Initial 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:
Alaska Fisheries Science Center: Seattle and Kodiak
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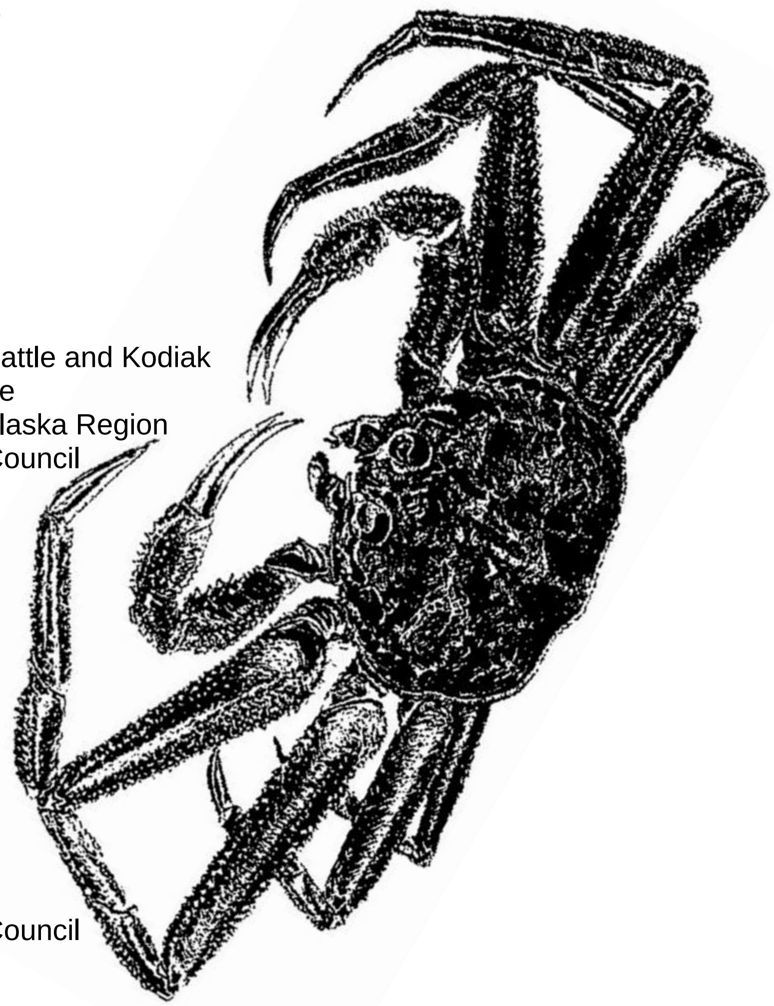

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Abstract: The Magnuson-Stevens Act Fishery Conservation and Management Act requires Fishery Management Plans to contain objective and measurable criteria for determining whether a stock is overfished or whether overfishing is occurring. The proposed 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 must immediately end overfishing and develop an FMP amendment to the rebuild the stock within two years.

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 the three alternatives and two sets of options. The alternatives and option analyzed in this EA are consistent with the Magnuson-Stevens Act and the national standard guidelines. Chapter 2 also provides (1) a comparison of the status determination criteria under each alternative, (2) a comparison of the two options for OFL setting and review process under Options 1 and 2, and (3) the a discussion of alternatives considered and eliminated from detailed study.

Table EX-1 Alternative and Options analyzed in this Environmental Assessment.

Alternatives	**Options**
Alternative 1: Status quo	Option A: Remove Specific Stocks from FMP or Option B: Status quo - no removal of stocks
Alternative 2: Tier system with five Tiers	Option 1: Council annually adopts OFLs in June or Option 2: Council annually reviews OFLs in the Fall
	Option A: Remove Specific Stocks from FMP or Option B: Status quo – no removal of stocks
Alternative 3: Tier system with six Tiers	Option 1: Council annually adopts OFLs in June or Option 2: Council annually reviews OFLs in the Fall

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: Tier system with five Tiers. The FMP amendment would specify the Tier system and a framework for annually assigning each crab stock to a Tier and for setting the OFLs (see Options 1 and 2). The Tier system with five Tiers would provide an OFL for all FMP stocks (see Options A and B).

Alternative 3: Tier system with six Tiers. The FMP amendment would specify the Tier system and a framework for annually assigning each crab stock to a Tier and for setting the OFLs (see Options 1 and 2). The Tier system with six Tiers would provide an OFL for stocks with sufficient catch history and, in Tier 6, set a default OFL of zero for those stocks with insufficient information from which to set an OFL, unless the SSC establishes an OFL based on the best available scientific information

The two sets of options are summarized as follows:

Options 1 and 2 provide options for the OFL setting and review process by which stocks would be annually assigned to Tier levels, the OFLs would be set, and the timing of the annual review process by the Crab Plan Team, Scientific and Statistical Committee, and Council.

Option 1: Council annually adopts OFLs. In June, the Council would adopt the final Tier level assignments 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.

Option 2: Council annually reviews OFLs. 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 the Fall.

Options A and B provide options for the stocks managed under the FMP, and therefore, determine the stocks for which OFLs are required.

Option A: This option would remove eleven stocks from the FMP for which the State is interested in the conservation of management of the stock and there is no need for additional Federal management.

Option B: Status quo FMP species

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

Biological Reference Points	Alternative 1 (Status quo)	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 * M)	Calculated by applying F_{MSY}† or F_{MSY} proxy† in Tier system to appropriate biomass estimate
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 or F_{OFL} control rule)	MSY control rule applied to the current total mature biomass	F_{OFL} control rule calculated by applying Tier system: Tiers 1 and 2 – MSY and F_{MSY} Tier 3 - F_{MSY} proxy = $F_{35\%}$† Tier 4 - F_{MSY} proxy = γ† * M
MSY control rule	M	F_{OFL} control rule
Natural mortality rate (M)	0.2 for all species of king crab 0.3 for all *Chionoecetes* species	0.18† for all species of king crab 0.23† for male and 0.29† for female *Chionoecetes* species
Sustainable yield (SY)	Total mature biomass * M	N/A
Optimum yield (OY)	OY range 0 - MSY	OY range 0 - < OFL level catch

† These parameters are frameworked in the Tier system and the values used for this analysis are based on the best available scientific information and can change with new scientific information through the OFL setting process outlined in Options 1 and 2.

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. Options 1 and 2 establish different processes for OFL setting and review. 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. This review process includes the SSC and the Council review for determining appropriate Tier levels and OFLs on an annual basis.

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.

Crab Stocks Under the FMP

The FMP manages 22 crab stocks. NMFS annually surveys five of these 22. Option A would remove eleven specific stocks from the FMP for which there is no directed fishery, a limited exploratory fishery, or the majority of catch occurs in State waters. The State would have sole management authority for these species, as they do for hair crab (the hair crab fishery, which occurs in the EEZ, was removed from the FMP).

Summary of the environmental consequences of the alternatives

This EA evaluates the alternatives and option for their effects within the action area. The environmental consequences of each alternative for 22 crab stocks 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. This EA details the specific impacts of the proposed action to establish overfishing definitions for the crab stocks under the FMP.

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 74.79 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 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 31.4 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 Tier system described in Chapter 2. The recommended OFL control rule for the Bristol Bay red king crab stock is an $F_{35\%}$ control rule.

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 B_{MSY} at 19.0 million pounds. Under Alternatives 2 and 3, the Pribilof Islands king crab estimate of B_{MSY} proxy would be 7.82 million pounds of mature male biomass. For comparison, the 2006 estimate of mature male biomass for this stock is 6.43 million pounds. Thus, this stock status would be below B_{MSY} proxy under the Alternative 2 and 3, rather than above it as with

Alternative 1. 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 Alternatives 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.

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.

The status of snow crab is similar under the three alternatives. 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 an $F_{35\%}$ control rule.

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 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 63.25 million pounds of mature male biomass, with an MSST of 31.62 million pounds. For comparison, the 2006 estimate of Tanner crab mature male biomass is 62.76 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, an $F_{35\%}$ control rule 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 $F_{35\%}$ control rule 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. Under Alternative 3, Western Aleutian Islands Tanner crab would be under Tier 6 due to lack of available information and a default OFL would be set a zero for this stock. Under Option A, Eastern and Western Aleutian Islands Tanner crabs would be removed from the FMP and managed by the State.

Blue King Crab

Under Alternative 1, Pribilof Islands blue king crab and Saint Matthew blue king crab have been declared overfished and are under rebuilding plans. 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.

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. Under Alternatives 2 and 3, the Pribilof Islands blue crab estimate of B_{MSY} proxy would be 6.68 million pounds of mature male biomass, with an MSST of 3.34. For comparison, the 2006 estimate of mature male biomass for this stock is 0.63 million pounds.

For Saint Matthew blue king crab, a B_{MSY} of 22.0 million pounds of total mature biomass 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, the Saint Matthew blue king crab estimate of B_{MSY} proxy would be 13.92 million pounds of mature male biomass, with an MSST of 6.96 million pounds. For comparison, the 2006 estimate of mature male biomass for this stock is 7.41 million pounds.

Under Option A, Saint Laurence blue king crab would be removed from the FMP and managed by the State.

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. Under Alternative 3, Saint Matthew golden king crab would be recommended for placement in Tier 6 whereby a default OFL would be set at zero. Option A would remove Saint Matthew golden king crab from the FMP to be managed by the State.

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 Alternative 2, these stocks would all be under Tier 5, OFLs would be calculated for each stock based upon average catch.

Under Alternative 3, these stocks would be under Tier 6. For Tier 6 stocks, a default OFL would be set equal to zero, unless the SSC determines a value based on the best available information. No additional status determination criteria are currently estimated for these stocks nor proposed under the revised definitions.

Option A would remove the following other crab stocks from the FMP; EBS grooved Tanner crab, Eastern Aleutian Islands grooved Tanner crab, and Western Aleutian Islands grooved Tanner crab, Aleutian Islands scarlet king crab, EBS scarlet king crab, Bering Sea triangle Tanner crab, and Eastern Aleutian Islands triangle Tanner crab. The State would continue to manage these stocks.

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 decline in the TAC is likely to contribute to reduced gross revenues to harvesters, processors, and other businesses that rely on the crab fishery. In addition, any prolonged reduction in the TAC could also contribute to fleet consolidation. Reductions in TAC could also negatively impact communities through reduced spending in that community by processors, harvesters, crab support businesses, residents that work in the crab industry, and other residents and businesses that indirectly depended on the snow crab industry. 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.

Any change in TAC resulting from the proposed action will likely impact several communities. The impacts will likely vary across communities depending on the degree of importance the crab fishery contributes to the local economy. Communities with a high degree of dependency on the crab fishery will likely be impacted to a heavier degree then communities with low a dependency on the fishery. For communities like St. Paul, St. George, and King Cove, EBS snow crab is crucial to the local economy. Any changes in the snow crab OFL that result in a change in the snow crab TAC will likely impact these community to a much higher degree than Dutch Harbor or Kodiak, which is more diversified across many different fisheries. Communities like Dutch Harbor, Kodiak, and Akutan are more dependent on Bristol Bay red king crab, so any changes in the TAC for this species will impact these communities. The Bering Sea Tanner crab fishery is primarily concurrent with the regionalized Bristol Bay red king crab and Bering Sea snow crab fisheries, which made the regional designation of Tanner crab landings unnecessary. As a result, Bering Sea Tanner crab fishery does not have regional delivery requirements. Looking at the 2005/2006 fishing season, approximately 38 percent of the Bering Sea Tanner crab was landed in Dutch Harbor, followed by St. Paul at 24 percent. Assuming similar delivery patterns in the future, any changes in the EBS Tanner crab TAC will likely impact St. Paul, Dutch Harbor, Akutan, and King Cove.

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.

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List of Acronyms and Abbreviations[1]

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

[1] Appendix A contains the notations used in the equations in this EA.

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:

1. Those that are fixed in the FMP and require a 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 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 must immediately end overfishing and develop an FMP amendment to rebuild the stock within two years. 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.

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (MSRA, Public Law 109-479) provided additional language to prevent overfishing by requiring that FMPs establish a mechanism for specifying annual catch limits in the plan (including a multiyear plan), implementing regulations, or annual specifications, at a level such that overfishing does not occur in the fishery, including measures to ensure accountability. The MSRA also modified the language in section 304(e)(3) of the Magnuson-Stevens Act to extend the time period for the Council and Secretary to develop and implement a rebuilding plan from one year to two years.

1.1.1 Definitions

Definitions of 'overfished' and 'overfishing' are provided in the national standard guidelines (50 CFR 600.310). While the Magnuson-Stevens 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

Section 304(e) of the reauthorized Magnuson-Stevens Act requires that, within two years of secretarial notification, the Council prepare and implement an FMP amendment to immediately end overfishing and rebuild the stock. The national standard guidelines 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.

(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 2 years 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 EA 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), which is available on the NMFS Alaska Region web site at http://www.fakr.noaa.gov/sustainablefisheries/crab/eis/default.htm. 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.

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 Tier system based status determination criteria for the crab stocks under the FMP. Relevant and recent information on each crab stock is contained in the chapter for that species.

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).

This EA also relies heavily on the information and analysis contained in the Council's annual BSAI Crab Stock Assessment and Fishery Evaluation (SAFE) Reports, available from the Council web site at http://www.fakr.noaa.gov/npfmc/SAFE/SAFE.htm or
http://www.fakr.noaa.gov/npfmc/membership/plan_teams/CPT/CRABSAFE06.pdf. The SAFE Reports contain the status of the crab stocks, the results of the NMFS EBS trawl survey, the annual management fisheries report, stocks assessments, and an economic report.

1.4 Next steps in the process

This analysis is scheduled for initial review at the June 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 October 2007 Council meeting.

2 Description of Alternatives

This Chapter provides (1) a description of the alternatives and options considered in this analysis, (2) a comparison of the status determination criteria in the alternatives, (3) a comparison of the two options for the OFL setting and review process, and (4) a discussion of the development of alternatives and the alternatives considered and eliminated from detailed study.

