Crab Plan Team Review Draft

ENVIRONMENTAL ASSESSMENT

For proposed

Amendment 24

To the Fishery Management Plan for

Bering Sea and Aleutian Islands
King and Tanner Crabs

to

Revise Overfishing Definitions

Prepared by staff of the:
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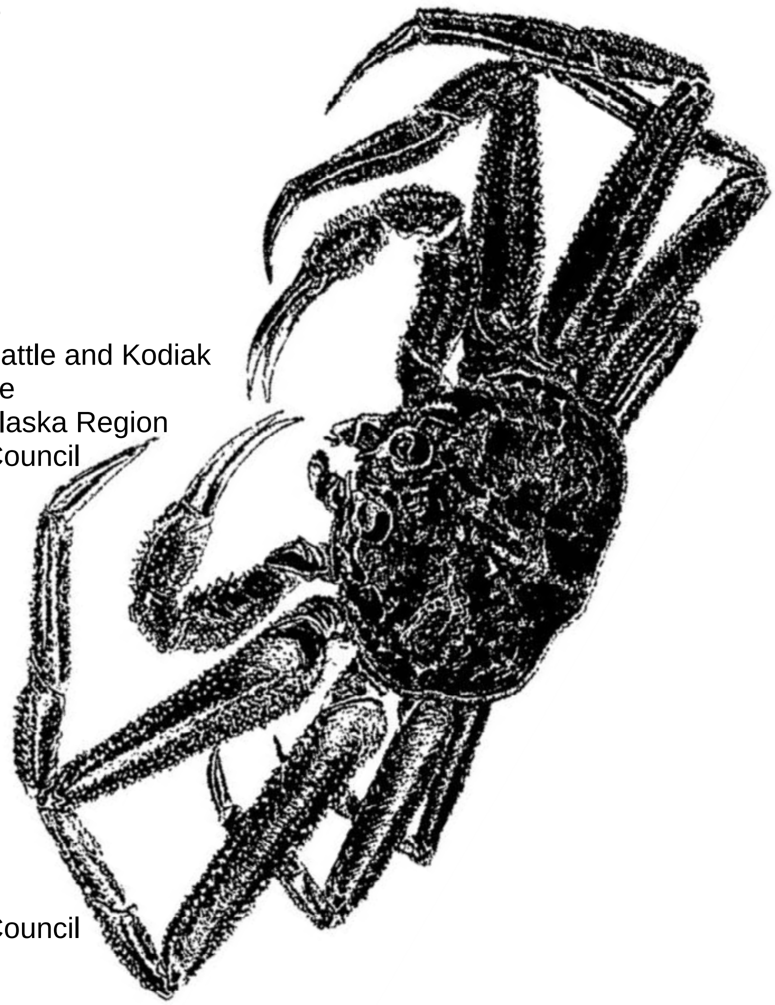

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Abstract: The Magnuson-Stevens Act Fishery Conservation and Management Act requires Fishery Management Plans to contain objective and measurable criteria for determining whether a stock is overfished or whether overfishing is occurring. The proposed action would establish a set of overfishing definitions that contain objective and measurable criteria for each managed stock. This Environmental Assessment provides decision makers and the public with an evaluation of the environmental, social, and economic effects of alternative overfishing definitions. This document addresses the requirements of the National Environmental Policy Act.

EXECUTIVE SUMMARY

The king and Tanner crab fisheries in the Exclusive Economic Zone (3 to 200 miles offshore) of the Bering Sea and Aleutian Islands (BSAI) off Alaska are managed under the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (FMP). The FMP establishes a State/Federal cooperative management regime that defers crab fisheries management to the State of Alaska with Federal oversight. The FMP defers much of the management of the BSAI crab fisheries to the State of Alaska using the following three categories of management measures:

1. Those that are fixed in the FMP and require an FMP amendment to change;
2. Those that are framework-type measures that the State can change following criteria set out in the FMP; and
3. Those measures that are neither rigidly specified nor frameworked in the FMP and are at the discretion of the State.

The proposed action is to establish a set of overfishing levels (OFLs) that provide objective and measurable criteria for identifying when a BSAI crab fishery is overfished or when overfishing is occurring, in compliance with the Magnuson-Stevens Act. The Magnuson-Stevens Act, in §303(a)(10), requires that FMPs specify objective and measurable criteria for identifying when the fishery is overfished (with an analysis of how the criteria were determined and the relationship of the criteria to the reproductive potential of stock). The OFLs are a Category 1 measure in the FMP. As such, revisions to the OFLs require an FMP amendment.

Determinations of total allowable catches (TACs) and guideline harvest levels (GHLs) are a Category 2 management measure and are deferred to the State following the criteria in the FMP. Catch levels established by the State must be in compliance with OFLs established in the FMP to prevent overfishing. As described in Chapter 2, NMFS annually determines if catch levels exceed OFLs or if stocks are overfished or are approaching an overfished status. If either of these occurs, NMFS notifies the North Pacific Fishery Management Council (Council) and the Council has one year to develop an FMP amendment to end overfishing and the rebuild the stock.

Purpose and Need

Chapter 1 describes the proposed action and its purpose and need. The purpose of the proposed action is to establish status determination criteria in compliance with the Magnuson-Stevens Act and the national standard guidelines. The current OFLs were implemented under Amendment 7 to the FMP in 1998. In the environmental assessment (EA) for that amendment, the Crab Plan Team stated its intent to review the definitions after 5 years or when environmental conditions have changed such that revising the definitions may be necessary.

The need for the proposed action is explained in the Crab Plan Team's problem statement:

New overfishing definitions are necessary to reflect current scientific information and accomplish the following:

- *Provide an FMP framework for definition values to facilitate use of the best available scientific information as it evolves.*
- *Provide a new tier system that accommodates varying levels of uncertainty of information and takes advantage of alternative biological reference points.*
- *Define the status determination criteria and their application to the appropriate component of the population.*

Alternatives

Chapter 2 describes and compares three alternatives. The alternatives analyzed in this EA are consistent with the Magnuson-Stevens Act and the national standard guidelines. The three alternatives are summarized as follows:

Alternative 1: **(Status Quo)** Amendment 7 provided fixed values in the FMP for the status determination criteria: minimum stock size threshold (MSST), maximum sustainable yield (MSY), optimum yield (OY), and maximum fishing mortality threshold (MFMT) for the BSAI king and Tanner crab stocks.

Alternative 2: Use tier system and OFL setting process to annually set OFLs for each crab stock. The FMP amendment would specify the tier system and process by which stocks are assigned to tier levels, the OFLs are set, and the timing of the annual review process by the Crab Plan Team, Scientific and Statistical Committee, and Council. In June, the Council would adopt the final tier levels and OFLs for each stock. OFLs would be determined based upon model estimates prior to the summer survey because the Council would adopt the OFLs before the survey.

Alternative 3: Use tier system and OFL setting process to annually set OFLs for each crab stock. The FMP amendment would specify the tier system and process by which stocks are assigned to tier levels, the OFLs are set, and the timing of the annual review process by the Crab Plan Team, Scientific and Statistical Committee, and Council. OFLs would be calculated after the survey data are available in late August. The Council would review the status of the stocks, the OFLs, and the TACs in October or December.

Chapter 2 also provides a comparison of the two main components of the alternatives: (1) the status determination criteria, and (2) the timing of the OFL determinations. Alternatives 2 and 3 contain the same tier system for establishing the status determination criteria. Alternatives 1 and 3 contain a similar process for the timing of the annual OFL determinations.

Status determination criteria

The status determination criteria provided in Alternative 1 are fixed in the FMP and reflect the understanding of crab biology and abundance at the time that Amendment 7 was adopted. Alternatives 2 and 3 were designed to incorporate this new scientific information and provide a mechanism to continually improve the status determination criteria as new information becomes available. Alternatives 2 and 3 use a tier system that accommodates varying levels of uncertainty of information and takes advantage of alternative biological reference points in setting the OFLs. The OFLs established under these alternatives would be specified for the appropriate component of the population.

Table Ex-1 provides a comparison of the biological reference points provided in the alternatives. Additional information on the biological reference points for specific species is contained in the Chapter for that species.

Table Ex-1 Comparison of biological reference points used in the alternatives.

Biological Reference Points	Alternative 1	Alternatives 2 and 3
Maximum Sustainable Yield (MSY) or MSY proxy	average of the annually computed sustained yield over the 15-year period, 1983-1997 (total mature biomass * natural mortality)	Tiers 1 and 2 (MSY) Tiers 3 and 4 (MSY proxy)
MSY Biomass (B_{MSY})	average annual estimated total mature biomass for the 15-year period, 1983-1997	Mature male biomass at MSY level
Minimum stock size threshold (MSST)	½ B_{MSY}	½ B_{MSY}
Maximum fishing mortality threshold (MFMT)	MSY control rule applied to the current total mature biomass	OFL fishing rate (F_{OFL}) calculated by applying tier system
MSY control rule	Natural mortality	F_{OFL} control rule
Natural mortality (M)	0.2 for all species of king crab 0.3 for all *Chionoecetes* species	0.18 for all species of king crab (default value) 0.23 for male and 0.29 for female *Chionoecetes* species (default values)
Sustainable yield (SY)	Total mature biomass * M	N/A
Optimum yield (OY)	OY range 0 - MSY	OY range 0 – MSY or MSY proxy

Timing of OFL determination

The timing of the OFL determinations is important because it determines two key factors: (1) who the decision-maker can be, and (2) what information is used in the OFL determinations. Timing also impacts the level and extent of peer review and information shared with the public. Alternatives 2 and 3 establish different processes for tier and OFL setting and review. This review process includes the SSC and the Council review for determining appropriate tier levels and OFLs on an annual basis. The OFL setting and review process establishes (1) the placement of stocks into tiers; (2) the information utilized in the projection models for OFL determination; (3) the setting of the OFLs; and (4) the determinations of the status of the stocks relative to the OFLs.

The timing of the OFL determinations similarly affect the fisheries for the surveyed stocks, Bristol Bay red king crab, snow crab, Tanner crab, Pribilof Islands king crab, and Saint Matthew blue king crab. Stocks not subject to the NMFS annual eastern Bering Sea trawl survey are not impacted by the timing of the OFL determinations.

Summary of the environmental consequences of the alternatives

This EA evaluates the alternatives for their effects within the action area. The environmental consequences of each alternative for 22 crab species under the FMP, crab bycatch in the groundfish fisheries, Endangered Species Act listed marine mammals and seabirds, and the economy, are assessed in Chapters 4 through 13 of this EA.

This EA tiers off of the Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement (NMFS/NPFMC 2004) to focus the analysis on the issues ripe for decision and eliminate repetitive discussions. The Crab EIS provides the status of the environment and analyzes the impacts of the crab fisheries on the human environment, including habitat, the ecosystem, non-target species, safety, and community impacts. The proposed action would establish overfishing definitions for the crab stocks under the FMP. This EA details the specific impacts of the proposed action.

Bristol Bay Red King Crab

Under Alternative 1, the B_{MSY} for Bristol Bay red king crab is 89.6 million pounds of total mature biomass and the MSST is 44.8 million pounds. The 2006 total mature biomass estimate is above B_{MSY} at 157.2 million pounds. Under Alternatives 2 and 3, the Bristol Bay red king crab estimate of B_{MSY} would be 76.6 million pounds of mature male biomass. For comparison, the 2006 estimate of mature male biomass for this stock is 65.5 million pounds. Thus, this stock status would be below its B_{MSY} under the Alternative 2 and 3, rather than above it as with Alternative 1.

Under Alternative 1, overfishing occurs when the TAC is above the estimated sustained yield (SY). The Bristol Bay red king crab TAC for the 2006/2007 fishery was 15.5 million pounds, which is below the 2006 SY of 31.5 million pounds. Under Alternatives 2 and 3, overfishing would be defined as any amount of fishing in excess of a prescribed maximum allowable rate as prescribed through the six tiers described in Chapter 2. The recommended OFL control rule for the Bristol Bay red king crab stock is $F_{35\%}$.

To evaluate the impacts of the alternatives on Bristol Bay red king crab, fourteen harvest strategy scenarios were investigated to predict the changes in stock abundance levels under various harvest rates. For Alternative 1, two harvest control rules were simulated to predict the possible effects of this alternative on stock biomass; the status quo harvest strategy and fishing at the status quo OFL control rule. For Alternative 2 and 3, an evaluation was made of control rules in Tiers 2 to 5.

The Alternative 2 and 3 harvest control rule scenarios produced higher retained yield and lower mean rebuilding time compared to the Alternative 1 scenarios. The status quo harvest strategy performed similarly or slightly worse than some of the Alternative 2 and 3 scenarios. Fishing under the Alternative 1 OFL control rule performed worst of all, with very low mean number of recruits, a higher overfished percentage, and no stock rebuilding.

Pribilof Islands Red King Crab

The Alternative 1 status determination criteria for Pribilof Island red king crab established a B_{MSY} of 6.6 million pounds of total mature biomass and an MSST of 3.3 million pounds. The 2006 total mature biomass estimate is above the B_{MSY} at 19.0 million pounds. Under Alternatives 2 and 3, this stock would be considered approaching an overfished condition because mature male biomass would be well below the B_{MSY} proxy. The stock would still be above its MSST proxy, and thus would not be considered overfished.

Other Red King Crab

For the remaining red king crab stocks, no status determination criteria were established under the Alternative 1. Under Alternatives 2 and 3, Dutch Harbor red king crab and Norton Sound red king crab stocks would be managed under Tier 4, while Adak red king crab would be managed under Tier 5. Status determination criteria are provided for Tier 4 stocks, while maximum fishing mortality rates would be prescribed by the Tiers 4 and 5 formulas. Under Alternative 2 and 3, the 2006 Norton Sound red king crab mature male biomass would be well above the B_{MSY} proxy and the MSST proxy.

Blue King Crab

Under Alternative 1, Pribilof Island blue king crab and Saint Matthew blue king crab have been declared overfished and are under rebuilding plans. The Alternative 1 status determination criteria for Pribilof Island blue king crab establish a B_{MSY} of 13.2 million pounds of total mature biomass and an MSST of 6.6 million pounds. The 2006 total mature biomass estimate is 1.6 million pounds, well below the MSST for this stock. For Saint Matthew blue king crab, a B_{MSY} of 22.0 million pounds was established with an MSST of 11.0 million pounds. The 2006 total mature biomass estimate for this stock is 11.2 million pounds, just slightly above the MSST.

Under Alternatives 2 and 3, both of these stocks would be managed as Tier 4 stocks. As such, proxy B_{MSY} values would be estimated but no MSST. Under Alternatives 2 and 3, the status of these blue king crab stocks would be similar to the status under Alternative 1.

Golden King Crab

Under Alternative 1, no estimates of B_{MSY} or MSST are made for any of the golden king crab stocks. Under Alternatives 2 and 3, two golden king crab stocks (Pribilof Islands, Aleutian Islands) are preliminarily recommended for Tier 5. Under Tier 5, the OFL would be set using a fishing mortality estimate based on average catch. For Aleutian Islands golden king crab, if average catch is used to establish an OFL for this stock, the OFL would be very close to the current total allowable catch. Saint Matthew golden king crab are recommended for placement in Tier 6 whereby no OFL would be determined for this stock.

Snow Crab

Under Alternative 1, snow crab has been declared overfished and is under a rebuilding plan. The Alternative 1 status determination criteria for snow crab establish a B_{MSY} of 921.6 million pounds of total mature biomass and an MSST of 460.8 million pounds. The 2006 total mature biomass estimate is 547.6 million pounds, above the MSST for this stock but below the B_{MSY}. While the estimated total mature biomass under Alternative 1 is above MSST, and hence no longer in an overfished condition, this stock remains under a rebuilding plan until the stock is above B_{MSY} for two consecutive years.

Under Alternatives 2 and 3, B_{MSY} for snow crab would be measured by mature male biomass. The long-term B_{MSY} estimate for the stock would be 413.4 million pounds of mature male biomass. An MSST for this stock would be 206.7 million pounds. The 2006 mature male biomass estimate is 211 million pounds and just above this MSST.

Under Alternative 1, overfishing occurs when the TAC is above the estimated SY. The snow crab TAC for the 2006/2007 fishery was 36.6 million pounds, which is below the 2006 SY of 164.5 million pounds. Under Alternatives 2 and 3, overfishing would be defined as any amount of fishing in excess of a prescribed maximum allowable rate as prescribed through the six tiers described in Chapter 2. The recommended OFL control rule for the snow crab stock is $F_{35\%}$.

To evaluate the impacts of the alternatives on snow crab, thirteen harvest strategy scenarios were investigated to predict the changes in stock abundance levels under various harvest rates. For Alternative 1, two harvest control rules were simulated to predict the possible effects of this alternative on stock biomass; the status quo harvest strategy, and fishing at the Alternative 1 OFL control rule. For Alternatives 2 and 3, an evaluation was made of the control rules in Tiers 2 to 5.

The status quo harvest strategy control rule and the $F_{35\%}$ control rule produced similar simulation results for rebuilding times, and short-term and long-term yields. Fishing at the Alternative 1 OFL control rule did not rebuild the stock.

Tanner Crab

Under Alternative 1, Tanner crab has been declared overfished and is under a rebuilding plan. The Alternative 1 status determination criteria for eastern Bering Sea Tanner crab establish a B_{MSY} of 189.6 million pounds of total mature biomass and an MSST of 94.8 million pounds. The 2006 total mature biomass estimate is 253.3 million pounds, above the B_{MSY} for this stock. While the total mature biomass under Alternative 1 estimate the stock above its B_{MSY}, this stock remains under a rebuilding plan until the stock is rebuilt. In order to be considered rebuilt, this stock must be above B_{MSY} two consecutive years.

Under the Alternative 2 and 3 status determination criteria, B_{MSY} for Tanner crab would be measured in mature male biomass. The long-term B_{MSY} estimate for the stock would be 67.4 million pounds of mature male biomass, with an MSST of 33.7 million pounds. For comparison, the 2006 estimate of Tanner crab mature male biomass is 62.8 million pounds. Therefore, under Alternatives 2 and 3, this stock would be above the MSST but below its B_{MSY} in 2006.

Under Alternative 1, overfishing occurs when the TAC is above the estimated SY. The Tanner crab TAC for the 2006/2007 fishery was approximately 3 million pounds, which is below the 2006 SY of 76.1 million pounds. Under Alternatives 2 and 3, overfishing would be defined as any amount of fishing in excess of a prescribed maximum allowable rate as prescribed through the six tiers described in Chapter 2. Overfishing would be evaluated by comparison of actual harvest rates and the recommended control rules for this stock. Under Alternatives 2 and 3, $F_{35\%}$ would be the recommended OFL control rule for Tanner crab. Harvest rates in recent years have been well below this control rule.

To evaluate the impacts of the alternatives on Tanner crab, twelve harvest strategy scenarios were investigated to predict the changes in stock abundance levels under various harvest rates. For Alternative 1, two harvest control rules were simulated to predict the possible effects of this alternative on stock biomass; the status quo harvest strategy and fishing at the Alternative 1 OFL control rule. For Alternatives 2 and 3, an evaluation was made of control rules under Tiers 2 to 4.

Alternatives 2 and 3 simulations with an $F_{35\%}$ produced higher retained short-term and long-term yields. The status quo harvest strategy was satisfactory, with performance similar to the Alternative 2 and 3 scenarios. Fishing under the Alternative 1 OFL control rule performed worst of all, with a very low mean number of recruits, higher overfished percentage, and much lower long-tern biomass.

Under Alternative 1, no estimates of B_{MSY} or MSST are made for the other Tanner crab stocks. Under Alternative 2 and 3, the eastern Aleutian Islands Tanner crab stock would be under Tier 4. For this analysis, average biomass from 1999 to 2005 was used as a B_{MSY} proxy for eastern Aleutian Islands Tanner crab. Stock status would be below its B_{MSY} proxy but above MSST proxy. Historical comparison of stock status shows that the stock was below the MSST proxy in all years prior to 2000, with the exception of 1999. Western Aleutian Islands Tanner crab would be under Tier 6 due to lack of available information and no OFL would be determined for this stock.

Other Crab Stocks

Under Alternative 1, no B_{MSY} or MSST was specified for these stocks and the maximum fishing mortality threshold was based on the MSY control rule of 0.3 for Tanner crabs and 0.2 for king crabs.

Under Alternatives 2 and 3, these stocks would all be under Tier 5, with an OFL calculated based upon average catch or other means depending on information availability, or under Tier 6, with no OFL determination. No additional status determination criteria are currently estimated for these stocks nor proposed under the revised definitions.

Incidental Catch Limits

Chapter 10 analyzes the effects of the alternatives on crab caught incidentally in the BSAI groundfish fisheries. Bycatch limits are established in BSAI groundfish fisheries for red king crab, Tanner crab, and snow crab. Once these limits are exceeded, the specified area closures are triggered for the fishery. Crab species are also incidentally caught in the Alaskan scallop fishery and bycatch limits by species are established for this fishery.

Under Alternatives 2 and 3, OFLs would restrict current harvest levels for crab and it is possible that this would likewise affect the stair-step regulations implementing the bycatch limits. Bycatch limits, however, are based on overall abundance, not on harvest amounts. If abundance is projected to increase over time under the new OFLs, then the amount allocated for bycatch would increase. If the abundance is projected to decrease under the alternatives, the bycatch allocation would decrease.

Endangered Species Act Listed Species

Chapter 11 analyzes the effects of the alternatives on species currently listed under the Endangered Species Act (ESA). Twenty-one species occurring in the action area are currently listed as endangered, threatened, or candidate species under the ESA. The group includes seven species of great whales, one pinniped, four Pacific salmon, three seabirds, one albatross, four sea turtles, and sea otters.

None of the alternatives would have direct effects on ESA-listed species or critical habitat. If NMFS declared a stock overfished under any of the alternatives, then the Council would take action to develop a rebuilding plan for the stock. If overfishing was predicted to occur, the State would reduce the TAC to below the OFL. Both of these actions would reduce any adverse effects of the crab fisheries on ESA-listed species and critical habitat by reducing or eliminating fishing for the crab stock.

Economic and Social Effects

Chapter 12 analyzes the economic and social effects of the alternatives. The economic and social impacts are largely qualitative and deal with impacts on persons and on communities. The economic impacts of Alternatives 2 and 3 depend on the extent to which those control rules constrain the status quo harvest strategies used in establishing TACs. The short-term simulation projections suggest that TACs under Alternatives 2 and 3 would be less than under Alternative 1. The extent of this difference depends on the degree to which actual TACs are set below the proposed OFLs. Under the Alternative 1, the MSY control rule for these fisheries has not been constraining. However, the proposed OFLs for Alternatives 2 and 3 would be lower than those under Alternative 1, so TACs would likely have to be set lower to adjust for the lower OFLs. In general, any TAC decline is likely to contribute to reduce revenues and profits to harvesters and processors in the fishery and could contribute to fleet contraction. However, in the long-term, Alternative 2 and 3 OFLs could result in higher retained yields and lower rebuilding times for these fisheries, which would likely contribute to increased gross revenues to harvesters and processors in the future and could contribute to some fleet expansion.

Cumulative Effects

Chapter 13 analyzes the cumulative effects of the alternatives. The cumulative effects of crab fishing are analyzed in the Crab EIS, including the interactive effects of any past, present, and reasonable foreseeable future external actions. That analysis is incorporated by reference. The Crab EIS concludes that for the majority of the components of the environment analyzed, the cumulative effects of the crab fisheries are insignificant based on the best available scientific information. For some environmental components analyzed, the Crab EIS determined the cumulative effects were unknown, because of a lack of sufficient information on the cumulative condition or the inability to predict effects of external future actions. No new significant information is available that would change these determinations in the Crab EIS. This action would not result in additional impacts beyond those considered in the Crab EIS and is not anticipated to change any of the cumulative effects conclusions.

National Standards and Fishery Impact Statement

Chapter 14 provides the ten Magnuson-Stevens Act National Standards, and a brief discussion of the consistency of the proposed alternatives with each of those National Standards, and the fisheries impact statement.

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LIST OF ACRONYMS AND ABBREVIATIONS

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AAC	Alaska Administrative Code
ADF&G	Alaska Department of Fish and Game
AFA	American Fisheries Act
AFSC	Alaska Fisheries Science Center
AP	advisory panel
B	biomass
Board	Board of Fisheries
BSAI	Bering Sea and Aleutian Islands
CP	catcher/processor
CDQ	community development quota
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CIE	Center for Independent Experts
CL	carapace length
cm	centimeter
COBLZ	*C. opilio* Bycatch Limitation Zones
Council	North Pacific Fishery Management Council
CPUE	catch per unit effort
CSA	catch survey analysis
CV	coefficient of variation
CW	carapace width
EA	environmental assessment
EAI	Eastern Aleutian Islands
EBS	Eastern Bering Sea
EEZ	Exclusive Economic Zone
EFH	essential fish habitat
EIS	environmental impact statement
ESA	Endangered Species Act
ESB	effective spawning biomass
FMP(s)	fishery management plan(s)
FONSI	finding of no significant impact
FR	Federal Register
GC	general counsel
GHL	guideline harvest level
GOA	Gulf of Alaska
HAPC	habitat area of particular concern
IFQ	individual fishing quota
IPQ	individual processing quota
ITQ	individual transferable quota
LBA	length-based analysis
LLP	License Limitation Program
M	natural mortality rate
Magnuson-Stevens Act	Magnuson-Stevens Fishery Conservation Management Act
MFMT	maximum fishing mortality threshold
MMB	mature male biomass

MSST	minimum stock size threshold
MSY	maximum sustainable yield
NA (na)	data not available/applicable
NEPA	National Environmental Policy Act
NMFS or NOAA Fisheries	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPFMC	North Pacific Fishery Management Council (the Council)
OY	optimum yield
pdf	probability density function
PQS	processor quota shares
PSC	Prohibited Species Catch
QS	quota shares
RAM	Restricted Access Management
SAFE	Stock Assessment and Fishery Evaluation
Secretary	Secretary of Commerce
SPR	spawner per recruit
SSC	Scientific and Statistical Committee
State	State of Alaska
SY	sustainable yield
TAC	total allowable catch
TMB	total mature biomass
U.S.	United States
USFWS	United States Fish and Wildlife Service

1 INTRODUCTION

The king and Tanner crab fisheries in the Exclusive Economic Zone (EEZ) (3 to 200 miles offshore) of the Bering Sea and Aleutian Islands off Alaska are managed under the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (FMP). This FMP was developed by the North Pacific Fishery Management Council (Council) under the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act). The Secretary of Commerce first approved the FMP on June 2, 1989, and approved the revised and updated FMP on March 3, 1999.

The FMP establishes a State/Federal cooperative management regime that defers crab fisheries management to the State of Alaska with Federal oversight. State regulations are subject to the provisions of the FMP, including its goals and objectives, the Magnuson-Stevens Act, and other applicable Federal laws. The FMP defers much of the management of the BSAI crab fisheries to the State of Alaska using the following three categories of management measures:

4. Those that are fixed in the FMP and require a FMP amendment to change;
5. Those that are framework-type measures that the state can change following criteria set out in the FMP; and
6. Those measures that are neither rigidly specified nor frameworked in the FMP and are at the discretion of the State.

The proposed action is to establish a set of overfishing levels (OFLs) that provide objective and measurable criteria for identifying when the fishery to which the FMP applies is overfished or when overfishing is occurring, in compliance with the Magnuson-Stevens Act. The Magnuson-Stevens Act, in §303(a)(10), requires that FMPs specify objective and measurable criteria for identifying when the fishery to which the FMP applies is overfished (with an analysis of how the criteria were determined and the relationship or the criteria to the reproductive potential of stocks of fish in that fishery). The OFLs are a Category 1 measure in the FMP. As such, revisions to the OFLs require an FMP amendment.

Determinations of total allowable catches (TACs) and guideline harvest levels (GHLs) are a Category 2 management measure and deferred to the State following the criteria in the FMP. Catch levels established by the State must be in compliance with OFLs established in the FMP, to prevent stocks from being overfished or for overfishing to occur. As described in Chapter 2, NMFS annually determines if catch levels have exceeded rates determined to constitute overfishing or if stocks have reached or are approaching an overfished status. If either of these occurs, NMFS notifies the Council and the Council has one year to develop an FMP amendment to end overfishing and to rebuild the stock. More information on the notification and actions necessary by the Council are described in Section 1.1.

Management actions for the BSAI crab fisheries must comply with applicable Federal laws and regulations. Although several laws and regulations guide this action, the principal laws and regulations that govern this action are the Magnuson-Stevens Act and the National Environmental Policy Act (NEPA). None of the alternatives contain implementing regulations and therefore the Regulatory Flexibility Act does not apply and review under Executive Order 12866 is not required.

1.1 National Standard 1

The Magnuson-Stevens Act national standard 1 states that "Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield (OY) from each fishery for the U.S. fishing industry." The specification of OY and the conservation and management measures to achieve it must explicitly prevent overfishing. NMFS published national standard guidelines (50 CFR part 600) to provide comprehensive guidance for the development of FMPs and FMP amendments that comply with the Magnuson-Stevens Act national standards.

1.1.1 Definitions

Definitions of 'overfished' and 'overfishing' are provided in the national standard guidelines (50 CFR 600.310). While the Magnuson Act §3(29) defines both "overfishing" and "overfished" as a rate or level of fishing mortality that jeopardizes a fishery's capacity to produce maximum sustainable yield (MSY) on a continuing basis, the national standard guidelines provide guidance on the specification of 'overfished' as a status determination different from 'overfishing'. Excerpts from the National Standard guidelines are provided below:

(d) *Overfishing—*

(1) *Definitions.*

(i) "To overfish" means to fish at a rate or level that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis.

(ii) "Overfishing" occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis.

(iii) In the Magnuson-Stevens Act, the term "overfished" is used in two senses: First, to describe any stock or stock complex that is subjected to a rate or level of fishing mortality meeting the criterion in paragraph (d)(1)(i) of this section, and second, to describe any stock or stock complex whose size is sufficiently small that a change in management practices is required in order to achieve an appropriate level and rate of rebuilding. To avoid confusion, this section uses "overfished" in the second sense only.

(2) *Specification of status determination criteria.* Each FMP must specify, to the extent possible, objective and measurable status determination criteria for each stock or stock complex covered by that FMP and provide an analysis of how the status determination criteria were chosen and how they relate to reproductive potential. Status determination criteria must be expressed in a way that enables the Council and the Secretary to monitor the stock or stock complex and determine annually whether overfishing is occurring and whether the stock or stock complex is overfished. In all cases, status determination criteria must specify both of the following:

(i) *A maximum fishing mortality threshold or reasonable proxy thereof.* The fishing mortality threshold may be expressed either as a single number or as a function of spawning biomass or other measure of productive capacity. The fishing mortality threshold must not exceed the fishing mortality rate or level associated with the relevant MSY control rule. Exceeding the fishing mortality threshold for a period of 1 year or more constitutes overfishing.

(ii) *A minimum stock size threshold or reasonable proxy thereof.* The stock size threshold should be expressed in terms of spawning biomass or other measure of productive capacity. To the extent possible, the stock size threshold should equal whichever of the following is greater: 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 or stock complex were exploited at the maximum fishing mortality threshold specified under paragraph (d)(2)(i) of this section. Should the actual size of the stock or stock complex in a given year fall below this threshold, the stock or stock complex is considered overfished.

(3) *Relationship of status determination criteria to other national standards*.

(i) *National standard 2.* Status determination criteria must be based on the best scientific information available (see §600.315). When data are insufficient to estimate MSY, Councils should base status determination criteria on reasonable proxies thereof to the extent possible (also see paragraph (c)(3) of this section). In cases where scientific data are severely limited, effort should also be directed to identifying and gathering the needed data.

(ii) *National standard 3.* The requirement to manage interrelated stocks of fish as a unit or in close coordination notwithstanding (see §600.320), status determination criteria should generally be specified in terms of the level of stock aggregation for which the best scientific information is available (also see paragraph (c)(2)(iii) of this section).

(iii) *National standard 6.* Councils must build into the status determination criteria appropriate consideration of risk, taking into account uncertainties in estimating harvest, stock conditions, life history parameters, or the effects of environmental factors (see §600.335).

(4) *Relationship of status determination criteria to environmental change.* Some short-term environmental changes can alter the current size of a stock or stock complex without affecting the long-term productive capacity of the stock or stock complex. Other environmental changes affect both the current size of the stock or stock complex and the long-term productive capacity of the stock or stock complex.

(i) If environmental changes cause a stock or stock complex to fall below the minimum stock size threshold without affecting the long-term productive capacity of the stock or stock complex, fishing mortality must be constrained sufficiently to allow rebuilding within an acceptable time frame (also see paragraph (e)(4)(ii) of this section). Status determination criteria need not be respecified.

(ii) If environmental changes affect the long-term productive capacity of the stock or stock complex, one or more components of the status determination criteria must be respecified. Once status determination criteria have been respecified, fishing mortality may or may not have to be reduced, depending on the status of the stock or stock complex with respect to the new criteria.

(iii) If manmade environmental changes are partially responsible for a stock or stock complex being in an overfished condition, in addition to controlling effort, Councils should recommend restoration of habitat and other ameliorative programs, to the extent possible (see also the guidelines issued pursuant to Section 305(b) of the Magnuson-Stevens Act for Council actions concerning essential fish habitat).

1.1.2 Notification and Council action requirements

The national standard guidelines also specify the considerations necessary for approval of proposed status determination criteria as well as the notification requirements for stocks failing to meet their approved criteria and resulting Council actions required. Council must take remedial action within one year of secretarial notification.

(5) *Secretarial approval of status determination criteria.* Secretarial approval or disapproval of proposed status determination criteria will be based on consideration of whether the proposal:

(i) Has sufficient scientific merit.

(ii) Contains the elements described in paragraph (d)(2) of this section.

(iii) Provides a basis for objective measurement of the status of the stock or stock complex against the criteria.

(iv) Is operationally feasible.

(6) *Exceptions.* There are certain limited exceptions to the requirement to prevent overfishing. Harvesting one species of a mixed-stock complex at its optimum level may result in the overfishing of another stock component in the complex. A Council may decide to permit this type of overfishing only if all of the following conditions are satisfied:

(i) It is demonstrated by analysis (paragraph (f)(6) of this section) that such action will result in long-term net benefits to the Nation.

(ii) It is demonstrated by analysis that mitigating measures have been considered and that a similar level of long-term net benefits cannot be achieved by modifying fleet behavior, gear selection/configuration, or other technical characteristic in a manner such that no overfishing would occur.

(iii) The resulting rate or level of fishing mortality will not cause any species or evolutionarily significant unit thereof to require protection under the ESA.

(e) *Ending overfishing and rebuilding overfished stocks*—

(1) *Definition.* A threshold, either maximum fishing mortality or minimum stock size, is being “approached” whenever it is projected that the threshold will be breached within 2 years, based on trends in fishing effort, fishery resource size, and other appropriate factors.

(2) *Notification.* The Secretary will immediately notify a Council and request that remedial action be taken whenever the Secretary determines that:

(i) Overfishing is occurring;

(ii) A stock or stock complex is overfished;

(iii) The rate or level of fishing mortality for a stock or stock complex is approaching the maximum fishing mortality threshold;

(iv) A stock or stock complex is approaching its minimum stock size threshold; or

(v) Existing remedial action taken for the purpose of ending previously identified overfishing or rebuilding a previously identified overfished stock or stock complex has not resulted in adequate progress.

(3) *Council action.* Within 1 year of such time as the Secretary may identify that overfishing is occurring, that a stock or stock complex is overfished, or that a threshold is being approached, or such time as a Council may be notified of the same under paragraph (e)(2) of this section, the Council must take remedial action by preparing an FMP, FMP amendment, or proposed regulations. This remedial action must be designed to accomplish all of the following purposes that apply:

(i) If overfishing is occurring, the purpose of the action is to end overfishing.

(ii) If the stock or stock complex is overfished, the purpose of the action is to rebuild the stock or stock complex to the MSY level within an appropriate time frame.

(iii) If the rate or level of fishing mortality is approaching the maximum fishing mortality threshold (from below), the purpose of the action is to prevent this threshold from being reached.

(iv) If the stock or stock complex is approaching the minimum stock size threshold (from above), the purpose of the action is to prevent this threshold from being reached.

(4) *Constraints on Council action.*

(i) In cases where overfishing is occurring, Council action must be sufficient to end overfishing.

(ii) In cases where a stock or stock complex is overfished, Council action must specify a time period for rebuilding the stock or stock complex that satisfies the requirements of Section 304(e)(4)(A) of the Magnuson-Stevens Act.

The national standard guidelines also provides guidelines for rebuilding overfished stocks, including specifying the time period for rebuilding (not listed here but found under §600.310). Further interim measures may be implemented by the Secretary while remedial actions (e.g., FMP amendment or regulations) are being developed in order to prevent overfishing.

Considerations of these measures are critical in the development and implementation of the overfishing definitions as provided in this analysis for BSAI crab stocks.

1.2 Purpose and need

The purpose of the proposed action is to establish status determination criteria in compliance with the Magnuson-Stevens Act and the national standard guidelines, as described above. The current definitions were implemented under Amendment 7 to the FMP in 1998. In the environmental assessment (EA) for that amendment, the Crab Plan Team stated its intent to review the definitions after five years or at such a time that environmental conditions have changed such that revising the definitions may be necessary. In 2003, the Crab Plan Team undertook a review of the current definitions and decided that it would be prudent at that time to begin the process of crafting updated definitions which would incorporate the extensive scientific developments to date and facilitate the incorporation of new scientific information as it becomes available. The fixed format of the current definitions does not allow for incorporation of new information without amending the FMP. More information on the development of alternatives for this analysis may be found in Section 2.4.

The need for the proposed action is explained in the Crab Plan Team's problem statement:

New overfishing definitions are necessary to reflect current scientific information and accomplish the following:

- *Provide an FMP framework for definition values to facilitate use of the best available scientific information as it evolves.*
- *Provide a new tier system that accommodates varying levels of uncertainty of information and takes advantage of alternative biological reference points.*
- *Define the status determination criteria and their application to the appropriate component of the population.*

1.3 Scope of this Environmental Assessment

This document relies heavily on the information and analysis contained in the Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement/Regulatory Impact Review/Initial Regulatory Flexibility Analysis/Social Impact Assessment (NMFS/NPFMC 2004). Throughout this analysis, that document is referred to as the "Crab EIS." Additional information concerning the crab fisheries and management under the Crab Rationalization Program (Program), and impacts of these on the human environment are contained in that document.

This EA tiers off of the Crab EIS to focus the analysis on the issues ripe for decision and eliminate repetitive discussions. The Crab EIS provides the status of the environment and analyzes the impacts of the crab fisheries on the human environment. The proposed action established overfishing definitions for the crab stocks under the FMP. This EA details the specific impacts of the proposed action.

The Council on Environmental Quality (CEQ) regulations encourages agencies preparing NEPA documents to "tier their environmental impact statements to eliminate repetitive discussions of the same issues and to focus on the actual issues ripe for decision at each level of environmental review":

> Whenever a broad environmental impact statement has been prepared (such as a program or policy statement) and a subsequent statement or environmental assessment is then prepared on an action included within the entire program or policy (such as a site specific action) the subsequent statement or environmental assessment need only summarize the issues discussed in the broader statement and incorporate discussions from the broader statement by reference and shall concentrate on the issues specific to the subsequent action. (40 CFR 1502.20)

In 40 CFR 1508.28, the CEQ regulations further define tiering as "the coverage of general matter in broader environmental impact statements … with subsequent narrower statements of environmental analyses….incorporating by reference the general discussion and concentrating solely on the issues specific to the statement subsequently prepared."

This section of the CEQ regulations further notes that "tiering is appropriate when the sequence of statements or analysis is from a program, plan, or policy environmental impact statement to a program, plan, or policy statement or analysis of lesser scope or to a site-specific statement or analysis." (40 CFR 1508.28).

1.4 Next steps in the process

This analysis is scheduled for initial review at the February 2007 Council meeting. At that time the Council will review the document, and take into consideration the Science and Statistical Committee's (SSC) recommendations on the scientific validity of the analysis. If the Council approves the document for public release, the document will be modified according to any specific recommendations from the Council, AP, and SSC, and subsequently released to the public for review. Final action on this analysis would likely be scheduled for the April 2007 Council meeting.

2 Description of Alternatives

Three alternatives are considered in this analysis.

2.1 Alternative 1: status quo

Alternative 1 utilizes the status determination criteria established in Amendment 7 to the FMP. The Council adopted Amendment 7 in 1998 and the Secretary approved Amendment 7 on March 3, 1999 (64 FR 11390). Amendment 7 provided fixed values in the FMP for the minimum stock size threshold (MSST), MSY, OY, and maximum fishing mortality threshold (MFMT) for the BSAI king and Tanner crab stocks, as shown in Table 2-1. The EA for Amendment 7 specified that the Crab Plan Team would reevaluate the status determination criteria every five years or when environmental conditions indicate a regime shift.

2.1.1 Current tier system for BSAI king and Tanner crab stocks

In the existing tier system, the harvest control rule for each crab species is based on the estimates of biomass and size frequency from the annual NMFS Eastern Bering Sea (EBS) trawl survey, and the natural mortality rate set in the FMP, and retained catch. The 22 king and Tanner crab stocks managed under the FMP are classified into three tiers according to level of data availability: Tier 1–unsurveyed stocks with minimal history of effort and harvest; Tier 2–stocks with sporadic or limited years of survey data, but well documented history of catch and effort; Tier 3–stocks with annual survey data, well documented history of catch and effort, and information pertaining to productivity parameters. There are six Tier 3 stocks that are annually surveyed by the NMFS EBS trawl survey: Bristol Bay red king crab, Pribilof Islands red king crab, St. Matthew Island blue king crab, Pribilof Islands blue king crab, eastern Bering Sea Tanner crab, and eastern Bering Sea snow crab.

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 = B_{MSY} *F_{MSY}.

MSY has been estimated for all stocks except Aleutian Islands scarlet king and EBS scarlet king crabs.

2.1.2 Status determination criteria

NMFS is required to determine the status of the stocks relative to the criteria and notify the Council once NMFS determines that overfishing is occurring, a stock or stock complex is overfished, a stock or stock complex is approaching its MSST, or the rate or level of fishing mortality for a stock or stock complex is approaching maximum fishing mortality threshold (MFMT). The Council has one year in which to take remedial action by preparing an FMP amendment to end overfishing and rebuild the stock.

The FMP establishes the status determination criteria shown in Table 2-1. For the Tier 3 stocks, the MSY control rule, the MFMT, B_{MSY}, the MSST, and MSY were defined as functions of survey estimates of total (male and female) mature biomass (TMB), and a fishing mortality rate (*F*) set equal to an estimate of the natural mortality rate (set at M=0.2 for all species of king crab and M=0.3 for all *Chionoecetes* species).

Table 2-1 MSST (minimum stock size threshold), MSY, and OY in millions of pounds (metric tons, t, in parentheses), and the MFMT (maximum fishing mortality threshold) values for BSAI king and Tanner crabs.

Stock	MSST	MSY	OY range	MFMT
WAI red king	NA	1.5 (680)	0-1.5 (0 – 680)	0.2
Bristol Bay red king	44.8 (20,321)	17.9 (8,119)	0-17.9 (0 – 8,119)	0.2
EAI red king	NA	NA	NA	0.2
Pribilof Islands red king	3.3 (1,497)	1.3 (590)	0-1.3 (0 – 590)	0.2
Norton Sound red king	NA	0.5 (227)	0-0.5 (0 – 227)	0.2
Pribilof Islands blue king	6.6 (2,994)	2.6 (1,179)	0-2.6 (0 – 1,179)	0.2
Saint Matthew blue king	11.0 (4,990)	4.4 (1,996)	0-4.4 (0 – 1,996)	0.2
Saint Lawrence blue king	NA	0.1 (45)	0-0.1 (0 – 45)	0.2
Aleutian Islands golden king	NA	15.0 (6,804)	0-15.0 (0 – 6,804)	0.2
Pribilof Islands golden king	NA	0.3 (136)	0-0.3 (0 – 136)	0.2
Northern District golden king	NA	0.3 (136)	0-0.3 (0 – 136)	0.2
Aleutian Islands scarlet king	NA	NA	NA	0.2
EBS scarlet king	NA	NA	NA	0.2
Total king crab		**43.9 (19,913)**	**0-43.9 (0 – 19,913)**	
Eastern Aleutian Tanner	NA	0.7 (318)	0-0.7 (0 – 318)	0.3
EBS Tanner	94.8 (43,001)	56.9 (25,810)	0-56.9 (0 – 25,810)	0.3
Western Aleutian Tanner	NA	0.4 (181)	0-0.4 (0 – 181)	0.3
Total Tanner		**58.0 (26,309)**	**0-58.0 (0 – 26,309)**	
EBS snow	460.8 (209,017)	276.5 (125,420)	0-276.5 (0 – 125,420)	0.3
Total snow		**276.5 (125,420)**	**0-276.5** (0 – 125,420)	
Eastern Aleutian triangle Tanner	NA	1.0 (454)	0-1.0 (0 – 454)	0.3
EBS triangle Tanner	NA	0.3 (136)	0-0.3 (0 – 136)	0.3
Eastern Aleutian grooved Tanner	NA	1.8 (816)	0-1.8 (0 – 816)	0.3
EBS grooved Tanner	NA	1.5 (680)	0-1.5 (0 – 680)	0.3
Western Aleutian grooved Tanner	NA	0.2 (91)	0-0.2 (0 – 91)	0.3
Total other Tanner		**4.8 (2,177)**	**0-4.8 (0 – 2,177)**	

NA: Indicates that insufficient data exists to calculate value.

NMFS determines the harvest rate that would constitute overfishing for the upcoming season by applying the MFMT to the survey abundance estimate of the TMB and comparing that to the TAC or GHL for that fishery. The MFMT is represented by the sustainable yield (SY) in a given year, which is the MSY rule applied to the current TMB. Overfishing occurs if the harvest level exceeds the SY in one year. This

MSY control rule was defined as Baranovs catch equation applied to TMB under the assumption that TMB estimated at the time of survey is the average TMB available for the year and because size, sex, and fishing season dates are optimum yield choices that can vary from stock to stock.

For Alternative 1, the MSY control rule is specified as:

$$SY = TMB*M.$$

MSY for a stock is defined as the average of the annually computed SY over the 15-year period, 1983-1997.

NMFS annually determines if a stock is overfished or approaching an overfished condition by comparing the estimates of TMB from the NMFS survey with the MSST (or proxies) defined in the FMP. MSST for a stock is defined as one-half of B_{MSY}. B_{MSY} for a stock is defined as the average annual estimated TMB for the 15-year period, 1983-1997. If the stock biomass drops below the MSST (or proxy thereof) then the stock is considered to be overfished.

2.2 Alternative 2: new tier system and Council annually adopts OFLs

Alternative 2 would amend the FMP to include the tier system in Table 2-2 and a framework for annually assigning each crab stock to a tier and for setting the OFLs. The FMP amendment would specify the process by which stocks are assigned to tier levels, the OFLs are set, and the timing of the annual review process by the Crab Plan Team, SSC, and Council.

The OFL setting and review process would be as follows. Annually, each stock would be assigned a tier based on availability of information. Tier levels and OFLs would be suggested by the stock assessment author, presented to the Crab Plan Team for comments and suggestions as to stock status, and then reviewed by the SSC. The SSC would make final recommendations to the Council on tier levels and OFLs. In June, the Council would then adopt the final tier levels and OFLs for each stock. OFLs would be determined based upon model estimates prior to the summer survey because the Council would adopt the OFLs before the survey.

The annual NMFS trawl survey data would be used in the models to estimate the stock abundance in the late summer. Status of stocks would be derived from comparing the recent abundance estimates to the adopted OFLs. The State would set TACs based on the recent abundance estimates, constrained by the adopted OFLs.

2.2.1 Tier system

The proposed tier system has analogs to the Council's current groundfish tier system. OFL is defined as any amount of fishing in excess of a prescribed maximum allowable rate. This maximum allowable rate is prescribed through a set of six tiers, which are listed below in descending order of preference, corresponding to descending order of information availability. The SSC has the final authority for determining whether a given item of information is "reliable" for the purpose of this definition, and may use either objective or subjective criteria in making such determinations. Abbreviations used in the overfishing definition include fishing mortality rate (F), natural mortality rate (M), biomass (B), probability density function (*pdf*), and biomass that produces MSY to the fishery (B_{MSY}).

In the groundfish tier system, the specified F_{ABC} is the maximum target F to ensure a buffer between the overfishing F_{OFL} and the target F as required by the national standard guidelines. For crab, the FMP defers the specification of the target F to the State, with Federal oversight. The target F corresponding to the annual TAC can be set anywhere below the F_{OFL}. To comply with the intent of the national standard guidelines, however, a buffer between the target *F* and the F_{OFL} would be encouraged to insure that the F_{OFL} is not exceeded.

The proposed tier system for crabs incorporates a threshold value (β) of B/ B_{MSY} below which directed fishing is prohibited. For example, the status quo harvest strategy for Bering Sea snow crab (not the overfishing definitions) reduces fishing mortality to 0 at 25% of B_{MSY}.

In Tiers 1 through 4, three levels of stock status are specified and denoted by 'a', 'b' and 'c'. At stock status level 'a', current stock biomass exceeds the B_{MSY}. For stocks in status 'b', current biomass is less than B_{MSY} but greater than a level specified as the 'critical biomass threshold' (β). Lastly, in stock status 'c', current biomass is below β. For each of these levels of stock status in Tiers 1 through 4, the fishing mortality rate corresponding to the overfishing limit (i.e., F_{OFL}) is specified in the tier system. In Tier 5, the OFL is specified in terms of an average catch value over an historical time period unless the SSC establishes an alternative value based on the best available scientific information. In Tier 6, available information is insufficient to determine the OFL.

Tiers 1 through 3

For Tiers 1 through 3, reliable estimates of *B*, B_{MSY} and F_{MSY}, or their respective proxy values are available. Tiers 1 and 2 are for stocks with a reliable estimate of the spawner/recruit relationship thereby enabling the estimation of the limit reference points B_{MSY} and F_{MSY}. Tier 1 is for stocks with assessment models in which the *pdf* of F_{MSY} is estimated. Tier 3 is for stocks where reliable estimates of the spawner/recruit relationship are not available, however, proxies for F_{MSY} and B_{MSY} can be estimated. For Tier 3 stocks, maturity and other essential life-history information are available to estimate proxy limit reference points. For Tier 3, a designation of the form "F_X" refers to the fishing mortality rate associated with an equilibrium level of spawning per recruit (SPR) equal to *X%* of the equilibrium level of spawning per recruit in the absence of any fishing. If reliable information sufficient to characterize the entire maturity schedule of a species is not available, the SSC may choose to view SPR calculations based on a knife-edge maturity assumption as reliable.

For Tiers 1 through 3, an F_{MSY} control rule reduces the F_{OFL} as biomass declines (Figure 2-1). For Tiers 1-3, the coefficient α is set at a default value of 0.1 with the understanding that the SSC may establish a different value for a specific stock or stock complex as merited by the best available scientific information. Biomass values should be proportional to fertilized egg production. In this analysis, mature male biomass (MMB) at the time of mating of primiparous females (February 15) is used as the best available proxy for fertilized egg production. Using MMB eliminated the need for estimating uncertain parameters such as, mating ratios, fertilization rates, and which males take part in mating. As research improves our estimates of key processes controlling crab reproduction, it is anticipated that alternative indices of biomass will be considered that are based on a combination of male and female biomass.

Tiers 4 through 6

Tiers 4 through 6 are for stocks with no stock assessment model and where essential life-history information and understanding is lacking. In Tier 4, a default value of *M* is used in the calculation of the F_{OFL}. Explicit to Tier 4 are reliable estimates of current survey biomass and the instantaneous *M*. A scaler, γ, is multiplied by *M* to estimate the F_{OFL} for stocks at status levels 'a' and 'b', and γ is allowed to be less than or greater than unity. Hence, the resultant overfishing threshold can be either more or less biologically conservative than fishing at *M*. Use of the scaler γ is intended to allow adjustments in the overfishing definitions to account for differences in biomass measures. Stocks belonging to Tier 4 are information-poor by definition, hence, γ should never be set to a value that would provide less biological conservation and more risk prone overfishing levels without defensible evidence that the stock could support fishing at levels in excess of *M*.

Tier 5 stocks have no reliable estimates of biomass or *M*, but a reliable catch history exists for these stocks. For stocks belonging to Tier 5, the historical performance of the fishery is used to set OFLs in terms of catch instead of fishing mortality. OFL represents the average catch from a time period determined to be representative of the production potential of the stock. The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion in terms pertaining to stock conservation and utilization goals. The SSC may establish a different OFL for stocks in Tier 5 based on the best available scientific information.

Tier 6 is for stocks where information necessary to establish an overfishing limit is unavailable. For these stocks, only exploratory fishing or incidental catch has occurred. These stocks are monitored for trends in fishing effort, CPUE, mean size of landed crab and ratio of newshell to oldshell crab. Stocks in Tier 6 would continue to be evaluated annually for possible upgrading to Tier 5 for OFL determination.

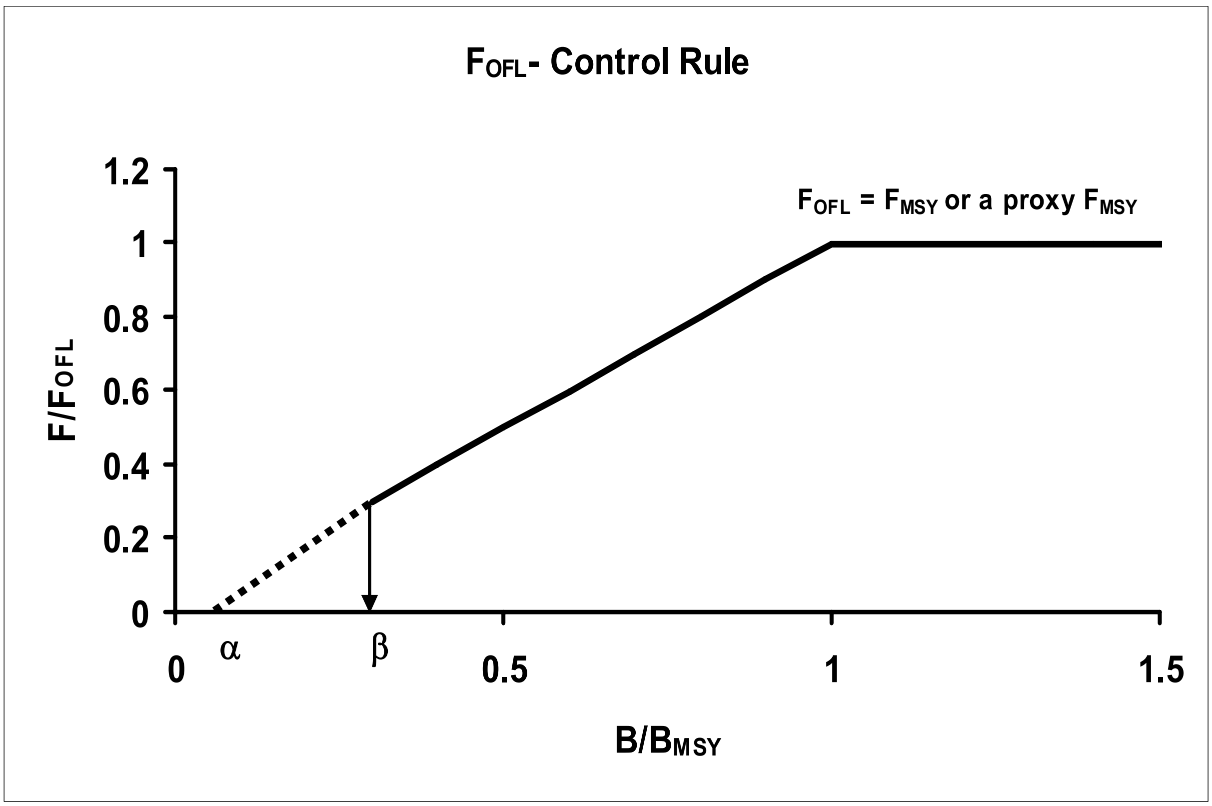

Figure 2-1 Proposed control rule for overfishing for Tiers 1 through 4 under Alternatives 2 and 3. Directed fishing mortality is 0 below beta.

The following represent the proposed tier assignments for purposes of this analysis (actual assignment to tiers under this alternative would occur annually during the review process and would be determined by the SSC, under recommendation from the Crab Plan Team):

Tier 1 stocks:
None.

Tier 2 stocks:
None.

Tier 3 stocks:
1. Bristol Bay red king crab (*Paralithodes camtschaticus*)
2. EBS Tanner crab (*Chionoecetes bairdi*)
3. EBS snow crab (*Chionoecetes opilio*)

Tier 4 stocks:
4. Pribilof Islands red king crab
5. Pribilof Islands blue king crab (*Paralithodes platypus*)
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

Tier 5 stocks:
10. Adak red king crab
11. Pribilof Islands golden king crab (*Lithodes aequispinus*)
12. Aleutian Islands golden king crab
13. Eastern Bering Sea grooved Tanner crab

Tier 6 stocks:
14. Saint Matthew golden king crab
15. Western Aleutian Tanner crab
16. Saint Lawrence Island blue king crab
17. Aleutian Islands scarlet king crab (Lithodes couesi)
18. Eastern Bering Sea scarlet king crab
19. Bering Sea triangle Tanner crab (Chionoecetes angulatus)
20. Eastern Aleutian Islands triangle Tanner crab
21. Eastern Aleutian Islands grooved Tanner crab (Chionoecetes tanneri)
22. Western Aleutian Islands grooved Tanner crab

2.2.2 Status determination

NMFS is required to determine the status of the stocks relative to the criteria and notify the Council once NMFS determines that overfishing is occurring, a stock or stock complex is overfished, a stock or stock complex is approaching its MSST, or the rate or level of fishing mortality for a stock or stock complex is approaching MFMT. The Council has one year in which to take remedial action by preparing an FMP amendment to end overfishing and rebuild the stock.

Annual determination of overfishing would occur by comparison of the estimated *F* from the previous year's fishery with the calculated F_{OFL} for the same time period. Overfishing is defined as any amount of fishing in excess of a prescribed maximum allowable rate as prescribed through the six tiers described in Section 2.2.1. The F_{OFL} for each stock would be annually estimated using the projection models and the tier system as described in Section 2.2.1. If the harvest rate utilized for the previous year's fishery is above the F_{OFL} then overfishing occured.

Annual scenarios would be run using the projection models to determine if a stock is overfished or approaching an overfished condition. For stocks where MSST (or proxies) are defined, if the stock biomass drops below the MSST (or proxy thereof) then the stock is considered to be overfished. A default MSST equal to ½ B_{MSY} may be used in the absence of any definition.

2.2.3 Biological reference points

Biological reference points are estimated for the different species managed under this FMP. A biological reference point is a level of a fishery and/or of a stock that can be used for management. Caddy and Mahon (1995) define a reference point as a conventional value, derived from technical analysis, which represents a state of the fishery or population, and whose characteristics are believed to be useful for the management of the unit stock. MRAG Americas Inc. (2000) further specify that biological reference points are quantifiable and verifiable points, expressed in terms of management and population variables, which include the amount of fishing (fishing mortality) and the condition of the fish stock (biomass). Biological reference points are defined solely using biological criteria associated with the productivity of the stock, but may be modified into management or technical reference points by incorporating social and /or economic criteria to define optimum yield.

Estimation of parameters varies by species and by availability of information for specific stocks. Under the review system for this alternative, biological parameters may be adjusted annually as information on stocks improve, or as information on specific parameters (e.g., handling mortality) becomes available to suggest alternate approaches. A review process is specifically included under this alternative in order to have adequate scientific review of the parameters which are utilized in the models used to estimate OFLs. This review process includes the CPT and SSC as described in Section 2.2. Further details on the timing of this review process in conjunction with establishment of OFLs are contained in Section 2.5.

2.2.3.1 Spawning biomass proxy

Female mature biomass is used as a proxy for egg production in many fisheries applications to determine reference points. Egg production in crab stocks, however, is complicated by mating in pairs, limited mobility relative to fish, and a male only fishery. Females may not mate due to insufficient males and may extrude eggs that are unfertilized and cannot be distinguished from fertilized eggs without laboratory procedures. Mating ratios have been proposed that define the number of females one male can mate with in a mating season to use in modifying female spawning biomass. Laboratory studies of mating have found males mating with multiple females (Powell et al. 1974, Powell and Nickerson 1965, Paul and Paul 1997, Paul 1984); however, mating ratios in the natural environment are unknown. Females of the *Chionoecetes* sp. may mate with more than one male in the same season which contravenes the mating ratio calculation. Another complication is that female snow crab inhabiting cold water realms have been shown to be on a two-year reproduction cycle. In addition, males that molt close to the mating season, may not participate in mating, which would effect the estimation of mature males available for mating. Also, female Tanner and snow crabs can store sperm for more than 1 year for fertilizing the egg clutches in the future. Spatial distribution of the fishery may affect local sex ratios at mating time. CIE review of the proposed OFL revisions (appendix D) recommended the use of male mature biomass at the time of mating as a proxy for egg production in the short term, due to the many uncertainties in mating ratios used to modified female mature biomass. The CIE review also recommended research be conducted toward estimating an egg production index that should replace the use of male mature biomass in future reference point estimation. Primiparous females (first brood) may mate at different times from multiparous females (second or later brood), however, a date of February 15 was selected for calculation of mature male biomass, prior to males molting. Another assumption we made to calculate mature male biomass is that all pot fishing occurred or will occur before February 15 during each fishing season.

B_{MSY} is defined as the biomass achieved when fishing at F_{MSY} where recruitment follows a spawner-recruit curve. F_{MSY} is the fishing mortality that results in the maximum sustainable yield. A stock that was exploited at F_{MSY} for some period of time may fluctuate around the B_{MSY} value under a relatively stable productivity regime. The use of average survey biomass over some time period assumes selectivity is 1.0, and that the stock is being fished at F_{MSY}. The use of mature male biomass from a stock assessment model takes into account survey selectivity, survey observation error and incorporates knowledge of life history parameters in the estimation of biomass reference points. Mature male biomass from a stock assessment model does not assume that the stock has been fished at F_{MSY}, since annual fishing mortality rates are estimated in the model. The estimation of a spawner-recruit curve requires estimates of recruitment and spawning biomass. B_{MSY} then can be estimated given the spawner-recruit curve. Proxy values for B_{MSY} are typically estimated from average recruitment over some time period and spawning biomass per recruit fishing at F = proxy for F_{MSY}. All of the above methods, however, assume that productivity is not changing over the time period considered.

2.3 Alternative 3: new tier system and Council annually review OFLs

Alternative 3 would amend the FMP to include the tier system in Table 2-2 and framework for assigning each crab stock into a tier and for setting the OFLs. The amendment specifies the process by which stocks are assigned to tier levels, the OFLs are set, and the timing of the annual review process by the Crab Plan Team, SSC, and Council.

The OFL setting and review process would be as follows. Annually, each stock would be assigned a tier based on availability of information. In the spring, stocks assessment authors would present tier levels and models to the Crab Plan Team for review. Final determination of model parameters and tier levels would be established by the SSC meeting and reviewed by the Council at the June meeting. OFLs would be calculated after the survey data are available in late August. Model parameters would not be changed in the interim. Following the incorporation of survey results, assessment authors would calculate the OFLs and NMFS would determine the status of the stocks relative to the OFLs. The State would set TACs based on the recent abundance estimates, constrained by these OFLs. The Council would then review the status of the stocks, the OFLs and the TACs in October or December.

Note that this alternative uses the same tier system, status determination criteria and biological reference points as for Alternative 2. See Sections 2.2.1 through 2.2.3 for more information.

Table 2-2 Proposed tier system for Alternative 2 and Alternative 3.

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	$\beta < \frac{B}{B_{msy}} \le 1$	$F_{OFL} = \mu_A \frac{B/B_{msy} - \alpha}{1-\alpha}$
	1c	$\frac{B}{B_{msy}} \le \beta$	$F_{OFL} = 0$
B, B_{MSY}, F_{MSY}	2a	$\frac{B}{B_{msy}} > 1$	$F_{OFL} = F_{msy}$
	2b	$\beta < \frac{B}{B_{msy}} \le 1$	$F_{OFL} = F_{msy} \frac{B/B_{msy} - \alpha}{1-\alpha}$
	2c	$\frac{B}{B_{msy}} \le \beta$	$F_{OFL} = 0$
B , $F_{35\%}$, $B_{35\%}$	3a	$\frac{B}{B_{35\%}} > 1$	$F_{OFL} = F_{35\%}$
	3b	$\beta < \frac{B}{B_{35\%}} \le 1$	$F_{OFL} = F_{35\%} \frac{\frac{B}{B_{35\%}} - \alpha}{1-\alpha}$
	3c	$\frac{B}{B_{35\%}} \le \beta$	$F_{OFL} = 0$
B, M, $B_{msy^{prox}}$	4a	$\frac{B}{B_{msy^{prox}}} > 1$	$F_{OFL} = \gamma M$
	4b	$\beta < \frac{B}{B_{msy^{prox}}} \le 1$	$F_{OFL} = \gamma M \frac{B/B_{msy^{prox}} - \alpha}{1-\alpha}$
	4c	$\frac{B}{B_{msy^{prox}}} \le \beta$	$F_{OFL} = 0$
Reliable catch history from 1985 to 2005.	5		OFL = The average catch from 1985 to 2005, unless the SSC establishes an alternative value based on the best available scientific information.
Insufficient catch history (for stocks with exploratory fishery or incidental fishery).	6		OFL = No sufficient information to determine OFL. Stocks are monitored for trends of fishing effort, CPUE, mean size of landed crab, and ratio of landed newshell to oldshell crab. Stocks are evaluated annually for upgrading to Tier 5 for OFL determination.

2.4 Comparison of alternatives

This section provides a comparison of the two main components of the alternatives: (1) the status determination criteria, and (2) the timing of the OFL determinations. Alternatives 2 and 3 contain the same status determination criteria. Alternatives 1 and 3 contain a similar process for the timing of the annual OFL determinations.

2.4.1 Status determination criteria

The status determination criteria provided in Alternative 1 are fixed in the FMP and reflect the understanding of crab biology and abundance at that time. However, since 1998, considerable work has been undertaken by ADF&G and NMFS to better understand and model the BSAI king and Tanner crab stocks. A number of the life history parameters that were unknown or controversial in 1998 have been determined to a degree of certainty. Other life history parameters that remain either unknown or controversial are the subject of ongoing research. Alternative 2 and 3 were designed to incorporate this new scientific information and provide a mechanism to continually improve the status determination criteria as new information becomes available. Alternatives 2 and 3 present a framework for the OFLs to facilitate use of the best available scientific information as information improves. Alternatives 2 and 3 provide the same tier system that accommodates varying levels of uncertainty of information and takes advantage of alternative biological reference points in setting the OFLs. The OFLs established under these alternatives would be specified for the appropriate component of the population. The impacts of the alternative status determination criteria are analyzed in Chapter 3 under the section for each stock because the impacts vary between stocks.

Table 2-3 provides a comparison of the biological reference points provided in the alternatives. Additional information on the biological reference points for specific species are in contained in the section for that species.

Table 2-3 Comparison of biological reference points used in the alternatives.

Biological Reference Points	Alternative 1	Alternatives 2 and 3
MSY (MSY proxy)	average of the annually computed SY over the 15-year period, 1983-1997. (TMB*M)	Tiers 1 and 2 (MSY) Tier 3 and 4 (MSY proxy)
B_{MSY}	average annual estimated TMB for the 15-year period, 1983-1997	Mature male biomass
MSST	½ B_{MSY}	½ B_{MSY}
MFMT	MSY control rule applied to the current TMB	F_{OFL} calculated by applying tier system
MSY control rule	*M*	
M	0.2 for all species of king crab 0.3 for all *Chionoecetes* species	king crab: 0.18 for male, 0.1 for female *Chionoecetes* species: 0.23 for male, 0.29 for female
SY	TMB**M*	
OY	OY range 0 - MSY	

2.4.1.1 Risks associated with continued use of the current status determination criteria (Alternative 1)

The MSST and MSY control rule in the status quo overfishing definitions (Alternative 1) provide two benchmarks to determine status of stocks and overfishing; the MSST is the benchmark used to determine if a stock is in overfished condition, whereas the MSY control rule is used to compute a benchmark to determine if overfishing has occurred or if a proposed TAC would constitute overfishing. MSST for each Tier 3 stock is fixed in the FMP by Amendment 7 (MSST is not defined for either the Tier 1 or Tier 2 stocks). Although not itself a fixed value, the MSY control rule for a stock is parameterized by the MFMT for the stock, which is fixed in the FMP by Amendment 7. MSST for a Tier 3 stock is defined as being ½ of the stock's B_{MSY}, which is defined by Amendment 7 as a fixed value for each of the Tier 3 stocks (MSST and B_{MSY} are not defined for either the Tier 1 or Tier 2 stocks). The MSY control rule for a stock is defined as the product of the stock's estimated total mature biomass (TMB) and the fixed-value MFMT defined for the stock in the FMP by Amendment 7.

The status quo overfishing definitions have the advantage of simplicity in definition, computation, and application. MSST is defined as ½ of B_{MSY}, which for Tier 3 stocks, is defined as the average annual TMB over the period 1983-1997 as estimated from results of the NMFS EBS trawl survey. If the TMB of a stock as estimated from the results of the NMFS EBS trawl survey is less than the fixed-value MSST, the stock is considered overfished. An overfished stock's progress towards rebuilding is tracked by comparing the annually estimated TMB with the fixed-value B_{MSY}; the TMB must meet or exceed B_{MSY} to be considered rebuilt. The process of comparing annual TMB estimates with fixed values requires no more analysis than is involved in estimating the TMB, an important consideration given the short time between availability of summer survey data and the opening of the fisheries in the fall.

Likewise, application of the MSY control rule to determine an overfishing level requires a simple multiplication of the TMB estimate and the MFMT. Under the status quo definitions, overfishing would occur if fishing mortality is greater than or equal to MFMT = F_{MSY}, which is fixed in the FMP as equal to an estimate of the natural mortality rate for the stock (0.2 for all king crab stocks and 0.3 for all stocks of *Chionoecetes*). To determine if overfishing has occurred or if a proposed TAC would result in overfishing, the MSY control rule is applied to the stock's estimated TMB for the year of interest and the resulting biomass value is compared with harvest or proposed TAC in question; a harvest is considered to constitute overfishing when it is equal to or greater than the product the stock's estimated TMB and the stock's MFMT. Again, the simplicity of this process is a benefit given the short time between availability of summer survey data and the beginning of the fisheries in the fall.

Although the status quo overfishing definitions have advantages of simplicity in definition, computation, and application, those definitions also carry risks in their application. Fixed values of B_{MSY}, MSST, and MFMT may not adequately reflect the realities of changing stock and environmental conditions. Additionally, there may be technical and conceptual problems in the definition and derivation of the values that are fixed in the FMP under the status quo definitions and in the status quo formulation of the MSY control rule. The B_{MSY} definition for Tier 3 stocks, for example, assumes that the average of the annual TMB for a stock during 1983-1997 is an adequate estimate of, what according to the 1998 Guidelines for National Standard 1 (Optimum Yield) of the Magnuson-Stevens Act, should be "the long-term spawning biomass … that would be achieved under an MSY control rule in which fishing mortality is constant." That assumption can be questioned regardless of the timeframe considered (i.e., regardless of whether the period 1983-1997 is the appropriate period to represent current prevailing environmental conditions). It has not been demonstrated that the TMB over the period of any Tier 3 stock was the result of application of an MSY control rule in which fishing mortality was constant. That several of the Tier 3 stocks were declared to be in overfished condition shortly after 1997 is evidence that the TMB during 1983-1997 were not the levels expected to be achieved under an MSY control rule.

Aside from technical issues that exist concerning the derivation of the status quo MSY control rule, the status quo definition of MFMT = F_{MSY} = M, and the estimated values of M under the status quo, there are issues in the application of the status quo MSY control rule. Due to problems that may be more "conceptual" than "technical," the status quo MSY control rule does not provide clear guidance for determining if overfishing is occurring or for developing harvest strategies that avoid overfishing. Although application of the status quo MSY control rule provides a biomass value that a harvest or proposed TAC can be compared to, the current definitions are not clear on how all sources of fishing mortality (e.g., bycatch mortality during the directed fisheries or other fisheries) are accounted for when determining if overfishing has or could occur.

