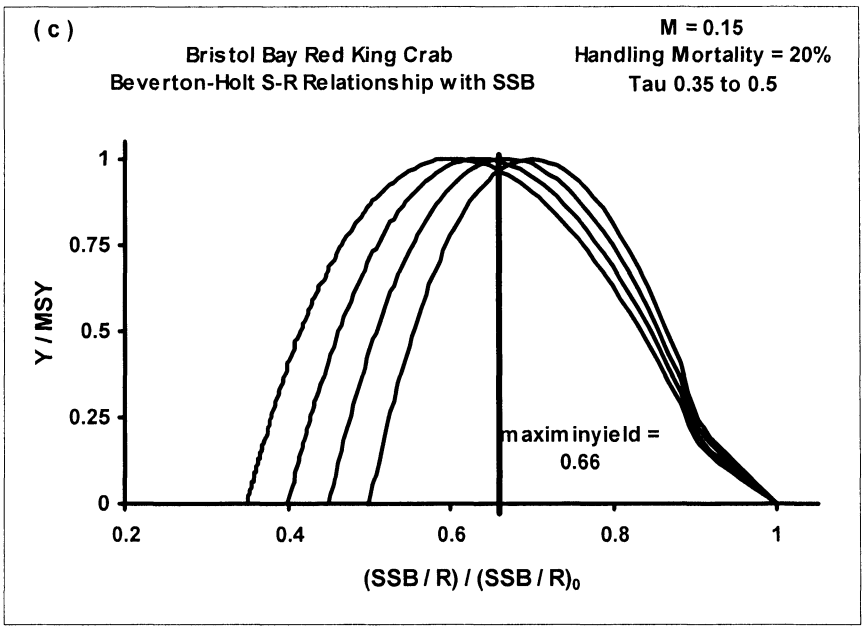
Equilibrium yield, spawning biomass, and recruitment for a range of Beverton-Holt spawner-recruit (S-R) curves for Bristol Bay red king crab, where subscript 0 represents unfished levels. The spawners are total spawning biomass without considering any mating ratio, M = 0.15, directed fishery handling mortality rate = 20%, and non-directed fisheries instantaneous bycatch mortality = 0.01.



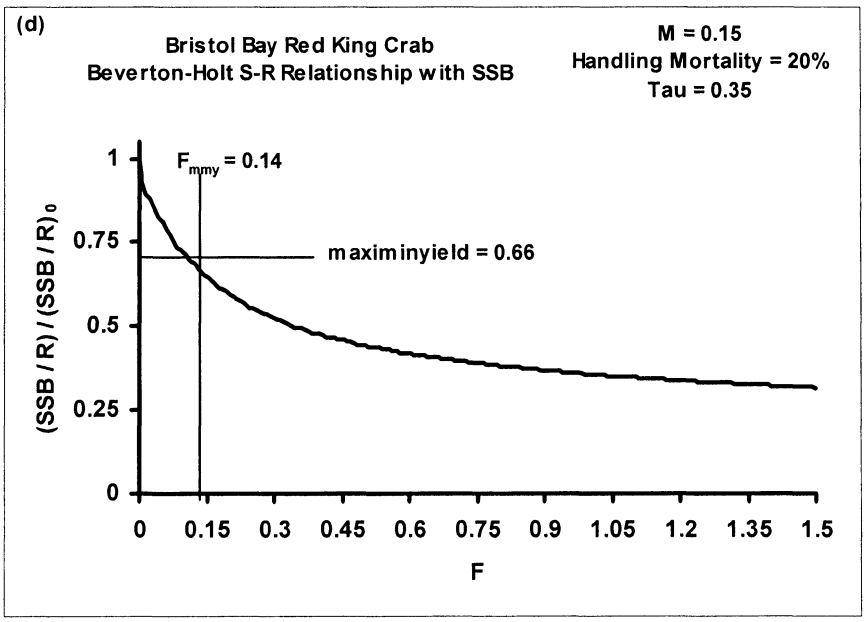
(a). Equilibrium yield (Y) vs. fishing mortality (F) for a Tau range 0.3 - 0.55.



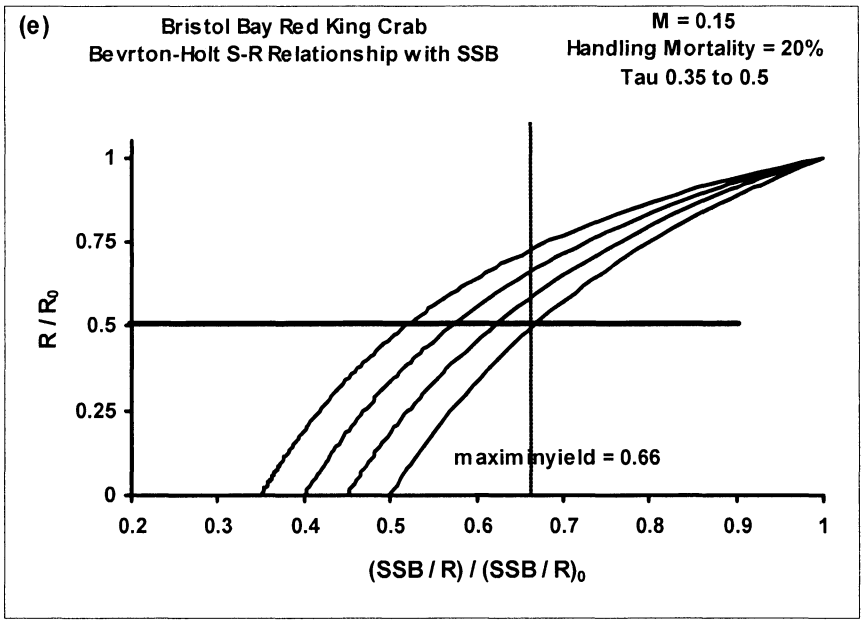
(b). Rel
ative yield (Y/MSY) vs. relative spawning stock biomass (SSB/SSB_0) for a Tau range 0.35 - 0.5.