Alternatives	Options
Alternative 1: Status quo	Option A: Remove Specific Stocks from FMP Option B: Status quo - no removal of stocks
Alternative 2: Tier system with five Tiers	Option 1: Council annually adopts OFLs in June Option 2: Council annually reviews OFLs in the Fall
	Option A: Remove Specific Stocks from FMP Option B: Status quo – no removal of stocks
Alternative 3: Tier system with six Tiers	Option 1: Council annually adopts OFLs in June Option 2: Council annually reviews OFLs in the Fall

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 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 MFMT.

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 ton, 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 total mature biomass (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.

2.1.3 Timing of status quo OFL setting process

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 2-2). NMFS conducts the annual trawl survey from June through mid-August. NMFS and ADF&G annually estimate stock abundance based on the NMFS EBS trawl survey. ADF&G sets the TACs on or immediately before October 1, and the crab fisheries open on October 15.

Table 2-2 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….).

2.2 Alternative 2: Tier system with five Tiers

Alternative 2 would amend the FMP to include the Tier system in Table 2-3 with five Tiers and an OFL setting and review process for assigning each crab stock into a Tier and for setting the OFLs. The process would either be as described in Option 1 or Option 2. Additionally, the Council may choose to remove specific crab stocks from the FMP, as described in Option A.

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 five 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' (see Table 2-2). 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.

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 2 is for stocks with assessment models in which reliable point estimate, but not the *pdf*, of F_{MSY} is made. 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. 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.

Tier 4

Tier 4 and 5 are for stocks 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. The most important parameter for Tier 4 is γ. A scalar, 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 scalar 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

Tier 5 stocks have no reliable estimates of biomass or M. For these stocks, the historical performance of the fishery would be 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.

Table 2-3 Alternative 2 Tier system.

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	$\frac{B}{B_{msy^{prox}}} \le \beta$	$F_{OFL} = 0$
Stocks with no reliable estimates of biomass or M.	5		OFL = average catch from a time period to be determined, unless the SSC establishes an alternative value based on the best available scientific information.

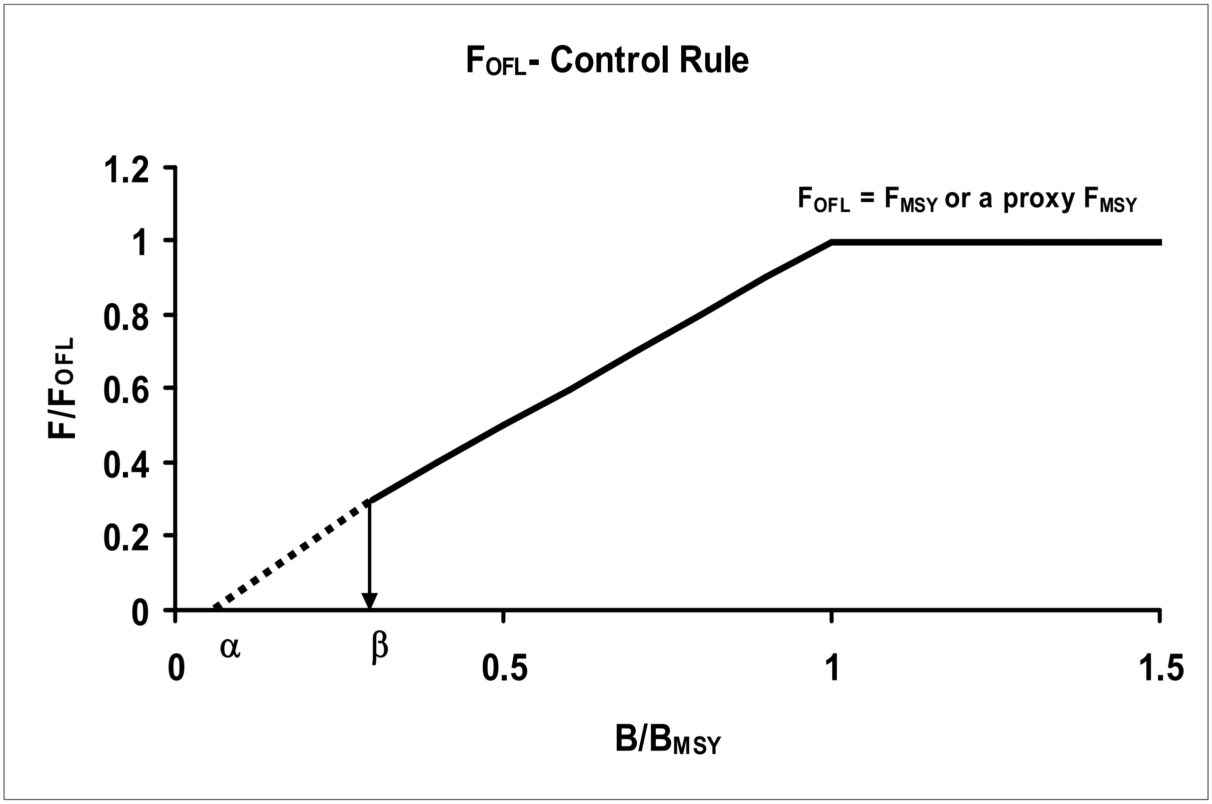

Figure 2-1 Proposed control rule for overfishing for Tiers 1 through 4 under Alternatives 2 and 3. Directed fishing mortality is 0 below β.

2.2.2 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 MFMT.

Annual determination of overfishing would occur by comparison of the estimated full selection fishing mortality F from the 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 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 occurred.

The overfishing criterion is expressed for each stock in terms of limits on the total annual fishing mortality rate or its total catch limit analog, while the overfished criterion is expressed in terms of a minimum stock biomass threshold. This alternative establishes the framework under which both status determination criteria are formulated and assessed.

The revised overfishing and overfished definitions of this alternative result from simulation modeling that captures the essential population dynamics of the stock as well as the performance of the fisheries. In formulating the annual catch limit corresponding to the threshold on fishing (i.e., the overfishing definition or OFL), the calculation must account for all losses to the stock not attributable to natural morality. Such an OFL is the total catch limit comprised of three catch components: [1] non-directed fishery discard losses; [2] directed fishery discard losses; and [3] directed fishery retained catch. If, in any year, the sum of all three catch components does not exceed the total catch OFL, then overfishing is not determined to have occurred.

The simulation modeling approach employed in the derivation of the annual OFLs captures the historical performance of the fisheries as seen in observer data from the early 1990s to present. These data allow the formulation and use of selectivity curves for the discard fisheries (directed and non-directed losses) as well as the directed fishery (retained catch) in the models. The OFL resulting from this approach, therefore, is the total catch OFL that includes the expected retained catch as well as all expected discard losses to the extent any is sufficiently known from the historical performance data. Given the modeled selectivity curves, the total catch OFL can be apportioned into its three components and limits conceived for each component separately. Accordingly, one may consider a so-called directed fishery retained catch OFL as being distinct from discard catch limits on the directed and non-directed fisheries.

Since such a directed fishery retained catch OFL could be derived from the total catch OFL, an appeal would be to compare only the directed fishery retained catch against the retained catch OFL to simplify the annual status determination of overfishing. Implicit in such an assessment is that the modeled inter-relationships between the three fishery components upon which the total catch OFL was determined have not changed in the fishery. Specifically, that there has been no change in the pattern of actual discard selectivities (directed and non-directed) and retained selectivities vs that modeled to derive the total catch OFL. If these relationships have been strictly maintained, then it may be sufficient to compare only the directed fishery retained catch and the retained catch OFL in evaluating whether overfishing has occurred. Retrospective analysis via stock assessment modeling and/or anecdotal fishery information may reveal whether that assumption is valid. Absent evidence that modeled component fishery selectivities have not changed, it would be risk prone to use only the directed fishery catch in comparing against the calculated overfishing limit.

Irrespective of whether the future performance of the fishery will be consistent with that modeled in the derivation of the OFL, the threshold limit of catch used to evaluate the status determination criterion of overfishing is the total annual catch that includes all sources of fishery-induced losses, retained and discarded. For EBS crab stocks under the aegis of the BSAI King and Tanner Crab Fishery Management Plan as amended by this EA, the inter-relationships between the three fishery components is reasonably anticipated to change in comparison to historical patterns, particularly under the current model of crab rationalization. In this regard as it relates to the use of only a directed fishery retained catch OFL, the pattern of retained and discarded selectivities by the directed fisheries has been found to have changed markedly under the first year of the rationalization model due to sorting and high-grading of the catch. This observed feature alone would invalidate the use of only the so-called directed fishery retained catch OFL to determine if overfishing has occurred. It will be required under any framework and set of assumptions to annually compile all discard losses and retained catches, and to compare that sum against the total catch OFL in order to evaluate the overfishing status determination criterion for each stock.

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.

2.3 Alternative 3: Tier system with six Tiers

Alternative 3 would amend the FMP to include the Tier system in Table 2-4 and an OFL setting and review process for assigning each crab stock into a Tier and for setting the OFLs, as described in Option 1 or Option 2.

2.3.1 Tier System

The Tier system in Alternative 3 is the same as Alternative 2 for the first four Tiers, however, Tier 5 is modified and Tier 6 is added (Table 2-4).

Tier 5

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, is on the best scientific information available and provides the required risk aversion in terms pertaining to stock conservation and utilization goals.

Tier 6

Tier 6 is for stocks where information necessary to establish an OFL is currently unavailable. The default OFL would be set at zero for the directed commercial fishery. No directed fishing would be allowed for stocks with an OFL=0. A directed commercial fishery means any fishing activity that results in the retention of an amount of a species on board a vessel. However, if ADF&G intends to open a directed fishery for a specific stock, then the SSC may recommend an OFL for that Tier 6 stock based on the best available scientific information through the OFL setting process and prior to the ADF&G GHL setting process. For these stocks, only exploratory fishing or incidental catch has occurred in the recent past. Incidental catch would be allowed as long as it remains within the historical norm. These stocks would be 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.

2.3.1 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 MFMT.

Annual determination of overfishing would occur by comparison of the estimated *F* from the 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 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 occurred.

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.

Table 2-4 Alternative 3 Tier system.

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 a time period to be determined.	5		OFL = average catch from a time period to be determined, unless the SSC establishes an alternative value based on the best available scientific information.
Stocks with insufficient catch history and limited scientific information.	6		Default OFL=0 for the directed fishery, unless the SSC establishes an OFL based on the best available scientific information.

2.4 Options for the OFLs setting and review process

Options 1 and 2 establish different annual processes for Tier and OFL setting and review. This review process includes the Crab Plan Team, SSC, and 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 is important because it determines two key factors: (1) who the decision-maker can be for the OFL determinations, 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.

Option 1: Council annually adopts OFLs in June

Option 1 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 to the SSC and Council, 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. The SSC and Council would review this information at the June meeting and adopt the OFLs. 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 Option 1 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….).

Option 2: Council annually reviews OFLs in the fall

Option 2 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 2-5). In the spring, the CPT would review model parameter choices by the stock assessment authors and resultant Tier levels and make recommendations to the SSC. Each June, the Council and SSC would subsequently review the choice of parameters 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. This option is similar to status quo.

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 many of the 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 Option 2 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….).

2.5 Options for Removal of FMP stocks

Option A: Remove Specific Stocks from FMP

Option A would remove specific stocks from the FMP for which: (1) there is no directed fishery; (2) harvest only occurs incidentally during fisheries targeting other crab stocks; (3) harvest only occurs in limited, exploratory fisheries; or (4) the majority of catch occurs in State waters. Under the Magnuson-Stevens Act, to remove these stocks from the FMP, NMFS and the Council need to find that there is a legitimate interest of the State of Alaska in the conservation and management of these stocks. The State would have sole management authority for these species, as they do for hair crab (the hair crab fishery, which occurs in the EEZ, was removed from the FMP). Currently, the FMP defers the management of these fisheries to the State. Therefore, the State already manages these stocks and collects all of the biological information. Except for the Eastern Aleutian Islands Tanner crab stock, none of these stocks are surveyed. Harvest histories of the unsurveyed stocks are sporadic and the harvests from those stocks are managed either as incidental catch in fisheries targeting other crab stocks or as limited, exploratory fisheries. Any future exploratory fishery would be operated by commissioner's permit, which means the State determines if and when these fisheries occur, who may participate, observer requirements, and how much is harvested. The Eastern Aleutian Islands Tanner crab fishery is essentially a state-waters fishery because 93 percent of landings from 1985-2006 were in state-waters statistical areas.

Option A would remove the following 11 stocks from the FMP:

1. Eastern Aleutian Islands Tanner crab
2. Western Aleutian Islands Tanner crab
3. EBS grooved Tanner crab (*Chionoecetes tanneri*)
4. Eastern Aleutian Islands grooved Tanner crab
5. Western Aleutian Islands grooved Tanner crab
6. Bering Sea triangle Tanner crab (*Chionoecetes angulatus*)

7. Eastern Aleutian Islands triangle Tanner crab
8. Saint Matthew golden king crab
9. Saint Lawrence Island blue king crab
10. Aleutian Islands scarlet king crab (*Lithodes couesi*)
11. EBS scarlet king crab

Section 306(a)(3) of the Magnuson-Stevens Act provides for State management authority in Federal waters off Alaska in the absence of Federal management of the species in question. Under Option A, the State of Alaska would continue existing State management for these crab stocks. The existing delegated authority is costly and burdensome for these stocks with limited fishery histories for the following reasons: (1) State personnel are required to comply with the additional Federal management processes; (2) the State needs to meet both state and federal requirements which are often on different timeframe for management (e.g., public meetings and reports); and (3) the State can not meet the costly assessment requirements for necessary of OFLs for these stocks. Instead, conservative management of the species under exclusive state management would be less costly and onerous.