Moreover, the status quo MSY control rule does not reflect the realities of the BSAI king and Tanner crab fisheries and their management. The MSY control rule was defined in the context of the broadest and most generalized fishery practices possible (year-around fishing and constant fishing selectivity over all sizes and both sexes of mature animals) within which sex, size, and season restrictions on harvest were considered OY choices. Since the inception of these FMP fisheries, however, sex restrictions (males-only harvests) have been applied; minimum-size-limit restrictions for harvesting males have been established in regulation or exist de facto due to market preferences; and, for all but a few stocks, seasonal harvest restrictions have been established. By ignoring the sex, size, and season restrictions that exist in regulation, the fishery practices that result in fishery selectivity varying by size or shell age of legal-sized males, and the potential for fishery harvests to occur during only a short period within a year, the status quo MSY control rule could allow for harvests that would clearly constitute overfishing without being formally recognized as such. Under the status quo MSY control rule, any harvest of less than 20% of a king crab stock's (or 30% of a Tanner crab stock's) mature biomass as estimated at the time of the summer stock assessment survey, when mature biomass is at or near it's annual peak, would not constitute overfishing. The MSY control rule does not consider the phase in the molting and spawning cycle that the harvest occurs, the biomass present at the time that the harvest occurs, or the component of the mature stock that is harvested. As a result, under certain—entirely realistic—conditions the status quo MSY control rule could allow for the all legal-sized or market-preferred males present in a stock to be harvested.

2.4.2 Timing of OFL determinations

The timing of the OFL determinations is important because it determines two key factors: (1) who the decision-maker can be, and (2) what information is used in the OFL determinations. Timing also impacts the level and extent of peer review and information shared with the public. Alternatives 2 and 3 establish different processes for tier and OFL setting and review. This review process includes the SSC and the Council review for determining appropriate tier levels and OFLs on an annual basis. The OFL setting and review process establishes (1) the placement of stocks into tiers; (2) the information utilized in the projection models for OFL determination; (3) the setting of the OFLs; and (4) the determinations of the status of the stocks relative to the OFLs.

The timing of the OFL determinations are discussed in this Chapter because they similarly effect the fisheries for the surveyed stocks, Bristol Bay red king crab, snow crab, Tanner crab, Pribilof Islands king crab, and St. Matthew blue king crab. Stocks not subject to the NMFS annual trawl survey are not impacted by the timing of the OFL determinations.

2.4.2.1 Alternative 1

Under Alternative 1, stock abundance estimations, status determinations, and TAC setting all occur in the fall, after the survey and before the start of the crab fisheries (see Table 2-4). NMFS conducts the annual trawl survey from June through mid-August. NMFS and ADF&G annually estimate stock abundance based on the NMFS trawl survey. ADF&G sets the TACs on or immediately before October 1, and the crab fisheries open on October 15. This tight timeframe does not allow for extensive peer review of and discussion on the survey data and stock health before the status is determined and the TACs are set.

Table 2-4 Timing of status quo process under Alternative 1.

by April	Assessment authors update assessment models.
May	CPT reviews models, assumptions, parameters, fishery data from prior year, etc.
June	SSC review of models, etc.
June-August	NMFS annual trawl survey.
August	NMFS and ADF&G produce abundance estimates from models and area-swept method using survey data.
September	NMFS determines status of stocks relative to OFDs. CPT review of survey results, abundance estimates, and status of the stocks– information compiled for SAFE.
October 1	State sets the TAC for the fall fisheries based on the abundance estimates from models or area-swept estimates of survey data. TACs are set using an established harvest strategy.
October	The Council and SSC review the survey results, status of the stocks relative to OFDs, and the TACs (and SAFE report….).

2.4.2.2 Alternative 2

Alternative 2 would establish a process whereby the Council would annually adopt the tier assignments and OFLs for each stock in June, prior to their application in the fall (Table 2-5). Each spring, the CPT would recommend, based on the work of the assessment authors, the placement of stocks into tiers and the resulting OFLs. The information utilized in the projection models for OFL determination would be based on the previous year's survey and the model simulations. After the summer survey, NMFS would base the determinations of the status of the stocks relative to these OFLs. Status of stocks would be derived from comparing the recent abundance estimates to the adopted OFLs. The State would also set TACs based on the recent abundance estimates, constrained by the adopted OFLs. The timing of the annual fall CPT meeting and resultant SAFE report to the Council may be modified under this alternative for either September CPT meeting and October Council report or October CPT meeting and December Council report.

Table 2-5 Alternative 2 Tier and OFL setting and review process.

Spring	Assessment authors prepare OFLs, including parameterization and tier assignments, using data from the previous year's survey.
May	Crab Plan Team reviews OFLs and recommends a set of OFLs to the Council.
June	Council and SSC review and adopt OFLs.
June-August	NMFS annual trawl survey.
late August	Assessment authors incorporate survey data into models to produce abundance estimates. NMFS prepares a report of the status of the crab stocks relative to the adopted OFLs.
October 1	State sets TACs for the fall fisheries based on the recent abundance estimates and constrained by the adopted OFLs.
September/October	The CPT reviews the status of the stocks report and survey results and compiles the SAFE report.
October/December	The Council and SSC review the TACs and the status of the stocks relative to the adopted OFLs (and SAFE report….).

2.4.2.3 Alternative 3

Alternative 3 would establish a process whereby the Council and SSC would review the models and tier system framework, tier levels, and model parameterization in June (Table 2-6). This review would begin with the Crab Plan Team. The CPT would review model parameter choices and resultant tier levels and make recommendations to the SSC. Each June, the Council and SSC would subsequently review the choice of parameters by the stock assessment authors and recommend which parameters and tier levels should be utilized in the final OFL calculation simulations. The OFL determinations would occur in the fall and involve the incorporation of new survey data into model formation for the OFL calculation.

The model simulations would be conducted after obtaining the most recent survey results. The OFLs and abundance estimates used to set the TACs would both be estimated using the same survey data. Therefore, while parameters and tier levels would be established following the June SSC review, OFLs would not be calculated until the survey results are available in late August. Model structure and parameterization would not be changed in the interim. Following the incorporation of survey results, assessment authors would calculate the OFLs and NMFS would determine the status of the stocks relative to the OFLs. The CPT would review the survey data, the OFLs, and the status of the stocks at its September meeting when it prepares the SAFE. The State would set the TACs on October 1. The CPT would then report the OFLs and TACs to the Council at the October Council meeting in conjunction with the presentation to the Council on the status of stocks.

Table 2-6 Alternative 3 Tier and OFL setting and review process.

Spring	Assessment authors prepare models, including parameterization and tier assignments.
May	CPT reviews models, assumptions, parameters, etc.
June	SSC review of models, etc.
June-August	NMFS annual trawl survey.
August	Models would be run using new survey data to produce abundance estimates and OFLs, and NMFS determines the status of the stocks relative to the OFLs.
September	CPT review of OFLs, survey results, status of the stocks, compile SAFE.
October 1	State sets the TAC for the fall fisheries based on the recent survey and OFLs based on same survey.
October	The Council and SSC review the status of the stocks relative to the OFLs and the TACs (and SAFE report….).

2.4.2.4 Impacts of timing of OFL determinations

The impacts of the timing of the OFL determinations similarly effect the fisheries for the surveyed stocks, Bristol Bay red king crab, EBS snow crab, Bering Sea Tanner crab, Pribilof District king crab, and Saint Matthew Section blue king crab. Stocks not subject to the NMFS EBS trawl survey are not impacted by the timing of the OFL determinations.

Under Alternative 1 (status quo) and Alternative 3, the most recent survey data would be used to estimate biomass, set the OFLs, evaluate the status of stocks in relation to the status determination criteria, and to set the TACs.

Under Alternative 2, the previous year’s data would be used to set the OFL, and the most recent survey data would be compared to that OFL to evaluate the status of stocks. The OFLs the Council adopts in June would be final. This may cause problems because the best available (i.e. recent survey year) data would be available within months of setting the OFLs. And, the State would use the recent survey data to set the TACs. This can be particularly problematic for crab stocks because abundance can fluctuate dramatically with no predictability. Therefore, the OFL could either be too constraining if stock abundance increases dramatically or too liberal if stock abundance decreases dramatically.

Crab stocks have frequently shown fluctuations in area-swept estimates of biomass from one year to the next. Changes in biomass for each stock are shown in the tables on the status of each stock relative to overfishing in Chapter 3.

Some potential implications of using the biomass estimate from the previous summer to set the OFL, as opposed to the biomass estimate from the current summer survey, can be seen by reviewing the 1997-2006 survey biomass estimates for the annually surveyed stocks (Table 2-7).

Table 2-7 Annual survey total mature biomass (TMB) for 6 surveyed stocks 1997-2006.

Surveyed Stock	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Bristol Bay red king crab	133.6	166.2	117.7	89.7	88	129.9	178.1	176.4	181.9	157.2
Pribilof District red king crab	14	7.7	12.8	10.2	25.5	18.1	14.5	9.9	8.1	19
Pribilof District blue king crab	11.7	11	9.2	7.4	7	4.5	4.1	0.5	1.6	1.6
St. Matthew Section blue king crab	32.7	24.1	4.8	5.2	9	4.7	12.8	7.3	5.9	11.2
EBS Tanner crab	40.6	37.6	70.1	59.1	67.7	69.4	100.8	86.8	162	253.3
EBS Snow crab	1,014.1	729.7	283.5	472.7	571	313.3	306.2	343.7	610.7	547.6

As shown in Table 2-7, the most dramatic example of a change in biomass between surveys occurred for snow crab between the 1998 survey and the 1999 survey. The snow crab biomass estimate from the 1998 survey was 729.7 million pounds (330,990 t). The biomass for the 1999 survey declined to 283.5 million pounds (128,595 t). The St. Matthew blue king crab stock also showed a marked and unexpected decline between the 1998 and the 1999 surveys; the total mature biomass estimate from the 1999 survey was 20% of that estimated from the 1998 survey.

For Alternative 2, crab abundance and biomass need to be projected one year forward. Under Alternative 2, the OFL for EBS snow crab fishery that opened in January 2000 would have been based on the 1998 summer survey biomass estimate. That would have resulted in OFLs almost double the level necessary to prevent overfishing; if the harvest rate was based on 75 percent of the OFL, overfishing would have occurred.

Another important criterion for comparing the timing of OFL determinations in Alternatives 2 and 3 is relative model projection errors for Alternative 2. Although year-to-year fluctuation of abundance estimates by the models will somewhat be less than the area-swept estimates, the model projection errors can be very large during some years. An analysis was conducted comparing model projections to actual abundance estimates for Saint Matthew blue king crab and Bristol Bay red king crab to determine the degree of errors in the model projection. Two comparisons were made. The first compares the model projection for a given year to the estimate made in that year, called the terminal year. The second compares the model projection to the estimate for the given year made in 2006. Abundances estimated in 2006 should be more reliable than those in terminal years because more data are available in 2006.

Table 2-8 illustrates the relative model projection errors from 1997 to 2006 with the current 4-stage stock assessment model for Saint Mathew blue king crab. Besides the exceptional year of 1999, relative projection errors range from a negative 19% to positive 22% for legal males and from negative 22% to positive 35% for mature males when compared to abundances estimated in terminal years. This means that during the 10 year period, in any given year the model would have either underestimated the abundance of legal males by up to 19% or overestimated the abundance of legal males by up to 22%. Relative errors of projected abundances to the abundances estimated in 2006 generally are larger than those to the abundances estimated in terminal years. Therefore, the model would have under or over estimated abundance by even greater amounts. The worst projection error (greater than positive 400%) occurred in 1999.

Table 2-8 Relative model projection errors from 1997 to 2006 with a 4-stage model for Saint Mathew blue king crab. Legal and mature male absolute abundances are in millions of crabs.

Year	Estimated in terminal year		Model one-yr projection		Estimated in 2006		% relative errors (vs terminal year)		% relative errors (vs 2006)	
	Legals	Matures	Legals	Matures	Legals	Matures	Legals	Matures	Legals	Matures
1997	3.12	5.09	2.73	4.77	2.85	5.11	-12.64	-6.44	-4.35	-6.77
1998	3.15	4.79	3.11	4.74	2.76	4.51	-1.18	-1.15	12.60	5.01
1999	0.60	0.81	3.14	4.21	0.60	0.93	427.87	422.48	420.23	353.07
2000	0.72	1.04	0.63	0.94	0.66	1.16	-12.02	-9.58	-3.45	-19.25
2001	0.99	1.52	0.81	1.19	0.77	1.24	-18.77	-21.94	5.27	-4.26
2002	1.10	1.60	1.21	1.95	0.82	1.36	10.05	21.95	48.14	43.69
2003	1.10	1.36	1.22	1.44	0.86	1.18	10.96	5.95	42.24	22.44
2004	0.88	1.27	1.07	1.71	0.82	1.26	22.10	34.73	30.30	35.49
2005	0.84	1.19	0.89	1.20	0.87	1.30	5.33	0.69	2.11	-7.72
2006	0.95	1.85	0.86	1.60	0.95	1.85	-9.45	-13.62	-9.45	-13.62

Table 2-9 illustrates the relative model projection errors from 1997 to 2006 with the stock assessment model for Bristol Bay red king crab. The updated model used to examine projection errors for Bristol Bay red king crab (Table 2-9) is described in Appendix B in the 2006 SAFE report (NPFMC 2006). Constant natural mortality of 0.18 and constant molting probabilities for males over time were used in the updated model.

Compared to abundances estimated in terminal years, relative projection errors range from negative 23% to positive 14% for mature females, from negative 18% to positive 21% for mature males, and from negative 13% to positive 19% for legal males. This means that during the 10 year period, in any given year the model would have either underestimated the abundance of legal males by up to 23% or overestimated the abundance of legal males by up to 14%.

Different market impacts may occur by virtue of establishing an OFL (and effectively a ceiling on the possible catch level) in June while actual TAC determination would not occur until October 1. More information on the economic impacts on the timing of the establishment of OFLs is included in Chapter 6 on Economic and Social Effects.

Table 2-9 Relative projection errors from 1997 to 2006 with the model for Bristol Bay red king crab. Absolute abundances are in millions of crabs.

Year	Estimated in terminal year			Model one-yr projection			Estimated in 2006		
	Mature females	Mature males	Legals	Mature females	Mature males	Legals	Mature females	Mature males	Legals
1997	23.484	10.101	7.106	19.623	8.258	6.153	34.142	11.837	8.193
1998	29.612	17.237	7.145	25.188	15.681	6.740	34.129	17.833	8.012
1999	25.326	20.219	10.084	28.362	20.993	9.664	30.432	20.658	10.526
2000	33.762	18.444	12.465	25.935	17.612	12.111	32.631	18.173	12.593
2001	28.455	13.755	10.119	32.523	16.605	12.027	36.120	16.540	12.215
2002	27.664	15.730	9.932	27.416	14.091	9.349	34.815	18.221	11.555
2003	38.997	17.711	10.588	36.018	15.567	10.145	40.573	18.540	12.219
2004	48.943	16.501	10.991	49.929	15.984	9.794	49.333	16.161	11.253
2005	52.325	19.472	9.476	55.566	22.691	10.346	50.956	20.449	10.302
2006	60.828	22.101	11.889	67.665	21.506	11.230	60.828	22.101	11.889
Year	**% relative errors (vs terminal year)**			**% relative errors (vs 2006)**					
	Mature females	Mature males	Legals	Mature females	Mature males	Legals			
1997	-16.44	-18.24	-13.41	-42.52	-30.23	-24.90			
1998	-14.94	-9.03	-5.68	-26.20	-12.07	-15.89			
1999	11.99	3.83	-4.17	-6.80	1.62	-8.19			
2000	-23.18	-4.51	-2.83	-20.52	-3.09	-3.83			
2001	14.30	20.72	18.86	-9.96	0.39	-1.54			
2002	-0.90	-10.42	-5.88	-21.25	-22.67	-19.09			
2003	-7.64	-12.11	-4.18	-11.23	-16.04	-16.97			
2004	2.01	-3.13	-10.89	1.21	-1.10	-12.97			
2005	6.19	16.53	9.17	9.05	10.97	0.42			
2006	11.24	-2.69	-5.55	11.24	-2.69	-5.55			

2.5 Development of alternatives and alternatives considered and eliminated from detailed study

The Crab Plan Team concluded in 2003 that an analysis of a new FMP amendment revising the current status determination criteria was warranted since the adoption of the 1998 overfishing definitions under Amendment 7. The plan team designated an inter-agency workgroup consisting of four members to devise alternative overfishing definitions for crab stocks and to periodically report to both the Crab Plan Team and the SSC on their progress. Progress on work by the interagency workgroup (WG) has been documented in the reports from the Crab Plan Team (see minutes from the Crab Plan Team 9/03, 5/04, 9/04, 5/05, 9/05, 5/06, 9/06) and minutes from the SSC (see SSC minutes 5/04, 10/04, 2/05, 6/05, 10/05, 4/06, 6/06, 10/06). These reports are available on the Council website.

A workshop consisting of inter-agency and outside crab experts was convened in February, 2006 in Seattle, WA to discuss various biological and model parameterization issues associated with the draft tier system and assessment models. The report from the workshop is attached as Appendix D. In April of 2006, another review was convened in Seattle, WA with the Center for Independent Experts (CIE) to provide guidance on the development of the tier system. The report from the three CIE reviewers is attached as Appendix E.

The Crab Plan Team crafted a problem statement and draft suite of alternatives at the May 2006 Crab Plan Team meeting. The alternatives to status quo use the same tier system but differ in the OFL decision making body and the timing of OFL determination.

During the three years of development, the Crab Plan Team, the WG, and the SSC considered many alternatives to most aspects of the proposed OFLs, including alternative biological parameters, such as *M* values, alternative modeling scenarios and methods, and alternative tier structures. This section provides a summary of the alternatives that were considered but received little analysis because they were scientifically unsuitable for the crab OFLs or contrary to the national standard guidelines. A brief rational as to why they were not included in this EA is presented below.

During the process of development of alternatives some consideration was given to analyzing fixed mortality values. This would be an approach similar to that utilized in the current overfishing definitions, however using updated mortality information to establish these fixed values. The SSC recommended that this alternative be dropped from the analysis (see SSC minutes February 2006) given that it was highly unlikely that fixed values would be retained under the FMP in light of the fact that the current fixed values are being revised due to their inflexibility to incorporating new scientific information. Substituting updated fixed values did not seem to represent a tenable solution nor provide meaningful analytical contrast and thus this alternative was dropped from the analysis.

A range of control rules were evaluated over the course of this analysis in conjunction with the recommended control rules for tiers 1-4 (Figure 2-1). Chosen values for α and β alter the slope and intercept for the control rule. A sensitivity analysis was conducted which evaluated a range of values for α and β. This analysis, as well as the justification for the chosen values for α and β for these control rules, are detailed in Section 3.1.4 and 3.5.3.

3 Effects on Crab Stocks

This chapter contains details information regarding the status of the 22 crab stocks managed under this FMP, the biological parameters employed in modeling the impacts of the alternatives for these stocks and the impacts of the OFL alternatives on these stocks.

Chapter 3 of the Crab EIS contains a complete description of the human environment, including the physical environment, habitat, crab life history, marine mammals, seabirds, crab fisheries, a management history, the harvesting sector, the processing sector, and community and social conditions. These descriptions are incorporated by reference.

In addition to the factors discussed in the Crab EIS, this action specifically concerns the annual establishment of OFLs using the biological reference points and tier system for the crab stocks under the FMP. Relevant and recent information on each crab stock is contained in this chapter.

3.1 Methodology for impact analysis

The following methodology was employed to evaluate the impacts of the alternatives on future crab stock abundance levels.

Tiers 1 through 3

A projection model was used to evaluate the alternatives for Bristol Bay red king crab, snow crab, and Tanner crab. For Alternative 1, both fishing at the current OFL and the current State harvest strategies were analyzed to demonstrate the predicted biomass estimates resulting from these control rules under this alternative. For Alternatives 2 and 3, various harvest control rules from the proposed tier system were analyzed to demonstrate predicted biomass estimates resulting from the possible control rules under these alternatives. The crab populations were simulated for 30, 100, and 200 years and fishing mortalities applied according to the particular harvest control rule. Mature male and female biomass values, total and retained catch, standard deviation of the retained catch, F, and the percent of the time the MMB was below B_{MSY} , below ½ B_{MSY}, percent of time when the fishery was closed, and final year B in relation to B_{MSY} were calculated. The average values for 1000 runs using the last 100 years of each simulation were calculated to compare control rules. The population was started from the abundance and biomass at ½ B_{MSY}, to evaluate rebuilding to B_{MSY} in the first 30 years (short term) or 100 years (long term) of the simulation. The population was also initialized at 10% B_{MSY} to evaluate alternative parameters of the control rule during rebuilding.

Since S-R relationships were lacking for many BSAI crab stocks and are difficult to establish, plausible ranges of the steepness parameter (h: 0.56–0.84 for red king crab and 0.53–0.84 for snow and Tanner crab) were considered to derive yield curves for reference point estimation (Mace 1994, Clark 1991, 1993). The steepness range was chosen following S-R fits to Bristol Bay red king, Bering Sea Tanner, and snow crab stock data during low productivity periods. The three stocks provided the steepness estimate range of 0.6–0.84 for different handling mortality values for the 1985-2005/06 stock recruitment data series. A conservative steepness parameter value of 0.84 was chosen as the higher limit in all simulations.

Because of uncertainty in the S-R models, steepness values, M, and many other vital stock parameters, the selected $F_{x\%}$ values and tier systems were assessed by a suite of performance statistics. Because the S-R relationships were based on low productivity period, the alternative strategies were evaluated under low productivity regimes. Tier formula parameters were chosen based on good performance under stochastic simulations. In the simulations certain stock specific characteristics were recognized: terminal molt at maturity for both sexes and differential *M* for male and female Tanner and snow crabs.

In the stochastic analysis of Bristol Bay red king and Tanner crabs, random variation in recruitment was introduced to the model using overall recruitment noise of 0.4 and an autocorrelation parameter of 0 based on S-R fit to red king crab using MMB. Recent data series suggested insignificant autocorrelation for red king crab.

For snow crab, process error was incorporated in recruitment using an autocorrelated lognormal error structure. The coefficient of variation was set equal to the variance of recruitment from the 2006 stock assessment model (0.86) (Turnock and Rugolo 2006). The correlation coefficient for autocorrelation was estimated from time series of recruitment from the snow crab stock assessment model (0.6). Rebuilding times derived from models that incorporate autocorrelated lognormal error structure will be slower than those estimated from models that assume random recruitment (no spawner-recruit curve), or recruitment generated from a S-R curve with lognormal error and no autocorrelation.

Observation and stock assessment errors were simulated with autocorrelated lognormal error applied to abundance. A cv = 0.15 and autocorrelation = 0.6 were used for errors on biomass. Fishing mortality from the harvest control rules was estimated using the biomass with added errors, resulting in the actual *F* applied to the true population being higher or lower than the *F* from the control rule, depending on the error in that year. No process errors on growth or *M* were simulated.

Formulas for tiers 1 to 3 consist of four parameters: α, β, B_{MSY} or $B_{X\%}$ and F_{OFL} or F_{TAR} while the Tier 4 formula consists of an additional γ parameter associated with *M* to replace F_{OFL} (Table 2-2). The stochastic simulation analysis was focused on determining these parameter values.

Tier 4

For Tier 4 stocks, abundance estimates are available, but complete population parameters are not available for computer simulation studies and spawning biomass per recruit analyses needed for Tier 3 stocks. Estimated abundance and catch information should be used to develop B_{MSY} proxy for Tier 4 stocks. Among the six crab stocks in Tier 4, eastern Aleutian Islands (Dutch Harbor) red king crab has been very depressed for a long time and few crabs have been caught during trawl surveys. The Tier 4 analyses focus on the other five stocks.

The most important parameter for Tier 4 is γ. In the simulation studies, the ratio of *Fmsy* and *M* is about 2 for Bristol Bay red king crab and 3.7 for eastern Bering Sea Tanner and snow crabs. Because Tier 4 is for stocks with limited data, harvest should be more conservative than these three stocks, which are in Tier 3. Therefore, γ for Tier 4 stocks should be less than these ratios.

A default γ value or a range of γ values can be set for all Tier 4 stocks. For these five blue king crab and red king crab stocks, current productivity is extremely low, and a low γ value may be appropriate for them. The current State of Alaska harvest strategy for Norton Sound red king crab has lower harvest rates than that resulted from $\gamma = 1$ and $M = 0.18$ when the stock abundance is above *Bmsy*. $\gamma = 1$ can somewhat restrict the fishery more than the current state harvest strategies when the abundance is high for these two blue king crab stocks. However, the current stock productivity is extremely low, the fisheries have been closed since 1999 for Pribilof Islands blue king crab and St. Matthew blue king crab stocks, and there is no sight for future opening. The suggested range of γ values are from 1 to 1.5 for red and blue king crab stocks.

Although there are no golden king crab stocks in Tier 4 currently, Aleutian Islands golden king crab could move up to Tier 4 soon. Section 3.4.3 discusses the impact of moving golden king crab stocks from Tier 5 to Tier 4. A range of γ values from 2 to 4 may be appropriate for golden king crab stocks with possible M values.

Like stocks in Tier 3, each stock in Tier 4 would be analyzed annually to determine the proxy for B_{MSY}. Because of data limitation, average estimated abundance or biomass from a specific period would be used as a proxy for Bmsy for Tier 4 stocks. The Alternative 1 overfishing definitions use estimated biomass from 1983 to 1997. For the overfishing definitions in Alternatives 2 and 3, this analysis uses the period from 1983 to the most recent year for Tier 4 stocks. This period from 1983 to present is relevant to current environmental conditions, did not have extremely high exploitation, and the populations were not be extremely depressed. This period is after the major regime shift in the North Pacific in 1976/1977. Crabs generally take 6 or 7 years from hatching to mature, so the impact of the 1976/1977 regime shift on crab recruitment affected the mature abundance starting in 1982/1983 or later. However, some years within this period should be excluded if the exploitation is extremely high or if the population is extremely depressed.

Tier 5

Different environmental regimes can result in different levels of mean yield for a stock. For overfishing definitions in Alternatives 2 and 3, the mean yield from the current regime is used. The regime shift in 1976/77 has been well documented. A regime shift may have occurred in 1989, but its effect in the eastern Bering Sea is not very strong. For this analysis, the mean yields after the 1976/77 regime shift is considered. The regime shift first affects the crab year class strength and then affects catch a few years later. It takes at least 8 years from hatching to growth into legal size for most crab species. Therefore, mean yields from 1985 to 2005 were used to develop the overfishing definitions.

Tier 6

No analyses were conducted to examine these stocks nor are OFL values proposed for them under the tier system presented in Alternatives 2 and 3.

3.1.1 Length-based projection model

Simulations were initiated with a fixed number of immature new-shell recruits divided equally between males and females and distributed to each length bin by a gamma probability function. Full age structure was established by projecting the initial recruits through the entire life span up to a maximum age with a given set of mortality and growth parameter values. Once the full age-structure was achieved, the same population structure was repeated for a number of years, equivalent to the recruitment age. Then the mature male biomass component of each full age-structured population was used in a Stock-Recruitment (S-R) model (Beverton-Holt 1957 or Ricker 1954) to generate the number of recruits entering the simulated population with a time lag equivalent to the recruitment age. Each full age-structured population was projected successively for a sufficient number of years with constant mortality, growth, and deterministic recruitment to stabilize the age structure (i.e., burn-in period), and thereafter the predicted number of recruits was randomized with a log-normal random error for a 30-year, 100-year or a 200-year fishing period to determine several performance statistics. The random error structure consisted of an overall recruitment variance ($\sigma2$) and serial correlation (ρ). The recent recruitment distributions indicated very low serial correlation, hence a base value of 0.4 for σ and 0 for ρ were used in the simulations. Lognormal observation errors on biomass ($\sigma1 = 0.2$) and truncated (80% truncation) normal errors on catch ($\sigma2 = 0.1$) were considered in the simulations. Appendix B provides the population dynamics formulas used in the simulations.

3.1.2 Estimation and evaluation of proxy B_{MSY}

The proxy mature male B_{MSY} parameter (Bx%) for the control rule was estimated from the stochastic simulation of a 100-year fishery with a Ricker S-R curve for the estimated steepness parameter (h) value. The $B_{x\%}$/B0 ratio was determined at $F_{x\%}$ (proxy F_{MSY}) from which the $B_{x\%}$ (proxy B_{MSY}) was calculated from an estimated virgin biomass, B0. The proxy B_{MSY} was evaluated with other control rule parameters described below.

3.1.3 Determination and evaluation of proxy F_{MSY}

Clark (1991, 1993) derived the F_x harvest rate for groundfish types of stock parameters under Beverton and Holt, and Ricker S-R models. For this analysis, Clark's equilibrium method was used only to locate an approximate F_x and detailed stochastic simulation analyses were then carried out to identify appropriate F_x values for each stock.

3.1.4 Evaluation of α and β

The α parameter in the tier formula determines the slope of the control rule line. The higher the α value the steeper the slope and hence the faster the rebuilding time of an overfished stock. The β parameter value determines the relative biomass level at which the fishery would be closed.

The probable values for α and β parameters were investigated by considering three step values around currently used values for α (0.0, 0.05, and 0.1) and two step values for β (0.0 and 0.25). An α value of 0.05 is used in the groundfish tier system (NPFMC 1998) whereas a β value of 0.25 is employed as a mature-stock biomass ratio (relative to MSY mature-stock biomass) to determine the fishery closure benchmark (NPFMC 1999). The parameters were evaluated by rebuilding analyses of a hypothetical overfished stock (10% B_{MSY} and 50% B_{MSY}) under a proxy F_{MSY} ($F_{x\%}$). A number of performance statistics were estimated from 1000 simulations of a 30-year fishery (a few years more than the maximum crab life span) with random recruitment to explore the viability of selected control rule parameter values: median rebuilding time, mean of overfished and fishery closure proportions, mean and coefficient of variation (CV) of mean yields during the first 10 years and the subsequent 20 years of the rebuilding time period, and the mean of the 30^{th} year B/B_{MSY} ratio.

4 Red king crab (*Paralithodes camtschaticus*)

Five stocks of red king crab are managed in the BSAI area. These are the red king crab stocks of Bristol Bay, Pribilof Islands, Western Aleutian Islands, Eastern Aleutian Islands, and Norton Sound. This section reviews the stock status and biological parameters relevant to overfishing definitions for these stocks and provides an overview of specific impacts on the stocks from the three alternatives under consideration in this analysis.

4.1.1 Red king crab stock status

Bristol Bay red king crab

This stock is annually surveyed by the NMFS EBS trawl survey. The current (2006) estimated total mature biomass is 157.2 million pounds (71,305 t). This is down slightly from the estimates of the preceding 3 years (approximately 180 million pounds (81,647 t)). However, the stock remains well above MSST and B_{MSY} as currently defined (Figure 4-1). The ADF&G length-based analysis (LBA) point estimates for mature-sized males and legal males in 2006 are both slightly higher than for 2005. The LBA model for 2006 estimates that mature-sized females increased to 40.469 million crabs in 2006 from 37.848 million in 2005, continuing a trend in annually increasing abundance since 2000. Although far below the levels estimated to have existed in the late 1970s, the 2006 LBA model estimates that mature males, mature females, effective spawning biomass and legal male abundance are each at their highest levels since the early 1980s.

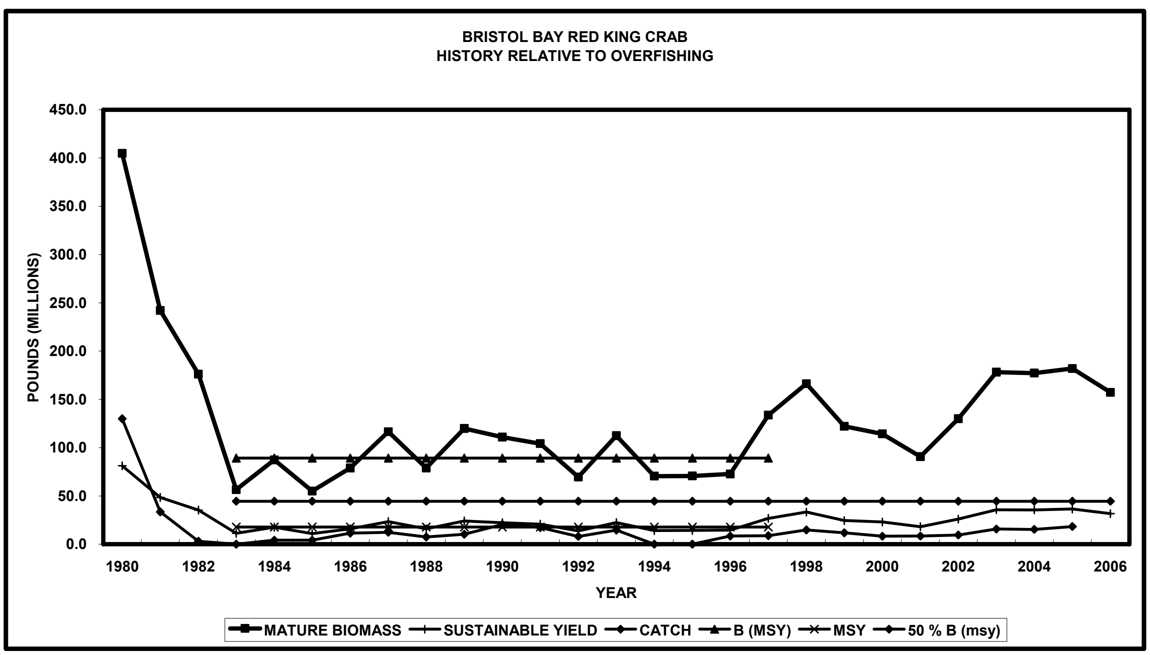

Figure 4-1 Bristol Bay Red King Crab stock status relative to overfishing

Recruitment to the stock is determined by following sex-specific size classes from the survey data and model estimates. As anticipated from the 2005 survey data, the 2006 LBA model estimated that recruits to the mature-sized female class in 2006 declined slightly from that of 2005. However, a mode of juvenile-sized crabs centered at approximately 72.5-mm CL in the 2005 male and female size-frequency distributions apparently tracked to a mode centered at approximately 87.5-mm CL in the size frequency distribution for each sex in 2006. Assuming that the 87.5-mm CL size mode continues to track into the future, it should provide good recruitment into the mature female size class (≥90-mm CL) in 2007, but would not provide strong recruitment to the mature male size class (≥120-mm CL) until 2008. Representation of juvenile crabs <70-mm CL, however, was poor for both sexes in the 2006 survey as compared to the 2002-2005 surveys (NPFMC 2006).

Pribilof District red king crab

This stock is annually surveyed by the NMFS EBS trawl survey. Stock levels and trends for this stock are difficult to evaluate due to the low precision of abundance estimates. However, the consistency of trend in data for the previous five survey years indicated that the TMB was in decline. Estimated TMB declined annually from 25.5 million pounds (11,567 t) in 2001 to 8.1 million pounds (3,674 t) in 2005. However, TMB in 2006 rose to 19.0 million pounds (8,618 t) (Figure 4-2). ADF&G catch survey analysis (CSA)-estimated mature male abundance has shown a declining trend since 2002 through 2006.

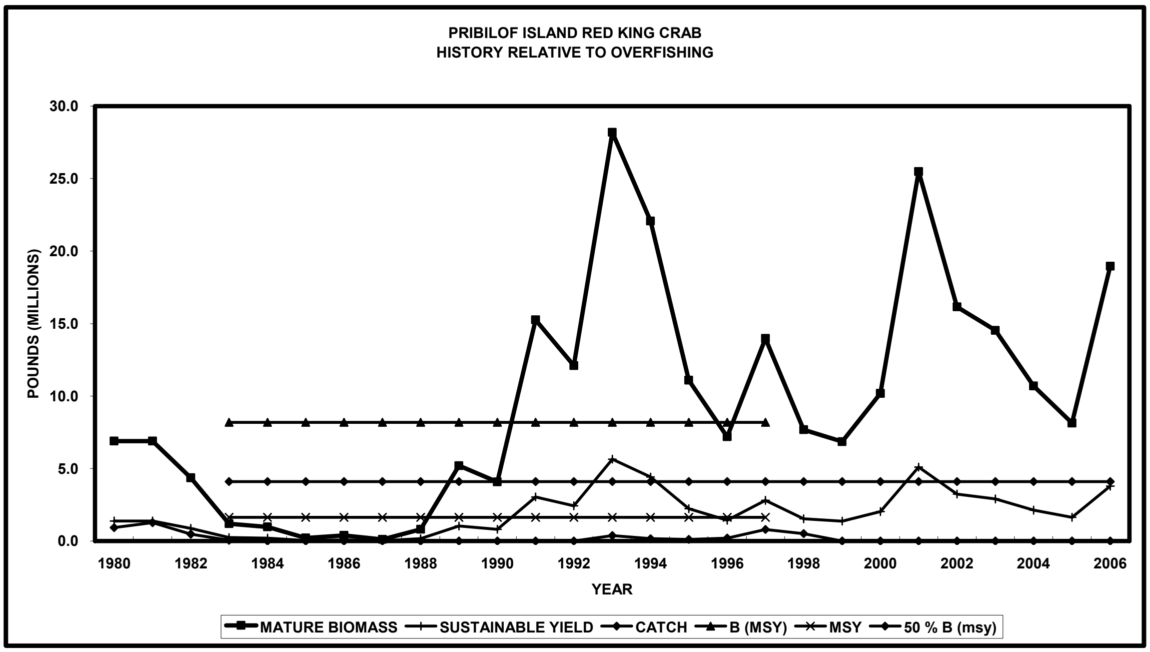

Figure 4-2 Pribilof District red king crab stock status relative to overfishing.

Mature-sized (≥120-mm CL) males captured in the 2006 trawl survey were largely legal sized (≥135-mm CL) and legal males were largely post-recruit-sized crabs ≥150-mm CL. The size-frequency distribution of males captured during the 2006 survey provides no expectation for significant recruitment to mature-sized males in 2006; after 2007, future declines in mature-size male abundance for this stock would be expected from the lack of sublegal-sized males <100-mm CL (NPFMC 2006).

There is no harvest strategy for this stock in State regulation. The fishery has been closed since 1999 due to the poor precision of the abundance estimates, poor performance of recent fisheries, and concerns for bycatch of blue king crabs of the overfished Pribilof blue king crab stock.

Aleutian Islands red king crab: WAI (Adak or Petrel Bank) and EAI (Dutch Harbor)

This stock is not annually surveyed by NMFS. ADF&G conducts annually surveys the EAI and triennial surveys of the WAI, the most recent of which was performed in 2004. Few red king crabs have been caught in surveys of the eastern Aleutians since 1995. The GHL for the eastern portion is based on the results of surveys, and has been closed since 1983. Historically, the GHL for the western portion has been based on the most recent fishery performance. The western portion was closed for the 1996/97 and 1997/98 seasons due to poor performance and poor signs of recruitment during the 1995/96 season. The western portion was reopened for limited exploratory fishing in some areas in 1998/99. Based on the results of the 1998/99 season, the fishery in the western portion was closed in 1999/2000.

In 1999 the Crab Plan Team identified the need for standardized surveys in areas of historical production prior to reopening the fishery in the western portion; prior to that meeting, the western portion had not been surveyed since 1977. A cooperative ADF&G-Industry pot survey was performed in the Petrel Bank area under the provisions of a permit fishery in January-February and November of 2001. Results of those surveys showed high densities of legal crabs within limited portions of the surveyed area. Survey catches of females and prerecruit sized males were low. Based on results of the 2001 surveys and recommendations from ADF&G and the public, the Alaska Board of Fisheries adopted pot limits, and modified the season opening date.

A GHL of 0.5 million pounds (227 t) was set for the 2002 season in the Petrel Bank area. Because only relative abundance information is available, ADF&G monitored the fishery utilizing inseason catch data. The management goal is to maintain a fishery CPUE of at least 10 legal crabs per pot lift. The 2002 fishery in the Petrel Bank area harvested 505,000 pounds (229 t). The fishery CPUE was 18 legal crabs per pot lift. Based on fishery performance, ADF&G announced a 0.5 million pound (227 t) GHL for the 2003 fishery and the fleet harvested 479,000 pounds (217 t). The 2003 catch rate dropped to 10 legal crabs per pot lift. The fishery was closed in 2004 and 2005. The Petrel Bank red king crab fishery will not open in 2006 due to low stock size. An additional pot survey is planned for November 2006.

In order to assess red king crab in other portions of the western AI, during November 2002, a survey was conducted between 172° W longitude, and 179° W longitude (waters in the vicinity of Adak, Atka, and Amlia Islands). The survey of these waters yielded very few red king crabs and the area remains closed until further notice.

Norton Sound red king crab

This stock is not annually surveyed by NMFS. Instead, ADF&G performs a triennial trawl survey in Norton Sound[1]. Population abundance estimates from the trawl survey are evaluated by ADF&G biometricians and incorporated into a model developed by Zheng et al. (1998). The mode provides estimates of the legal and sublegal male population sizes. Trawl survey and model population estimates are limited to abundances because reliable paired weight-length information is not available to estimate biomass (Soong and Banducci 2006). Estimated biomass is calculated by multiplying by 3.0 pounds (1.36 kg), the average weight of legal male crabs from the summer fishery (Soong and Banducci 2006). The king crab population model estimated legal male crab abundance for the 2006 summer commercial crab fishery at 4.5 million pounds (2,041 t). This is down 27% from the 2005 model abundance estimate of 6.2 million pounds (2,812 t) for legal male crab. It should be noted that this apparent 27% decline is due to a revision of the model following the 2005 season rather than an actual loss of crab in the population. The revised model estimated the 2005 population at 4.8 million pounds (2,177 t) making the decline approximately 5%. Current size composition data from the 2006 winter pot study indicates that the

[1] With the exception of 2006 where 4 years transpired since the 2002 triennial survey

portion of the crab population classified as recruits has decreased 9.8% since the 2005 winter survey and the post recruit male crab population has decreased 11.6%. The winter pot study also points to an above average prerecruit-1 and prerecruit-2 populations and a very small prerecruit-3 population. The prerecruit-1 crab will molt and become part of the legal population next year. These findings indicate the legal crab population has peaked and is expected to decrease in 2007 followed by an increase in 2008 and 2009.

A 10% exploitation rate on the legal population (over 4.75 inch carapace width) equates to a guideline harvest level of 454,000 pounds (206 t) of crab. The CDQ allocation for 2006 was 34,050 pounds (16 t) with the remaining 419,950 pounds (190 t) allocated to the open access fishery. This follows the harvest strategy set by the Board of Fisheries and is the highest GHL since 1982.

In 2006, a total of 224 landings were made during the open access season for a harvest of 139,131 crabs and 419,191 pounds (190 t), equating to 99.8% of the open access quota. The CDQ catch was 32,557 pounds (15 t) making the total crab harvest during the summer season 451,748 pounds (205 t).

Results from the 2006 summer trawl survey suggest that the 2008 and 2009 legal king crab populations should increase from the current population, with the 2006 pre-2 estimate at more than 80% above the 2002 estimate. Pre-2 crabs will molt over the next 2 years and contribute to the legal portion of the population in 2008 and 2009 (Soong and Banducci 2006).

4.1.2 Biological parameters

This section examines relevant and recent biological information necessary to understand the overfishing definitions for red king crab.

Male crabs in the Bristol Bay red king crab stock are considered functionally mature for management purposes at 120 mm CL (Zheng et al. 1995a). In the Bristol Bay red king crab stock, approximately 50% of the females that are 89 mm CL are mature and approximately 80% of the females that are 95 mm CL are mature (Otto et al. 1990). A size range of 65-200 mm CL for males and a size range of 65-165 mm CL for females were considered in the simulations. This was to include immature sizes of crabs as initial recruits to the cohorts. Appendix B provides the input base parameter values.

4.1.2.1 Steepness parameter estimate

The Beverton-Holt and Ricker stock-recruitment (S-R) models were fitted to the Bristol Bay red king crab stock with mature male biomass on February 15 as the index of spawning biomass, when mature biomass is expected to be relatively low during the year. The 1985-2006 S-R data for different handling mortality (hm) values (0.1, 0.2, and 0.3) and the two S-R fits are depicted in Figure 4-8**.** The least square fits suggested that Ricker curves were more appropriate to these data sets than the Beverton-Holt curves. Zheng et al. (1995a) also fitted Ricker S-R curves to a longer time series of data. The steepness parameter values for the Ricker curve ranged from 0.81-0.84. For stochastic simulations, an average value of 0.82 was used.

4.1.2.2 B_{MSY} and proxy B_{MSY} estimate

The simulated population with a maximum number of 29 million recruits produced a B_{MSY} of 76.57 million pounds (34,731 t) and a B_{35} of 79.30 million pounds (35,969 t) (proxy B_{MSY}, see the next section for justification of the use of B35) for the Ricker S-R curve with the estimated steepness parameter value of 0.82. These B_{MSY} and B35 values were used in the Tier 2-4 formulas for stochastic simulations.

4.1.2.3 $F_{x\%}$ estimate

For this analysis, a steepness range of 0.56–0.84 to determine $F_{x\%}$ for different handling mortality values (Figure 3-8) was used. Slight changes in $F_{x\%}$ values occurred: F_{32}, F_{33}, and F_{34} for *hm* = 0.1, 0.2, and 0.3, respectively. We considered F_{35} as a candidate proxy F_{MSY} for detailed stochastic simulations. The corresponding F was 0.35, legal male harvest rate (at the time of the fishery) was 25%, and the mature male harvest rate (at the time of the survey, June 15) was 14%.

4.1.3 Effects on Bristol Bay red king crab

4.1.3.1 Comparison of status determination criteria

Bristol Bay red king crab

The Alternative 1 status determination criteria for Bristol Bay red king crab establish a B_{MSY} value of 89.6 million pounds (40,642 t) with an MSST value of 44.8 million pounds (20,321 t) (Figure 4-1). The 2006 biomass, derived from the TMB of the survey area-swept estimate, is above B_{MSY} at 157.2 million pounds (71,305 t). The revised tier system (under Alternatives 2 and 3) estimates B_{MSY} differently by using MMB rather than TMB (which includes males and females). The justification for this is provided in Section 2.2.3.1. The Alternative 2 and 3 estimate of B_{MSY} is 76.57 million pounds (34,731 t). For comparison, the estimate of MMB for this stock in 2006 is 65.54 million pounds (29,728 t). Thus, this stock status would be below its B_{MSY} value under the Alternative 2 and 3 estimates of status determination criteria rather than above it as with Alternative 1.

Annual determination of overfishing under Alternatives 2 and 3 would occur by comparison of the estimated *F* from the previous year's fishery with the calculated F_{OFL} for the same time period. Overfishing is defined as any amount of fishing in excess of a prescribed maximum allowable rate as prescribed through the six tiers described in Section 2.2.1. Overfishing would be determined under Alternatives 2 and 3 by comparing the total harvest rate on the fishery with the approved F_{OFL} rate on the MMB. For example, Figure 4-3 shows historical harvest rates in conjunction with F_{35} and F_{40} control rules for F_{OFL} for this stock. Here harvest rates in excess of the OFL control rule (e.g. F_{35}) would constitute overfishing.

Under Alternatives 2 and 3 the recommended control rule for the Bristol Bay red king crab stock is F_{35} (see Section 3.2.3 for additional information and simulation studies). With a recommended control rule of F_{35}, fishing rates in the years 1997, 1998, 2004 and 2005 would have constituted overfishing for this stock. If F_{40} were the recommended OFL control rule, overfishing would also have occurred in 1996 and 2003. Under Alternatives 2 and 3, harvest rates would have been constrained by the OFL control rule in those years. Legal harvest rates must be below the recommended F_{OFL}, thus annual determinations would be made to ensure that the TAC is set at a level whereby the legal harvest rate would be below the F_{OFL} for each stock.

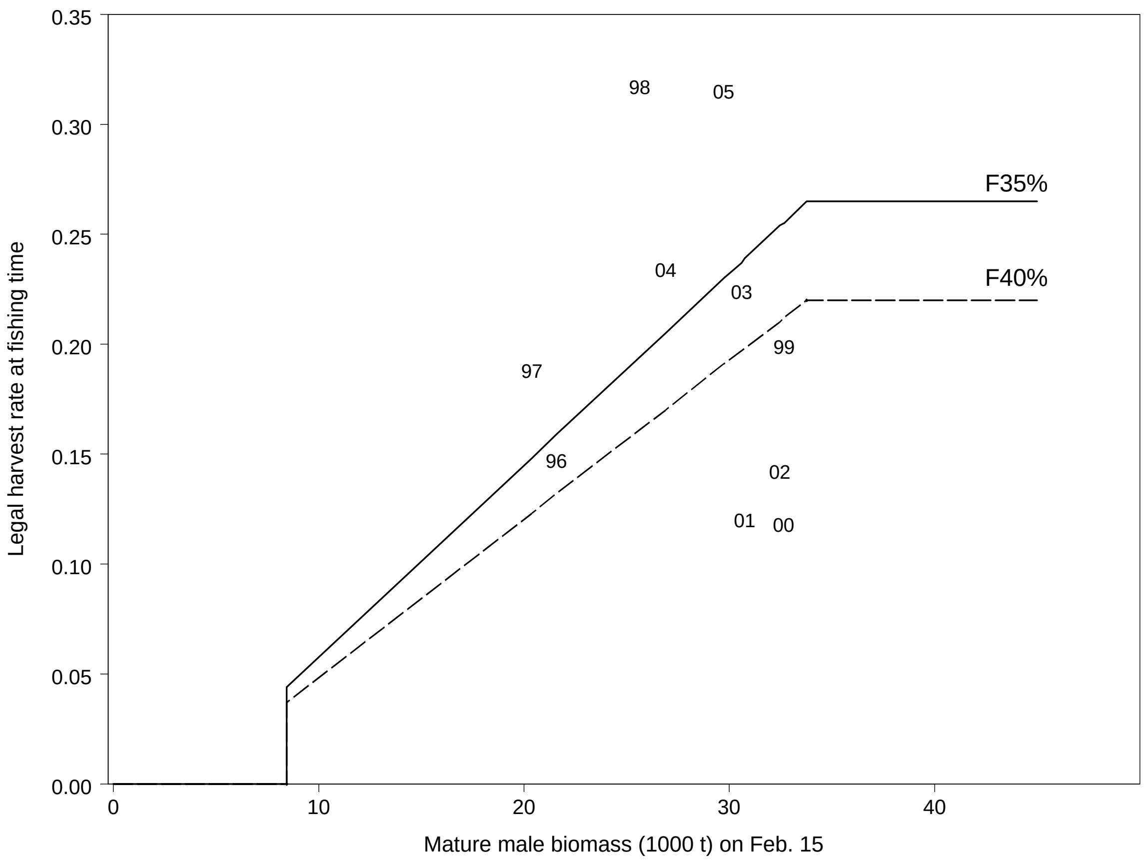

Figure 4-3 Relationships between legal harvest rate and mature male biomass on Feb. 15 for Bristol Bay red king crab. The dotted points are legal harvest rates from 1996 to 2005.

Pribilof District red king crab

The Alternative 1 status determination criteria for Pribilof Island red king crab establishes a B_{MSY} value of 6.6 million pounds (2,944 t) with an MSST of 3.3 million pounds (1,497 t) (Figure 4-2). The 2006 survey abundance estimate is above the B_{MSY} value at 19.0 million pounds (8,618 t). Under the Alternative 2 and 3 tier system, this stock would be managed under Tier 4 and B_{MSY} and MSST are provided based upon MMB. Additionally, the MFMT for determining overfishing is prescribed by the Tier 4 formula. Figure 4-4 provides estimated MMB and B_{MSY} proxy and MSST proxy (1/2 B_{MSY}) for the Pribilof Island red king crab stock. Average abundance from 1990 to 2006 was used for a proxy for this stock given that the estimated abundance was zero or extremely low prior to 1990.

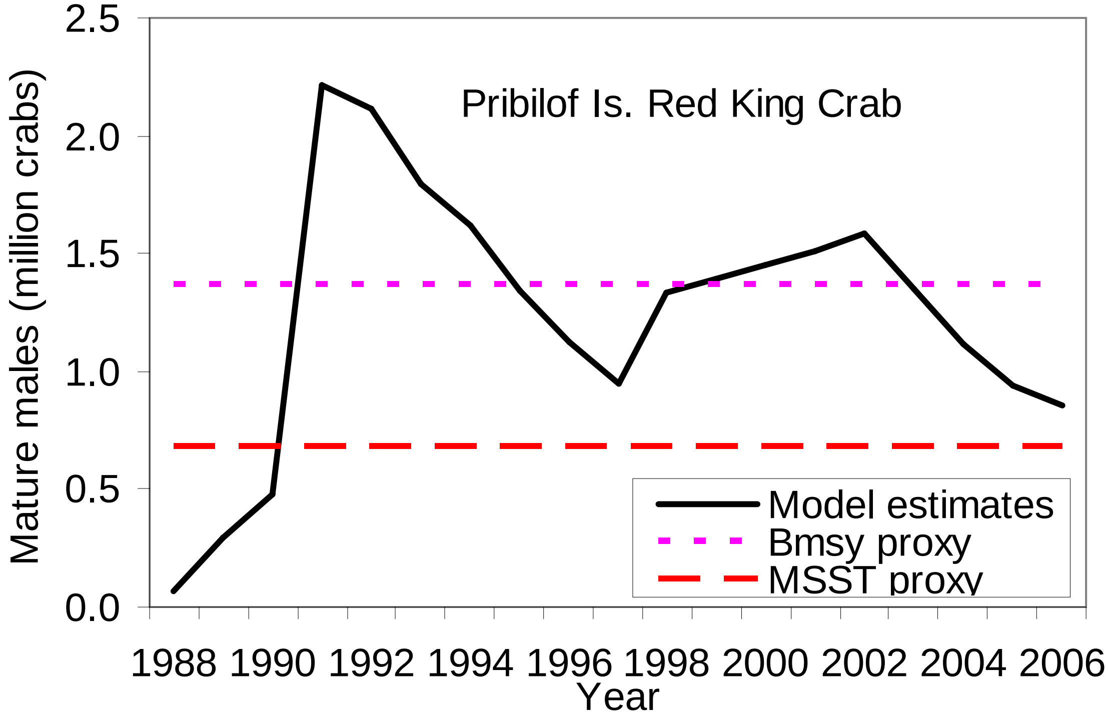

Figure 4-4 Pribilof Islands red king crab estimated mature male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

Stock status for this stock under Alternatives 2 and 3 as shown in Figure 4-4 results in a different status determination than under the status quo (Alternative 1) determination. Under Aternative 1 as shown in Figure 2-1, the TMB is well above the B_{MSY} for this stock. In contrast, Figure 4-4 for Alternatives 2 and 3 indicate that this stock would not only be considered well below B_{MSY} proxy, but it would be considered approaching an overfished condition. The stock would still be above its MSST proxy and thus is not considered overfished. However, under all alternatives, the stock would remain closed to directed fishing thus overfishing is not occurring on this stock.

Catch and CPUE for Pribilof Islands red king crab are provided in Figure 4-5. As discussed previously, due to conservation concerns on blue king crab, Pribilof Islands red king crab had been opened to fishing only for six years, and four of these six years were for a two-species fishery (combined GHL for both blue king and red king crabs). Thus catch and CPUE data are not very informative for this stock.

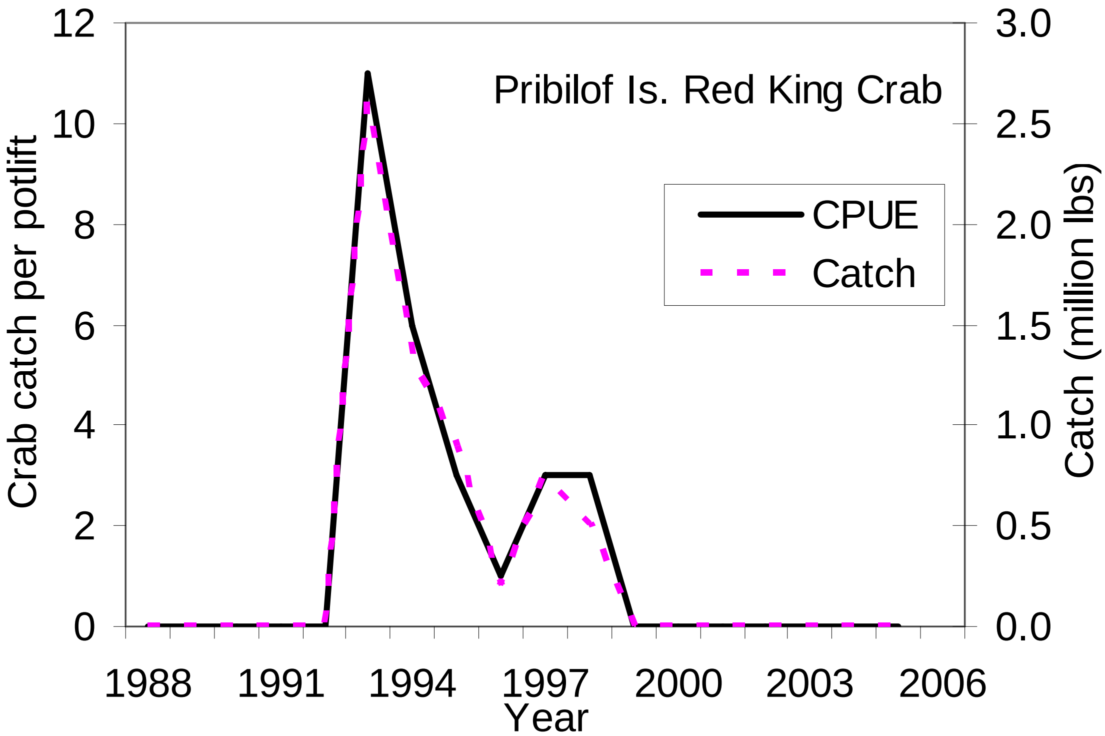

Figure 4-5 Catch and catch per potlift for Pribilof Islands red king crab.

Other red king crab stocks

For the remaining red king crab stocks, no status determination criteria were established under the Alternative 1. Under Alternatives 2 and 3, Dutch Harbor red king crab and Norton Sound red king crab stocks would be managed under Tier 4 while Adak (WAI) red king crab would be managed under Tier 5 Status determination criteria are provided for Tier 4 stocks whereas maximum fishing mortality rates would be prescribed by the Tiers 4 and 5 formulas.

Figure 4-6 provides estimated MMB and B_{MSY} proxy and MSST proxy (1/2 B_{MSY}) for the Norton Sound red king crab stock. Model estimated male mature biomass is well above the B_{MSY} proxy for this stock. Catch and CPUE were extremely high during the late 1970s for this stock when the fishery just started. The CPUE after 1992 may not be comparable to those before 1993 due to change in fishing vessels for Norton Sound red king crab (Figure 4-7).

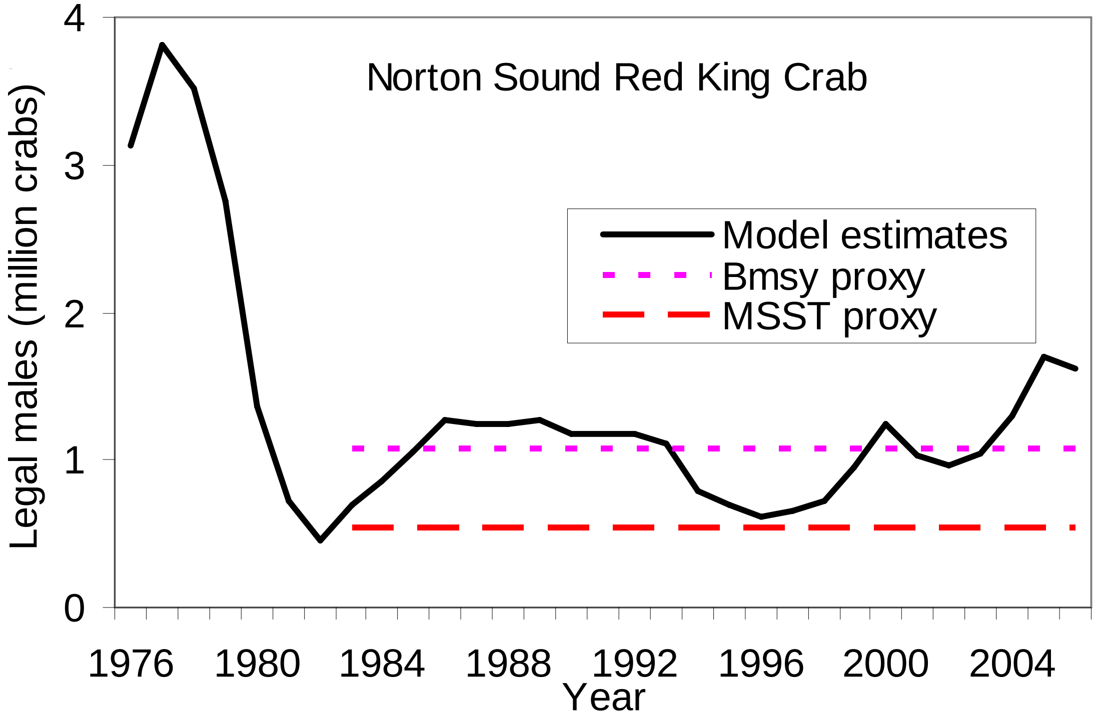

Figure 4-6 Norton Sound estimated legal male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

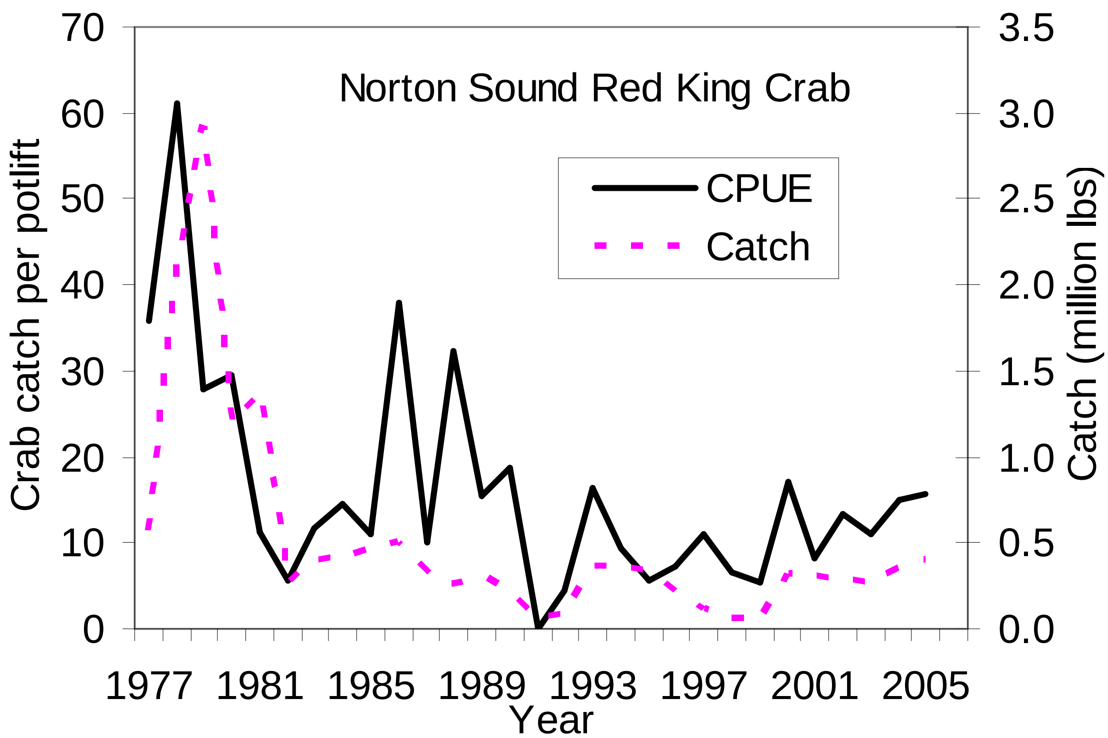

Figure 4-7 Catch and catch per pot lift for Norton Sound red king crab.

4.1.3.2 Alternative 1, Status Quo

Under Alternative 1, two harvest control rules were simulated to predict the possible effects of this alternative on stock biomass. The first represents fishing under the existing State harvest strategy. The second represents fishing at the status quo OFLs.

The State of Alaska harvest strategy for the Bristol Bay red king crab has the following criteria (5 AAC 34.816):

Threshold levels: 8.4 million mature female crabs, 14.5 million pounds (6,577 t) of effective spawning biomass (ESB), and a minimum total allowable catch of 4.444 million pounds (2,016 t). When the threshold levels are met, the harvest rate is determined as follows:

- Mature harvest rate = 10%, if ESB is greater than14.5 million pounds (6,577 t) but less than 34.75 million pounds (15,762 t)
- Mature harvest rate = 12.5%, if ESB is at least 34.75 million pounds (15,762 t) but less than 55 million pounds (24,948 t)
- Mature harvest rate = 15%, if ESB is at least 55 million pounds (24,948 t)

In addition, the harvest is capped at 50% of available legal male abundance.

The State harvest strategy was simulated following the above criteria. The ESB was estimated using size-specific mating ratio (Zheng et al. 1995a). The abundances were estimated at the survey time using survey selectivity, and harvest rates were applied to molting mature male and legal male abundances at the time of the survey. Annual fishing mortality was approximated from harvest rates with an average fishing selectivity.

The Alternative 1 OFL harvest strategy for red king crab was simulated using the following formula:
Sustainable yield = 0.2* total survey mature biomass (male + female)

Note that, under Alternative 1, this OFL harvest strategy is not used for TAC determination, but considered for determining whether the estimated TAC exceeds the OFL or not. If it exceeds the OFL, then it leads to overfishing.

4.1.3.3 Sensitivity analysis of α and β

When the initial biomass was 10% B_{MSY} the median rebuilding time, overfished and closure percentages and the mean first 10-yr yield tended to be lower as α value increased. On the other hand, mean 30th year relative mature male biomass and mean next 20-year yield tended to be higher as α values increased. The performance statistics were slightly better for β = 0.25 than β = 0, except that the mean first 10-year yield was lower with β = 0.25 (Table 4-1).

When the initial biomass was 50% B_{MSY} the trends were similar to that for 10% B_{MSY} initial biomass, but the magnitudes were different. Overall, the rebuilding time, overfished, and closure percentages were lower and the yields were higher (Table 4-2). Although further increases in α and β values have the potential to result in better performance statistics, we selected the upper limits of α and β ranges (i.e., α = 0.1 and β = 0.25) as appropriate for the tier system formulas.

4.1.3.4 Evaluation of alternatives with short-term and long-term performance statistics

To evaluate the impacts of the alternatives on Bristol Bay red king crab, fourteen harvest strategy scenarios were investigated to predict the changes in stock abundance levels under various harvest rates. For Alternative 1, two harvest control rules were simulated to predict the possible effects of this alternative on stock biomass; the status quo harvest strategy and fishing at the status quo OFL. For Alternative 2 and 3, an evaluation was made of Tier 2 to 5. For analytical purposes, additional scenarios considered included a flat $F_{x\%}$, F = M, and F = 0 using performance statistics estimated from short-term (30 years) and long-term (100 years) fishery simulations with stochastic recruitment, observation errors for biomass, and implementation errors for harvest. One thousand simulations were carried out with initial biomasses of 50% B_{MSY} and 100% B_{MSY} to estimate the following performance statistics: median rebuilding time; mean number of recruits; total (retained+discard+trawl bycatch) yield; retained yield; mature male and female B; 30th year or 100th year B/B_{MSY} ratio; years overfished (percentage); and years of fishery closure (percentage); and mean and coefficient of variation of first 10-year and subsequent 20-year mean yields.

Table 4-3 lists the results of performance statistics for short-term (30 years) fishery simulations with initial mature male biomass equal to 50% B_{MSY}. Fourteen harvest strategy scenarios were investigated: Tier 2 with the F_{MSY} (F = 0.35), tier3 with F_{35} (F = 0.33) and F40 (F = 0.26), Tier 4 with 1.75 times natural mortality M, Tier 5 with mean catch (1985-2000 mean yield = 11.09 million pounds (5,031 t) during which the catch-per-unit-effort values were nearly constant), the current State harvest strategy, OFL, Flat F_{MSY} (i.e., no sliding fishing mortality for any level of B), F = M, and F = 0 harvest strategies. Following Restrepo et al. (1998), a default harvest strategy of 75%F was also considered for Tiers 2 and 3.

Tier 2 and Tier 3 with F_{35} produced higher retained yield, lower mean rebuilding time, above B_{MSY} on the 30th year, as well as higher first 10-year and subsequent 20-year yields. The Tier 4 harvest strategy produced closer performance to Tier 3 with F35. Thus, for red king crab with an M of 0.18, a γ value up to 1.75 is feasible. The current State harvest strategy was satisfactory, but the performance was slightly worse than Tier 3 with F_{40} (target fishing mortality candidate). However, the approach used to simulate the current harvest strategy was only an approximation to the actual procedure being followed by the State. Tier 5 performed worse than the current harvest strategy. The OFL harvest performed worst of all, with a very low mean number of recruits, higher overfished percent, and lower 30th year relative mature male biomass. The stock did not rebuild during this time period under OFL. Flat F_{MSY} and Flat F_{35} performed worse than the sliding scale counterparts, not reaching B_{MSY} on the 30th year. Thus, a control rule that responds to changes in biomass on a sliding scale is a beneficial harvest strategy.

Table 4-4 provides the same performance statistics for the short-term (30 years) fishery when the initial mature male biomass was set to 100% B_{MSY}. The OFL control rule performed the worst (low mean recruitment, low 30th year relative mature male biomass, and no stock rebuilding) at this initial biomass level as well.

Table 4-5 and Table 4-6 list the same performance statistics as Table 4-3 and Table 4-4, respectively, but they were based on a long-term fishery (100 years). The OFL control rule performed the worst (low mean recruitment and very low 100th year relative MMB). Although mean yields tend to be higher under the OFL control rule for the short-term fishery (Table 4-3 and Table 4-4), the yield dropped dramatically under the long-term fishery scenario (Table 4-5 and Table 4-6). It is to be noted, however, that the OFL simulations were approximate to the actual calculation made on survey data.

The F = 0 scenarios in to Table 4-3 through Table 4-6 provide the non fishery yields, which are mainly trawl bycatch yields. The results indicated that nearly 1.85 million pounds (837 t) of trawl bycatch was possible at B_{MSY} level under the selected maximum number of recruits (29 million crabs).

Table 4-1 Sensitivity analysis of α and β under Tier 3 control rule with F35 for red king crab. Mean and median were estimated from 1000 simulations of a 30-year fishery with an initial mature male biomass of 10% B_{MSY} with biomass observation error (lognormal, σ1 = 0.2), harvest implementation error (normal, σ2 = 0.1), stochastic Ricker stock-recruitment model with an estimated steepness = 0.82, and recruitment variability (σ = 0.4, auto-correlation = 0). The maximum number of recruits was set at 29 million crabs. Base stock parameter values (Appendix B) were used in the model. CV = coefficient of variation.

Harvest Control Rule Parameters: α, β	**0.0, 0.25**	**0.05, 0.25**	**0.1, 0.25**	**0.0, 0.0**	**0.05, 0.0**	**0.1, 0.0**
Rebuilding time (y)[a]	24	24	23	26	25	24
Years overfished (%)[b]	46.9	46.5	46.1	51.2	49.5	47.6
Years fishery closed (%)[c]	24.2	24.1	24.1	25.8	25.2	24.6
30th year biomass ratio (%)[d]	104	105	107	101	103	105
First 10-yr mean retained yield (t)	150	135	118	289	240	186
CV first 10-yr mean retained yield	0.80	0.81	0.83	0.30	0.36	0.46
Next 20-yr mean retained yield (t)	4821	4843	4874	4233	4406	4618
CV next 20-yr mean retained yield	0.16	0.16	0.16	0.18	0.17	0.17

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time
[b]Mean percent of years in a 30-year fishery the mature male biomass < 50% MSY mature male biomass
[c]Mean percent of years in a 30-year fishery the mature male biomass < 25% MSY mature male biomass
[d]Mean percent of 30th year mature male biomass relative to MSY mature male biomass

Table 4-2 Sensitivity analysis of α and β under Tier 3 control rule with F_{35} for red king crab. Mean and median were estimated from 1000 simulations of a 30-year fishery with an initial mature male biomass of 50% B_{MSY} with biomass observation error (lognormal, σ_1 = 0.2), harvest implementation error (normal, σ_2 = 0.1), stochastic Ricker stock-recruitment model with an estimated steepness = 0.82, and recruitment variability (σ = 0.4, auto-correlation = 0). The maximum number of recruits was set at 29 million crabs. Base stock parameter values (Appendix B) were used in the model. CV = coefficient of variation.