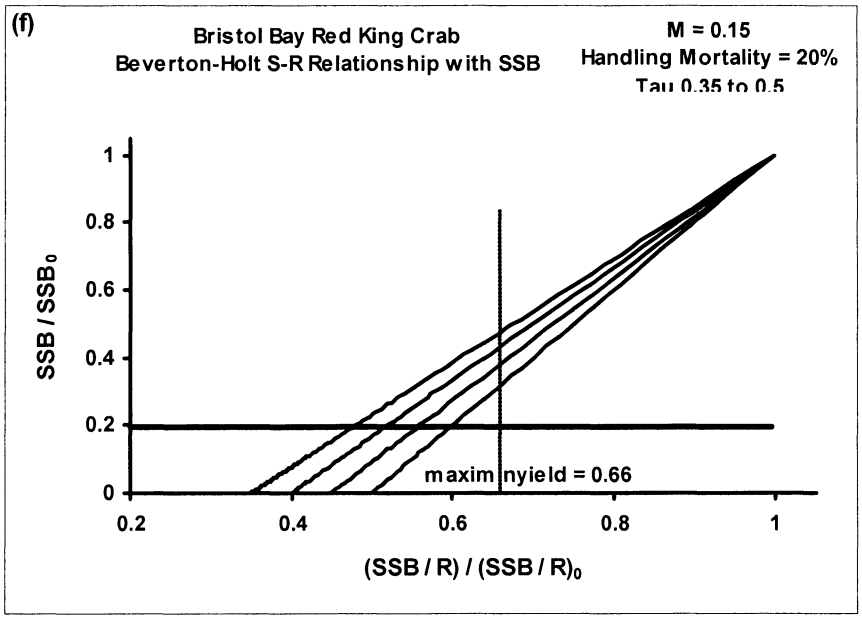
c). Rel
ative yield (Y/MSY) vs. relative spawning stock biomass-per-recruit $(SSB/R)/(SSB/R)_0$ for a Tau range 0.35 - 0.5.



(d). Relative spawning stock biomass-per-recruit $(SSB/R)/(SSB/R)_0$ vs. F for Tau = 0.35.



(e). Relative recruitment (R/R_0) vs. relative spawning stock biomass-per-recruit $(SSB/R)/(SSB/R)_0$ for a Tau range 0.35 - 0.5.



(f). Relative spawning stock biomass (SSB/SSB_0) vs. relative spawning stock biomass-per-recruit $(SSB/R)/(SSB/R)_0$ for a Tau range 0.35 - 0.5.

VI. A Tier System for Bering Sea / Aleutian Island King and Tanner Crab Stocks

The Current Tier System for BSAI King and Tanner Crab Stocks (Crab FMP 1998)
The existing tier system is based mostly on the amount of survey information since survey data is used to estimate overfishing definitions. Tier 1 is the least amount of information, tier 3 the most information. Overfishing is evaluated by comparing MSY (includes mature males and females) to the Guideline Harvest Level (GHL) (includes retained males only, no bycatch).

Tier 1. Crab stock is not surveyed. Some catch data available.
F_{MSY} = M = 0.2 (King), 0.3 (Tanner and snow)
B_{MSY} not estimable
MSY is estimated from a proxy of mature biomass and stock utilization rate

Tier 2. Sporadic or limited years of survey data. Catch and effort data on each crab stock is well documented.
F_{MSY} = M = 0.2 (King), 0.3 (Tanner and snow)
B_{MSY} not estimable
MSY is estimated from a proxy of mature biomass and stock utilization rate

Tier 3. Data available: historical catch, continuous inseason catch and effort data, stock assessment, growth, maturity, limited natural mortality and stock recruitment relationship information.
F_{MSY} = M = 0.2 (King), 0.3 (Tanner and snow)
B_{MSY} is the average survey biomass of mature males and females from 1983 to 1997
MSY = F_{MSY} x B_{MSY}

MSY has been estimated for all stocks except Aleutian Islands scarlet king and Eastern Bering Sea scarlet king crabs.