Under this option, Federal management would be removed, including the Magnuson-Stevens Act measures, such as the limited access requirements, Essential Fish Habitat (EFH) designation, and status determination criteria. Currently, vessels that intend to participate in these fisheries need a Federal license limitation program (LLP) license with a minor species or AI Tanner crab endorsement. NMFS issued new crab LLP licenses with new species endorsements to crab LLP holders subsequent to removing the LLP requirements for the fisheries under the Crab Rationalization Program. NMFS issued an Aleutian Islands Tanner crab endorsement to holders of crab LLP with a BSAI snow and Tanner crab endorsement and issued crab LLPs with minor species endorsements to all crab LLP holders. Therefore, the LLP requirement does not limit access to these potential fisheries to historic or recent participants.

Although a Magnuson-Stevens Act requirement, insufficient information is available to determine EFH for grooved Tanner, triangle Tanner, and scarlet king crab (See EFH EIS). The EFH designated for golden king crab, Tanner crab, and blue king crab species would not change with the removal of western and eastern Aleutian Islands Tanner crab, Saint Matthew golden king crab, and Saint Laurence Islands blue king crab stocks. Additionally, these stocks would continue to benefit from the Federal habitat protection measures for the EFH for these three species.

As described under Alternative 1, the current status determination criteria only established an MFMT for these species based on the natural mortality rate set for king and Tanner crabs in 1999. The information necessary to establish an overfishing limit for these stocks is currently unavailable (except for AI Tanner crabs). In the future, NMFS and the State will need to ensure that these stocks comply with the new MSRA requirement for Annual Catch Limits (ACLs) and Accountability Measures (AMs) for all species under FMPs. NMFS is developing guidelines on ACLs and AMs. FMPs will have to be in compliance with these guidelines by 2010. Additionally, there may be State confidentiality issues that may restrict the reporting of status of these stocks relative to the OFLs because many of these exploratory fisheries are prosecuted by fewer that three vessels and processed by fewer than three processors.

Option B Status quo – No removal of stocks

Under this option the current 22 stocks would remain in the FMP and, as required by the Magnuson-Stevens Act, OFLs would need to be established for all FMP stocks.

2.6 Comparison of status determination criteria

This section provides a comparison of the status determination criteria in Alternatives 1, 2, and 3. 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 for each stock in Chapters 4 through 9 because the impacts vary between stocks.

2.6.1 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 specifies 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 or economic criteria to define OY.

Estimation of base input parameters to determine biological reference points varies by species and by availability of information for specific stocks. Under the review system for Alternatives 2 and 3, 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 Options 1 and 2 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, SSC, and Council, as described in Section 2.4. Unlike Alternative 1, an FMP amendment would not be required to changes these biological parameters. Further details on the timing of this review process in conjunction with establishment of OFLs are contained in Section 2.6.

Table 2-7 provides a comparison of the biological reference points provided in the alternatives. Additional information on the biological reference points for specific species are provided in the Chapter for that species.

Table 2-7 Comparison of biological reference points used in the alternatives.

Biological Reference Points	Alternative 1 (Status quo)	Alternatives 2 and 3
Spawning biomass (B)	Total mature biomass (TMB, males + females)	Mature male biomass† (MMB)
Maximum Sustainable Yield (MSY) or MSY proxy	Fixed value from the average of the annually computed sustained yield over the 15-year period, 1983-1997	Calculated by applying F_{MSY}† or F_{MSY} proxy† in Tier system to appropriate biomass estimate
MSY Biomass (B_{MSY})	Fixed value of 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 or F_{OFL} control rule)	MSY control rule applied to the current total mature biomass	F_{OFL} control rule calculated by applying Tier system: Tiers 1 and 2 – MSY and F_{MSY} Tier 3 - F_{MSY} proxy = $F_{35\%}$† Tier 4 - F_{MSY} proxy = γ† * M
MSY control rule	M	F_{OFL} control rule
Natural mortality rate (M)	0.2 for all species of king crab 0.3 for all *Chionoecetes* species	0.18† for all species of king crab 0.23† for male and 0.29† for female *Chionoecetes* species
Sustainable yield (SY)	Total mature biomass * M	N/A
Optimum yield (OY)	OY range 0 - MSY	OY range 0 - < OFL level catch

† These parameters are frameworked in the Tier system and the values used for this analysis are based on the best available scientific information and can change with new scientific information through the OFL setting process outlined in Options 1 and 2.

Table 2-8 provides a comparison of the application of alternative status determination criteria for the six surveyed stocks using 2006 data.

Table 2-8 Comparison of the application of the status determination criteria in the Alternatives for the six surveyed stocks using 2006 data (in millions of pounds).

	Alternative 1						Alternatives 2 and 3			
Stock	**B(06) = TMB**	**B_{MSY}**	**MSST**	**OFL(06) =SY**	**06/07 TAC**	**06/07 F**	**B(06) = MMB**	**B_{MSY}**	**MSST**	**F_{OFL}**
Bristol Bay red king crab	157.2	89.6	44.8	31.44	15.5	0.30	65.54	74.79	37.4	0.31
Pribilof Islands red king crab	19	6.6	3.3	3.8	0	0	6.43	7.82	3.91	0.29
Pribilof Islands blue king crab	1.6	13.2	6.6	0.32	0	0	0.63	6.68	3.34	0.0
St. Matthew blue king crab	11.2	22	11	2.24	0	0	7.41	13.92	6.96	0.17
EBS Tanner crab	253.3	189.6	94.8	75.99	2.969	0.30	62.76	63.25	31.62	0.67
Snow crab	547.6	921.6	460.8	164.28	36.6	0.8	211	413.4	206.68	0.51

The $F_{35\%}$ for Tanner crab is 0.8. This applies when the mature male biomass is above $B_{35\%}$. However in 2006, the mature male biomass is 62.76 lower than the$B_{35\%}$ If the proposed sliding control rule is applied due to this, then the $F_{35\%}$ would be reduced to 0.67 as listed above. A similar explanation applies to the listed rate for Bristol Bay red king crab. Bristol Bay red king crab $F_{35\%}$ is 0.36. But, since the 2006 MMB is 65.54 which is lower than the $B_{35\%}$, the sliding control rule applies here as well. So, 0.36 is reduced to 0.31. The same sliding control rule is applied to Pribilof and St. Mathew blue king crab stocks with lambda*M = 0.36. The actual F_{OFL} will be less than 0.36.

2.6.2 Risks associated with continued use of the Alternative 1 status determination criteria

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 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 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 sustainable yield (SY=M*TMB) 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 SY. 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 sustainable yield 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 all legal-sized or market-preferred males present in a stock to be harvested.

2.7 Comparison of the Options for the OFL Setting and Review Process

The timing of 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. 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.

The OFL setting and review process establishes the timing for (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. This review process includes the SSC and the Council review for determining appropriate Tier levels and OFLs on an annual basis. Options 1 and 2 establish different processes for Tier and OFL setting and review. Under Option 1, the Council would adopt the final Tier level assignments and OFLs for each stock in June. OFLs would be determined based upon model estimates prior to the summer survey because the Council would adopt the OFLs before the survey. Under Option 2, 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 the fall.

Under Alternative 1 (status quo) and Option 2, 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. Potential problems with Option 2 arise from the short time period from when the survey data is available after the summer survey in mid-August to when the State sets the TACs on October 1. During this period, the survey data is analyzed, assessment models are run, NMFS determines the status of the stocks, the CPT meets to discuss the status of the stocks and compile the SAFE, and the State sets the TACs for the fisheries opening October 15. The Council then reviews this information after the fact. This process provides limited time for peer review and public involvement.

Under Option 1, the previous year's data would be used to set the F_{OFL}, and the most recent survey data would be compared to that F_{OFL} to evaluate the status of stocks. The F_{OFL}s adopted by the Council in June would be final. This option would provide more time for peer review and provide advanced notice of the OFLs to the industry and public.

However, Option 1 may cause problems because the best available (i.e. recent survey year) data would be available within months of the Council adopting the F_{OFL}s in June. 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 F_{OFL} could either be too constraining if stock abundance increases dramatically or too liberal if stock abundance decreases dramatically. In instances when the F_{OFL} is too liberal, the State could correct for this by setting TACs based on the recent survey data to avoid overfishing.

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 figures on the status of each stock relative to overfishing in Chapters 4 though 9.

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 2-9).

Table 2-9 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 red king crab	14	7.7	12.8	10.2	25.5	18.1	14.5	9.9	8.1	19
Pribilof blue king crab	11.7	11	9.2	7.4	7	4.5	4.1	0.5	1.6	1.6
St. Matthew 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 2-9, 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 percent of that estimated from the 1998 survey.

For Option 1, crab abundance and biomass need to be projected one year forward. Under Option 1, 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 Options 1 and 2 is relative model projection errors for Option 1. 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 2-10 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 2-10 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 2-11 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 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 Bristol Bay red king crab 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 12 on Economic and Social Effects.

Table 2-11 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

2.8 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 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 interagency 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 E. 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 F.

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 3.1.6.

The workgroup and the Crab Plan Team spent a considerable amount of time debating the best method for setting OFLs for the data-poor crab stocks. The problem with the stocks with little or no information is that there is not a satisfactory solution to the Magnuson-Stevens Act requirement to set an OFL that is not arbitrary due to lack of information. In addition to the alternatives and options presented in this EA, the Crab Plan Team discussed the following different ways to address data poor crab stocks.

- not address data-poor stocks and return to the original Tier system with five Tiers from the November 2006 EA for Amendment 24.
- modify Tier 5 to include these stocks by saying "For stocks with insufficient catch history, an OFL would only be established in the case of a directed fishery, or if bycatch increased to a level of concern."
- add a Tier 6 that sets OFL = X% of historic catch.
- add a Tier 6 that says “No OFL, unless the SSC establishes an OFL based on the best available scientific information.”
- add a Tier 6 that puts these stocks into a complex and sets an OFL for the complex, based either on a percent of the sum of historic catches or an number such as 100k.
- keep the status quo OFDs for these stocks and not include them in the Tier system (so the Tier system would only apply to stocks that fit in Tiers 1-5 and the default OFL for the rest would be status quo).

3 Methodology for impact analysis

This chapter contains detailed information regarding methodology for analyzing the impacts of the alternatives on the crab stocks under the FMP. Chapters 4 though 9 contain detailed 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

The following table provides the proposed Tier assignments for the 22 FMP crab stocks for purposes of this analysis. Actual assignment to Tiers under Alternatives 2 and 3 would occur annually during the OFL setting and review process in either Option 1 or 2, and would be determined by the SSC and Council, under recommendation from the Crab Plan Team.

Table 3-1 Proposed Tier assignments for the 22 FMP crab stocks for purposes of this EA.

Tier	Alternative 2	Alternative 3
Tier 1	None	None
Tier 2	None	None
Tier 3	1. Bristol Bay red king crab (*Paralithodes camtschaticus*) 2. EBS Tanner crab (*Chionoecetes bairdi*) 3. EBS snow crab (*C. opilio*)	1. Bristol Bay red king crab 2. EBS Tanner 3. EBS snow crab
Tier 4	4. Pribilof Islands red king crab 5. Pribilof Islands blue king crab (*P. platypus*) 6. Saint Matthew blue king crab 7. Dutch Harbor red king crab 8. Norton Sound red king crab 9. Eastern Aleutian Islands Tanner crab	4. Pribilof Islands red king crab 5. Pribilof Islands blue king crab 6. Saint Matthew blue king crab 7. Dutch Harbor red king crab 8. Norton Sound red king crab 9. Eastern Aleutian Islands Tanner crab

Tier 5	10. Adak red king crab 11. Pribilof Islands golden king crab (*Lithodes aequispinus*) 12. Aleutian Islands golden king crab 13. EBS grooved Tanner crab (*C. tanneri*) 14. Western Aleutian Islands grooved Tanner crab 15. Eastern Aleutian Islands grooved Tanner crab 16. Saint Matthew golden king crab 17. Western Aleutian Tanner crab 18. Saint Lawrence Island blue king crab 19. Aleutian Islands scarlet king crab (*L. couesi*) 20. EBS scarlet king crab 21. Bering Sea triangle Tanner crab (*C. angulatus*) 22. Eastern Aleutian Islands triangle Tanner crab	10. Adak red king crab 11. Pribilof Islands golden king crab 12. Aleutian Islands golden king crab
Tier 6	NA	13. EBS grooved Tanner crab 14. Western Aleutian Islands grooved Tanner crab 15. Eastern Aleutian Islands grooved Tanner crab 16. Saint Matthew golden king crab 17. Western Aleutian Tanner crab 18. Saint Lawrence Island blue king crab 19. Aleutian Islands scarlet king crab 20. EBS scarlet king crab 21. Bering Sea triangle Tanner crab 22. Eastern Aleutian Islands triangle Tanner crab

3.1 Spawning biomass proxy - mature male biomass

The measure of spawning biomass is a framework measure in Alternatives 2 and 3. This analysis uses male mature biomass (MMB) at the time of mating as a proxy for egg production largely as a result of the uncertainties in modifying female mature biomass by the appropriate sex ratios and the component of mature males that participate in mating, and secondly since the directed fishery occurs on males. In future years, the stock assessment authors, Crab Plan Team, SSC, and Council may determine, through the OFL setting process, a more appropriate value for biomass based on improvements in scientific information.

Female mature biomass is used as a proxy for egg production in many fisheries applications to determine SR relationships, harvest control rules and reference points. Egg production in crab stocks, however, is complicated by obligate mating in pairs, limited spatial mobility in crabs relative to fish, and a male only directed 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 for crab stocks, that define the number of females that can be mated by each male within a mating season to modify 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 fertilizing egg clutches in the absence of males. Spatial distribution of the fishery may affect local sex ratios at mating time.

CIE review of the proposed OFL revisions (Appendix F) recommended the use of MMB 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 suggested three definitions for Biomass in the control rules and spawner-recruit relationships:

- total mature male biomass
- a function of total mature male biomass
- a function of total female egg production and a "fertilization factor".