Harvest Control Rule Parameters: α, β	0.0, 0.25	0.05, 0.25	0.1, 0.25	0.0, 0.0	0.05, 0.0	0.1, 0.0
Rebuilding time (y)[a]	11	11	11	11	11	11
Years overfished (%)[b]	4.1	3.9	3.8	4.1	3.9	3.8
Years fishery closed (%)[c]	0	0	0	0	0	0
30th year biomass ratio (%)[d]	110	111	111	110	111	111
First 10-yr mean retained yield (t)	3316	3262	3203	3316	3262	3204
CV first 10-yr mean retained yield	0.19	0.20	0.20	0.19	0.20	0.20
Next 20-yr mean retained yield (t)	7877	7941	8014	7877	7941	8014
CV next 20-yr mean retained yield	0.12	0.12	0.12	0.12	0.12	0.12

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time
[b]Mean percent of years in a 30-year fishery the mature male biomass < 50% MSY mature male biomass
[c]Mean percent of years in a 30-year fishery the mature male biomass < 25% MSY mature male biomass
[d]Mean percent of 30th year mature male biomass relative to MSY mature male biomass

Table 4-3 Short-term performance statistics under various control rules for red king crab. Mean and median were estimated from 1000 simulations of a 30-year fishery with an initial mature male biomass of 50% B_{MSY} with biomass observation error (lognormal, $\sigma 1 = 0.2$), harvest implementation error (normal, $\sigma 2 = 0.1$), stochastic Ricker stock-recruitment model with an estimated steepness = 0.82, and recruitment variability ($\sigma = 0.4$, auto-correlation = 0). The maximum number of recruits was set at 29 million crabs. Base stock parameter values (Appendix B) were used in the model. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, CV = coefficient of variation, NR = not rebuilt, and NA = information not available.

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=1.75*M CR)	Tier 5 Limit (Mean Catch)	Tier 5 Target (75%Mean Catch)	ADF&G Harvest CR	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	26.2	26.9	26.4	27.0	26.9	26.5	24.0	25.9	26.0	15.9	24.6	24.8	27.3	24.9
Mean total yield (t)	7699	7048	7599	6931	7057	7485	6413	4939	6429	8690	7478	7399	5993	668
Mean retained yield (t)	6487	5946	6411	5849	5957	6313	5233	3984	5303	6730	6205	6148	5020	0
Mean mature male biomass (t)	31609	35531	32529	36451	35728	32993	26603	34942	33302	12723	26602	27374	40840	62963
Mean mature female biomass (t)	38525	39318	38738	39485	39353	38837	35671	37875	37908	29051	36570	36845	40018	40483
Mean F	0.28	0.22	0.27	0.21	0.22	0.26	0.34	0.20	0.25	0.97	0.35	0.33	0.16	0
Rebuilding time (y)[a]	12	10	11	10	10	11	21	14	13	NR	20	18	9	7
Years B< B_{MSY} (%)[b]	66.0	50.8	62.2	47.9	50.2	60.4	80.9	57.1	62.3	100.0	84.4	81.8	37.4	25.2
Years overfished (%)[c]	4.2	3.2	3.8	3.0	3.1	3.8	18.2	8.2	5.9	90.9	10.7	9.6	2.4	1.4
Years fishery closed (%)[d]	0	0	0	0	0	0	0	0	0	NA	0	0	0	0
30th year biomass ratio (%)[e]	107	126	111	129	126	114	112	162	130	30	94	98	151	260
First 10-yr mean retained yield (t)	3390	2792	3203	2640	2725	3167	5212	3998	3395	7858	4593	4468	2107	0
CV first 10-yr mean retained yield	0.20	0.21	0.20	0.22	0.21	0.21	0.03	0.02	0.16	0.07	0.09	0.11	0.22	0
Next 20-yr mean retained yield (t)	8035	7523	8014	7453	7574	7886	5244	3978	6258	6167	7011	6988	6477	0
CV next 20-yr mean retained yield	0.12	0.11	0.12	0.11	0.11	0.11	0.02	0.01	0.16	0.12	0.11	0.11	0.10	0

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time
[b]Mean percent of years in a 30-year fishery the mature male biomass < MSY mature male biomass
[c]Mean percent of years in a 30-year fishery the mature male biomass < 50% MSY mature male biomass
[d]Mean percent of years in a 30-year fishery the mature male biomass < 25% MSY mature male biomass
[e]Mean percent of 30th year mature male biomass relative to MSY mature male biomass

Table 4-4 Short-term performance statistics under various control rules for red king crab. Mean and median were estimated from 1000 simulations of a 30-year fishery with an initial mature male biomass of B_{MSY} with biomass observation error (lognormal, σ1 = 0.2), harvest implementation error (normal, σ2 = 0.1), stochastic Ricker stock-recruitment model with an estimated steepness = 0.82, and recruitment variability (σ = 0.4, auto-correlation = 0). The maximum number of recruits was set at 29 million crabs. Base stock parameter values (Appendix B) were used in the model. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, CV = coefficient of variation, and NA = information not available.

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=1.75*M CR)	Tier 5 Limit (Mean Catch)	Tier 5 Target (75%Mean Catch)	Current State Harvest Strategy	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	27.7	28.4	27.9	28.4	28.4	28.0	28.3	27.9	28.1	20.9	27.3	27.5	28.6	25.1
Mean total yield (t)	9819	8846	9644	8662	8846	9485	6303	4910	8758	12947	10044	9883	7421	794
Mean retained yield (t)	8267	7457	8126	7302	7459	7993	5179	3905	7300	10384	8434	8305	6217	0
Mean mature male biomass (t)	36403	41104	37389	42057	41210	38061	49175	54926	39273	19704	34636	35483	47438	73858
Mean mature female biomass (t)	47218	48056	47430	48190	48078	47556	48629	48852	47446	41008	46814	47012	48685	47896
Mean F	0.32	0.25	0.31	0.24	0.25	0.29	0.15	0.10	0.28	0.89	0.35	0.33	0.18	0
Rebuilding time (y)[a]	2	1	1	1	1	1	1	1	1	NA	2	2	1	0
Years B<B_{MSY} (%)[b]	47.3	29.4	43.0	26.4	29.0	40.2	15.6	10.1	35.9	99.4	55.5	51.7	14.9	3.9
Years overfished (%)[c]	0.2	0	0.1	0	0	0.1	0	0	0.1	41.8	0.4	0.3	0	0
Years fishery closed (%)[d]	0	0	0	0	0	0	0	0	0	NA	0	0	0	0
30th year biomass ratio (%)[e]	108	126	111	129	126	114	173	196	119	38	100	104	150	244
First 10-yr mean retained yield (t)	7949	6505	7622	6226	6463	7412	5202	3942	6684	13628	8456	8188	4865	0
CV first 10-yr mean retained yield	0.10	0.10	0.10	0.10	0.10	0.10	0.02	0.02	0.09	0.06	0.07	0.07	0.10	0
Next 20-yr mean retained yield (t)	8426	7933	8378	7839	7956	8284	5168	3886	7608	8763	8423	8364	6892	0
CV next 20-yr mean retained yield	0.11	0.10	0.11	0.10	0.10	0.11	0.01	0.01	0.10	0.11	0.10	0.10	0.09	0

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time
[b]Mean percent of years in a 30-year fishery the mature male biomass < MSY mature male biomass
[c]Mean percent of years in a 30-year fishery the mature male biomass < 50% MSY mature male biomass
[d]Mean percent of years in a 30-year fishery the mature male biomass < 25% MSY mature male biomass
[e]Mean percent of 30th year mature male biomass relative to MSY mature male biomass

Table 4-5 Long-term performance statistics under various control rules for red king crab. Mean and median were estimated from 1000 simulations of a 100-year fishery with an initial mature male biomass of 50% B_{MSY} with biomass observation error (lognormal, $\sigma_1 = 0.2$), harvest implementation error (normal, $\sigma_2 = 0.1$), stochastic Ricker stock-recruitment model with an estimated steepness = 0.82, and recruitment variability ($\sigma = 0.4$, auto-correlation = 0). The maximum number of recruits was set at 29 million crabs. Base stock parameter values (Appendix B) were used in the model. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, CV = coefficient of Variation, NR = not rebuilt, and NA = information not available.

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=1.75*M CR)	Tier 5 Limit (Mean Catch)	Tier 5 Target (75%Mean Catch)	Current State Harvest Strategy	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	27.3	28.0	27.5	28.1	28.0	27.6	26.7	26.7	27.5	11.8	26.3	26.6	28.2	24.3
Mean total yield (t)	9307	8735	9237	8616	8746	9135	6264	4852	8257	6127	9109	9072	7606	801
Mean retained yield (t)	7854	7401	7806	7304	7413	7723	5150	3867	6910	4697	7627	7610	6429	0
Mean mature male biomass (t)	35220	40688	36360	41788	40795	37126	47752	57302	41307	8950	31645	32746	48197	77337
Mean mature female biomass (t)	44569	46070	44965	46286	46107	45191	44366	45069	44884	20803	42797	43295	46901	42260
Mean F	0.31	0.24	0.29	0.23	0.24	0.28	0.19	0.11	0.26	1.0	0.35	0.33	0.17	0
Rebuilding time (y)[a]	12	10	11	10	10	11	21	14	13	NR	19	18	9	7
Years B<B_{MSY} (%)[b]	52.1	31.6	47.2	28.4	31.2	44.2	29.7	17.7	36.8	100.0	67.0	62.4	16.0	7.6
Years overfished (%)[c]	1.3	0.9	1.2	0.9	0.9	1.2	5.8	2.4	1.7	97.4	3.7	3.2	0.7	0.4
Years fishery closed (%)[d]	0	0	0	0	0	0	0	0	0	NA	0	0	0	0
100th year biomass ratio (%)[e]	106	124	110	128	124	113	180	198	129	17.6	99	102	149	242

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time
[b]Mean percent of years in a 100-year fishery the mature male biomass < MSY mature male biomass
[c]Mean percent of years in a 100-year fishery the mature male biomass < 50% MSY mature male biomass
[d]Mean percent of years in a 100-year fishery the mature male biomass < 25% MSY mature male biomass
[e]Mean percent of 100th year mature male biomass relative to MSY mature male biomass

Table 4-6 Long-term performance statistics under various control rules for red king crab. Mean and median were estimated from 1000 simulations of a 100-year fishery with an initial mature male biomass of B_{MSY} with biomass observation error (lognormal, σ_1 = 0.2), harvest implementation error (normal, σ_2 = 0.1), stochastic Ricker stock-recruitment model with an estimated steepness = 0.82, and recruitment variability (σ = 0.4, auto-correlation = 0). The maximum number of recruits was set at 29 million crabs. Base stock parameter values (Appendix B) were used in the model. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, and NA = information not available.

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=1.75*M CR)	Tier 5 Limit (Mean Catch)	Tier 5 Target (75%Mean Catch)	Current State Harvest Strategy	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	27.7	28.4	27.9	28.5	28.5	28.1	27.9	27.2	28.2	14.0	27.2	27.5	28.6	24.3
Mean total yield (t)	9945	9274	9850	9135	9281	9736	6199	4833	9062	7856	9946	9879	8032	837
Mean retained yield (t)	8389	7854	8320	7739	7861	8228	5106	3834	7583	6131	8352	8310	6785	0
Mean mature male biomass (t)	36663	42361	37815	43465	42429	38651	57998	64136	40201	11640	34261	35374	50169	80473
Mean mature female biomass (t)	47253	48759	47635	48957	48781	47881	48985	48210	47943	26049	46284	46731	49548	44448
Mean F	0.32	0.25	0.31	0.24	0.25	0.30	0.12	0.08	0.28	0.98	0.35	0.33	0.18	0
Rebuilding time (y)[a]	2	1	2	1	1	1	1	1	1	NA	2	2	1	0
Years B<B_{MSY} (%)[b]	46.5	25.2	41.4	22.0	24.9	38.2	5.5	3.2	32.8	99.7	57.5	52.6	9.2	1.1
Years overfished (%)[c]	0.2	0	0.1	0	0	0.1	0	0	0.1	82.8	0.6	0.4	0	0
Years fishery closed (%)[d]	0	0	0	0	0	0	0	0	0	NA	0	0	0	0
100th year biomass ratio (%)[e]	106	124	110	128	124	113	180	198	117	18	99	102	149	242

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time
[b]Mean percent of years in a 100-year fishery the mature male biomass < MSY mature male biomass
[c]Mean percent of years in a 100-year fishery the mature male biomass < 50% MSY mature male biomass
[d]Mean percent of years in a 100-year fishery the mature male biomass < 25% MSY mature male biomass
[e]Mean percent of 100th year mature male biomass relative to MSY mature male biomass

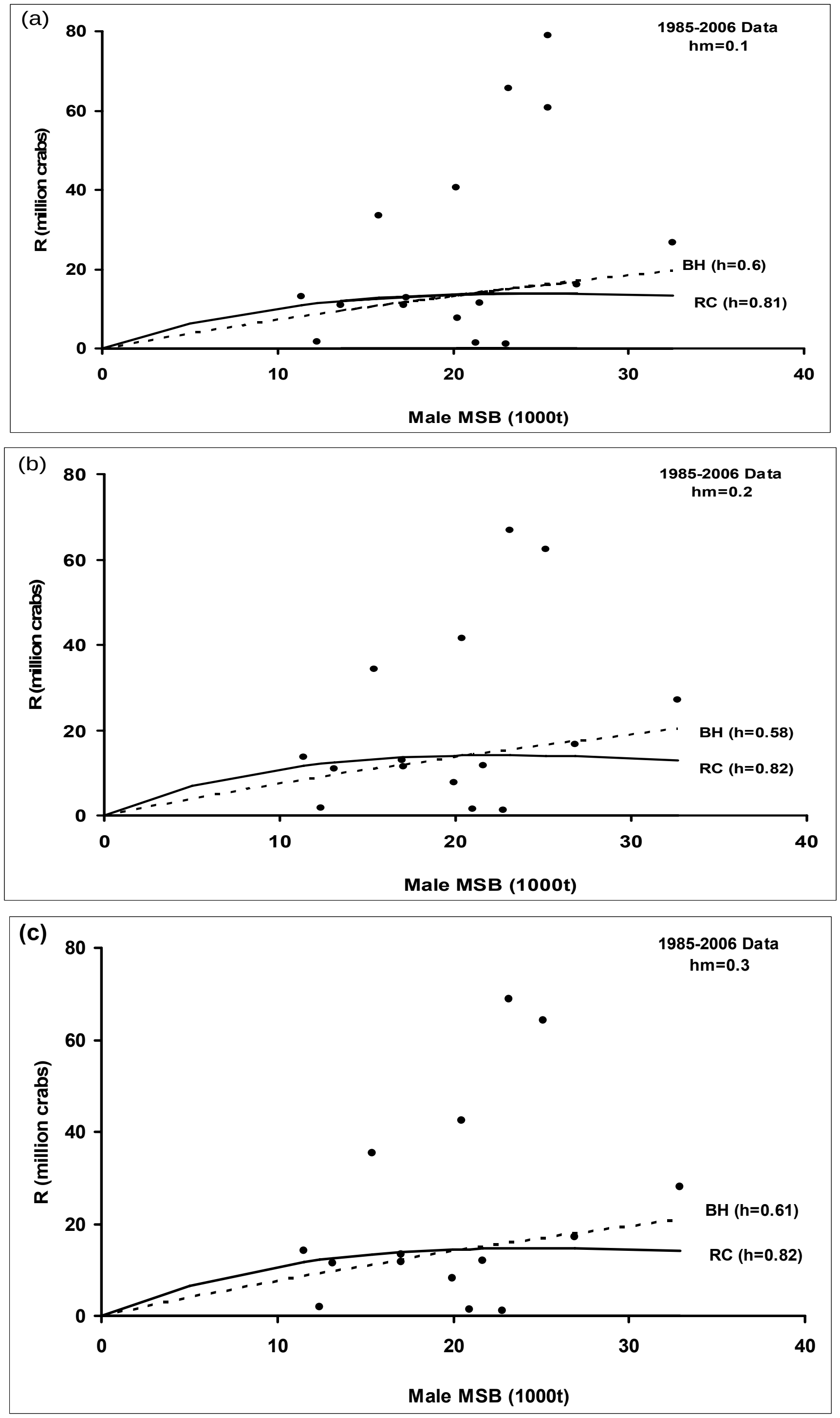

Figure 4-8 Stock-recruitment fit for the Bristol Bay red king crab 1985-2006 data assessed at M = 0.18 and handling mortality, hm (a) 0.1, (b) 0.2, and (c) 0.3. The steepness parameters, h, are given in parentheses. BH = Beverton and Holt curve, RC = Ricker curve.

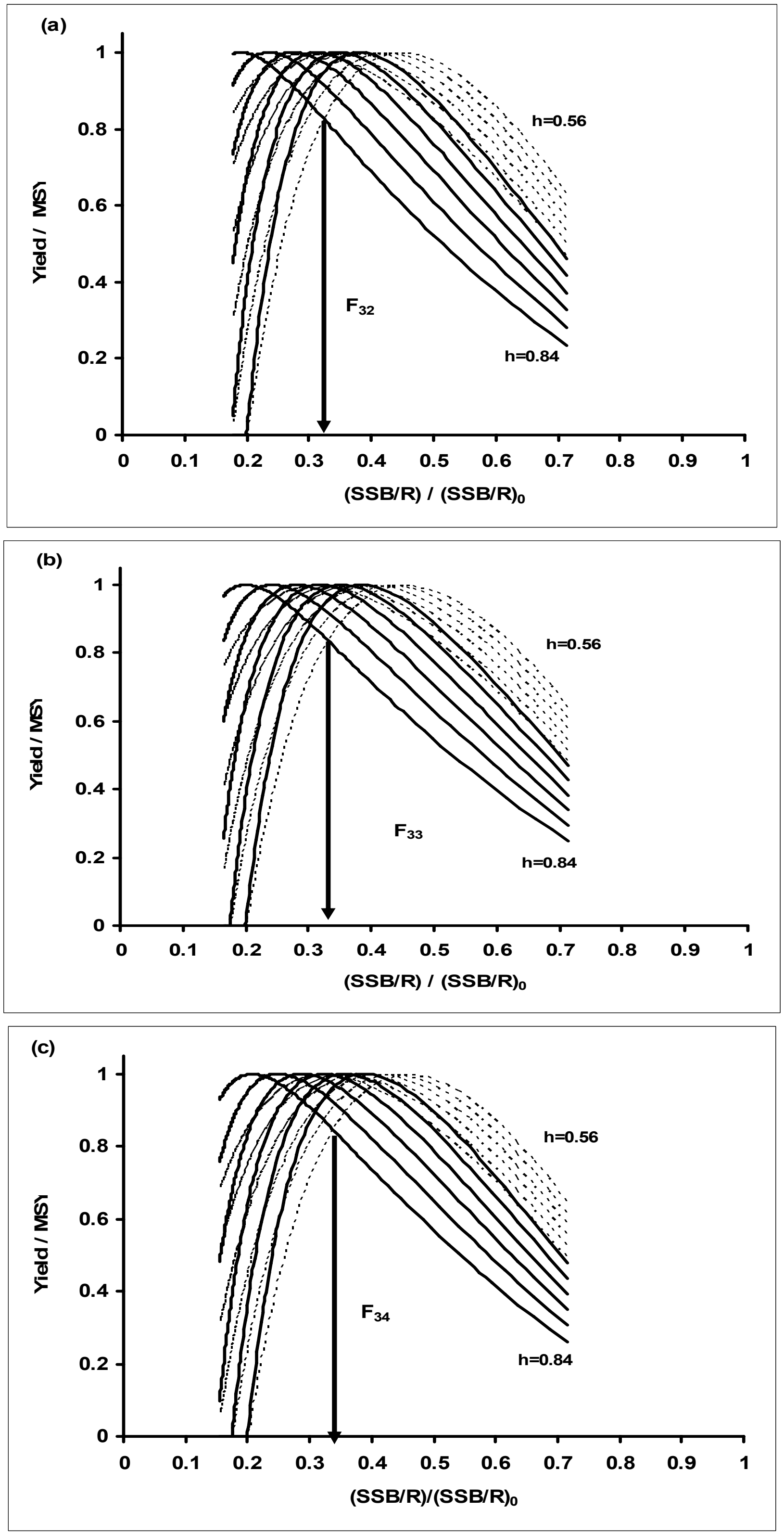

Figure 4-9 Approximate locations of spawning potential ratio ($F_{x\%}$) by equilibrium yield method for different handling mortality rates: (a) 0.1, (b) 0.2, and (c) 0.3 for red king crab. Solid lines: Ricker S-R model, dotted lines: Beverton-Holt S-R model.

Additional evaluations of Bristol Bay red king crab simulations were done in order to examine the applicability of the Tier 5 formulation for a well studied stock. The applicability of average catch as an OFL control rule using the well studied Bristol Bay red king crab stock was investigated. The OFL was set as the mean fishery yield from 1985-2000 of 11.09 million pounds (5,030 t) and 75% of mean catch was set as the target. Then, the same performance statistics under stochastic simulations (Table 4-3 through Table 4-6) were calculated. The mean retained yields were lower compared to F_{MSY} estimates, but the short-term and the long-term final year biomasses far exceeded the B_{MSY}. Thus, in the absence of stock assessment, setting OFL as the mean yield estimated from carefully chosen time period as the OFL could be beneficial to data poor stocks.

4.1.3.5 Five-year projections of stock biomass under alternative control rules

Short-term (5 years) projections of current stock biomass under four control rules were run to look at impacts on mature male biomass estimates of fishing under the proposed control rules compared to the current harvest strategy and fishing at the status quo OFL (Table 4-7). Starting at the estimated abundance in 2006 and with estimated parameters, short-term projections using the current State harvest strategy, fishing at the status quo OFL, F_{40}, and F_{35} harvest control rules for 2007 to 2012 were made for Bristol Bay red king crab (Table 4-7). The 2006 catch was set according the current State harvest strategy for all scenarios. Recruitment was projected by an S-R curve and R_{max} was assumed to be 29 million crabs. Because the annual mature male biomass is projected above B_{MSY} during 2007 to 2012 for F_{40} and F_{35} scenarios, annual fishing mortality is set to equal to those corresponding to F_{40} and F_{35} for these two scenarios. Projected catch and mature biomasses for the State harvest strategy are generally between those of F_{40} and F_{35} scenarios but are more stable over time than those produced by F_{40} and F_{35}. The current OFL results in much higher fishing mortality, higher catch and lower mature male biomass on February 15 than those by the current State harvest strategy, F_{40}, and F_{35} harvest control rules.

Table 4-7 Short-term projections using F_{40}, F_{35}, and the status quo harvest control rules for 2007 to 2011 for Bristol Bay red king crab. The 2006 catch was set according the status quo control rules for all scenarios. Recruitment was projected by an S-R curve and R_{max} was assumed to be 29 million crabs. Catch and biomass are in 1000 t.

Year	Retained Catch	F	Survey Time Mature Male Bio.	Feb 15 Mature Female Bio.	Feb 15 Mature Male Bio.
ADF&G					
2006	7.043	0.296	46.870	51.339	29.728
2007	8.328	0.340	53.080	59.919	34.448
2008	10.670	0.392	66.964	62.225	38.365
2009	11.262	0.330	73.271	62.440	48.043
2010	10.658	0.277	71.159	62.264	53.188
2011	10.156	0.262	67.931	61.911	52.139
2012	9.782	0.260	64.977	61.288	49.857
F_{40}					
2006	7.043	0.296	46.870	51.339	29.728
2007	7.225	0.290	53.080	59.919	34.448
2008	8.463	0.290	68.142	62.277	39.481
2009	10.747	0.290	76.768	62.603	51.382
2010	11.884	0.290	74.862	62.462	56.831
2011	11.560	0.290	69.967	62.079	54.216

Year	Retained Catch	F	Survey Time Mature Male Bio.	Feb 15 Mature Female Bio.	Feb 15 Mature Male Bio.
2012	10.805	0.290	65.325	61.405	50.282
		F_{35}			
2006	7.043	0.296	46.870	51.339	29.728
2007	8.705	0.360	53.080	59.919	34.448
2008	9.797	0.360	66.531	62.203	37.980
2009	12.200	0.360	73.788	62.453	48.556
2010	13.211	0.360	70.605	62.245	52.694
2011	12.547	0.360	64.779	61.802	49.108
2012	11.502	0.360	59.696	61.077	44.694
		Current OFL			
2006	7.043	0.296	46.870	51.339	29.728
2007	15.578	0.759	53.080	59.919	34.448
2008	15.790	0.880	58.903	61.794	30.943
2009	16.040	0.785	59.433	61.501	35.231
2010	15.446	0.743	52.796	60.902	35.710
2011	14.277	0.798	45.917	60.166	30.835
2012	13.077	0.896	40.490	59.142	25.983

4.1.4 Effects on Other red king crab stocks

The Pribilof Islands, Norton Sound, and the Dutch Harbor red king crab stocks are preliminarily placed into Tier 4 for purposes of this analysis. A default γ value or a range of γ values can be set for all Tier 4 stocks. For these red king crab stocks, current productivity is extremely low, and a low γ value may be appropriate for them. The suggested range of γ values are from 1 to 1.5 for red and blue king crab stocks.

There is no formal harvest strategy in State regulations for Pribilof Island red king crab, but this stock has been very conservatively managed due to concern of blue king crab bycatch.

The current State of Alaska harvest strategy for Norton Sound red king crab has lower harvest rates than that resulted from $\gamma = 1$ and $M = 0.18$ when the stock abundance is above B_{MSY}. A length-based model is used for stock assessments for Norton Sound red king crab.

The Dutch Harbor red king crab stock has been extremely depressed during the last two decades, and the fishery has been closed since 1983. The new overfishing definitions will not have any impact on this stock in the near future because no fishery is predicted.

The Adak red king crab is preliminarily placed in Tier 5 for purposes of this analysis. This stock has only been opened to fish in a very small area for 4 years during the last 10 years. Average yield though the history of the fishery was very high for this stock, but average yield since 1985 is only 870,000 pounds (395 t). The OFL could be set as 870,000 pounds (395 t), if average catch is chosen as the means to establish an OFL for this stock, and the suggested TAC of 75% of OFL of 650,000 pounds (295 t). This stock could be promoted to Tier 4 if routine surveys are conducted.

5 Blue King Crab (*Paralithodes platypus*)

Three stocks of blue king crab are managed under this FMP, the Pribilof Islands stock, the Saint Matthew Islands stock, and the Saint Lawrence stock. Of these, both the St. Matthew blue king crab and Pribilof Islands blue king crab stocks are under rebuilding plans following overfished declarations in 1999 and 2002, respectively. This section reviews the stock status and biological parameters relevant to overfishing definitions for these stocks and provides an overview of specific impacts on the stocks from the three alternatives under consideration in this analysis.

5.1.1 Blue king crab stock status

Pribilof District blue king crab

This stock is annually surveyed by NMFS. Based on survey biomass estimates, the stock remains in "overfished" condition for the fifth year in a row. A rebuilding plan was implemented for this stock in 2002 following an overfished declaration in 2001. The rebuilding plan does not allow for any harvest until the stock is fully rebuilt. This depressed stock continues to show declines with little indications for recovery in the near future. Estimated total mature biomass for 2006 is 1.6-million pounds, the same as in 2005 and at the second lowest on record (Figure 5-1). The ADF&G CSA estimates for abundance of mature males, legal males, and mature females in 2006 are the lowest estimated for the period 1975-2006. A continued decline in mature male and female abundance should be expected for at least the next two years. Although relatively high numbers of small crab (< 70 mm-CL) were caught, mainly at one haul, during the 2005 trawl survey, there is very little representation of juvenile crabs in the 2006 survey (NPFMC 2006a).

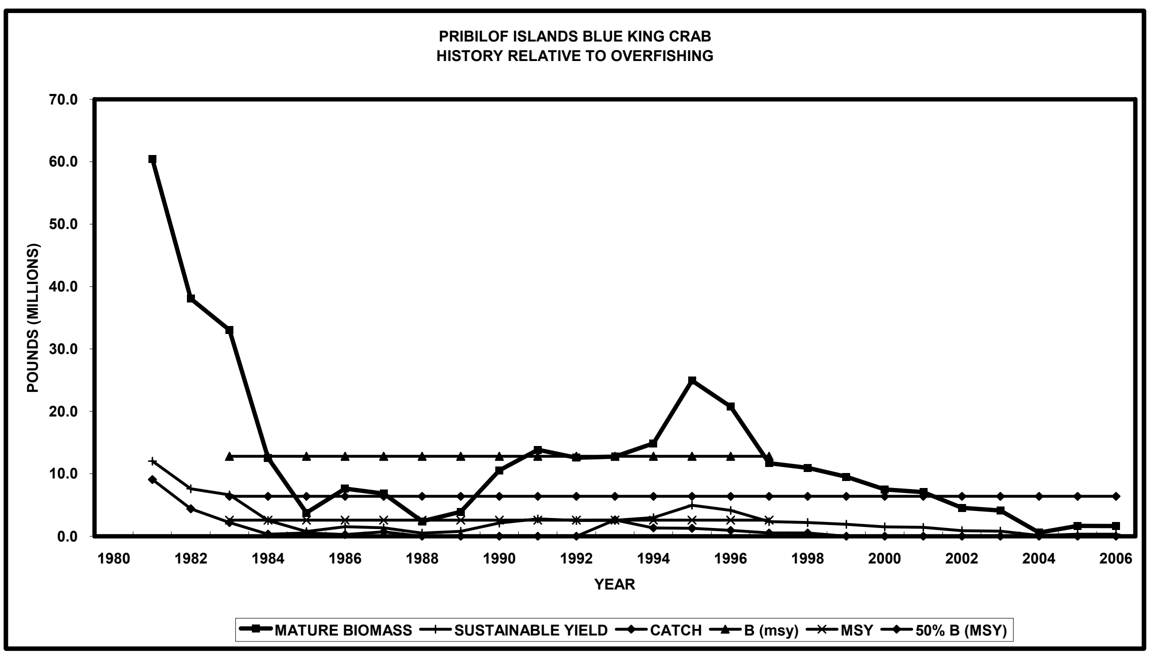

Figure 5-1 Pribilof District blue king crab stock status relative to overfishing.

Because estimated total mature biomass in 2005 was less than 13.2 million pounds (5,987 t), the fishery on this stock cannot open for the 2006/2007 season under the State harvest strategy. Also, because estimated total mature biomass in 2006 was less than 13.2 million pounds (5,987 t), the fishery on this stock cannot open for the 2007/2008 season under the State harvest strategy. This fishery has been closed since 1999.

Saint Matthew Island Section blue king crab

This stock is annually surveyed by NMFS. Total mature biomass (TMB) in 2006 was estimated to be 11.2 million pounds (5,080 t), at its second highest level since the overfished declaration of 1999. A rebuilding plan was implemented for this stock in 2000. The series of annually estimated TMB since 1999 shows at best a slow rate of stock recovery and TMB in 2006 is at approximately ½ the "rebuilt" level of 22.0 million pounds (9,979 t) (Figure 5-2).

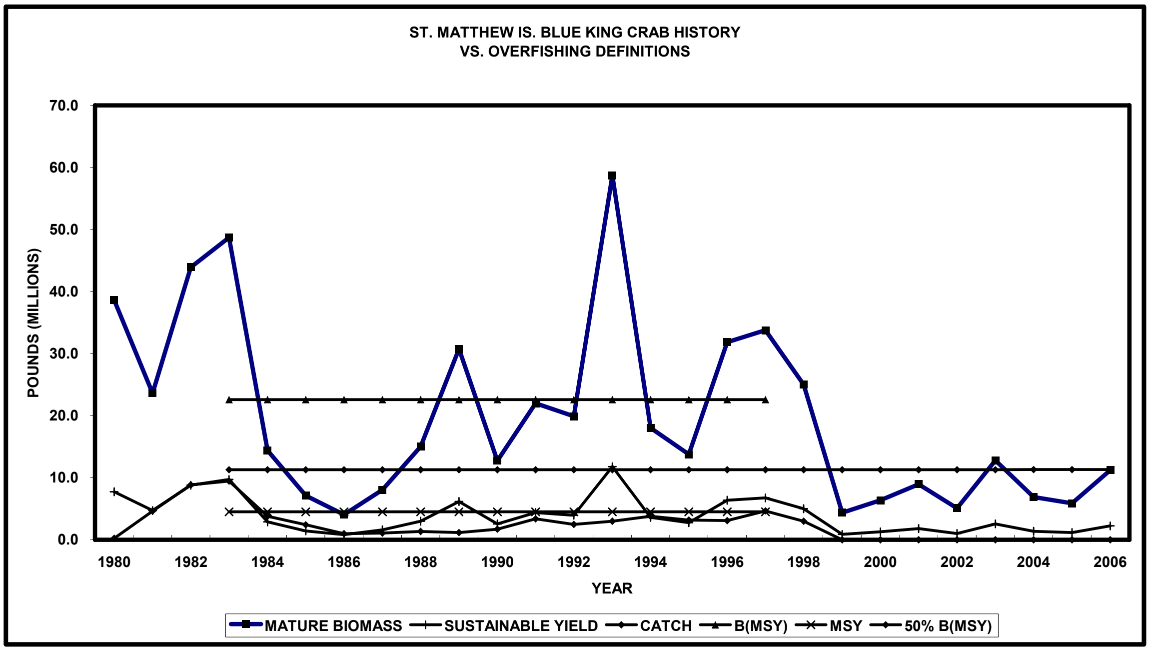

Figure 5-2 St. Matthew blue king crab stock status relative to overfishing.

From all indications, this stock continues to remain at a depressed level, comparable to that of the mid-1980s. Unlike the mid-1980s, however, the stock is in a prolonged period (now in its seventh year) of depressed status. There are some promising indications for the stock in this year's survey data, however. Although low relative to pre-1999 levels, NOAA Fisheries area-swept estimates of sublegal, mature-sized males (105- to 119-mm CL) and legal-sized males (≥120-mm CL) in 2006 are, at 0.74 million and 1.38 million crabs, both more than twice the estimates for 2005 (0.3 million and 0.6 million crabs, respectively). The current ADF&G CSA estimate of the mature-sized male abundance shows the first signs of improvement since the marked stock decline observed between the 1998 and 1999 surveys. The mode of small crab (approximately 65- to 70-mm CL) observed in 2003, apparently followed into 2004 (mode near 80- to 85-mm CL) and again into 2005 (mode between 90- to 95-mm CL). In 2006, that mode has apparently provided some recruitment into the mature size class. Males 80- to 104-mm CL that appeared in this year's survey may also provide recruitment in the next 2-3 years (NPFMC 2006a).

Abundance estimates are heavily influenced by the catch in relatively few tows and precision of estimates is generally poor. Bottom temperatures in the survey stations southwest of St. Matthew Island that are important for providing catches of male blue king crab during the trawl survey were much colder in 2006 than in recent years. Bottom temperatures may affect the distribution of blue king crab within the surveyed area and that could affect the susceptibility of crabs to be caught during the survey.

Additionally, it's important to note that, although poorly estimated, female blue king crabs are showing no indications of increasing in abundance; NOAA Fisheries area-swept estimates of female size classes remain low and have declined from an estimate of 1.0-million females in 2003 to 0.4 million female crabs in 2006.

Total mature biomass would need to increase nearly double to 22.0 million pounds from the 2006 estimate for the stock to be considered "rebuilt." Data from the 2006 survey do not provide any expectations for such an increase in the near-term future; the estimates from 1999 through 2006 indicate at best only a weakly increasing trend in total mature biomass. The fishery has been closed since 1999.

Saint Lawrence blue king crab

This stock is not annually surveyed by NMFS. Little is known about stock status of blue king crab in the St. Lawrence Island region. Commercial harvests in the St. Lawrence Section have only been reported for four years. The largest of these four was a harvest of 52,557 pounds (24 t) in 1983. This was caught primarily near the southeast shore of St. Lawrence Island (Kohler and Soong, 2005). The following year regulations were adopted which closed all waters within ten miles of all inhabited islands in the St. Lawrence Section (St. Lawrence Island, Little Diomede and King Island). Since that time the other three harvests on record are 984 pounds (0.4 t) in 1989, 53 pounds (0.02 t) in 1992, and 7,913 pounds (3.6 t) in 1995 (Kohler and Soong, 2005). This stock is not surveyed and while commercial harvest and sale of blue king crab from near shore during winter are permitted under regulations, there are no reports to ADF&G of commercial sales in recent years (Kohler and Soong, 2005).

5.1.2 Biological Parameters

This section examines relevant and recent biological information necessary to understand the overfishing definitions.

5.1.3 Effects on Blue King Crab

5.1.3.1 Comparison of status determination criteria

The current status determination criteria for Pribilof District blue king crab establish a B_{MSY} value of 13.2 million pounds (5,987 t) with an MSST value of 6.6 million pounds (2,994 t). Currently biomass as measured by the TMB of the area-swept estimate from the survey is 1.6 million pounds (726 t), well below the MSST for this stock (Figure 5-1). For St. Matthew blue king crab, a B_{MSY} of 22 million pounds (9,979 t) is established with an MSST of 11 million pounds (4,990 t). Current biomass as measures by the area-swept survey estimate for this stock is 11.2 million pounds (5,080 t), just slightly above the MSST for this stock (Figure 5-2).

Both stocks are under rebuilding plans and are not fully rebuilt until biomass is above B_{MSY} for two years in a row. With a survey estimate just above MSST, the St. Matthew stock is no longer in an overfished condition. The Pribilof stocks remains in an overfished condition with no indication of stock recovery.

Under the new tier system, both of these stocks would be managed as Tier 4 stocks. As such proxy B_{MSY} values may be estimated. Figure 5-3 provides estimated mature male biomass and B_{MSY} proxy and MSST proxy (1/2 B_{MSY}) for the Pribilof District blue king crab stock. Estimated mature male biomass, B_{MSY} proxy and MSST proxy (1/2 B_{MSY}) for the St. Matthew blue king crab stock are shown in Figure 5-4. For illustration purposes, average abundance from 1983 to 1998 was used as a proxy for two blue king crab stocks. The two blue king crab stocks have been extremely depressed since 1999, so the estimated abundance after 1998 was not used for the average. Catch and CPUE for Pribilof District blue king crab and St. Matthew blue king crab were high before 1983, corresponding to the high population abundance (Figure 5-4, Figure 5-6).

Given that both stocks are under rebuilding plans and new biological parameters for these stocks are proposed, their rebuilding plans may need to be re-evaluated and potentially revised to reflect new information on the stock, including new estimates of stock recovery in relation to B_{MSY}.

The Saint Lawrence blue king crab stock does not have a current estimate of B_{MSY}. Under Alternatives 2 and 3, this stock would be managed under Tier 6 and no OFL would be established for this stock due to lack of information.

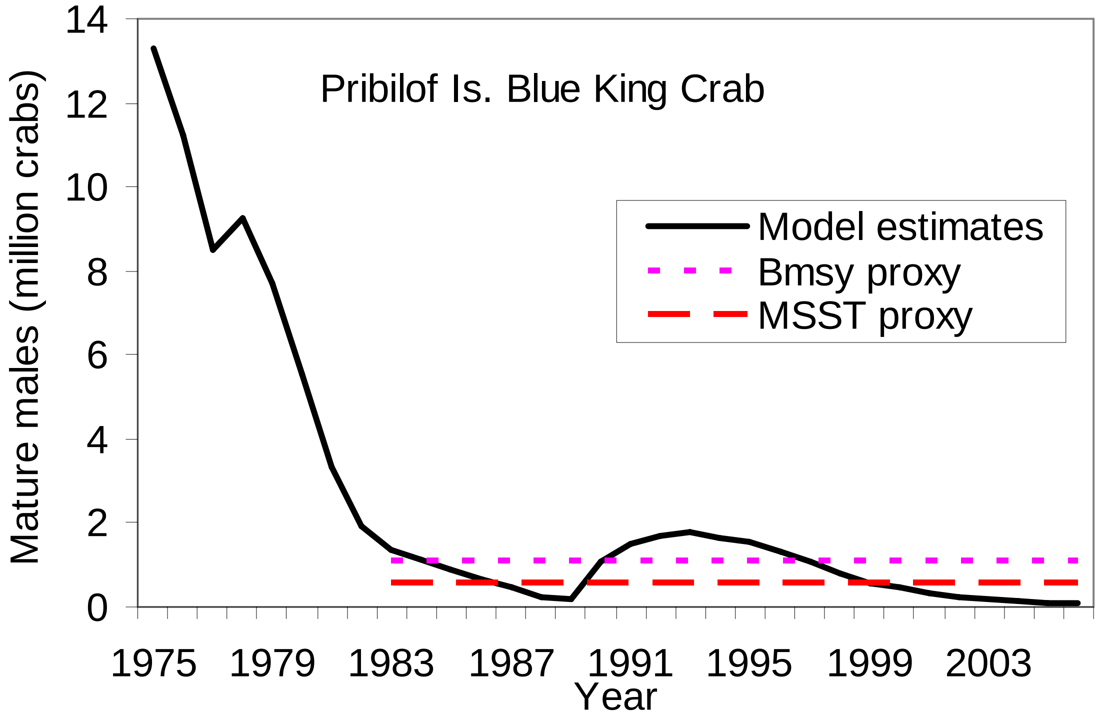

Figure 5-3 Pribilof Islands blue king crab estimated mature male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

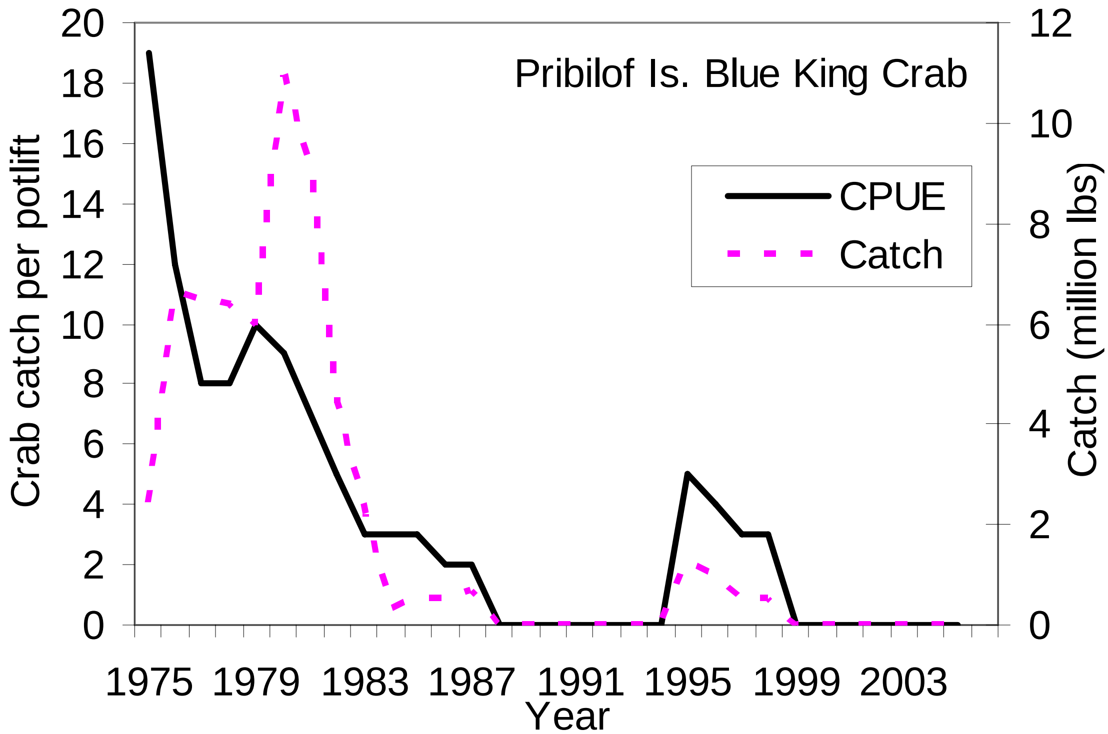

Figure 5-4 Catch and catch per pot lift for Pribilof District blue king crab.

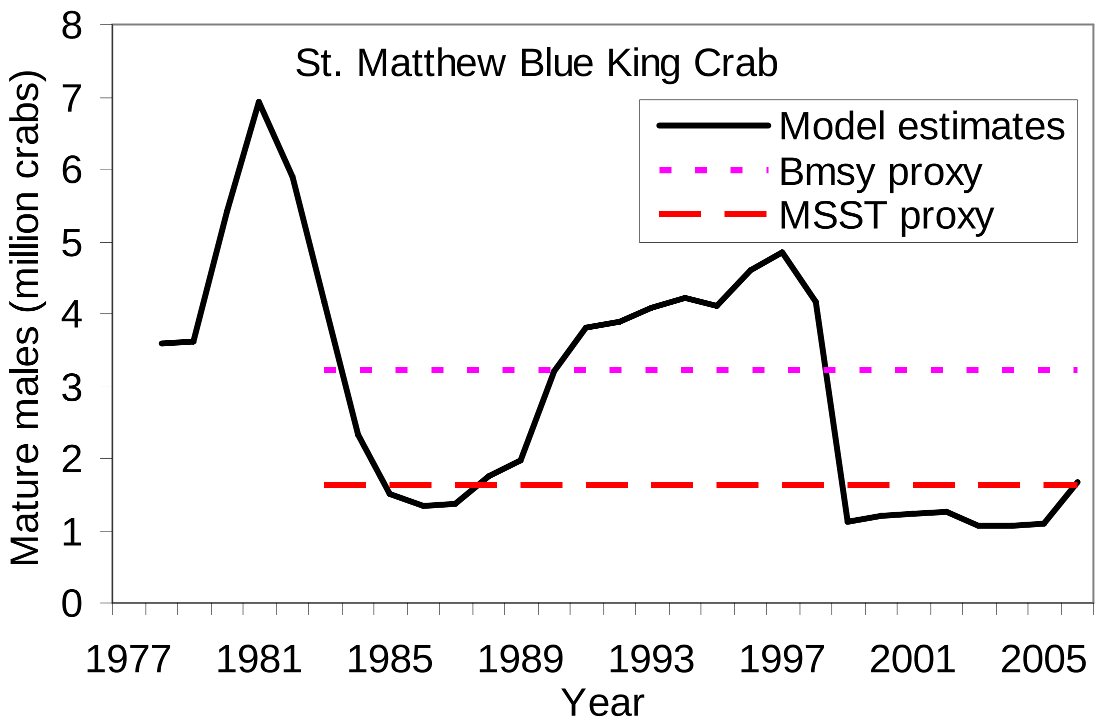

Figure 5-5 Saint Matthew blue king crab estimated mature male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

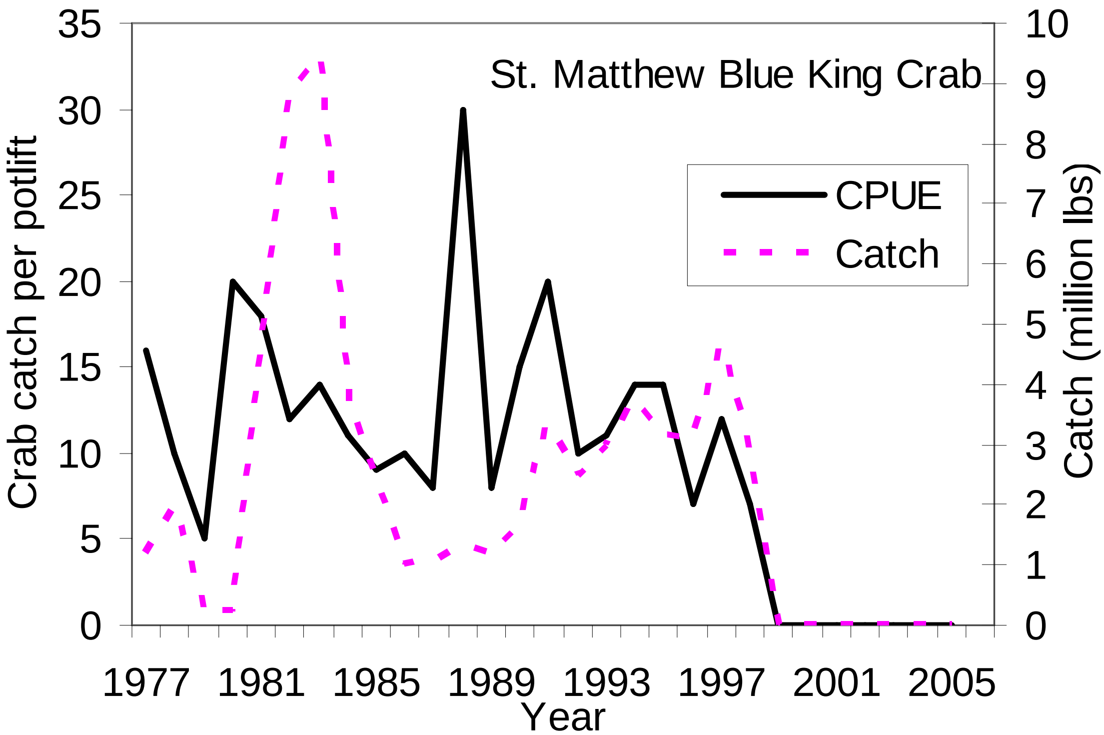

Figure 5-6 Catch and catch per pot-lift for St. Matthew Island blue king crab.

As described in previous sections (3.1, 3.3.2.1), both the St. Matthew stock and the Pribilof stock are currently under rebuilding plans following overfished declarations for both stocks in 1999 and 2002 respectively. These stocks TMB dropped below their MSST at that time prompting the declaration that the stock was in an overfished condition. No fishing had been occurring for Pribilof District blue king crab since 1999, and other crab management measures and bycatch closure zones had been enacted. Rebuilding plans for both stocks were implemented with extensive analyses provided in the EA for those amendments regarding the rebuilding strategy and estimated time to stock recovery. See NPFMC 2000 (St. Matthew) and NPFMC 2003 (Pribilof Islands) for more information on the rebuilding plans and subsequent analysis of these stocks.

Under the revised tier system (Alternatives 2 and 3), the Pribilof District blue king crab and St. Matthew blue king crab stocks are preliminarily placed into Tier 4 for purposes of this analysis. A default λ value or a range of γ values can be set for all Tier 4 stocks. For these blue king crab stocks, current productivity is extremely low, and a low γ value may be appropriate for them. The suggested range of γ values are from 1 to 1.5 for blue king crab stocks. $\gamma = 1$ will restrict the fishery more than the current state harvest strategies when the abundance is high for these two blue king crab stocks. However, the current stock productivity is extremely low and the fisheries have been closed since 1999 for these two stocks. The new overfishing definitions, no matter how conservative, would not have any impact on these two stocks in the near future.

Under Alternative 1, the harvest strategy was adopted as part of the rebuilding plan for Pribilof blue king crab in Amendment 17 to the FMP. Note that under rationalization, a TAC and IFQs will only be issued for Pribilof king crab (i.e., for the pooled Pribilof red king crab and Pribilof blue king crab).

The State harvest strategy has three components for computing the blue king crab component of the Pribilof king crab TAC (5 AAC 34.918).

- Minimum stock conditions for a fishery opening: The fishery will open only if the estimated TMB is at least 13.2 million pounds (5,987 t) for two consecutive years.
- A rule for computing the TAC if the stock meets minimum conditions for an opening:
  The minimum of:
  - 10% of the estimated abundance of mature males at the time of the survey times the average weight of legal males; or
  - 20% of the estimated abundance of legal males at the time of the survey times the average weight of legal males.
- A minimum TAC for a fishery opening: 0.556 million pounds (252 t).

Under Alternative 1, the State harvest strategy for St. Matthew blue king crab was adopted as part of the rebuilding plan in Amendment 15 to the FMP. The harvest strategy has four components for determining the TAC (5 AAC 34.917):

- A threshold of 2.9 million pounds (1,315 t) of mature male biomass,
- An exploitation rate on mature male abundance that is a function of mature male biomass,
- A 40% cap on the harvest of legal males, and
- A minimum 2.778 million pounds (1,260 t) TAC for a fishery opening.

Mature male biomass (MMB) is defined for management purposes as the biomass of males ≥105-mm carapace length (CL). When MMB is below the 2.9 million pounds (1,315 t) threshold of the State's harvest strategy, the stock is closed to commercial fishing. When the stock is above that threshold, an exploitation rate on mature male abundance (defined for management purposes as the abundance of all males ≥105-mm CL) is determined as a function of MMB. The exploitation rate on mature male abundance increases linearly from 10% when MMB = 2.9 million pounds (1,315 t) to 20% when MMB = 11.6 million pounds (5,262 t). For MMB >11.6 million pounds (5,262 t), the exploitation rate on mature male abundance remains at 20%. Application of the mature male exploitation rate to mature male abundance determines the targeted number of legal-sized males for commercial harvest. Minimum legal size is 5.5-in carapace width (CW), but 120-mm CL is used as a proxy for the size limit in stock assessment computations. To protect from excessive harvest of the legal-sized component of the mature male stock, the targeted number of legal-sized males for commercial harvest is capped at 40% of the estimated legal-sized male abundance.

The St. Lawrence Island blue king crab stock is preliminarily placed into Tier 6 for purposes of this analysis. No OFL determination is made and there is currently no fishery for this stock.

6 Golden king crab

There are three stocks of golden king crab managed under this FMP, the Aleutian Islands golden king crab stock, the Pribilof golden king crab stock, and the Northern District golden king crab stock. This section reviews the stock status and biological parameters relevant to overfishing definitions for these stocks and provides an overview of specific impacts on the stocks from the three alternatives under consideration in this analysis.

6.1.1 Golden king crab stock status

Aleutian Islands golden king crab

This stock is not annually surveyed by NMFS. Triennial pot surveys are conducted for a portion of the Aleutian Islands golden king crab stock. The fishery is evaluated based on commercial fishery CPUE. Currently, work is being completed on a catch-survey model that uses data from the commercial fishery and triennial surveys. Once completed, this model should provide managers with additional information to assess stock status and harvest rate. Prior to the 1996/97 season, the Aleutian Islands king crab fisheries were managed as two distinct areas: the Dutch Harbor Area (east of 171° W. longitude) and the Adak Area (west of 171° W. longitude). In 1996, the Alaska Board of Fisheries (Board) noted that the management boundary at 171° W. longitude apparently bisected a single stock of golden king crab. At that meeting, the Board combined the Dutch Harbor and Adak Areas into a single management area. The Board also directed the department to conservatively manage golden king crab, east and west of 174° W. longitude, as two distinct stocks. Prior to combining the two management areas, the Dutch Harbor Area had been managed on the basis of fishery performance with the historic average landings providing an informal harvest guideline. The Adak Area was formerly managed under a size-sex-season (3-S) policy.

In the Aleutian Islands east of 174° W. longitude, the total number of crab per pot captured over the last eight seasons appears stable, although the legal-male catch rates have increased and the catch rates for sublegal and female crab have decreased. Legal male CPUE, based on fish ticket data, was 25 crabs per pot for the 2005/06 fishery, which is the highest on record and a 39% increase from the 2004/05 CPUE of 18 crabs per pot lift. The increase in CPUE is likely due to many factors including, but not limited to increased soak times, fewer pots being utilized, and fewer vessels participating. Escape mechanisms in golden king crab pots are very effective in allowing smaller golden king crabs to escape, especially with the longer soak times relative to other king crab fisheries.

With the implementation of the Crab Rationalization program during the 2005/06 season observer coverage changed. Catcher-only vessels are required to carry an observer for 50% of the total golden king crab harvest by each vessel during each of three trimesters (August 15 to November 15, November 16 to February 15, and February 16 to May 15). Catcher-processor vessels are required to carry an observer for 100% of the harvest.

Sublegal male and female golden king crab also occur over a wider depth range than legal crab and may not be equally represented in the commercial catch. Recently, sublegal male CPUE has decreased and there are no indications that legal male CPUE will remain at the current high level if sublegal male CPUE is viewed as an index of possible future recruitment. Commercial fishery catch data does not provide adequate information to accurately predict future recruitment. Harvest level decisions are difficult to discern based solely on CPUE. A review of observer size frequency data and CPUE data are used in a qualitative measure to ensure there are no adverse effects from the current constant-catch harvest strategy. The constant-catch harvest strategy assumes that fishing mortality changes annually, however those changes are currently not measured in these golden king crab stocks. Based on a review of available data ADF&G set the 2006/07 TAC at 3.0 million pounds (1,361 t) for the area east of 174° W. longitude.

To establish the 2006/07 TACs, fishery data, observer data, and tag recovery information were used in reviewing stock status, previously established GHLs, and TACs. Fishery data, through the 2005/06 season, were examined for CPUE and geographic harvest trends. Observer data from the 1998/99 to 2005/06 seasons were examined for size composition of retained and discarded crabs, shell-age of male and female crabs, stock composition and reproductive condition of female crabs.

In the Aleutian Islands west of 174° W. longitude TAC remained at the same level as the previous year, 2.7 million pounds (1,225 t). Fishery catch statistics have not markedly changed since the GHL was developed in 1996/97. The size frequency of the retained catch continues to be stable though there appear to be fewer of the smaller pre-recruits. CPUE of pre-recruit and female crabs are also relatively stable in the catch. Most commercial fishing effort occurs at depths less than 200 fathoms. Deeper than 200 fathoms, the abundance of small male and female crab is generally greater than legal males. Recent fishery data from the western Aleutian Islands implies that the stock in that area is stable, catches of sublegal males have been steady and there are no indications of a strong recruitment episode.

Pribilof golden king crab

The golden king crab population in the Bering Sea (both Pribilof District and Northern District) is not surveyed and there is no estimate available of its abundance. There are no plans to survey this population nor has a harvest strategy been developed. The population size is believed to be limited by the available habitat in the Bering Sea for this species (NMFS 2004a). In the Pribilof District, golden king crabs have only been caught in a few deep canyons. Historic harvests have occurred in the area to the south of the Pribilof Islands (NMFS 2004a).

Northern District golden king crab

As with golden king crab in the Pribilof District, the golden king crab population in the Northern District is not surveyed and no estimate of population abundance is available. Since the 1982/83 season, harvest has only been documented for seven seasons (NMFS 2004a). Most of the harvest has occurred west of St. Matthew Island and no harvest has occurred since 1996 (NMFS 2004a).

6.1.2 Biological Parameters

This section examines relevant and recent biological information necessary to understand the overfishing definitions.

6.1.3 Effects on Golden King Crab

6.1.3.1 Comparison of status determination criteria

Under Alternative 1, no estimates of B_{MSY} or MSST are made for any of the golden king crab stocks. Under Alternatives 2 and 3, two golden king crab stocks are preliminarily recommended for Tier 5 (Pribilof Islands, Aleutian Islands). Under Tier 5, no estimates of status determination criteria are made and management uses a fishing mortality estimated based on average catch. Improved biomass estimates for the Aleutian Islands golden king crab stock are likely in the future as a stock assessment model utilizing fishery data as well as triennial pot data will be utilized to provide estimates of stock status and harvest rate (Siddeek et al. 2005). St. Matthew golden king crab are recommended for placement in Tier 6 whereby no OFL is to be determined for this stock.

Aleutian Islands Golden King Crab

The fishery has been conducted since 1981. The current TAC of 5.7 million pounds has been used for about 10 years. Catches are managed based on CPUE. The current trend for the CPUE is up, and the CPUE in 2005/2006 has been the highest since the fishery started in 1981. The highest annual catch was about 15 million pounds (6,804 t) in 1986. Average yield from 1985 to 2005 is 7.527 million pounds (3,414 t).
Under Alternative 1, the AI golden king crab stock is managed as a Tier 2 stock with sporadic or limited years of survey data available. B_{MSY} is not estimable for this stock and no OFL is determined for this stock.

Under Alternatives 2 and 3, the AI golden king crab stock is preliminarily placed into Tier 5 for purposes of this analysis. If average catch is used from 1985 to 2005 to establish an OFL for this stock, the OFL would be 7.527 million pounds (3,414 t). This would not constrain the current TAC but could constrain increases in TAC that might be considered given the high CPUE. A TAC set at 75% of OFL would be 5.646 million pounds (2,561 t), which is very close to the status quo TAC of 5.7 million pounds (2,585 t).

Although there are no golden king crab stocks in Tier 4 currently, Aleutian Islands golden king crab could move up to Tier 4 soon. A model has been developed for this stock (Siddeek et al 2005), and once the model is used for annual stock assessments, this stock would fall into Tier 4. Golden king crab has different larval biology than other crabs, and preliminary results from the modeling work indicate golden king crab can sustain much higher harvest rates than red and blue king crabs. With an assumed $M = 0.3$ for a catch-length analysis, legal male harvest rates were estimated to be about 50% during the early 2000s for Aleutian Islands golden king crab, or $F = 0.693$, which results in $\gamma = 2.31$. If $M = 0.18$ is used like other king crab stocks, γ would be greater than 3.8. Under the current harvest rates, the stock has been stable or an upward trend. So maintaining the current harvest levels with the Tier 4 approach would require γ values greater than 2, depending on M values. A range of γ values from 2 to 4 may be appropriate for golden king crab stocks with possible M values ranging from 0.18 to 0.3.

Pribilof Islands and Saint Matthew Golden King Crab

For the Pribilof Islands golden king crab stock, fishing effort is sporadic before 1993 and CPUE has fluctuated quite a bit over time. The current GHL is 150,000 pounds, but due to economic factors, the GHL has not been taken in some years. Under Alternative 1, the Pribilof Islands golden king crab stock is managed as a Tier 1 stock with no survey data available. B_{MSY} is not estimable for this stock and no OFL is determined for this stock.

Under Alternative 2 and 3, the Pribilof Islands golden king crab stock would be placed into Tier 5. Based on fishing effort data, the appropriate period for catch average may be 1993 to 2005. The average yield during this period is 153,000 pounds (69 t). If the OFL were established for this stock based upon the use of average yield over this time period, the OFL would be 153,000 pounds (69 t). A GHL set at 75% of OFL would be 115,000 pounds (52 t). This would be a substantially reduced GHL from status quo.

There has been limited fishing effort on the Saint Matthew golden king crab stock in the last 10 years. No OFL determination is made for purposes of this analysis under all of the alternatives. Under Alternative 2 and 3, this stock would be placed in Tier 6, thus no OFL would be determined.

7 Snow crab (*Chinoecetes opilio*)

There is one stock of snow crab managed under this FMP. This section reviews the stock status and biological parameters relevant to overfishing definitions for this stock and provides an overview of specific impacts on the stock from the three alternatives under consideration in this analysis.

7.1.1 Snow crab stock status

This stock is annually surveyed by NMFS. The survey total mature biomass (TMB) estimate for this stock in 2006 is 547.6 million pounds **(248,390 t),** above MSST but slightly below the estimate for 2005 of 610.7 million pounds (277,012 t). This stock has been under a rebuilding plan since 2000, following the overfished declaration of 1999. The estimated TMB in 2006 remains below the rebuilt level (it is 59% of the "rebuilt level of 921.6 million pounds or 418,035 t) and maintains the trend in TMB of "hovering about" MSST for the last eight surveys without any apparent trend towards rebuilding (Figure 7-1). Since 1999, however, 2006 represents the first year that estimated TMB has been above MSST for 2 years in a row.

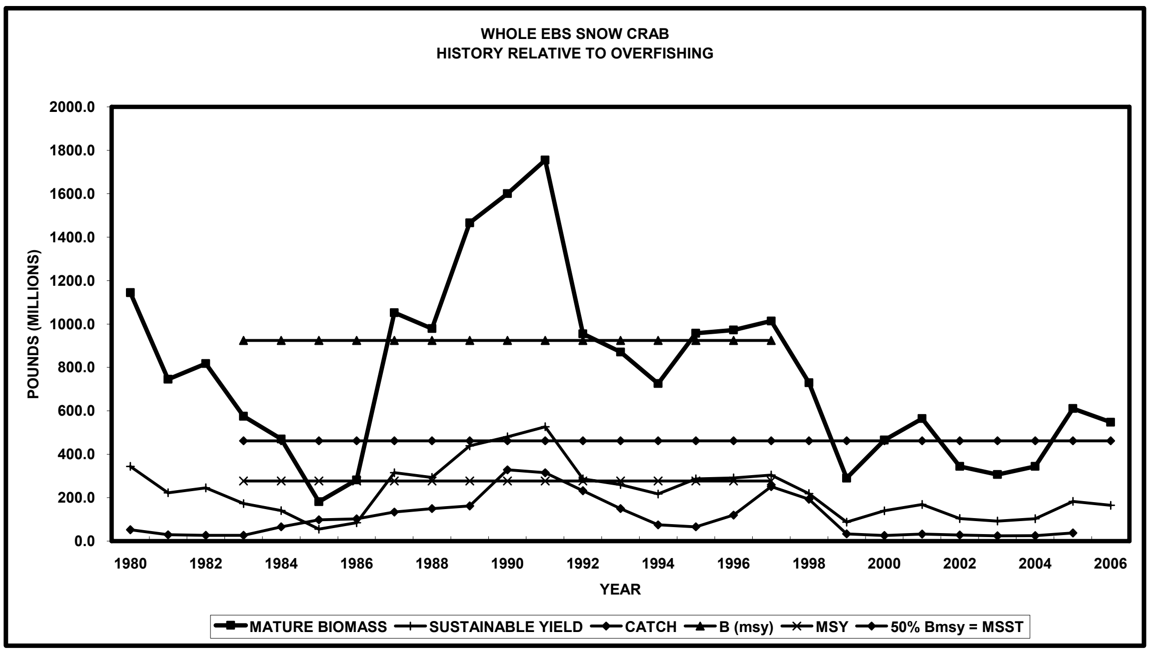

Figure 7-1 Snow crab stock status relative to overfishing.

The abundance estimate for males ≥4-inches CW in 2006 (143.89 million crabs) is by far the highest value since 1998 and twice the estimate for 2005 (72.1 million crabs). However, this area-swept estimate of abundance of males ≥4 inches in 2006 is associated with poor precision (±76.4% of the point estimate) and the doubling of abundance from 2005 is unexpected from the 2005 survey data; the 2006 snow crab model estimate for this value in 2006 is 80.9 million crabs. The Crab Plan Team supported this biomass estimate over the area-swept abundance estimate from the survey due to the poor precision in the survey estimate. The abundance estimate for males 78-101 (288.38 million crabs) is essentially the same as for 2005 (284.1 million crabs) and compares to annual estimates during 1999-2004 ranging from 106.2 million crabs (for 2004) to 287.7 million crabs (for 2001). Estimated abundance of males <78-mm CW (1,106.91 million crabs) is lower than the 2005 estimate (1,911.2 million crabs); the 2006 estimate is greater than each of the annual estimates for 1997-2000, but is lower than 4 out of the 5 annual estimates for 2001-2005. The abundance estimate for females ≥50-mm CW in 2006 (1,045.53 million crabs) is

64% of the 2005 estimate and the abundance estimate for females <50-mm CW (669.77 million crabs) is 48% of the 2005 estimate. Since the 1999 survey, estimated abundance of females ≥50-mm CW has ranged from 510.5 million crabs (for 2002) to 1,630.8 million crabs (for 2005), whereas estimated abundance of females <50-mm CW has ranged from 180.5 million crabs (for 2002) to 1,869.2 million crabs (for 2004). Estimated mature female biomass in 2006 (214.7 million pounds or 97,387 t) is lower than in 2005 (313.1 million pounds or 142,021 t). Estimated mature male biomass in 2006 (332.9 million pounds or 151,002 t) is up slightly from the 2005 estimate (297.6 million pounds or 134,990 t), but more than half of that estimate (180.98 million pounds or 82,092 t) is attributable to males ≥4-inch CW. So, regardless of the increase in estimated abundance of males ≥4-inch CW, the 2006 standard survey area-swept estimates provide no strong evidence that the stock currently or potentially rebuilding (NPFMC 2006).

7.1.2 Biological Reference Points

This section examines relevant and recent biological information necessary to understand the overfishing definitions.

Estimated biological parameters for snow crab utilized in this analysis are listed in Table 7-1 below.

Table 7-1 Parameters for Bering Sea snow crab simulations. Fishery selectivity curves are for the 50% discard mortality model.

Parameter	Male	Female
Size range (mm Carapace Width)	25-140	25-140
Natural Mortality	0.23	0.29
Trawl fishery bycatch discard mortality	0.8	0.8
Time lapsed from survey to fishery	0.625	0.625
Growth increment a,b (postmolt CW = a + b* premolt CW	a = 8.436, b = 1.128	a = 5.1, b = 1.07
Beta parameter for gamma growth distribution	0.75	0.75
Molting probability(terminal molt males and females)	Immature 100%, mature 0%	Immature 100%, mature 0%
Recruit distribution (parameters of the gamma distribution)	Alpha = 12.0, beta = 1.5	Alpha = 12.0, beta = 1.5
Directed fishery selectivity		
Retention curve* (slope, 50%)	Slope 50% New 0.261666 95.76024 Old 0.297873 94.84013	
Total(slope, 50%)	New 0.194253 101.6297 Old 0.149547 118.2826	
Weight –length a,b Wt = a * length ^b	a=0.00000023 b=3.12948	Immature females a=0.00000253 b=2.56472 Mature females a=0.000675 b=2.943352

7.1.3 Effects on Snow Crab

7.1.3.1 Comparison of status determination criteria

The Alternative 1 status determination criteria for snow crab establish a B_{MSY} value of 921.6 million pounds (418,035 t) with an MSST value of 460.8 million pounds (209,018 t). The 2006 TMB estimate is 547.6 million pounds (248,390 t), above the MSST for this stock but below the B_{MSY} value.

Under Alternative 2 and 3, B_{MSY} for snow crab is measured in mature male biomass only (see Section 2.2.3.1 for rationale). This long-term B_{MSY} estimate for the stock is 413.36 million pounds (187,500 t). An MSST value for this stock would be estimated as ½ B_{MSY}. The current mature male biomass estimate for 2006 is 210.98 million pounds (95,700 t). This is just above the revised (1/2 B_{MSY}) MSST value for this stock.

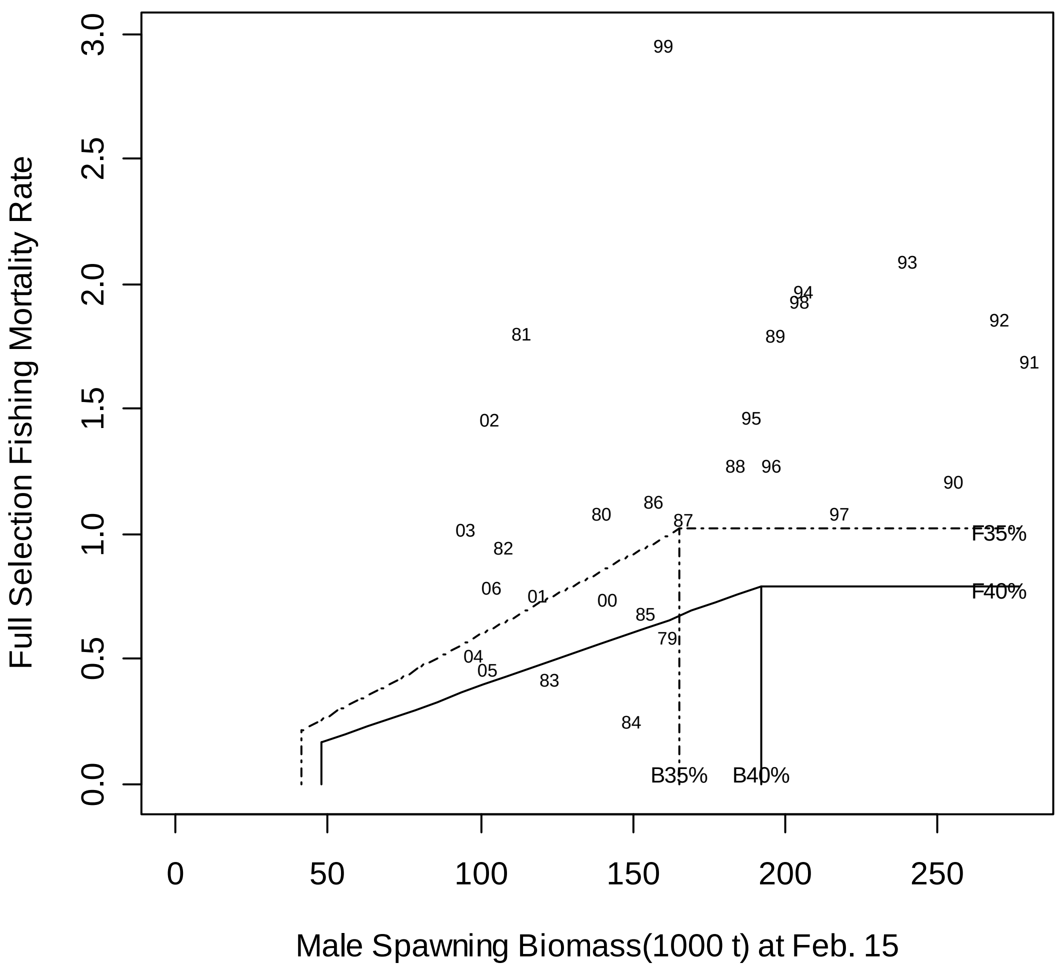

Figure 7-2 Full selection fishing mortality rate and male spawning biomass at February 15 estimated from the snow crab stock assessment model (Turnock and Rugolo 2006 Crab SAFE).