Draft Tier System for BSAI King and Tanner Crab Stocks
The proposed tier system has six tiers that have been modified from the current NPFMC groundfish tier system. Tiers are based on whether reliable estimates are available for biomass (survey or model) and reference points, and whether a model has been implemented for the assessment. Tiers 1 through 3 are for stocks with length or age structured models which incorporate survey and fishery data. For tiers 1 through 3, reliable estimates of necessary input data and parameters are needed for models that provide estimates of a time series of B, and of Bmsy and Fmsy or their proxies. Stocks in tiers 1 through 3 do not necessarily have annual surveys, however surveys and other information have to be reliable to be used in a stock assessment model. Tiers 1 and 2 are for stocks with a reliable estimate of the spawner recruit relationship. Tier 1 is for stock assessments where the probability density function of F_{MSY} is estimated. Tier 3 is for stocks where reliable estimates of the spawner recruit curve are not available, however, proxies for F_{MSY}, B_{MSY} and F_{Target} can be estimated.

F_{ABC} is the maximum target F to ensure a buffer between the overfishing F and the target F as required by National Standard Guidelines 1 (NSG1). The setting of the target F has been deferred to Alaska Department of Fish and Game (ADF&G) with oversight by the Federal Government. The target F corresponding to the annual quota can be set anywhere below the F_{OFL} however, to comply with NSG1 there must be a buffer between the target F and the F_{OFL} to ensure that the F_{OFL} is not exceeded.

Tiers 4 through 6 are for stocks with no stock assessment model. The MSY control rule for tiers 4 and 5 declines with B similar to tiers 1-3, however, a proxy for B_{Target} is estimated based on survey data instead of through modeling. Tier 4 is where maturity information and other life history information are available to estimate proxies for F_{MSY} and F_{Target} however, there is no stock assessment model. B_{Target} would need to be determined based on survey data. Tier 5 stocks have no estimates of proxy F_{MSY} or F_{Target} so a default value of M is used, i.e. there is a reliable estimate of current biomass (survey biomass) and of M. Tier 6 stocks have no reliable estimates of biomass and/or M, so catch history is used to set limits and targets in terms of catch instead of fishing mortality.

The control rule reduces F as biomass declines for tiers 1 through 5 (groundfish control rule reduces F for tiers 1 through 3 only). A proxy for B_{Target} would need to be estimated for tiers 4 and 5. The groundfish control rule uses an α of 0.05 (F is zero at 0.05 x B_{MSY}), uses F35% as a proxy for F_{MSY} and F40% as a target F when F_{MSY} is not estimable. The proxy values are being determined for crab stocks based on modeling work. Biomass values for groundfish are female spawning biomass. Crab stocks will use effective spawning biomass, which incorporates female and male spawning biomass with an adjustment for the mating ratio. If there are not enough mature males to fertilize females, then the effective spawning biomass will be lowered. This requires assumptions regarding the optimum mating ratio and the component of the male stock that is effective at mating. All mature males may not be successful at mating depending on their size and molt history.

The proposed tier system for crabs incorporates a relative biomass value (β) below which F is 0 (Figure 1). This would result in F=0 at a biomass value most likely above the value implied by α. For example, the current harvest strategy for Bering Sea snow crab (not the overfishing definitions) reduces fishing mortality to 0 at 25% of B_{MSY}.

Tiers:

1. Information available: *Reliable point estimates of B and B_{MSY} and reliable pdf of F_{MSY}*

   a. Stock status: $B/B_{MSY} > 1$
   $F_{OFL} = \mu_A$, *the arithmetic mean of the pdf*
   $F_{ABC} \leq \mu_H$, *the harmonic mean of the pdf*

   b. Stock status: $\beta < B/B_{MSY} \leq 1$
   $F_{OFL} = \mu_A \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
   $F_{ABC} \leq \mu_H \times (B/B_{MSY} - \alpha)/(1 - \alpha)$

   c. Stock status: $B/B_{MSY} \leq \beta$
   $F_{OFL} = 0$
   $F_{ABC} = 0$

2. Information available: *Reliable point estimates of B, B_{MSY}, F_{MSY}, F_{Limit} (proxy for F_{MSY}), and F_{Target}. The F% proxies for F_{MSY} and F_{Target} would need to be determined for crab stocks.*

   a. Stock status: $B/B_{MSY} > 1$
   $F_{OFL} = F_{MSY}$
   $F_{ABC} \leq F_{MSY} \times (F_{Target}/F_{Limit})$

   b. Stock status: $\beta < B/B_{MSY} \leq 1$
   $F_{OFL} = F_{MSY} \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
   $F_{ABC} \leq F_{MSY} \times (F_{Target}/F_{Limit}) \times (B/B_{MSY} - \alpha)/(1 - \alpha)$

   c. Stock status:: $B/B_{MSY} \leq \beta$
   $F_{OFL} = 0$
   $F_{ABC} = 0$

3. Information available: *Reliable point estimates of B, B_{Target}, F_{Limit}, F_{Target}. The F% and B% proxies for F_{MSY}, F_{Target} and B_{Target} would need to be determined for crab stocks.*

   a. Stock status: $B/B_{Target} > 1$
   $F_{OFL} = F_{Limit}$
   $F_{ABC} \leq F_{Target}$

   b. Stock status: $\beta < B/B_{Target} \leq 1$
   $F_{OFL} = F_{Limit} \times (B/B_{Target} - \alpha)/(1 - \alpha)$
   $F_{ABC} \leq F_{Target} \times (B/B_{Target} - \alpha)/(1 - \alpha)$