Total mature male biomass (MMB) will restrict egg production when the sex ratio is at low levels due to depletion of mature males. In contrast, it will probably not be restrictive at levels where the sex ratio is near virgin.

The CIE review recommended research be conducted toward estimating an egg production index that should replace the use of male mature biomass in future reference point estimation. There are two components of information necessary to needed to apply an egg production index in place of MMB. First, is a set of basic reproductive dynamic relationships and the second is the set of observed information collected annual from the survey. A number of components to the egg production index are currently unknown. A total female egg production index (TFEP) would incorporate a number of components including mature male numbers and/or biomass. These components include:

- number of mature females by shell condition and size
- fecundity of females by shell condition and size
- fecundity to clutch score relationship by shell condition and size
- fraction of eggs unfertilized
- quality of eggs (may effect hatching and survival of larvae),
- stored sperm (an indication of male limitation),
- number of mature males by shell condition and size,
- mature males that take part in mating by shell condition and size,
- optimum sex ratio using males that take part in mating to mature females,
- fraction of females in biennial and annual spawning cycles
- Spatial sex ratios, affected by spatial patterns in fishing mortality

Research is needed to allow estimation of TFEP and its incorporation in the control rules and reference points. Some components of the TFEP are currently available, however, not all components are available for any BSAI crab stock. Shell age is an important component for both females and males, at present only shell condition is assessed, which is not a reliable index of shell age. Research on aging of crab is also needed to complete the estimation of TFEP.

Total MMB is a much simpler measure of spawning biomass that meets the criteria of being related to egg production and affected by fishing. The annual variability of the fraction of snow crab females that are barren, and the clutch size by shell condition indicates a relationship with the levels of exploitation of males (Turnock and Rugolo 2006).

Spawner-recruit relationships (SRR) indicate there is some level of correlation between MMB and recruitment estimated from stock assessment models. A SRR model was fit to the Bering Sea Tanner and Bristol Bay red king crab data (see Chapters 6 and 4, respectively). The SRR data for snow crab is highly variable and fitting a Ricker or Beverton-Holt curve was problematic (see Chapter 5). A range of curves was considered in this analysis for crab stocks given the variability of the SR data.

Primiparous females (first brood) may mate at different times from multiparous females (second or later brood), however, this analysis selected a date of February 15 for calculation of mature male biomass, prior to males molting. To calculate MMB, this analysis assumes that all pot fishing occurred or will occur before February 15 during each fishing season.

Under Alternatives 2 and 3, 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 (Alternative 1) rather than a model based B_{MSY} or proxy for B_{MSY}, over some time period assumes selectivity is 1.0, and that the stock is being fished at F_{MSY}. The use of MMB 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 some $F_{x\%}$ proxy for F_{MSY}. Where $F_{x\%}$ is the fishing mortality that reduces the spawning biomass to x percent of the unfished level. All of the above methods, however, assume that productivity is not changing over the time period considered.

3.2 Tiers 1 through 3

3.2.1 Simulation procedure

Stochastic projection models were used to evaluate the alternatives for Bristol Bay red king crab, snow crab, and Tanner crab stocks. For Alternative 1, both fishing at the status quo OFL control rule and the status quo harvest strategies were analyzed to demonstrate the predicted yield and 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 yield and biomass estimates resulting from the application of those control rules under these alternatives.

The crab populations were simulated for 30 and 100 years and fishing mortalities applied according to the particular harvest control rule. Maximum numbers of recruits (R_{max}) of 29 millions for red king, 104 millions for Tanner, and 2000 millions for snow crabs were considered in the simulations. These values were averages of the top 50% stock assessment estimated number of recruits for these stocks. 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 (Rugolo et al. 2005 and Tamone et al. 2005). No process errors on growth or *M* were considered for any of the three stocks. Log normal biomass observation errors ($\sigma_1 = 0.2$) and truncated normal harvest implementation errors ($\sigma_2 = 0.1$) were introduced in the red king and Tanner crab simulations. The implementation errors are minimum in the crab fisheries hence a low standard deviation was used. For snow crab simulations, observation errors on biomass were simulated with autocorrelated lognormal errors applied to abundance. A coefficient of variation of 0.15 and an autocorrelation of 0.6 were used.

As performance statistics, mature male and female biomass values, total and retained catch, standard deviation of the retained catch, *F*, the rebuilding time, and the percent of the time the biomass (B) was below B_{MSY} , below ½ B_{MSY}, percent of time when the fishery was closed (i.e., when B < 25%B_{MSY}), and final year B in relation to B_{MSY} were calculated. The average values for 1000 runs using 30 or 100 fishing years of each simulation were calculated to compare control rules. For these simulations the population was started from the biomass levels at ½ B_{MSY} and B_{MSY}, respectively. Simulations were also carried out to evaluate alternative values of α and β of the control rule. For these simulations, the population was initialized at 10% and 50% B_{MSY}, respectively (section 3.1.6).

Size-structured models were used for red king, Tanner, and snow crab population projections. The population dynamics equations used in all simulations are listed in Appendix A, and the base input parameter values for the three stocks are listed in Appendixes B (red king crab), C (Tanner crab), and D (snow crab). The Ricker and Beverton-Holt stock-recruitment models were used in all simulations and the approach to select plausible stock-recruitment relationships are described in the subsequent section.

3.2.2 Size-structured model for red king and Tanner crab

Simulations were initiated with a fixed number of immature new-shell recruits to the modeled population, divided equally between males and females and distributed between length bins by a probability function. Full age structure was established by deterministically projecting the initial recruits through their entire life span up to a maximum age with a given set of mortality and growth parameter values. Equilibrium yield curves for a range of steepness (h) values were used to estimate a proxy value for F_{MSY} using spawning biomass per recruit similar to Clark's (1991) method. For the stochastic simulations to evaluate various harvest control rules, the recruits were generated by a stochastic S-R model with log-normal random errors (variance σ^2 and a temporal correlation ρ). Simulations were started at various biomass levels relative to B_{MSY}. The population was first simulated using a fishing mortality that reduced the biomass to the desired initial levels, to evaluate rebuilding, then the harvest control rule was applied for 30 years or 100 years depending on the scenario.

3.2.3 Size-structured model for snow crab

The size-based model developed for snow is described in 2006 SAFE Report (NPFMC 2006). The model equations are provided in Appendix A. The population dynamics equations, incorporating the growth transition matrix and molting probabilities are similar to other size based crab models (Zheng et al. 1995 and 1998). Molting probabilities were fixed at 1.0 for immature females and males and zero for mature males and females (terminal molt). Yield curves for a range of steepness (h) values were used to estimate a proxy value of F_{MSY} using spawning biomass per recruit similar to Clark's (1991) method. For the stochastic simulations to evaluate various harvest control rules, the recruits were generated by a stochastic S-R model with log-normal random errors (variance σ^2 and a temporal correlation ρ). Simulations were started at various biomass levels relative to B_{MSY}. The population was first simulated using a fishing mortality that reduced the biomass to the desired initial levels, to evaluate rebuilding, then the harvest control rule was applied for 30 years or 100 years depending on the scenario.

3.2.4 Stock-recruitment relationship

The 1985-05 male mature biomass (MMB or in short B) and corresponding recruit data sets for handling mortality rate 0.1, 0.2, and 0.3 were used to establish the Beverton-Holt and Ricker stock-recruitment models for the Bristol Bay red king crab. The SAS (ver 9-1-3) AUTOREG procedure was used to test for autocorrelation. The Durbin-Watson statistics produced non-significant ($p>0.6$) results for presence of autocorrelation, hence the SAS Model procedure was used to fit nonlinear stock-recruitment models without autocorrelation. Free ranges of parameter values did not produce significant parameter estimates hence the η and θ parameters were fixed for fitting the two models. The estimated Beverton-Holt parameters were nonsignificant, but the Ricker parameters were significant.

Table 3-2 Stock- recruitment parameter estimates for Bristol Bay red king crab

Handling mortality rate	Ricker S-R curve		Beverton-Holt S-R curve	
0.1	γ	1.5165 ($p<0.01$)	κ	0.7482 ($p=0.15$)
	Standard error	0.4993	Standard error	0.4926
	θ (fixed)	0.04	η (fixed)	0.04
0.2	γ	1.5592 ($p<0.01$)	κ	0.7065 ($p=0.16$)
	Standard error	0.5131	Standard error	0.4764
	θ (fixed)	0.04	η (fixed)	0.04
0.3	γ	1.6036 ($p<0.01$)	κ	0.6693 ($p=0.17$)
	Standard error	0.5276	Standard error	0.4651
	θ (fixed)	0.04	η (fixed)	0.04

For the evaluation of Tier system for red king crab, the Ricker S-R model with a steepness parameter *h* value of 1.41, a R_{max} value of 29 million crabs, a handling mortality *hm* value of 0.2, an overall recruitment standard deviation σ of 0.5, and an autocorrelation ρ of 0 were chosen.

Steepness for the Ricker curve is defined as the fraction of R_0 (the recruitment at B_0) that occurs at a spawning biomass of 20% of B_0. Since the maximum recruitment R_{max} for the Ricker curves estimated here is closer to 20% B_0 than to B_0, the steepness parameter is greater than one. Under this definition, the steepness parameter can range from 0.2 to above 1. The steepness for the Beverton-Holt curve uses the same definition, however since the curve is asymptotic, h is between 0.2 and 1.0. Steepness for the Ricker curve can also be defined as the fraction of R_{max} that occurs at a spawning biomass of 20% of B_0 (This was followed in previous versions of EA). This steepness has bounds of 0 to 1.0, however, does not have the same meaning as the steepness in the Beverton-Holt curve. The formula to estimate *h* from γ is provided in Appendix A.

The 1977-05 male mature biomass and corresponding recruit data sets for the handling mortality rate 0.2 was used to establish the Beverton-Holt and Ricker stock-recruitment models for the ESB Tanner crab. The SAS AUTOREG procedure was used to test for autocorrelation. The Durbin-Watson statistics produced significant ($p<0.0001$) result for presence of autocorrelation when the Ricker model was used, hence the same AUTOREG procedure was used to fit the Ricker model. On the other hand, the SAS Model procedure was used to fit the nonlinear Beverton-Holt S-R model with a fixed value of η for the same data set because the Beverton-Holt model with free parameters did not produce significant fit.

Table 3-3 Stock- recruitment parameter estimates for EBS Tanner crab

Handling mortality rate	Ricker S-R curve		Beverton-Holt S-R curve	
0.2	γ	6.9452 ($p<0.05$)	κ	0.1465 ($p=0.34$)
	Standard error	2.1494	Standard error	0.1483
	θ	0.0604 ($p<0.02$)	η (fixed)	0.03
	Standard error	0.0228		

For the evaluation of Tier system for Tanner crab, the Ricker S-R model with a steepness parameter *h* of 1.6, a R_{max} value of 104 million crabs, a handling mortality *hm* value of 0.2, an overall recruitment standard deviation σ of 0.80 and a ρ of 0.69 were chosen.

The 1978-06 male mature biomass and corresponding recruit data sets for handling mortality rates 0.25 and 0.50 were used to estimate stock-recruitment curves for the EBS snow crab stock. The Ricker and Beverton-Holt model parameter estimates are listed in Table 3-4.

Table 3-4 Stock- recruitment parameter estimates for EBS snow crab

Handling mortality rate	Ricker S-R curve		Beverton-Holt S-R curve	
0.25	Steepness	0.895	Steepness	0.467
	R_{max}	2000 millions	R_0	2000 millions
0.50	Steepness	0.895	Steepness	0.494
	R_{max}	2000 millions	R_0	2000 millions

A recruitment standard deviation σ of 0.86 and an autocorrelation ρ of 0.6 were used in simulations based on 2006 stock assessment (Turnock and Rugolo, 2006).

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

3.2.5 Fx%, Bx%, F_{MSY}, and B_{MSY}

Stock-recruitment relationships were lacking for most BSAI crab stocks for direct estimation of F_{MSY} and B_{MSY} and qualify for Tier 1 or 2 group. The S-R fits to red king, Tanner, and snow crabs were not considered reliable for Tier 1 or 2. Therefore, plausible ranges of S-R steepness parameter *h* were considered to determine spawning potential ratio ($F_{x\%}$) and $B_{x\%}$ values as proxies for F_{OFL} and B_{MSY} in Tier 3 equations. The steepness ranges were chosen based on *h* estimates from S-R fits to Bristol Bay red king, Bering Sea Tanner, and snow crab stock data during low productivity periods. An *h* range of 0.72 - 1.59 for the Ricker S-R model and a corresponding *h* range of 0.56 - 0.77 for the Beverton-Holt S-R model were chosen for $F_{x\%}$ estimation by Clark's (1991) method for the red king crab. The corresponding *h* ranges for Tanner and snow crab $F_{x\%}$ determination were 0.66-1.59 and 0.53-0.77, respectively. The $F_{x\%}$ was determined as the 'minimax' point (Clark, 1991) from relative equilibrium yield vs relative spawning potential ratio curves. The $B_{x\%}$ was estimated from the stochastic simulation with the selected S-R curve for the base *h* value and the selected fixed $F_{x\%}$ value. The average $B_{x\%}/B_0$ ratio was used as a proxy B_{MSY}/B_0 from which the $B_{x\%}$ was determined knowing B_0. The B_0 was estimated at F = 0. When the true S-R curve with the estimated *h* value was used the same procedure provided F_{MSY} and B_{MSY} estimates.

3.2.6 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 α and β parameters used for the Alternatives 2 and 3 status determination criteria are shown in Figure 2-1.

A sensitivity analysis of the α and β parameters was investigated by considering a range of values for α (0.0, 0.05, 0.1, 0.25) 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 in some crab stocks. 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. Only red king and snow crabs were considered for these simulations. For the Bristol Bay red king crab a handling mortality rate of 0.2 and for the snow crab a handling mortality rate of 0.25 were used. The results are discussed in Chapters 4 and 5.