Annual determination of overfishing would occur by comparison of the estimated *F* from the previous year's fishery with the calculated F_{OFL} for the same time period. Overfishing is defined as any amount of fishing in excess of a prescribed maximum allowable rate as prescribed through the six tiers described in

Section 2.2.1. Figure 7-2 shows the historical harvest rates and mature male biomass in conjunction with proposed F35 and F40 control rules under Alternatives 2 and 3. The recommended control rule for the snow crab stock is F_{35} (see Section 3.5.3 for additional information and simulation studies). Under Alternatives 2 and 3, with a recommended control rule of F_{35}, fishing rates in the years 1980-1982, 1986-1999, 2001-2003 and 2006 would have constituted overfishing for this stock. If F_{40} were the recommended OFL control rule, overfishing would have also been occurring in 1985, 2000, and 2004-2005. Under Alternatives 2 and 3, harvest rates would have been constrained in those years. Legal harvest rates must be below the recommended F_{OFL}, thus annual determinations would be made to ensure that the TAC is set at a level whereby the legal harvest rate would be below the F_{OFL} for each stock.

While the survey TMB under Alternative 1 estimates the stock above its MSST and hence no longer in an overfished condition, this stock remains under a rebuilding plan until the stock is above B_{MSY} for two years in a row. Given that Alternatives 2 and 3 estimate new biological parameters for this stock if either of these alternatives are adopted, the rebuilding plan may need to be re-evaluated and potentially revised to reflect new information on the stock, including new estimates of stock recovery in relation to new estimates of B_{MSY}.

The impact of fishing at the current status quo OFL and the status quo snow crab harvest strategy were simulated in conjunction with proposed control rules under the new tier system in Alternative 2 and 3. The harvest control rules applied to the simulated population follow the control rules in the proposed tier system as well as fishing at the current status quo OFL and the status quo harvest strategy. Table 7-2 through Table 7-11 provide the results of performance statistics for short-term (6 years and 30 years) and long-term (100 years) fishery simulations. Different harvest strategy scenarios were investigated to predict the changes in stock abundance levels under various harvest rates. The Alternative 2 and 3 scenarios include: Tier 2 with the F_{MSY}, Tier 2 at 75% F_{MSY}, Tier 3 with F_{35}, Tier 3 at 75% F_{35}, Tier 3 at 75% F_{40}, Tier 4 with 1.5*M, Tier 4 at M, and Tier 5 with mean constant catch. The scenario that best represents the potential OFL for snow crab under Alternatives 2 and 3 is Tier 3 with F_{35}. The Alternative 1 scenarios include the State harvest strategy and fishing at the status quo OFL, with the State harvest strategy representing status quo. For analytical purposes, additional scenarios considered include a default harvest strategy of a flat F_{MSY} (i.e., no sliding fishing mortality for any level of B), $F = 0$, and F_{MSY} control rule with the status quo harvest strategy.

Simulations for this analysis used a Beverton-Holt S-R curve with steepness h = 0.68, and R_0 = 2.0 billion recruits (male+female) for snow crab.

Projections based on alternative harvest strategies applied the proposed Tier 3 harvest control rule. Average recruitment was estimated from the most recent stock assessment model (Turnock et al. 2006). Following Clark (2000) a proxy for limit reference points (F_{OFL}) were derived from SPR analysis. Based on SPR analyses, $F_{35\%}$ is considered as a proxy for F_{MSY} and B_{MSY} proxy is equal to $B_{35\%}$. $F_{xx\%}$ is the fishing mortality rate at which the equilibrium spawning biomass per recruit is reduced to xx% of its value in the equivalent unfished stock. The time period used to estimate average recruitment will influence the B% values. The complete time period used in the snow crab stock assessment model from 1978 to 2006 was used to estimate an average recruitment.

Simulation results are presented for two model scenarios, 25% and 50% mortality on discarded crab from the directed pot fishery.

7.1.3.2 Alternative 1

Under Alternative 1, the snow crab stock was declared overfished in 1999 and has been under a rebuilding plan since this time period. In conjunction with this rebuilding plan, the harvest strategy for snow crab was modified in 2000 to allow for greater probability of rebuilding the depleted stock.

Under Alternative 1, the current F_{MSY} is 0.3 for snow crab. The OFL is the expected retained catch (SY) derived by multiplying F_{MSY} by the total survey mature biomass in the current year.

For snow crab the calculation is,

OFL = SY = 0.3 * total survey mature biomass (males plus females),

where SY is the retained catch (total catch less discards).

The status quo harvest strategy uses fixed values of biomass reference points and harvest rates that will affect their performance depending on the estimated or true values of F_{MSY} and B_{MSY} or their proxy values. Under the status quo harvest strategy, the exploitation rate (*E*) is a function of Total Mature Biomass (TMB, males plus females).

When TMB ≥ $B_{MSY,}$ *E* = (F_{MSY} * 0.75) = 0.225. When TMB < 0.25*B_{MSY} *E* = 0.

When the TMB is ≥ B_{MSY} and TMB < 0.25*B_{MSY}:

$$E = \frac{0.75 * Fmsy * \left[\frac{TMB}{Bmsy} - \alpha \right]}{(1-\alpha)}$$

where B_{MSY} is average survey total mature biomass from 1983 to 1997 (418,900 tons), α = -0.35, and F_{MSY}=0.3.

The maximum retained catch is determined by using the *E* determined from the control rule as an exploitation rate on mature male biomass (MMB) at the time of the survey,

- Retained Catch = *E*•MMB.

In addition to the control rule described above, there is a 58% maximum harvest rate on exploited legal male abundance. Exploited legal male abundance is defined as the estimated abundance of all new shell legal males >=4.0-in (102 mm) CW plus a percentage of the estimated abundance of old shell legal males >=4.0-in CW. The percentage to be used is determined using fishery selectivities for old shell males.

7.1.3.3 Sensitivity analysis of α and β

Various combinations of the alpha (0, 0.05, 0.1, 0.25) and beta (0, 0.25) parameters of the control rule were used to evaluate short-term performance and rebuilding (Table 7-2 and Table 7-3). The F_{MSY} control rule was used for all simulation runs. The rebuilding time starting at 10% B_{MSY} was 26 years for alpha = 0.1 and beta = 0.25. Lower alpha values resulted in an increase of 1 year on the rebuilding time. With beta = 0.25, the fishery was closed about 8%–10% of the time in the first 30-year period, however, mean yields were similar between scenarios. If alpha is 0.25 (beta = 0.25, however, not needed), rebuilding time was 25 years, fishery closures were lower than other scenarios with beta= 0.25 (6%), however, mean yields were lower in the first 10 years than for all other scenarios.

There was very little difference in rebuilding times or other measures of performance between alpha and beta values considered when rebuilding from 50% B_{MSY} (Table 7-2). The scenario with alpha = 0.25 resulted in 1 year less rebuilding time, and a slightly smaller mean yield in the first 10 years than the other scenarios.

The F_{MSY} control rule (alpha = 0.1 and beta = 0.25), resulted in shorter rebuilding time (14 yr) relative to a constant F_{MSY} strategy (17 yr) when starting from 50% B_{MSY} (Table 7-4). Mean yield in the first 10 years of rebuilding was about 10% less with the sloping control rule; however, over the 30-year period mean yields were equal for the control rule and the constant F_{MSY} strategy, due to faster rebuilding with the sloping control rule. The rebuilding time for the status quo harvest strategy was 13 years, while 75% F_{MSY} CR and $F_{40\%}$ CR rebuilding times were 11 years.

7.1.3.4 Mortality 25% on directed pot fishery discards

Short-term (30 years) and long-term (100 years) simulations were conducted using a model with 25% discard mortality from the directed pot fishery (Tables 4-11 and 4-12). Long-term (100 years) simulation results estimated F_{MSY} at 1.0 and B_{MSY} (male mature biomass at mating time) at 391.98 million pounds (177,800 t) (Table 7-5) using a Beverton and Holt S-R curve with steepness 0.68 and R0 = 2.0 billion recruits. $F_{35\%}$ was estimated at 1.03, and $F_{40\%}$ = 0.78. $B_{35\%}$ (336.64 million pounds or 152,700 t) and $B_{40\%}$ (384.70 million pounds or 174,500 tons) were estimated using ½ mean estimated recruitment from the stock assessment model (0.63 billion) and male mature biomass at mating time per recruit fishing at $F_{35\%}$ (0.61 pounds or 0.000242 t) or $F_{40\%}$ (0.53 pounds or 0.000277 t). The long-term average retained catch for the F_{MSY} control rule was 119.34 million pounds (54,130 t), a little higher than the MSY (fishing at constant F_{MSY}) of 116.38 million pounds (52,790 t).

Under Alternative 1, fishing at the current OFL control rule results in mean mature male biomass at 26% of B_{MSY}, and mean retained catch of 64.86 million pounds (29,420 t) (56% of MSY). The status quo harvest strategy is between the F_{MSY} control rule and the 75% F_{MSY} control rule. The $F_{35\%}$ control rule results in lower mature male biomass, although similar mean yields, due to $B_{35\%}$ being lower than B_{MSY} in the control rule. A scenario was also run with the F_{MSY} control rule together with the status quo harvest strategy. The F in each year of the simulation was estimated for both strategies and the lower F applied. In some years the status quo harvest strategy was constrained by the F_{MSY} control rule, however, mean yield was very similar to the status quo harvest strategy alone, while the mean F was lower, and mature male biomass about 10% higher.

Constant catch (Tier 5) can drive the stock to low levels if catch is greater than about 60% of MSY and there is no reliable estimate of relative stock size to gauge when to decrease catches. If a reliable index of stock size is available so that catch can be decreased as relative stock size goes down then a higher fraction of MSY could be used as constant catch. Simulations were run at a constant 50% MSY, which resulted in mean male biomass 2.6 times B_{MSY}, however higher percent of the time below 50% B_{MSY} (5.2%) than the F_{MSY} control rule (2.5%). The percentage of time below 50% B_{MSY} increases rapidly as constant catch increases above about 60% B_{MSY} (simulations results not shown).

7.1.3.5 Mortality 50% on directed pot fishery discards

Short-term (30 years) and long-term (100 years) simulations were conducted using a model with 50% discard mortality from the directed pot fishery.

Rebuilding times ranged from 3 years (directed F=0) to 15 years ($F_{35\%}$ and the status quo harvest strategy CR), except for fishing at the current OFL, which did not rebuild the stock (Table 7-7). Fishing mortality values were lower for the 50% discard model compared to the 25% discard model and biomass was higher, however, average yields were only slightly lower. The F_{MSY} control rule (alpha=0.1 and beta=0.25), resulted in shorter rebuilding time (13 years) relative to a constant F_{MSY} strategy (16 years). The status quo harvest strategy CR was similar to the $F_{35\%}$ CR in rebuilding times and short-term yields.

Long-term (100 years) simulation results estimated F_{MSY} at 0.86 and B_{MSY} (male mature biomass at mating time) at 413.36 million pounds (187,500 t) (Table 7-9) using a Beverton and Holt S-R curve with steepness 0.68 and R0 = 2.0 billion recruits. $F_{35\%}$ was estimated at 0.93, and $F_{40\%}$= 0.72. $B_{35\%}$ (354.72 million pounds or 160,900 t) and $B_{40\%}$ (405.21 million pounds or 183,800 t) were estimated using ½ mean estimated recruitment from the stock assessment model (0.656 billion) and male mature biomass per recruit at mating time, fishing at $F_{35\%}$ (0.61 pounds or 0.000245 t) or $F_{40\%}$ (0.62 pounds or 0.00028 t). The long-term average retained catch for the F_{MSY} control rule was 114.07 million pounds (51,740 t), a little higher than the MSY (fishing at constant F_{MSY}) of 111.33 million pounds (50,500 t). Long-term average results were similar for the $F_{35\%}$ CR and the status quo harvest strategy CR, with F and retained catch slightly lower and biomass slightly higher for the status quo harvest strategy CR. When the F_{MSY} and status quo harvest strategy CR were simulated together (whichever F was lower was applied to the stock), the results were similar to the F_{MSY} CR, with slightly lower F and retained yields. Figure 7-3 shows one simulation run of 200 years, each run will have a different trajectory of recruitment, biomass, F and catch values. Values would be different when each CR is applied separately. The F_{MSY} CR constrained the catch from the status quo harvest strategy CR when stock biomass declined to lower levels. The status quo harvest strategy CR estimated F sometimes higher and sometimes lower than the F_{MSY} CR at higher stock size. The maximum F from the status quo harvest strategy CR is a little higher than F_{MSY}.

Catch and mature male biomass at time of mating for winter/spring 2007 to 2012 were projected using the simulation model and starting at the current abundance and biomass from the 2006 stock assessment model using 50% discard mortality (Table 7-9). The 2007 fishery catch was fixed for all scenarios at 37.04 million pounds (16,800 t). Fishing at the current OFL catch is almost 3 times the F35% catch in 2008 and 50% higher in 2009. These initial high catches resulted in declining biomass to about 31% of B_{MSY} (127.87 million pounds or 58,000 t) in 2010. Due to low biomass, catches were lower in 2010 to 2012; however, the biomass stays at about 31% B_{MSY}. The mean mature male biomass for 100 year simulations using the current OFL rule was 16% of B_{MSY} (Table 7-9). Catch using the status quo harvest strategy CR is similar to the $F_{35\%}$ CR in 2008 and 2010 and lower in 2009. The 2011 and 2012 catch is projected to be slightly higher than $F_{35\%}$ CR. 95% probability intervals on catch are included in Table 7-9 to show uncertainty in future catches incorporating process and sampling errors. $F_{40\%}$ CR projects catch about 25% lower in 2008, 3.5% higher in 2009 and about 10% lower in 2010 and 2011. However, the $F_{40\%}$ CR results in higher biomass values which would result in faster rebuilding times.

Table 7-2 Snow crab simulation for 25% discard mortality model starting at 50% B_{MSY}, using the F_{MSY} control rule for 30 year time period. Mean and medians are estimated from 1000 simulations of a 30-year fishery

	Alpha,beta			F_{MSY} Control Rule			
Harvest Control Rule Parameters: α, β	**0.0, 0.25**	**0.05, 0.25**	**0.1, 0.25**	**0.0, 0.0**	**0.05, 0.0**	**0.1, 0.0**	**.25,.25**
Median rebuilding time (yr) from 1000 simulations of a 30-year fishery	14.00	14.00	14.00	14.00	14.00	14.00	13.00
Mean Overfished % (mature male B < 100% mature male B_{MSY})	70.33	70.05	69.76	70.33	70.05	69.76	68.63
Mean Overfished % (mature male B < 50% mature male B_{MSY})	3.29	2.98	2.58	3.29	2.98	2.58	1.53

Mean Fishery Closure %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean 30th Year mature male B/mature male B_{MSY} ratio	1.07	1.08	1.08	1.07	1.08	1.08	1.10
Mean First 10-yr Mean Yield (t)	34.57	34.43	34.27	34.57	34.43	34.27	33.70
CV First 10-yr Mean Yield (t)	0.57	0.57	0.58	0.57	0.57	0.58	0.61
Mean Next 20-yr Mean Yield (t)	50.30	50.35	50.41	50.30	50.35	50.41	50.61
CV Next 20-yr Mean Yield (t)	0.74	0.74	0.74	0.74	0.74	0.74	0.75

Table 7-3 Snow crab simulation for 25% discard mortality model starting at 10% B_{MSY}, using the F_{MSY} control rule for a 30-year period. Mean and medians are estimated from 1000 simulations of a 30-year fishery

	Alpha,beta			F_{MSY} control rule			
Harvest Control Rule Parameters: α, β	**0.0, 0.25**	**0.05, 0.25**	**0.1, 0.25**	**0.0, 0.0**	**0.05, 0.0**	**0.1, 0.0**	**.25,.25**
Median rebuilding time (yr) from 1000 simulations of a 30-year fishery	27.00	27.00	26.00	28.00	27.00	27.00	25.00
Mean Overfished % (mature male B < 100% mature male B_{MSY})	87.89	87.51	87.12	88.28	87.79	87.30	85.36
Mean Overfished % (mature male B < 50% mature male B_{MSY})	47.96	46.74	45.45	48.80	47.43	45.84	40.70
Mean Fishery Closure % (mature male B < beta* mature male B_{MSY} or alhpa * mature male B_{MSY})	9.95	9.24	8.50	0.00	0.00	0.03	6.32
Mean 30th Year mature male B/mature male B_{MSY} ratio	0.96	0.97	0.98	0.95	0.96	0.98	1.01
Mean First 10-yr Mean Yield (t)	5.75	5.52	5.25	6.12	5.80	5.43	4.01
CV First 10-yr Mean Yield (t)	0.96	0.98	1.01	0.80	0.85	0.92	1.32
Mean Next 20-yr Mean Yield (t)	34.89	35.13	35.42	34.26	34.67	35.12	36.70
CV Next 20-yr Mean Yield (t)	0.85	0.85	0.86	0.86	0.86	0.86	0.87

Table 7-4 25% discard mortality. Short-term rebuilding simulations, starting from an initial mature male biomass = 50% mature male B_{MSY}. Mean and median are estimated from 1000 simulations of a 30-year fishery

Harvest Control Rule	Tier 2 limit (F_{MSY} in CR)	Tier 2 target (75% F_{MSY} in CR)	Tier 3 limit (F35% in CR)	Tier 3 target (75% F for F35% in CR)	Tier 3 limit (F40% in CR)	Tier 4 limit (F=1.5*M in CR)	Tier 4 target (1.0*M in CR)	Tier 5 target (50% MSY constant Catch)	Status quo Harvest CR	Status quo OFL CR	Flat F_{MSY}	F=0
Mean Recruit No. in 30-yr fishery (billions)	1.41	1.46	1.38	1.44	1.45	1.57	1.64	1.48	1.41	0.96	1.33	1.75
Mean Total Yield in 30-yr fishery (t)	52.00	49.98	52.34	50.04	50.00	39.22	30.79	30.98	50.43	48.38	52.06	0.62
Mean Retained Yield in 30-yr fishery (t)	44.65	42.78	44.98	42.88	42.83	33.31	26.01	26.19	43.27	40.72	44.77	0.00
Mean Mature Male Biomass in 30-yr fishery (t)	168.09	192.44	159.79	183.34	186.91	263.89	313.67	266.44	175.11	64.36	148.00	461.76
Mean Mature Female Biomass in 30-yr fishery (t)	118.63	122.57	116.85	120.33	121.22	129.42	133.40	121.96	118.63	89.47	113.33	140.45
Mean F	0.79	0.64	0.86	0.68	0.66	0.34	0.20	0.69	0.74	4.98	1.00	0.00
Median Rebuilding Time in 30-yr fishery (y)	14.00	11.00	15.00	12.00	11.00	6.00	4.00	9.00	13.00	NA	17.00	3.00
Mean %times B<B_{MSY} in 30-yr fishery	69.82	58.78	73.68	62.74	60.84	34.05	17.18	47.50	65.30	99.04	76.16	7.28
Mean Overfished in 30-yr fishery% (B<50% B_{MSY})	2.63	1.12	4.63	2.06	1.38	0.42	0.00	10.62	4.24	85.28	13.38	0.00
Mean Fishery Closure in 30-yr fishery% (B<25% B_{MSY})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	100.00
Mean 30th Year mature male B/mature male B_{MSY} Ratio	1.08	1.27	1.03	1.22	1.24	1.90	2.31	2.20	1.17	0.32	0.96	3.72
Mean First 10-yr Mean Yield (t)	33.35	31.19	34.77	31.69	30.92	22.83	15.04	26.56	33.12	45.17	36.91	0.00
CV First 10-yr Mean Yield (t)	0.63	0.57	0.59	0.58	0.62	0.48	0.68	0.07	0.56	0.50	0.50	NaN
Mean Next 20-yr Mean Yield (t)	50.30	48.58	50.08	48.47	48.78	38.55	31.50	26.01	48.35	38.49	48.70	0.00
CV Next 20-yr Mean Yield (t)	0.74	0.71	0.73	0.71	0.72	0.64	0.64	0.10	0.72	0.79	0.71	NaN

Table 7-5 25% discard mortality. Long-term simulations, starting from an initial mature male biomass = 100% mature male B_{MSY}. Mean and median are estimated from 1000 simulations of a 100-yr fishery

Harvest Control Rule	Tier 2 limit (F_{MSY} in CR)	Tier 2 target (75% F_{MSY} in CR)	Tier 3 limit (F35% in CR)	Tier 3 target (75% F for F35% in CR)	Tier 3 limit (F40% in CR)	Tier 4 limit (F=1.5*M in CR)	Tier 4 target (1.0*M in CR)	Tier 5 target (50% MSY consta nt catch)	Status quo Harves t CR	Status quo OFL CR	Flat F_{MSY}	F=0	F_{MSY} CR with Status quo harvest CR
Mean Recruit No. in 100-yr fishery (billions)	1.52	1.59	1.49	1.57	1.58	1.77	1.85	1.80	1.55	0.71	1.44	2.00	1.57
Mean Total Yield in 100-yr fishery (t)	63.19	62.10	62.89	62.16	62.35	51.90	43.45	31.48	62.21	34.90	61.59	0.92	62.11
Mean Retained Yield in 100-yr fishery (t)	54.13	52.98	53.90	53.06	53.22	43.80	36.51	26.16	53.18	29.42	52.79	0.00	53.04
Mean Mature Male Biomass in 100-yr fishery (t)	196.27	231.88	187.10	223.45	225.54	353.00	422.39	467.29	215.62	46.59	177.76	696.42	223.40
Mean Mature Female Biomass in 100-yr fishery (t)	139.93	147.11	137.25	145.08	145.88	164.00	170.57	166.53	143.24	65.59	133.02	186.21	145.01
Mean F	0.86	0.68	0.92	0.73	0.71	0.35	0.23	0.39	0.76	4.98	1.00	0.00	0.73
Median Rebuilding Time in 30-yr fishery (y)	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean %times B<Bmsy in 100-yr fishery	52.78	37.56	57.66	41.58	40.14	10.50	4.25	13.65	43.89	99.46	60.25	0.06	41.46
Mean Overfished in 100-yr fishery% (B<50% B_{MSY})	2.46	0.97	4.29	1.74	1.18	0.23	0.04	5.22	3.43	91.44	12.52	0.00	1.93
Mean Fishery Closure in 100-yr fishery% (B<25% B_{MSY})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	100.00	0.06
Mean 100th Year mature male B/mature male B_{MSY} Ratio	1.10	1.30	1.05	1.26	1.27	1.98	2.38	2.63	1.21	0.26	1.00	3.92	1.26

Table 7-6 50% discard mortality. Short-term rebuilding simulations, starting from an initial mature male biomass = 50% mat. Male B_{MSY}. Mean and median are estimated from 1000 simulations of a 30-year fishery

Harvest Control Rule	Tier 2 limit (F_{MSY} in CR)	Tier 2 target (75% F_{MSY} in CR)	Tier 3 limit (F35% in CR)	Tier 3 target (75% F for F35% in CR)	Tier 3 limit (F40% in CR)	Tier 4 limit (F=1.5*M in CR)	Tier 4 target (1.0*M in CR)	Tier 5 target (1/2 MSY Catch)	Status quo Harvest CR	Status quo OFL CR	Flat F_{MSY}	F=0	F_{MSY} CR with Status quo harvest CR
Mean Recruit No. in 30-yr fishery (millions)	1.43	1.48	1.40	1.45	1.46	1.51	1.63	1.51	1.40	0.89	1.36	1.76	1.45
Mean Total Yield in 30-yr fishery (t)	52.77	49.84	53.60	51.02	51.14	38.55	33.14	30.99	52.59	47.59	53.16	0.65	51.32
Mean Retained Yield in 30-yr fishery (t)	43.18	40.83	43.82	41.78	41.89	31.61	27.12	25.08	43.03	35.46	43.44	0.00	42.03
Mean Mature Male Biomass in 30-yr fishery (t)	179.73	205.61	166.52	192.24	194.30	249.36	310.83	285.89	171.59	55.80	158.98	476.82	189.51
Mean Mature Female Biomass in 30-yr fishery (t)	121.67	124.97	119.23	122.85	123.54	123.51	133.98	125.93	119.35	86.61	116.67	142.69	122.49
Mean F	0.69	0.55	0.78	0.62	0.60	0.34	0.23	0.58	0.75	4.99	0.86	0.00	0.63
Median Rebuilding Time in 30-yr fishery (y)	13.00	10.00	15.00	12.00	12.00	8.00	4.00	9.00	15.00	NA	16.00	3.00	13.00
Mean %times B<B_{MSY} in 30-yr fishery	69.12	57.48	74.95	63.70	62.62	40.14	24.03	46.02	71.27	99.68	75.46	7.31	64.89
Mean Overfished in 30-yr fishery% (B<50% B_{MSY})	2.41	1.00	4.93	2.12	1.51	0.73	0.16	8.88	6.48	92.88	12.78	0.00	2.29
Mean Fishery Closure in 30-yr fishery% (B<25% B_{MSY})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	100.00	0.04
Mean 30th Year mature male B/mature male B_{MSY} Ratio	1.09	1.29	1.00	1.20	1.20	1.85	2.15	2.18	1.06	0.24	0.97	3.58	1.18
Mean First 10-yr Mean Yield (t)	32.81	29.68	34.74	31.65	31.09	20.66	17.90	25.40	34.56	43.10	36.17	0.00	32.00
CV First 10-yr Mean Yield (t)	0.58	0.58	0.55	0.54	0.57	0.48	0.48	0.06	0.52	0.50	0.47	NaN	0.54
Mean Next 20-yr Mean Yield (t)	48.37	46.41	48.35	46.85	47.29	37.09	31.73	24.92	47.27	31.64	47.08	0.00	47.04
CV Next 20-yr Mean Yield (t)	0.74	0.70	0.73	0.70	0.71	0.64	0.61	0.09	0.72	0.81	0.70	NaN	0.70

Table 7-7 50% discard mortality. Long-term simulations, starting from an initial mature male biomass = 100% mat. Male B_{MSY}. Mean and median are estimated from 1000 simulations of a 100-yr fishery

Harvest Control Rule	Tier 2 limit (F_{MSY} in CR)	Tier 2 target (75% F_{MSY} in CR)	Tier 3 limit (F35% in CR)	Tier 3 target (75% F for F35% in CR)	Tier 3 limit (F40% in CR)	Tier 4 limit (F=1.5*M in CR)	Tier 4 target (1.0*M in CR)	Tier 5 target (50% MSY Catch)	Status quo Harvest CR	Status quo OFL CR	Flat F_{MSY}
Mean Recruit No. in 100-yr fishery (millions)	1.54	1.62	1.49	1.58	1.58	1.76	1.84	1.78	1.52	0.5	1.46
Mean Total Yield in 100-yr fishery (t)	63.39	61.82	63.22	62.31	62.61	53.08	44.53	30.77	62.71	25	61.93
Mean Retained Yield in 100-yr fishery (t)	51.74	50.49	51.56	50.88	51.13	43.32	36.27	24.69	51.2	18.62	50.51
Mean Mature Male Biomass in 100-yr fishery (t)	207.53	246.95	191.36	230.49	230.06	347.83	421.09	468.9	204.54	29.28	187.48
Mean Mature Female Biomass in 100-yr fishery (t)	141.98	149.35	137.84	145.97	146.31	162.73	170.01	164.3	140.27	46.61	134.94
Mean F	0.74	0.59	0.82	0.65	0.65	0.34	0.23	0.46	0.76	4.99	0.86
Median Rebuilding Time in 30-yr fishery (y)	0	0	0	0	0	0	0	0	0	0	0
Mean %times $B<B_{MSY}$ in 100-yr fishery	52.65	36.74	60.55	43.62	43.15	11.24	5.7	15.95	53.32	99.92	60.35
Mean Overfished in 100-yr fishery% ($B<50\% B_{MSY}$)	2.35	0.9	4.9	1.94	1.41	0.26	0.07	7.4	5.87	98	12.61
Mean Fishery Closure in 100-yr fishery% ($B<25\% B_{MSY}$)	0	0	0	0	0	0	0	0	0.15	0	0
Mean 100th Year mature male B/mature male B_{MSY} Ratio	1.11	1.32	1.02	1.23	1.23	1.96	2.25	2.5	1.09	0.16	1

Table 7-8 Short-term rebuilding simulations, starting from an initial mature male biomass = 100% mature male B_{MSY}. Mean and median are estimated from 1000 simulations of a 30-year fishery

50% discard h=.68 BV Fem M=0.29

Harvest Control Rule	Tier 2 limit (F_{MSY} in CR)	Tier 2 target (75% F_{MSY} in CR)	Tier 3 limit (F35% in CR)	Tier 3 target (75% F for F35% in CR)	Tier 3 limit (F40% in CR)	Tier 4 limit (F=1.5*M in CR)	Tier 4 target (1.0*M in CR)	Tier 5 limit (75% MSY Catch)	Tier 5 target (1/2 MSY Catch)	Status quo Harvest CR	Status quo OFL CR	Flat F_{MSY}	F=0	F_{MSY} CR with Status quo harvest CR
Mean Recruit No. in 30-yr fishery (millions)	1.58	1.64	1.55	1.61	1.61	1.74	1.79	1.61	1.77	1.57	1.08	1.55	1.92	1.61
Mean Total Yield in 30-yr fishery (t)	63.31	59.66	64.42	61.11	61.28	48.16	38.97	47.45	32.65	63.25	61.20	64.17	0.75	61.50
Mean Retained Yield in 30-yr fishery (t)	51.68	48.77	52.52	49.93	50.08	39.39	31.83	38.05	26.40	51.64	45.69	52.33	0.00	50.25
Mean Mature Male Biomass in 30-yr fishery (t)	204.91	236.38	191.61	223.42	222.95	314.00	367.33	284.21	385.40	203.45	71.07	192.90	558.26	219.93
Mean Mature Female Biomass in 30-yr fishery (t)	140.37	144.03	138.32	142.40	142.51	150.77	154.29	142.64	152.40	139.86	108.28	138.18	162.20	141.98
Mean F	0.75	0.59	0.84	0.66	0.66	0.34	0.23	1.11	0.33	0.77	4.97	0.86	0.00	0.68
Median Rebuilding Time in 30-yr fishery (y)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean %times B<Bmsy in 30-yr fishery	55.13	33.32	64.30	42.70	43.78	11.22	5.13	35.19	11.88	57.69	99.11	62.91	0.12	47.97
Mean Overfished in 30-yr fishery% (B<50% Bmsy)	1.22	0.47	2.66	1.00	0.75	0.23	0.03	15.44	2.99	3.36	80.14	6.70	0.00	1.08
Mean Fishery Closure in 30-yr fishery% (B<25% Bmsy)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	100.00	0.01
Mean 30th Year mature male B/mature male Bmsy Ratio	1.11	1.32	1.03	1.23	1.23	1.84	2.22	1.64	2.45	1.10	0.27	1.02	3.68	1.21
Mean First 10-yr Mean Yield (t)	50.66	45.79	52.74	47.82	47.89	33.77	25.86	39.76	26.53	50.92	63.12	52.26	0.00	48.42
CV First 10-yr Mean Yield (t)	0.49	0.48	0.48	0.46	0.48	0.46	0.46	0.07	0.05	0.48	0.56	0.46	0.00	0.47
Mean Next 20-yr Mean Yield (t)	52.19	50.26	52.42	50.99	51.17	42.20	34.81	37.20	26.34	52.00	36.98	52.36	0.00	51.16
CV Next 20-yr Mean Yield (t)	0.72	0.69	0.72	0.69	0.70	0.62	0.60	0.19	0.05	0.71	0.80	0.69	0.00	0.69

Table 7-9 Six-year projections of catch (tons x 10-3) and mature male biomass at time of mating (after the fishery), starting from the 2006 Bering sea snow crab population numbers using fishing at the status quo OFL, F35%, F40%, and the status quo harvest strategy control rules. TAC in 2007 is fixed at 16,800 tons for all scenarios. 95% probability interval for retained catch in parentheses

Year of fishery	Status quo OFL retained catch	Status quo OFL MMB	F35% CR retained catch	F35% CR MMB	F40% CR retained catch	F40% CR MMB	Status quo harvest strategy CR retained catch	Status quo harvest strategy CR MMB
2007	16.8	95.7	16.8	95.7	16.8	95.7	16.8	95.7
2008	79.4 (71.8,86.1)	75.7	28.1 (16.9,41.6)	120.2	21.1 (12.2,32.7)	126.4	27.9 (17.9, 40.5)	120.3
2009	62.8 (53.6,71.5)	63.7	45.6 (31.0,60.6)	136.8	38.7 (25.2,53.6)	150.8	37.4 (22.8, 55.1)	144.4
2010	30.3 (25.1,36.2)	57.9	35.1 (24.3,47.5)	133.8	32.0 (21.4,44.5)	150.9	35.6 (22.6, 48.2)	141.9
2011	27.1 (21.1,37.7)	58.2	25.7 (16.2,37.0)	128.2	24.0 (14.8, 35.0)	144.8	26.7 (19.1, 34.2)	134.0
2012	38.6 (16.1,95.9)	59.7	31.0 (14.4, 65.8)	132.4	28.2 (13.2, 59.2)	149.2	32.4 (16.9, 67.6)	135.7

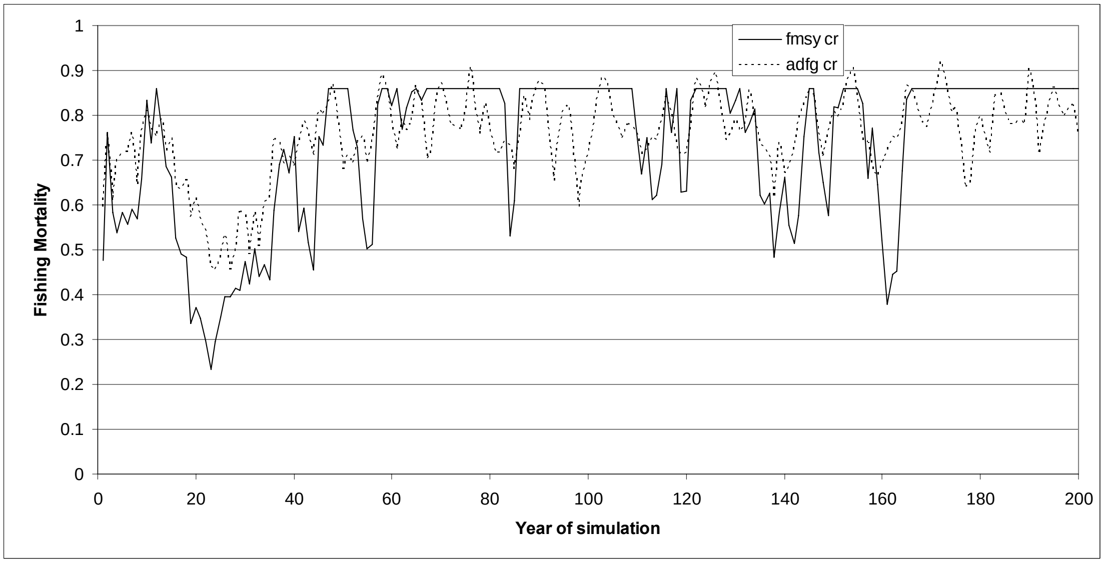

Figure 7-3 Comparison of fishing mortality estimated each year using the status quo harvest strategy CR and the F_{MSY} CR for one simulation run of 200 years, using the 50% discard mortality model

7.1.3.6 Handling mortality impacts

The F_{MSY} control rule was used to calculate long- and short-term values for yield, biomass and other measures under different handling mortality estimates. The value of F_{MSY} decreases from 1.0 using 25% discard mortality to 0.82 at 60% handling mortality, and B_{MSY} increases for 177.7 to 190.7, due to changes in fishery selectivity curves and average recruitment estimated from the stock assessment model. The long-term retained catch declines from 119.34 million pounds (54,130 t) with the 25% handling mortality scenario to 112.50 million pounds (51,030 t) using the 60% handling mortality scenario, a decline of about 5.7%. Average retained catches during the first 10 years with a starting biomass of 50% B_{MSY}, were 6.5% lower with 60% handling mortality than with 25% handling mortality. Average retained catches during the next 20 years (11^{th} to 30^{th} years) were similar to long-term averages, at 5.5% lower for 60% handling mortality than 25% handling mortality (Table 7-10 and Table 7-11).

Table 7-10 Long-term (100-yr) simulation comparing the F_{MSY} control rule with 25%, 40%, 50% and 60% handling mortality (hm) starting at B_{MSY}.

Harvest Control Rule	25% hm	40% hm	50% hm	60% hm
F_{MSY}, B_{MSY}	1.0, 177.7	0.91, 183.9	0.86, 187.5	0.82, 190.7
Mean Recruit No. in 100-yr fishery (millions)	1.52	1.53	1.54	1.54
Mean Total Yield in 100-yr fishery (t)	63.19	63.33	63.39	63.44
Mean Retained Yield in 100-yr fishery (t)	54.13	52.58	51.74	51.03
Mean Mature Male Biomass in 100-yr fishery (t)	196.27	203.42	207.53	211.21
Mean Mature Female Biomass in 100-yr fishery (t)	139.93	141.26	141.98	142.61
Mean F	0.86	0.78	0.74	0.70
Median Rebuilding Time in 100-yr fishery (y)	0	0	0	0
Mean %times B<B_{MSY} in 100-yr fishery	52.78	52.69	52.65	52.63
Mean Overfished in 100-yr fishery% (B<50% B_{MSY})	2.46	2.38	2.35	2.34
Mean Fishery Closure in 100-yr fishery% (B<25% B_{MSY})	0.00	0.00	0.00	0.00
Mean 100th Year mature male B/mature male B_{MSY} Ratio	1.10	1.11	1.11	1.11

Table 7-11 Short-term (30 years) simulation comparing the F_{MSY} control rule with 25%, 40%, 50% and 60% discard mortality starting at 50% B_{MSY}.

Harvest Control Rule	25% dm	40% dm	50% dm	60% dm
Mean Recruit No. in 30-yr fishery (millions)	1.41	1.42	1.43	1.44
Mean Total Yield in 30-yr fishery (t)	52.45	52.40	52.77	52.64
Mean Retained Yield in 30-yr fishery (t)	45.03	43.62	43.18	42.45
Mean Mature Male Biomass in 30-yr fishery (t)	169.09	175.24	179.73	182.67
Mean Mature Female Biomass in 30-yr fishery (t)	119.34	120.36	121.67	121.99
Mean F	0.80	0.72	0.69	0.65
Median Rebuilding Time in 30-yr fishery (y)	14.00	14.00	13.00	13.00
Mean %times B<B_{MSY} in 30-yr fishery	69.76	69.58	69.12	69.15
Mean Overfished in 30-yr fishery% (B<50% B_{MSY})	2.58	2.53	2.41	2.40
Mean Fishery Closure in 30-yr fishery% (B<25% B_{MSY})	0.00	0.00	0.00	0.00
Mean 30th Year mature male B/mature male B_{MSY} Ratio	1.08	1.09	1.09	1.09
Mean First 10-yr Mean Yield (t)	34.27	32.91	32.81	32.03
CV First 10-yr Mean Yield (t)	0.58	0.58	0.58	0.59
Mean Next 20-yr Mean Yield (t)	50.41	48.97	48.37	47.66
CV Next 20-yr Mean Yield (t)	0.74	0.74	0.74	0.73

Additional evaluations of snow crab were done to evaluate handling mortality. A size range of 25- to 135-mm CW for both sexes was considered in the simulations to include immature sizes of crabs as initial recruits to the cohort. A detailed analysis of the snow crab fishery was conducted by J. Turnock and L. Rugolo (In Press). Figure 7-4 shows S-R models fit to 1985-2005 data and determined $F_{x\%}$ for different handling mortality values (hm= 0.25, 0.4, 0.5, 0.6), using Clark's method for a steepness parameter range of 0.53–0.84. The steepness parameter values for the Ricker curve ranged 0.72–0.80. The $F_{x\%}$ value was F_{35} for all handling mortality levels. This resulted in an *F* range of 1.03–1.13 and a legal male harvest rate range of 30%–36%. Lower handling mortalities produced higher harvest rates (Figure 7-5).

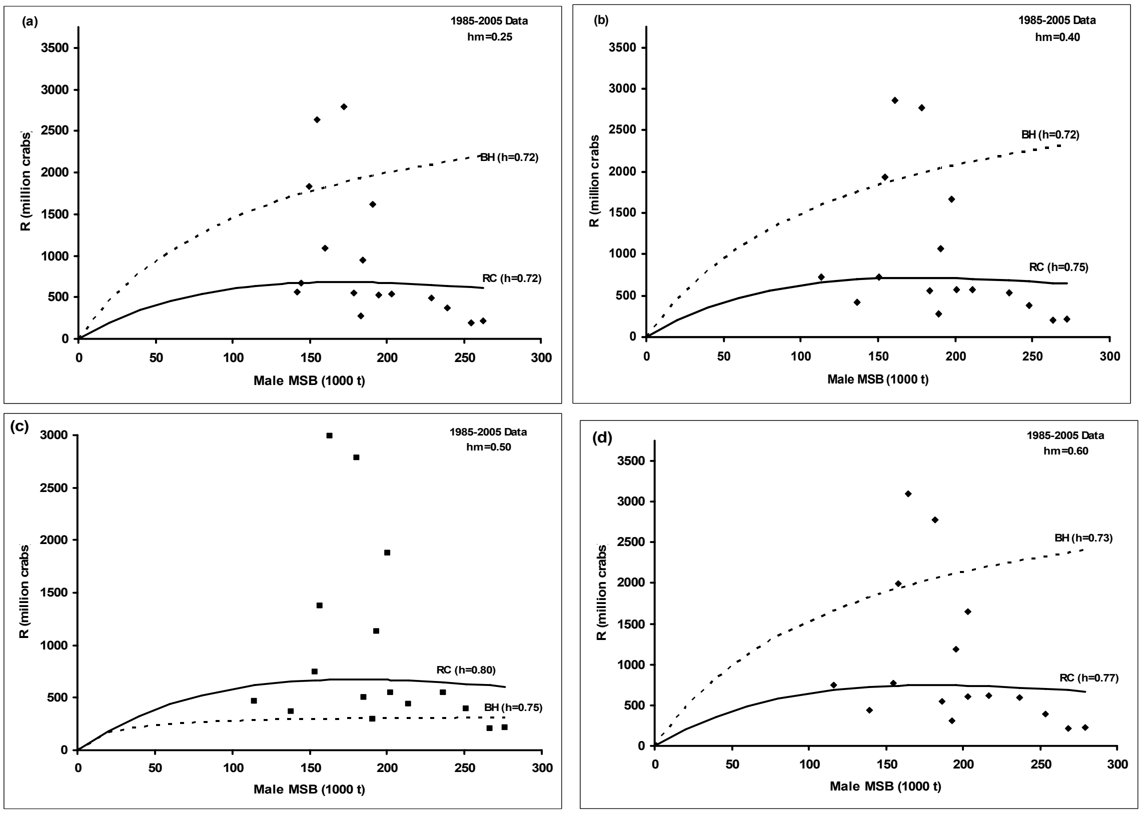

Figure 7-4 Stock-recruitment fit for the Bering Sea snow crab 1985-2005 data assessed at M = 0.23 and handling mortality, hm (a) 0.25, (b) 0.4, (c) 0.5, and (d) 0.6. The steepness parameters, h, are given in parentheses. BH = Beverton and Holt curve, RC = Ricker curve.

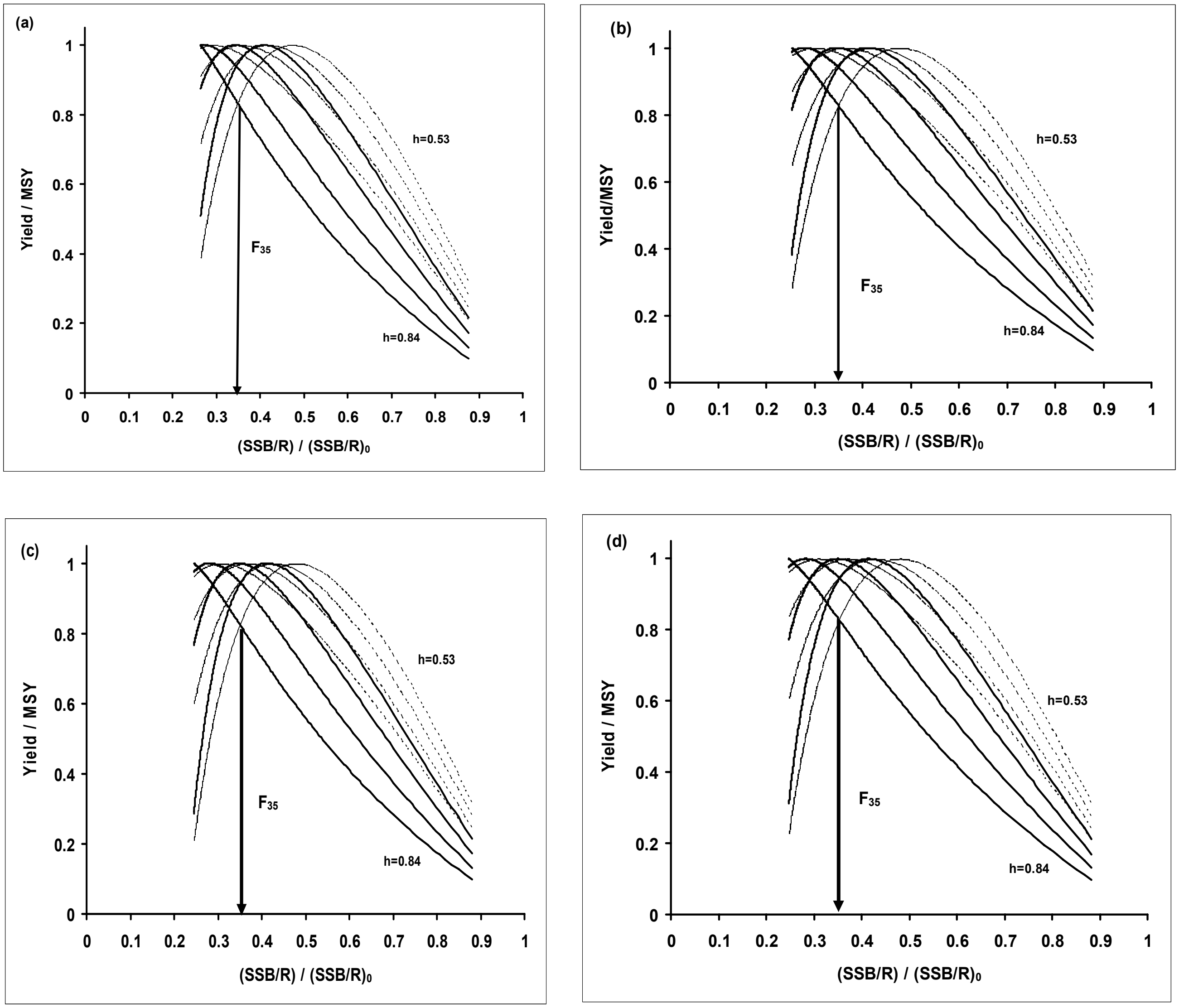

Figure 7-5 Approximate locations of spawning potential ratio ($F_{x\%}$) by equilibrium yield method for different handling mortality rates: (a) 0.25, (b) 0.4, (c) 0.5, and (d) 0.6 for snow crab. solid lines: Ricker S-R model, dotted lines: Beverton-Holt S-R model.

8 Tanner crab (*Chionoecetes bairdi*)

Three stocks of *C. bairdi* Tanner crab are managed under this FMP, the Bering Sea Tanner crab stock, the Eastern Aleutian Islands Tanner crab stock, and the Western Aleutian Islands Tanner crab stock. This section reviews the stock status and biological parameters relevant to overfishing definitions for these stocks and provides an overview of specific impacts on the stock from the three alternatives under consideration in this analysis.

8.1.1 Tanner crab stock status

Bering Sea Tanner crab

This stock is annually surveyed by NMFS. This stock was declared overfished in 1998 and a rebuilding plan was subsequently adopted in 1999. The survey abundance estimate of total mature biomass for this stock in 2006 is 253.3 million pounds (114,896 t), a significant increase above the 2005 estimate (162.0 million pounds or 73,483 t) and above the B_{MSY} for the first time since the overfished declaration of 1998 (Figure 8-1). Note that under the rebuilding plan established for this stock, this stock is considered rebuilt if total mature biomass is above the B_{MSY} level (189.6 million pounds or 86,002 t) for two years in a row. If the stock is estimated above B_{MSY} in 2007 the stock would be considered rebuilt. For the first time since the overfished declaration, estimated TMB in the last 2 years has shown consistent sharp annual increases comparable to that seen in the mid-1980s.

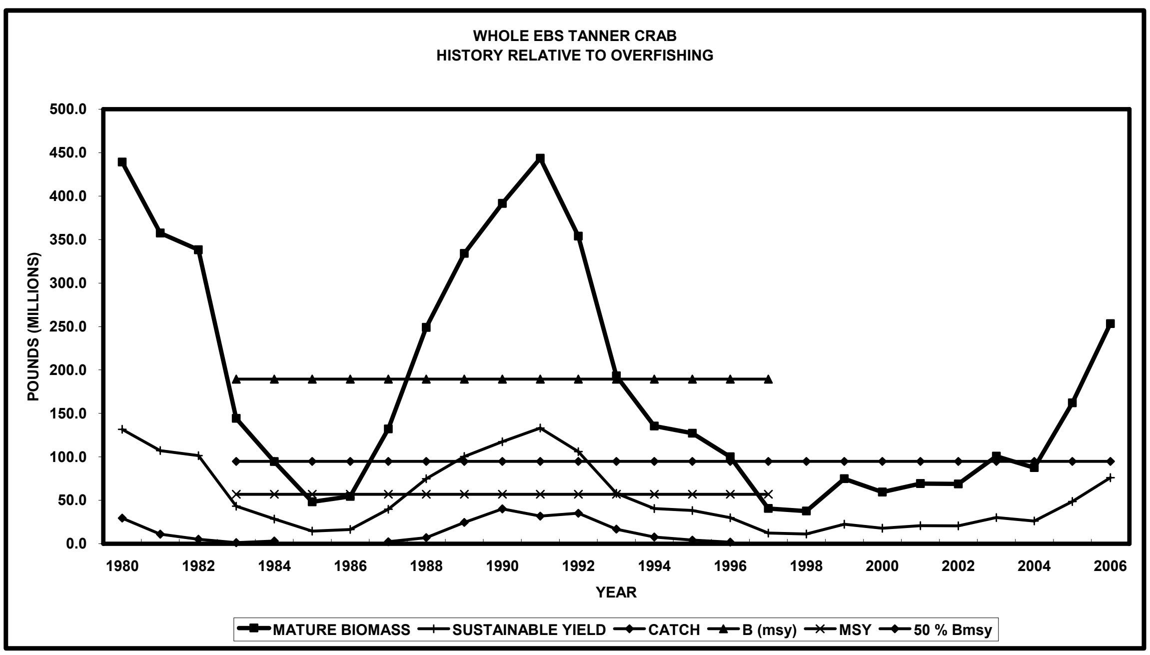

Figure 8-1 EBS Tanner crab stock status relative to overfishing

Recruitment trends are estimated by survey abundance of size categories. ADF&G's area-swept estimates for mature-sized female abundance in the Eastern Subdistrict increased by approximately 50% between 2005 and 2006; from 42.513 million crabs in 2005 to 65.500 million crabs in 2006. Prior to the results for 2005, abundance estimates of mature-sized females have shown only minor fluctuations about depressed levels in the overall Eastern Subdistrict. Given the size frequency distribution of females in 2005, the increase in mature female abundance and biomass in 2006 is not entirely unexpected, although the level of increase is higher than was expected from the 2005 data. There is a relatively large mode at roughly 75-mm CW in the size frequency distributions for both males and females in 2006. That may provide continued recruitment into the mature size classes in the near-term future. However, unlike the size frequency distributions for the previous four years, there is very poor representation of males or females <50-mm CW in 2006 and that is not promising for continued recruitment to mature size classes in the long-term future.

The area-swept abundance estimates for mature-sized males in the Eastern Subdistrict has shown an increasing trend since 1997, with a marked increase between 2004 and 2005. Separate TACs are established for the areas east and west of 166° W longitude. During a large majority of years, most of the mature-sized males in the Eastern Subdistrict occurred in the area east of 166° W longitude. Since 2004, however, a majority of the estimated mature-sized male abundance has occurred west of 166° W longitude; in 2006 two-thirds of the estimated abundance of mature-sized males was from the area west of 166° W longitude. Old-and-older-shelled crabs dominated the legal-sized males in the Eastern Subdistrict during the 2006 survey; approximately 80% of the legal males were in old- or older-shell condition. Although, the high incidence of old- or older-shelled crab among the legal males may be due to later than usual molting associated with the cold water temperatures recorded during the 2006 summer survey, it is more likely that the old shell crabs represent males that terminally molted to maturity a year earlier. Hence, in terms of growth, low future productivity would be expected from the legal males (as well as from sublegal, mature-sized males).

Eastern Aleutian Islands Tanner crab

This stock is not annually estimated by NMFS. ADF&G conducted pot surveys targeting king and Tanner crabs in the Eastern Aleutian District (EAD) during 1979, 1984, 1986 and 1987. A partial pot survey targeting Tanner crabs was conducted in 2003. Pot survey results provide general information on relative abundance and distribution of Tanner crabs in the district; however no estimates of abundance have been made with their results. Prior to 1990, the fishery was managed under a size-sex-season (3S) policy. In most years, the season was open until the regulatory closure date. The closure date was formerly June 15, and is currently March 31.

Beginning in 1990, triennial trawl survey results were used to evaluate the health of the stock and Tanner crab abundance estimates were made for the areas surveyed. Results of the 1990 and 1991 trawl surveys provided impetus for setting a GHL of 100,000 pounds (45 t) for the EAD; however it is apparent from season length and commercial harvests in the 1990 to 1994 seasons that the 3S management policy was still being applied.

Based on results of the 2005 EAD trawl survey, only the Makushin/Skan Bay portion of the EAD met ADF&G criteria for opening the commercial fishery. A GHL of 87,241 pounds (40 t) was set for Makushin/Skan Bays while the remainder of the district remained closed.

Data from the 2006 EAD trawl survey have yet to be analyzed and no stock status determination has been made at this time.

The EAD Tanner crab fishery began in 1973 and harvest peaked at 2.5 million pounds (1,134 t) in 1977. Harvest decreased to a low of 0.05 million pounds (23 t) in 1991 and increased to 0.17 million pounds (77 t) in 1994. The fishery was closed from 1995 to 2003. The 1985 to 1994 (10-year average) harvest is 0.18 million pounds (82 t).

Western Aleutian Islands Tanner crab

No stock assessment surveys are conducted for Tanner crab in the Western Aleutian District; thus no population estimates are available. Stock status is currently unknown. Historic fisheries were managed using GHLs set from commercial catch data (ADF&G 2005). Harvest of Tanner crab from the Western Aleutian District has, in general, been incidental to the directed red king crab fishery in that area. Commercial harvest has ranged from a high of over 800,000 pounds during the 1981/82 season to less than 8,000 pounds (4 t) in 1991/92 (ADF&G 2005). No commercial harvest of Tanner crab has occurred in the Western Aleutian District since 1995/96. Tanner crab abundance in the Western Aleutian District is probably limited by available habitat. Most of the historical harvest occurred within a few bays in the vicinity of Adak and Atka Islands (ADF&G 2005).

8.1.2 Biological Parameters

This section examines relevant and recent biological information necessary to understand the overfishing definitions.

8.1.2.1 Male Maturity Probabilities for Tanner Crab

In many majid (true) crabs, it has been hypothesized that the maturity molt is the last or terminal molt (Hartnoll 1963). Maturity is often assessed with morphometric data. For males, morphometrically mature crabs are distinguished from morphometrically immature crabs by an increase in chela height for a given CW (Somerton 1980; Conan and Comeau 1986). For females, a prominent increase in the width of the abdomen indicates sexual maturity (Somerton 1981). It is commonly accepted that female Tanner and snow crabs undergo a terminal molt at maturity.

The terminal molt assumption for male snow crab has been well accepted for Atlantic stocks (e.g., Conan and Comeau, 1986; Jamieson et al., 1988; Saint-Marie et al., 1995). Although evidence exists that some tagged mature male snow crab molted in Conception Bay, Newfoundland (Dawe et al., 1991), molting rates were probably very low and the terminal molt assumption was practically accepted (Earl Dawe, Department of Fisheries and Oceans, St. John’s, Newfoundland, Canada, pers. comm.).

For Tanner crab in Alaska, some studies support terminal molt for males (Tamone et al. 2005), and data from some other studies contradict it (Donaldson and Johnson 1988; Paul and Paul 1995). Because of Tamone’s study, we tend to accept terminal molt for male Tanner crab. However, we need to find a way to reconcile the survey data with the terminal molt assumption in stock assessments and harvest strategy evaluation.

Tanner crab chela height data have been collected during the eastern Bering Sea summer trawl survey since 1990. These data can be used to estimate male maturity probability. Table 8-1 shows proportions of immature males within newshell crab from 1990 to 1997 based on the chela height data. If maturity probability is equal to 1 minus proportion of immature males within newshell crab, then only a very small proportion of males can grow to legal size of 138 mm or larger. We will have difficulty to explain where the legal males come from during the 1970s, late 1980s and early 1990s for eastern Bering Sea Tanner crab. However, these maturity probabilities can be used to explain the survey data during the early and mid 1980s and after 1995.

The consequence for this approach is that a large amount of mature males are not available for fishing and that estimated F_{MSY} is extremely high. Considering these problems with terminal molt and the real data, the analyst used the chela height data from 1990 to 1993 (high proportions of immature males) and assumed all immature oldshell males as immature newshell males to estimate maturity probabilities for male Tanner crab for the work group study (Option 1). Estimated F_{MSY} from option 1 is still very high, and these probabilities may still be difficult to explain where legal males come from.

Alternatively, the analyst ignored the chela height data and assumed that the average of three levels of estimated molting probabilities for newshell males from 1975 to 1994 (Zheng et al. 1998) as maturity probabilities (Option 2) because molting probabilities for oldshell crab were estimated to be close to zero in the model. Molting probabilities during the 1970s and late 1980s were estimated to be higher than those during the other years (Zheng et al. 1998). Option 2 was used as a base scenario for simulation studies to estimate Fmsy. Options 1 and 2 are compared with estimated proportions of maturity by Dr. Otto of Kodiak Lab of Alaska Fisheries Science Center from data in the early 1990s, which are used for the current overfishing definitions, in Table 3-20. The estimated proportions of maturity by Dr. Otto includes crabs of all shell condition and should be higher than maturity probabilities for a given size. The fraction of new shell crab which are mature in the survey data should be an estimate of the probability of new shell crab maturing with the terminal molt. However the survey estimates are affected by errors in shell condition as a proxy for shell age and the reliability of chela height measurements to determine maturity.

Table 8-1 Proportions of immature males within newshell Tanner crab from 1990 to 1997

Width	90	91	92	93	94	95	96	97
95.5	0.84	0.85	0.68	0.47	0.16	0.54	0.76	0.67
100.5	0.81	0.88	0.77	0.82	0.31	0.40	0.65	0.74
105.5	0.63	0.75	0.69	0.64	0.89	0.37	0.29	0.78
110.5	0.55	0.83	0.52	0.80	0.38	0.23	0.37	0.50
115.5	0.50	0.75	0.67	0.76	0.08	0.11	0.34	0.39
120.5	0.33	0.56	0.39	0.69	0.18	0.17	0.00	0.14
125.5	0.31	0.52	0.35	0.70	0.18	0.00	0.00	0.00
130.5	0.30	0.34	0.17	0.44	0.03	0.00	0.00	0.00
135.5	0.41	0.15	0.59	0.34	0.23	0.00	0.00	0.00
140.5	0.13	0.04	0.25	0.00	0.00	0.00	0.00	0.00
145.5	0.10	0.02	0.00	0.09	0.00	0.00	0.00	0.00
150.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
155.5	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
160.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
165.5	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00

If male terminal molt at maturity assumption is correct, then one has to question the chela height and shell condition data. Indeed, crab were not randomly sampled for chela height measurement. Old-shell crabs tend to be sampled more than new-shell crab. However, separating new-shell and old-shell crab, as shown in Table 8-1, can overcome this sampling bias. Shell conditions can be a problem. If a high proportion of old-shell crab were misclassified as new-shell, the estimated maturity probability could be higher than the true values because higher proportions of old-shell crab than those of new-shell crab are mature. However, unlike snow crab, old-shell Tanner crab were abundant in the survey data (Table 8-3). Indeed, in some years there were hardly any new-shell male crab >110 mm. So it is difficult to completely blame shell aging errors for this problem.

The current Tanner crab stock assessment model for Bristol Bay Tanner crab does not separate immature and mature males (Zheng et al. 1998). Based on the survey data, the molting probability declines sharply in the model after males become old-shell (about 0 to 10%). In the future development of spatial model for eastern Bering Sea Tanner crab, maturity probabilities for male crab will be closely examined.

Table 8-2 Estimated maturity probabilities (options 1 and 2) and estimate proportions of mature males at size (Otto) for eastern Bering Sea Tanner crab

Width	Option 1	Option 2	Otto
95.5	0.12	0.06	0.527
100.5	0.17	0.08	0.588
105.5	0.23	0.12	0.647
110.5	0.30	0.17	0.701
115.5	0.39	0.24	0.750
120.5	0.49	0.31	0.794
125.5	0.59	0.40	0.832
130.5	0.68	0.49	0.863
135.5	0.76	0.59	0.890
140.5	0.82	0.67	0.912
145.5	0.87	0.75	0.930
150.5	0.91	0.82	0.945
155.5	0.94	0.87	0.956
160.5	0.96	0.91	0.966
165.5	0.97	0.94	0.973

Table 8-3 Proportions of old-shell male crab for eastern Bering Sea Tanner crab from summer trawl survey

Width	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
95.5	0.19	0.26	0.33	0.41	0.62	0.71	0.39	0.23
100.5	0.17	0.29	0.22	0.54	0.79	0.88	0.38	0.23
105.5	0.23	0.25	0.30	0.53	0.68	0.84	0.65	0.36
110.5	0.39	0.34	0.27	0.47	0.65	0.90	0.86	0.46
115.5	0.31	0.36	0.32	0.48	0.73	0.93	0.94	0.54
120.5	0.33	0.35	0.33	0.50	0.73	0.97	0.98	0.65
125.5	0.37	0.36	0.30	0.42	0.84	0.97	0.98	0.73
130.5	0.32	0.36	0.41	0.48	0.79	0.96	1.00	0.89
135.5	0.31	0.46	0.45	0.54	0.79	0.96	1.00	0.91
140.5	0.24	0.36	0.30	0.39	0.72	0.92	0.99	0.97
145.5	0.16	0.30	0.21	0.34	0.52	0.87	0.98	1.00
150.5	0.13	0.28	0.13	0.18	0.31	0.87	0.94	0.92
155.5	0.09	0.30	0.12	0.06	0.33	0.86	0.93	1.00
160.5	0.05	0.27	0.27	0.14	0.22	0.84	1.00	1.00
165.5	0.04	0.16	0.28	0.07	0.11	0.79	0.89	1.00

8.1.2.2 Steepness parameter estimate

The Beverton-Holt and Ricker stock-recruitment (S-R) models were fitted to the Tanner crab stock in Bristol Bay with mature male biomass as the spawner unit. Because of the lack of recent stock assessment information on this stock, the 1977-2005 data (post-regime shift) were used to determine the steepness parameter. The S-R data were generated for a handling mortality (hm) value of 0.2. Figure 8-5 depicts the stock-recruitment scatter plot and the S-R fits. The least square fits suggested that the Ricker curve was more appropriate to this data set than the Beverton-Holt curve. The steepness parameter value for the Ricker curve was 0.826. We used this value for performance statistics calculations by stochastic simulations.

8.1.2.3 B_{MSY} and proxy B_{MSY} estimate

The simulated population with a maximum number of 104 million recruits produced a B_{MSY} of 67.44 million pounds (30,590 t) and B35 of 75.61 million pounds (34,298 t) (proxy B_{MSY}) for the Ricker S-R curve with the estimated steepness parameter value of 0.829. These B_{MSY} and proxy B_{MSY} values were used in the Tier 2-4 formulas for stochastic simulations.

8.1.2.4 $F_{x\%}$ estimate

We used a steepness range of 0.53-0.84 to determine $F_{x\%}$ (Figure 8-6). The $F_{x\%}$ value was F_{34}. We selected a conservative F_{35} for detailed stochastic simulations. The corresponding F was 0.754, the legal male harvest rate (at the time of the fishery) was 34%, and the mature male harvest rate (at the time of survey, June 15) was 15%.

8.1.3 Effects on Tanner Crab

8.1.3.1 Comparison of status determination criteria

The current status determination criteria for EBS Tanner crab establish a B_{MSY} value of 189.6 million pounds (86,002 t) with an MSST value of 94.8 million pounds (43,001 t). Currently biomass as measured by the TMB of the area-swept estimate from the survey is 253.3 million pounds (114,896 t), above the B_{MSY} for this stock. In order to be considered rebuilt, this stock must be above its estimated B_{MSY} two years in a row. 2006 represents the first time the TMB was above the B_{MSY} for this stock since the overfished declaration of 1998. While the survey TMB under the current status determination criteria estimate the stock above its B_{MSY}, this stock remains under a rebuilding plan until the stock is above B_{MSY} for two years in a row.

Under the revised status determination criteria, B_{MSY} for Tanner crab is measured in mature male biomass only (see Section 2.2.3.1 for rationale). This long-term B_{MSY} estimate for the stock is 67.44 million pounds (30,590 t). For comparison, the mature male biomass for the stock is 62.76 million pounds (28,470 t). This is still above MSST as per Alternative 1; thus the stock is not in an overfished condition; however it remains under a rebuilding plan. The revised status determination puts this stock below its B_{MSY} thus despite indications from the TMB under Alternative 1 of the stock being above B_{MSY} last year this stock would not be considered rebuilt as it is well below its revised B_{MSY} stock status.

Given that new biological parameters for this stock have been re-estimated, the rebuilding plan may need to be re-evaluated and potentially revised to reflect new information on the stock, including new estimates of stock recovery in relation to new estimates of B_{MSY}.

Annual determination of overfishing would occur by comparison of the estimated *F* from the previous year's fishery with the previously calculated F_{OFL} for the same time period. Overfishing is defined as any amount of fishing in excess of a prescribed maximum allowable rate as prescribed through the six tiers described in Section 2.2.1. Overfishing is evaluated by comparison of actual harvest rates and the recommended control rules for this stock. F_{35} is the recommended OFL control rule (see Section 3.6.3 for simulation and results). Figure 8-2 shows the relationship between legal harvest rates and mature male biomass for both the F_{35} and F_{40} control rules. Harvest rates in recent years have been well below both control rules depicted.

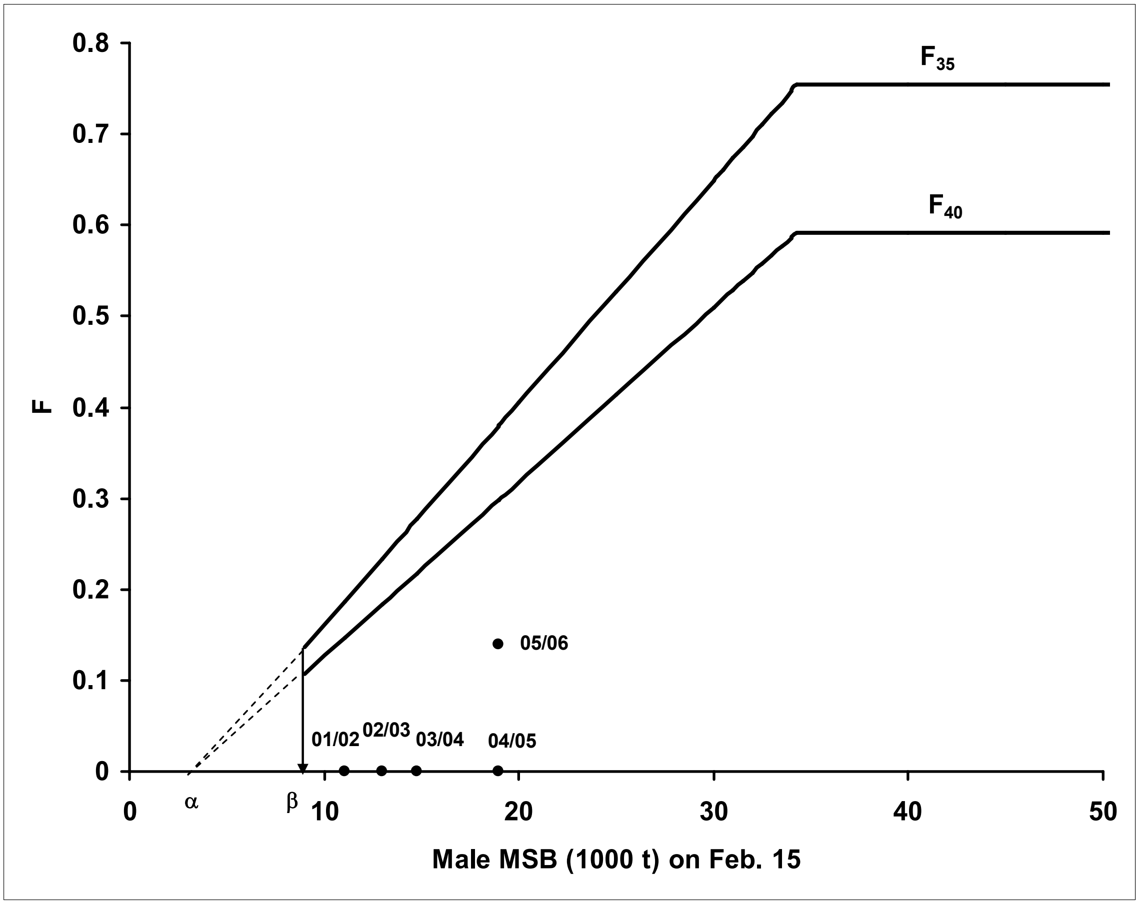

Figure 8-2 Relationship between legal male F and male mature stock biomass (MSB) on February 15 for Eastern Bering Sea Tanner crab. F_{35} and F_{40} control rules are included. The filled circles are F values for respective fishing seasons, 2001/2002 – 2005/2006.

B_{MSY} proxy estimates are available for the EAI Tanner crab stocks (Figure 8-3). Under the revised tier system this stocks would be suggested for management under Tier 4. Average abundance from 1999 to 2005 was used as a proxy for EAI Tanner crab; estimated abundance from 1990 to 1995 was extremely low. No survey data are available for this stock during the other years. Stock status is below its B_{MSY} proxy but above the MSST proxy. Historical comparison of stock status shows that the stock was below the MSST proxy in all years prior to 2000 with the exception of 1999.