   c. Stock status:: $B/B_{Target} \leq \beta$
   $F_{OFL} = 0$
   $F_{ABC} = 0$

4. Information available: *Reliable point estimates of B, F_{Limit}, F_{Target}. No stock assessment model, but reliable estimate of a proxy for $B_{Target\%}$ based on survey data. The F% and B% proxies for F_{MSY}, F_{Target} and B_{Target} would need to be determined for crab stocks.*

   a. Stock status: $B/B_{Target} > 1$
      $F_{OFL} = F_{Limit}$
      $F_{ABC} \leq F_{Target}$

   b. Stock status: $\beta < B/B_{Target} \leq 1$
      $F_{OFL} = F_{Limit} \times (B/B_{Target} - \alpha)/(1 - \alpha)$
      $F_{ABC} \leq F_{Target} \times (B/B_{Target} - \alpha)/(1 - \alpha)$

   c. Stock status:: $B/B_{Target} \leq \beta$
      $F_{OFL} = 0$
      $F_{ABC} = 0$

5. Information available: *Reliable point estimates of B and natural mortality rate M. No stock assessment model, but reliable estimate of a proxy for B_{Target} (B% would need to be determined for crab stocks) based on survey data. There may need to be a multiplier on natural mortality (γ) to get F_{OFL} if M is determined not to be a good proxy for a target F for crab stocks.*

   a. Stock status: $B/B_{Target} > 1$
      $F_{OFL} = \gamma \times M$
      $F_{ABC} \leq 0.75 \times F_{OFL}$

   b. Stock status: $\beta < B/B_{Target} \leq 1$
      $F_{OFL} = \gamma \times M \times (B/B_{Target} - \alpha)/(1 - \alpha)$
      $F_{ABC} \leq 0.75 \times F_{OFL} \times (B/B_{Target} - \alpha)/(1 - \alpha)$

   c. Stock status:: $B/B_{Target} \leq \beta$
      $F_{OFL} = 0$
      $F_{ABC} = 0$

6. Information available: *Reliable catch history from a time period to be determined (groundfish uses 1978 through 1995). Need to evaluate 0.75 reduction for crab stocks.*

   OFL = the average catch from a time period to be determined, unless an alternative value is established by the SSC on the basis of the best scientific information available.

   $ABC \leq 0.75 \times OFL$

Incorporating the Limit Reference Point System into the Tier System

The limit reference point system proposed for crab stocks would result in an overall score based on scores for individual components of the health and status of a stock. This overall score would be used to adjust the Fofl and Fabc values in the above tier system. The scoring system, which tiers to apply it to and the method of application will be recommended by the working group.

Current tier system assignment

Tier 1 stocks
Pribilof Islands golden king
Saint Matthew golden king
Western Aleutian Tanner crab ©. bairdi)
Saint Lawrence Island blue king
Aleutian Islands scarlet king
Bering Sea triangle Tanner
Eastern Aleutian Islands triangle Tanner
Eastern Aleutian Islands grooved Tanner
Western Aleutian Islands grooved Tanner
Bering Sea grooved Tanner

Tier 2 stocks
Adak red king
Dutch harbor red king
Norton Sound red king
Aleutian Islands golden king
Eastern Aleutian Islands Tanner (bairdi)

Tier 3 stocks
Bristol Bay red king
Pribilof Islands red king
Pribilof Islands blue king
Saint Matthew Island blue king
Bering Sea C. bairdi Tanner
Bering Sea C. opilio snow

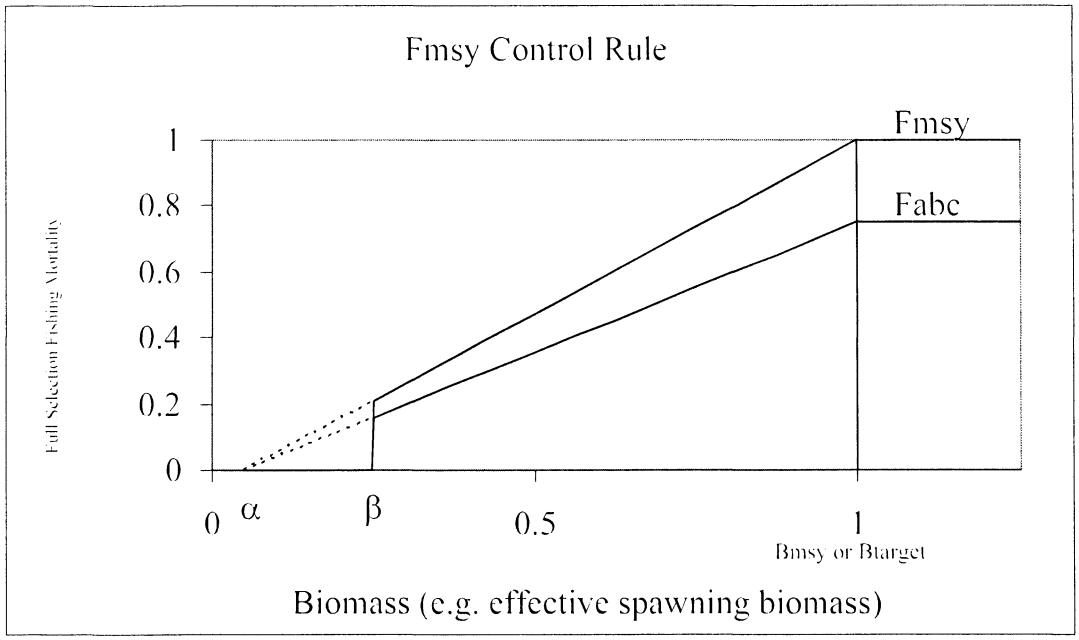


Figure 1. F_{MSY} Control Rule Example.