3.3 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 biomass 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. A default γ value or a range of γ values can be set for all Tier 4 stocks. In the simulation studies, the ratio of $F_{35\%}$ to M is 2.0 for Bristol Bay red king crab and 2.44 for EBS Tanner crab, after adjusting the shell condition selectivity. Because Tier 4 is for stocks with limited data, harvest should be more conservative than for these two stocks, which are in Tier 3. This conservation is reflected by the assumption that trawl survey catchability for legal males is equal to 1 for Tier 4 stocks, whereas the survey catchability may be estimated to be less than 1 in a model for Tier 3 stocks. The default γ for Tier 4 stocks is set to be the ratios of $F_{35\%}$ to M based on computer simulation studies (Table 3-5). For these five blue king crab and red king crab stocks, the default γ is set to be $F_{35\%}/M$ (0.36/0.18 = 2.0) from Bristol Bay red king crab. For *Chionoecetes* species, the default γ is set to be $F_{35\%}/M$ (0.5616/0.23 = 2.44) from EBS Tanner crab after adjusting the shell condition selectivity. The value for γ is frameworked, depending on the values of $F_{35\%}$ and M.

Table 3-5 Default *M* values, estimated γ and F_{OFL} values, and estimated B_{MSY} and MSST proxy values (million pounds) for proposed Tier 4 stocks based on the computer simulation studies of Bristol red king crab and eastern Bering Sea Tanner crab using the stock assessment results in 2006.

Stock	M	γ	F_{OFL}	B_{MSY}	MSST
Pribilof Islands red king crab	0.18	2.00	0.36	7.82	3.91
Pribilof Islands blue king crab	0.18	2.00	0.36	6.68	3.34
St. Matthew Island blue king crab	0.18	2.00	0.36	13.92	6.96
Dutch Harbor red king crab	0.18	2.00	0.36	NA	NA
Norton Sound red king crab	0.18	2.00	0.36	3.76	1.88
Eastern Aleutian Island Tanner crab	0.23	2.44	0.56	1.62	0.81

Table 3-6 illustrates the relationships among F, legal harvest rates, and γ for king and Tanner crabs for OFL and suggested target levels. Fishing season was assumed to be short so that legal harvest rates were estimated as 1-exp(-F).

Although there are no golden king crab stocks in Tier 4 currently, Aleutian Islands golden king crab could move up to Tier 4 soon. Chapter 8 discusses the impact of moving golden king crab stocks from Tier 5 to Tier 4. A range of γ values may need to be evaluated for golden king crab stocks with possible M values if they are moved from Tier 5 to Tier 4.

Table 3-6 Relationships among F, legal harvest (L.H.) rates, and γ for red and blue king, snow, and Tanner crabs.

Red and blue king crabs (Assuming 4.5 months from survey to fishing)						
	OFL Levels			Target Levels		
	F	L.H. Rate at Fishing time	L.H. Rate at Survey time	F	L.H. Rate at Fishing time	L.H. Rate at Survey time
0.5 M	0.09	0.09	0.08	0.07	0.07	0.06
1 M	0.18	0.16	0.15	0.14	0.13	0.12
1.5 M	0.27	0.24	0.22	0.20	0.18	0.17
2 M	0.36	0.30	0.28	0.27	0.24	0.22

Tanner and snow crabs (Assuming 6 months from survey to fishing)						
	OFL Levels			Target Levels		
	F	L.H. Rate Fishing time	L.H. Rate Survey time	F	L.H. Rate Fishing time	L.H. Rate Survey time
0.5 M	0.12	0.11	0.10	0.09	0.08	0.07
1 M	0.23	0.21	0.18	0.17	0.16	0.14
1.5 M	0.35	0.29	0.26	0.26	0.23	0.20
2 M	0.46	0.37	0.33	0.35	0.29	0.26
2.5 M	0.58	0.44	0.39	0.43	0.35	0.31
3 M	0.69	0.50	0.44	0.52	0.40	0.36

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 biomass from a specific period would be used as a proxy for B_{MSY} for Tier 4 stocks. The Alternative 1 overfishing definitions use estimated total mature biomass from 1983 to 1997 with an area-swept approach. For the overfishing definitions in Alternatives 2 and 3, this analysis uses the average mature male biomass from 1983 to the most recent year for Tier 4 stocks (Table 3-5). If a stock assessment model is available, the mature male biomass is estimated from the model; otherwise, an area-swept approach is used. The period from 1983 to present is relevant to current environmental conditions. 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 stocks are in the overfished condition, such as from 1999 to 2006 for two blue king crab stocks. A MSST proxy is estimated as 50% of the B_{MSY} proxy (Table 3-5).

3.4 Tiers 5 and 6

Different environmental regimes can result in different levels of mean yield for a stock. For OFLs in Alternatives 2 and 3, the mean yield from the current regime is used for Tier 5 stocks. The regime shift in 1976/77 has been well documented and so these OFLs consider mean yields after the 1976/77 regime shift. A regime shift may have occurred in 1989, but its effect in the EBS is not very strong. The regime shift affects the crab year classes first and then impacts catch a few years later. It takes at least 8 years from hatching to grow into legal size for most crab species. Therefore, mean yields from 1985 to 2005 were used for the Alternative 2 and 3 Tier 5 OFLs, with some excluded years that were strongly influenced by regulatory actions. The excluded years are from 1995 to 2005 for Adak red king crab when the fishery was closed, fishing effort was less than 10% of the average, or fishing was allowed only in a small part of the fishing ground. The excluded years are from 1985 to 1992 and from 2000 to 2005 for Pribilof Islands golden king crab when the fishing effort was less than 10% of the average or the TAC was set below the previous average catch. Years from 2000 to 2005 were excluded for Aleutian Island golden king crab when the TAC was set below the previous average catch.

Under Alternative 2, all stocks not in the previous Tiers would be in Tier 5, including stocks with very limited catch history. The problems with establishing an OFL based on catch history for these stocks include: (1) catch data come from exploratory and incidental fisheries for most stocks, (2) there are only 2 to 4 years of catch data for several stocks and hardly any catch data for St. Lawrence Island blue king crab, (3) mean catch for Eastern Aleutian Islands groove Tanner crab may be too high (only 4 years of data and the CPUE declined during these 4 years), and (4) mean catch for Aleutian Islands scarlet king crab and St. Matthew Island golden king crab may be too low (the maximum annual catch is more than 4.7 times of the average).

Under Alternative 3, only stocks with reliable catch histories would be in Tier 5. Alternative 3 includes a Tier 6 for stocks with insufficient catch history and limited scientific information. For Tier 6 stocks, the default OFL would be set at zero because there is no directed fishing for these stocks and available information is not sufficient to determine an OFL. Since OFLs are set for the directed fishery only, incidental harvests of Tier 6 stocks would not be affected by an OFL of zero. Prior to the opening of a directed/exploratory fishery for a Tier 6 stock, the OFL would be developed along with ADF&G's TAC for that fishery. The SSC would review and establish that OFL during the annual OFL setting and review process. Under any directed or exploratory fisheries, these stocks would be monitored for trends of fishing effort, CPUE, mean size of landed crab, and ratio of landed newshell to oldshell crab. Tier 6 stocks would be evaluated for upgrading to Tier 5 for OFL determination as information becomes available

4 Red king crab (*Paralithodes camtschaticus*)

Five stocks of red king crab are managed in the BSAI area: Bristol Bay, Pribilof Islands, Western Aleutian Islands, Eastern Aleutian Islands, and Norton Sound. This Chapter 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 Red king crab stock status

<u>Bristol Bay red king crab</u>

This stock is annually surveyed by the NMFS EBS trawl survey. The 2006 estimated TMB is 157.2 million pounds (71,305 t) of TMB. 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.

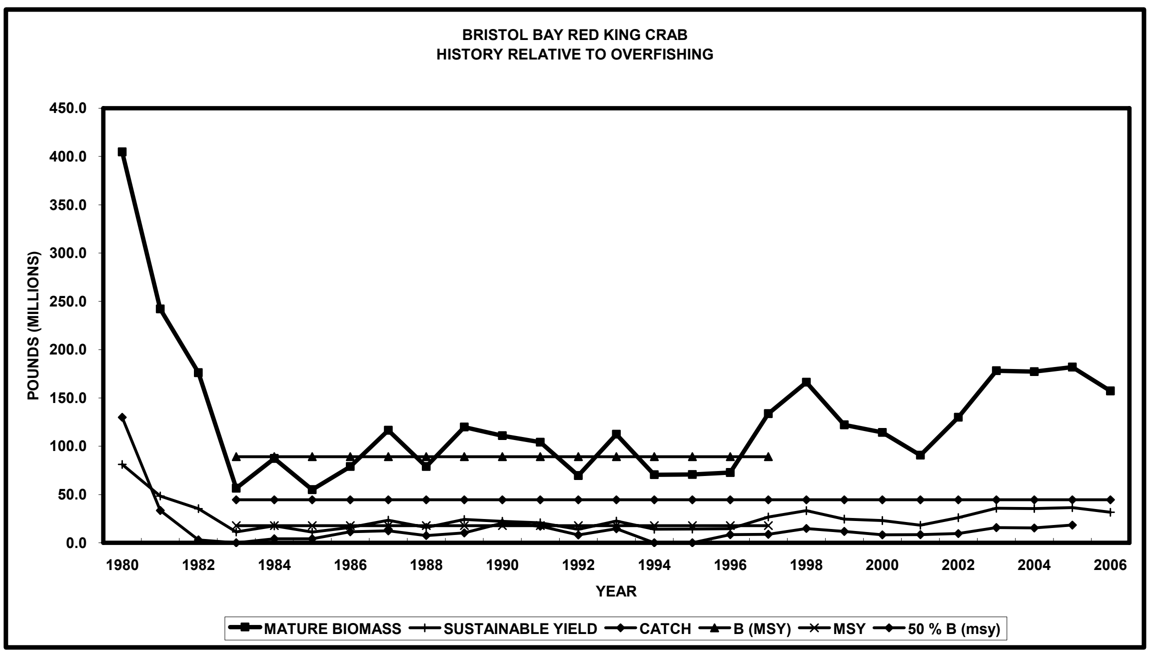

Figure 4-1 Bristol Bay Red King Crab stock status relative to overfishing

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 carapace length (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.

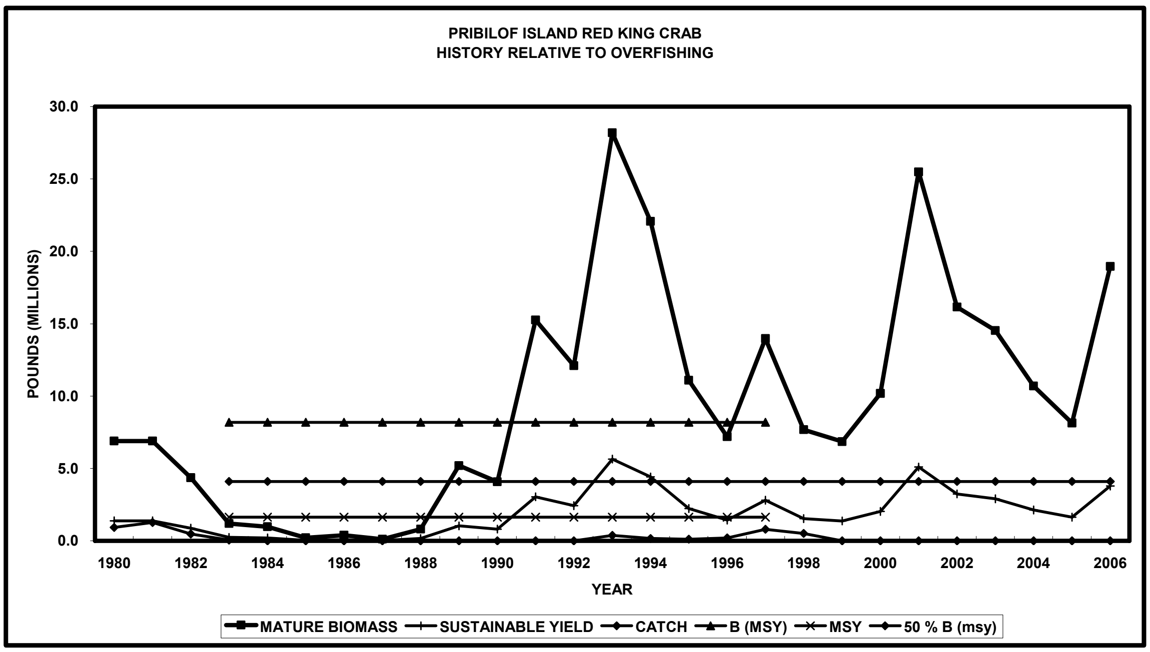

Figure 4-2 Pribilof District red king crab stock status relative to overfishing.

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[2]. 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 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.

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

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).

4.2 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.

4.2.1 Steepness parameter estimate

The Beverton-Holt and Ricker stock-recruitment (S-R) models were fitted to the Bristol Bay red king crab stock with MMB 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 4-4**.** The Ricker curves were more appropriate to these data sets than the Beverton-Holt curves (Chapter 3). 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 1.40-1.44. For stochastic simulations, a value of 1.41 was used based on the fit to the S-R data for *hm*=0.2.

4.2.2 B_{MSY} and proxy B_{MSY} estimate

The simulated Bristol Bay red king crab population with a maximum number of 29 million recruits produced a B_{MSY} of 74.79 million pounds (33,923 t) of MMB and a $B_{35\%}$ of 74.01 million pounds (33,569 t) of MMB for the Ricker S-R curve with the estimated steepness parameter value of 1.41. These B_{MSY} and $B_{35\%}$ values were used in the Tier 2-4 formulas for stochastic simulations.