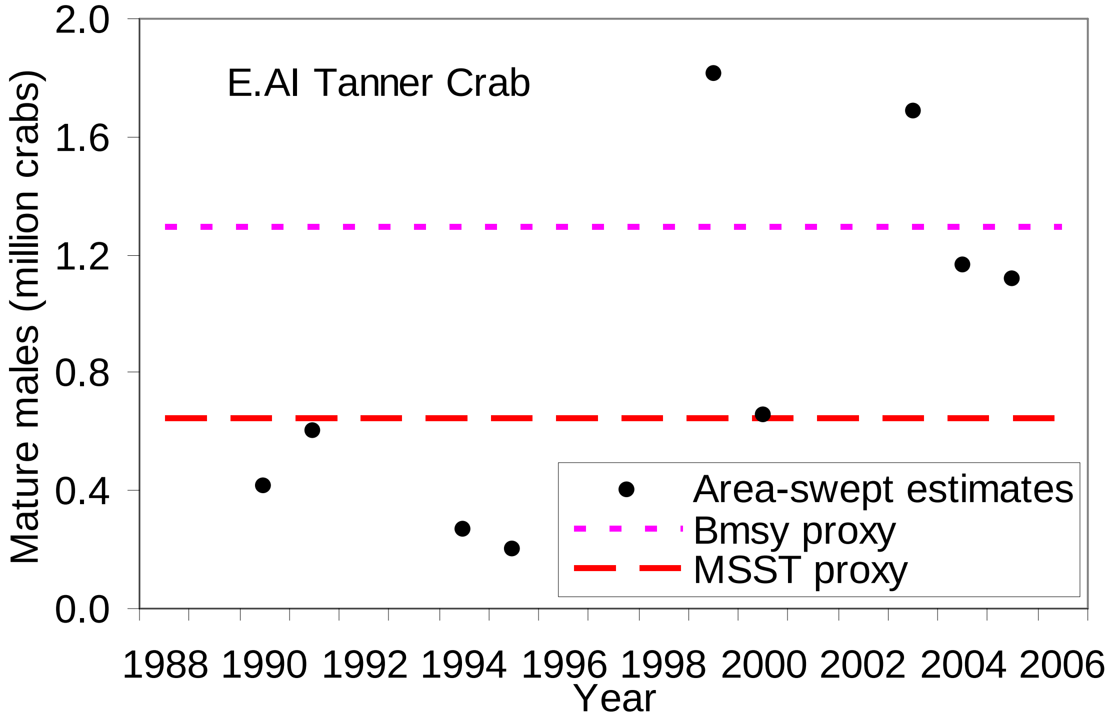

Figure 8-3 EAI Tanner crab estimated mature male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

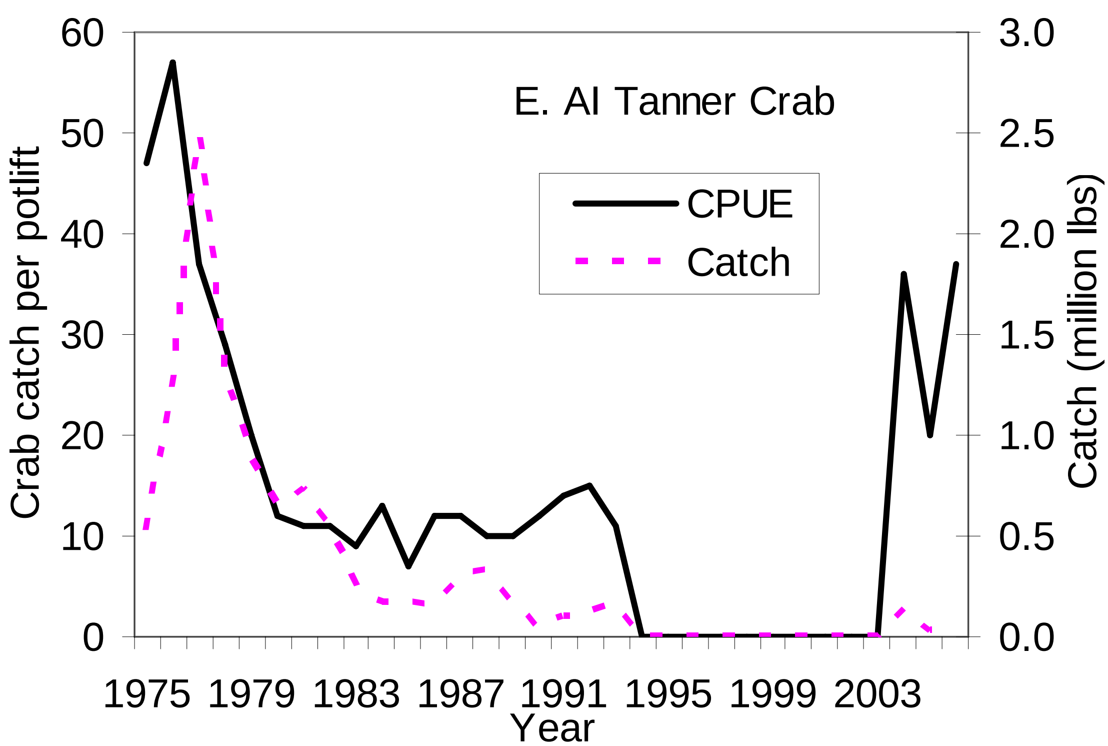

Figure 8-4 Catch and catch per pot lift for eastern Aleutian Islands Tanner crab.

Western Aleutian Islands Tanner crab is suggested for management as a Tier 6 stock due to lack of available information. No OFL would be determined for this stock.

A size range of 70-170 mm CW for both sexes was considered in the simulations. The lower limit was less than the 50% maturity lengths for Bering Sea Tanner crabs (113 mm CW for males and 83.5 mm CW for females; Zheng, unpublished). This size range was chosen to include immature sizes of crabs as initial recruits to the cohorts. Appendix D provides the input base parameter values. Terminal molt at maturity was assumed for both sexes in all simulations.

8.1.3.2 Evaluation of different tier systems with short-term and long-term performance statistics

Table 8-4 lists the results of performance statistics for short-term (30 years) fishery simulations with initial mature male biomass equal to 50% B_{MSY}. Twelve control rule scenarios were investigated: Tier 2 with the F_{MSY} (F = 0.874), Tier 3 with F_{35} (F = 0.754) and F_{40} (F = 0.592), Tier 4 with three times natural mortality M, the current State harvest strategy, the status quo, OFL, Flat F_{MSY} Flat F_{35}, F = M, and F = 0 harvest strategies. A default harvest strategy of 75%F was also considered for tiers 2 and 3. The mean catch scenarios were not considered because we could not find a fairly long period of constant CPUE to determine appropriate mean catch.

Tier 2 and Tier 3 with F_{35} produced higher mean retained yield and resulted in higher biomass relative to B_{MSY} on the 30th year, as well as higher first 10-year and subsequent 20-year mean retained yields. The Tier 4 harvest strategy produced similar performance to Tier 3 with F_{35}. Thus, for Tanner crab with a male M of 0.23, a γ value up to 3 is feasible. The current State harvest strategy was satisfactory, with performance somewhat lower than Tier 3 with F_{40}. However, the simulation procedure for application of the state harvest strategy was an approximation to the actual procedure being followed by the State. The SQ OFL control rule performed worst of all, with very low mean number of recruits, higher overfished percent, and much lower 30th year relative mature male biomass. The stock did not rebuild during this time period under the SQ OFL control rule. Flat F_{MSY} and Flat F_{35} performed worse than the sliding scale counterparts.

Table 8-4 provides the same performance statistics for the short-term (30 years) fishery when the initial mature male biomass was set to B_{MSY}. The performance statistics patterns were similar, but the mean yields were higher and the rebuilding times were shorter compared to those under 50% B_{MSY} initial biomass. The OFL control rule performed the worst of the scenarios (low mean recruitment, low 30th year relative mature male biomass, and no rebuilding of the stock) while the initial mature male biomass was set to B_{MSY}.

Table 8-5 provides the same performance statistics for the long-term (100 years) fishery when the initial biomass was set to 50% B_{MSY}. The retained yield under Tier 3 control rule with F_{35} was lower, but closer to that of Tier 2 control rule with F_{MSY}. The long-term projection of biomass exceeded the B_{MSY} level much more than under Tier 2 control rule, suggesting that F_{35} was a good choice as a proxy for F_{MSY}. The Tier 4 control rule with 3M (3 * 0.23) performed well except it produced a lower retained yield compared to the F_{MSY} level. Thus a γ value up to 3 (or higher) is feasible for Tanner crab stocks.

Table 8-6 provides the same performance statistics for the long-term (100 years) fishery when the initial mature male biomass was set to 100% B_{MSY}. The performance statistics patterns were similar, but the mean yields were higher and the rebuilding times were shorter compared to those under 50% B_{MSY} initial biomass. The performance of the SQ OFL control rule was again the worst at this initial biomass level.

The F = 0 scenarios provide the non fishery yields, mainly trawl bycatch yields. The results indicated that nearly 3395 t of trawl bycatch was possible under the selected maximum number of recruits (104 million crabs).

Because a stock assessment model has not been developed for assessing Tanner crab abundance in the whole eastern Bering Sea, the average of survey abundance during 2004-2006 was used as the initial abundance in 2006 for projection to smooth survey measurement errors. Starting at the abundance in 2006 and with assumed parameters, short-term projections using the current State harvest strategy, current OFL, F_{40}, and F_{35} harvest control rules for 2007 to 2012 were made for eastern Bering Sea Tanner crab (Table 8-8). The 2006 catch was set according the current State harvest strategy for all scenarios. Recruitment was projected by an S-R curve and Rmax was assumed to be 104 million crabs. Because the annual mature male biomass is projected above B_{MSY} during 2008 to 2012 for F_{40} and F_{35} scenarios, annual fishing mortality is set to equal to those corresponding to F_{40} and F_{35} for these two scenarios. Projected catch and mature biomasses for the State harvest strategy are generally between those of F_{40} and F_{35} scenarios but are more stable over time than those produced by F_{40} and F_{35}. The current OFL results in much higher fishing mortality, higher catch and lower mature male biomass on February 15 than those by the current State harvest strategy, F_{40}, and F_{35} harvest control rules. The results are highly dependent on the abundance estimate in 2006 and assumed population parameters.

8.1.3.3 Alternative 1

Under Alternative 1, the EBS Tanner crab stock was declared overfished in 1998 and has been under a rebuilding plan since then. In conjunction with this rebuilding plan, the harvest strategy was modified to allow for greater probability of rebuilding the depleted stock.

The impact of fishing under the status quo OFL and the status quo harvest strategy were simulated in conjunction with proposed control rules under the new Tier system in Alternatives 2 and 3.

The State of Alaska harvest strategy for the Eastern Bering Sea Tanner crab has the following criteria (5 AAC 35.508):

- Threshold level: 21 million pounds (9,526 t) of mature female (>79 mm CW) biomass (FSSB). When the threshold level is met, the harvest rate is determined as follows:
- Mature harvest rate on molting mature male (100% new-shell and 15% old-shell >112-mm CW) abundance = 10%, if FSSB is greater than 21 million pounds (9,526 t) but less than 45 million pounds (20,412 t)
- Mature harvest rate on molting mature male abundance = 20%, if FSSB is at least 45 million pounds (20,412 t)

In addition, the harvest is capped at 50% of exploitable legal male (100% new-shell and 32% old-shell >138-mm CW) abundance.

The State harvest strategy was simulated following the above criteria. The abundances were estimated at the survey time using survey selectivity, and harvest rates were applied to molting mature male biomasses at the time of the survey. Fishing mortalities were approximated from harvest rates.

Fishing at the current OFL control rule for Tanner crab was simulated using the following formula:

Sustainable yield = 0.3* total survey mature biomass (male + female)

Table 8-4 Short-term performance statistics under various control rules for Tanner crab. Mean and median were estimated from 1000 simulations of a 30-year fishery with an initial mature male biomass of 50% B_{MSY} with biomass observation error (lognormal, $\sigma_1 = 0.2$), stochastic Ricker stock-recruitment model with an estimated steepness = 0.83, and recruitment variability ($\sigma = 0.4$, auto-correlation = 0). The maximum number of recruits was set at 104 million crabs. Base stock parameter values (Appendix C) were used in the model. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, CV = coefficient of Variation, NR = not rebuilt, and NA = information not available..

Harvest Control Rule (CR)	Tier 2 Limit (F_{MSY} CR)	Tier 2 Target (75% F_{MSY} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=3*M CR)	State Harvest CR	OFL CR	Flat F_{MSY}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	93.8	96.9	96.5	98.4	98.2	96.4	99.4	52.8	87.3	90.7	97.6	90.1
Mean total yield (t)	12675	11902	12242	11329	11491	12061	11175	12758	12450	12152	7836	3043
Mean retained yield (t)	7796	7277	7519	6865	6984	7388	5972	6654	7562	7401	4104	0
Mean mature male biomass (t)	28313	32221	31333	35250	34607	31489	34762	10533	23751	26271	46866	60825
Mean mature female biomass (t)	36422	37943	37686	38888	38718	37693	41554	21170	33643	35017	40510	40019
Mean F	0.71	0.57	0.60	0.48	0.50	0.59	0.66	3.01	0.87	0.75	0.21	0
Rebuilding time (y)[a]	10	8	8	7	7	8	6	NR	19	14	5	5
Years $B<B_{msy}$ (%)[b]	64.5	47.1	50.2	36.5	38.4	49.8	38.8	100.0	83.7	72.7	20.7	16.3

Table 3-22. continued:

Harvest Control Rule (CR)	Tier 2 Limit (F_{MSY} CR)	Tier 2 Target (75% F_{MSY} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=3*M CR)	State Harvest CR	OFL CR	Flat F_{MSY}	Flat F_{35}	F=M CR	F=0
Years overfished (%)[c]	3.2	2.3	2.4	1.9	1.9	2.5	1.8	91.9	9.6	6.5	1.2	0.8
Years fishery closed (%)[d]	0	0	0	0	0	0	0	NA	0	0	0	0
30th year biomass ratio (%)[e]	106	125	119	137	134	121	133	27	94	106	191	237
First 10-yr mean retained yield (t)	5324	4672	4779	4122	4228	4792	4747	8122	6113	5722	2328	0
CV first 10-yr mean retained yield	0.19	0.19	0.20	0.20	0.20	0.19	0.13	0.10	0.12	0.12	0.18	0
Next 20-yr mean retained yield (t)	9032	8579	8889	8237	8362	8687	6585	5921	8286	8241	4992	0
CV next 20-yr mean retained yield	0.12	0.11	0.11	0.10	0.11	0.11	0.11	0.15	0.12	0.11	0.08	0

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time

[b]Mean percent of years in a 30-year fishery the mature male biomass < MSY mature male biomass

[c]Mean percent of years in a 30-year fishery the mature male biomass < 50% MSY mature male biomass

[d]Mean percent of years in a 30-year fishery the mature male biomass < 25% MSY mature male biomass

[e]Mean percent of 30th year mature male biomass relative to MSY mature male biomass

Table 8-5 Short-term performance statistics under various control rules for Tanner crab. Mean and median were estimated from 1000 simulations of a 30-year fishery with an initial mature male biomass of B_{MSY} with biomass observation error (lognormal, $\sigma_1 = 0.2$), stochastic Ricker stock-recruitment model with an estimated steepness = 0.83, and recruitment variability ($\sigma = 0.4$, auto-correlation = 0). The maximum number of recruits was set at 104 million crabs. Base stock parameter values (Appendix C) were used in the model. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, CV = coefficient of Variation, NR = not rebuilt, and NA = information not available..

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=3*M CR)	State Harvest CR	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	98.7	101.0	101.0	102.0	102.0	101.0	103.0	67.5	97.1	99.3	99.8	90.5
Mean total yield (t)	15325	14194	14640	13398	13612	14418	12738	17927	15553	14955	9006	3363
Mean retained yield (t)	9431	8700	9007	8149	8302	8852	6684	9690	9539	9186	4758	0
Mean mature male biomass (t)	32140	36669	35279	39786	39046	35822	38596	15269	30458	33175	53116	68035
Mean mature female biomass (t)	42350	43947	43531	44754	44587	43692	47792	29112	41615	42759	45975	44496
Mean F	0.80	0.63	0.68	0.53	0.56	0.66	0.71	2.96	0.87	0.75	0.23	0
Rebuilding time (y)[a]	2	1	1	1	1	1	1	NR	2	1	0	0
Years B<B_{msy} (%)[b]	46.3	27.5	32.2	18.4	20.0	30.4	22.7	98.3	55.4	41.8	4.6	2.3

Table 3-23. continued:

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=3*M CR)	State Harvest CR	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Years overfished (%)[c]	0.1	0	0	0	0	0	0.1	57.9	0.4	0.1	0	0
Years fishery closed (%)[d]	0	0	0	0	0	0	0	NA	0	0	0	0
30th year biomass ratio (%)[e]	107	126	119	138	134	122	134	32.8	100	111	190	236
First 10-yr mean retained yield (t)	9232	8060	8419	7264	7451	8274	6318	13682	9590	8920	3980	0
CV first 10-yr mean retained yield	0.13	0.13	0.14	0.14	0.14	0.13	0.11	0.09	0.11	0.11	0.12	0
Next 20-yr mean retained yield (t)	9531	9021	9301	8592	8727	9140	6867	7695	9513	9319	5147	0
CV next 20-yr mean retained yield	0.11	0.10	0.11	0.10	0.10	0.10	0.09	0.13	0.10	0.10	0.07	0

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time

[b]Mean percent of years in a 30-year fishery the mature male biomass < MSY mature male biomass

[c]Mean percent of years in a 30-year fishery the mature male biomass < 50% MSY mature male biomass

[d]Mean percent of years in a 30-year fishery the mature male biomass < 25% MSY mature male biomass

[e]Mean percent of 30th year mature male biomass relative to MSY mature male biomass

Table 8-6 Long-term performance statistics under various control rules for Tanner crab. Mean and median were estimated from 1000 simulations of a 100-year fishery with an initial mature male biomass of 50% B_{MSY} with biomass observation error (lognormal, $\sigma_1 = 0.2$), stochastic Ricker stock-recruitment model with an estimated steepness = 0.83, and recruitment variability ($\sigma = 0.4$, auto-correlation = 0). The maximum number of recruits was set at 104 million crabs. Base stock parameter values (Appendix C) were used in the model. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, CV = coefficient of Variation, NR = not rebuilt, and NA = information not available..

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=3*M CR)	State Harvest CR	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	97.3	100.0	99.7	101	101	99.9	102.0	38.7	93.5	96.8	98.6	88.7
Mean total yield (t)	14590	13842	14205	13215	13399	14011	12477	8871	14401	14200	8967	3294
Mean retained yield (t)	8992	8517	8765	8083	8213	8631	6580	4597	8809	8722	4799	0
Mean mature male biomass (t)	31163	36249	34669	39670	38847	35293	38634	7243	27956	31359	54224	69676
Mean mature female biomass (t)	40591	42694	42158	43666	43471	42367	46588	14749	38590	40487	44490	41858
Mean F	0.78	0.61	0.67	0.53	0.55	0.64	0.70	3.02	0.87	0.75	0.22	0
Rebuilding time (y)[a]	10	8	8	7	7	8	6	NR	19	15	5	4
Years $B<B_{msy}$ (%)[b]	51.5	29.9	35.3	19.9	21.8	33.2	23.1	100.0	66.8	50.5	6.7	4.8

Table 3-24. continued:

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=3*M CR)	State Harvest CR	OFL CR	Flat F_{msy}	Flat F_{35}	F=M	F=0
Years overfished (%)[c]	0.9	0.6	0.6	0.5	0.5	0.7	0.4	97.5	3.3	2.0	0.3	0.2
Years fishery closed (%)[d]	0	0	0	0	0	0	0	NA	0	0	0	0
100th year biomass ratio (%)[e]	106	125	118	136	134	121	137	15	99	111	188	242

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time

[b]Mean percent of years in a 100-year fishery the mature male biomass < MSY mature male biomass

[c]Mean percent of years in a 100-year fishery the mature male biomass < 50% MSY mature male biomass

[d]Mean percent of years in a 100-year fishery the mature male biomass < 25% MSY mature male biomass

[e]Mean percent of 100th year mature male biomass relative to MSY mature male biomass

Table 8-7 Long-term performance statistics under various control rules for Tanner crab. Mean and median were estimated from 1000 simulations of a 100-year fishery with an initial mature male biomass of B_{MSY} with biomass observation error (lognormal, $\sigma_1 = 0.2$), stochastic Ricker stock-recruitment model with an estimated steepness = 0.83, and recruitment variability ($\sigma = 0.4$, auto-correlation = 0). The maximum number of recruits was set at 104 million crabs. Base stock parameter values (Appendix C) were used in the model. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, CV = coefficient of Variation, NR = not rebuilt, and NA = information not available..

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=3*M CR)	State Harvest CR	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	98.8	102.0	101.0	103.0	102.0	101.0	102.0	45.5	96.6	99.5	99.2	88.7
Mean total yield (t)	15389	14531	14924	13835	14034	14720	12932	11064	15407	15083	9319	3395
Mean retained yield (t)	9484	8945	9211	8467	8608	9070	6783	5839	9448	9284	4996	0
Mean mature male biomass (t)	32318	37586	35853	41027	40176	36597	39686	9201	30146	33550	56102	71960
Mean mature female biomass (t)	42385	44503	43916	45425	45231	44176	48425	18212	41198	42940	46135	43268
Mean F	0.80	0.63	0.69	0.54	0.56	0.66	0.72	3.0	0.87	0.75	0.23	0
Rebuilding time (y)[a]	2	1	1	1	1	1	1	NR	2	1	0	0
Years $B<B_{msy}$ (%)[b]	46.1	24.0	29.8	14.4	16.2	27.3	18.3	99.5	57.5	40.6	1.8	0.6

Table 3-25. continued:

Harvest Control Rule (CR)	Tier 2 Limit (F_{msy} CR)	Tier 2 Target (75% F_{msy} CR)	Tier 3 Limit (F_{35} CR)	Tier 3 Target (75% F_{35} CR)	Tier 3 (F_{40} CR)	Tier 4 (F=3*M CR)	State Harvest CR	OFL CR	Flat F_{msy}	Flat F_{35}	F=M	F=0
Years overfished (%)[c]	0.1	0	0	0	0	0	0	87.0	0.5	0.1	0	0
Years fishery closed (%)[d]	0	0	0	0	0	0	0	NA	0	0	0	0
100th year biomass ratio (%)[e]	106	125	118	136	134	121	137	16	99	111	188	242

[a]Median number of years taken for mature male biomass to reach MSY mature male biomass for the first time

[b]Mean percent of years in a 100-year fishery the mature male biomass < MSY mature male biomass

[c]Mean percent of years in a 100-year fishery the mature male biomass < 50% MSY mature male biomass

[d]Mean percent of years in a 100-year fishery the mature male biomass < 25% MSY mature male biomass

[e]Mean percent of 100th year mature male biomass relative to MSY mature male biomass

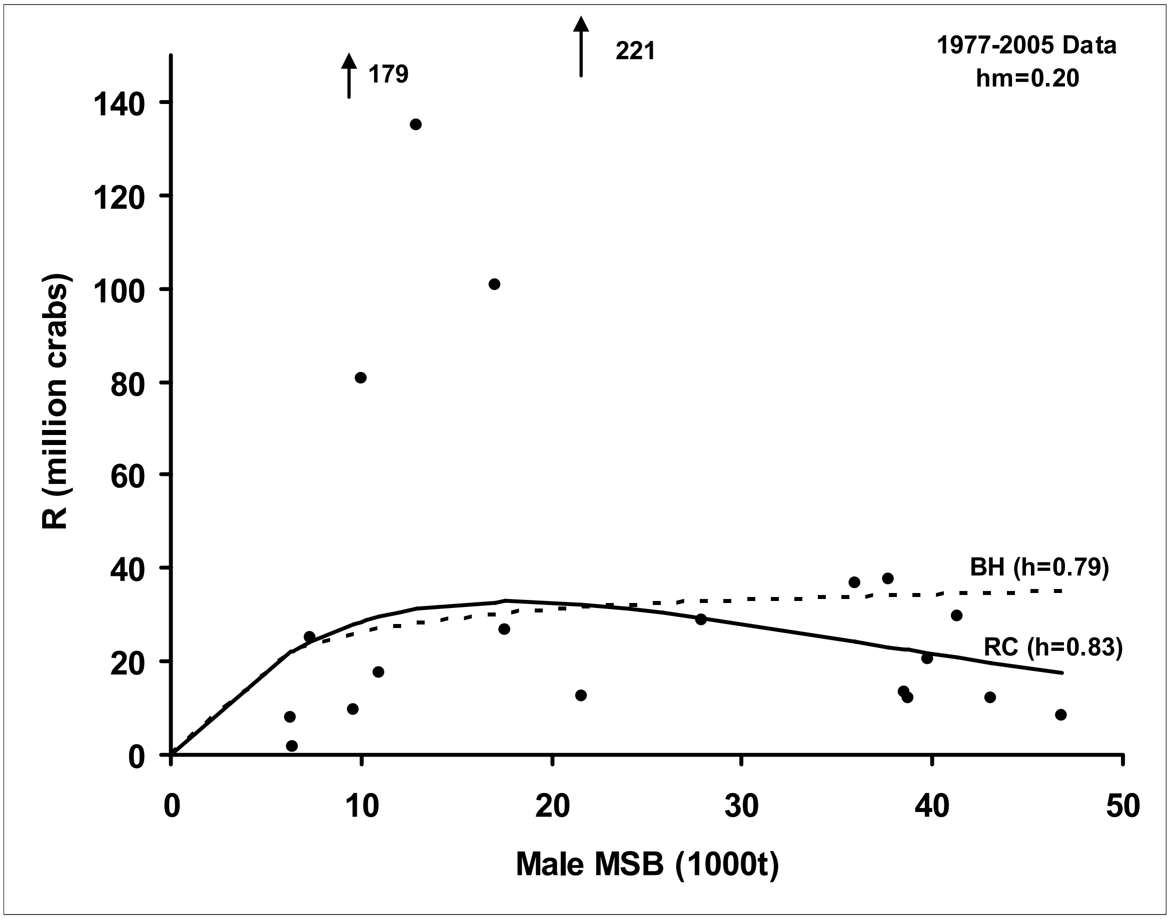

Figure 8-5 Stock-recruitment fit for the Bering Sea Tanner crab 1977-2005 data assessed at male M=0.23 and female M=0.29 and handling mortality, hm=0.2. The steepness parameter (h) values are given in parentheses. BH=Beverton and Holt curve, RC=Ricker curve.

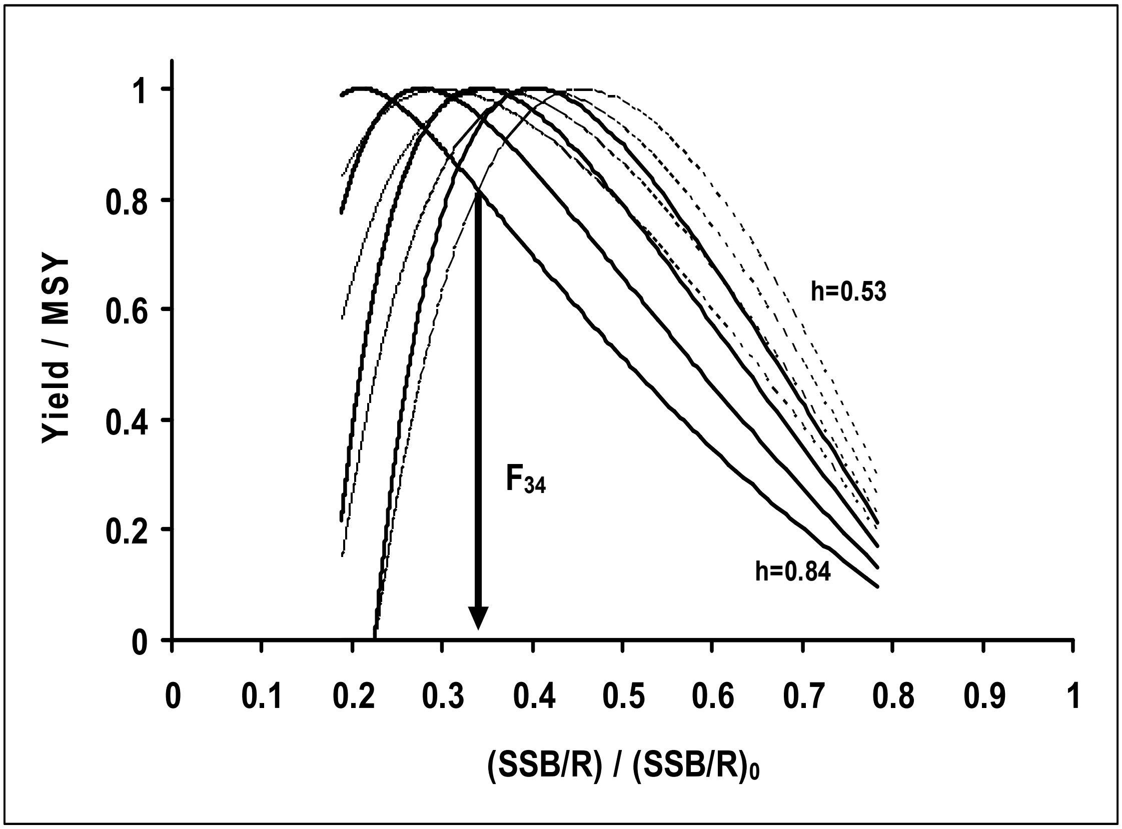

Figure 8-6 Approximate locations of spawning potential ratio ($F_{x\%}$) by equilibrium yield method for a handling mortality rate of 0.2 for Tanner crab. Solid lines = Ricker S-R model, dotted lines = Beverton-Holt S-R model.

Table 8-8 Short-term projections using the current State harvest strategy, current OFL, F_{40}, and F_{35} harvest control rules for 2007 to 2012 for eastern Bering Sea Tanner crab. Average of survey abundance during 2004 through 2006 was used as the initial abundance in 2006. The 2006 catch was set according the current ADF&G control rules for all scenarios. Recruitment was projected by an S-R curve and R_{max} was assumed to be 104 million crabs. Catch and biomass are in 1000 t. Year X is from June 15, X to June 14, X+1.

			Survey Time		Feb. 15
	Retained Catch	F	Mature Male Bio.	Mature Female Bio.	Mature Male Bio.
State Harvest Strategy					
2006	1.347	0.303	34.830	16.419	28.470
2007	6.718	0.762	42.563	23.292	30.482
2008	8.880	0.766	48.724	27.345	33.981
2009	9.534	0.603	51.963	29.968	36.515
2010	8.065	0.698	48.750	33.129	34.439
2011	7.135	0.739	45.112	36.205	32.098
2012	7.301	0.746	44.036	39.945	31.123
F_{40}					
2006	1.347	0.303	34.830	16.419	28.470
2007	5.559	0.592	42.563	23.292	31.491
2008	7.663	0.592	50.151	27.403	36.235
2009	10.008	0.592	54.801	30.091	38.504
2010	7.405	0.592	50.754	33.227	36.709
2011	6.400	0.592	47.489	36.339	34.765
2012	6.602	0.592	46.890	40.139	34.149
F_{35}					
2006	1.347	0.303	34.830	16.419	28.470
2007	6.656	0.753	42.563	23.292	30.536
2008	8.798	0.754	48.800	27.348	34.116
2009	11.294	0.754	52.137	29.976	35.212
2010	8.030	0.754	46.975	33.058	32.953
2011	6.916	0.754	43.548	36.120	30.976
2012	7.118	0.748	42.939	39.872	30.366
SQ Current OFL					
2006	1.347	0.303	34.830	16.419	28.470
2007	12.973	2.518	42.563	23.292	24.644
2008	12.256	2.450	40.546	26.827	23.862
2009	13.035	1.870	38.801	28.931	22.575
2010	9.314	2.990	32.285	31.786	19.046
2011	7.386	2.990	28.163	34.175	17.292
2012	7.837	2.990	27.619	37.332	16.592

The Eastern Aleutian Tanner crab stock is preliminarily placed in Tier 4 for purposes of this analysis. The harvest rates have not been examined for Eastern Aleutian Island Tanner crab. Generally, Tanner and snow crabs could sustain a higher harvest rate than red and blue king crabs as shown in the ratios of *Fmsy* and *M* for Bristol Bay red king crab and eastern Bering Sea Tanner and snow crabs. A range of γ values, maybe from 1 to 2, should be considered for Tanner crab stocks.

For Western Aleutian Islands Tanner crab, bycatch data is available from the directed red king crab fishery. No catch has occurred since 1997. No OFL determination is made for purposes of this analysis as this stock is suggested for Tier 6 management.

9 Other Crab Stocks

The FMP also covers scarlet king crab (*L. couesi*), triangle Tanner crab (*C. angulatus*), and grooved Tanner crab (*C. tanneri*) fisheries. Stock status for these species is largely unknown. This section reviews the stock status and biological parameters relevant to overfishing definitions for these stocks and provides an overview of specific impacts on the stocks from the three alternatives under consideration in this analysis.

9.1.1 Stock status

Scarlet king crab

Two stocks of scarlet king crab are managed under this FMP, AI scarlet king crab and EBS scarlet king crab. No surveys are conducted, nor are any estimates of population abundance made for scarlet king crabs in the Aleutian Islands; consequently, stock status and distribution are not well known. There is little stock assessment data and the stock appears small and geographically limited to deep-water areas. Scarlet king crabs are associated with steep rocky outcrops and narrow ledges (NMFS 2004a). Mature scarlet king crabs are caught incidentally in the golden king crab and Tanner crab fisheries (NMFS 2004a). Scarlet king crab males larger than or equal to five and one-half inches in CW may be taken as incidental harvest up to 20% of the directed fishery under the conditions of a commissioner's permit. Currently, ADF&G does not register vessels to fish directly for scarlet king crabs in the Bering Sea because stock size appears low and not capable of supporting a directed fishery. Retention of scarlet king crabs captured in other deepwater crab fisheries will be permitted at low levels. Observer coverage on each vessel registered for the king crab fisheries of the Aleutian Islands has provided biological information that will be used by the department to develop future management measures for scarlet king crab (ADF&G 2005).

Triangle Tanner crab

Two stocks of triangle Tanner crab are managed under this FMP, EAI triangle Tanner crab and EBS triangle Tanner crab. Surveys of population abundance are not conducted for triangle Tanner crabs; thus the status of this stock is unknown. This species occurs on the continental slope in waters > 300 m. and has been reported as deep as 2,974 m. in the eastern Bering Sea (NMFS 2004a). Historically, triangle Tanner crabs were taken as incidental harvest in the grooved Tanner crab fishery. Because of the paucity of population level data for this species and the history of the fishery, additional fishing for triangle Tanner crabs in the Eastern Aleutian District is limited to incidental harvest during the grooved Tanner crab fishery. Vessels registered to fish for grooved Tanner crabs are permitted to harvest triangle Tanner crabs at up to 50% of the weight of the target species. This harvest level is consistent with the historic development of the fishery.

Grooved Tanner crab

Three stocks of grooved Tanner crab are managed under this FMP, EAI grooved Tanner, WAI grooved Tanner and EBS grooved Tanner crab stocks. Little information is available on the biology of this species. It occurs in deep water and is not common at depths <300 m. (NMFS 2004a). The grooved Tanner crab population in the Eastern Aleutian District is not surveyed; consequently, no estimates of population abundance are available for this stock. Fishery data from the mid 1990s is the primary source of information regarding abundance and stock status. Catch per unit of effort declined from 15 legal crabs per pot lift in 1993 to two in 1996 and catches decreased from over 850,000 pounds in 1995 to 106,000 pounds in 1996. In addition, fishing effort was concentrated in three statistical areas immediately to the south of Unalaska Island. Fishery data is the primary source of information regarding abundance and stock status. Based on the available information, the Bering Sea grooved Tanner crab stock was heavily exploited in the mid-1990s and catch rates decreased to a level where the commercial fishery was no longer economically viable. Since then, the stock has been managed more conservatively and appears to have stabilized or recovered slightly (ADF&G 2005).

Given poor fishery performance and declining harvests of the mid 1990s, ADF&G re-evaluated deepwater Tanner crab guideline harvest levels in 2000. A GHL range of 50,000 (23 t) to 200,000 (91 t) pounds was established for the Eastern Aleutian District. The GHL was set as a range to provide greater flexibility for inseason management and to better inform the public of the department's management goals for the fishery. The fishery is managed so that the upper end of the GHL range is reached only when catch rates similar to, or greater than those documented prior to the harvest declines of the mid 1990s are observed. In addition to new GHL requirements, the department specified that four 4.5-inch escape rings be placed on the lower third of each pot and required that pots be fished over multiple depth strata. Observers required on all vessels registered for the fishery collect biological and fishery data.

9.1.2 Relevant biological information

This section examines relevant and recent biological information necessary to understand the overfishing definitions.

9.1.3 Effects on Other Crab Stocks

9.1.3.1 Comparison of status determination criteria

Information is insufficient to define B_{MSY} for these crab stocks currently.

Under Alternative 1, no MSST was specified for these stocks and the MFMT was based on the MSY control rule of 0.3 for Tanner crabs and 0.2 for king crabs. These stocks are all currently managed as Tier 1 stocks with some catch data available for some stocks.

Under Alternatives 2 and 3, these stocks would all be managed under Tier 5 and Tier 6 strategy with an OFL calculated based upon average catch or other means depending on information availability for Tier 5 stocks and no OFL determination is made for Tier 6 stocks. No additional status determination criteria are currently estimated for these stocks nor proposed under the revised definitions.

Under the revised tier system in Alternatives 2 and 3, all stocks in this section are recommended for Tier 5 and Tier 6 consideration for purposes of this analysis. The stocks in Tier 6 are stocks with incidental fisheries and include Western Aleutian Tanner crab, Aleutian Islands scarlet crab, eastern Bering Sea scarlet crab, and Bering Sea triangle Tanner crab.

For Aleutian Islands scarlet king crab, bycatch data are available from the directed golden king crab fishery. This stock is suggested for placement in Tier 6 for management. No OFL determination is made for purposes of this analysis.

For Eastern Bering Sea scarlet king crab, bycatch data are available from the directed grooved Tanner crab fishery. This stock is suggested for placement in Tier 6 for management. No OFL determination is made for purposes of this analysis.

For Bering Sea triangle Tanner crab, bycatch data are available from the directed grooved Tanner crab fishery. This stock is suggested for placement in Tier 6 for management. No OFL determination is made for purposes of this analysis.

For Eastern Aleutian Islands triangle Tanner crab, this stock has only been fished for 808 pot lifts during the last 10 years (bycatch). This stock is suggested for placement in Tier 6 for management. No OFL determination is made for purposes of this analysis.

For Western Aleutian Islands grooved Tanner crab, there has been no fishing effort during the last 10 years. This stock is suggested for placement in Tier 6 for management. No OFL determination is made for purposes of this analysis.

For Eastern Bering Sea grooved Tanner crab, there has been sporadic fishing effort during the last 10 years. The average yield is 248,000 pounds (112 t) for this stock. This stock is suggested for Tier 5 management. If an OFL is determined based upon average yield, the OFL could be set at 248,000 pounds (112 t) for this stock, with a GHL set at 75% of the OFL equivalent to 186,000 pounds (84 t).

10 Effects on incidental catch limits

Incidentally caught crab species are treated as prohibited species in BSAI groundfish fisheries. Regulations for prohibited species are defined in 50 CFR 672.21b. Crab bycatch in groundfish fisheries are enumerated by on-board observers and then returned to the sea. Bycatch limits are established in BSAI groundfish fisheries for the following species: red king crab, Tanner crab, snow crab. Once these limits are exceeded as described below, the specified area closures are triggered for the fishery. Limits are specified by target fishery. Crab species are also incidentally caught in the Alaskan Scallop fishery. Limits are species by species for this fishery. Bycatch of crab species by fishery (directed crab, groundfish trawl, groundfish fixed gear, scallop) is summarized in the annual Crab SAFE report (NPFMC 2006).

10.1 Snow Crab PSC limits

Bycatch limits for snow crab in groundfish trawl fisheries were established under Amendment 40 to the BSAI groundfish FMP, which became effective in 1998. Snow crab PSC limits are apportioned among fisheries in anticipation of their bycatch needs for the year. A PSC limit is established for snow crab in a defined area that fluctuates with abundance except at high and low stock sizes. The PSC cap is established at 0.1133% of the total Bering Sea snow crab abundance (as indicated by the NMFS trawl survey or other approved abundance estimate as with the 2006 use of the assessment model estimate of trawl survey biomass, see NPFMC Crab SAFE 2006 for more information), with a minimum PSC of 4.5 million snow crabs and a maximum PSC of 13 million snow crabs. Snow crab taken within the "*C. opilio* Bycatch Limitation Zone" (COBLZ) accrue towards the PSC limits established for individual trawl fisheries (Figure 10-1). Upon attainment of a snow crab PSC limit apportioned to a particular trawl target fishery, that fishery is prohibited from fishing within the COBLZ. In 1998 the bycatch limit for snow crab was further reduced by an additional 150,000 crabs as part of Amendment 57.

The total snow crab limit in 2005 was established as 4,858,992 crabs. Fisheries in 2005 had the following bycatch (and associated fishery-specific limits) within the COBLZ (Table 10-1 , data from NMFS Catch Accounting).

Table 10-1 Bycatch of EBS snow crabs in the COBLZ

Fishery	Limit	Total Catch
Pacific cod	139,331	31,865
Rockfish	44,945	0
Rock sole, flathead sole, other flatfish	1,082,528	197,350
Pollock, Atka Mackerel, other species	80,903	1,623
Yellowfin sole	3,101,915	3,006,557
Greenland turbot, Arrowtooth, Sablefish	44,946	0
Opilio crab PSQ (CDQ fishery)	364,424	7,558
Total	**4,858,992**	**3,244,954**

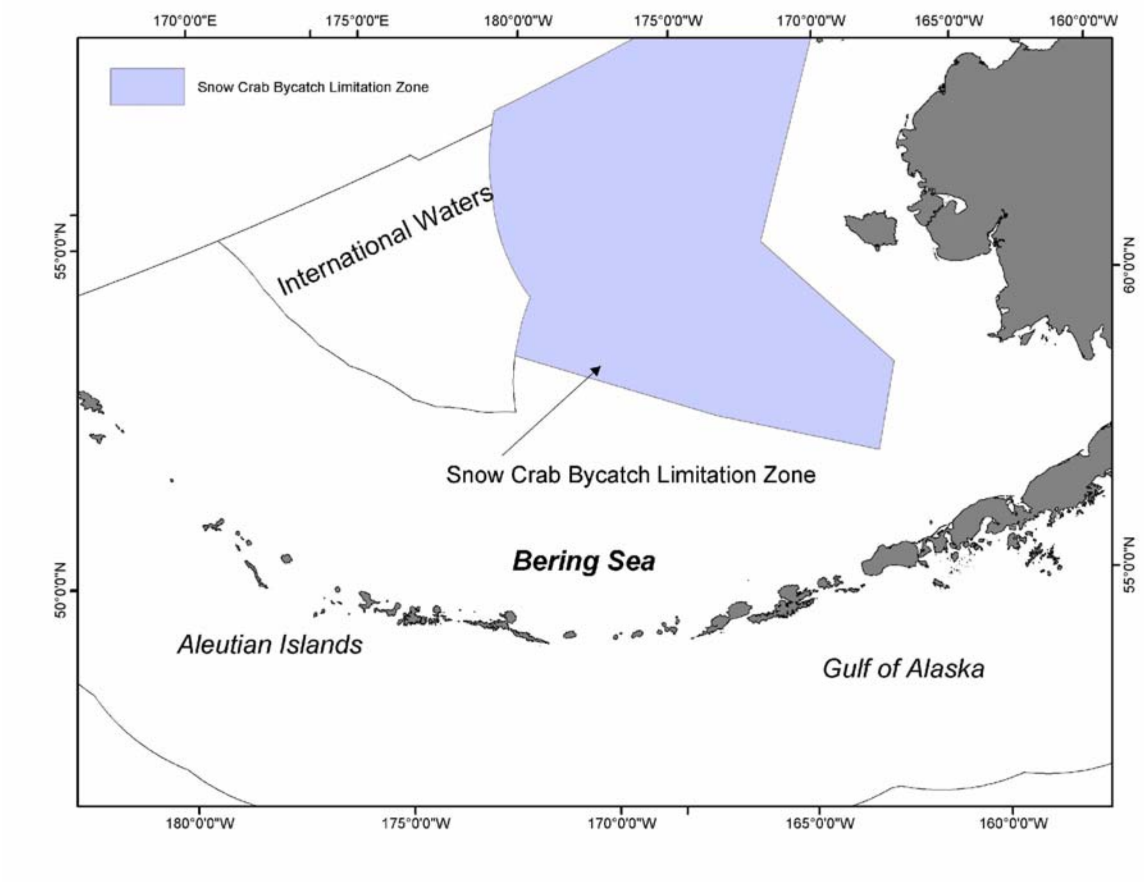

Figure 10-1 ***C. opilio*** **Bycatch Limitation Zone (COBLZ)**

Under the proposed Amendment 80, the current bycatch limits as established by Amendment 40 (and modified by Amendment 57) for snow crab will be modified. Under the preferred alternative for Amendment 80, once annually calculated according to the formula noted above (0.1133% of the total Bering Sea abundance), 61.44% of the cap would be allocated to the head and gut (H&G) sector of the trawl fleet. To accommodate the potential PSC savings the sector will likely enjoy from development of cooperatives, the calculated allocation (61.44%) to the H&G sector would be reduced by 20%, which would be phased in at 5% per year over a four-year period starting in the second year of the program. The remaining sectors of the trawl fleet would be limited to their sideboard amounts. The overall effect of this adjustment (and the limitation by the American Fisheries Act (AFA) sector to their sideboards) would be a reduction in the total limit (and overall catch) for snow crab in the COBLZ. Additional information can be found in the EA/RIR/IRFA for Amendment 80.

10.2 Red King Crab PSC limits

PSC limits are based on the abundance of Bristol Bay red king crab as shown in the adjacent box. In 1999, red king crab bycatch was reduced by an additional 3,000 crabs. In years when the abundance of red king crab in Bristol Bay is below the threshold of 8.4 million mature crabs, a PSC limit of 35,000 red king crab is established in Zone 1 (Figure 10-2). In years when the

PSC limits for Zone 1 red king crab.

Abundance	PSC Limit
Below threshold or 14.5 million lbs of effective spawning biomass (ESB)	33,000 crabs
Above threshold, but below 55 million lbs of ESB	97,000 crabs
Above 55 million lbs of ESB	197,000 crabs

stock is above the threshold but below the target rebuilding level of 55 million pounds of effective spawning biomass, a PSC limit of 97,000 red king crab is established. A 197,000 PSC limit is established in years when the Bristol Bay red king crab stock is rebuilt (above threshold and above 55 million pounds of effective spawning biomass). Based on the 2005 estimate of effective spawning biomass (68 million pounds), the PSC limit for 2006 is 197,000 red king crabs. The regulations also specify that up to 35% of the PSC apportioned to the rock sole fishery can be used in the 56º–56º10'N-strip of the Red King Crab Savings Area. The red king crab cap has generally been allocated among the pollock/mackerel/other species, Pacific cod, rock sole, and yellowfin sole fisheries. Once a fishery exceeds its red king crab PSC limit, Zone 1 is closed to that fishery for the remainder of the year, unless further allocated by season.

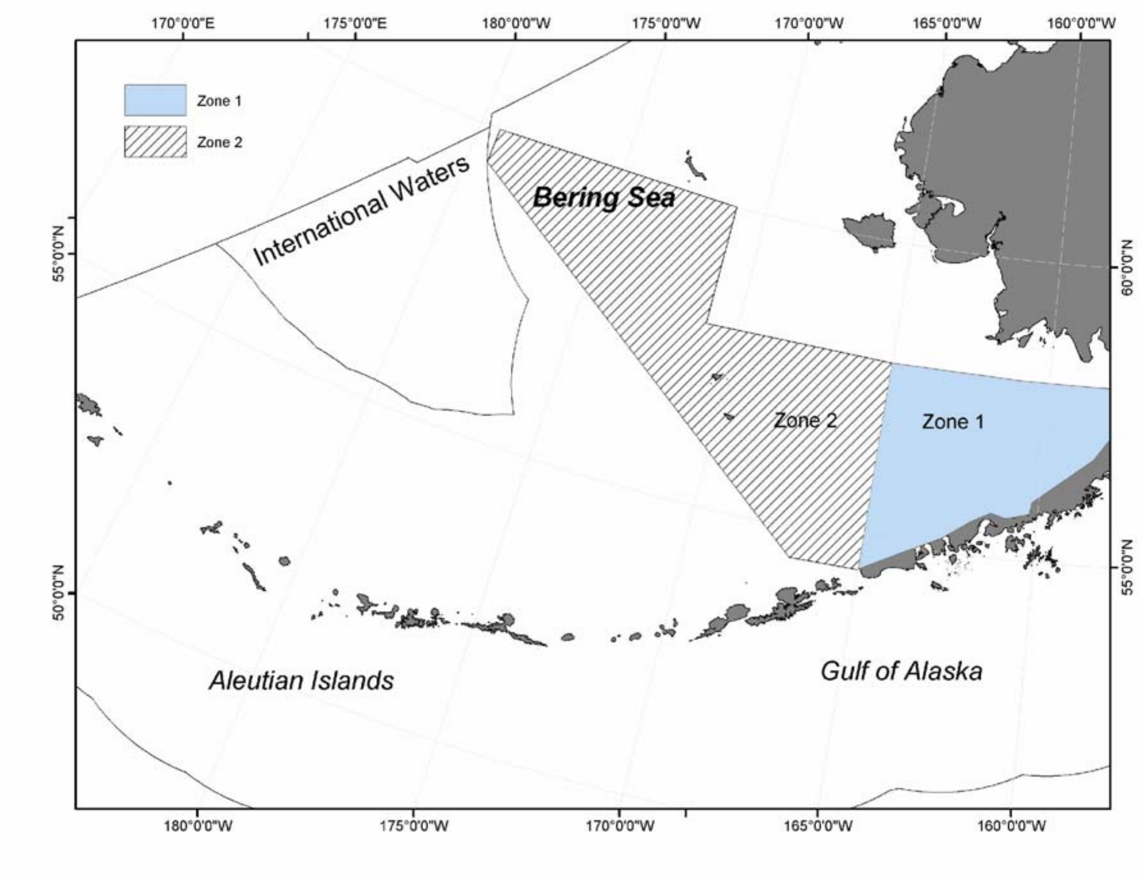

Figure 10-2 Zones 1 and 2 for red king crab and Tanner crab

10.3 Tanner crab PSC limits

PSC limits are also established for *C. bairdi* Tanner crab under Amendment 41 to the BSAI FMP. These limits are established in Zones 1 and 2 (Figure 10-2) based on total abundance (shown in adjacent box) of Tanner crab as indicated by the NMFS trawl survey. Based on 2005 abundance (763 million crabs), and an additional reduction implemented in 1999, the PSC limit for Tanner in 2006 is 980,000 crabs (1,000,000

PSC limits for Tanner crab.

Zone	Abundance	PSC Limit
Zone 1	0-150 million crabs	0.5% of abundance
	150-270 million crabs	750,000
	270-400 million crabs	850,000
	over 400 million crabs	1,000,000
Zone 2	0-175 million crabs	1.2% of abundance
	175-290 million crabs	2,100,000
	290-400 million crabs	2,550,000
	over 400 million crabs	3,000,000

minus 20,000) in Zone 1 and 2,970,000 crabs (3,000,000 minus 30,000) in Zone 2.

10.4 Scallop fishery crab bycatch limits

Crab bycatch limits (CBLs) are established for three crab species in the Alaskan Scallop fishery. CBLS are established for red king crab, Tanner crab, and snow crab according to Table 10-2 below.

Table 10-2 Scallop Fishery Crab Bycatch Limits (CBLs)

Registration Area	Red king crab	Tanner crab	Snow crab
Bering Sea (Q)	500[a]	3-tier system	3-tier system
Dutch (O)	0.5% or 1.0 %[b]	0.5% or 1.0 %[b]	NA
Adak (R)	50[c]	10,000[c]	NA

[a] fixed number of crabs
[b] percent of overall survey abundance
[c] bycatch limit set to allow fleet to explore and harvest scallops

In the Dutch Harbor Registration Area, the CBLs are set at 0.5% or 1.0% of the total crab stock abundance estimate based on the most recent survey data. In registration areas or districts where red king crab or Tanner crab abundance is sufficient to support a commercial crab fishery, the cap is set at 1.0% of the most recent red king crab or Tanner crab abundance estimate. In registration areas or districts where the red king crab or Tanner crab abundance is insufficient to support a commercial fishery, the CBL is set at 0.5% of the most recent red king crab or Tanner crab abundance estimate. Bycatch caps are expressed in numbers of crabs and include all sizes of crabs caught in the scallop fishery.

CBLs in the Bering Sea (registration Area Q) have evolved from fixed numbers in 1993 to a three tier approach used in the current fishery.

In 1998, consistent with the Tanner crab rebuilding plan in the Bering Sea, crab bycatch limits were modified. The current three tier approach was established utilizing the bycatch limits established in Amendment 1 of the FMP, 300,000 snow crab and 260,000 Tanner crab. The three tiers include (1) Tanner crab spawning biomass above MSST; bycatch limit is set at 260,000 crabs, (2) Tanner crab spawning biomass below MSST; bycatch limit is set at 130,000 crabs, and (3) Tanner crab spawning biomass is below MSST and the commercial fishing season is closed; Tanner crab limit is set at 65,000 crabs.

A similar three tier approach was taken with the snow crab bycatch caps. The three tiers include (1) snow crab spawning biomass above the MSST; bycatch limit is set at 300,000 crabs, (2) snow crab spawning biomass below MSST; bycatch limit is set at 150,000 crabs, and (3) snow crab spawning biomass below MSST and the commercial fishing season is closed; the snow crab limit is set at 75,000 crabs.

Closures based on the fleet reaching crab bycatch limits have decreased over the years since inception of CBLs in 1993, possibly due to decreased crab abundance (Barnhart and Rosenkranz 2003). During the 1993/94 season four statewide areas were closed due to crab bycatch. Since the 2000/01 season two areas have closed due to crab bycatch (NPFMC 2005).

10.5 Effects of alternatives on incidental catch limits

The proposed action would establish alternative biomass-based OFLs for management of crab species. If these OFLs restrict current harvest levels for crab, it is possible that this would likewise affect the stair-step regulations implementing the PSC caps. PSC caps, however, are based on overall abundance, not on harvest amounts. If abundance is projected to increase over time for snow crab under the new OFLs, then the amount allocated for PSC would increase. If the abundance is projected to decrease under the alternatives, the snow crab PSC allocation would decline. PSC limits for red king crab and Tanner crab are also stair-stepped based on the abundance. Only the lowest stair step is controlled by percent of abundance, thus declines in overall abundance would affect the lower limit for those species.

11 ESA-listed Species

Twenty-one species occurring in the action area are currently listed as endangered, threatened, or candidate species under the ESA (Table 11-1). The group includes seven species of great whales, one pinniped, four Pacific salmon, three seabirds, one albatross, four sea turtles, and sea otters. These listed species may be affected by the BSAI crab fisheries.

With some exceptions, NMFS oversees marine mammal species, marine and anadromous fish species, and marine plant species. USFWS oversees walrus, sea otter, seabird species, and terrestrial and freshwater wildlife and plant species. Federal actions must be in compliance with the provisions of the ESA. Section 7 of the ESA provides a mechanism for consultation by the Federal action agency with the appropriate expert agency (NMFS or USFWS). NMFS Sustainable Fisheries Division consults on fisheries management actions that may affect marine mammals with NMFS Protected Resources Division. For fisheries management actions that may affect seabirds, NMFS consults with USFWS.

Informal consultations, resulting in letters of concurrence, are conducted for Federal actions that have no adverse affects on the listed species. The action agency can prepare a BA to determine if the proposed action would adversely affect listed species or modify critical habitat. The BA contains an analysis based on biological studies of the likely effects of the action on the species or habitat.

Formal consultations, resulting in BiOps, are conducted for Federal actions that may have an adverse affect on the listed species. Through the BiOp, a determination is made about whether the proposed action poses “jeopardy” or “no jeopardy” of extinction to the listed species.

Summaries of the ESA consultations before 2004 on individual listed species are located in Section 3.3.3 of the Crab EIS (NMFS 2004a).

NMFS reinitiated consultation with USFWS and NMFS Protected Resources on the BSAI crab fisheries to include the Crab Rationalization Program (NMFS 2004b, NMFS 2004c). On May 26, 2004, NMFS Protected Resources concurred with the determination that the Program, and crab fishing under the Program, are not likely to adversely affect listed species of marine mammals, salmon or leatherback sea turtles, or destroy or adversely modify Steller sea lion critical habitat (NMFS 2004c). On June 16, 2004, USFWS concurred with NMFS’ determination that the Program, and crab fishing under the Program, are not likely to adversely affect listed species of seabirds or destroy or adversely modify critical habitat (USFWS 2004).

Since the conclusion of those consultations, NMFS has designated critical habitat for the northern right whale in Alaskan waters (71 FR 38277, July 6, 2006) and USFWS has listed the southwest Alaska distinct population segment of northern sea otter as threatened under the ESA (70 FR 46365, August 9, 2005). NMFS also is considering listing the North Pacific right whale as a separate species from the Atlantic right whale (70 FR 1830, January 11, 2005). Designations of a species and/or critical habitat are triggers for reinitiating a consultation under the ESA regulations (50 CFR 402.16).

In 2006, NMFS consulted with USFWS on the effects of crab fishing on northern sea otters (Mecum 2006). The consultation concluded that any potential effects from the crab fisheries are discountable and therefore, NMFS determined that the crab fisheries are not likely to adversely affect northern sea otters.

NMFS is beginning the process of consultation on the effects of the crab fisheries on North Pacific right whale critical habitat.

Table 11-1 ESA listed and candidate species that range into the BSAI management areas.

Common Name	Scientific Name	ESA Status
Blue Whale	*Balaenoptera musculus*	Endangered
Bowhead Whale	*Balaena mysticetus*	Endangered
Fin Whale	*Balaenoptera physalus*	Endangered
Humpback Whale	*Megaptera novaeangliae*	Endangered
Right Whale[1]	*Balaena glacialis*	Endangered
Sei Whale	*Balaenoptera borealis*	Endangered
Sperm Whale	*Physeter macrocephalus*	Endangered
Steller Sea Lion (Western Population)	*Eumetopias jubatus*	Endangered
Steller Sea Lion (Eastern Population)	*Eumetopias jubatus*	Threatened
Chinook Salmon (Lower Columbia R.)	*Oncorhynchus tshawytscha*	Threatened
Chinook Salmon (Upper Columbia R. Spring)	*Oncorhynchus tshawytscha*	Endangered
Chinook Salmon (Upper Willamette)	*Oncorhynchus tshawytscha*	Threatened
Chinook Salmon (Snake River spring/summer)	*Oncorhynchus tshawytscha*	Threatened
Chum Salmon (Hood Canal Summer run)	*Oncorhynchus keta*	Threatened
Coho Salmon (Lower Columbia R.)	*Oncorhynchus kisutch*	Threatened
Steelhead (Snake River Basin)	*Oncorhynchus mykiss*	Threatened
Steller's Eider [2]	*Polysticta stelleri*	Threatened
Short-tailed Albatross [2]	*Phoebaotria albatrus*	Endangered
Spectacled Eider[2]	*Somateria fishcheri*	Threatened
Kittlitz's Murrelet[2]	*Brachyramphus brevirostris*	Candidate
Northern Sea Otter	*Enhydra lutris*	Threatened
Olive Ridley turtle	*Lepidochelys olivacea*	Threatened/ Endangered
Loggerhead turtle	*Caretta caretta*	Threatened
Green turtle	*Chelonia mydas*	Threatened/ Endangered
Leatherback sea turtle	*Dermochelys coriacea*	Endangered

[1]NMFS designated critical habitat for the northern right whale on July 6, 2006 (71 FR 38277).
[2] The Steller's eider, short-tailed albatross, spectacled eider, and Northern sea otter are species under the jurisdiction of the USFWS. For the bird species, critical habitat has been established for the Steller's eider (66 FR 8850, February 2, 2001) and for the spectacled eider (66 FR 9146, February 6, 2001). The Kittlitz's murrelet has been proposed as a candidate species by the USFWS (69 FR 24875, May 4, 2004).

11.1 Effects of Alternatives on ESA-listed Species

The proposed action would establish criteria from which to measure the status of the BSAI crab stocks to determine whether they are overfished and set a fishing rate, harvest above which would be considered overfishing. As such, the proposed action would have no direct effects on ESA-listed species or critical habitat. If NMFS declared a stock overfished, then the Council would take action to develop a rebuilding plan to rebuild the stock. If overfishing were predicted to occur, the State would reduce the TAC to below the overfishing level. Both of these actions would reduce any adverse effects of the crab fisheries on ESA-listed species and critical habitat by reducing or eliminating fishing for the crab stock.

12 Economic and Social Effects

This section summarizes the effects on the social and economic environment. The economic and social impacts differ in fundamental ways from other resource components examined in this EA. They deal with impacts on persons and on communities, while other impacts deal with the natural environment. Significance findings for social and economic impacts would not affect a finding of no significant impact (FONSI); see 40 *CFR* 1508.14.

Since the analysis of social and economic factors is largely qualitative, this analysis does not make precise findings of significance, based on quantitative thresholds. Instead, significance findings are based on the qualitative analytical findings concerning whether an action has a substantial impact. Any impact that is deemed to be substantial would be characterized as significant in this analysis.

12.1 Crab Management Background[2]

In August 2005, fishing began under the BSAI Crab Rationalization Program (Program), developed by the Council. The Program established a quota share system for allocating the harvest in each of the Bristol Bay red king crab, St. Matthew blue king crab, Pribilof red and blue king crab, Bering Sea snow crab, Bering Sea east Tanner crab, Bering Sea west Tanner crab, Eastern Aleutian Islands golden king crab, Western Aleutian Islands golden king crab, and Western Aleutian Islands red king crab fisheries. The 2005/2006 commercial crab fishing season was the first to be prosecuted under the new management regime.

Prior to the implementation of the Program, the BSAI crab fisheries were prosecuted as a limited access, derby fishery, under which the participants raced for crab after the opening with the fishery closing once managers estimated that the GHL was fully taken. The ADF&G managed the competitive general fisheries by establishing GHLs prior to the season, monitoring the harvest during the season, estimating the date and time that the harvest would attain the GHL, and closing the general fishery at that estimated date and time. After closure of the general fishery, the CDQ fishery for the season would open and participating vessels were allowed to fish until the CDQ allocation was harvested or until the regulatory season closing date.

Under the Program, ADF&G establishes a TAC for each fishery according to State regulations and NMFS distributes 10% of the TAC to the CDQ groups and the remaining 90% of the TAC to quota share (QS) holders as individual fishing quotas (IFQs). NMFS also allocates individual processing quota (IPQ) representing 90% of the IFQ TAC to processor quota share (PQS) holders.

ADF&G no longer manages the rationalized fisheries inseason; harvesters may harvest their IFQ at any time within the fishery seasons established in State regulations. Federal regulations also established other provisions for implementing the Program, including those for allocating processor shares to processors, those for governing the consolidation of QS and IFQ by vessels through leasing or purchasing of IFQs, and those for governing the formation of vessel cooperatives.

[2] A large part of the crab management background section originates from the introduction to Estimates of Red King Crab Bycatch during the 2005/2006 Bristol Bay Red King Crab Fishery with Comparisons to the 1999-2004 Seasons, Fishery Data Series No. 06-23, written by David R. Barnard and Douglas Pengilly, ADF&G.

Crab pots are the legal gear for the BSAI commercial crab fisheries and only males meeting or exceeding the minimum size limits can be harvested. Females and sublegal males are also caught as bycatch but harvesters are required to immediately return these crabs to the sea. Table 12-1 provides season open dates for BSAI crab fisheries.

Table 12-1 Season opening dates for BSAI crab species

Crab Species	Season Open Dates
Snow crab	October 15
Aleutian Islands golden king crab	August 15
St. Matthew/Pribilof Islands king crab	September 15
Bristol Bay red king crab	October 15
Bering Sea Tanner Crab	October 15
Norton Sound king crab	July 1

12.2 Participation and Harvests

This section provides a brief summary of BSAI crab fishery vessel participation and season length from the 2001 to 2005 season. Information on vessel participation and season length from 1995 to 2000 are located in the Crab EIS.

The program has reduced the number of vessels participating in the BSAI crab fisheries and has slowed the pace of the BSAI crab fisheries.

Table 12-2 depicts these dramatic effects in participation and season length. For example, prior to the 2005/2006, the season length for the Bristol Bay red king crab season was 3 to 5 days. However, during the 2005/2006 season, the Bristol Bay red king crab season lengthened to 93 days. At the same time the number of participating vessels declined from 251 in 2004 to 89 during the 2005/2006 season. For the Bering Sea snow crab fishery, the season lengthened to 229 days from 6 days the previous year and the number of vessels declined from 169 in 2005 season to 78 for the 2005/2006 season. For the WAI and EAI golden king crab, the number of vessels participating in the fishery declined and the season length increased from 141 days for the WAI to 273 days and from 14 days in the EAI to 273 days. Fishing was closed for Pribilof blue king crab, Pribilof red king crab, St. Matthew blue king crab, and Adak red king crab. The Bering Sea Tanner crab fishery was opened for fishing for the first time since 1996.

Table 12-2 Number of vessels and season length by BSAI crab species

Fishery	Season	Number of Vessels	Season Length
WAI Golden King	2001-2002	9	227.0
	2002-2003	6	205.0
	2003-2004	6	175.0
	2004-2005	6	141.0
	2005-2006	3	273.0
Adak Red King	1995-2005	FISHERY CLOSED	
Bristol Bay Red King	2001-2001	230	3.3
	2002-2002	242	2.8
	2003-2003	252	5.1
	2004-2004	251	3.3
	2005-2005	89	93.0
Bering Sea Snow Crab	2001-2001	207	30.0
	2002-2002	191	24.0
	2003-2003	192	9.0
	2004-2004	189	8.0
	2005-2005	169	6.0
	2005-2006	78	229.0
Bering Sea Tanner Crab	1997-2004	FISHERY CLOSED	
	2005-2006	43	168.0
EAI Golden King	2001-2002	19	26.0
	2002-2003	19	23.0
	2003-2004	18	24.0
	2004-2005	19	14.0
	2005-2006	7	273.0
Pribilof Blue King	1999-2005	FISHERY CLOSED	
Pribiliof Red King	1999-2005	FISHERY CLOSED	
St. Matthew Blue King	1999-2005	FISHERY CLOSED	

Source: 2006 Crab SAFE

12.3 Processor Participation

This section summarizes processor participation in the different BSAI crab fisheries. For each fishery, the number of processors participating and the pounds delivered are presented and discussed for 2001 to 2005. Information on deliveries to processors and the number of processors from 1995 to 2000 are located in the Crab EIS. (NMFS 2004a)

12.4 Estimated Ex-vessel Prices

This section provides a brief summary of the annual harvest, exvessel price, and value from 2001 to 2005 by BSAI crab fishery. Information on harvest, exvessel price, and value from 1995 to 2000 are located in the Crab EIS.

Table 12-3 provides annual harvest, exvessel price, and value information by crab fishery from 2001 to 2005 where available. Observations from this table shows that Bering Sea snow crab had the highest harvest, but the Bristol Bay red king crab fishery has consistently had the highest exvessel price and value over the 2001 to 2005 period. Harvest of Bristol Bay red king has increased over the last five seasons from 7.8 million pounds (3,538 t) during the 2001 season to 16.5 million pounds (7,484 t) in the 2005 season. Average exvessel price for the fishery has fluctuated between $4.24 a pound in 2005 season to over $6 a pound in 2002. Value of the Bristol Bay red king crab fishery during the 2001 to 2005 seasons has ranged from $38 million in 2001 to $73 million in 2003. In recent years, the value of the fishery has ranged from $66 to $70 million. For Bering Sea snow crab, the harvest has fluctuated between the 22 million pounds (9,979 t) in 2004 to 33 million pounds (14,969 t) in the 2005/2006 season. Average exvessel prices ranged from nearly $1.50 a pound to a little over $2 a pound between 2001 and 2005. During the 2005/2006 season, exvessel prices dropped dramatically to $0.84 a pound. The value of the Bering Sea snow crab fishery has consistently been in the $40 million range during the 2002 to 2005 period, but the value of the fishery dropped to $28 million during the most recent season (2005/2006). Harvest in the Aleutian Islands golden king crab fishery has consistently been in the 5 to 6 million-pound range annually over the past five years, with approximately 2.7 million pounds (1,225 t) harvested in the WAI and 2.9 million pounds (1,315 t) harvested in the EAI. In the 2005/2006 season, the harvest declined slightly from the previous year. Average exvessel price has ranged from $3 to $3.50 over the past several years and the value has ranged from $8 to $10 million during this same period. However, in the 2005/2006 fishing season, the average exvessel price and value of the fishery declined. In the WAI, the exvessel priced declined from $3.09 to $2.05 and the value dropped from $8.16 million to $4.89 million. In the EAI the average exvessel price declined from $3.18 from the previous season to $2.53 and the value dropped from $9.05 million to $6.50 million. Finally, the Bering Sea Tanner crab fishery was opened for the first time during the 2005/2006 season since being closed in 1997. Forty-three vessels harvested 791,000 pounds (359 t) at a value of $0.9 million. The average exvessel price for that season was $1.28. The remaining BSAI crab fisheries were closed to fishing.

Table 12-3 Exvessel price, total value and total landed pounds by crab fishery from 2001 to 2006

Fishery	Season	Total Landed Pounds	Total Value[a]	Exvessel Price[b]
WAI Golden King	2001-2002	2,740,054	$7.87	$2.93
	2002-2003	2,640,604	$9.13	$3.50
	2003-2004	2,688,773	$10.11	$3.83
	2004-2005	2,688,234	$8.16	$3.09
	2005-2006	2,384,567	$4.89	$2.05
Adak Red King	1995-2005	FISHERY CLOSED		
	2002-2003	505,642	$3.29	$6.51
	2003-2004	479,113	$2.45	$5.14
Bristol Bay Red King	2001-2001	7,786,446	$37.50	$4.81
	2002-2002	8,856,828	$54.20	$6.14
	2003-2003	14,529,124	$72.70	$5.08
	2004-2004	14,112,438	$65.70	$4.71
	2005-2005	16,478,458	$69.50	$4.24
Bering Sea Snow Crab	2001-2001	23,382,046	$32.12	$1.53
	2002-2002	30,233,494	$44.20	$1.49
	2003-2003	26,198,024	$46.98	$1.83
	2004-2004	22,170,150	$44.99	$2.05
	2005-2005	23,036,287	$41.47	$1.80
	2005-2006	33,256,146	$27.66	$0.84
Bering Sea Tanner Crab	1997-2004	FISHERY CLOSED		
	2005-2006	791,315	$0.90	$1.28
EAI Golden King	2001-2002	3,178,652	$10.26	$3.30
	2002-2003	2,821,851	$9.13	$3.30
	2003-2004	2,977,055	$10.05	$3.46
	2004-2005	2,886,817	$9.05	$3.18
	2005-2006	2,567,781	$6.50	$2.53
Pribilof Blue King	1999-2005	FISHERY CLOSED		
Pribiliof Red King	1999-2005	FISHERY CLOSED		
St. Matthew Blue King	1999-2005	FISHERY CLOSED		

Source: 2006 Crab SAFE
[a]Millions of dollars
[b]Average price per pound

12.5 Product Market and Prices

The information in this section is intended to provide some background concerning the role of the US producers in the current world market and a historical description of the markets for crab. A brief summary of crab production and prices is provided in the Crab EIS. The information in the Crab EIS is intended to provide some background concerning the role of the US producers in the current world market and a historical description of the markets for crab.

Since the publishing of the Crab EIS, the 2005 and 2006 BSAI Crab SAFE have include a summary of recent research on the Alaska snow and king crab market by Dr. Joshua Greenberg and Dr. Mark Herrmann from the University of Alaska Fairbanks. The studies examine influences of the snow and king crab world market and the relationship between Alaska snow and king crab landings and the world demand for these crabs. Using these influences and interrelationships, the authors develop a model to study the effects supply and demand on the Alaska snow and king crab markets. The study shows that Alaska is no longer the largest supplier of snow crab or king crab. Both snow and king crab world market prices are not responsive to changes in Alaska snow and king crab harvests. As noted in the study, this implies that the Alaska crab industry cannot rely on increases in crab prices to reduce the impacts of declining crab harvests. For snow crab, the increased harvest from Canada and the emergence of Greenland and Russia snow crab harvests has softened the Alaska snow crab market. For king crab, the introduction of Russian king crab in the Barents Sea in recent years and North Pacific for the past decade has had a major impact on the Alaska king crab market price. Given that Alaska crab markets are price takers rather price makers, there is little potential for improvements in Alaska crab prices in the near future despite the implementation of crab rationalization.