VII. **Tier System Presentation to the SSC:**

In June 2004, Jack Turnock presented the draft Tier System for BSAI King and Tanner Crab Stocks to the Scientific and Statistical Committee of the North Pacific Fishery Management Council. The following is an overview of the SSC's comments on the Work Plan from notes taken by the presenter.

In general, the SSC thought that the draft tier system was good, and liked that it was based on the groundfish tier system.

The SSC reviewed comments on the overfishing definitions when they were last before the SSC in June 1998. The SSC had reservations about the overfishing definitions, wanted them to be similar to groundfish, did not want fixed numerical values in the FMP, did not think average survey biomass over some time period was a good proxy for B_{MSY} as the average biomass depends on the F that was occurring at the time.

In the April 1998 minutes the SSC noted that there was no clear definition of how overfishing would be determined, which is true for the final version of the BSAI King and Tanner Crab Plan. The SSC also did not like the use of the ratio of catch to mature biomass to come up with proxy values of B_{MSY} for stocks with little survey data.

Summarized comments:

1. Include density dependent effects, e.g., growth, maturity if there is evidence that they occur for crab stocks
2. Change F_{PMSY} (the proxy for F_{MSY}) in the tier system to F_{Limit}.
3. Initially the SSC thought that Alternative 2 (fixed reference points) should be eliminated now, however, since many members of the public may like the fixed numerical value approach he says to leave it as an alternative.
4. Would like to see simulations that incorporate switching between low and high B_{MSY} values (low and high productivity regimes) and having different control rules for increasing vs decreasing B_{MSY}.
5. There was a suggestion that we could have a steeper slope at beta in the control rule instead of simply going to zero.
6. Need to add in variability in current biomass in the simulations. West coast stock assessments did not do this and it may have made a difference in the decline of stocks there.

A question was asked about how biomass estimates and reference point estimates would be determined to be reliable. For groundfish it is written in the FMP that the SSC is the ultimate decision making on that. We could do the same for crab.

A comment was made that MSST may not be appropriate for crab stocks due to high variability in recruitment.

The SSC commented that the spring CPT meeting was a good idea.

The following are the SSC's comments on the Tier System as extracted from the NPFMC's Minutes of the June 2004 SSC meeting:

> Jack Turnock (NMFS) gave a presentation on progress by a NMFS-ADF&G working group toward development of revised overfishing definitions for BS/AI crab. Gary Painter (Bering Sea Fisheries Research Foundation) provided public testimony.
>
> Principal topics discussed at the CPT meeting included implications of the data quality act on the Crab Plan Team, survey catchability studies for snow crab, industry-funded augmentation to the NMFS annual trawl survey, updates on crab rationalization, and a report on overfishing working group progress. The CPT seeks guidance from the Council as to whether the CPT should continue their spring meeting in the future in addition to their usual fall meeting. CPT members felt that the spring meeting was a useful venue to discuss important crab issues, because there is often insufficient time to do so at their fall meeting that tends to focus on stock assessments and fishery management. The SSC continues to support the CPT meeting in spring, as long as there are sufficient issues to justify this meeting.
>
> Original consideration of crab overfishing definitions occurred in April and June 1998. The SSC had several concerns about the overfishing definitions at that time. First, numerical values were used, instead of frame working a general procedure. Second, there was not always more conservatism with less information. Third, there were differences between definitions between the groundfish and the crab FMPs that did not seem to be necessary. Because the CPT was planning to review the crab definitions every five years, the SSC accepted the proposed definitions.
>
> At the February 2004 Council meeting, the SSC heard a report on the progress of the NMFS-ADF&G working group. At that time, the SSC requested that the working group focus on a careful evaluation of crab overfishing definitions, including a more formalized procedure for setting overfishing levels, such as the tier system used for groundfish. At the present meeting, an outline of such a tier system for crab was presented. The plan for further analysis, including simulation modeling, appears reasonable to the SSC and resolves many of the issues raised in 1998.
>
> The SSC offers the following comments to the Crab Working Group:
>
> - Under tier 2, the scalar F_{Target}/F_{PMSY} is used to buffer the difference between ABC and OFL. The SSC was confused by the use of the proxy F_{PMSY} when an estimate of this value F_{MSY} is available. Part of the SSCs concern may be semantic. Perhaps it would be better to define the scalar in terms of a limit reference point (F_{Lim}), as in the National Standard Guidelines, and then to assign F_{PMSY} as the available reference point for F_{Lim}.

- Consider whether there is evidence for density dependence in biological parameters, such as growth and maturity. If so, consider including these in the analysis.

- The SSC supports the three alternatives presented (status quo, numerical values for overfishing definitions fixed in the FMP, and overfishing definitions frame worked in the FMP). These alternatives will foster an analysis of the timing and review process for stock assessment relative to overfishing on an annual basis. The SSC notes that the timing of decision-making and the overall process differ between crab and groundfish, so that there may be reasons for having fixed numerical values instead of a framework in the crab FMP.