4.2.3 $F_{x\%}$ estimate

The $F_{x\%}$ estimates for the Bristol Bay red king crab analysis for different handling mortality values were shown in Figure 4-5. 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 0.36, legal male harvest rate (at the time of the fishery) was 26%, and the mature male harvest rate (at the time of the survey, June 15) was 15%.

4.3 Effects on Bristol Bay red king crab

4.3.1 Comparison of status determination criteria

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) of TMB, with an MSST value of 44.8 million pounds (20,321 t) (Figure 4-1). The 2006 TMB, derived from survey area-swept estimate, is above B_{MSY} at 157.2 million pounds (71,305 t).

The Alternatives 2 and 3 Tier system estimates B_{MSY} differently by using MMB rather than TMB (which includes males and females), as discussed in Section 2.4.1. The Alternative 2 and 3 estimate of B_{MSY} is 74.79 million pounds (33,923 t) of MMB. 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.

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 (2,015 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 (2,015 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 (24,947 t)
- Mature harvest rate = 15%, if ESB is at least 55 million pounds (24,947 t)

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

For the status quo harvest strategy, abundances are estimated at the survey time using survey selectivity, and harvest rates are applied to molting MMB at the time of the survey.

Under Alternative 1, overfishing occurs when the TAC is above the estimated SY. The Bristol Bay red king crab TAC for the 2006/2007 fishery was 15.5 million pounds (7,031 t), which is below the 2006 SY of 31.44 million pounds (14,288 t).

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 and Table 2-2. 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. $F_{35\%}$ control rule) would constitute overfishing.

Under Alternatives 2 and 3 the recommended control rule for the Bristol Bay red king crab stock is $F_{35\%}$. 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.

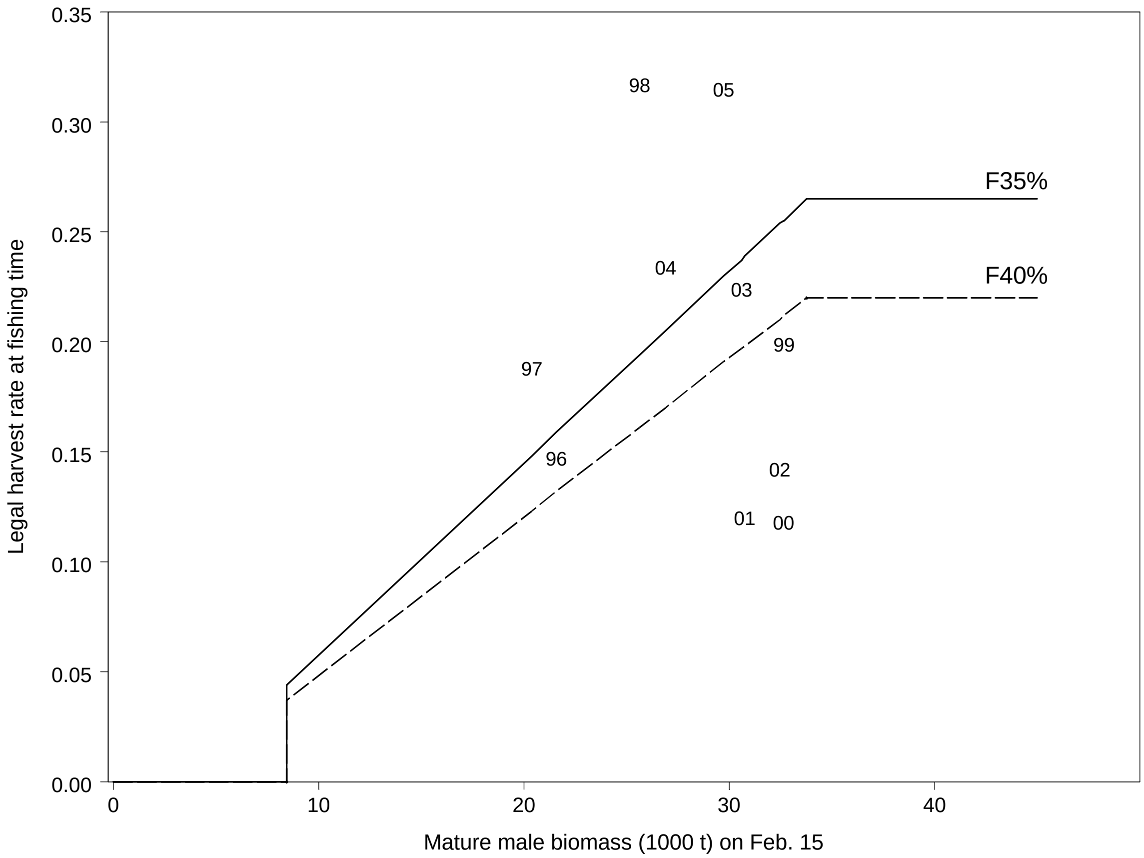

Figure 4-3 Relationships between legal harvest rate and mature male biomass on Feb. 15 for Bristol Bay red king crab. The dotted points are legal harvest rates from 1996 to 2005.

The change in currency from the total mature biomass (TMB) to mature male biomass (MMB) unit affected 'overfishing' and 'overfished' definitions for the Bristol Bay red king crab during 1985-2006 (Table 4-1). Under current FMP, the historical harvest has not exceeded OFL (overfishing level) and TMB has been above MSST (=50%B_{MSY}). TMB remained above B_{MSY} in the late 1990s and 2000s. Therefore, there have not been overfishing or overfished for this stock during this period under the current plan. On the other hand, the MMB did not exceed B_{MSY} even though an increasing trend was observed during this time period. Change in currency from TMB to MMB resulted in an overfished status in years 1985, 1986, 1993, and 1994 (Table 4-1). Under the proposed plan, F_{OFL} is affected by the change in currency as well as biological reference points: lower MMB than $B_{35\%}$ reduces F_{OFL} and proposed maximum F_{OFL} is much lower than the maximum legal fishing mortality resulted from 0.2 times TMB under the current plan. Under the proposed plan, almost all years before 1994 were overfishing, and in some years after 1995 were also overfishing due to proposed lower F_{OFL} and change in currency. Overall the differences in overfishing definitions for Bristol Bay red king crab are due to the change in currency and subsequent estimation of biological reference points.

Table 4-1 Comparison of total mature biomass (TMB) and mature male biomass used for current and proposed 'overfishing' and 'overfished' definitions for Bristol Bay red king crab. The biomasses are expressed in millions of pounds.

Year	TMB	$\%B_{MSY}$	Current OFL = SY	TAC	Feb 15 MMB	$\%B_{35\%}$	Proposed F_{OFL}
1985	54.98	61	11.00	4.17	25.12	34	0.10
1986	78.92	88	15.78	11.40	27.21	37	0.11
1987	116.40	130	23.28	12.29	37.57	51	0.16
1988	78.92	88	15.78	7.39	46.31	63	0.21
1989	119.93	134	23.99	10.26	55.38	75	0.26
1990	110.89	124	22.18	20.36	59.17	80	0.28
1991	104.08	117	20.82	17.18	50.10	68	0.23
1992	69.47	78	13.89	8.04	37.42	51	0.16
1993	112.43	125	22.49	14.63	33.88	46	0.14
1994	70.57	79	14.11	Closed	28.97	39	0.12
1995	70.61	79	14.12	Closed	43.90	59	0.20
1996	72.75	81	14.55	8.41	50.86	69	0.23
1997	133.60	149	26.72	8.76	47.57	64	0.22
1998	166.23	186	33.25	14.23	44.94	61	0.20
1999	122.13	136	24.43	11.09	56.50	76	0.27
2000	114.20	127	22.84	7.55	72.01	97	0.35
2001	90.61	101	18.12	7.79	71.97	97	0.35
2002	129.85	145	25.97	8.86	67.82	92	0.33
2003	178.13	199	35.63	14.53	71.55	97	0.35
2004	177.25	198	35.45	14.11	67.46	91	0.32
2005	181.88	203	36.38	18.51	59.32	80	0.28
2006	157.19	175	31.44	15.53	65.54	89	0.31

4.3.2 Sensitivity analysis of α and β

The mean 30th year B/B_{MSY} ratio and the mean next 20-yr mean yield increased as α and β values increased. The opposite was true for the mean first 10-yr mean yield. The stock either reached or exceeded B_{MSY} (or its proxy) in the 30th year for all combinations of α and β values. For the (α,β) combination of (0.1, 0.25) the mean first 10-yr mean yield was higher, but the mean next 20-yr mean yield was lower than under the (α,β) combination of (0.25, 0.25). Although higher (α, β) values tend to produce higher next 20-yr mean yields and 30th year B/B_{MSY} ratio, the differences in a number of performance statistics were not significant. Therefore, we chose the (α,β) combination of (0.1, 0.25) as a default for the Tier formulas (Tables 4-1 and 4-2).

4.3.3 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 Tiers 2 to 5. For analytical purposes, additional scenarios considered included a flat $F_{x\%}$, F = M, and F = 0. Performance statistics were 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 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.

The status quo harvest strategy was simulated following the harvest strategy in 5 AAC 34.816 (see section 4.3.1). 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 control rule 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 control rule is not used for TAC determination, but considered for determining whether the TAC exceeds the OFL. If the TAC exceeds the OFL, then it results in overfishing.

Table 4-3 lists the results of performance statistics for short-term (30 years) fishery simulations with initial MMB equal to 50% B_{MSY}. Fourteen harvest strategy scenarios were investigated: Tier 2 with the F_{MSY}, Tier 3 with $F_{35\%}$ and $F_{40\%}$,Tier 4 with two times 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 status quo harvest strategy, the status quo OFL control rule, 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 $F_{35\%}$ control rule 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 2 with F_{MSY} and Tier 3 with $F_{35\%}$ control rules. Thus, for red king crab stocks in Tier 4 with an M of 0.18, a γ value up to two 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 status quo harvest strategy. The harvests at the status quo OFL control rule performed worst of all, with a very low mean number of recruits, higher overfished percent, and lower 30th year relative MMB. The stock did not rebuild during this time period with fishing at the status quo OFL control rule. 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 4-5 provides the same performance statistics for the short-term (30 years) fishery when the initial MMB was set to B_{MSY}. The status quo OFL control rule performed the worst (low mean recruitment, low 30th year relative MMB, and no stock rebuilding) at this initial biomass level as well (i.e., stock depleted from the initial MSY level).

Table 4-6 and Table 4-7 list the same performance statistics as Table 4-4 and Table 4-5 respectively, but they were based on a long-term fishery (100 years). The status quo 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 status quo OFL control rule for the short-term fishery (Table 4-4 and Table 4-5), the yield dropped substantially under the long-term fishery scenario (Table 4-7). 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 Table 4-4 through 4-7 provide the non-fishery yields, which are mainly trawl bycatch yields. The results indicated that nearly 1.76 million pounds (800 t) of trawl bycatch was possible at B_{MSY} level under the selected maximum number of recruits (29 million crabs).

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 10% B_{MSY} with biomass observation error and harvest implementation error. 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	0.25, 0.25
Rebuilding time (y)[a]	26	26	25	27	27	26	23
Years overfished (%)[b]	48.9	48.4	48.0	53.6	51.8	49.6	45.8
Years fishery closed (%)[c]	24.7	24.5	24.5	26.4	25.8	25.1	24.2
30th year biomass ratio (%)[d]	96	97	98	94	96	98	103
First 10-yr mean retained yield (t)	203	184	162	334	285	230	82
CV first 10-yr mean retained yield	0.85	0.86	0.90	0.39	0.45	0.56	1.25
Next 20-yr mean retained yield (t)	4917	4945	4970	4323	4497	4708	5191
CV next 20-yr mean retained yield	0.20	0.20	0.20	0.22	0.22	0.21	0.21

[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 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 and harvest implementation error. 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	0.25, 0.25
Rebuilding time (y)[a]	13	12	12	13	12	12	11
Years overfished (%)[b]	5.8	5.6	5.4	5.8	5.6	5.4	4.6
Years fishery closed (%)[c]	0	0	0	0	0	0	0
30th year biomass ratio (%)[d]	104	104	104	104	104	104	106
First 10-yr mean retained yield (t)	3658	3609	3555	3658	3609	3555	3359
CV first 10-yr mean retained yield	0.23	0.24	0.25	0.23	0.24	0.25	0.29
Next 20-yr mean retained yield (t)	7883	7944	8013	7883	7944	8013	8299
CV next 20-yr mean retained yield	0.15	0.15	0.15	0.15	0.15	0.15	0.15