12.6 Community Existing Conditions

Detailed community profiles for Unalaska/Dutch Harbor, Akutan, King Cove, Sand Point, Adak, St. Paul, St. George, Kodiak, and Seattle may be found in the Crab EIS. These profiles contained detailed description of the existing conditions in these communities, as well as overview treatments of potential social impact issues relative to BSAI crab rationalization for the particular communities.

Since the publishing of the Crab EIS, the Alaska BSAI crab fishery has been under the Program for one season. Limited observations from that first season are now available and a summary of these observations are provided below. This summary originates from an October 2006 discussion paper prepared by Council staff on cooperative vessel use caps under the Program.

Utilizing observations from the first season under the Program, changes in participation patterns in the crab fisheries have been seen and these changes may have had an impact on some communities that depend economically and socially on the fisheries. Many of those effects on the communities are less direct and difficult to estimate, in part due to data shortages. To date, two studies have examined the effects of the Program on four communities. One, undertaken on behalf of the City of Kodiak, examines effects on crew employment and support businesses in that city; the other undertaken on behalf of the Aleutians East Borough, examines economic and social effects on King Cove, Akutan, and False Pass (Knapp, 2006; Lowe, et al., 2006). The most evident local impacts arise from the reduction in crew. Declines in crew positions are believed to be in direct proportion to declines in vessel participation. No specific data are available concerning residence of crew, compelling analysts in the recent studies to rely on the knowledge of local residents for estimating crew job losses. Those studies estimate that 25 residents of the three Aleutians East Borough communities lost crab crew positions, while Kodiak crew are estimated to have lost 125 positions in the Bristol Bay red king crab and approximately 60 positions in the Bering Sea snow crab fishery in the first year of the program. Estimates of job losses in other communities are unavailable at this time. Although crab crew typically are short term positions that account for only a portion of a person's income, the loss of this income to residents of remote communities is likely of greater consequence than job losses in larger communities, since job markets in remote areas are more limited. In some cases, the job losses will be transitional for individuals, as they work to find substitute income or adjust their lifestyles to account for losses of income. In some cases, the absence of opportunities could compel out migration. The extent of any out migration, if occurs, is not known. In small economies, the loss of crew jobs can also have indirect effects, if local spending of resident crew declines.

Fleet contraction is also felt by communities whose businesses have suffered because of a drop in demand for goods and services from their businesses. Attribution of these effects on the change in crab management is difficult, since data isolating spending of crab vessels and fishery participants from spending associated with other fishery and non-fishery activities are not available. In the Kodiak study, anecdotal evidence suggest declines in spending at some businesses, but evidence of a broad decline in total local spending could not be identified. In the Aleutians East Borough study, King Cove saw a decline in revenues from harbor and moorage fees. In addition, declines in revenues of many support industries are cited (although the magnitude of these declines is not specified). At the same time, one business in King Cove—a support industry business owned the local processor—has experienced an increase in revenues during the first crab season under the Program. This increase may have resulted from activities other than crab fishing. Some vessel owners asserted that they have increased their purchases from communities proximate to the fishing grounds since the Program was implemented. These owners state that their extended stays in the communities require them to make local purchases to sustain their fishing activities. Most of these owners assert that they prefer to make these purchases prior to positioning their vessels near the fishing grounds, because of the comparatively high prices in remote Alaskan communities. The extent to which these additional purchases have offset declines in spending because of the removal of vessels from the fleet is uncertain.

Both studies caution that effects may lag. For example, vessels that did not fish in the first year of the Program may still buy some inputs to allow their use in other fisheries. If these vessels are retired over time, effects may be felt until some time in the future.

12.7 Effects of Alternatives

This section provides the social and economic analysis of the three alternatives: (1) Status Quo/No Action, (2) new tier system and Council annually adopts OFLs, and (3) new tier system and Council annually review OFLs. Assessing the social and economic effects of the alternatives involves some degree of speculation. In general, the effects arise from the actions of individual participants in the crab fisheries under the incentives created by the different alternatives. Predicting these individual actions and their effects is constrained by the action under consideration and incomplete information concerning the crab fisheries, including the absence of complete economic information and well-tested models that predict behavior under different institutional structures. In addition, exogenous factors, such as stock fluctuations, market dynamics, and macro condition in the global economy will influence the responses of the participants under each of the alternatives.

The economic and social analysis of fishing at these proposed OFL control rules is limited to qualitative descriptions of potential impacts rather than quantitative estimates because of uncertainty in crab TACs and prices. Because of the nature of the proposed action and the indeterminacy of prices, the discussion that follows considers the impact of the changes in finishing under OFL control rules independent of any price changes. In all cases, price increases would mitigate negative impacts of an alternative; price declines would exacerbate negative impacts.

This section is organized according to the tier structure in Alternatives 2 and 3, which is discussed in Chapter 2.

12.7.1 Tier 3 stocks

The economic impacts of the proposed OFL control rules depend on the extent to which those control rules constrain the existing harvest strategies used in establishing TACs. This analysis utilizes the results of short-term simulations of fishing at proposed OFL control rules on current biomass estimates for tier 3 stocks in order to estimate the potential constraint the proposed OFL control rules may have on the current (and projected) TACs for these species. Tier 3 stocks include Bristol Bay red king crab, snow crab, and Tanner crab. In addition, longer-term simulation results were also utilized in order to estimate long-term yield of these stocks under different control rules. While simulations were run in order to test the flexibility of these control rules for stock rebuilding scenarios, simulations provide some indication of potential yield from rebuilt and rebuilding stocks under these alternatives. Descriptions of the simulations and results of these simulations are found in Chapter 3.

Alternative 1 would maintain the existing status determination criteria. NMFS would still continue to determine whether a crab stock is overfished or approaching an overfished status by comparing the annual survey or model abundance estimate to the MSST for each surveyed stock. The MSST would continue to be set as ½ B_{MSY}, where B_{MSY} is the average of the survey biomass estimates from 1983-1997. Once a stock's total spawning biomass falls below MSST, the stock is considered overfished and a rebuilding plan must be developed. Currently, snow crab and Tanner crab are under rebuilding plans. The rebuilding plans for snow and Tanner crab allow for continued harvest while the stock is rebuilding. However, the Tanner crab fishery was closed from 1997 through 2005 due to low stock biomass levels. A BSAI crab stock is considered rebuilt when the stock exceeds the B_{MSY} for two consecutive years.

Alternatives 2 and 3 would revise the manner in which OFLs are established for BSAI crab stocks. Chapter 2 provides details regarding the proposed tier system to be utilized under these alternatives. Figure 12-1 and Figure 12-2 show historical harvest rates in conjunction with the proposed F_{35} and F_{40} control rules for F_{OFL} for Bristol Bay red king crab and snow crab. Looking at Bristol Bay red king crab in Figure 12-1, the legal harvest rates for 1997, 1998, 2004, and 2005, exceeded the F_{35} control rule, and 1996 and 2003 exceeded F_{40} control rule. Harvest rates in excess of the OFL control rule (F_{35}) would constitute overfishing, and thus the fishery would likely have been constrained during those years. For snow crab, Figure 12-2 is even more telling of the potential effects the proposed OFL control rule could have on the fishery. Using the proposed OFL control rule (F_{35}), the legal harvest rate exceeded the OFL control rule in 21 out of last 28 years. Only the harvest rate in 1979, 1983, 1984, 1985, 2000, 2004, and 2005, were below the proposed OFL control rule (F_{35}).

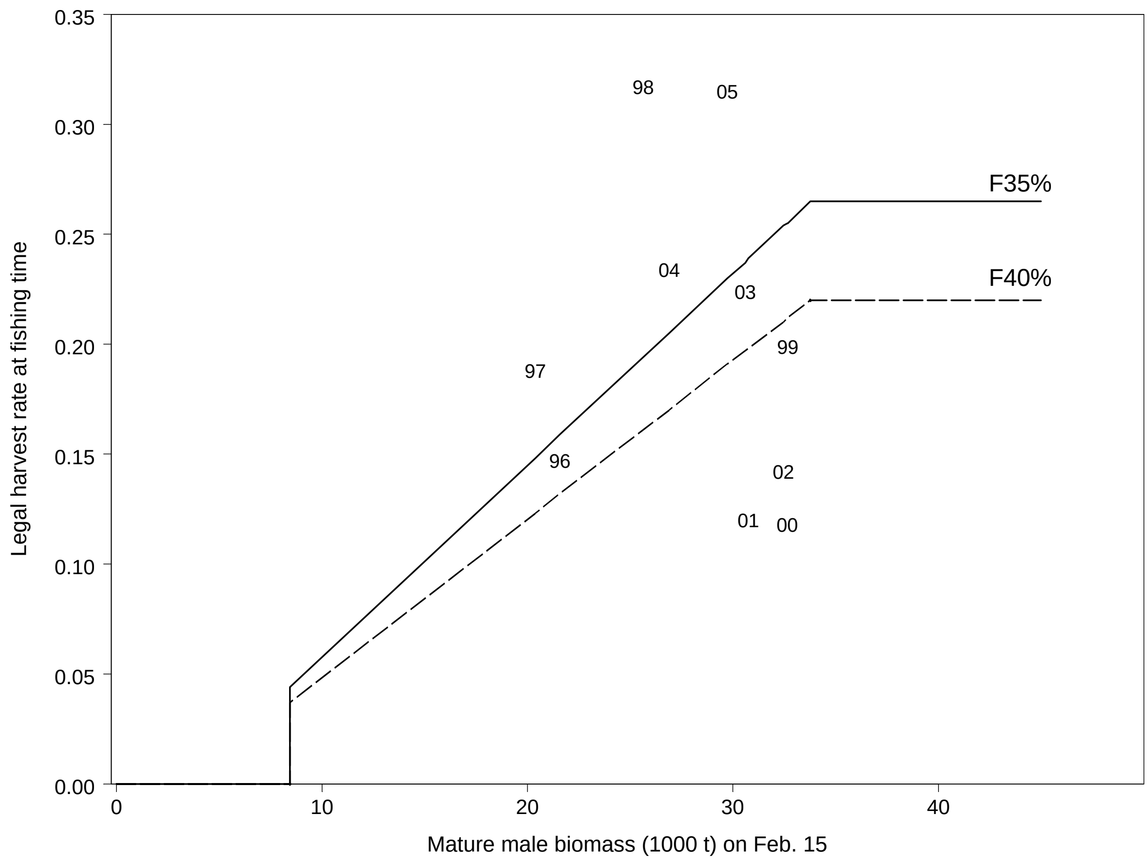

Figure 12-1 Relationships between legal harvest rate and mature male biomass on Feb. 15 for Bristol Bay red king crab. The dotted points are legal harvest rates from 1996 to 2005.

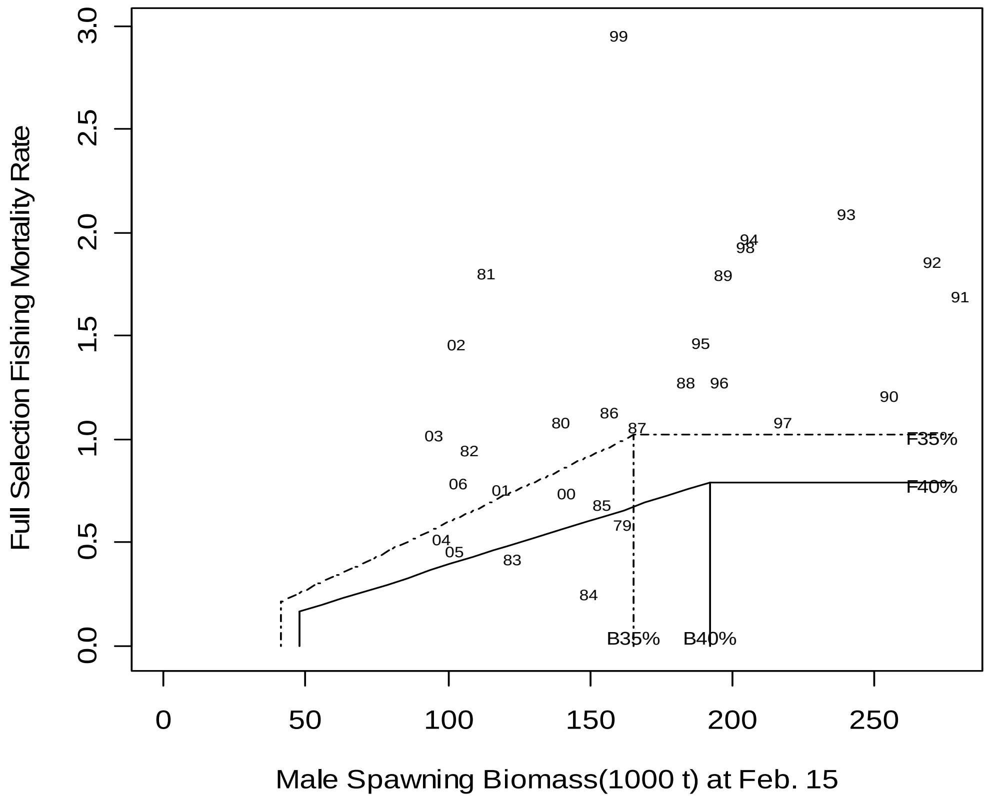

Figure 12-2 Full selection fishing mortality rate and male spawning biomass at February 15 estimated from the snow crab stock assessment model (Turnock and Rugolo 2006).

The impact of these proposed OFL control rules on future harvests is evaluated here using short-term simulations of the maximum allowable retained yield under the control rules for the current stock biomass for Bristol Bay red king crab, snow crab, and Tanner crab. These retained catch scenarios for F_{35} and F_{40} control rules are compared with the harvest projected under the status quo harvest strategy over the same time period. In order to avoid overfishing, TACs must be established below OFLs. Projections of the TACs under the status quo harvest strategy in conjunction with the maximum retained catch permitted by the proposed OFL control rules give an indication of the potential for the harvest strategy to be constrained by the proposed OFL, in which case the TAC would be adjusted downward accordingly.

Table 12-4 and Table 12-5 provide projected annual maximum retained catch from 2007 to 2012 using the existing status quo harvest strategy and F_{35} and F_{40} harvest control rules in the Bristol Bay red king crab, snow crab, and Tanner crab fisheries. The projected retained catch under F_{35} and F_{40} harvest control rules is an indication of the maximum retained catch that would be possible. Actual TACs would be below this but the exact buffer between projected OFL and TAC is unknown. For Bristol Bay red king crab, implementing either control rule would be projected to constrain harvests compared to the status quo harvest strategy in 2008. In 2009, projections indicate that the F_{40} control rule would constrain Bristol Bay red king crab harvests compared to the status quo harvest strategy, but the F_{35} would not. For snow crab, F_{35} control rule would constrain the status quo harvest strategy in 2010, 2011, and 2012, whereas F_{40} would be constraining for these same years plus 2008. Finally, for Tanner crab projections, the F_{35} and F_{40} harvest control rule would constrain harvests compared to the status quo harvest strategy for all years except 2009.[3] Figure 12-3, Figure 12-4, and Figure 12-5 demonstrate these simulation results for Bristol Bay red king crab, snow crab, and Tanner crab from 2010 to 2012.

Table 12-4 Projected retained catch for Bristol Bay red king crab and snow crab using existing harvest strategies and F40 and F35 harvest control rules from 2007 to 2012.

	Bristol Bay Red King Crab Projected Retained Catch (million of pounds)			Snow Crab Projected Retained Catch (millions of pounds)		
Year	**Status quo**	**F40**	**F35**	**Status quo**	**F40**	**F35**
2007	18.32	15.90	19.15	36.96	36.96	36.96
2008	23.47	18.62	21.55	61.38	46.42	61.82
2009	24.78	23.64	26.84	82.28	85.14	100.32
2010	23.45	26.14	29.06	78.32	70.40	77.22
2011	22.34	25.43	27.60	58.74	52.80	56.54
2012	21.52	23.77	25.30	71.28	62.04	68.20

Table 12-5 Projected retained catch for Tanner crab using existing harvest strategies and F40 and F35 harvest control rules from 2007 to 2012.

	Tanner Crab Projected Retained Catch (million of pounds)		
Year	**Status quo**	**F40**	**F35**
2007	14.78	12.23	14.64
2008	19.54	16.86	19.36
2009	20.97	22.02	24.85
2010	17.74	16.29	17.67
2011	15.70	14.08	15.22
2012	16.06	14.52	15.66

[3] Because a stock assessment model has not been developed for assessing Tanner crab abundance in the whole eastern Bering Sea, average of survey abundance during 2004-2006 was used as the initial abundance in 2006 for projection to smooth survey measurement errors.

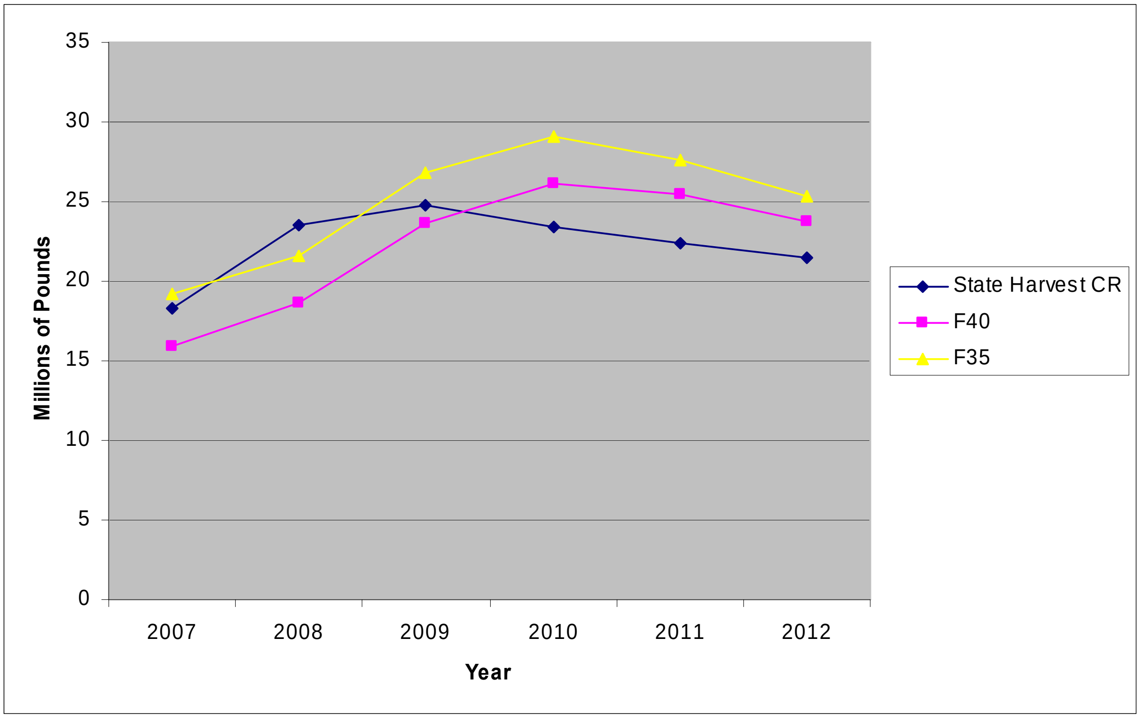

Figure 12-3 Projected retained catch for Bristol Bay red king crab under F40, F35, and existing harvest control rules from 2007 to 2012

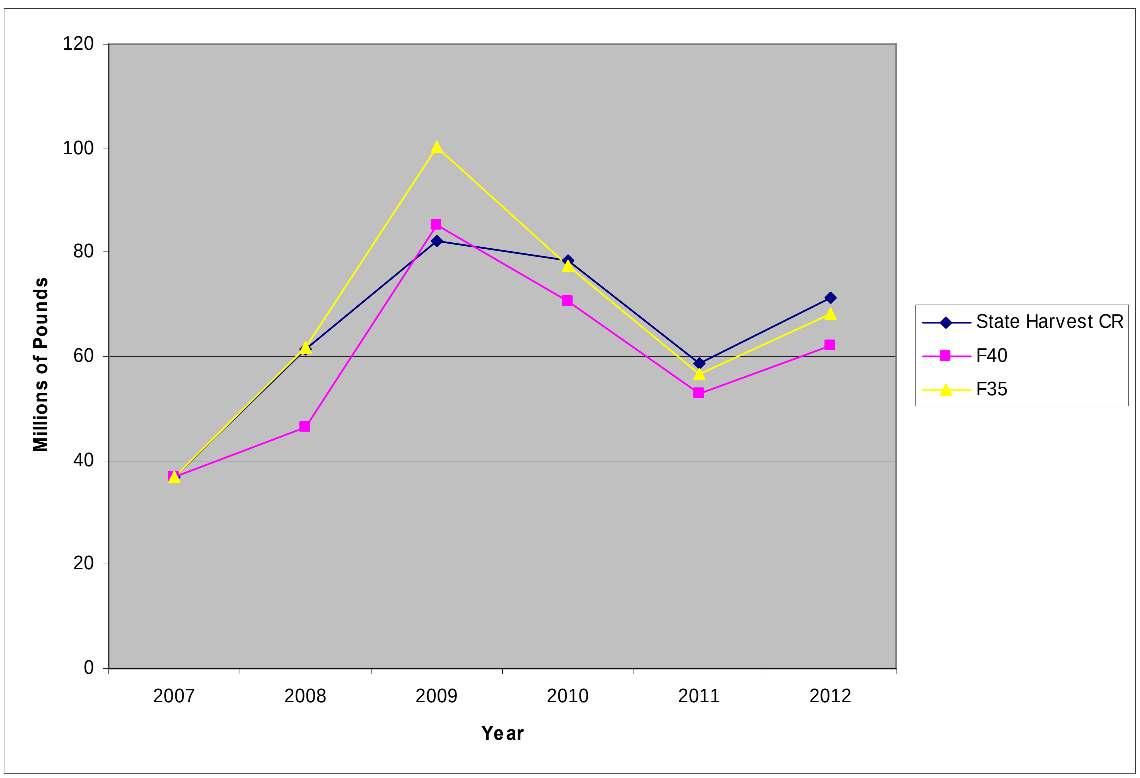

Figure 12-4 Projected retained catch for snow crab under F40, F35, and existing harvest control rules from 2007 to 2012

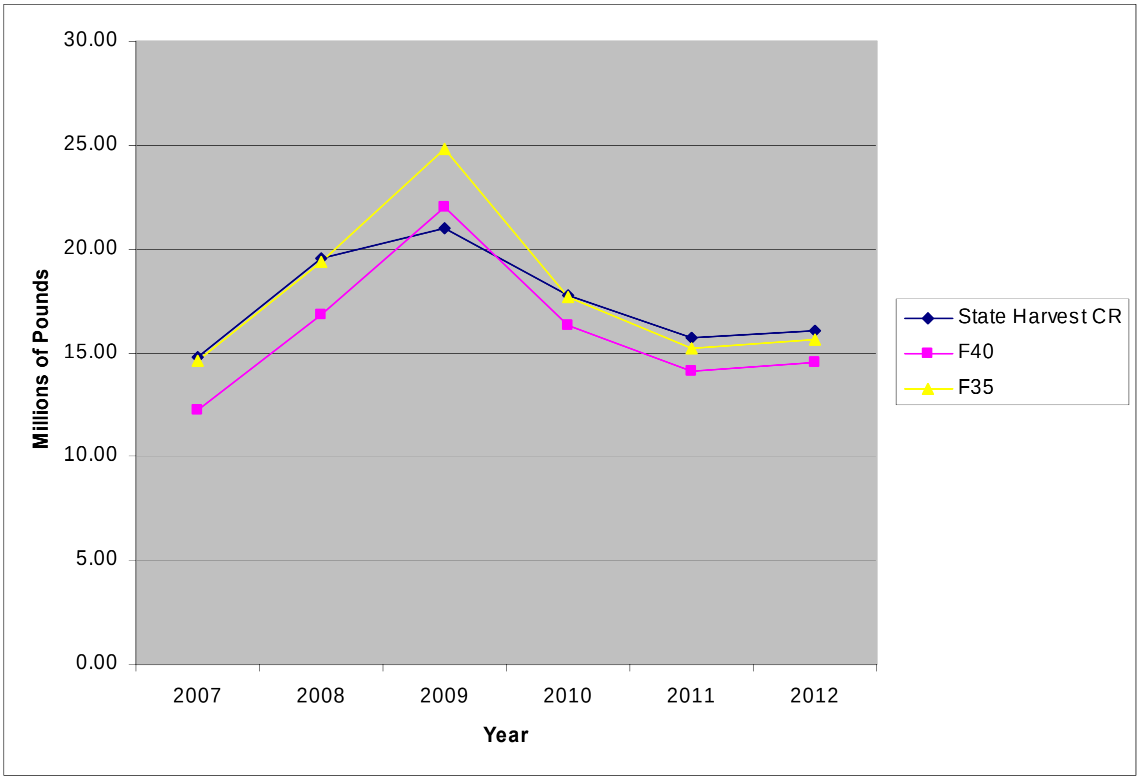

Figure 12-5 Projected retained catch for Tanner crab under F40, F35, and existing harvest control rules from 2007 to 2012

The short-term simulation projections suggest that TACs under Alternatives 2 and 3 would be less than under Alternative 1. The extent of this difference depends on the degree to which actual TACs are set below the proposed OFLs. Under the current status determination criteria, the MSY control rule for these fisheries has not been constraining. However, the proposed OFLs for Alternatives 2 and 3 would be lower than those under Alternative 1, so TACs will likely have to be set lower to adjust for the lower OFLs.

Setting TACs at or near the OFL creates some risk that the OFL could be exceeded, resulting in overfishing. Therefore, a buffer between the OFL would need to be incorporated into the setting of the TAC. The size of the buffer would depend on a number of factors. In general, the Crab Rationalization Program has reduced the potential for overharvest of the TAC. However, the risk of overharvest is increased by high discard rates. If discard practices observed in the first year of the program persist, it is necessary to establish a large buffer between the OFL and TAC to protect stocks.

In general, any decline in TACs is likely to contribute to reduced gross revenues to harvesters and processors in the fishery and could contribute to fleet consolidation. The reduction in revenues should be minimized to some degree given that the BSAI crab fisheries are rationalized. A rationalized crab fishery should allow harvesters and processors to operate more efficiently. In instances when TACs increase in later years because of lower TACs earlier years, gross revenues to harvesters and processors could increase and potentially result in some expansion of the fleet.

Thirty-year fishery simulations of ½ B_{MSY} and B_{MSY} in Table 12-6 and Table 12-7 provide an indication of the short-term yield under the status quo harvest strategy as compared to the proposed OFL control rules. The mean yields were estimated from 1000 simulations of a 30-year fishery with an initial mature male biomass of B_{MSY} and ½ B_{MSY}.

Table 12-6 First 10-year mean yield and next 20-year mean yield under existing harvest strategy for Bristol Bay red king crab and snow crab at an initial mature biomass of B_{MSY} and ½ B_{MSY}.

		Bristol Bay Red King Crab Projected Retained Catch (million of pounds)			Snow Crab Projected Retained Catch (millions of pounds)		
		Status quo	OFL CR	F35	Status quo	F40	F35
½ B_{MSY}	First 10yr mean yield	11.07	8.89	10.27	76.03	68.4	76.43
	Next 20yr mean yield	15.17	17.56	18.46	103.99	104.04	106.37
Bmsy	First 10yr mean yield	21.25	19.09	22.3			
	Next 20yr mean yield	17.75	18.05	18.94			

Table 12-7 First 10-year mean yield and next 20-year mean yield under the existing harvest strategy for Tanner crab at an initial mature biomass of B_{MSY} and ½ B_{MSY}.

		Tanner Crab Projected Retained Catch (million of pounds)		
		Status quo	F40	F35
½ B_{MSY}	First 10yr mean yield	10.44	9.3	10.51
	Next 20yr mean yield	14.49	18.4	19.56
B_{MSY}	First 10yr mean yield	13.9	16.39	13.9
	Next 20yr mean yield	15.12	19.2	20.46

For Bristol Bay red king crab at ½ B_{MSY} using the existing harvest control rule, simulated first 10-year mean retained yield is estimated to be approximately 11 million pounds (4,990 t), while the prediction for the next 20-year mean retained yield is estimated to be 15 million pounds (6,804 t). In contrast, ½ B_{MSY} using F_{40} is estimated 10-year mean retained yield is 9 million pounds (4,082 t), while the next 20-year mean retained yield is projected to be 18 million pounds (8,165 t). For F_{35}, the projections are slightly higher at 10 million pounds (4,536 t) for the first 10-year mean retained yield and 18 million pounds (8,165 t) for the next 20-year mean retained yield. At B_{MSY} using existing harvest control rule, the first 10-year mean retained yield is estimated to be 21 million pounds (9,526 t) while the next 20-year mean retained yield would be 18 million pounds (8,165 t). In contrast, using F_{40}, the first 10-year mean retained yield is projected to be 19 million pounds (8,618 t) while the next 20-year mean retained yield is projected to be 18 million pounds (8,165 t). Using F_{35}, the first 10-year mean retained yield is projected to be 22 million pounds (9,979 t) and the next 20-year mean retained yield is projected to be 19 million pounds (8,618 t). Overall, simulation results indicated the proposed OFLs for red king crab could result in slightly lower retained yield in the first ten years, which could result in some fleet contraction, followed by slightly higher retained yield during the next twenty years.

Looking at snow crab, at ½ B_{MSY} using the status quo harvest strategy, the first 10-year mean retained yield was estimated to be 76 million pounds (34,473 t), while the estimated mean yield for next 20 years is 104 million pounds (47,174 t). In contrast, using the proposed F_{40} harvest control rule, the first 10-year mean retained yield is 68 million pounds (30,845 t), while the next 20 years is projected to yield 104 million pounds (47,174 t). Using the proposed F_{35} harvest control rule, the projected first 10-year mean retained yield is 76 million pounds (34,473 t), while the next 20-year mean retained yield is projected to be 106 million pounds.

Looking Tanner crab, at ½ B_{MSY} using status quo harvest strategy, the first 10-year mean retained yield was estimated to be 10 million pounds (4,536 t), while the estimated mean yield for next 20 years is 14 million pounds (6,350 t). In contrast, using the proposed F_{40} harvest control rule, the first 10-year mean retained yield is 9 million pounds (4,082 t) which indicates a constrained fishery during this period, while the next 20 years is projected to yield 18 million pounds (8,165 t). Using the proposed F_{35} harvest control rule, the projected first 10-year mean retained yield is 11 million pounds (4,990 t), while the next 20-year mean retained yield is projected to be 20 million pounds (9,072 t).

Although in the short-run, retained yields could decline for Bristol Bay red king crab, snow crab, and Tanner crab, the proposed F_{35} and F_{40} control rules are estimated to produced higher retained yields and lower mean rebuilding time in the long-run. Given that the proposed OFLs control rules could result in higher retained yields and lower rebuilding times for these fisheries, this likely to contribute to increased gross revenues to harvesters and processors in the future and could contribute to some fleet expansion in the long-term.

12.7.2 Tier 4 stocks

Stocks that are proposed for Tier 4 management in this analysis are the following: Saint Matthew blue king crab, Pribilof Island blue king crab, Pribilof Island red king crab, EAI (Dutch Harbor) red king crab and Norton Sound red king crab. Of these, only the Norton Sound red king crab stock is currently open to fishing. Under Alternatives 2 and 3, the model estimate of mature male biomass for the Norton Sounds red king crab stock (Figure 4-6) is well above the B_{MSY} proxy for this stock, thus there is no indication that the fishery will be constrained by Alternatives 2 or 3.

Saint Matthew blue king crab and Pribilof Islands blue king crab stocks are both under rebuilding plans and are closed to fishing. Revised estimates of stock status under Alternatives 2 and 3 remain similar to estimates under Alternative 1. Should either Alternative 2 or 3 be adopted, rebuilding plans for both stocks may need to be re-evaluated and potentially revised given new estimates of stock recovery in relation to overfishing.

The Pribilof Island red king crab stock remains closed due to concerns with reliability of biomass estimates for the red king crab stock as well as the potential for bycatch of blue king crabs. There is no separate harvest strategy for the Pribilof Island red king crab stock (separate from the blue king crab stock). There has been some interest from the public in recent years for the Board of Fisheries to consider adopting a separate harvest strategy for this stock such that it may open on its own, given that stock status estimates (under Alternative 1) indicate that this stock is above its estimated $B_{MSY.}$ However, estimates of stock status in relation to B_{MSY} under Alternatives 2 and 3 (Figure 4-4) show the stock below the B_{MSY} and approaching an overfished condition. Should either Alternative 2 or 3 be adopted, it is unlikely that this stock will open to directed fishing.

Additional analysis of the economic and social effects of the proposed action for Tier 4 stocks is not included at this time due to insufficient analysis of proxy OFLs for these stocks at this time. A description of these effects will be included with an expanded analysis of these Tier 4 stocks.

12.7.3 Tier 5 stocks

Tier 5 stocks have no stock assessment model and essential life-history information and understanding is lacking. Under Alternatives 2 and 3, the historical performance of the fishery would be used to set the OFLs for stocks belonging to tier 5, unless the SSC established an alternative value based on the best available scientific information.

The golden king crab fishery in the Aleutian Islands has never failed to open due to low stock abundance, making it unique among BSAI king crab fisheries. Since 1998/1999 season, the State has set the AI golden king crab harvest level at 5.7 million pounds (2,586 t); 3.0 million pounds (1,361 t) of which is apportioned to the area east of 174° W. longitude, and 2.7 million pounds (1,225 t) is apportioned to the area west of 174° W longitude. During this time, an average of 19 vessels participated in this fishery. The average yield of the Aleutian Islands golden king crab from 1985 to 2005 is 7.527 million pounds (3,414 t), therefore, the OFL would be 7.527 million pounds (3,414 t) if historical fishery performance was used to set the OFL.

Pribilof golden king crab are found in commercial concentrations in only a few deep canyons in the Bering Sea and have never sustained a large harvests when compared to other Bering Sea king crab fisheries. The Pribilof District golden king crab fishery reached a maximum exvessel value of just over $1 million in 1995 and the highest price fishers received per pound was $3.81 in 1994. Fishing effort for the Pribilof Islands golden king crab was sporadic before 1993. CPUE fluctuated quite a bit over time. Based on fishing effort data, the appropriate period for catch average may be 1993 to 2005. The average yield during this period is 153,000 pounds (69 t). The State currently sets that GHL at 150,000 pounds (68 t), but due to economic factors, the GHL has not been harvested in some years. Under Alternatives 2 and 3, if historical fishery performance was used to set the OFL, OFL would be 153,000 pounds (69 t).

The Eastern Bering Sea grooved Tanner crab has had sporadic fishing effort during the last 10 years. CPUE appeared to have peaked in the early 1990s. The average yield is 248,000 pounds (112 t) for this stock. Under Alternatives 2 and 3, if historical fishery performance was used to set the OFL, OFL would be 248,000 pounds.

Adak red king crab has only been opened to fish for 4 years during the last 10 years. The average yield was very high for this stock, but the average yield since 1985 is 870,000 pounds (395 t). Under Alternatives 2 and 3, if historical fishery performance was used to set the OFL, OFL would be 870,000 pounds (395 t).

In general, the TACs or GHLs for tier 5 stocks that are open for fishing will likely not be constraining as a result of redefining the OFLs. Since tier 5 stocks have no stock assessment model and essential life-history information, the average historical performance of the fishery (CPUE) would be used to set the OFL, unless the SSC established an alternative value based on the best available scientific information. In most cases, the average historic yield is higher than the current yield for these stocks, so TACs or GHLs will not be affected by the proposed action. However, if CPUE increases in the future, TACs or GHLs could be constrained by the proposed OFLs. In general, a constrained TAC or GHL would result in short-term reduced gross revenue for harvesters and processors and a potential for long-term increases in biomass and therefore long-term increases in TACs or GHLs.

12.7.4 Tier 6 stocks

Tier 6 stocks lack sufficient information to determine an OFL. Stocks are monitored for trends in fishing effort, CPUE, mean size landed crab, and ratio of landed newshell to oldshell crab. Under Alternatives 2 and 3, stocks would be evaluated annually for upgrading to tier 5 for OFL determination. Since these stocks will not receive an OFL, these stocks would not be affected by the proposed action.

The following tier 6 crab species are bycatch fisheries only:

- Western Aleutian Tanner crab is a bycatch fishery for the directed red king crab fishery. There has been no catch since 1997 for this fishery.
- Aleutian Islands scarlet king crab is also a bycatch fishery for the directed golden king crab fishery.
- Eastern Bering Sea scarlet king crab is a bycatch fishery for the directed grooved Tanner crab fishery.
- Bering Sea triangle Tanner crab is a bycatch only fishery for the directed grooved Tanner crab fishery.

The following tier 6 crab species are exploratory fisheries only:

- Saint Matthew golden king crab has since hardly any fishing effort during the last 10 years.
- Saint Lawrence Islands blue king crab has little or no fishing effort.
- Eastern Aleutian Islands triangle and grooved Tanner crab has only since 808 pot lifts during the last years.
- Western Aleutian Islands grooved Tanner crab has no fishing effort during the last 10 years.

13 Cumulative Impacts

Analysis of the potential cumulative effects of a proposed action and its alternatives is a requirement of NEPA. Cumulative effects are those combined effects on the quality of the human environment that result from the incremental impact of the proposed action when added to other past, present, and reasonably foreseeable future actions, regardless of what Federal or non-Federal agency or person undertakes such other actions (40 CFR 1508.7, 1508.25(a), and 1508.25(c)). Cumulative impacts can result from individually minor, but collectively significant actions taking place over a period of time. The concept behind cumulative effects analysis is to capture the total effects of many actions over time that would be missed by evaluating each action individually. At the same time, the CEQ guidelines recognize that it is not practical to analyze the cumulative effects of an action on the universe, but to focus on those effects that are truly meaningful.

The cumulative effects of the Crab Rationalization Program are analyzed in Section 4.9 of the Crab EIS, including the interactive effects of any past, present, and reasonable foreseeable future external actions. That analysis is incorporated by reference. The Crab EIS concludes that for majority of the components of the environment analyzed, the cumulative effects of the Crab Rationalization Program are insignificant based on the best available scientific information. For some environmental components analyzed, the Crab EIS determined the cumulative effects were unknown, because of a lack of sufficient information on the cumulative condition or the inability to predict effects of external future actions. The cumulative effects analysis in the Crab EIS is detailed and broad enough to encompass the likely cumulative effects of fishing under the Crab Rationalization Program. No new significant information is available that would change these determinations in the Crab EIS. This action will not result in additional impacts beyond those considered in the Crab EIS and is not anticipated to change any of the cumulative effects conclusions. As previously discussed, the alternatives are only expected to impact the BSAI crab stocks and fisheries.

The following reasonably foreseeable future actions may have a continuing, additive and meaningful relationship to the direct and indirect effects of the alternatives.

Implementation of the non-AFA trawl CP cooperatives under Amendment 80 and the establishment of separate PSC allocations to this sector (proposed under both Amendments 80 and 85), this sector should be better able to utilize its PSC in relation to its target fisheries. This may result in harvesting a greater share of the BSAI Pacific cod allocated to the trawl CP sector than has been harvested in the past and potentially reducing overall PSC use. Currently, the entire trawl CP sector is allocated 23.5% of the BSAI Pacific cod ITAC and the non-AFA trawl CP sector has harvested about 13%–14% of the ITAC on average during 1995–2003, with the highest shares (15%–18%) in the most recent years (1999–2003). Note that the AFA CP sector has harvested about 2%–3% of the ITAC on average during 1995–2003, with the lowest shares (about 1%) in the most recent years (2000–2003). Together the two trawl CP sectors harvested (retained catch) an average of 15%–16% of the BSAI Pacific cod ITAC, compared to the 23.5% allocated. Crab PSC is typically not a strong concern for the BSAI Pacific cod trawl fisheries; however, there have been occasional PSC crab closures in the past. In 2002, both the A season trawl CP fishery and the A season trawl CV fisheries were closed by red king crab PSC harvests in zone 1. In 1997, both the A season trawl CP and trawl CV fisheries were similarly closed in zone 1 due to the PSC limit for snow crab (NPFMC 2005 AM80 ref).

13.1 Amendment 80 Cumulative Impacts

In June 2006, the Council approved a bycatch reduction program in the BSAI for the Head and Gut (H&G) trawl CP sector, which target flatfish, Pacific cod, and Atka mackerel. The H&G trawl CP primarily participates in multi-species fisheries that operates under a management regime that results in a "race for fish", wherein vessels attempt to maximize their harvest in as little time as possible, in order to claim a larger share of the available quota. Because vessels are competing with each other for shares of a common quota, an individual vessel may be penalized for undertaking actions to reduce unwanted incidental catch, such as searching for cleaner fishing grounds. To provide the sector with a tool to increase economic efficiency, while reducing incidental catch and minimizing waste, the Council in June 2006, approved an action that would eliminate the race for fish among members of the sector that agreed to join an Amendment 80 cooperative.

Among the most significant elements of this action was allocation of groundfish species and PSC and cooperative formation. Allocation percentages selected were 100 percent of rock sole and flathead sole. For yellowfin sole, the allocation percent is variable dependent upon the ITAC level, but ranges between 93 percent at ITAC level ≤ 87,500 and 60 percent at ITAC level > 125,000. For Atka mackerel and AI POP, the Council selected an approach that would phase in the final allocation percentages over a period of years. The Council also allocated halibut PSC and crab PSC to the H&G trawl CP sector. For halibut, the allocation in the first year would be 2,525 mt. During the second, third, fourth, and fifth year after implementation, the allocation to the H&G sector would be reduced from 2,525 mt to 2,325 mt by 50 mt for each year. The remaining 875 mt of halibut PSC would be apportioned to the remaining trawl sectors (BSAI trawl limited access). For crab PSC, the Council selected percentages based on the historic usage of crab PSC in all groundfish fisheries from 2000-2002, for red king crab and from 1995-2002, for snow and Tanner crab. Below are the crab PSC limits selected by the Council for the H&G trawl CP sector:

Red king crab	62.48%
Snow crab	61.44%
Zone 1 Tanner	52.44%
Zone 2 Tanner	29.59%

Like halibut, the crab PSC limit to the H&G trawl CP sector would be reduced to 80 percent of the initial allocation. This reduction would be phased in gradually at 5 percent per year starting in the second year of the program. Allocation of crab PSC to the trawl limited access group (all other trawl sectors minus the H&G trawl CP sector) equal to the sum of the AFA CP and CV sideboards.

Based on the eligibility requirements under this action, 26 vessels appear to qualify for the H&G trawl CP sector. Thirty percent of these eligible vessels would be needed to form a cooperative. Allocation of Amendment 80 species and PSC allowance would be allocated to cooperatives and non-cooperative pool based on total catch using years 1998-2004, dropping the two lowest annual aggregate catch years.

13.2 Expected Effects

According to the Public Review Draft EA/RIR/IRFA prepared by the NPFMC (2006), the H&G trawl CP sector is likely to realize some games in production efficiency under the cooperative program, capturing greater rents from the fishery. The favorable groundfish allocation, PSC allocation, and the ability to form cooperatives, contribute to increases in efficiency gains. Gains in efficiency should also occur as participants are able to slow the pace of fishing and processing. In the slower fishery, participants are likely to be able to reduce expenditures on inputs to some

In a cooperative, participants will be free to consolidate fishing up the 20 percent vessel cap. Consolidating catch on fewer vessels in the fishery should also reduce harvest costs. In addition, the action would reduce the overall allowance of halibut PSC and crab PSC to the trawl sectors. For halibut PSC, the reduction in trawl PSC will result in a total of 300 mt of halibut savings during the second, forth, and fifth years combined after implementation and then additional 150 mt every year after the fifth year, not including any halibut savings from rollovers. For crab PSC, the effect of Amendment 80 will result in reduction in the trawl crab PSC allowance and ultimately crab PSC savings. Table 13-1 provides a comprehensive view of the allocations of crab PSC under Amendment 80, the percent of crab PSC available to the trawl limited access fishery (i.e., the sum of the AFA CP and AFA CV sideboard percentages), the percent of crab PSC available to the H&G trawl CP sector during the first five years of the program, and the percent of trawl crab PSC that would be unavailable in the first five years of the program, as a result of the limited allocations under Amendment 80.

Table 13-1 Crab PSC apportionment rate and amounts using 2005 PSC limits for the H&G trawl CP sector and the trawl limited access group during the first five years.

		Apportionment Percent to Sector and Staying In Water			Apportionment Amount Using 2005 PSC Limits		
	PSC Species	**Non-AFA Trawl CP Sector**	**Trawl Limited Access**	**Remaining % of Crab Staying in Water**	**Non-AFA Trawl CP Sector**	**Trawl Limited Access**	**Remaining % of Crab Staying in Water**
Year 1	Red King Crab	62.68%	30.58%	6.74%	114,219	55,724	12,282
	Opilio	61.44%	32.14%	6.42%	3,274,474	1,712,917	342,157
	Zone 1 Bairdi	52.64%	46.90%	0.46%	477,182	425,149	4,170
	Zone 2 Bairdi	29.59%	23.60%	46.81%	812,911	648,351	1,285,988
Year 2	Red King Crab	59.55%	30.58%	9.87%	108,515	55,724	17,986
	Opilio	58.37%	32.14%	9.49%	3,110,857	1,712,917	505,774
	Zone 1 Bairdi	50.01%	46.90%	3.09%	453,341	425,149	28,011
	Zone 2 Bairdi	28.11%	23.60%	48.29%	772,252	648,351	1,326,647
Year 3	Red King Crab	56.41%	30.58%	13.01%	102,793	55,724	23,707
	Opilio	55.30%	32.14%	12.56%	2,947,240	1,712,917	669,391
	Zone 1 Bairdi	47.38%	46.90%	5.72%	429,500	425,149	51,852
	Zone 2 Bairdi	26.63%	23.60%	49.77%	731,593	648,351	1,367,306
Year 4	Red King Crab	53.28%	30.58%	16.14%	97,089	55,724	29,411
	Opilio	52.22%	32.14%	15.64%	2,783,090	1,712,917	833,541
	Zone 1 Bairdi	44.74%	46.90%	8.36%	405,568	425,149	75,783
	Zone 2 Bairdi	25.15%	23.60%	51.25%	690,933	648,351	1,407,966
Year 5	Red King Crab	50.14%	30.58%	19.28%	91,368	55,724	35,133
	Opilio	49.15%	32.14%	18.71%	2,619,473	1,712,917	997,158
	Zone 1 Bairdi	42.11%	46.90%	10.99%	381,727	425,149	99,624
	Zone 2 Bairdi	23.67%	23.60%	52.73%	650,274	648,351	1,448,625

13.3 Bristol Bay Drilling Cumulative Effects

President Bush on January 9, 2007 lifted a ban on new oil and gas drilling in Alaska's Bristol Bay. The area stretches from Port Moller to Unimak Pass and ranges from 11 to more than 100 miles offshore. The area has been closed to drilling since 1989. The government estimates the area could contain large amounts of oil and natural gas reserves, although no oil or gas reserve have yet to be discovered in the area. Within the basin, the marine environment is home to pollock, Pacific cod, flatfish, and crab fisheries as well as many of the salmon species. The basis is also home to a protected halibut area and critical habitat area for red king crab. Oil development in the area could have an impact on the marine environment and its many commercial fisheries if a significant oil spill were to happen. As seen in the Exxon Oil spill, a marine oil spill will severally harm critical habitat and those that rely on that habitat for biological or economic survival.

14 National Standards and Fishery Impact Statement

14.1 National Standards

Below are the ten National Standards as contained in the Magnuson-Stevens Act, and a brief discussion of the consistency of the proposed alternatives with each of those National Standards, as applicable.

National Standard 1

Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery

National Standard 2

Conservation and management measures shall be based upon the best scientific information available.

National Standard 3

To the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination.

National Standard 4

Conservation and management measures shall not discriminate between residents of different states. If it becomes necessary to allocate or assign fishing privileges among various U.S. fishermen, such allocation shall be (A) fair and equitable to all such fishermen, (B) reasonably calculated to promote conservation, and (C) carried out in such a manner that no particular individual, corporation, or other entity acquires an excessive share of such privileges.

National Standard 5

Conservation and management measures shall, where practicable, consider efficiency in the utilization of fishery resources, except that no such measure shall have economic allocation as its sole purpose.

National Standard 6

Conservation and management measures shall take into account and allow for variations among, and contingencies in, fisheries, fishery resources, and catches.

National Standard 7

Conservation and management measures shall, where practicable, minimize costs and avoid unnecessary duplication.

National Standard 8

Conservation and management measures shall, consistent with the conservation requirements of this Act (including the prevention of overfishing and rebuilding of overfished stocks), take into account the importance of fishery resources to fishing communities in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities.

National Standard 9

Conservation and management measures shall, to the extent practicable, (A) minimize bycatch, and (B) to the extent bycatch cannot be avoided, minimize the mortality of such bycatch.

National Standard 10

Conservation and management measures shall, to the extent practicable, promote the safety of human life at sea.

14.2 Section 303(a)(9) – Fisheries Impact Statement

Section 303(a)(9) of the Magnuson-Stevens Act requires that any management measure submitted by the Council take into account potential impacts on the participants in the fisheries, as well as participants in adjacent fisheries. The impacts of the alternatives participants in the fisheries have been discussed in Chapter 11 of this document.

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Appendix A.

A.1 Notations used in the equations

B = a general term for spawning biomass,

et = average time elapsed between the mid molting date (i.e., start of a biological year) and start date of a fishing period as a fraction of a year,

F_T = bycatch fishing mortality by the trawl fishery, a fixed value of 0.01 was used,

HM_j = instantaneous handling mortality for size j,

HR = harvest rate,

$immatN_{i,k,t}$ = new-shell immature abundance of length-class i, age k, and year t,

$immatO_{i,k,t}$ = old-shell immature abundance of length-class i, age k, and year t,

$mmolt_i$ = mature crab molt probability of length-class i,

$immolt_i$ = immature crab molt probability of length-class i,

L_c = minimum legal size,

mat = maturity probability,

n = total number of length intervals available in a cohort for $P_{i,j}$ estimation,

$N_{i,k,t}$ = new-shell stock abundance in number in length-class i, age k, and year t,

$O_{i,k,t}$ = old-shell stock abundance in number in length-class i, age k, and year t,

$P_{i,j}$ = probability of crabs in a length-class i growing into a length-class j,

R_0 = number of recruits to model at F=0,

R_{max} = maximum number of recruits to model,

s'_i = trawl bycatch selectivity for length-class i,

s_i = pot fishery retained/discard selectivity for length-class i (For convenience, the same notation is used, but the function takes different forms and/or parameter values in each case.),

S-R = spawner-recruit relationship,

k = age in years,

W_i = mean weight of crabs in a length-class i,

x = a random variable representing the annual growth increment,

α, β, γ, ϕ, ω, θ, a, b, c, d = parameters in the control rule formula, and primary and auxiliary models,

τ = extinction parameter, and

δ = duration of average fishing period as a fraction of a year (handling and fishing mortalities occur during this time period).

A.2 Equations

The following assumptions are made to simplify the derivation in all analyses:

1. Mortality takes place immediately before growth.
2. Instantaneous natural mortality, M, is constant.
3. Mature male biomass is estimated after the fishery before the next molting period
4. Recruits generated from S-R models have 1:1 sex ratio.

1 The population dynamics model

1.1 Basic dynamics

The abundance of different stages and shell conditions of crabs (in number) of age k growing from smaller size classes i into a larger size class j at the start of year t+1 was determined by,

$$matN_{j,k+1,t+1} = \sum_{i=1}^{j} \begin{bmatrix} (matN_{i,k,t} + matO_{i,k,t})\ mmolt_i\ P_{i,j} + \\ (immatN_{i,k,t} + immatO_{i,k,t})\ immolt_i\ mat_j P_{i,j} \end{bmatrix} e^{-(M + F_T s'_i + (F s_i + HM_i)\ \delta)}$$

(B.1)

$$matO_{j,k+1,t+1} = \sum_{i=1}^{j} [(matN_{i,k,t} + matO_{i,k,t})(1 - mmolt_i)]\ e^{-(M + F_T s'_i + (F s_i + HM_i)\ \delta)}$$

(B.2)

$$immatN_{j,k+1,t+1} = \sum_{i=1}^{j} [(immatN_{i,k,t} + immatO_{i,k,t})\ immolt_i\ (1 - mat_j) P_{i,j}]\ e^{-(M + F_T s'_i + (F s_i + HM_i)\ \delta)}$$

(B.3)

$$immatO_{j,k+1,t+1} = \sum_{i=1}^{j} [(immatN_{i,k,t} + im\,matO_{i,k,t})(1 - immolt_i)]\ e^{-(M + F_T s'_i + (F s_i + HM_i)\ \delta)}$$

(B.4)

The size specific abundances in the last age group were adjusted to include the plus groups by adding the final year abundances projected by the annual growth and mortality.

The size specific abundances in numbers are converted to biomasses by multiplying them by size specific weights. Total mature male biomass (B) for S-R is calculated by projecting the abundances from molting time (April 1) to February 15.

The total mature male biomass-per-recruit is calculated as

$$B/R = \text{mature male biomass}/R_{male} \quad \text{(B.5)}$$

2 Stochastic S-R models and steepness parameter

$$R = \frac{B}{\alpha + \beta B} e^{\varepsilon_t - \sigma^2_{\varepsilon_t}/2} \quad \text{(Beverton and Holt, 1957)} \quad \text{(B.6)}$$

$$R = \gamma B e^{-\theta B} e^{\varepsilon_t - \sigma^2_{\varepsilon_t}/2} \quad \text{(Ricker, 1954)} \quad \text{(B.7)}$$

where,

$\varepsilon_t = \rho * \varepsilon_{t-1} + e_t$ and $e_t \sim N(0, \sigma^2_e)$
(ρ is the autocorrelation)

Mace (1994) defined the extinction parameter, τ, as

$$\tau = \frac{(B/R)_{B=0}}{(B/R)_{F=0}} \quad \text{(B.8)}$$

where $(B/R)_{F=0}$ = B/R estimated at F = 0, and
$(B/R)_{B=0}$ = reciprocal of the slope at the origin of the S-R curve, equal to α for the Beverton and Holt S-R model and $1/\gamma$ for the Ricker S-R model.

Therefore,

$$\alpha = \tau (B/R)_{F=0} \quad \text{for Beverton and Holt S-R curve, and} \quad \text{(B.9)}$$

$$\gamma = \frac{1}{\tau (B/R)_{F=0}} \quad \text{for the Ricker S-R model.} \quad \text{(B.10)}$$

The τ is related to the S-R steepness parameter, h,

$$h = 0.2 \times e \times \tau^{0.2} \ln(\frac{1}{\tau}) \quad \text{(B.11)}$$

for Ricker S-R model with *h* defined as $h \times R_{max} = R$, where R is estimated from the S-R curve with $0.2*B_0$, and

$$h = \frac{1}{1 + 4\tau} \quad \text{(B.12)}$$

for Beverton-Holt S-R model with *h* defined as $h \times R_0 = R$, where R is estimated from the S-R curve with $0.2*B_0$.

3 Catch

3.1 Retained catch

Estimation of legal-sized male catch and abundance at the fishing time in year t:

Total retained catch:

$$c_t = \sum_{j=L_c,k} (N_{j,k,t} + O_{j,k,t})(\frac{F s_j}{(M+F_T s'_j+F s_j+HM_j)})(e^{-(M+F_T s'_j) et}(1-e^{-(M+F_T s'_j+F s_j+HM_j)\delta})$$

(B.13)

$$y_t = \sum_{j=L_c,k} (N_{j,k,t} + O_{j,k,t})(\frac{F s_j}{(M+F_T s'_j+F s_j+HM_j)})(e^{-(M+F_T s'_j) et}(1-e^{-(M+F_T s'_j+F s_j+HM_j)\delta}) w_j$$

(B.14)

3.2 Total catch

Discard catch was computed using the same equations (B.13 and B.14) replacing F s_j in the numerator by HM_j (i.e., size specific handling mortality). Trawl bycatch was estimated similarly replacing F s_j by F_T s'_j. Retained, discard, and trawl bycatch were summed up to get the total catch.

Note: In the stochastic simulations, the annual total catch and abundance were averaged for a number of years of the fishery to estimate relevant statistics for each simulation.

Total abundance of crabs that contribute to the catch are also estimated as,

$$N_t = \sum_{k=t_r}^{\lambda} \sum_{j=1}^{n} N_{j,t} e^{-(M+F_T s'_j)et} \quad \text{(B.15)}$$

The harvest rate (HR) for a given F is estimated as

$$HR = \frac{C}{N} \quad \text{(B.16)}$$

4 Auxiliary Models

1.The instantaneous handling mortality for size j, HM_j, is defined as a function of F with discard selectivity s_j, ignoring M and trawl and other bycatch mortality as follows:

$$1 - e^{-HM_j \delta} = h(1 - e^{-F s_j \delta}) \quad \text{(B.17)}$$

Where s_j = discard selectivity.

2. Logistic model is used to estimate molt probability and maturity probability. For Tanner and snow crab, the immature crab molt probability is set to 1 and mature crab molt probability is set to zero. For red king crab, female molt probability is set to 1.

3. Gamma distribution function is used to estimate growth increment probability and recruit distribution probability.

4. Standard size-weight equation ($W = aL^b$) was used to determine weight (W) by size (L).

Appendix B. Base parameters of red king crab for simulations.

CL=carapace length. Molt probability, growth matrix, recruit proportion in each length bin, retained and discards selectivity values were directly used from the length-based model outputs.

Parameter	Male	Female	Remarks
Size range (mm CL)	65-200	65-165	
Instantaneous M	0.18	0.1	Based on 26-year longevity with 1% survival at maximum age
Pot fishery handling mortality rate (hm)	0.1, 0.2[a], 0.3	0.1, 0.2[a], 0.3	[a]Kruse et al., 2000; Model estimate of discard selectivity with M=0.18 using 1985-2006 data
Trawl fishery bycatch death proportion	0.8	0.8	Model estimate of trawl selectivity with M=0.18 using 1985-2006 data
Mean fishing period (yr)	0.2534	0.2534	October 15 – January 15 fishing
Lapsed time (yr)	0.5425	0.5425	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	[a] Model output	100% molt[b]	[a]Model estimates with M=0.18 using 1985-2006 data; [b]Zheng et al.,1995a
Recruit distribution	Model output	Model output	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	0.000361, 3.16[a]	0.022863, 2.23382[b]	[a]Balsiger, 1974; [b] Brad Stevens, personal communication (unpublished)

Appendix C. Base parameters of Tanner crab for simulations.

CW=carapace width

Parameter	Male	Female	Remarks
Size range (mm CW)	70-170	70-170	
Instantaneous M	0.23	0.29	Based on 20-year and 16-year longevity with 1% survival at maximum age
Pot fishery handling mortality rate (hm)	0.20	0.20	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)	0.3356	0.3356	October 15 – arbitrary cut off fishing date, February 14
Lapsed time (yr)	0.5425	0.5425	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	0.07754, 130.854	0.126, 83.51	Zheng, unpublished
Molt Probability:			
Immature	100% molt	100% molt	
Mature	0%	0%	
Recruit Distribution	mean 82.5 mm, β_r = 1.023	mean 80.7 mm, β_r = 0.955	Recruit proportion Gamma distribution, β_r from Zheng and Kruse, 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, 3.09894	0.003661, 2.563912	Somerton, 1981; Brad Stevens, personal communication (unpublished)

Appendix D. Crab Workshop Report

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

April 20, 2006

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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 necessary to 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 pending approval by an open peer review process. 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 (20 years) being used at present is too high. Maximum age depends upon the instar at which terminal molt (maturity) is attained and how long females survive thereafter. 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. Therefore, based on growth data for the Atlantic, the maximum age of females maturing in instar X (mean size of about 56 mm CW) is more likely to be 12-13 years. Females maturing one or two instars larger (i.e., XI at about 66 mm CW or XII at about 77 mm CW) would respectively live to be about 13-14 and 14-15years 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 slightly greater if appropriate (depending on instar for maturity)
- 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	$\beta < \frac{B}{B_{msy}} \le 1$	$F_{OFL} = \mu_A \frac{B/B_{msy} - \alpha}{1-\alpha}$
	1c	$\frac{B}{B_{msy}} \le \beta$	$F_{OFL} = 0$
B, B_{msy}, F_{msy},	2a	$\frac{B}{B_{msy}} > 1$	$F_{OFL} = F_{msy}$
	2b	$\beta < \frac{B}{B_{msy}} \le 1$	$F_{OFL} = F_{msy} \frac{B/B_{msy} - \alpha}{1-\alpha}$
	2c	$\frac{B}{B_{msy}} \le \beta$	$F_{OFL} = 0$
B, F_{msy}, $B_{msy^{prox}}$	3a	$\frac{B}{B_{msy^{prox}}} > 1$	$F_{OFL} = F_{msy}$
	3b	$\beta < \frac{B}{B_{msy^{prox}}} \le 1$	$F_{OFL} = F_{msy} \frac{B/B_{msy^{prox}} - \alpha}{1-\alpha}$
	3c	$\frac{B}{B_{msy^{prox}}} \le \beta$	$F_{OFL} = 0$
B, M, $B_{msy^{prox}}$	4a	$\frac{B}{B_{msy^{prox}}} > 1$	$F_{OFL} = \gamma M$
	4b	$\beta < \frac{B}{B_{msy^{prox}}} \le 1$	$F_{OFL} = \gamma M \frac{B/B_{msy^{prox}} - \alpha}{1-\alpha}$
	4c	$\frac{B}{B_{msy^{prox}}} \le \beta$	$F_{OFL} = 0$
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 spawning 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 determination 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.

Crab Overfishing Definitions Inter-Agency Workshop

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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)

Attachment 3: Powerpoints presented during the workshop (contact the Council office for copies)

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 Structutures**

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** (contact the Council office for copies)

Attachment 5 **Progress report of workgroup** (contact the Council office for copies)

Appendix E. CIE Review

Center for Independent Experts (CIE)

Reviews of the Crab Stock Overfishing Definition

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Review of

Alaska Crab Overfishing Definitions

24-28 April 2006, Seattle, Washington

Report to

University of Miami Independent System for Peer Reviews

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Contents

Executive summary

- This report is a review of proposed overfishing definitions (OFD) for Bering Sea and Aleutian Islands (BSAI) king and Tanner crab stocks. An OFD is required to meet National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. The proposal is for a five tier system, specifying an MSY control rule within each tier, and is intended to replace the existing three tier system.
- The existing OFD provides no effective cap on exploitation rates. As a framework, the proposed OFD represents a major improvement. If successfully implemented it will meet the National Standard 1 requirement for MSY control rules which, if implemented as a harvest strategy, would be expected to result in a long-term average yield approximating MSY. There are, however, a number of issues that need to be addressed before the proposed OFD could be implemented.
- The proposed framework is comprehensive and adaptable, allowing the definition of MSY control rules in a very flexible way. The disadvantage of this flexibility is that it also implies complexity – there are a number of parameters for which default values will need to be determined before implementation.
- The main difficulty in establishing default parameter values, and in finding proxy values for reference points in Tiers 3 and 4 of the proposed OFD, is in the definition of effective spawning biomass (ESB). ESB is used in the MSY control rules and in the stock-recruitment relationships that are used to find proxy values for F_{MSY} and to test the performance of the proposed OFD under various parameterisations. Any satisfactory definition of ESB must (a) be demonstrably proportional to total fertilised egg production (TFEP), and (b) be responsive to fishing mortality. The first criterion is met by none of the definitions of ESB considered thus far. The problem arises out of the complex mating systems of king and Tanner crabs coupled with fisheries directed only at males. Simple mating ratios appear inadequate to capture this complexity.
- Suggestions for simple interim definitions of ESB are made in this report, together with recommendations for further research to identify more satisfactory alternatives to be used in the future.
- Simulation modelling was used to compare the performance of OFDs and to provide insight into likely default values for parameters in the proposed OFD. This approach is sound in principle and correctly specified in practice (in terms of model structures), but given that the simulation outcomes depend on a correctly specified measure for ESB no default parameter values can yet be recommended.
- Simulations were undertaken by two modelling teams. This is a strength in terms of allowing critical analysis of assumptions and robust conclusions. However, there are differences between the teams in their interpretation of the available scientific evidence on some fundamental issues of crab life history. These differences will need to be resolved in order to progress the simulation modelling to a final outcome.
- Simulation outcomes were largely judged in terms of rebuilding times for depleted stocks. Other aspects of OFD performance will need to be tested, such as the trade-off

between rebuilding times and level and constancy of yield. It should also be recognised that maintaining sustainable exploitation of healthy stocks is as important a function of an OFD as allowing recovery of depleted stocks.

- An important problem with the simulations was that the MSY control rule was treated as if it was a harvest control rule. This fails to recognise the role of the State in defining a precautionary buffer between target and limit fishing mortality rates. It is also likely to lead to selection of default parameter values for the proposed OFD that will place undue constraints on the capacity of the State to manage the fisheries according to precautionary and other objectives. It is recommended that MSY control rules are always tested in conjunction with realistic State harvest strategies in the simulations.
- It is concluded that, although work remains to be done before the proposed OFD can be implemented, the obstacles to successful implementation are not insurmountable. Given the urgent need for the existing OFD to be replaced by a more satisfactory alternative, it is recommended that a simple interim definition of ESB be adopted in the immediate term and that new simulations aimed at identifying default parameter values are undertaken at the earliest opportunity. These simulations will involve harvest strategies as well as MSY control rules.

Recommendations

Recommendations arising from this review are listed under *ToR (b): Recommendations of improvements to proposed overfishing definitions* (p.21) and *ToR (e): Suggested research priorities* (p.24).

Background

The North Pacific Fishery Management Council (NPFMC) has determined that the current overfishing definitions (OFD) for Bering Sea and Aleutian Islands (BSAI) crab stocks are in need of revision. Proposals for revised OFDs have been developed by a four member Work Group reporting to the Crab Plan Team (CPT). A panel of three independent reviewers was invited by the Alaska Fisheries Science Center (AFSC) to review these proposals, along with simulation models used to test their performance and to determine default parameter values and proxies.

The review panel members were Patrick Cordue (independent consultant, New Zealand), Nick Caputi (Department of Fisheries, Western Australia) and the present author (Michael Bell, independent consultant, UK). The Terms of Reference for the review were:

(a) A statement of the strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches.

(b) Recommendations for improvements to proposed overfishing definitions or alternative definitions,

(c) A review of the model configurations, formulations and methods used to account for uncertainty.

(d) A review of input parameters (fishery, biological and life history parameters and spawner recruit relationships) used in simulation models.

(e) Suggested research priorities to improve our understanding of essential population and fishery dynamics necessary to formulate best management practices.

The summary of review findings given below is structured according to these Terms of Reference, although overlaps in the relevance of items means that most of the issues are covered under ToR (a). This report represents the individual opinion of the present author. No attempt was made to reach a consensus among the three reviewers, but it was apparent during the review meeting that differences among the reviewers are likely to be in emphasis rather than substance.

Description of review activities

Documents relating to overfishing definitions and management of Bering Sea and Aleutian Islands (BSAI) crab stocks were provided to reviewers on the web site www.afsc.noaa.gov/refm/stocks/CrabWs.htm. This web site was initially developed as part of an inter-agency workshop on crab overfishing definitions held in February 2006 in preparation for the CIE review and NPFMC action. Appendix 1 lists the key documents on this web site and other documents provided during and after the meeting. Prior to the meeting attention was drawn to a number of key documents which provide the necessary background for the review meeting:

(1) the Statement of Work for the Work Group responsible for developing proposals for the overfishing definition (Rugolo, 2004);

(2) a description of the proposed tier system for the overfishing definition (NPFMC, 2006; Siddeek & Zheng, 2006; Turnock & Rugolo, 2006a);

(3) stock assessments for Bristol Bay red king crab (Zheng, 2004) and eastern Bering Sea snow crab (Turnock & Rugolo, 2005);

(4) position papers discussing unresolved issues for the Work Group (Turnock & Rugolo, 2006b; Zheng, 2006)

(5) report and recommendations from the February workshop (NPFMC, 2006); and

(6) results of projections examining the performance of the proposed overfishing definition (Siddeek & Zheng, 2006; Turnock & Rugolo, 2006a).

A review meeting took place at the Alaska Fisheries Science Center, Seattle, 24-28 April 2006 (see Agenda at Appendix 2). The meeting was chaired by Anne Hollowed and Jim Ianelli of the NMFS. The meeting was introduced by Anne Hollowed, followed by a description of crab management and the need for a revised overfishing definition by Diana Stram, NPFMC. Over the course of three days, members of the interagency Work Group charged with developing proposals for a revised OFD (Shareef Siddeek and Jie Zheng of ADF&G, Jack Turnock and Lou Rugolo of NMFS) presented overviews of the proposed OFD and tier system, assessments for snow crab in the eastern Bering Sea and red king crab in Bristol Bay, approaches to estimating proxy values for biological reference points and simulations testing the performance of OFDs. Extensive discussions with CIE panel members took place alongside the presentations, so that this part of the programme extended to the end of the third day of the meeting. CIE panel members met on day 4 to discuss the main issues raised during the presentations, and sought some clarifications from NMFS staff involved in the review meeting. The remainder of the review meeting time was spent in preparing to write individual review reports.

Summary of findings

General

The existing OFD for BSAI crab stocks consists of three tiers, from Tier 1 for stocks with the least amount of information on stock status and exploitation to Tier 3 for stocks with the most amount of information (Turnock & Rugolo, 2006a). The maximum fishing mortality threshold (MFMT) is set to F_{MSY}, assumed to be equal to M (set to 0.2 for king crabs and 0.3 for snow and Tanner crabs). The minimum stock size threshold (MSST) is set to $\frac{1}{2}B_{\mathrm{MSY}}$ for stocks in Tier 3, where B_{MSY} is assumed to take the value of the average of survey estimates of mature male and female biomass during 1983-97. MSST is undefined for stocks in Tiers 1 and 2. MSY is determined either as the product of F_{MSY} and B_{MSY} (Tier 3) or from a proxy of mature biomass and stock utilisation rate (Tiers 1 and 2).

As pointed out in a presentation on the Statement of Work for the CPT Work Group (Rugolo, 2006), the existing OFD is unsatisfactory in a number of respects. Most importantly, the definition of sustainable yield involves all mature crabs, both sexes and all shell classes, irrespective of vulnerability to the directed fishery, and provides no effective cap on exploitation rates. Rugolo (2006) provides an example where catch levels for snow crabs could be set higher than the total exploitable biomass (legal males), without overfishing being declared. Projection models used by Turnock & Rugolo (2006a) demonstrate that fishery management under the current OFD cannot provide effective rebuilding to B_{MSY} from overfished stock levels for both red king and snow crab stocks (notwithstanding concerns about definitions of effective spawning biomass in these simulations – see below, p.15). The need for a revised OFD is very clearly established. The review findings presented below indicate that much work remains to be done before a revised OFD could be accepted, but retaining the *status quo* OFD is not a tenable option for the immediate future.

ToR (a): Strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches

Framework for overfishing definitions

Proposals for a revised OFD for BSAI crab stocks involve a system of five tiers, from Tier 1 for stocks with the most complete and reliable assessments to Tier 5 for stocks with data only on the catch history (Siddeek & Zheng, 2006; Turnock & Rugolo, 2006a). An MSY control rule for Tiers 1 to 4 involves defining F_{MSY} and B_{MSY} or proxies, and calculating the overfishing limit for fishing mortality F_{OFL} in terms of these values and parameters which define the slope of F_{OFL} in relation to stock biomass and the threshold stock level below which the fishery is closed. Figure 1 shows this proposed MSY control rule compared with the default MSY control rule advocated by Restrepo *et al.* (1998) in technical guidance on implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). The proposed OFD is much more conservative than the default OFD in that for any positive value of the parameter α the value of F_{OFL} will always be lower for any given stock biomass level. The suggested default for MSST is $(1–M)*B_{MSY}$, which accords with the notion that under MSY harvest levels the scale of fluctuations in biomass around B_{MSY} is likely to be in the order of $M*B_{MSY}$. Although the proposed setting of MSST at $½B_{MSY}$ is lower than this default, this is scarcely relevant since reductions in fishing mortality at higher biomass levels provide for returning stock trajectories towards B_{MSY} even in the absence of special stock rebuilding plans. Indeed, it could be argued that MSST could be dispensed with altogether under the new proposals, although there is certainly merit in having a trigger point at which the effectiveness of F_{OFL} levels under the control rule are re-examined.