- One weakness of constant harvest control rules for rapidly fluctuating stocks is that they may not efficiently adapt to changing conditions. The SSC would like to see an evaluation of a harvest control rule that recognizes fluctuations between different periods of productivity and the possibility of implementing a switching rule between overfishing reference points. This evaluation could consider the prospects of both higher reference points during periods of greater productivity, as well as the need to constrain harvest to avoid potential stock depletion during the next phase of low productivity.

- The working group should explicitly consider whether parameter β, the biomass below which fishing is curtailed, is also defined to be the MSST. If it is also the MSST, then the National Standard Guidelines require that a rebuilding plan be established within one year. However, a crab stock could be classified as overfished and in need of rebuilding one year, but be totally rebuilt one or two years later, independent of any management measures. This volatility in crab populations could thus create a chaotic management environment requiring continual attention to revising rebuilding plans. The SSC has learned that MSST may be of lesser importance in new National Standard Guidelines, so defining an explicit MSST may not be necessary.

- The SSC recognizes a pressing time frame for completion of this overfishing analysis, and encourages the working group to work efficiently and to provide routine updates on progress to the CPT and SSC.

VIII. **Depensation in the Stock-Recruitment Relationship:**

Describing the relationship between parent stock size and subsequent recruitment to the population is a fundamental underpinning of population dynamic modeling, the definition of biological reference points, and the design of effective harvest strategies. A notable feature of the customary analytical stock-recruitment relationship, whether it be of the depensatory Ricker, or the non-depensatory Beverton-Holt form, is the expectation of increased production rate (i.e., recruits per spawner) at very low levels of spawning stock biomass (ssb) compared to that at moderate or high levels of ssb. This is expressed in the slope of the stock-recruitment curve at the origin [i.e., as ssb tends toward zero], which characterizes the resiliency of the stock to decreased abundance, whether due to fishing mortality, natural or environmental causes.

The expectation of increased productivity as the stock declines toward the origin is a highly *risk prone* assumption to the management of a stock as it results in higher target or threshold exploitation rates, and lower stock biomass thresholds than the alternatives - i.e, a shallow steepness, or depensation at low parent stock size. Indeed, the steepness parameter of the stock-recruitment relationship is critical in the design of any fisheries management system in which S-R modeling is used to set threshold rates. Ideally, the value of this parameter would be guided by empirical data. If such data are unavailable, the value of the steepness parameter should be explicitly *risk averse* as emphasized by the precautionary principle concept discussed in the NSG1.

The Majid crab stocks subject to this management plan may fall to levels of stock density where mating success is effected by the difficulty of finding mates for many obvious reasons. The reproductive dynamics and strategies of these crab species contrast the majority of Bering Sea fish stocks, for example, which undergo spawning migrations from great distances and employ broadcasting of eggs and sperm for fertilization. Crab stocks in the Gulf of Alaska declined to low levels from which they have not recovered even after more than two and one-half decades under the most extreme conservation measures. This fact contravenes the expectation of an increased production rate at low spawning stock abundance. Alternatively, if the spawner-recruit curve has a shape where expected recruits are below the replacement line at low spawning biomass levels, then the stock may have difficulty rebuilding from low levels of ssb. Such a structural derivative to the customary form of the stock-recruitment relationship is concordant with observations of the failure of GOA stocks of *C. bairdi* and *P. camtschaticus* to rebuild despite fishery closures for significant portions of the species' life span and, similarly, with Bering Sea *C. bairdi*. These stocks have demonstrated conspicuously low resiliency, and no empirical evidence exists to support compensatory responses of the stock at low spawning stock biomass as represented by a steep, or even a moderately steep slope of the S-R curve at the origin. The implication is that these stocks reach some critical biomass threshold below which recruitment generation is insufficient for stock rebuilding, or perhaps stock replacement.

Figure 1 shows a comparison of the shape of a standard Beverton-Holt spawner recruit curve with and without depensation at low spawning stock biomass. The curve with depensation falls below the replacement line at about 25% of virgin biomass (B_0) in this example. Recruits are generally less than the standard curve below about 40% of B_0. Such a % B_0 may be illustrative in prescribing the value β which represents the critical biomass threshold below

which there's a low probability of stock rebuilding or stock maintenance. The β value would suggest a threshold level for management to guard against occurring. The level of depensation for crab stocks would have to be determined by examination of con-generic stocks that have collapsed and failed to rebuild after significant time periods under no fishery exploitation, or of other crustacean stocks that express similar life-history traits and reproductive strategies. With depensation, a higher level of spawning biomass would need to be maintained to prevent collapse of the stock to levels where expected recruitment may be below the replacement line.