[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 4-4 Short-term rebuilding simulations 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 and harvest implementation error. 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=2*M CR)	Tier 5 Limit (Mean Catch)	Tier 5 Target (75%Mean Catch)	Status quo Harvest CR	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	26.0	26.7	25.9	26.7	26.5	26.0	23.6	25.7	25.8	16.1	24.2	24.1	27.1	25.0
Mean total yield (t)	7731	7084	7735	7086	7263	7731	6406	4930	6360	8646	7509	7529	5952	654
Mean retained yield (t)	6529	5990	6527	5988	6138	6529	5233	3985	5253	6726	6240	6254	4996	0
Mean mature male biomass (t)	31288	35150	30921	34834	33837	31288	26378	34699	33680	12958	26065	25878	40786	62353
Mean mature female biomass (t)	37359	38155	37250	38079	37894	37359	34510	36718	36774	28295	35328	35262	38903	39349
Mean F	0.28	0.22	0.29	0.23	0.24	0.28	0.35	0.20	0.25	0.95	0.36	0.364	0.16	0
Rebuilding time (y)[a]	12	10	12	10	11	12	21	14	13	NR	20	0.20	9	7
Years B< B_{MSY} (%)[b]	68.0	53.7	69.3	54.8	58.2	68.0	80.8	58.7	62.4	100.0	85.2	85.8	38.9	25.5
Years overfished (%)[c]	5.1	3.8	5.4	3.9	4.2	5.1	21.8	9.8	7.0	87.6	14.0	14.4	2.9	1.6
Years fishery closed (%)[d]	0	0	0	0	0	0	0	0	0	NA	0	0	0	0
30th year biomass ratio (%)[e]	106	123	104	122	118	106	109	159	134	31	91	90	150	250
First 10-yr mean retained yield (t)	3475	2864	3555	2933	3082	3475	5213	3999	3444	7814	4714	4749	2114	0
CV first 10-yr mean retained yield	0.26	0.26	0.25	0.25	0.25	0.26	0.03	0.03	0.20	0.09	0.13	0.13	0.26	0
Next 20-yr mean retained yield (t)	8056	7554	8013	7516	7667	8056	5242	3978	6157	6182	7003	7007	6437	0
CV next 20-yr mean retained yield	0.15	0.14	0.15	0.14	0.14	0.15	0.02	0.02	0.24	0.16	0.15	0.15	0.12	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 Short-term rebuilding simulations 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 BMSY with biomass observation error and harvest implementation error. B = total mature male biomass, BMSY = 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=2*M CR)	Tier 5 Limit (Mean Catch)	Tier 5 Target (75%Mean Catch)	Status quo Harvest Strategy	Status quo OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	27.5	28.2	27.5	28.1	28.0	27.5	28.2	27.8	27.9	21.1	27.0	27.0	28.4	25.2
Mean total yield (t)	9873	8904	9907	8927	9183	9873	6287	4894	8841	12850	10112	10152	7376	774
Mean retained yield (t)	8337	7529	8362	7547	7764	8337	5180	3906	7390	10354	8510	8541	6196	0
Mean mature male biomass (t)	36054	40681	35768	40474	39278	36054	48938	54676	38720	20028	34004	33792	47419	73132
Mean mature female biomass (t)	45478	46315	45412	46280	46094	45478	46885	47120	45666	39688	44992	44939	46986	46199
Mean F	0.32	0.26	0.33	0.26	0.27	0.32	0.15	0.10	0.29	0.87	0.36	0.364	0.18	0
Rebuilding time (y)[a]	2	1	2	1	1	2	1	1	1	NR	2	2	1	0
Years B<B_{MSY} (%)[b]	50.5	33.4	51.8	34.1	38.0	50.5	18.1	11.6	40.2	98.4	59.1	59.9	17.2	4.4
Years overfished (%)[c]	0.4	0.1	0.4	0.1	0.2	0.4	0	0	0.2	40.2	1.2	1.2	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]	106	123	105	123	118	106	170	193	116	39	99	99	149	232
First 10-yr mean retained yield (t)	8121	6656	8212	6721	7077	8121	5205	3945	6850	13536	8680	8749	4871	0
CV first 10-yr mean retained yield	0.13	0.13	0.13	0.13	0.13	0.13	0.03	0.02	0.11	0.08	0.10	0.10	0.13	0
Next 20-yr mean retained yield (t)	8445	7966	8437	7960	8107	8445	5168	3886	7660	8763	8425	8437	6859	0
CV next 20-yr mean retained yield	0.14	0.14	0.14	0.13	0.13	0.14	0.02	0.02	0.12	0.14	0.13	0.13	0.12	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 4-6 Long-term rebuilding simulations 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% BMSY with biomass observation error and harvest implementation error. B = total mature male biomass, BMSY = 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=2*M CR)	Tier 5 Limit (Mean Catch)	Tier 5 Target (75%Mean Catch)	Status quo Harvest Strategy	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	27.0	27.8	27.0	27.8	27.6	27.0	26.5	26.6	27.2	19.0	25.8	25.8	28.1	24.6
Mean total yield (t)	9290	8724	9284	8727	8892	9290	6254	4836	8133	7962	9014	9018	7520	774
Mean retained yield (t)	7861	7412	7851	7412	7546	7861	5154	3869	6816	6410	7557	7557	6370	0
Mean mature male biomass (t)	34728	40045	34355	39788	38390	34728	46584	56435	41734	16618	30596	30317	47943	75459
Mean mature female biomass (t)	42779	44240	42633	44173	43854	42779	42570	43533	43058	30165	40717	40578	45140	41208
Mean F	0.31	0.25	0.32	0.25	0.27	0.31	0.20	0.11	0.26	0.63	0.36	0.364	0.17	0
Rebuilding time (y)[a]	12	10	12	10	10	12	21	14	13	NR	20	20	9	7
Years B<B_{MSY} (%)[b]	55.6	36.3	57.2	37.2	41.8	55.6	32.3	18.5	39.2	99.8	71.0	72.0	18.3	7.7
Years overfished (%)[c]	1.8	1.2	1.9	1.2	1.3	1.8	7.0	2.6	2.2	61.2	5.8	6.0	0.8	0.5
Years fishery closed (%)[d]	0	0	0	0	0	0	0	0	0	NA	0	0	0	0
100th year biomass ratio (%)[e]	105	122	103	121	117	105	175	193	129	46	99	99	147	234

[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 4-7 Long-term rebuilding simulations 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 and harvest implementation error. 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=2*M CR)	Tier 5 Limit (Mean Catch)	Tier 5 Target (75%Mean Catch)	Status quo Harvest Strategy	OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	27.5	28.2	27.4	28.2	28.0	27.5	27.8	27.2	27.9	20.4	26.7	26.7	28.4	24.7
Mean total yield (t)	9932	9269	9935	9279	9468	9932	6182	4814	9074	9283	9869	9880	7944	808
Mean retained yield (t)	8402	7871	8400	7878	8033	8402	5107	3834	7611	7536	8300	8306	6727	0
Mean mature male biomass (t)	36156	41698	35808	41476	40019	36156	57050	63108	39375	18989	33204	32921	49919	78544
Mean mature female biomass (t)	45256	46720	45128	46669	46353	45256	47090	46450	45827	34150	44006	43880	47576	43221
Mean F	0.32	0.26	0.33	0.26	0.28	0.32	0.12	0.08	0.29	0.63	0.36	0.364	0.18	0
Rebuilding time (y)[a]	2	1	2	1	1	2	1	1	1	NR	2	2	1	0
Years $B<B_{MSY}$ (%)[b]	50.4	30.2	51.9	31.0	35.8	50.4	7.3	4.1	38.5	98.9	62.4	63.5	11.8	1.3
Years overfished (%)[c]	0.5	0	0.5	0.1	0.1	0.5	0	0	0.2	45.9	1.8	2.0	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]	105	122	103	121	117	105	176	193	114	47	99	99	147	234

[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

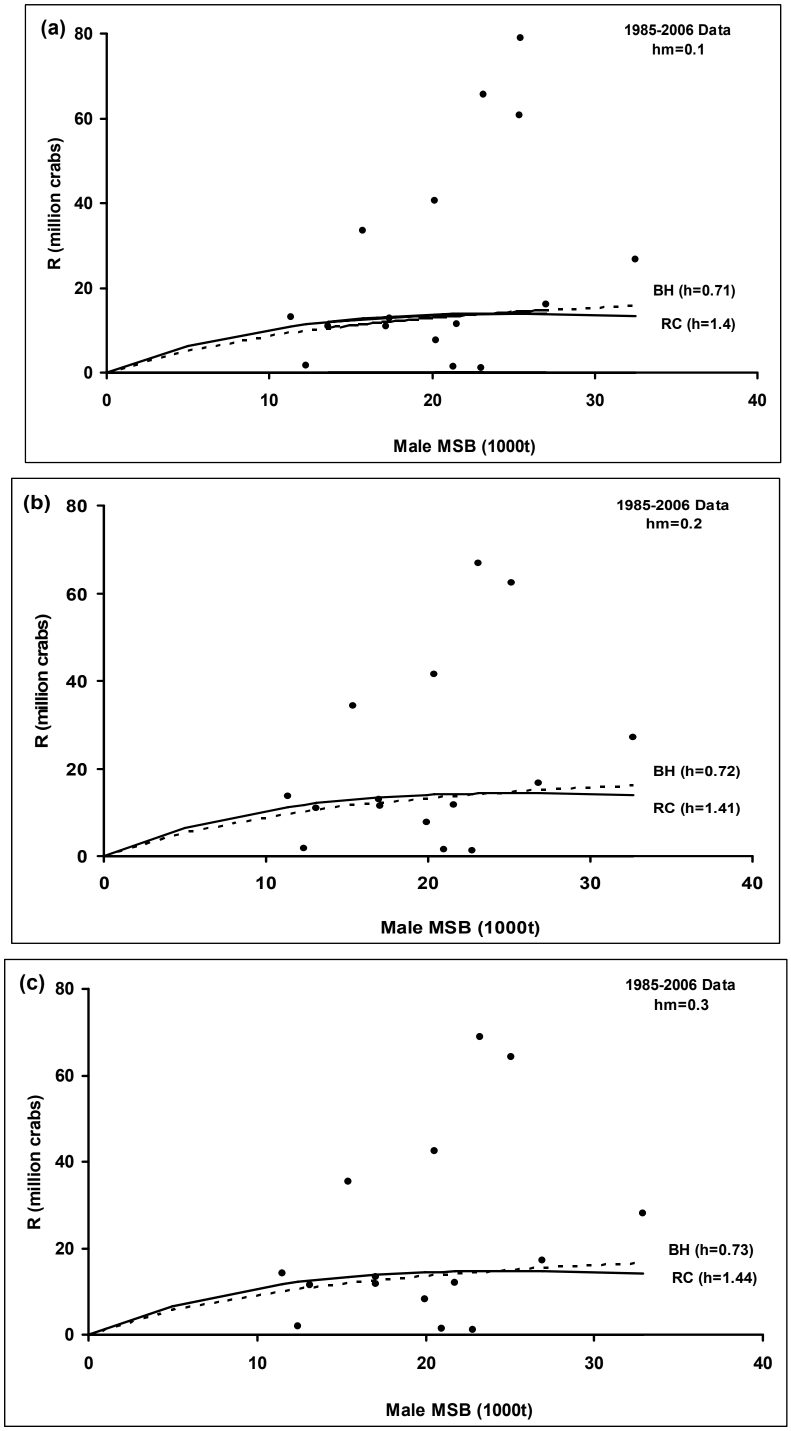

Figure 4-4 Stock-recruitment fit for the Bristol Bay red king crab 1985-2006 data assessed at M = 0.18 and handling mortality, hm (a) 0.1, (b) 0.2, and (c) 0.3. The steepness parameters, h, are given in parentheses. BH = Beverton and Holt curve, RC = Ricker curve.

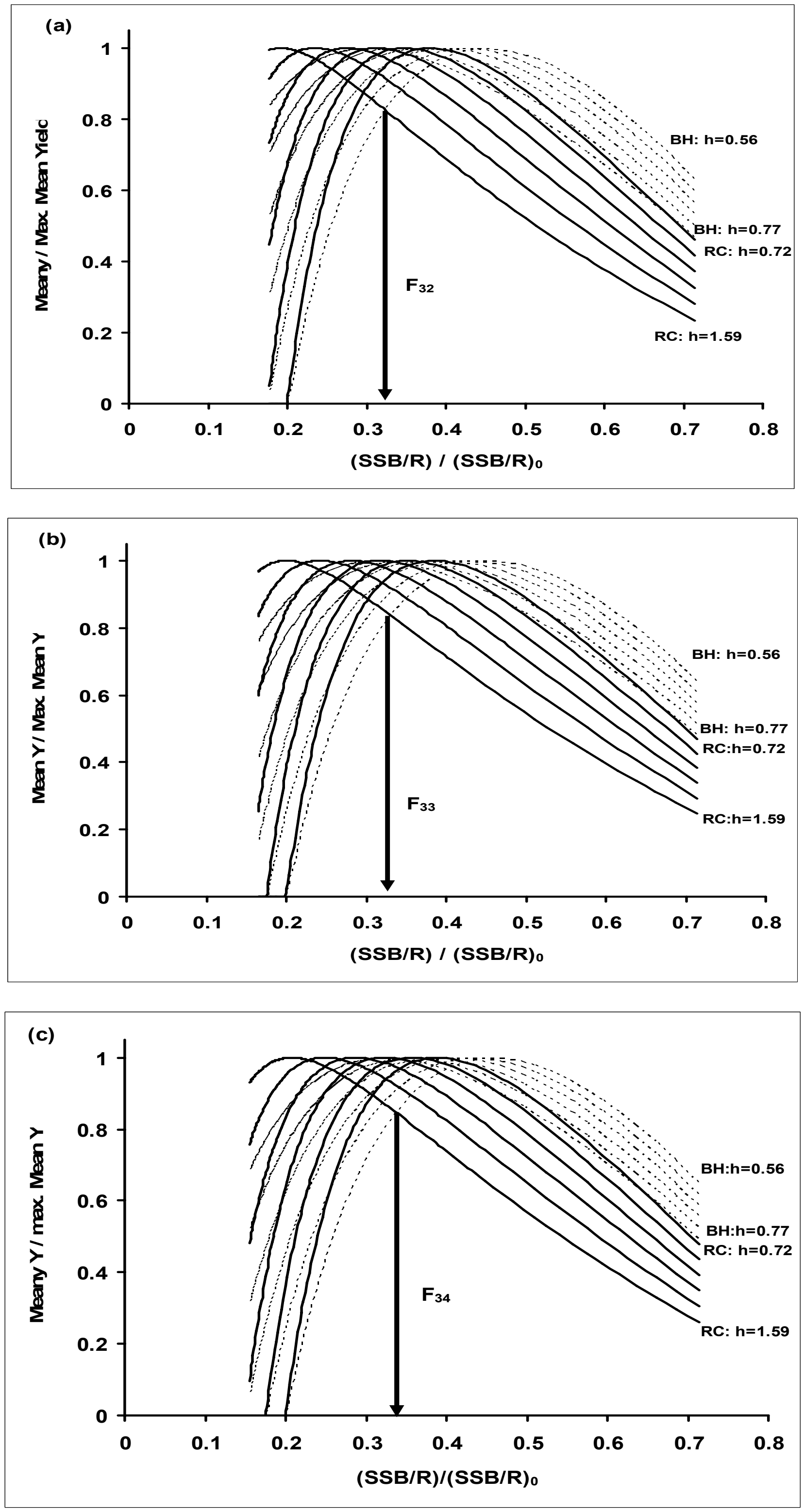

Figure 4-5 Approximate locations of spawning potential ratio ($F_{x\%}$) by equilibrium yield method for different handling mortality rates: (a) 0.1, (b) 0.2, and (c) 0.3 for red king crab. Solid lines: Ricker S-R model, dotted lines: Beverton-Holt S-R model.