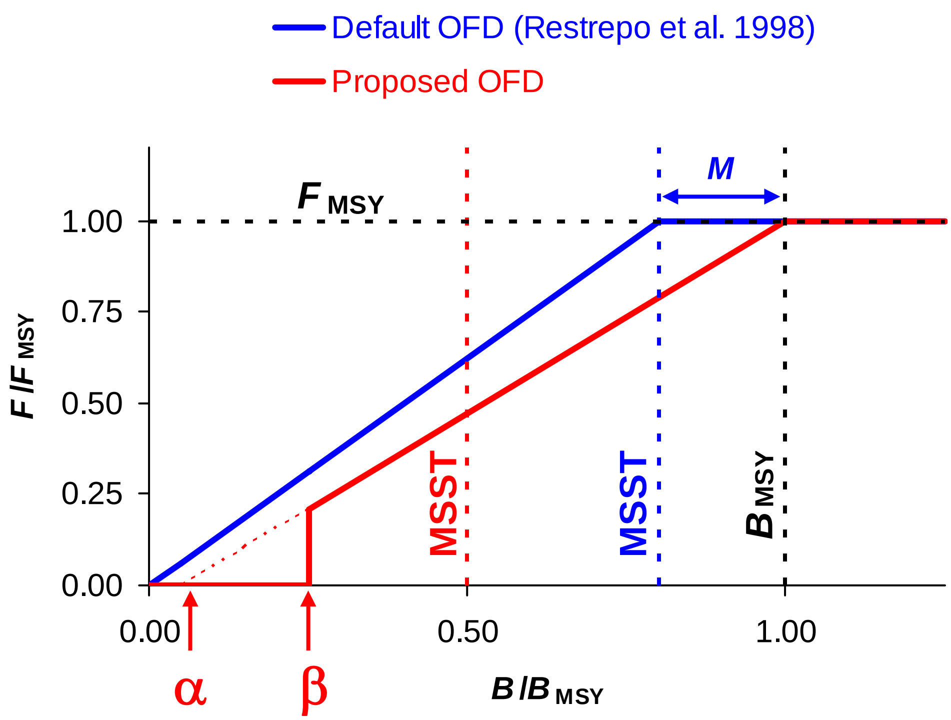

FIGURE 1. Proposed MSY control rule (red lines and captions) shown in relation to the default MSY control rule (blue lines and captions) put forward in technical guidance by Restrepo *et al.* (1998).

As a framework, the proposed OFD represents a major improvement over the existing OFD. National Standard 1 of the MSFCMA requires an MSY control rule which, if implemented as a harvest strategy, would be expected to result in a long-term average catch approximating MSY. If (and only if) successfully implemented, the proposed OFD would be expected to fulfil this requirement in the sense that the capacity of stocks to support harvests up to MSY should not be compromised by excessive fishing mortality. The same certainly could not be said of the existing OFD. As described below, there are a number of issues which need to be addressed before the proposed OFD could successfully be implemented. Given the inadequacy of the current OFD, it is vital that issues related to the implementation of the proposed OFD be resolved. Emphasis is given below to short-term actions that could be progressed on a time-scale to allow early implementation of the proposed OFD.

A second major strength of the proposed framework is that it is comprehensive. This is true in two senses. First, the use of a five tier system allows account to be taken of the state of knowledge of the stock and the reliability of assessments and monitoring data. Siddeek & Zheng (2006) and Turnock & Rugolo (2006a) allocate most of the 22 BSAI crab stocks to Tier 5, for which the overfishing limit depends only on an average of historical catches. No stock is expected to be allocated to Tiers 1 and 2, which require at least point estimates for F_{MSY} and $B_{MSY,}$ and only three stocks are allocated to Tier 3, requiring a reliable proxy for F_{MSY}. As surveys, assessments and monitoring systems improve, and as improved estimates of biological parameters become available, it would be expected that stocks could be promoted within the tier system. This perhaps applies mostly to Tier 3 and 4 stocks; information is perhaps likely to remain scanty for Tier 5 stocks taken mainly as a by-catch in groundfish-directed fisheries.

Second, the framework is comprehensive in the sense that it has several parameters which allow the dependence of F_{OFL} on stock biomass to be defined in a very flexible way. The α parameter acts as an *x*-intercept on the MSY control rule graph, determining how quickly F_{OFL} is reduced as biomass decreases, while the β parameter sets a biomass threshold for closure of the fishery (Figure 1). This allows great flexibility in defining the MSY control rule: *e.g.* $\alpha=-\infty$, $\beta=0$ defines a flat F_{MSY} control rule; $\alpha=\beta$ allows F_{OFL} to take any value between 0 and F_{MSY}, depending on biomass; *etc*. This flexibility allows the capacity for evolution, adaptation and refinement in the implementation of the OFD for individual stocks as more information becomes available.

There are also disadvantages to this flexibility. In the first place, freedom in defining the shape of the MSY control rule presents challenges for setting up starting defaults. Parameters α and β are arbitrary, in the sense that they have no objective definition – *e.g.* β is not defined as the threshold biomass at which there is an *x*% probability of event *y* occurring. This in itself is not necessarily a drawback, since it is the operational properties of the parameters that we are interested in, but it does mean that we can only determine the best combinations of parameters by examining the emergent properties of the systems in which they are defined. This requires extensive simulations (as by Siddeek & Zheng, 2006), in which we need to determine the criteria by which we judge one outcome better than another (see below).

A second disadvantage of the flexible formulation for the MSY control rule is that capacity for evolution also implies being subject to change. Given revision of assessments on an annual basis, there is the capacity to revise the parameters of the OFD on each occasion that it is applied. Revision of biomass and fishing mortality estimates as new data are added inevitably will change the perception of past stock status: biomass and fishing mortality levels previously considered as being within precautionary limits might, in the light of new data, be considered as representing overfished or overfishing states, and *vice versa*. This in itself is not a problem, as we can only act in the present, based on the best available information on current conditions. What is a problem, however, is that it is not just the estimates themselves that change, but also the reference points against which they are compared. This applies to F_{MSY}, B_{MSY} and their proxies (*i.e.* Tiers 1 to 3), which depend on the nature of the stock-recruitment relationship (SRR). Given poorly defined SRRs (*e.g.* Zheng, 2004), there is the capacity for new data points to be highly influential. Values α and β are less subject to annual change, given that they are selected rather than estimated, but it should be remembered that their influence on the performance of the OFD is inextricably linked with the particular values taken by F_{MSY} and B_{MSY}. For stocks close to overfished thresholds, even minor changes in the OFD could lead to instability in the management regime – *e.g.* opening and closing of the fishery. Radical changes in perception, if accepted as plausible, of course require radical management responses. Otherwise protocols are required for stabilising the OFD in the face of changing assessments. One approach would be to use moving averages (*e.g.* of F_{MSY} and B_{MSY} proxies in Tier 3) to reduce annual biases (as suggested by Nick Caputi during the review meeting). Another approach would be to set up a cycle of regular update assessments, where many assessment parameters would remain unchanged, and occasional full assessments with revision of F_{MSY} and B_{MSY} or proxies and testing whether current values of α and β remain appropriate. 'Update' assessments would be the sole responsibility of assessment authors, whereas 'full' assessments would have consequences for rigorous documentation and Council review. The latter approach is similar to that adopted by ICES in recent years.

The two most important components of the OFD are stock biomass and fishing mortality, *i.e.* the *x*- and *y*-axes for the MSY control rule (Figure 1). The way these two parameters are defined is critical to the successful operation of the OFD. In the existing OFD there are logical inconsistencies between the way these are defined in the threshold values and the way they are applied in determining harvest levels. The proposed OFD potentially resolves these inconsistencies, but successful implementation of the proposed framework depends critically on the correct definitions of biomass and fishing mortality. The definition of fishing mortality appears not to be a concern. As defined in the framework, *F* applies to all vulnerable portions of the population, including discards of females and undersized/unmarketable males. Mortality of trawl by-catch is a separate issue (see below), but provided that this is adequately accounted for in the assessment and simulation models, this is not a problem in terms of the framework. Within the framework, '*F*' refers to δF for fully selected crabs, where δ is the time interval over which the fishery occurs. Provided that F_{MSY} and F_{OFL} are expressed in this same currency, then the way that fishing mortality is defined in the OFD framework is satisfactory. The same cannot be said of stock biomass. 'Biomass' here refers to spawning potential, and in fact need not be expressed in biomass units at all. As emphasised by Patrick Cordue on numerous occasions during the review meeting, the biomass measure would be expected to be proportional to total fertilized egg production (TFEP). Discussion of this critical issue in relation to MSY control rules and SRRs is deferred to a later section (see p.15). It is enough to note here that the various options for defining effective spawning biomass (ESB) considered in the simulation studies (Siddeek & Zheng, 2006; Turnock & Rugolo, 2006a) appear unlikely to meet this criterion of proportionality with TFEP. Successful implementation of the proposed OFD will not be possible until a satisfactory definition of ESB is determined. This issue affects the definition of SRRs on which estimation of F_{MSY} or proxies and testing of the OFD depends.

Estimating proxy values for biological reference points

In 'data-rich' situations (stocks in Tiers 1 and 2), F_{MSY}, B_{MSY} and associated quantities can be estimated directly, but for all other cases we need proxies for these values. Restrepo *et al.* (1998) offer extensive guidance on selecting among the various candidates for proxies in 'data-moderate' and 'data-poor' situations. Siddeek & Zheng (2006) and Turnock & Rugolo (2006a) opted to consider $F_{x\%}$ values as proxies for F_{MSY} for Tier 3 stocks, where x is the percentage of virgin spawning potential per recruit (SPR) at equilibrium. Given that the OFD requires a working definition of spawning potential (*i.e.* ESB) irrespective of the approach to deriving proxies, selection of proxy values on the basis of SPR is a sensible approach despite the difficulty in defining ESB. Restrepo *et al.* (1998) advocate the use of $F_{x\%}$ in preference to yield per recruit reference points ($F_{0.1}$ and F_{max}) and SRR-based reference points (F_{med}). NPFMC (2006) recommended the range $F_{50\%}$ to $F_{60\%}$ based on previous work by the CPT Work Group. According to the method of Clark (1991), whereby the most likely value of F_{MSY} is selected at the intersection of yield curves from the most and least productive of a plausible range of SRRs, this range of $F_{x\%}$ appears reasonable. At present, the use of $F_{x\%}$ and the approach to selecting the appropriate x% can both be endorsed as satisfactory approaches to deriving F_{MSY} proxies for Tier 3 stocks, but the issue cannot reasonably be progressed further towards selection of actual values without first resolving issues relating to the definition of ESB and hence SRRs (see p.15). Two further points can be made in this context. First, SPR-based reference points are likely to be highly sensitive to assumptions about growth. Estimation of growth patterns was not discussed in detail during the review meeting, but it seems safe to suppose that moult frequencies and increments are fairly poorly resolved for BSAI crab stocks. New information on growth potentially could be very influential in identifying reference points. It is recommended that the sensitivity of reference points and the performance of the OFD be explored in relation to uncertainty about growth. Second, the question of the likely form of the SRR should be addressed. For example, are there *a priori* reasons for selecting a Ricker rather than a Beverton-Holt SRR, *e.g.* likely cannibalism of pre-recruits by the adult stock? It is recommended that the plausible range of SRR types be examined carefully in the light of what is known about recruitment biology, with a view to constraining the range of SRRs that are considered in selecting biological reference points.

For Tier 4 stocks the proxy for F_{MSY} is defined as γM. The use of M as the basis for a proxy is consistent with the guidelines given by Restrepo *et al.* (1998) for 'data-poor' situations, and appears sensible given the available options. However, determining default values for γ presents difficulties. Presumably, values would be selected at the group- rather than stock-level, where one group was king crabs (*Lithodes* and *Paralithodes* spp.) and the other was snow and Tanner crabs (*Chionoecetes* spp.). Additional information on individual stocks seems likely to result in promotion to Tier 3 rather than modification of γ. The precise role of γ in the proxy needs to be clarified. It appears that it is not involved in a 'currency' change in the OFD, given that fishing mortality is already expressed in terms that account for the timing and selectivity of the fishery (see above). Instead, γ appears genuinely to scale M towards the appropriate F_{MSY}. In the absence of further information, it seems reasonable to suppose that $\gamma=1$ would be an appropriate default, but analyses and simulations of the type applied to Tier 3 stocks may be informative about the most likely values.

Simulation modelling

Simulation models were separately developed by ADF&G staff (Siddeek & Zheng, 2006) and NMFS staff (Turnock & Rugolo, 2006). Differences of approach potentially shed light on the sensitivity of simulation outcomes to particular modelling choices, and final conclusions about the performance and parameterization of the OFD could be more robust as a result. There is a need for critical analyses comparing the results of the two simulation approaches, but this will first need agreements on some critical biological issues and some common grounds for comparison (see below).

Simulation models for BSAI crabs are likely to have much in common with the length-based assessment (LBA) models: the first are used for forward projections, the second to estimate parameters. If assessment parameters (both estimated parameters and those fixed *a priori*) are to be used in simulation models, it is vital that the model structures be identical, since they are likely to be valid only in the context in which they are estimated or applied. Modelling of uncertainty in the population dynamic and survey processes should preserve the covariance structure of parameters estimated in the assessments.

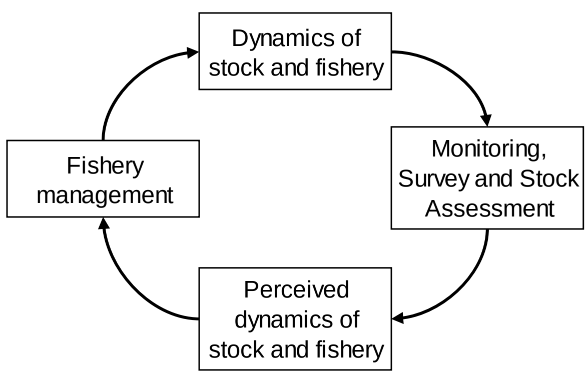

FIGURE 2. Processes involved in simulating fishery management.

As noted by Restrepo *et al.* (1998), various sources of uncertainty are involved in modelling fishery management. These include uncertainty owing to the accuracy and precision of estimates, choice of model structure, natural variability of stock dynamics and errors in the implementation of management measures. Figure 2 shows schematically the major processes involved in simulating a fishery management system – each box and each arrow comes with its own component of uncertainty which should be incorporated within the simulation. The distinction between the 'perceived' and 'true' dynamics is particularly important. Turnock & Rugolo (2006a) incorporate observation errors by applying autocorrelated lognormal errors to abundance within the simulations. This approach is probably adequate for the purposes of comparing the performance of alternative OFDs, but it is recommended that in the long-term the model be extended to include the full assessment-management processes.

An important issue for the simulations undertaken by both Siddeek & Zheng (2006) and Turnock & Rugolo (2006a) is that they treat the MSY control rule as if it were both a harvest strategy and a rebuilding plan. Fishing mortality in the simulations always takes the value of F_{OFL}. In one sense this could be seen as fair enough, since this is a worst case scenario and the OFD is already very precautionary as a framework and could conceivably be viewed as constituting a default rebuilding plan for depleted stocks. Restrepo *et al.* (1998) note that an MSY control rule that incorporated 'built-in' rebuilding might be used "if a Council wished to minimize the range of stock sizes within which special rebuilding plans would be required". However, if it really is the case that the MSY control rule is seen as sufficiently precautionary to be used as a harvest strategy, then either it implies that the OFD is likely to be unduly restrictive in that it allows very little room for manoeuvre by the State fishery managers, or else it appears to by-pass the requirement for the State to act in a precautionary manner in maintaining a buffer between F_{OFL} and the target F used in setting TACs. At the State level, harvest strategies may well incorporate multiple management objectives, going beyond mere stock conservation. Indeed, for fisheries that are economically as well as biologically healthy, it is desirable that management objectives incorporating socio-economic aims should explicitly be stated. An MSY control rule that seeks to take the role of a default harvest strategy is unlikely to be conducive to such enlightened management. This is relevant to the current simulations, because it implies that they are modelling scenarios that will never (or at least should never) happen in practice. The role of the OFD is not to replace the requirement for precautionary management by the State, but to provide the context in which this can occur. State management could either use the OFD as a Federal check on the admissibility of their preferred harvest strategy, or as a fixed point of reference to determine their harvest strategy (*e.g.* setting TACs consistent with 0.75 F_{OFL}). In either case, it is the harvest strategy, not the MSY control rule, that is applied to the stock. It is therefore recommended that a credible State harvest strategy is *always* included in simulations of the performance of an OFD for BSAI crab stocks. If, on the other hand, it *is* intended that the OFD should take on the role of a precautionary harvest strategy, this should be explicitly stated and the performance of the OFD should be considered in terms beyond average stock size and rebuilding times.

It is in any case desirable to examine multiple aspects of the performance of a proposed OFD. It is relatively easy to define management measures that are just precautionary, less easy to define ones that balance precaution against other objectives for a fishery. For depleted stocks, there is an obvious trade-off between short-term pain and long-term gain. In other words, shorter rebuild times to higher stock levels come at the expense of immediate losses of yield. More generally, management responses to changing stock sizes have consequences for the level and, particularly, the variability of yield. Different

OFDs with similar properties in terms of rebuild time and probability, may differ strongly in their properties with respect to short-term losses and long-term constancy of yield. It is recommended that trade-offs involving yield (or any other fishery management objectives) be included in simulation studies of the performance of OFDs for BSAI crabs. Again, it should be emphasised that simulations should not consider OFDs in isolation from harvest strategies.

Even if we set aside management objectives other than stock conservation, an OFD can be viewed as serving two roles: (i) it is intended to allow depleted stocks to grow towards biomass levels capable, on average, of supporting MSY; and (ii) it is intended to prevent the fishery from causing stock biomass to decline below these levels. The simulations for BSAI crabs have focussed on the first role to the exclusion of the second. In part this is natural, since the α and particularly β parameters are most relevant to recovery from low stock sizes. However, recognising the role of the OFD in allowing fisheries to operate at sustainable levels over the long-term, it is recommended that the simulations use a variety of different starting biomass levels up to B_{MSY}, rather than just considering depleted stocks. Note that, for the purposes of comparing between the Siddeek & Zheng (2006) and the Turnock & Rugolo (2006) modelling approaches, the same selection of starting biomass levels (in terms of fractions of B_{MSY}) should be used by both modelling teams.

The biggest differences between the two modelling teams were in their interpretation of certain biological issues critical to the definition of the spawning stocks. Many issues that divide the two groups are highlighted in the ADF&G and NMFS position documents (Turnock & Rugolo, 2006b; Zheng, 2006). The February Workshop Report (NPFMC, 2006) makes what are intended to be definitive statements on some of these issues, but it is apparent that it is possible to interpret these statements in more than one way. For example, at the review meeting it was particularly apparent that different views had been taken about the minimum interval between moulting and mating for new shell male snow crabs, with strong implications for their participation in primiparous and multiparous matings and hence for the definition of the male spawning stock. It is beyond the remit of the present review to arbitrate on such issues, but there is a strong need either for the two modelling teams to agree on the interpretation of the best available scientific information, or for this interpretation to be determined by a third party. In cases of genuine uncertainty about the biological processes, this should be included in the simulations as sensitivity analyses.

Effective spawning biomass and the stock-recruitment relationship

If there is one crucial issue on which the proposed OFD succeeds or fails, it is in the definition of effective spawning biomass (ESB). ESB plays two roles in the OFD: first, it is the *x*-axis of the MSY control rule, determining the value of F_{OFL} and being the scale on which MSST and B_{MSY} are measured; second, it is the controlling variable for the stock-recruitment relationship (SRR), used in determining F_{MSY} or its proxy and in testing the performance of the OFD. The two roles are linked, since the outcome of applying the MSY control rule is intended to be a long-term average catch approximating

MSY (Restrepo *et al.*, 1998), and this outcome is achieved through translation of ESB into future recruits. To clarify: the MSY control rule does not simply avoid the recruitment failure that ultimately leads to stock extinction, although successful operation of the rule should in fact achieve this aim; rather, it has the more positive aim of encouraging stock size to reach a level that maximizes the delivery of biomass to the directed fishery. The first is more characteristic of the ICES paradigm of precautionary fishery management, and requires knowledge or assumptions about the left-hand portion of the SRR, *i.e.* what happens to recruitment at low stock sizes. The second, which applies under the National Standard Guidelines, requires knowledge or assumptions about the full form of the SRR, *i.e.* what happens at all stock sizes.

As noted above, it was agreed at the review meeting that the first essential property of any measure of ESB is that it should be proportional to total fertilised egg production (TFEP). A secondary property, needed for successful definition of an OFD, is that ESB should be sensitive to fishing mortality. Indeed, if ESB was not responsive to changes in fishing mortality, there would be no point in having an OFD! These two requirements have led to some widely varying definitions of ESB by the two Work Group teams (Siddeek & Zheng, 2006; Turnock & Rugolo, 2006a). The most obvious definition for ESB is the total biomass of mature females. This falls at both hurdles – the first because TFEP depends also on the availability of males as mating partners, the second because fishing mortality is directed at males, females being sensitive only to by-catch and discard mortality. The next step is to suppose that each male present in the population can mate with a certain number of females (the 'mating ratio') and that ESB is best defined by the minimum of total biomass of mature females and the biomass of mature females that is capable of being mated by the mature males present in the population. Setting aside the issue of determining which males participate in mating (see above), this is an improvement in that it recognises that TFEP is limited by the availability of males. However, the use of a mating ratio is a gross simplification of the complex mating system of snow, Tanner and king crabs, and this definition of ESB is still only weakly sensitive to fishing mortality. Turnock & Rugolo (2006a) attempted to deal with the latter issue by adding in the total biomass of mature males. This, however, is logical only as an *ad hoc* measure, and takes a step further away from a definition of ESB that is acceptable on biological grounds. Siddeek & Zheng (2006) used the mating ratio to calculate a male component to ESB in complement to the female component. Although an improvement, this still falls a long way short of a biologically realistic definition that could be used with confidence to test, parameterise and apply a working OFD. Estimation of F_{MSY} and proxies and other outcomes of simulations were found to be very sensitive to mating ratio and other facets of the definition of ESB.

The central problem is that a simple, robust and biologically meaningful index of TFEP is required, whereas the complexities of BSAI crab mating systems allow no simple answers. Sperm storage by females, sperm rationing by males, size-assortative mating, non-participation in mating by new shell males, lower clutch fullness in primiparous females, the existence of 'graveyard' females – these and, no doubt, many other factors make it extremely difficult *a priori* to write down a suitable expression for ESB based on simple, easily measurable quantities. Given size-fecundity relationships that appear to be linear rather than cubic functions of carapace width in snow crabs (within clutch fullness categories), it is even questionable whether spawning potential is best measured as a biomass. Patrick Cordue suggested during the review meeting that it would be enlightening to construct an individual-based model (IBM), incorporating and simulating the various features of crab mating and egg production systems. Hypotheses about the causes and consequences of size-assortative mating may profitably be explored in this context – changes in the rate of successful mating as population density changes are likely to differ strongly according to whether male-male competition (ousting of small males by large males) or loading constraints (limits to the size of female that can be handled by a male of a given size) are the primary cause of size-assortation. Spatial factors, in relation to migration patterns and the location of primiparous and multiparous matings, could also be explored using an IBM. Imperfect knowledge of some or even many aspects of these systems may make it difficult to parameterise an IBM with any certainty. However, given plausible assumptions it may be possible to draw deductions about at least the functional form of any satisfactory definition of ESB. Furthermore, an IBM may provide insights into the conditions under which the effective sex ratio may be genuinely limiting for egg production. Although the primary aim of the OFD is to allow optimum recruitment rather than to prevent recruitment failure, it is nevertheless useful to know the circumstances under which this might be expected to occur.

A second approach to finding an appropriate functional form for ESB would be to examine data that are already available from the annual surveys. In some years at least, when environmental temperatures favour the presence of ovigerous females in the population at the time of the survey, it may be possible to measure egg production directly. Data on female size and clutch fullness are routinely collected, which would allow calculation of total egg production. Calculation of TFEP would depend on whether or not it is possible to draw deductions about fertilisation rates from egg colour (blue coloration means a developing and hence definitely fertilised egg, orange coloration could mean either unfertilised or simply early stage). Is it perhaps possible to make deductions about relative fertilisation rates, even if there is no confidence that these can absolutely be estimated? If so, then both sides of the equation relating TFEP to crab population structure are known in at least relative terms – it merely (!) remains to estimate the functional form.

The IBM and the survey data approaches to estimating ESB, or at least a functional form for ESB, are both medium- to long-term projects, and are thus unlikely to yield results that are useful for the timely implementation of the proposed OFD. A short-term, probably interim, solution is required. Replacement of the existing OFD is an urgent priority, even if this requires a less than perfect solution to the definition of ESB. Given fisheries that preferentially remove males from their target populations, we know that male availability is the most likely limiting factor for successful reproduction in BSAI crabs. Accordingly, any meaningful definition of ESB must include mature males. Perhaps the most likely candidate for an interim definition of ESB is the total mature male biomass. This definition was proposed at the review meeting by Nick Caputi. It has the virtues of being simple (given agreement as to what constitutes the mature male population) and being responsive to fishing mortality. This definition will certainly be *wrong*, particularly at higher stock sizes where it is more likely that recruitment will be egg-limited than sperm-limited[1], but it has the highly desirable property that it may be a very good measure of the degree to which spawning potential is impaired at low stock sizes, at which the MSY control rule will cause fishing mortality to be reduced or the fishery to be closed. As noted above, this does not accord entirely with the philosophy of the OFD, but it is nevertheless an extremely important function for it to fulfil. Moreover, if at higher biomass levels stock size assumes a relatively minor role compared with environmental factors (see below), *i.e.* 'noise' makes a greater contribution to recruitment variation than the underlying SRR, then an incorrectly specified ESB is much less of a problem.

The following course of action is recommended for incorporating a stock biomass measure into the OFD and in modelling SRRs for BSAI crab stocks:

(1) Agree a simple short-term interim measure for ESB and prescribe that this is the definition that will be used in implementing the proposed OFD. Total mature male biomass is a strong candidate for this measure.

(2) Again in the short-term, use estimates from the stock assessments to explore the relationship between recruitment and the two axes of mature male biomass and mature female biomass. It is unlikely that data will be available over much of this surface, but it is worth establishing the extent to which variability in recruitment can be accounted for by the joint effects of these two variables.

(3) In the medium-term, examine the suitability of survey data for estimating TFEP, and explore the possibility of using these data to determine the appropriate functional form for ESB. If necessary, this should be supplemented with direct field measurements of clutch fertilisation rates.

(4) In the medium- to long-term, construct an IBM of BSAI crab mating and egg production systems, aiming to determine the appropriate functional form for ESB. It is important that the IBM be spatially structured, to examine the spatial co-incidence of different population components at mating time and to consider the delivery of larvae to suitable settlement areas.

Before leaving the topic of SRRs it is worth considering sources of variation in recruitment other than ESB. This is relevant in two respects. First, if ESB plays a relatively minor role in determining recruitment, this is important both for simulating the performance of the OFD and for approaches to management. For recruitment-driven fisheries, conservation of spawning stock biomass becomes less important compared with managing the mortality of recruits that are delivered to the fishery (subject, of course, to precautionary minimum stock biomass levels). This is particularly so if natural mortality is high and recruitment is very variable between years. This is perhaps more typical of

[1] In fact the application of a mating ratio to mature female biomass could be seen as dealing with the transition from sperm-limitation to egg-limitation as stock size increases, but the sensitivity of F_{MSY} to choice of mating ratio together with other uncertainties make it preferable to adopt a more simple approach. The use of mature male biomass will introduce its own problems for selection of an F_{MSY} proxy, but choice of a value between $F_{50\%}$ and $F_{60\%}$ could be made based on operational properties even if it could not be defended as an unbiased proxy.

shorter-lived species than snow, Tanner or king crabs, such as estuarine bivalves or blue crabs, but it might be worth considering the effects of such recruitment patterns in the simulation models (some simulations of random recruitment were shown by Shareef Siddeek during the review meeting). This also highlights the importance of ensuring that the error components of the SRRs in the simulations are adequately characterised.

The second point of relevance is the issue of regime shift and stock productivity. Changes in abundance and distribution of some BSAI crab stocks have been attributed to changes in the climatic and oceanographic regime in the Bering Sea, although a lack of coherence of change between different stocks may cast some doubt on this hypothesis (Zheng & Kruse, 2006). Dew & McConnaughey (2005) emphasise the role of fishing mortality rather than regime shift in causing the decline of Bristol Bay red king crab after 1980, suggesting *inter alia* that intensive trawling in an area important to spawning females may have affected delivery of larvae to the most suitable grounds for settlement. Deciding whether or not regime shift is responsible for recent recruitment levels is extremely important, given that management priorities for a depleted stock will be very different to those for a stock which has simply become less productive. Restrepo *et al.* (1998) note that "for a period of declining abundance, the 'burden of proof' should initially rest on demonstrating that the environment (as opposed to fishing) caused the decline, and that, therefore, the target control rule should be modified". It is beyond the scope of the current review to offer a view on which are the most likely causes of changes in abundance of BSAI crab stocks, but it is recommended that a consensus be sought among the relevant experts about whether regime shift or fishing mortality are the most likely causes of change, and that this consensus be used to inform development of the most appropriate OFD.

Stock assessments

Stock assessments for Bristol Bay red king crab (Zheng, 2004) and eastern Bering Sea snow crab (Turnock & Rugolo, 2005) were briefly presented at the meeting. In both cases a length-based assessment (LBA) model was constructed, accounting for the complex, discontinuous growth patterns of the two species. Given the emphasis on other issues, it was not possible to examine the assessments in detail during the meeting. However, the assessments are essential to the OFDs because: (i) they yield values which will eventually be compared with the criteria of the MSY control rules; and (ii) they yield values which allow the OFD to be parameterised and tested. Brief comments on some of the main features of the assessments are given below, but this should not be treated as a full assessment of the assessment methodologies and outcomes. A review of the eastern Bering Sea snow crab assessment has recently been undertaken on behalf of CIE by Maunder (2003).

LBA models are used for both red king crab and snow crab assessments. The two approaches differ principally in the number of free parameters (more for snow crabs) and method of estimation (sum-of-squares based on lognormal errors for red king crabs, maximum likelihood for snow crabs). The method of dealing with size transitions in each model appears satisfactory, if based on rather slender data resources. Lack of opportunity to examine this in detail prevents further comment on this potentially important issue, but the dependence on and sensitivity to poorly known biological parameters in the assessments warrants further study in the future. Given the complexity of these models – in terms of both structure and number of parameters – it would be reassuring to see corroboration of the broad patterns of assessment results drawn from comparisons with the outcomes of simpler assessment approaches (*e.g.* Collie-Sissenwine Analyses) which make fewer demands on knowledge of biological parameters such as growth.

In general, biological realism is a strength in these LBA models (to the extent that this realism can be supported by available information), but within the biologically realistic model structures it is desirable to seek the most parsimonious descriptions (fewest parameters) of the data and processes. In the case of the snow crab model almost 300 parameters are estimated and it is appropriate to ask whether every one of these is necessary, or indeed supported by the data. In particular, selectivity parameters proliferate, with variation according to years, sexes and shell conditions; it seems likely that this complexity could be drastically reduced by applying a few well chosen *a priori* assumptions about selectivity patterns, with advantages for the precision of estimates. Some parameter sharing may also be possible within models. For example, in the red king crab model is it reasonable to suppose that patterns of annual recruitment are likely to be similar between males and females? If so, there is no need to estimate the two patterns separately; any departures from 1:1 sex ratio at recruitment can be dealt with by including an additive parameter rather than treating the patterns as completely independent. In general, it is recommended that maximum use be made of external information, whether as potential explanatory variables (*e.g.* environmental signals) for recruitment patterns or to determine the likely values of parameters to be estimated.

Both assessments are tied in to survey data, with the assumption that the survey represents the complete population. This assumption is precautionary, since it will tend to give an upwards bias to estimates of F and a downwards bias to estimates of population abundance. However, the assumption is unnecessary since the survey catchability could be estimated within the assessment: it is recommended that estimation of survey q be included within the assessments. It is further recommended that depletion experiments be undertaken using the survey gear and vessel to assess gear efficiency and selectivity. This approach is preferable to the 'underbag' experiments which have so far been used.

The red king crab assessment model includes estimation of M values for four different periods in females and for three different periods in males. This is done primarily to account for differences in population dynamics during the early 1980s. It is not clear that there is an objective basis for selection of the periods (which differ between males and females) beyond achieving a closer fit to the survey data. Without data on changes in specific mortality factors, it is not defensible to use *ad hoc* model adjustments to infer changes in M on the basis of model fit. Lack-of-fit could be due to factors other than natural mortality, such as catchability changes or changes in the relative spatial distributions of the stock and the fishery. Furthermore, 'M' as estimated in the red king crab assessments is actually a compound of natural mortality and indirect (by-catch) fishing mortality. It is highly desirable to separate these components, perhaps using effort data from the by-catch fleets.

More use of fishing effort data could be made in both snow crab and red king crab assessments. There may well be problems in defining meaningful effort and CPUE indices, particularly for the by-catch fleets, but there are potentially great benefits in doing so. Firstly, it may be important to understand spatial processes in the stocks and the fisheries. It is probably unrealistic to expect that spatial processes could be incorporated in the LBA models in the near future, but statistical analyses of CPUE and effort data may well be informative about shifts in the location of the stock or the fishery, which in turn may be informative about selectivity and mortality processes that are addressed within the models. Secondly, it is important to gain a better insight into the contribution of by-catch mortality to overall mortality in BSAI crab stocks. In this case direct use of effort data in the LBA may be possible. According to Dew & McConnaughey (2005), by-catch mortality of females could have been an important factor in the decline of Bristol Bay red king crab stocks after 1980. Whilst this is not the only view of causes of decline, it does highlight the importance of understanding by-catch mortality. Dew & McConnaughey (2005) also question the representation of 'red bag' catches in estimates of the by-catch component of red king crab removals. Again, whether or not this proves to be a real source of bias in the data, it highlights the importance of understanding and quantifying the contribution of by-catch to overall fishing mortality. This is important for both assessments and OFDs.

ToR (b): Recommendations of improvements to proposed overfishing definitions

Recommendations about how the proposed OFD could be developed or improved are scattered through the preceding sections. The main points are highlighted again below, together with some additional recommendations on the simulations and OFD framework.

- The proposed OFD can be accepted as a framework, but it is urgently necessary to make progress on defining values for the reference points (F_{MSY} or proxies) and defaults for parameters α, β and γ. This will only be possible when a satisfactory interim definition for ESB is derived and the proposed OFD is tested in conjunction with realistic harvest strategies. Retention of the existing OFD is not an option.
- Protocols are needed for dealing with the addition of new annual assessment estimates to existing OFDs. This might involve use of running averages or a cycle of update assessments and full revisions to the OFD.
- In the short-term, there needs to be a prescriptive interim definition of how ESB is to be calculated and used in the OFD and simulations. Mature male biomass is a strong candidate for this definition. Subsequent improvements to the definition of ESB, *e.g.* based on the analysis of survey data or the outcome of an IBM, should be extensively reviewed and documented before being adopted in a revised OFD.

- In the immediate term, simulations to test the performance of the proposed OFD and to determine appropriate values for α, β and γ in the MSY control rule must include realistic harvest strategies. To do otherwise is either to take the view that no precautionary buffer is needed between F_{OFL} and the target F or to determine OFDs that allow the State very little room for manoeuvre in setting harvest strategies to meet precautionary and other objectives.
- There needs to be agreement on the criteria used to test OFDs in the simulations. Rebuilding time for a depleted stock would be an important criterion, but trade-off statistics involving the level and variability of yield in the short- and long-term are also needed.
- The default OFD of Restrepo *et al.* (1998) should be included in comparisons of the performance of different OFDs. This is less precautionary than the proposed OFD framework, but specifies a higher value of MSST given M<0.5 (see Figure 1). It will need to be established that the increased complexity involved in the proposed OFD (*i.e.* the α and β parameters) offers significant improvements over the default OFD in terms of the agreed test criteria.
- The simulations should include a range of starting values for stock biomass, in terms of fractions of B_{MSY}. This is because rebuilding is not the only function of an effective OFD – it is also intended to define sustainable exploitation of a healthy stock.
- There needs to be agreement between ADF&G and NMFS teams on the interpretation of the available evidence on biological processes (*e.g.* moulting/mating cycles) in BSAI crab stocks. In cases of genuine uncertainty, this should be included in sensitivity analyses. Comparisons between the ADF&G and NMFS simulation modelling approaches would be facilitated by the use of common starting points for the simulations (fractions of B_{MSY}).
- Simulation testing of the performance of proposed OFDs must take appropriate account of observation error, *i.e.* the difference between the simulated 'reality' and the 'observations' used in applying the OFD. Ideally, this would involve simulating the survey and assessment processes (see Figure 2), but simulating the errors directly would probably be adequate given knowledge of their likely magnitude and autocorrelations.
- For Tier 5 stocks, it is not appropriate to use the average catch for a single fixed period of years to define the OFL. The period should be defined separately for each stock based, where possible, on four criteria: (i) stability of catches; (ii) lack of trend in CPUE; (iii) lack of trend in fishing effort; and (iv) a stable spatial distribution of the fishery, showing no expansion or shift in the distribution of fishing effort. If possible, the use of these criteria should be supported by simulation studies.
- In the medium-term, consideration should be given to including uncertainty measures within the Tiers of the OFD. This might involve estimating probabilities for the current location of a stock in relation to status determination criteria rather than just using point estimates.
- In the medium-term, consideration should be given to reducing the complexity of the OFD. For example, would a flat F_{MSY} control rule (in conjunction with a

precautionary harvest strategy) perform as well as the proposed MSY control rule, thus removing the need to define α and β?

- In the medium-term, further attention should be paid to the role of by-catch mortality in determining the effectiveness of the OFD. At present, by-catch mortality is seen as a context for the OFD, but it is a context that readily changes in response to the fortunes of other fisheries. Ideally, by-catch mortality should be included in the F that is compared with F_{OFL} (with implications for defining F_{OFL}). This has the disadvantage that the by-catch F will need to be projected before the TAC can be calculated, but it does allow an OFD that does not require revision each time the by-catch mortality regime changes.
- In the long-term, it is recommended that OFDs include multi-species considerations. This is necessary because: (i) by-catch of BSAI crabs in trawl fisheries, whether or not removed in the form of commercial landings, is potentially an important contribution to overall fishing mortality; and (ii) the catches of even directed fisheries are often mixed in species composition. Construction of robust single species OFDs is a necessary precursor to more complex management systems, but management of trade-offs between competing objectives for mixed or interacting fisheries potentially offers the capacity to maximize overall conservation (and revenue) benefits.
- Another long-term objective should be to include spatial considerations within the OFD. For spatially structured stocks, the consequences of fishing mortality for future recruitment depend heavily on when and where the mortality occurs. As an example, the hypothesis of Dew & McConnaughey (2005) that trawling in the south-eastern Bering Sea has disrupted the ‘endless belt’ reproductive strategy of red king crabs holds strong implications for spatial management. In this case the implications apply to the by-catch fleets, but it is easy to envisage cases where spatial management considerations would apply to the directed fishery. The inclusion of spatial management criteria in an OFD implies that the current type of MSY control rule would no longer be appropriate. Equilibrium recruitment at a given level of fishing mortality is the determinant of F_{MSY}, but in the case of spatial management there is no single F_{MSY}, and recruitment is determined by considerations beyond a ‘global’ SRR.

ToR (c): Review of model configurations, formulations and methods used to account for uncertainty

The model configurations, formulations and methods used to account for uncertainty have already been reviewed under ToR (a) alongside the OFDs and simulation models. Model structures (LBAs and projection models) appear to be sufficient and appropriate to the life-histories of BSAI crab stocks, although there remain some disagreements about the details of some biological processes. Likewise, model fitting procedures for the LBAs appear satisfactory, although this was not an aspect that could be examined in detail during the review. The review team did not take up the offer of access to AD Model Builder and Fortran code for the models. This was partly because there would have been insufficient time to read and thoroughly understand the code, but also because the presentations and documentation for the review made it clear that the technical expertise of the modelling teams was not in question.

ToR (d): Review of input parameters used in simulation models

Input parameters used in the simulation models included biological and fishery parameters and SRRs. Again, these have largely been discussed already under ToR (a). It is worth re-iterating that there remain several important points of difference between ADF&G and NMFS teams in interpretation of the scientific evidence on biological processes in BSAI crab stocks, and it is important that these differences are resolved. For progress in parameterising the OFDs it is necessary to draw up a clear and unequivocal agreed framework of crab life-history processes. Irresolvable points of genuine uncertainty should (a) be accounted for in sensitivity analyses, and (b) serve as a focus for future research efforts.

Opportunity to examine important fundamental biological parameters was limited during the review. In common with many if not most exploited species, M is poorly known for BSAI crab stocks, and there is a slender basis for drawing inferences about likely values. Values of 0.2 or 0.3 used as proxies for F_{MSY} for Tier 4 stocks and alternative values for M used in the simulation models appear to have been derived from considerations of longevity. The estimates are satisfactory to the extent that they are at least plausible. There is no obvious basis for their revision, although it should be noted that there should be consistency of selected best values across assessment models, simulation models and OFDs, unless precautionary considerations dictate otherwise.

Growth parameters are also poorly known, which could have important implications for assessments, simulation models and estimation of $F_{x\%}$ values in the selection of F_{MSY} proxies. The sensitivity of the models to assumptions about growth are certainly worth exploring, although it is also possible that internal consistency in the assessment-simulation-OFD model complex may be more important than absolute lack of bias when determining the most effective OFD.

ToR (e): Suggested research priorities

Some priorities for research have already been identified in the preceding sections. These are collected together below, together with some further suggestions aimed at improving the understanding of essential population and fishery dynamics necessary to formulate best management practices.

- The first and most urgent research priority is to determine the appropriate functional form for calculating a measure of ESB that is proportional to TFEP. This is required for the MSY control rules and for the SRRs that are used to derive F_{MSY} values and proxies, to find likely default values to parameterise the OFDs and to test the performance of OFDs. As described under ToR (a), mature male biomass may be an appropriate candidate for an interim definition of ESB, but cross-correlations between the various options (*e.g.* B_0 mating ratio applied to mature female biomass) should be examined to determine the extent to which they are measuring the same dimension of variability (*i.e.* measures that go up and down in rough concert with various alternative formulations of spawning potential, even if the correspondences are non-linear). In the medium- to long-term, construction of an IBM and analysis of survey data are the most likely routes to improving the formulation of ESB (see under ToR (a) above).

- Field estimation of clutch fertilisation rates during annual surveys is important for improving the understanding of the determinants for TFEP. This would need to be carried out over a number of years (preferably contrasting) for meaningful conclusions to be drawn. The study may shed light on whether it is possible to use records of egg colour to drawn conclusions about variations in fertilisation rates over a longer series of years.
- Depletion experiments using the survey vessel and gear should be used to obtain estimates of survey efficiency and selectivity. This information could be incorporated into the assessments for snow crab and red king crab, allowing more robust and parsimonious models. As pointed out by Nick Caputi during the review meeting, catch rate data from intensively fished areas may also allow estimation of selectivity and catchability parameters for commercial fishing operations.
- It is recommended that spatial management considerations be included in the future development of OFDs (see recommendation under ToR (b)).
- It is recommended that multi-species considerations be included in the future development of OFDs (see recommendation under ToR (b)).
- Further use of CPUE and fishing effort data could be made in the assessments. It is recommended that effort and CPUE data be collated for both directed fisheries and by-catch fleets and that trends in these data be examined in a spatial context. Generalised linear modelling or other appropriate statistical techniques could be used to extract annual and spatial signals. Use of these signals in the assessments should be investigated, *e.g.* to improve understanding of the contribution of by-catch mortality to overall levels of fishing mortality.
- It is recommended that there be an investigation of the sensitivity of biological reference points and the performance of the OFD to uncertainty about biological parameters, especially growth.
- If lack of information about growth is determined to be an important source of uncertainty about the effectiveness of assessment and precautionary fishery management, it is recommended that field tagging studies be used to estimate growth increments and moulting frequency in BSAI crab stocks. Properly designed tagging studies, *e.g.* involving sufficiently large samples of crabs tagged in relatively shallow waters, could also shed light on rates of natural mortality. Lipofuscin measurements could also be used to investigate the relationship of size with age, although this may depend on the development of routine methods of lipofuscin determination that can be applied to large samples.
- Under ToRs (a) and (b) it was recommended that that the ADF&G and NMFS teams need to reach agreement on the interpretation of the available information on some key

biological processes in BSAI crabs, *e.g.* the interval between moulting and participation in mating by new shell male snow crabs. Where genuine uncertainty remains about key biological processes, this should be used as a focus for new research on crab life-histories, particularly if simulations reveal that the OFD is sensitive to this uncertainty.

- Further research is needed into the relative roles played by fishing operations and changes in the climatic and oceanographic regime in determining past trends in BSAI crab stocks. A consensus on this contentious issue is needed before progress can be made in determining agreed protocols for detecting the effects of regime shifts on crab productivity and in determining the appropriate management response to such shifts.

Conclusions

A great deal of effective research and analytical work has been undertaken to put forward proposals for an OFD that is a vast improvement on the current flawed OFD. In my view this effort has been largely successful in that the proposed OFD is one that can now be accepted as a framework. The challenge now is to progress the parameterisation of the framework to the point where it can be implemented. This means finding default values for the parameters within each tier, *e.g.* stock-specific values for α and β in Tier 3 and group-specific values of α, β and γ in Tier 4, and proxy values for F_{MSY} in Tier 3. At present it is not yet possible to recommend particular values for these parameters, because certain issues need to be resolved before the performance of the OFD under any given parameterisation can effectively be tested. The approach to finding appropriate defaults using simulation models can nevertheless be endorsed as sound in principle and correctly specified in practice (in terms of model structures).

There are two main obstacles to finding default values for the OFD parameters. The first is that there is not yet a satisfactory measure of ESB to used in the MSY control rules and in the SRRs within the simulations. Ideally, ESB should be a measure that is proportional to TFEP; none of the candidate measures considered so far meet this criterion. Recommendations are made in this report for a simple interim measure that could be used immediately and for research aimed at finding more satisfactory long-term solutions.

The second main obstacle is that the role of the harvest strategy in determining the performance of the OFD has not yet been considered. Simulations have so far treated MSY control rules as if they were harvest strategies. On the one hand, this does not recognise the requirement for the State to maintain a precautionary buffer between F_{OFL} and the target F. On the other hand, choice of an MSY control rule on this basis is likely to result in an OFD that places undue constraints on the capacity of the State to manage BSAI crab fisheries according to precautionary and other objectives. What is needed is for MSY control rules to be tested in conjunction with realistic State harvest strategies. Only then can an OFD be selected that serves its proper role of providing limits rather than targets for safe management.

From this I conclude that there remains some work to be done before the OFD can be accepted for implementation. However, the obstacles are not insurmountable, even in the short-term. Given the urgent need for the current OFD to be replaced by a more satisfactory alternative, the Crab Plan Team and its Work Group should be encouraged to select an interim measure for ESB and to use simulations of MSY control rules in conjunction with harvest strategies to select appropriate parameters for an OFD that can be implemented in the short-term. This report also contains recommendations for improvements and developments to the OFD in the medium- to long-term and for supporting research, but these should not be seen as reasons to delay implementation.

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Rugolo, L., 2004. *North Pacific Fisheries Management Council Bering Sea/Aleutian Islands King and Tanner Crab Working Group: Draft Statement of Work.* NMFS/ADF&G, Kodiak/Seattle/Juneau.

Rugolo, L. 2006. *Statement of Work: NPFMC BSAI King and Tanner Crab Working Group*. www.afsc.noaa.gov/refm/docs/2006/crab/Statement%20of%20Work.ppt

Siddeek, M.S.M. & Zheng, J., 2006. *Reference point estimation analysis for the Bering Sea and Aleutian Islands (king and Tanner) crab revised fisheries management plan.* ADF&G, Juneau.

Turnock, B.J. & Rugolo, L.J., 2005. *Stock assessment of eastern Bering Sea snow crab.* NMFS, Seattle/Kodiak.

Turnock, B.J. & Rugolo, L.J., 2006a. *Analysis of proposed overfishing tier system for BSAI king and Tanner crab stocks.* NMFS, Seattle/Kodiak.

Turnock, B.J. & Rugolo, L.J., 2006b. *Unresolved issues concerning proposed overfishing definitions for Bering Sea and Aleutian Islands king and Tanner crab stocks: National Marine Fisheries Service.* NMFS, Seattle/Kodiak.

Zheng, J., 2004. *Bristol Bay red king crab stock assessment in 2004.* ADF&G, Juneau.

Zheng, J., 2006. *Issues dividing the Crab Work Group.* ADF&G, Juneau.

Zheng, J. & Kruse, G.H., 2006. Recruitment variation of eastern Bering Sea crabs: Climate-forcing or top-down effects? *Progress in Oceanography*, **68**, 184-204.

APPENDIX 1: Bibliography of materials provided during the review meeting

The key documents referred to during the review are listed below:

Dew, C.B. & McConnaughey, R.A., 2005. Did trawling on the brood stock contribute to the collapse of Alaska's king crab? *Ecological Applications*, **15**, 919-941.

Maunder, M.N., 2003. *Review of the stock assessment and harvest strategy for eastern Bering Sea snow crab.* CIE, University of Miami.

NPMFC, 2006. *Workshop Report: Crab Overfishing Definitions Inter-agency Workshop. February 28-March 1, 2006, Alaska Fisheries Science Center, Seattle, WA.* NPMFC, Anchorage.

Restrepo, V.R., Thompson, G.G., Mace, P.M., Gabriel, W.L., Low, L.L., MacCall, A.D., Methot, R.D., Powers, J.E., Taylor, B.L., Wade, P.R. & Witzig, J.F., 1998. *Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act.* NOAA Technical Memorandum NMFS-F/SPO-##.

Rugolo, L., 2004. *North Pacific Fisheries Management Council Bering Sea/Aleutian Islands King and Tanner Crab Working Group: Draft Statement of Work.* NMFS/ADF&G, Kodiak/Seattle/Juneau.

Rugolo, L. 2006. *Statement of Work: NPFMC BSAI King and Tanner Crab Working Group*. www.afsc.noaa.gov/refm/docs/2006/crab/Statement%20of%20Work.ppt

Siddeek, M.S.M. & Zheng, J., 2006. *Reference point estimation analysis for the Bering Sea and Aleutian Islands (king and Tanner) crab revised fisheries management plan.* ADF&G, Juneau.

Turnock, B.J. & Rugolo, L.J., 2005. *Stock assessment of eastern Bering Sea snow crab.* NMFS, Seattle/Kodiak.

Turnock, B.J. & Rugolo, L.J., 2006a. *Analysis of proposed overfishing tier system for BSAI king and Tanner crab stocks.* NMFS, Seattle/Kodiak.

Turnock, B.J. & Rugolo, L.J., 2006b. *Unresolved issues concerning proposed overfishing definitions for Bering Sea and Aleutian Islands king and Tanner crab stocks: National Marine Fisheries Service.* NMFS, Seattle/Kodiak.

Zheng, J., 2004. *Bristol Bay red king crab stock assessment in 2004.* ADF&G, Juneau.

Zheng, J., 2006. *Issues dividing the Crab Work Group.* ADF&G, Juneau.

Zheng, J. & Kruse, G.H., 2006. Recruitment variation of eastern Bering Sea crabs: Climate-forcing or top-down effects? *Progress in Oceanography*, **68**, 184-204.

Further documentation available to the reviewers, including presentations given to the crab overfishing workshop is given at:

http://www.afsc.noaa.gov/refm/stocks/CrabWs.htm

APPENDIX 2: Agenda for the review meeting

Center of Independent Experts
Alaska Crab Overfishing Definitions

April 24 - 29, 2006

Alaska Fisheries Science Center, Seattle, WA

Apr 14th 2006 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 (Center Director's Conference Room)

8:00 Coffee and informal discussions

8:30 Introductions - Charge for the CIE –Hollowed

8:50 History of crab management - current overfishing definitions and need for revision - Stram or Designee

9:10 Overview of proposed revisions - Working group

- Working group Statement of Work (20 min) - Rugolo
- Tier System review (20 min) - Zheng
- Brief Description of Snow Crab Assessment (40 min) -Turnock

10:30 Break

10:30 – 12:00 Overview continued – working group

- Brief Description of Red King Crab Assessment (40 min) -Zheng
- Projection Model structure (Siddeek and / or Turnock)

12:00 – 1:00 Break for lunch

1:00-1:30 Overview continued – working group

- Approaches to estimate proxy values for biological reference points – Turnock
- Approaches to estimate proxy values for biological reference points - Siddeek

1:30 – 2:00 Review Workshop Report and Recommendations on crab biology – Stram or designee

2:00 – 2:30 Review of Workshop Report and Recommendations on crab modeling - Ianelli

2:30 Break

2:45-3:45 Review of information available for managed crab stocks - Rugolo

3:45 – 5:00 Performance of Tier System Preliminary results

- Red King Crab – Siddeek
- Red King Crab – Turnock

DAY 2 (CD Conference Room)

8:30 Coffee and informal discussions

8:30 – 10:00 Performance of Tier System Preliminary results continued

- Snow Crab – Turnock
- Snow Crab – Siddeek
- Blue King Crab/Golden Crab - Siddeek

10:00 Break

10:30 – 12:00 Questions and Answers for panel.

12:00 Lunch

1:00 – 5:00 Open question and answer session – or independent work sessions with CIE reviewers.

DAY 3 (CD Conference Room)

8:30 Coffee and informal discussions

9:00 Open question and answer session – or independent work sessions with CIE reviewers.

DAY 4 (CD Conference Room)

8:30 Panel discussions and writing team – NMFS and ADF&G biologists return to offices but remain on cal questionsl

DAY 5 (CD Conference Room)

8:30 Panel discussions and writing team – NMFS and ADF&G biologists return to offices but remain on call to answer questions

APPENDIX 3: Statement of Work

STATEMENT OF WORK

April 19, 2006

General

The Alaska Fisheries Science Center (AFSC) requests review of proposed overfishing definitions and simulation models used to evaluate biological reference points for Bering Sea and Aleutian Islands King and Tanner crab stocks. The North Pacific Fishery Management Council (NPFMC) has determined that the existing overfishing definitions for Bering Sea and Aleutian Islands King and Tanner crab stocks need revision. The AFSC is seeking review of the population dynamics models developed for revising the overfishing definitions.

There are currently 22 Bering Sea and Aleutian Islands crab stocks under the Federal Bering Sea Aleutian Island Crab Fishery Management Plan (FMP) of which 7 are considered major stocks. Four of the seven major crab stocks have been declared overfished and rebuilding plans developed within the last 7 years. Of the remaining three stocks, only one has been relatively stable at a low level, another has maintained stable catch for several years, however, even for this stock it appears recruitment may be declining. While the remaining stock has increased, survey abundance estimates have low precision and the fishery is closed due to bycatch concerns. There is no consensus on the principal cause of declines in Bering Sea crab stocks.

A panel of 3 consultants is requested for this review. The panel will need to be thoroughly familiar with various subject areas involved in analytical stock assessment, including population dynamics theory, length based stock assessment models, rebuilding analyses, estimation of biological reference points and harvest strategy modeling for invertebrates, as well as invertebrate biology. The CIE consultants will travel to Seattle, Washington to meet with the four member Interagency Work Group charged with developing the new overfishing definitions. We request that one member of the Panel should be present at the May meeting of the NPFMC Crab Plan Team in Anchorage, Alaska. The report generated by the consultants should include:

a. A statement of the strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches.
b. Recommendations for improvements to proposed overfishing definitions or alternative definitions,
c. A review of the model configurations, formulations and methods used to account for uncertainty.
d. A review of input parameters (fishery, biological and life history parameters and spawner recruit relationships) used in simulation models.

e. Suggested research priorities to improve our understanding of essential population and fishery dynamics necessary to formulate best management practices.

AFSC will provide copies of the NPFMC Work Group statement of work, proposed overfishing definitions, preliminary results of simulations, discussion of input parameters, a copy of the code for the snow crab stock assessment, and the AD Model Builder and Fortran code used for reference point estimation. The panel will meet with scientists from the Alaska Fisheries Science Center and the Alaska Department of Fish and Game from April 24 to April 28, 2006, in Seattle, Washington.

Expected Products:

- One member of the panel will attend the May meeting of the Crab Plan Team to discuss the panels findings regarding the strengths and weaknesses of proposed definitions and modeling approaches.
- No later than June 1, 2006, panelists will submit a written report of findings, analysis, and conclusions. The report should be addressed to the "UM Independent System for Peer Reviews", and sent to David Die, UM/RSMAS, 4600 Rickenbacker Causeway, Miami, FL 33149 (or via email to ddie@rsmas.miami.edu).

Signed________________________

Date____________

ANNEX I: REPORT GENERATION AND PROCEDURAL ITEMS

1. The report should be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report should consist of a background, description of review activities, summary of findings, and conclusions/recommendations.

3. The report should also include as separate appendices the bibliography of materials provided by the Center for Independent Experts and the center and a copy of the statement of work.

4. Individuals shall be provided with an electronic version of a bibliography of background materials sent to all reviewers. Other material provided directly by the center must be added to the bibliography that can be returned as an appendix to the final report.

Please refer to the following website for additional information on report generation: http://www.rsmas.miami.edu/groups/cimas/Report_Standard_Format.html

Alaskan Crab Overfishing Definitions Review

Seattle, Washington

24-28 April 2006

Dr Nick Caputi

Department of Fisheries (Western Australia)
Western Australian Fisheries and Marine Research Laboratories
PO Box 20, North Beach, WA 6920, Australia

Representing the Center of Independent Experts,
University of Miami

Executive Summary

The Alaska Fisheries Science Center (AFSC) requested a review of proposed overfishing definitions and simulation models used to evaluate biological reference points for Bering Sea and Aleutian Islands King and Tanner crab stocks. The North Pacific Fishery Management Council (NPFMC) has determined that the existing overfishing definitions for Bering Sea and Aleutian Islands King and Tanner crab stocks needed revision. The AFSC sought a review of the population dynamics models developed for revising the overfishing definitions.

There are currently 22 Bering Sea and Aleutian Islands crab stocks under the Federal Bering Sea Aleutian Island Crab Fishery Management Plan (FMP) of which 7 are considered major stocks. Four of the seven major crab stocks have been declared overfished and rebuilding plans developed within the last 7 years. Of the remaining three stocks, only one has been relatively stable at a low level, another has maintained stable catches for several years, however, even for this stock it appears recruitment may be declining. While the remaining stock has increased, survey abundance estimates have low precision and the fishery is closed due to bycatch concerns. There is no consensus on the principal cause of declines in Bering Sea crab stocks.

A panel of three consultants undertook the review. The panel met with scientists from the Alaska Fisheries Science Center and the Alaska Department of Fish and Game charged with developing the new overfishing definitions from April 24 to 28, 2006, in Seattle, Washington. The crab team presented the key aspects of their research on the first three days. Throughout the presentations the CIE panel asked detailed questions on issues of the stock assessment related research that was presented. All members of the crab team answered questions and expanded on some aspects of the stock assessment.

AFSC provided access to a number of relevant papers that were listed on their web site www.afsc.noaa.gov/refm/stocks/CrabWs.htm and provided some additional documents by email. The key papers that focused on the area of review were:

- Statement of work for working group.
- Description of proposed overfishing definition tier system.
- Stock assessments for Red King Crab and Snow Crab.
- Working group position papers.
- Workshop report recommendations.
- Projection model results.

This CIE review team was asked to focus on:

a. A statement of the strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches.
b. Recommendations for improvements to proposed overfishing definitions or alternative definitions,

c. A review of the model configurations, formulations and methods used to account for uncertainty.
d. A review of input parameters (fishery, biological and life history parameters and spawner recruit relationships) used in simulation models.
e. Suggested research priorities to improve our understanding of essential population and fishery dynamics necessary to formulate best management practices.

Federal legislation requires an overfishing definition (OFD) that specifies whether the stock is overfished and whether there is overfishing occurring. The proposed system represents a significant improvement as it is based on the current NPFMC groundfish system which has been reviewed and tested. A buffer is incorporated between the overfishing limit (FOFL) and the target F level as required on the National Standard guidelines 1 (NSG1). In the current crab tier system there is no buffer between the target F and FOFL.

The proposed framework is comprehensive having five tiers which take into account the level of knowledge and uncertainty about the stocks being managed. However the uncertainty within a tier has not been thoroughly taken into account and should be considered when considering the overfishing and overfished definitions and the strategies for rebuilding. For Tiers 1 to 4 there are three levels of stock status with a corresponding target fishing mortality rate corresponding to the overfishing limit (FOFL).

The annual assessment of the stock provides for an annual revised estimate of the OFD levels with a revision of the model approach, the parameters of the model and the new year's data. This provides the 'best' indication of the status of stock. However this could also be viewed as a weakness of the proposed OFD approach in that the OFD can change with each year's stock assessment. A two-stage approach should be considered for each year's stock assessment: (1) a comparison of the latest year's stock level and exploitation with the OFD level set in the previous year's definition for overfished and overfishing; and (2) undertake a revised stock assessment which may include a new model approach, revised biological parameters as well as the addition of the usual new year's data.

Modelling of the proposed overfishing tier system by the two modeling groups is viewed as a strength in the process of determining the OFD in that it provides a comparison of alternative approaches, different set of assumptions about the features in the model such as the measure of stock (B) which is the basis of the overfished assessment and the type of the stock-recruitment relationship (SRR). However to gain maximum benefit from the two modeling approaches it is important to undertake critical analysis of the results and provide a revision and improvement to the models. Some revision of the models has occurred but no consensus on the optimum model has been reached.

The projection model to compare rebuilding strategies and different parameters should have the same starting biomass for each simulation. This was undertaken by Turnock and Rugolo (2006) but Siddeek and Zheng (2006) use a different starting value (beta x Bmsy) for some of the different comparison of parameters. This means that some of the simulations are not comparable in assessing the parameters. The different levels of alpha

(0 to 0.1) tested show little difference in rebuilding time and long-term mean yield so any value in this range appears satisfactory. One of the weaknesses in the new OFD approach in the choice of alpha and beta in the OFD are somewhat arbitrary and default levels of 0 and 0.2 can be used in the absence of evidence to indicate that there are more appropriate measures.

The projection model tests the harvest rule from the proposed Tier system as well as the current OFL and the current ADFG harvest strategies. The simulation confirms that the current OFL is not sustainable and there is a good comparison of a large number of rebuilding strategies.

As you move down the Tiers 2 to 4, the models are more sensitive to scientist decisions as less information is available and hence require additional simulations to assess the relative merits of the model. Tier 5 should consider effort data in setting a target catch level. For example, has there been an increase or decrease in effort for the periods under consideration for setting the target catch? If there is considerable annual variation in recruitment then this increases the chance of overfishing if there is a series of below-average recruitment. Simulation analyses associated with this Tier should be conducted to assist in determining a sustainable control rule.

Some additional recommendation to assess the OFDs:

- An assessment should be made of the short-term impact of rebuilding on catch compared to the rebuilding time.
- There is a need to consider variability in the parameters, observation error, and hence the uncertainty associated with the current status relative to the decision rules within each of the tiers and the uncertainty associated with rebuilding strategies so that managers can be aware of the variability associated with these assessments.
- Additional simulations are required to assess the relative merits of the OFD models as you move down the tiers 2 to 4, the models are more sensitive to scientist decisions as less information is available. Tier 4 requires additional simulations to assess an additional parameter (gamma).

The measurement of egg production is particularly difficult for the Alaskan crab fishery which is a male only fishery resulting in a large numbers of mature females that are unmated, females with clutches that are not filled, females with unfertilized eggs, and barren and senescent females. These are all indicators of a relatively much lower abundance of mature males compared to mature females which results in the mature males being the limiting factor in the determining the egg production. Hence the annual mature male abundance (taking into account sperm variation with size) in the appropriate location may be the key determinant to egg production and should be considered as a possible indicator of egg production. The indicator used by Turnock and Rugolo (2006) take into account the fact that mature males are limited in determining effective mature female biomass but then it adds the effective male mature biomass which does not appear appropriate.

The cause of the reduction in the king crab stocks since the 1980's is critical in determining what are the target Bmsy levels. If the reduction is due to a regime shift then basing the Bmsy on the lower levels of mature biomass since the 1980's is appropriate. There is evidence of the negative effects of the increase in trawling since 1980, particularly in the most productive spawning grounds off Unimak and Amak Islands, on the breeding stock. However it may not be possible to restrict trawling from the more productive spawning areas in which case basing the Bmsy on the lower levels of mature biomass since the 1980's is still appropriate as the breeding stock will not return to the levels of the 1970's.

An adaptive management approach should be considered to assess the effects of fishing on these productive grounds by closing an appropriately-sized area to trawling to determine the impact on the stock in that area. The two competing hypotheses on decline of the king crab stocks since the 1980's, i.e. regime shift and the effects of increased targeted and trawling, may both be contributing to the decline in recruitment. Many stocks quite often collapse when there is the combined effect of poor environmental conditions at a time when the breeding stock is reduced due to changes in fishing practices.

The SRR is also affected by the years chosen to assess the fit and the significant change to the recruitment pattern before and after 1976. Irrespective of whether this change is due to a regime shift or the effects of trawling, there will be a change in the shape of the SRR and this should be taken into account.

The choice of the stock-recruitment relationship (SRR) is important in the stock assessment of the Alaskan crab fisheries and both modeling groups have given this issue a significant level of attention. The Maximin Clark (1991) method provides a basis to assess different steepness levels of the SRRs when there is no empirical data available. However in many cases there are some data available to at least make a choice about whether the SRR is likely to be a Ricker or Beverton-Holt curve.

As the relative size of mature males and females is import in the mating process, it is important to monitor the changes in mean size and length frequency for mature males and females that occur. The ratio of mature male to mature female mean size could also be used to measure the relative changes in mean size.

The Turnock and Rugolo (2006) population models have a large number of parameters estimated and it appears these could be significantly reduced eg there appears to be little biological basis for having separate male and female recruitment indices (even if they 'were constrained to be similar'). The annual recruitment of males and females should be similar and set at appropriate sex ratio if the recruitment sex ratio is not 1:1. Also the biological basis for having different selectivities for new and old shell is not clear. Annual parameters are estimated for selectivities and again it is not clear why selectivity should change every year. The use of different natural mortality levels for 3 different periods for males and 4 different periods for females does not appear to be biologically sensible (Zheng 2006).

Estimation of survey catchability for snow crabs using underbag have been undertaken. However this may not provide a complete assessment of the catchability. The use of a depletion experiment should be considered to estimate survey catchability for different sizes, shell condition and sexes. Environmental factors can have a significant impact on the efficiency of the gear and it would be useful to have an assessment of this issue. The key environmental indices during the surveys should be summarized so that the potential biases in the indices are identified.

Some suggested research priorities to improve our understanding of essential population and fishery dynamics necessary to formulate best management practices include:

1. As mature males may be the limiting factor in the determining the egg production, the annual variation in the mature male abundance should be considered in modelling as a possible indicator of egg production.
2. Depletion experiments should be considered to estimate survey catchability for different sizes, shell condition and sexes.
3. A depletion analysis of some blocks that are heavily fished during a season such that there is a significant decline in catch rate due to the effects of fishing could provide some valuable insights into some fishery dynamics. A comparison of the daily retained male CPUE in a block (or groups of blocks) and the cumulative legal catch removed from that block over the period that the fishery operates enables an estimate of the residual legal biomass at the end of fishing, the catchability of the male crabs and the exploitation rate.
4. A depletion analysis may also be applied to assess the impact of fishing on discards if there is sufficient observer data on the daily catch rate of discards in a heavily fished block(s) and an estimate of discard numbers can be made from those block(s). A significant decline in the discard rate during the course of fishing would indicate a significant level of discard mortality.
5. The change in management of the fishery to an individual transferable quota (ITQ) is likely to result in high grading and hence an increase in the rate of discarding and hence associated discard mortalities. Consideration should also be given to retaining some of the discards by providing a separate quota for discards. If there is a high mortality (50-100%) associated with discards it may be worth retaining some of them (if there a market for them) and reducing the ITQ for the first-grade crabs. This issue is also related to Recommendation 7.
6. While considerable research on escape gaps and subsequent changes have been undertaken on escape gaps, it appears that there is still considerable retention of undersize crabs, most (50-100%) of which may die as a result of being captured. This makes it imperative to undertake further research (if necessary) to choose the number and size of the escape gaps that maximizes the escape of undersize male and female crabs even if it means that some of the smaller legal-size males are allowed to escape. Additional research on the

handling practices (dropping crabs on a hard surface from a height of greater than 4 ft) onboard should also be undertaken to assess if there are ways to improve handling practices to increase survival of discards.

7. An evaluation should be undertaken on the merits of retaining some female king crabs that are marketable as part of the catch. There appears to be a surplus number of mature females relative to the number of mature males in the fishery resulting in unmated and senescent females. These females could contribute to significant loss of productivity due to density dependent mortality and growth, particularly if habitat is limiting. A modeling of harvest strategies should be examined that includes the retention of an appropriate quantity of females that results in an optimum ratio of mature males to mature females and hence a reduction in unmated mature females.
8. The modeling of the shell condition is a critical part of the population dynamics of the crab fishery as it affects the catch that is targeted and retained, molting, growth, maturity and the mating dynamics. There appears to be uncertainty about the relationship that has been assumed between shell condition and time since last moulting and this relationship needs to be examined further.
9. An economic assessment of the fishery should be undertaken in conjunction with the stock assessment modelling to assess ways to improve the economic performance of the fishery. The maximum economic yield (MEY) which is less than MSY should be considered as a performance indicator for the fishery as it would be a more conservative indicator.

Background

The Alaska Fisheries Science Center (AFSC) requested a review of proposed overfishing definitions and simulation models used to evaluate biological reference points for Bering Sea and Aleutian Islands King and Tanner crab stocks. The North Pacific Fishery Management Council (NPFMC) has determined that the existing overfishing definitions for Bering Sea and Aleutian Islands King and Tanner crab stocks needed revision. The AFSC sought a review of the population dynamics models developed for revising the overfishing definitions.

There are currently 22 Bering Sea and Aleutian Islands crab stocks under the Federal Bering Sea Aleutian Island Crab Fishery Management Plan (FMP) of which 7 are considered major stocks. Four of the seven major crab stocks have been declared overfished and rebuilding plans developed within the last 7 years. Of the remaining three stocks, only one has been relatively stable at a low level, another has maintained stable catch for several years, however, even for this stock it appears recruitment may be declining. While the remaining stock has increased, survey abundance estimates have low precision and the fishery is closed due to bycatch concerns. There is no consensus on the principal cause of declines in Bering Sea crab stocks.

A panel of three consultants was requested for this review. The panel was familiar with various subject areas involved in analytical stock assessment, including population dynamics theory, length based stock assessment models, rebuilding analyses, estimation of biological reference points and harvest strategy modeling for invertebrates, as well as invertebrate biology. The CIE consultants travelled to Seattle, Washington to meet with the four member Interagency Work Group charged with developing the new overfishing definitions. One member of the Panel was present at the May meeting of the NPFMC Crab Plan Team in Seattle.

Description of Review Activities

AFSC provided access to a number of relevant papers that were listed on their web site www.afsc.noaa.gov/refm/stocks/CrabWs.htm and provided some additional documents by email. The key papers that focused on area of review were:

- Statement of work for working group.
- Description of proposed overfishing definition tier system.
- Stock assessments for Red King Crab and Snow Crab.
- Working group position papers.
- Workshop report recommendations.
- Projection model results.

A copy of the code for the snow crab stock assessment, and the AD Model Builder and FORTRAN code used for reference point estimation was offered to the review team but this was not required.

This CIE review team was asked to focus on:

a. A statement of the strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches.
b. Recommendations for improvements to proposed overfishing definitions or alternative definitions,
c. A review of the model configurations, formulations and methods used to account for uncertainty.
d. A review of input parameters (fishery, biological and life history parameters and spawner recruit relationships) used in simulation models.
e. Suggested research priorities to improve our understanding of essential population and fishery dynamics necessary to formulate best management practices.

The panel met with scientists from the Alaska Fisheries Science Center and the Alaska Department of Fish and Game from April 24 to April 28, 2006, in Seattle, Washington. The meeting was chaired by Dr Anne Hollowed and Dr Jim Ianelli. The crab team presented the key aspects of their research on the first three days according to the agenda in Appendix 2. Throughout the presentations the CIE panel asked detailed questions on issues of the stock assessment and related research that was presented. All members of the crab team answered questions and expanded on some aspects of the stock assessment. On the fourth day the CIE panel met to highlight the key issues in the stock assessment modeling and overfishing definitions that would require some comment. They sought clarification from some members of the crab team on a number of issues before preparing to write their individual independent reports.