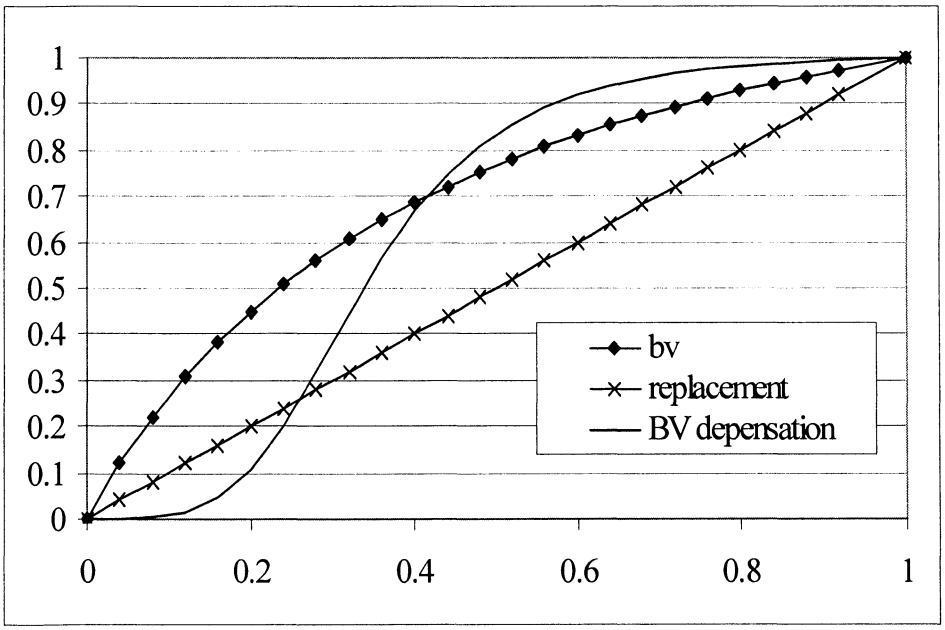


Figure 1. Example of a Beverton and Holt spawner recruit curve with and without depensation. R_0 and B_0 are 1.0 for both curves.

Attachment 5

North Pacific Fisheries Management Council
Bering Sea / Aleutian Islands Crab Working Group Meeting
4-6 November 2003, Anchorage, AK

Meeting Agenda

Tuesday, 4 November '03; [1000-1700 hr]

1. Elect Working Group Chair
2. Discuss Working Group membership
3. Review / Amend Draft Agenda
4. Discuss CPT guidance to Working Group on amending the Plan
5. Discuss guidance from NPFMC, SSC or Council staff on amending Plan
6. *Lunch*
7. Distribute Lou's 10.4.03 Addendum to CPT 22-24 Meeting Minutes
8. Review Draft Statement of Work for Working Group [Rugolo]
9. Other Issues

Wednesday, 5 November '03; [0800-1700 hr]

1. Finalize Statement of Work for Working Group [WG]
2. *Lunch*
3. Discuss modeling approaches to meet Action Items
4. Other Issues

Thursday, 6 November '03; [0800-1100 hr]

1. Develop Draft Work Plan:
    a. Work Assignments
    b. Work Time Line
2. Meeting Schedule
3. Other Issues
4. Adjourn

North Pacific Fisheries Management Council
Bering Sea / Aleutian Islands Crab Working Group Meeting
25-26 March 2004, Seattle, WA

Meeting Agenda

Thursday, 25 March 2004: [0900-1700 hr]

1. Tier System:
    a. Organizational Structure
    b. Basis of Different Tiers
    c. Proxies for B_{MSY} and MSY
    d. α, β, γ Parameters
    e. Stock-Recruitment Depensation
2. *Lunch*
3. Life-History Parameters as Inputs
    a. Empirical vs Model-Based Estimates
    b. Theoretical Considerations
4. Projection Modeling:
    a. Recruitment Generation
    b. Scenarios:
        i. Fishing Mortality Rate [F]
        ii. Projection Time Period
        iii. Rebuilding Trajectories in Biomass
        iv. Rebuilding Monitoring / Assessment

Friday, 26 March 2004: [0830-1700 hr]

1. Tier System Background / Writeup
2. Presentations:
    a. Review Conceptual / Computational Framework of Life-Table Modeling
    b. M Estimation: Practical Application of Longevity Theory
3. *Lunch*
4. Council Meeting Schedule
    a. SSC Presentation
5. Items Not Covered
    a. Life-History Table
    b. Terminal Molt in *Chionoecetes*
    c. Review Process
    d. Next Meeting

North Pacific Fisheries Management Council
Bering Sea / Aleutian Islands Crab Working Group Meeting
2-4 June 2004, Seattle, WA

Meeting Agenda

KEY: Normal Text = covered; *Italic Text* = partially covered; **Bold Text** = not covered

Wednesday, 2 June 2004: [0900-1700 hr]

1. Review / Amend Draft Agenda
2. Meeting Minutes
    a. Administrative Record
    b. Summary Overview vs Complete
3. Tier System:
    a. Goal
    b. MSY Control Rule vs Harvest Control Rule
    c. Conceptual Framework
        i. Organizational Structure
        ii. Basis of Different Tiers
        iii. α, β Parameters
    d. Stock-Recruitment Depensation
    e. Proxy B_{MSY} and MSY Values
        i. Life-History Strategies / Recruitment Dynamics
    f. Shape of MSY Control Rule
        i. Buffer Zone: F_{OFL} vs F_{TARGET}
        ii. Precautionary Principle re: Overfishing & Rebuilding
    g. Tier Assignment of Stocks
        i. Information Reliability
        ii. Static [Fixed in FMP] vs Dynamic [Defined in SAFE]
    h. Revised NSG1 re: MSST Definition

Thursday, 3 June 2004: [0900-1700 hr]

1. Terminal Molt in *Chionoecetes* sp.
    a. *opilio* [Rugolo et al., Tamone, ...]
    b. *bairdi* [Donaldson, Paul, Munk, ...]
2. Modeling Activities of Working Group
    a. Authorship vs Stewardship
    b. Documentation & Code
    c. Information Requests / Configurations

3. Life-History Parameters as Inputs
    a. Empirical vs Model-Based Estimates
    b. Theoretical Considerations
    c. M Estimation: Practical Application of Longevity Theory
4. Life-History Table
    a. Selection of Parameter Sets
    b. Time Periods to Select for Tier 6 Stocks
5. RACE Discussion with Conan
6. Mating Ratio
7. Polygyny & Polyandry
8. Effective Spawning Biomass
9. Shell Aging Errors & Uncertainties
    a. Tagging Data
    b. Effect on Precautionary Principle
10. Male Maturity and Mating Success
    a. Availability of Molting Males

<u>Friday, 5 June 2004: [0900-1700 hr]</u>

1. Working Group Report:
    a. Draft Outline
    b. Schedule of Work Activities
2. Modeling Aspects
    a. How to Define Proxy Values
    b. How to Define Effective Spawning Biomass
3. Recruitment Scenarios to Consider in Simulations
    a. Constant vs Periodic
    b. Autocorrelated
    c. Proxies for Recruitment Scenarios
4. Stock Recruitment Modeling
    a. Model Form [Ricker vs Beverton-Holt]
    b. Range of Models to Consider
    c. Steepness Parameter
    d. Depensation
    e. Quantifiy β Parameters

5. MSY Contol Rule
    a. Slope of Line [α Parameter]
    b. Defintion of Buffer Zone
        i. Ratio of F_{TARGET} / F_{MSY}

    c. Definition of Effective Spawning Biomass
        i. Annual vs Biennial Reproductive Cycles
        ii. Definition of Proxy Values
6. Next Meeting

North Pacific Fisheries Management Council
Bering Sea / Aleutian Islands Crab Working Group Meeting
1-3 September 2004, Anchorage, AK

Meeting Agenda

Wednesday, 1 September 2004: [1000-1800 hr]

1. Discuss Draft Agenda
2. Report on June '04 SSC Meeting Minutes:
   Working Group Presentation on Draft Tier System and Overfishing Definitions
   a. Amendment Alternatives for Environmental Assessment
   b. Definition in FMP on How Overfishing is to be Determined
   c. Current Proxy Values for B_{MSY}
      i. Definition of New Proxy Values
   d. Consideration of Variability in Biomass for Stock Simulations + Projections
   e. Size of Buffer Zone: F_{OFL} vs F_{TARGET}
   f. Consideration of Serial and Random Variation in Recruitment on Definitions
   g. High vs Low Productivity Periods and Effect on MSY Control Rule
   h. Specification of F_{LIMIT} as Proxy for F_{MSY}
   i. MSST as Threshold Given High Natural Recruitment Variability
3. Depensatory Stock-Recruitment:
   a. Model Form [Ricker vs Beverton-Holt]
   b. Ranges of Models to Consider
   c. Steepness Parameter
   d. Quantifying Tier System β Parameter
   e. Scaling Depensation to Critical Biomass Threshold

Thursday, 2 September 2004: [0830-1930 hr]

1. Specification Contents Draft Progress Report to CPT
   a. Work Plan Overview
      i. Listing / Description of Action Items
   b. Revised Tier System
      i. Turnock's Report - Extract / Insert
      ii. Graphs of MSY Control Rules
   c. NPFMC SSC Presentations:
      i. Summary Pertinent Comments Feb., '04 Meeting: on Work Plan
      ii. Summary Pertinent Comments Jun., '04 Meeting: on Tier System
   d. Critical Biomass [β] Parameter
      i. Overview of Concept:

ii. Examination Historical Data for Insight re: Level @ Cascade Failure
iii. Likelihood of Theoretical Value as Fixed Percentage of B_o

e. Analytical Progress
i. Theoretical Analytical Framework Underlying BRP Approach: Produced for All 22 BS Crab Stocks
ii. Description of Full Set Reference Point Output
iii. Proxy Reference Points for Data Poor Stocks
iv. Turnock's Approach for Opilio as Redundancy
v. Preliminary Results

f. Remaining Work Tasks:
i. Specification of Method to Reach Status Determination Criteria of Overfishing and Overfished
ii. Limit Reference Point System:
- Status of Stocks Determination
- γ Scaler to MSY Control Rule
- Quinn's High/Low Productivity Periods
- Conservation Equivalency

g. Schedule of Future Activities

2. Peer Review of Draft Report: CIE vs Co-Opted Experts
a. Regional Experts
b. Timing wrt CPT and Council Submissions

3. Opilio Spatial Distribution and Reproductive Dynamics wrt Biological Reference Points and Quota Setting

4. Review Draft Working Group Report

<u>Friday, 3 September 2004: [0830-1500 hr]</u>

1. Continued Analytical Work / Model Development for Estimation of BRPs
a. Deterministic Model Structure
b. Stochastic Approach with Recruitment Variability
c. Stochastic Approach with Random Recruitment

2. Evolution of Draft Tier System