Summary of Findings

The findings of the review have been presented based according to the terms of reference set of the panel:

1. *A statement of the strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches.*

Federal legislation requires an overfishing definition (OFD) that specifies whether the stock is overfished and whether there is overfishing occurring. The proposed OFD is a tier system that represents a significant improvement on the current system. The proposed system is based on the current NPFMC groundfish system which has been reviewed and hence provides a good basis for developing OFD. The groundfish system has incorporated a buffer between the overfishing limit (FOFL) and the target F level as required on the National Standard guidelines 1 (NSG1). In the current crab tier system there is no buffer between the target F and FOFL.

The proposed framework is comprehensive having five tiers which take into account the level of knowledge and uncertainty about the stocks being managed, i.e. whether reliable estimates are available for biomass and reference points and whether a stock assessment model has been implemented. However the uncertainty within a tier has not been thoroughly taken into account and should be considered when considering the overfishing and overfished definitions and the strategies for rebuilding. For Tiers 1 to 4 there are three levels of stock status with a corresponding target fishing mortality rate corresponding to the overfishing limit (FOFL).

The annual assessment of the stock provides for an annual revised estimate of the OFD levels with a revision of the model approach, the parameters of the model and the new year's data. This provides the 'best' indication of the status of stock. However this could also be viewed as a weakness of the proposed OFD approach in that the OFD can change with each year's stock assessment. There does not appear to be an assessment that compares the latest year's stock level and exploitation with the OFD level set the previous year for overfished and overfishing.

A two-stage approach should be considered for each year's stock assessment: (1) a comparison of the latest year's stock level and exploitation with the OFD level set the previous year definition for overfished and overfishing; and (2) undertake a revised stock assessment which may include a new model approach, revised biological parameters, new time series of data as well as the addition of the usual new year's data (such as survey, catch and effort). The changes to the previous years' assessment should be well documented and subject to review.

Modelling of the proposed overfishing tier system by the two modeling groups is viewed as a strength in the process of determining the OFD in that it provides a comparison of alternative approaches, different set of assumptions about the features in the model such as the measure of stock (B) which is the basis of the overfished assessment and the type of the stock-recruitment relationship (SRR). However to gain maximum benefit from the two modeling approaches it is important to undertake critical analysis of the results and provide a revision and improvement to the models. Some revision of the models has occurred but no consensus on the optimum model has been reached.

The projection model to compare rebuilding strategies should have the same starting biomass for each simulation. This was undertaken by Turnock and Rugolo (2006) but Siddeek and Zheng (2006) use a different starting value (beta x Bmsy) for some of the different models that evaluate the parameters. This means that the simulations are not comparable. Siddeek and Zheng (2006) have undertaken simulations to compare alpha and beta however because of the different starting values in biomass for different levels of beta, only alpha levels can be compared for different levels of beta. A range of starting values, eg .1-.7 Bmsy, should be used to test alpha and beta parameters. The different levels of alpha (0 to 0.1) tested show little difference in rebuilding time and long-term mean yield so any value in this range appears satisfactory. This is one of the weakness in the approach in the choice of alpha and beta are somewhat arbitrary and default levels of 0 and 0.2 can be used in the absence of evidence to indicate that there are more appropriate measures.

A weakness of the analysis is that there should be an assessment of the short-term impact of rebuilding on catch. There is no assessment of short-term impact on yield of the rebuilding strategies. This is usually one of the key elements of rebuilding that is required by managers and industry.

The projection model tests the harvest rule from the proposed Tier system as well as the current OFL and the current ADFG harvest strategies. The simulation confirms that the current OFL is not sustainable (Turnock and Rugolo 2006). Turnock and Rugolo (2006) provide a good comparison of a large number of rebuilding strategies including the F=0 and Fmsy strategies to help select the set of appropriate strategies. Siddeek and Zheng (2006) only focus on the OFL as the harvest strategy to test the rebuilding strategy which unnecessarily constrains the harvest strategy that may be required.

As you move down the Tiers 2 to 4, the models are more sensitive to scientist decisions as less information is available and hence require additional simulations to assess the relative merits of the model.

Tier 5 average catch may not be a conservative OFD depending on exploitation and recruitment patterns. Tier 5 should consider effort data in setting a target catch level. For example, has there been an increase and decrease in effort for the periods under consideration? If there is considerable annual variation in recruitment then this increases the chance of overfishing if there as a series of below-average recruitment. Simulation analyses associated with this Tier should be conducted to assist in determining a sustainable control rule. An initial OFL at a level below the average catch should be considered until there is evidence that the stock can support a higher catch.

A 3-year moving average of the levels in the overfished and overfishing definitions should be considered to assess the trends in the abundance and exploitation indices and reduce the possible biases in the annual indices. Therefore an average over 3 years will avoid the short-term impact of factors such catchability variability and assist in focusing the control rules on the significant trends in the fisheries.

2. *Recommendations for improvements to proposed overfishing definitions or alternative definitions,*

Some recommendations for improvements to the OFDs are described above. This section contains some additional recommendation to assess the OFDs:

- An assessment should be made of the short-term impact of rebuilding on catch. The trade-off relationship between rebuilding time and loss of short-term yield should be examined to determine an appropriate rebuilding time that minimises the short-term impact on the industry.
- There is a need to consider variability in the parameters, observation error, and hence the uncertainty associated with the current status relative to the decision rules within each of the tiers and the uncertainty associated with rebuilding

strategies so that managers can be aware of the variability associated with these assessments.

- A range of starting values, eg .1-.7 Bmsy, should be used in the rebuilding simulations to test alpha and beta to assess if there are more appropriate levels of alpha and beta than the arbitrary levels of 0 and 0.2.
- Additional simulations are required to assess the relative merits of the OFD models as you move down the tiers 2 to 4. These models are more sensitive to scientist decisions as less information is available. Tier 4 requires additional simulations to assess an additional parameter (gamma).
- Simulation analyses should be conducted with Tier 5 to assist in determining a sustainable control rule. An initial OFL at a level below the average catch should be considered until there is evidence that the stock can support a higher catch.

3. *A review of the model configurations, formulations and methods used to account for uncertainty.*

4. *A review of input parameters (fishery, biological and life history parameters and spawner recruit relationships) used in simulation models.*

This section deals with Terms of Reference 3 and 4.

A measure of the egg production is a critical component of the population dynamics. This measure is particularly difficult for the Alaskan crab fishery which is a male only fishery resulting in a large numbers of mature females that are unmated, females with clutches that are not filled, females with unfertilized eggs, barren and senescent females. These are all indicators of a much lower abundance of mature males compared to mature females which results in the mature males being the limiting factor in the determining the egg production. There appears to be considerable annual variation in the fraction barren females and clutch fullness and it is important to understand the factors affecting this annual variation such as the effects of fishing and the environment. There is evidence that relates the level of exploitation (on the males) to the level of barren females, clutch fullness and females with unfertilized eggs.

Despite the harvest strategy with size limits set so that the males can mate at least once before being retained, the number of males still appear to be a bottleneck in the reproduction process. Hence the annual variation in the mature male abundance (taking into account sperm relationship with size) in the appropriate location may be the key determinant to egg production and should be considered as a possible indicator of egg production.

The current indicators being used for mature biomass in the OFD and the stock recruitment relationships do not appear good indicators of egg production and should be reviewed. The indicator used by Turnock and Rugolo (2006) takes into account the fact that mature males are limited in determining effective mature female biomass but then it adds the effective male mature biomass which does not appear appropriate.

The cause of the reduction in the king crab stocks since the 1980's is critical in determining what are the target Bmsy levels. If the reduction is due to a regime shift then basing the Bmsy on the lower levels of mature biomass since the 1980's is appropriate. Dew and McConnaughey (2005) provide evidence of the negative effects of the increase in trawling in 1980, particularly in the most productive spawning grounds off Unimak and Amak Islands, on the breeding stock. This impact would be exacerbated if the area is correctly identified as a valuable 'source' area and contains high abundance of multiparous crabs. The highly aggregated behaviour of the king crabs further increases their susceptibility to overfishing. Even if the reduced biomass is due to the effects of trawling, it may not be possible to restrict trawling from the more productive spawning areas and re-introduce the appropriate sanctuary zones. In this case basing the Bmsy on the lower levels of mature biomass since the 1980's is still appropriate as the breeding stock will not return to the levels of the 1970's under the current levels of trawling. However if the impact on the trawling on the spawning biomass can be reversed then basing the Bmsy on the level of mature biomass of the 1980's may significantly underestimate the true potential of the stock. An adaptive management approach should be considered to assess the effects of fishing on these productive grounds by closing an appropriately-sized area to trawling to determine the impact on the mature stock in that area.

The two competing hypotheses on decline of the king crab stocks since the 1980's, i.e. regime shift and the effects of increased targeted and trawling, may both be contributing to the decline in recruitment. Many stocks quite often collapse when there is the combined effect of poor environmental conditions at a time when the breeding stock is reduced to changes in fishing practices.

The relationship between male molting and subsequent mating of snow crab has been a source of different interpretations between the research teams. While after the males molt, they '**can potentially mate** with primiparous females the following winter and with multiparous females in the spring of the following year', however the newshell males are **outcompeted as mates** (Workshop report, 2006). If these males are used as contributors to the egg production (Zheng 2006) then they should be discounted to reflect the biological qualifications associated with the mating contribution by these males.

As the relative size of mature males and females is import in the mating process, it is important to monitor the changes in mean size and length frequency for mature males and females that occur. The ratio of mature male to mature female mean size could also be used to measure the relative changes in mean size.

The choice of the stock-recruitment relationship (SRR) is important in the stock assessment of the Alaskan crab fisheries and both modeling groups have given this issue a significant level of attention. The Maximin Clark (1991) method provides a basis to assess different steepness levels of the SRRs when there is no empirical data available. However in many cases there are some data available to at least make a choice about whether the SRR is likely to be a Ricker or Beverton-Holt curve. This would at least restrict the choices available and result in a more appropriate choice. This empirical data can also be used in the development of informed priors, eg relative probabilities Beverton-Holt and Ricker curve, when in the stock assessment models. Siddeek provided a valuable assessment on the relationship between Tau and steepness in the SRR of the Ricker and Beverton-Holt curves.

The SRR is affected by the years chosen to assess the fit. There is a significant change to the recruitment pattern before and after 1976. Irrespective of whether this change is due to a regime shift or the effects of trawling, there will be a change in the shape of the SRR and this should be taken into account. The change in shape of the SRR may take the form of a stock-recruitment-environment relationship (SRR-E) which takes into account the regime shift or the effect of wind on the recruitment of Tanner crabs (Rosenkranz et al. 1998). Even if the reduction in recruitment is due to the effects of fishing, then a dummy variable can be used in the SRR to differentiate the years before and after 1976.

The Turnock and Rugolo (2006) population models have a large number (276) of parameters estimated and it appears these could be significantly reduced. For example, there appears to be little biological basis for having separate male and female recruitment indices (even if they 'were constrained to be similar'). The annual recruitment of males and females should be similar and set at appropriate sex ratio if the recruitment sex ratio is not 1:1.

The biological basis for having different selectivities for new and old shell is not clear (Fig 20 and 21 in Turnock and Rugolo 2006). Annual parameters are estimated for selectivities and again it is not clear why selectivity should change every year. In fact Figure 21 indicates that selectivity for new shell appears constant over the years and hence the number of parameters could be reduced. There appears to be a dramatic difference in the shape of the survey selectivity before and after 1982 (Fig. 22 in Turnock and Rugolo 2006) with an increase in selectivity for the larger sizes and decrease in selectivity for smaller crabs. However the reason for this change in selectivity is not explained.

The use of different natural mortality levels for 3 different periods for males and 4 different periods for females (Zheng 2006) does not appear to be biologically sensible. While it is possible for mortality to vary over the years it does not appear to be reasonable for the differences to be at different times for the sexes. The application of different levels of mortality appears to be based on the statistical fit of the model which could be explained by a number of reasons of which variation in natural mortality is only one possibility.

Estimation of survey catchability for snow crabs using underbag have been undertaken. However this may not provide a complete assessment of the catchability. The use of a depletion experiment should be considered to estimate survey catchability for different sizes, shell condition and sexes.

Environmental factors can have a significant impact on the efficiency of the gear and it would be useful to have an assessment of this issue. The key environmental indices during the surveys should be summarized so that the potential biases in the indices are identified and whether that bias is likely to be positive or negative. If the relationship between the environmental factors and gear efficiency can be determined then this relationship can be used to standardize the catch rates so that they better reflect the abundance of the year-classes.

5. *Suggested research priorities to improve our understanding of essential population and fishery dynamics necessary to formulate best management practices.*

    a. A measure of the egg production is a critical component of the population dynamics. This measure is particularly difficult for the Alaskan crab fishery which is a male only fishery resulting in a large numbers of mature females that are unmated, females with clutches that were not filled, females with unfertilized eggs, barren and senescent females. These are all indicators of a relatively lower abundance of mature males compared to mature females which results in the mature males being the limiting factor in the determining the egg production. Hence the annual variation in the mature male abundance may be the key determinant to egg production and should be considered as a possible indicator of egg production. The current indicators being used for mature biomass in the OFD and the stock recruitment relationships do not appear good indicators of egg production and should be reviewed. An adaptive management approach should be considered to assess the effects of trawling on the previously productive breeding grounds off Unimak and Amak Islands by closing an appropriately-sized area to trawling to determine the impact on the stock in that area.
    b. Depletion experiments should be considered to estimate survey catchability for different sizes, shell condition and sexes.
    c. A depletion analysis of some blocks that are heavily fished during a season such that there is a significant decline in catch rate due to the effects of fishing could provide some valuable insights into some fishery dynamics. A comparison of the daily retained male CPUE in a block (or groups of blocks) and the cumulative legal catch removed from that block over the period that the fishery operates enables an estimate of the residual legal biomass at the end of fishing, the catchability of the crabs and the exploitation rate.
    d. A depletion analysis may also be applied to assess the impact of fishing on discards if there is sufficient observer data on the daily catch rate of discards in a heavily fished block(s) and an estimate of discard numbers can be made from those block(s). A significant decline in the discard rate during the course of fishing would indicate a significant level of discard mortality.
    e. The change in the management of the fishery to an individual transferable quota (ITQ) is likely to result in high grading and hence increase the rate of discarding and associated discard mortalities. Consideration should also be given to retaining some of the discards by providing a separate quota for discards. If there is a high mortality (50-100%) associated with discards it

may be worth retaining some of them (if there a market for them) and reducing the ITQ for the first-grade crabs.

f. While considerable research on escape gaps and subsequent changes have been undertaken on escape gaps, it appears that there is still considerable retention of undersize crabs, most (50-100%) of which may die as a result of being captured. This makes it imperative to undertake further research (if necessary) to choose the number and size of the escape gaps that maximizes the escape of undersize male and female crabs even if it means that some of the smaller legal-size males are allowed to escape. Additional research on the handling practices (dropping crabs on a hard surface from a height of greater than 4 ft) onboard should also be undertaken to assess if there are ways to improve handling practices to increase survival of discards.
g. An evaluation should be undertaken on the merits of retaining some female king crabs that are marketable as part of the catch. There appears to be a surplus number of mature females relative to the number of mature males in the fishery resulting in unmated and senescent females. These females could contribute to significant loss of productivity due to density dependent mortality and growth, particularly if habitat is limiting. The discarding of female crabs results in a high discard mortality in which case there appears to be a significant wastage of product. The retention of an approved quantity of females would provide a basis for increasing the overall yield or can be used to offset a reduction a male catch and hence result in an optimum sex ratio for mating. A modeling of harvest strategy should be examined that includes the retention of an appropriate quantity of females that results in an optimum ratio of mature males to mature females and hence a reduction in unmated mature females.
h. The modeling of the shell condition is a critical part of the population dynamics of the crab fishery as it affects the catch that is targeted and retained, molting, growth, maturity and the mating dynamics. There appears to be uncertainty about the relationship that has been assumed between shell condition and time since last moulting and this relationship needs to be examined further.
i. An economic assessment of the fishery should be undertaken in conjunction with the stock assessment modelling to assess ways to improve the economic performance of the fishery. The maximum economic yield (MEY) which is less than MSY should be considered as a performance indicator for the fishery as it would be a more conservative indicator.
j. An assessment should be made of the short-term impact of rebuilding on catch. The time trend in rebuilding of biomass has been presented by Turnock and Rugolo (2006). Trade-off relationship between rebuilding time and loss of short-term yield should be examined to determine an appropriate rebuilding time that minimises the short-term impact on the industry. This information is vital for economic analysis of any rebuilding strategy.

References

Dew, C.B. and McConnaughey, R (2005). Did trawling on the brood stock contribute to the collapse of the Alaska's king crab? Ecological applications 15: 919-941.

Rosenkranz, G, Tyler, A. Kruse, G. (2001). Effects of water temperature and wind on year-class success of Tanner crabs in Bristol Bay, Alaska. Fisheries Oceanography 10: 1-12.

Siddeeek, S., Zheng, J. (2006). Reference point estimation analysis for the Bering Sea and Aleutian Islands (King and Tanner) crab revised fisheries management plan. Alaska Department of Fish and Game (draft).

Turnock, B., Rugolo, L. (2006). Stock assessment of eastern Bering Sea snow crab. National Marine Fisheries Service (draft).

Workshop Report (2006). Crab overfishing definitions inter-agency workshop. February 28 – March 1, 2006.

Zheng, J. (2006). Bristol Bay red kink crab stock assessment in 2004. Alaska Department of Fish and Game (draft).

Appendix 1

Consulting Agreement between the University of Miami and Dr. Nick Caputi

STATEMENT OF WORK

April 27, 2006

Background

The Alaska Fisheries Science Center (AFSC) requests review of proposed overfishing definitions and simulation models used to evaluate biological reference points for Bering Sea and Aleutian Islands King and Tanner crab stocks. The North Pacific Fishery Management Council (NPFMC) has determined that the existing overfishing definitions for Bering Sea and Aleutian Islands King and Tanner crab stocks need revision. The AFSC is seeking review of the population dynamics models developed for revising the overfishing definitions.

There are currently 22 Bering Sea and Aleutian Islands crab stocks under the Federal Bering Sea Aleutian Island Crab Fishery Management Plan (FMP) of which 7 are considered major stocks. Four of the seven major crab stocks have been declared overfished and rebuilding plans developed within the last 7 years. Of the remaining three stocks, only one has been relatively stable at a low level, another has maintained stable catch for several years, however, even for this stock it appears recruitment may be declining. While the remaining stock has increased, survey abundance estimates have low precision and the fishery is closed due to bycatch concerns. There is no consensus on the principal cause of declines in Bering Sea crab stocks.

Review Requirements

A panel of three consultants is requested for this review. In aggregate, the panel will need to be thoroughly familiar with various subject areas involved in the review: crab biology; analytical stock assessment, including population dynamics theory, length-based stock assessment models, rebuilding analyses, estimation of biological reference points and harvest strategy modeling for invertebrates; and AD Model Builder. The CIE consultants will travel to Seattle, Washington to meet with the Interagency Work Group charged with developing the new overfishing definitions. We request that one member of the Panel should be present at the May meeting of the NPFMC Crab Plan Team in Anchorage, Alaska. We also request that one member of the Panel be present at the June meeting of the NPFMC Scientific and Statistical Committee meeting in Kodiak, Alaska. It would be preferable that the same individual attends both of these meetings, but this is not a requirement.

The report generated by each consultant should include:

f. A statement of the strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches.

g. Recommendations for improvements to proposed overfishing definitions or alternative definitions,
h. A review of the model configurations, formulations and methods used to account for uncertainty.
i. A review of input parameters (fishery, biological and life history parameters and spawner recruit relationships) used in simulation models.
j. Suggested research priorities to improve our understanding of essential population and fishery dynamics necessary to formulate best management practices.

AFSC will provide copies of the NPFMC Work Group statement of work, proposed overfishing definitions, preliminary results of simulations, discussion of input parameters, a copy of the code for the snow crab stock assessment, and the AD Model Builder and Fortran code used for reference point estimation. The panel will meet with scientists from the Alaska Fisheries Science Center and the Alaska Department of Fish and Game from April 24 to April 28, 2006, in Seattle, Washington (see attached agenda).

It is estimated that the duties of each reviewer will occupy a maximum of 14 days each: several days for preparation, five days for the workshop, several days for writing their reports, and two days for travel. In addition, a maximum of nine reviewer days will be allowed for attending the two council meetings, including preparation time, travel, and one day to attend each meeting. The total level of effort is 51 days of reviewer time.

Products

- One member of the panel will attend the May meeting of the Crab Plan Team on May 17, 2006 in Anchorage, Alaska, to discuss the panel's findings regarding the strengths and weaknesses of proposed definitions and modeling approaches.
- One member of the Panel will attend the June meeting of the NPFMC Scientific and Statistical Committee meeting on June 5, 2006 in Kodiak, Alaska, to discuss the panel's findings regarding the strengths and weaknesses of proposed definitions and modeling approaches.
- No later than May 12, 2006, each panelist shall submit a written report of findings, analysis, and conclusions. See Annex 1 for details on the report outline. The reports should be sent via e-mail to Dr. David Die at ddie@rsmas.miami.edu, and to Mr. Manoj Shivlani at mshivlani@rsmas.miami.edu.

Appendix 2 Meeting Agenda

Center of Independent Experts
Alaska Crab Overfishing Definitions

April 24 - 29, 2006

Alaska Fisheries Science Center, Seattle, WA

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 (Center Director's Conference Room)

8:00 Coffee and informal discussions

8:30 Introductions - Charge for the CIE –Hollowed

8:50 History of crab management - current overfishing definitions and need for revision - Stram or Designee

9:10 Overview of proposed revisions - Working group

- Working group Statement of Work (20 min) - Rugolo
- Tier System review (20 min) - Zheng
- Brief Description of Snow Crab Assessment (40 min) -Turnock

10:30 Break

10:30 – 12:00 Overview continued – working group

- Brief Description of Red King Crab Assessment (40 min) -Zheng
- Projection Model structure (Siddeek and / or Turnock)

12:00 – 1:00 Break for lunch

1:00-1:30 Overview continued – working group

- Approaches to estimate proxy values for biological reference points – Turnock
- Approaches to estimate proxy values for biological reference points - Siddeek

1:30 – 2:00 Review Workshop Report recommendations on crab biology – Stram or designee

2:00 – 2:30 Review of Workshop Report recommendations on crab modeling - Ianelli

2:30 Break

2:45-3:45 Review of information available for managed crab stocks - Rugolo

3:45 – 5:00 Performance of Tier System Preliminary results

- Red King Crab – Siddeek
- Red King Crab – Turnock

DAY 2 (CD Conference Room) 8:30 Coffee and informal discussions

8:30 – 10:00 Performance of Tier System Preliminary results continued

- Snow Crab – Turnock
- Snow Crab – Siddeek
- Blue King Crab/Golden Crab - Siddeek

10:00 Break

10:30 – 12:00 Questions and Answers for panel.

12:00 Lunch

1:00 – 5:00 Open question and answer session – or independent work sessions with CIE reviewers.

DAY 3 (CD Conference Room)

8:30 Coffee and informal discussions

9:00 Open question and answer session – or independent work sessions with CIE reviewers.

DAY 4 (CD Conference Room)

8:30 Panel discussions and writing team – NMFS and ADF&G biologists return to offices but remain on call to answer questions

DAY 5 (CD Conference Room)

8:30 Panel discussions and writing team – NMFS and ADF&G biologists return to offices but remain on call to answer questions

APPENDIX 3: Bibliography of materials provided during the review meeting

The key documents referred to during the review are listed below:

Dew, C.B. & McConnaughey, R.A., 2005. Did trawling on the brood stock contribute to the collapse of Alaska's king crab? *Ecological Applications*, **15**, 919-941.

Maunder, M.N., 2003. *Review of the stock assessment and harvest strategy for eastern Bering Sea snow crab.* CIE, University of Miami.

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Restrepo, V.R., Thompson, G.G., Mace, P.M., Gabriel, W.L., Low, L.L., MacCall, A.D., Methot, R.D., Powers, J.E., Taylor, B.L., Wade, P.R. & Witzig, J.F., 1998. *Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act.* NOAA Technical Memorandum NMFS-F/SPO-##.

Rugolo, L., 2004. *North Pacific Fisheries Management Council Bering Sea/Aleutian Islands King and Tanner Crab Working Group: Draft Statement of Work*. NMFS/ADF&G, Kodiak/Seattle/Juneau.

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Siddeek, M.S.M. & Zheng, J., 2006. *Reference point estimation analysis for the Bering Sea and Aleutian Islands (king and Tanner) crab revised fisheries management plan.* ADF&G, Juneau.

Turnock, B.J. & Rugolo, L.J., 2005. *Stock assessment of eastern Bering Sea snow crab.* NMFS, Seattle/Kodiak.

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Zheng, J., 2004. *Bristol Bay red king crab stock assessment in 2004.* ADF&G, Juneau.

Zheng, J., 2006. *Issues dividing the Crab Work Group.* ADF&G, Juneau.

Zheng, J. & Kruse, G.H., 2006. Recruitment variation of eastern Bering Sea crabs: Climate-forcing or top-down effects? *Progress in Oceanography*, **68**, 184-204.

Further documentation available to the reviewers, including presentations given to the crab overfishing workshop is given at:

http://www.afsc.noaa.gov/refm/stocks/CrabWs.htm

REPORT ON

BERING SEA & ALEUTIAN ISLANDS

CRAB STOCK OVERFISHING DEFINITIONS

24-27 APRIL, 2006

SEATTLE, WASHINGTON

Prepared by

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New Zealand

for

University of Miami
Independent System for Peer Review

6 June 2006

EXECUTIVE SUMMARY

A CIE Review Panel considered a proposed overfishing definition for Bering Sea and Aleutian Islands crab stocks from April 24-27, 2006 at Alaska Fisheries Science Center, Seattle, WA. The existing definition had been found to be in need of revision and an interagency work group had been charged with developing a new definition. They had encountered difficulties in doing this and a two-day workshop had been held to discuss and resolve issues. The CIE review took place about 8 weeks after the workshop. In the interim, the work group had continued working on the overfishing definition framework. In particular, they had attempted to find suitable default parameter values and proxies needed to complete the overfishing definition.

The proposed overfishing definition is an improvement on the existing definition in that it provides some constraint on fishing mortality. The existing definition is flawed in concept, does not constrain fishing mortality, and needs to be replaced.

The proposed definition is:

- an improvement on the existing definition
- comprehensive (as a framework)
- borrowed from groundfish (so is already reviewed to some extent).

Weaknesses of the proposed definition:

- complicated
- it is still a work in progress
    - default values for parameters are not yet determined
    - sensible definition of biomass in the stock recruit relationship is not determined/specified
    - criteria for determining optimal default parameters are not determined/specified
- extensive simulations are needed to determine suitable default parameters
- potentially, it may unnecessarily constrain harvest strategies.

I make several recommendations. The most important of these concern two central issues: the definition of biomass in the stock recruit relationship, and the criteria for choosing between overfishing-definition MSY control rules.

The issue of the definition of "biomass" in the stock recruit relationship is peculiar to crabs because fishing mortality is only directed at males. In groundfish stocks it is not an issue because female spawning biomass is a good proxy for total fertilized egg production. For crabs it is a crucial issue for the proposed overfishing definition because the biomass proxy for total fertilized egg production is a primary determinant of F_{MSY} and F_{MSY} proxies. To date, the analysis of this issue has been inadequate. Immediate efforts

need to go into the derivation of appropriate functional forms. In the short term, if a default definition is needed, mature male biomass should be seriously considered.

Also, there is the issue of what constitutes a “good” overfishing definition, in general, and for Bering Sea Aleutian Islands crabs in particular. The answer to this question needs to be clearly stated. It is then relatively straightforward to define the analysis and simulations needed to test alternative overfishing definitions (and to determine default parameter values for the MSY control rules in the proposed tier system). The function of an MSY control rule in an overfishing definition must be acknowledged. The preliminary simulations aimed at determining default parameter values tested MSY control rules as rebuilding plans and harvest strategies. They are neither. MSY control rules must be evaluated in conjunction with harvest strategies (either existing harvest strategies, or a default harvest strategy).

The parameterization of the proposed MSY control rules implies a reduction in F at B_{MSY}. It does allow flat control rules (alpha = –infinity) but it precludes the suggested default overfishing definitions of Restrepo et al. 1998 (where the reduction in F occurs below B_{MSY}). I suggest that an extra parameter is added to the framework to allow MSY control rules of the form proposed by Restrepo et al. (1998). In the absence of this parameter, the proposed framework may unnecessarily restrict harvest strategies.

BACKGROUND

A three person CIE Review Panel considered a proposed overfishing definition (OFD) for Bering Sea and Aleutian Island (BSAI) crab stocks from April 24-27, 2006 at Alaska Fisheries Science Center, Seattle, WA. The North Pacific Fishery Management Council had determined that the existing OFD needed revision. A four member interagency work group had been charged with developing the new OFD. They had already participated in, and taken direction from an interagency workshop on crab OFDs which had met February 28-March 1, 2006. Simulation studies, aimed at determining default parameter values and proxies needed in the proposed OFD framework, were undertaken between the OFD workshop and the CIE review meeting.

This report presents my personal view with regard to the proposed OFD and the methods and techniques needed to determine appropriate default parameter values and proxies. I also comment on the stock assessment models and estimation methods in general. Finally, I suggest some research priorities. This report should be read in conjunction with those of my fellow reviewers Dr Mike Bell and Dr Nick Caputi. Although there was no attempt to reach a consensus on any of the issues it was apparent that the Review Panel shared many common views with regard to the proposed OFD and associated research.

REVIEW ACTIVITIES

Meeting Preparation

Prior to the meeting I read the main documents and consulted the background material made available on a website (Appendix 1). I also consulted material on the Web and conversed with colleagues with regard to crab biology.

Meeting Attendance

A brief narrative of the meeting is given below.

24 April

The meeting was convened at 8.30 am and began with a round of introductions. The meeting Chair, Dr Anne Hollowed, gave an introductory presentation on the purpose of the review and the "charge for the CIE". Dianna Stram reviewed the history of crab management and the existing OFD and the reasons for revision. Simply put, the existing OFD had been rushed through; it was conceptually flawed and provided no constraint on fishing mortality.

The four member Working Group then covered material relating to their statement of work, that of the two-day workshop, the proposed OFD structure (tier system and parameters) and two example stock assessments (snow crab and red king crab).

The Review Panel asked many questions during the presentations. We were aware that slow progress was being made in terms of the original agenda but thought that it was best to fully explore the issues during the presentations. We had already advised the Chair that we would not need to use the whole week. The scheduled "writing team" days were not needed as Panel members agreed that we could best do this after returning to our home locations.

25 & 26 April

The meeting resumed at 8.30 am with Dr Jim Ianelli in the Chair. We began with a presentation on the projection model structure (Dr Siddeek). This was followed by a presentation on approaches for estimating F_{MSY} and B_{MSY} proxies (Dr Turnock). The report on the interagency workshop (Anon. 2006) was reviewed briefly since we had already discussed most of the issues considered in it.

During the rest of the day and during the next day, preliminary simulation results were presented by the Working Group members. Attempts had been made to evaluate different alpha, beta, and gamma parameter values. Also, some proxies for F_{MSY} had been tested. However, in all cases the results were preliminary and no firm recommendations could properly be made with regard to proxies or default parameter values on the basis of the simulations.

27 April

The Review Panel convened at 9.30 am to identify, discuss, and clarify all relevant issues relating to the proposed OFD and to supporting research. We covered points a.-e. as per our Statement of Work (Appendix 3). Late in the day we had a question and answer session with Dr Hollowed, Dr Turnock, and Dr Rugolo.

Post Meeting Activities

Prior to and during my return journey to New Zealand I considered the two main problems that the Working Group were grappling with.

First, they had not fully defined the criteria for choosing between alternative tier-structure parameter values (in terms of being the best defaults). This, I believe, stemmed from the fact that the problem had not been fully specified. In order to determine the best defaults, one must define what it is for one MSY control rule to be better than another when they are used as part of an OFD.

Second, there had been inadequate analysis used to define "biomass" (B) in the stock recruit relationship (SRR). The Working Group had found that their results were very sensitive to the definition of B. They did not have an adequate definition and had no means of choosing between the alternatives they had proposed. I spent considerable time exploring alternatives for deriving appropriate functional forms – the aim being to illustrate how total fertilized egg production could be expressed as a function of population parameters (which could conceivably be measured or estimated).

The lead reviewer, Dr Bell, was to present our findings at two meetings which were scheduled earlier than the original deadline for production of our reports. On my return to New Zealand I produced an interim report for Dr Bell, in advance of his first meeting, which, while short on detail, differed little in the conclusions and recommendations of this report. I also undertook to produce my final report well in advance of Dr Bell's second meeting (but some days after the new deadline specified in the revised SOW – see Appendix 3).

SUMMARY OF FINDINGS

The existing OFD is conceptually flawed and as a consequence places no constraints on fishing mortality. It clearly needs to be replaced, but care must be taken to ensure that its replacement does not overly constrain potential harvest strategies.

To my mind, there are two central issues to consider with regard to the proposed OFD.

First, there is the issue of what constitutes a "good OFD", in general, and for BSAI crabs in particular. If the answer to this question is clearly stated it is relatively straightforward to define the analysis and simulations needed to test alternative OFDs (and to determine default parameter values for the MSY control rules in the proposed tier structure). Related to this issue is the question of whether an OFD MSY control rule can be appropriately tested in isolation from a harvest strategy (HS). In reality, the MSY control rule imposes constraints on the HS which is used and so management strategy evaluation must test MSY-control-rule:harvest-strategy pairs.

The second central issue is the definition of B in the SRR. This issue is peculiar to crabs because fishing mortality is only directed at males. In groundfish stocks it is not an issue because female spawning biomass is a good proxy for total fertilized egg production (TFEP). This is a crucial issue for the proposed OFD because the biomass proxy for TFEP is a primary determinant of F_{MSY} and F_{MSY} proxies.

What constitutes a good OFD?

We should first consider the question, exactly what is an OFD? We should distinguish between an OFD for a particular stock and an "OFD framework" which specifies a family of OFDs. It is the latter which the review is concerned with and the "family" consists of OFDs for BSAI crab stocks. Central to an OFD is the concept of an MSY control rule, which defines F_{OFL} as a function of biomass and from which derives the overfished threshold (MSST). A "good OFD" (framework) can sensibly be defined as one which specifies "good MSY control rules".

The proposed OFD has a five level tier structure to accommodate stock assessments with different levels of reliability (Anon. 2006, page 8). The fifth tier is for stocks which are not formally assessed. In the first four tiers a linear parameterized MSY control rule is specified. F_{OFL} is constant above B_{MSY} and set equal to F_{MSY} or a proxy. Below B_{MSY} there is a linear reduction in F_{OFL} governed by two parameters alpha and beta. In tier 4, the F_{MSY} proxy is the product of the parameter gamma and M. The fishery is closed when estimated biomass (as a proportion of B_{MSY} or its proxy) is less than beta.

As it stands, the OFD appears incomplete until some default parameter values and proxy definitions are specified. In order to do this, criteria must be specified for determining when one MSY control rule is better than another. Given the criteria, alternative parameter values and proxies can be tested by doing model simulations over an appropriately broad range of population models (i.e., with different biological parameters and/or SRRs and/or model structures; the range being appropriate to the tier being tested).

The criteria for determining whether one MSY control rule is better than another were not discussed during the review meeting. From the preliminary simulations it appears that the implicit criteria relate to their performance as rebuilding strategies (since simulations were done from starting values less than BSST or at beta, with catches set at the OFL). The ranking of MSY control rules on the basis of their performance as rebuilding plans, or more generally as harvest strategies, is inappropriate given that is not their *function* (when specified in an OFD). The function of an OFD MSY control rule is to constrain (estimated) fishing mortality and to provide Status Determination (i.e., MFMT and MSST). It impacts on whatever harvest strategy is used for setting OY but it is not the harvest strategy (or the rebuilding plan).

I note that simulations using an MSY control rule as a harvest strategy are required to determine MSST (Restrepo et al. 1998). This is because the full definition of MSST is the maximum of two values: half B_{MSY} and “the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold”. (During the review meeting no such simulations were discussed and it was (implicitly) assumed that MSST always equaled half B_{MSY}. In general, this should not be taken for granted.)

Restrepo et al. (1998) offer some advice on choosing an MSY control rule. Two factors are mentioned. First, the position of MSST may be of interest in that a council could “minimize the range of stock sizes within which special rebuilding plans would be required” if it opted “for an MSY control rule that afforded a good deal of ‘built-in’ rebuilding”. The proposed OFD has such MSY control rules in that the linear decrease in F_{OFL} begins at B_{MSY} (which is even more conservative than the default MSY control rule suggested by Restrepo et al. 1998). Second, they suggest that the “tradeoff between magnitude of yield and constancy of yield” could be used. This involves testing the MSY control rules as harvest strategies. As already discussed this is inappropriate since that is not their function in an OFD setting.

In practice, an (OFD) MSY control rule is never used as the harvest strategy. Councils are required to “adopt a precautionary approach to the specification of OY” (Restrepo et al. 1998). Obviously, from a management strategy evaluation perspective, MSY control rules cannot be tested in isolation. They must be tested with an associated harvest strategy.

The choice of an MSY control rule is primarily a management decision. The tradeoff is between potential yield and risk. If an MSY control is too constraining on harvest strategies it may unnecessarily reduce long term yield. Conversely, if it is too liberal it may allow harvest strategies which are not precautionary. Given the current requirement for an (OFD) MSY control rule and a precautionary harvest strategy, constrained by the MSY control rule, it is necessary to test MSY-control-rule:harvest-strategy pairs.

Once this conclusion is reached it becomes a matter of detail on how to determine appropriate defaults to complete the specification of the proposed OFD framework (or to justify a choice of OFD for a particular stock assessment). Any existing harvest strategies are candidates to be tested. In their absence I suggest adopting some “default” harvest strategies in the simulations (e.g., those derived from the MSY control rule by applying 75% of the estimated OFL in each year).

When doing such simulations it is important to distinguish each of the individual components. There is the "operating model", which is the model of reality, within which everything is known exactly (e.g., B_0, F_y for each year y, $F_{MSY,}$ etc). There is also the "estimation frame" where quantities are estimated, such estimates being a function of the truth (from the operating model) and error (e.g., an estimate from a stock assessment). When evaluating an OFD MSY control rule there must also be a HS. The role of the MSY control rule is limited. It defines F_{OFL} for any given biomass *estimate* and it defines whether the stock is overfished or not (on the basis of the biomass *estimate*). On the other hand, the HS is used to set the TAC in each year that an assessment is conducted (within the simulation model). There is a requirement for a buffer between the OFL and the TAC. Hence, simulations using the MSY control rule as the harvest strategy (i.e., $F_y = F_{OFL}$ in every year y) are entirely inappropriate.

Definition of B in the SRR

The definition of B in the SRR is of crucial importance in obtaining a precautionary OFD. Since the directed fishing mortality is only on males, females suffer fishing mortality only as incidental bycatch (and subsequent handling/discard mortality). If the usual groundfish definition for B, of total female spawning/mature biomass, is used then F_{MSY} and proxies for F_{MSY} (such as $F_{50\%}$) are very large in an absolute sense. Crab biology is such that the role of males is crucial in the production of fertilized eggs and it is clear that the males must be brought into the definition of B.

In the long term, a suite of deterministic population dynamics models should be derived specifically for crab stocks, taking account of the important role played by males in the SRR. In the interim, it is probably best to derive an appropriate functional form for TFEP and simply assume that mean recruitment is a Beverton Holt or Ricker function of TFEP.

The review material contains several alternative proposed definitions for B. Total female mature biomass was, I assume, used for illustrative purposes only. Total male and female mature biomass was put forward as a candidate. This must be rejected because as male biomass approaches zero, TFEP approaches zero, but total mature biomass does not. There were at least two variations of female mature biomass scaled down by an "effective fertilization factor" (derived from an assumed "mating ratio"). The concept behind these definitions is that TEP is proportional to female biomass and that successful fertilization depends on the proportion of mature males in the mature population and the average number of females that each male can mate (the "mating ratio" which is assumed to be constant).

The concept of a "mating ratio" is sound in principle. In practice, it was found that F_{MSY} and F_{MSY} proxies were sensitive to the assumed mating ratio. So, even if one of the proposed formulations was accepted it still leaves the problem of determining an appropriate parameter range for the mating ratio.

During the review I questioned the validity of the assumption that TEP is proportional to mature female biomass. Dr Rugolo presented results from trawl survey and experimental data on the total number of eggs per female as a function of clutch fullness, shell condition, mating category, and carapace width. It is known that older females tend to have lower clutch fullness and that crabs with very old shell condition (4 & 5) tend to be barren. This is a problem for the proportionality assumption in that increasing biomass (with age) is inversely proportional to EP. Though, if the proportion of older females stays relatively constant it may not of itself be a major problem. However, it was also indicated that clutch fullness is strongly related to mating category, at least in snow crabs, with primiporous females typically having a0.75 clutch fullness and first time multiporous females typically having full clutches. Further, within clutch fullness category, the number of eggs appeared to be linearly related to the carapace width. While these data cast considerable doubt on the biomass proportionality assumption, their existence provides the very means by which to construct a sensible functional form for TEP and possibly to estimate a mating ratio.

I have undertaken some preliminary work on the derivation of a suitable equation for TFEP (Appendix 2). This work is illustrative and not definitive. An experienced mathematician should work with crab biologists to derive appropriate forms (at different levels of complexity) for TFEP. I also indicate how the trawl survey data (available since 1995) could be used to estimate unknown parameters, including a mating ratio, within the equation for TFEP (Appendix 2). In the absence of this sort of work (i.e., given time constraints), the best proxy for TFEP may be total mature *male* biomass (TMMB).

This suggestion was made by Dr Caputi at the review meeting and at the time, after discussion, was considered to be deficient in that it was inappropriate for stocks near their virgin level. It was considered that we needed a relationship which would be sensible over the full range of stock sizes. In a severely depleted stock, it is clear that sperm availability is the determining factor in fertilization success (since there are plenty of females). It is reasonable to argue that TMMB could be approximately proportional to TFEP when a stock (through removal of males) is depleted below some level. The effective mating ratio doesn't need to be known – the assumption is made that there are always enough females and that the mating ratio is constant. Of course, above some level of TMMB the proportionality assumption must fail. In Appendix 2 I have suggested an appropriate functional form to adjust for this effect. It adds an extra level of complexity to the SRR but will be more realistic than assuming full proportionality.

Other issues

Most other issues are minor in comparison to the two central issues already discussed. However, they are numerous and potentially time consuming in their detail. Below, I give some general comments on some of the issues.

Having two modeling groups is both a strength and a weakness. The exchange of ideas is valuable. The natural competition which arises can be stimulating and lead to improved methods and models. However, differences in modeling approaches can become entrenched; argument rather than discussion can be the outcome. While all members of the Working Group were cordial, helpful, and professional during the review meeting, there was clearly some tension between the two groups. In New Zealand, “contested stock assessment” is a common feature of our annual stock assessment cycle (Starr et al. 1998). We have recently agreed on some principles to help competing modeling groups work together:

- consider all components of the models and estimation procedures
- identify where differences exist between the two approaches
- where there is a “best” way to do something, agree to do it that way
- where there are two (or more) reasonable alternatives, implement both (all) options
- ideally, each modeling group should be able to reproduce the results of the other group (but, if totally different estimation procedures are being used, this is probably not an option).

Difference results do not present a problem if the reason for the differences is understood. In New Zealand the two competing groups use Bayesian estimation methods implemented with their own software packages. The use of the same estimation method is very helpful in terms of making comparisons. The two crab team groups use completely different estimation methods, neither of which is entirely satisfactory.

The weighted least squares method (Zheng 2004) does not allow the production of standardized residuals. It is not a “fully statistical” model: diagnostics cannot be properly evaluated. The maximum likelihood approach (Turnock & Rugolo 2005) at least allows the production of standardized residuals even if this has not been routinely done. However, the use of penalty functions is not ideal and where possible they should be replaced by properly formed priors. Indeed, both modeling groups need to move towards fully Bayesian assessment methods as soon as possible. There simply is no other generally accepted method for incorporating prior/ancillary information and statistically accounting for uncertainty. It is not perfect, but it is currently the “state of the art” and will be so for some time to come.

The assumption by both modeling groups that the trawl survey q is known exactly (on the basis of “under-bag” experiments) ignores the uncertainty due to unknown aerial availability (i.e., the proportion of the population within the survey area). The estimates are conservative but they are definitely biased. The assumption is neither necessary nor desirable and the trawl survey q should be estimated. The information from the under-bag experiments, and whatever else is “known” about q, can be incorporated in a prior (or, if necessary, a penalty function).

The estimation of natural mortality (M) is always problematic whether it is done inside or outside of a stock assessment model. This is true for a single M assumed constant over the whole history of a fishery. Attempts to estimate different M for different time periods in a stock assessment (Zheng 2004) are ill-advised unless there are ancillary data which can reasonably be argued to index M in some way (e.g., a biomass index for a known major predator).

Many of the problems facing the crab team are generic in nature, some are crab specific (definition of B) and some are even more general (testing of OFDs). Wherever possible, efforts should be made to establish collaborative projects to share the workload.

CONCLUSIONS

The conclusions are organized according to the headings provided in the SOW (Appendix 3).

a. Strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches.

The proposed OFD is:

- an improvement on the existing OFD
- comprehensive (as a framework)
- borrowed from groundfish (so is already reviewed to some extent).

The existing OFD does not provide any sensible constraints on fishing mortality and in that regard it appears fatally flawed. The proposed OFD will at least provide constraints.

Weaknesses of the proposed OFD:

- complicated
- it is still a work in progress
  - default values for parameters are not yet determined
  - sensible definition of B not determined/specified
  - criteria for determining optimal default parameters not determined/specified
- extensive simulations are needed to determine suitable default parameters
- it may potentially unnecessarily constrain existing harvest strategies.

The Review Panel were shown the results of preliminary simulations aimed at determining suitable default values for alpha, beta, and gamma. One can envisage an extensive suite of simulations which could determine suitable default values, but this can only happen after:

- sensible definitions of B are derived (being proportional to total fertilized egg production)
- the criteria for optimal default parameter values are defined.

An important issue, relating to the optimality of default parameter values, is how to define a "good OFD". The current simulations test an OFD MSY control rule by using it as a HS (i.e., assuming that catch is always set at the OFL) and testing its performance when the stock is initially overfished. However, this ignores the fact that a council is required to act in a precautionary manner when setting TACs and, as such, the simulations are testing something which will never occur.

b. Recommendations for improvements to proposed overfishing definitions or alternative definitions.

The parameterization of the proposed MSY control rules implies a reduction in F at B_{MSY}. It does allow flat control rules (alpha = –infinity) but it precludes the suggested default overfishing definitions of Restrepo et al. 1998 (where the reduction in F occurs below B_{MSY}). I suggest that an extra parameter is added to the framework to allow MSY control rules of the form proposed by Restrepo et al. (1998). In the absence of this parameter, the proposed framework may unnecessarily restrict harvest strategies.

c. Review of model configurations, formulations and methods used to account for uncertainty.

The model configurations and formulations are generally appropriate, but there may have been some implementation error in some of the models (e.g., mating dynamics not consistent with expert opinion). There needs to be more effort made to ensure that both modeling groups correctly implement the agreed population dynamics. When alternative dynamics are considered possible they should also be implemented to allow sensitivity analyses to be performed.

d. Review of input parameters (fishery, biological and life history parameters and spawner recruit relationships) used in the simulation models.

The determination of an appropriate SRR is one of the central issues of the review. All of the alternative definitions of B used in the preliminary simulations were inappropriate. They were either demonstrably inadequate (e.g., female mature biomass, total mature biomass) or inadequately justified (i.e., no analysis or derivation). Total fertilized egg production does not appear to be proportional to female mature biomass. Therefore, definitions of B should not be based on scaled female mature biomass (e.g., through an assumed mating ratio) .

Other life history parameters appeared to be appropriately estimated (except, in one model where M was estimated to change during different time periods – not appropriate without additional data – see recommendations).

e. Research priorities to improve understanding of essential population and fishery dynamics necessary to formulate best management practices.

Recommendations, with regard to all aspects of the review, are given in the section below.

RECOMMENDATIONS

It appears that the proposed overfishing framework can be considered "acceptable" (complete) without default parameter values, F_{MSY} proxies, or a definition for B. If this is the case, then the first assessment for each stock, under the new framework, will require a full suite of simulation results justifying the OFD used. As more stocks are assessed "default" definitions and parameter values will materialize as scientists borrow them from the previously accepted assessments. Such an evolution is far from ideal and the process will need to be managed carefully. It would be better to get agreement on as much as possible in the proposed OFD before it is "accepted". Certainly a default definition for B is desirable.

In any case, irrespective of the timing relative to the acceptance of the proposed OFD framework, I have the following recommendations.

- Derive sensible definitions of B:
    - being defensibly proportional to total fertilized egg production
    - consider primiporous and multiporous matings separately
    - get the cycle consistent with the best available expert opinion (i.e., which males can participate in which matings)
    - B is not proportional to mature female biomass (e.g., clutch size is not proportional to biomass)
    - use an analytical approach to derive suitable functional relationships (see Appendix 2)
    - estimate parameters of the relationship in the stock assessment models using available data on egg production by color class (see Appendix 2)
    - mature male biomass appears to be defensible (use as a default?)

- Agree on the criteria and method for testing (OFD) MSY control rules:
    - these methods could be applied to tiers 1-4 (e.g., not only to determine "good" alpha and beta values, but also to choose between different proxies, e.g., $F_{50\%}$ or $F_{60\%}$)
    - it must be decided what makes one MSY control rule better than another when they are part of an OFD (i.e., test their *function*, they are not rebuilding plans or harvest strategies)
    - test MSY control rules in conjunction with a HS (e.g., an existing HS or a "default" OY control rule which takes 75% of the OFL – see Restrepo et al. 1998)

- compare with a flat control rule ($F = F_{MSY}$, i.e. are alpha and/or beta even needed?)
- examine performance over a range of starting biomasses (not just overfished; you want to know how they perform “going down” as well as “going up”)
- incorporate observation error (i.e., true B and observed B can differ)
- incorporate stochastic recruitment
- examine trade-off statistics (e.g., what is forgone in yield to achieve higher biomass/lower probability of being declared overfished)
- use the full definition of MSST (i.e., not just 0.5 B_{MSY} – see Restrepo et al. 1998)
- include an extra parameter in the MSY control rules so as not to exclude the suggested default rules of Restrepo et al. (1998) (this parameter can have a default of 0 if desired)

The following two recommendations only apply if it is decided to use tier 1-2 simulations to derive default alpha and beta for tiers 1-4. It may not be the case that “good” alpha and beta values in tiers 1-2 will necessarily be any good when used in conjunction with F_{MSY} proxies. However, it may be a necessary assumption given time constraints.

- Agree on criteria for testing F_{MSY} proxies (stock specific, Tier 3):
  - using expert judgment choose a range of steepness/SRR relationships (after sensible definition of B)
  - use minimax or some other agreed principle to choose the best proxy

- Agree on criteria for testing gamma (group specific, Tier 4):
  - explicitly and precisely define gamma (in relation to selectivity and timing of the fishery)
  - use the same approach as for tier 3, but wider parameter space
  - obtain default gamma for each of several species/stock groups

- Consider what simulations, if any, could help for tier 5:
  - to define the period over which catches should be averaged (e.g., guiding principles on “not too much catch variability”; not a “declining trend in biomass” over the period)

- Stock assessment models
  - estimate the survey catchability q
  - start with parsimonious models
  - only introduce extra parameters if absolutely necessary
  - do not confound M with possible changes in catchability
  - estimating changes in M is only defensible if supported by auxiliary data on known predators/disease
  - calculate standardized residuals
  - iteratively re-weight indices so that residuals are consistent with variance assumptions

- as soon as possible move to fully Bayesian assessments

- Trawl survey

  - if feasible, routinely retain a sample of female crabs with orange colored eggs to estimate the proportion of fertilized orange-colored egg-production (i.e. to estimate, at the time of the survey, what proportion of orange colored eggs are actually fertilized)
  - if feasible, routinely retain a sample of females (of the relevant species) to estimate "sperm load" (i.e., for those species which retain sperm).

REFERENCES

(see Appendix 1 for further references)

Mace, P.M.; Doonan, I.J. 1988: A generalised bioeconomic simulation model for fish population dynamics. New Zealand Fisheries Assessment Research Document 88/4. 51 p.

Starr, P.; Annala, J.H.; Hilborn, R. 1998: Contested stock assessment: two case studies. *Can. J. Fish. Aquat. Sci. 55*: 529–537.

APPENDIX 1: MATERIAL PROVIDED

The website from the interagency workshop was made available to the Review Panel. This contained documents and presentations, but also contained links to other related material. Below I list the material which I obtained from the website (or related links) and additional documents which were emailed to the Review Panel or provided as hardcopy, before or during the review meeting. I do not include several documents which were emailed to the Review Panel after the meeting (as I did not consult them).

Anon. 1998. Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs. Exec summary. July 18, 1998. 5 p.

Anon. 1999. Draft for Secretarial Review: Environmental Assessment for Amendment 7 to the Fishery Management Plan for the commercial king and tanner crab fisheries in the Bering Sea/Aleutian Islands. 53 p.

Anon. 2005. Magnuson-Stevens Act Provisions; National Standard Guidelines; Proposed Rule. Federal Register Vol 70, No. 119. 21 p.

Anon. 2006. Center of Independent Experts, Alaska Crab Overfishing Definitions, April 24-29, 2006. Alaska Fisheries Science Center, Seattle, WA. Apr 14th 2006 Draft Agenda. 2 p.

Anon. 2006. Current Overfishing Definitions in Crab FMP (FMP Section 6.0 revised from Amendment 7 1998). 2 p.

Anon. 2006. Workshop Report Crab Overfishing Definitions Inter-agency Workshop, February 28-March 1, 2006. Alaska Fisheries Science Center Seattle, WA. 21 p.

Anon. 2006. Alaska Crab Overfishing Definitions Workshop, February 28 – March 1, 2006. Alaska Fisheries Science Center, Seattle, WA. Feb 22, 2005. Draft Agenda . 2 p.

Anon. 2006. Draft report of the Scientific and Statistical Committee to the North Pacific Fishery Management Council, April 3-5, 2006 . 17 p.

Anon. 2006. Participant list for interagency workshop. 1 p.

Anon. 2006. Roadmap for Crab Workshop Documents. 1 p.

Anon. 2006. Tier system. 7 slides.

Maunder, M.N. 2003. Review of the stock assessment and harvest strategy for the eastern Bering Sea snow crab. CIE review report. 29 p.

Punt, A.E. 2003. The performance of a size-structured stock assessment method in the face of spatial heterogeneity in growth. *Fisheries Research 65*: 391–409.

Restrepo, V.R. et al. 1998: Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. 56 p.

Rugolo, L.J.: Simplifications in population models and fishery dynamics modeling approaches. 16 slides

Rugolo, L.J.: Statement of work: NPFMC BSAI King & Tanner Crab Working Group. 30 slides.

Rugolo, L.J.; Siddeek, M.S.M., Turnock, B.J.; Zheng, J. 2004. 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. 34 p.

Siddeek, M.S.M: Parameters input to SPR models. 8 slides.
Siddeek, M.S.M.: Preliminary results. 7 slides.
Siddeek, M.S.M.: Model structures. 3 slides + 2 spreadsheets.
Siddeek, M.S.M.: Approaches to estimate proxy BRP values. 9 slides.
Siddeek, M.S.M.; Zheng, J. 2006. Reference point estimation analysis for the Bering Sea and Aleutian Islands (king and tanner) crab revised Fisheries Management Plan. 68 p.
Stram, D.L.: Overview of crab management and background on current overfishing definitions. Alaska Crab Overfishing Definitions Workshop, AFSC, Seattle, WA, February 28-March 1, 2006. 10 slides.
Thompson, G.: National Standard 1 Guidelines: use of SPR reference points, and incorporating uncertainty. 14 slides.Turnock, B.J. Snow crab stock assessment. 30 slides
Turnock, B.J.: Proposed tier system. 9 slides.
Turnock, B.J.: Input values to SPR models estimated from stock assessment models. 15 slides.
Turnock, B.J.; Rugolo, L.J. 2005. Stock Assessment of eastern Bering Sea snow crab. 96 p.
Turnock, B.J.; Rugolo, L.J. 2006. Analysis of proposed overfishing tier system for BSAI king and tanner crab stocks. 28 p.
Zheng, J.: Population Dynamics and Stock Assessment of Red King Crab in Bristol Bay, Alaska. 29 slides
Zheng, J. 2004. Bristol Bay red king crab stock assessment in 2004. 72 p.

APPENDIX 2: DEFINITION OF B IN THE SRR

Below I present three suggestions for the definition of B in the SRR, each being a proxy for total fertilized egg production (TFEP). They range from simple to complex. For the most complex method I also illustrate how some of the unknown parameters in the functional form might be estimated.

The three suggested definitions for B in the SRR are:

- total mature male biomass
- a function of total mature male biomass
- a function of total female egg production and a "fertilization factor".

The first suggestion was made by Dr Caputi in the review meeting. It is appealing in its simplicity and it makes sense for crab stocks when the male population is severely depleted. It is deficient for crab populations when the sex ratio is near its virgin level. However, we can derive a functional form to correct for its deficiency.

Suppose that,

$$TFEP = \min \{ P, q\ SP \}$$

where P = total egg production, SP = sperm production, and q is a constant which translates sperm production into number of eggs. In reality, q is not a constant; it depends on any and all factors which affect fertilization success (e.g., size and age structure, environmental effects on sperm potency, spawning migration patterns). In fish stocks we expect that $q\ SP >> P$ and thus accept any reasonable proxy for P as a proxy for TFEP for use in the SRR. However, in crab stocks where fishing mortality is directed only at males we must incorporate sperm production.

Consider a deterministic model for a crab population where fishing mortality (F) is primarily on males. Let,

B_F = male mature biomass at equilibrium under fishing mortality F
P_F = total egg production at equilibrium under fishing mortality F
$a_F = P_F / B_F$

and let $TFEP_F$ and SP_F denote TFEP and SP respectively at equilibrium under fishing mortality F.

We then have,

$$TFEP_F = \min \{ P_F, q\ SP_F \}$$

Now, suppose that sperm production is proportional to male biomass: $SP_F = s\ B_F$.

Hence, when q $SP_F \leq P_F$, we have

$$TFEP_F = q\ s\ B_F$$

and when q $SP_F \geq P_F$, we have

$$TFEP_F = P_F = a_F\ B_F.$$

Note, that when q $SP_F = P_F$, we have a_F = q s. Denote the F at this point as F_a and the associated B as $B(F_a)$.

Now, as F varies from 0 to infinity, B_F varies from its virgin level, B_0, to 0. From 0 to $B(F_a)$, $TFEP_F$ is a linear function of B_F (which passes through the origin). The form of $TFEP_F$ between $B(F_a)$ and B_0 depends on the nature of a_F. However, since males are preferentially exploited it follows that as F decreases that a_F also decreases. Hence, $TFEP_F$ is a linear function of B_F from 0 to $B(F_a)$, and then is convex from $B(F_a)$ to B_0.

This deduction allows us to use an approximate functional form which is independent of the details of any particular model. We will use an exponential function which is approximately linear over part of its range and then convex. Changing the notation somewhat, let,

$$TFEP(B) = b\ [\ 1 - \exp(\ -aB)\ ]$$

where B = male mature biomass, and a, b, are unknown parameters.

Let, $TFEP(B_0) = P_0$, then since,

$$TFEP(B_0) = b\ [\ 1 - \exp(\ -aB_0)\ ] = P_0$$

it follows that,

$$a = \frac{-\ln(1-\frac{P_0}{b})}{B_0}$$

and

$$\text{TFEP}(B) = b\left[1-\left(1-\frac{P_0}{b}\right)^{\frac{B}{B_0}}\right]$$

This can be better expressed as,

$$\text{TFEP}(B) = \frac{P_0}{1-\eta}\left[1-\eta^{\frac{B}{B_0}}\right]$$

where $0 < \eta < 1$.

This equation provides a simple generalization of total male mature biomass as the definition of "B". The range of η values to consider depends on how effective one believes the males can be at fertilizing eggs when at depleted biomass levels (or how many surplus males there were at virgin levels). Values of $\eta > 0.5$ provide fairly linear functions, with TFEP at 20% B_0 not much more than 20% P_0. For approximately 40% P_0 at 20% B_0 use $\eta = 0.1$ and for approximately 60% P_0 at 20% B_0 use $\eta = 0.01$.

This equation should be used in conjunction with an assumed SRR as a function of TFEP to produce a SRR as a function of mature male biomass. For example, if mean recruitment is given by R(TFEP), then use R(TFEP(B)) – i.e., to get mean recruitment as a function of B rather than TFEP.

For example, if a Beverton Holt SRR is assumed with steepness Δ (Mace & Doonan 1988), then

$$R = R_0 \left[\frac{4\Delta\left(1-\eta^{\frac{B}{B_0}}\right)}{(1-\Delta)(1-\eta)+(5\Delta-1)\left(1-\eta^{\frac{B}{B_0}}\right)} \right]$$

which behaves much like a Beverton Holt SRR unless both Δ and η are small (i.e., is similar to a Beverton Holt SRR with Δ set equal to the proportion of R_0 obtained at 20%B_0 from the full relationship). Information on η may be available from trawl survey data in which case it may be possible to estimate η within the stock assessment model, or even externally.

The third suggested definition for B is arrived at using a somewhat different approach. The idea is to start with an unspecified functional form and then, through a series of assumptions, and bearing in mind what data are available, arrive at a particular form.

Consider a particular mating (i.e., the primiporous or multiporous mating, or perhaps a combined mating for modeling convenience) in a particular year and suppose that sperm are not stored by the females ("sperm storage" across matings could perhaps be incorporated if data on stored sperm levels from the trawl survey were available).

Let C = { c_i | i ε n } be the set of all crabs involved in the mating (i.e., there are n crabs labeled 0,…,n –1). Each crab has various biological characteristics. E.g,: s(c_i) = sex of the ith crab, cw(c_i) = carapace width of the ith crab, a(c_i) = age of ith crab, f(c_i) = clutch fullness category of ith crab. Subsets of crabs can be specified. E.g., s(C, male) = { c_i | s(c_i) = male }. Let TFEP = Γ(C). That is, the total fertilized egg production (of this mating) potentially depends on every characteristic of every crab involved in the mating. True, but unhelpful. We will split TFEP into tow components: total egg production (P), and a fertilization factor (G):

$$\Gamma(C) = P[\, s(C, fem) \,]\, G(C)$$

Now, we have assumed that egg production depends only on the females; fertilization is still dependent on all crabs (e.g., male and female length frequencies, as well as sex ratio).

From data presented during the review meeting and subsequent discussion it is clear that quite a lot is known about clutch fullness as a function of various categorical variables (e.g., primiporous females typically have 0.75 clutch fullness, 2^{nd} clutches are typically full, shell condition 4 and 5 females are typically barren, older females have lower clutch fullness). For a given clutch fullness it appeared that egg production of an individual female was a linear function of carapace width. In any case, the data exist and can be analyzed to provide an appropriate functional form and parameterization for P. One approach would be to use a GLM to explain individual egg production as a function of variables which could reasonably be incorporated in the stock assessment model.

For example, for a combined mating, the data may be consistent with a single categorization within which a linear function of carapace width may be adequate for average individual egg production. The functional form could be as follows:

$$P[s(C, fem)] = \sum_{i \varepsilon cat} \sum_{j \varepsilon cat_i} a_i + b_i cw(c_j)$$

where cat = { primiporous, 2^{nd} mating, shell condition > 3, other }, a_i and b_i are the linear coefficients for each category member, and cw denotes carapace width.

The above form is just an example which may or not be suitable. However, given the available data I am confident that a suitable form will be derived. It will be defensible and I doubt that female mature biomass will be seen to be an adequate proxy.

The fertilization factor is a more difficult challenge. However, there are also data available which may enable the estimation of relevant parameters if an appropriate form can be hypothesized. The simplest form for G(C) is a constant. However, this would make TFEP independent of males – clearly not appropriate. The fertilization factor, at a minimum, must use the relative number of males and females. Other elements, such as relative size distributions and the propensity for males to fight for “desirable females” could also be brought in (but not easily).

A candidate, already used as a component of some of the Work Group definitions of B is:

$$G(C) = \min \{\, n[\, s(C, male) \,] / n[\, s(C, fem) \,]\, r,\ 1 \,\}$$

where r is an unknown “mating ratio” and n[] denotes cardinality of a set (i.e., the number of members).

There are data available from the trawl surveys which could be used to estimate r, preferably within the stock assessment model (so that trawl survey catchability and selectivity can be estimated simultaneously). I refer to the individual egg production data which includes a color classification. Clutches are orange to begin with and at the time of the survey clutches are either orange or another color. If they are non-orange then they are fertilized, but some proportion of orange clutches are also fertilized (and haven't changed color yet). To use these data in a stock assessment model, we need to be able to formulate predictions for orange and non-orange trawl-survey egg production. Below I give a sketch of how to do this.

We already have an expression for total egg production, P[s(C, fem)] which could be modified in the model to account for trawl survey selectivity and catchability to become an expression for "trawl-survey egg production". We shall denote this simply by P. In the following, assume that trawl-survey selectivity and catchability have been appropriately dealt with in all components of (predicted) egg production.

Let,

P_o = orange egg production
P_{of} = orange fertilized egg production
P_{oun} = orange unfertilized egg production
P_{non} = non-orange egg production
p_f = proportion of fertilized eggs
p_{fo} = proportion of fertilized eggs that are orange

We have,

$$P_o = P_{of} + P_{oun} = P\, p_f\, p_{fo} + P\,(1 - p_f)$$

and

$$P_{non} = P - P_o.$$

Which gives,

$$P_0 = P\,[\, p_f\, p_{fo} + 1 - p_f\,]$$

$$P_{non} = P\, p_f\,[\,1 - p_{fo}\,].$$

We have two unknown parameters: p_f and p_{fo}.

However, p_f = n[s(C, male)] / n[s(C, fem)] r. So there is only one extra parameter: p_{fo}. Data on this could be available for each (future) survey if a random sample of females with orange clutches was retained and observed in the lab to see what proportion of orange clutches were fertilized (noting that p_{fo} = "proportion orange and fertilized"/p_f).

Alternatively, some assumptions about the distribution of mating times would be needed together with some knowledge of how long it takes fertilized eggs to change color.

For example, assume a normal distribution for the mating time X of a female: $X \sim \mathrm{N}(t_m, \sigma_m^2)$. Suppose that a females' clutch will change color after a time interval δ, and let $Y = X + \delta$. Suppose that the survey occurs at time t_s and let $q(t_s)$ = the proportion of (fertilized) eggs that are non-orange.

Then,

$$q(t_s) = \mathrm{Prob}\left(Y < t_s\right) = \mathrm{Prob}\left(Z < \frac{t_s - (t_m + \delta)}{\sigma_m}\right)$$

where Z is the standard normal random variable. Some educated guesses will help define a range for $q(t_s)$ and hence to $p_{fo} = 1 - q(t_s)$. Another approach is to look at the relative distribution of clutches within color classes to try to directly estimate the proportion of orange clutches which are fertilized (e.g., a disjunction between the proportion of orange clutches and the proportion of the next color class may indicate that very few orange clutches are fertilized – for a particular survey).

Trying to include competition between males is an interesting exercise. It can be approached by setting up a system of differential equations with coupling, decoupling, and fighting rates. It gets sufficiently complicated that it may not be a worthwhile exercise in itself. Perhaps it is better to do the full job and look to set up a system of differential equations for crab-specific population dynamics – a medium to long term project.

APPENDIX 3: STATEMENT OF WORK

The statement of work given below was received in early May after I returned from the Seattle meeting. It differs from the original statement of work in two respects. First, it clarified some issues which the Review Panel raised while we were in Seattle. Second, it contains a new date for submission of reports. I was not able to accommodate the shift of the deadline from 1 June 2006 to 12 May 2006. However, I did produce an interim report with the highlights of my findings and recommendations which I supplied to Dr Bell before his attendance at the May 17 meeting.

Consulting Agreement between the University of Miami and Reviewer

April 27, 2006

Background

The Alaska Fisheries Science Center (AFSC) requests review of proposed overfishing definitions and simulation models used to evaluate biological reference points for Bering Sea and Aleutian Islands King and Tanner crab stocks. The North Pacific Fishery Management Council (NPFMC) has determined that the existing overfishing definitions for Bering Sea and Aleutian Islands King and Tanner crab stocks need revision. The AFSC is seeking review of the population dynamics models developed for revising the overfishing definitions.

There are currently 22 Bering Sea and Aleutian Islands crab stocks under the Federal Bering Sea Aleutian Island Crab Fishery Management Plan (FMP) of which 7 are considered major stocks. Four of the seven major crab stocks have been declared overfished and rebuilding plans developed within the last 7 years. Of the remaining three stocks, only one has been relatively stable at a low level, another has maintained stable catch for several years, however, even for this stock it appears recruitment may be declining. While the remaining stock has increased, survey abundance estimates have low precision and the fishery is closed due to bycatch concerns. There is no consensus on the principal cause of declines in Bering Sea crab stocks.

Review Requirements

A panel of three consultants is requested for this review. In aggregate, the panel will need to be thoroughly familiar with various subject areas involved in the review: crab biology; analytical stock assessment, including population dynamics theory, length-based stock assessment models, rebuilding analyses, estimation of biological reference points and harvest strategy modeling for invertebrates; and AD Model Builder. The CIE consultants will travel to Seattle, Washington to meet with the Interagency Work Group charged with developing the new overfishing definitions. We request that one member of the Panel should be present at the May meeting of the NPFMC Crab Plan Team in

Anchorage, Alaska. We also request that one member of the Panel be present at the June meeting of the NPFMC Scientific and Statistical Committee meeting in Kodiak, Alaska. It would be preferable that the same individual attends both of these meetings, but this is not a requirement.

The report generated by each consultant should include:

a. A statement of the strengths and weaknesses of the proposed overfishing definitions, simulation models and analytical approaches.
b. Recommendations for improvements to proposed overfishing definitions or alternative definitions,
c. A review of the model configurations, formulations and methods used to account for uncertainty.
d. A review of input parameters (fishery, biological and life history parameters and spawner recruit relationships) used in simulation models.
e. Suggested research priorities to improve our understanding of essential population and fishery dynamics necessary to formulate best management practices.

AFSC will provide copies of the NPFMC Work Group statement of work, proposed overfishing definitions, preliminary results of simulations, discussion of input parameters, a copy of the code for the snow crab stock assessment, and the AD Model Builder and Fortran code used for reference point estimation. The panel will meet with scientists from the Alaska Fisheries Science Center and the Alaska Department of Fish and Game from April 24 to April 28, 2006, in Seattle, Washington (see attached agenda).

It is estimated that the duties of each reviewer will occupy a maximum of 14 days each: several days for preparation, five days for the workshop, several days for writing their reports, and two days for travel. In addition, a maximum of nine reviewer days will be allowed for attending the two council meetings, including preparation time, travel, and one day to attend each meeting. The total level of effort is 51 days of reviewer time.

Products

- One member of the panel will attend the May meeting of the Crab Plan Team on May 17, 2006 in Anchorage, Alaska, to discuss the panel's findings regarding the strengths and weaknesses of proposed definitions and modeling approaches.
- One member of the Panel will attend the June meeting of the NPFMC Scientific and Statistical Committee meeting on June 5, 2006 in Kodiak, Alaska, to discuss the panel's findings regarding the strengths and weaknesses of proposed definitions and modeling approaches.
- No later than May 12, 2006, each panelist shall submit a written report of findings, analysis, and conclusions. See Annex 1 for details on the report outline. The reports should be sent via e-mail to Dr. David Die at ddie@rsmas.miami.edu, and to Mr. Manoj Shivlani at mshivlani@rsmas.miami.edu.

ANNEX I: REPORT GENERATION AND PROCEDURAL ITEMS

1. The report should be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report should consist of a background, description of review activities, summary of findings, and conclusions/recommendations.

3. The report should also include as separate appendices the bibliography of materials provided by the Center for Independent Experts and the center and a copy of the statement of work.

4. Individuals shall be provided with an electronic version of a bibliography of background materials sent to all reviewers. Other material provided directly by the center must be added to the bibliography that can be returned as an appendix to the final report.

Please refer to the following website for additional information on report generation: http://www.rsmas.miami.edu/groups/cimas/Report_Standard_Format.html