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 (Tables 4-4 through 4-7) 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 could be beneficial to data poor stocks.

4.3.4 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 MMB estimates of fishing under the Alternative 2 and 3 proposed control rules ($F_{40\%}$ and $F_{35\%}$) compared to the status quo harvest strategy and fishing at the status quo OFL control rule (Table 4-8). Starting at the estimated abundance in 2006 and with estimated parameters, short-term projections using the status quo harvest strategy, fishing at the status quo OFL control rule, $F_{40\%}$, and $F_{35\%}$ harvest control rules for 2007 to 2012 were made for Bristol Bay red king crab (Table 4-8). The 2006 catch was set according the status quo harvest strategy for all scenarios. Recruitment was projected by an estimated S-R curve. Because the annual MMB is projected above $B_{35\%}$ 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 status quo 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 $F_{35\%}$. Fishing at the status quo OFL control rule resulted in much higher fishing mortality, higher catch, and lower mature male biomass on February 15 than those by the status quo harvest strategy, $F_{40\%}$, and $F_{35\%}$ harvest control rules.

Table 4-8 Short-term projections using $F_{40\%}$, $F_{35\%}$, and the status quo harvest control rules for 2007 to 2012 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 estimated S-R curve. Catch and biomass are in 1000 t.

Year	Retained Catch	F	Survey Time Mature Male Bio.	Survey Time Mature Female Bio.	Feb 15 Mature Male Bio.
Status quo harvest strategy					
2006	7.043	0.296	46.870	51.339	29.728
2007	8.341	0.340	53.080	59.919	34.448
2008	10.709	0.392	66.952	62.160	38.353
2009	11.252	0.330	73.196	62.201	47.996
2010	10.642	0.276	70.869	61.832	53.131
2011	10.073	0.260	67.262	61.297	51.904
2012	9.627	0.258	63.983	60.487	49.357
$F_{40\%}$					
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	62.213	39.481
2009	10.747	0.290	76.740	62.365	51.382
2010	11.877	0.290	74.604	62.030	56.807
2011	11.514	0.290	69.314	61.463	53.999
2012	10.699	0.290	64.308	60.601	49.760
$F_{35\%}$					
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	62.139	37.980
2009	12.200	0.360	73.761	62.215	48.556
2010	13.202	0.360	70.347	61.813	52.671
2011	12.492	0.360	64.133	61.187	48.895
2012	11.377	0.360	58.697	60.275	44.187
Status quo OFL control rule					
2006	7.043	0.296	46.870	51.339	29.728
2007	15.577	0.758	53.080	59.919	34.448
2008	15.783	0.879	58.904	61.730	30.944
2009	16.012	0.783	59.415	61.265	35.240
2010	15.375	0.738	52.587	60.475	35.726
2011	14.151	0.792	45.401	59.566	30.735
2012	12.891	0.893	39.717	58.365	25.676

4.4 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 based on the simulation study of Bristol Bay red king crab was set to 2.0 for these Tier 4 stocks. The γ value is frameworked and will be derived each year based the M value and estimated F_{OFL} for Bristol Bay red king crab.

Pribilof District red king crab

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 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 4-6 and Table 3-1 provides estimated MMB and B_{MSY} proxy and MSST proxy (½ B_{MSY}) for the Pribilof Island red king crab stock. Average abundance from 1988 to 2006 was used for a proxy for this stock because model estimates of biomass were not available before 1988.

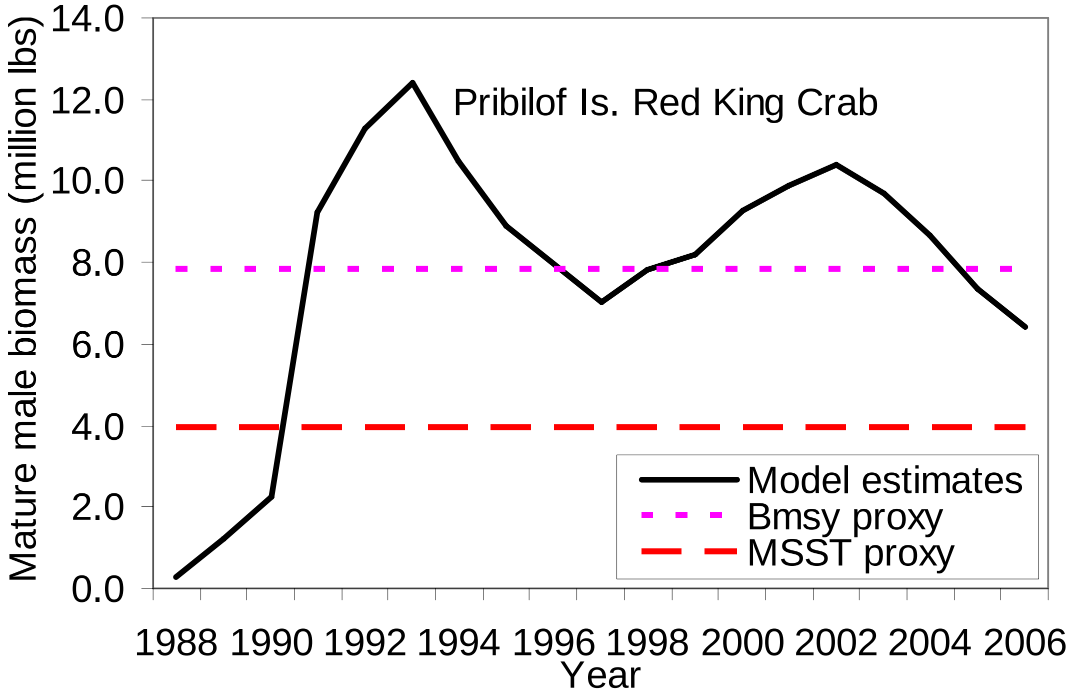

Figure 4-6 Pribilof Islands red king crab estimated mature male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

Stock status for this stock under Alternatives 2 and 3, as shown in Figure 4-6, results in a different status determination than under the status quo (Alternative 1) determination. Under Alternative 1, as shown in Figure 2-1, the TMB is well above the B_{MSY} for this stock. In contrast, Figure 4-6 for Alternatives 2 and 3 indicate that this stock would not only be considered well below B_{MSY} proxy. 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 4-7. 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.

The change in currency from the current total mature biomass to the proposed mature male biomass does not affect the overfished definitions greatly for Pribilof Islands red king crab (Figure 4-8). After 1987, under the current definition, the stock was overfished in 1988 and 1990 whereas the stock would have been overfished in 1988, 1989 and 1990 under the proposed definition. The difference may mainly be due to survey measurement errors of total mature biomass, which was directly based on area-swept estimates. The mature male biomass used for the Tier 4 OFL was derived from a catch-survey model. Another big difference between the current B_{MSY} and the Tier 4 B_{MSY} proxy is that the former was based on the biomass from 1983 to 1997 when the biomass was low, and the later was based on the biomass from 1983 to 2006, including all years with a high biomass. There may be a big difference between the current overfishing rates (F_{OFL}) and the proposed rate due to a change in the biological reference point for Pribilof Islands red king crab (Figure 4-8). The current F_{OFL} is applied to both mature male and female crabs whereas the Tier 4 F_{OFL} is for legal males only, and the default M for the proposed biological points is 0.18, as opposed to 0.2 used in the current definitions. For legal males, the proposed F_{OFL} should be more conservative than the current overfishing rate. Overall, for this stock, the difference in F_{OFL} between the current and proposed definitions may mainly be due to a change in the biological reference point.

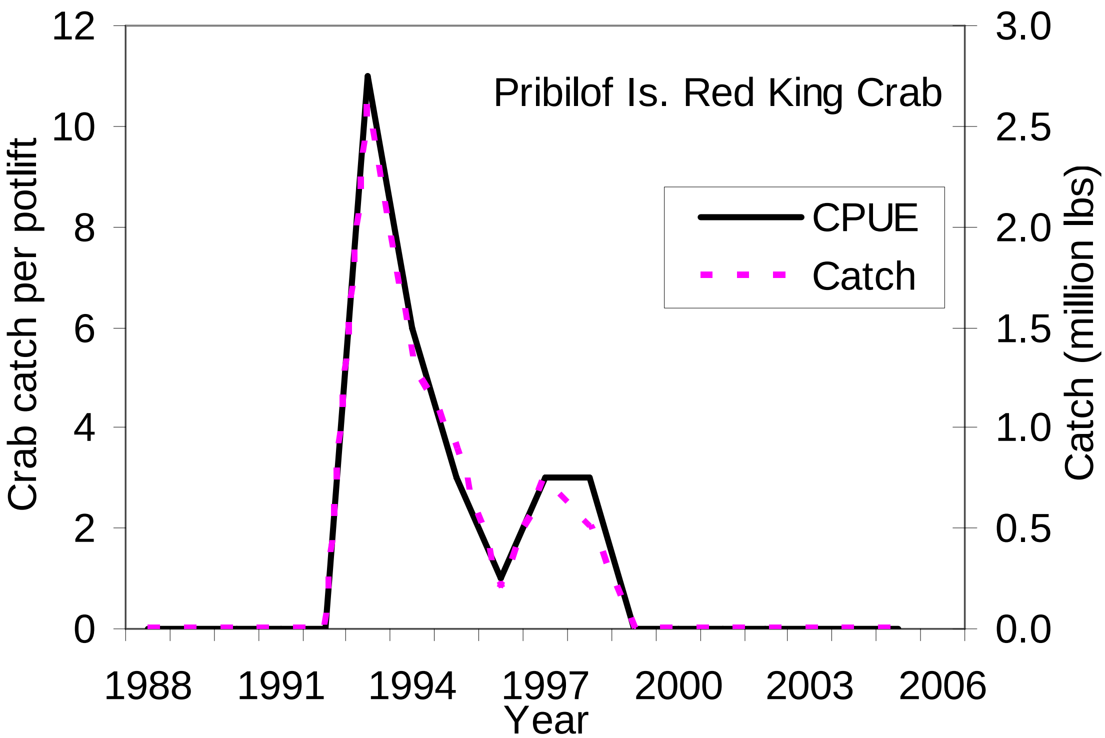

Figure 4-7 Catch and catch per potlift for Pribilof Islands red king crab.

Other red king crab stocks

All stocks except Norton Sound red king crab are currently closed to directed fishing due to depressed stock conditions.

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.

Figure 4-9 and Table 3-5 provide estimated MMB (>93 mm CL) and B_{MSY} proxy and MSST proxy (1/2 B_{MSY}) for the Norton Sound red king crab stock. Model estimated MMB is well above the B_{MSY} proxy for this stock. The current State of Alaska harvest strategy for Norton Sound red king crab has lower harvest rates than that resulted from $\gamma = 2.0$ and $M = 0.18$ when the stock abundance is above B_{MSY}. A tri-annual trawl survey is conducted on Norton Sound red king crab. A length-based model is used for stock assessments for Norton Sound red king crab. 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 4-10).

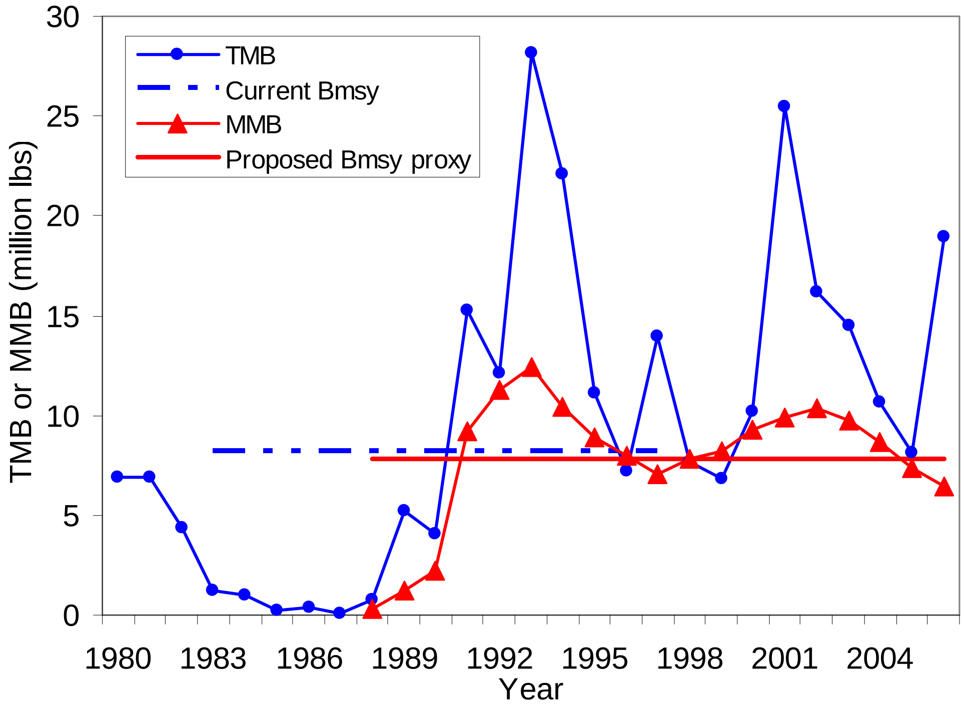

Figure 4-8 Comparison of total mature biomass and mature male biomass used for the current and proposed overfishing/overfished definitions for Pribilof Islands red king crab.

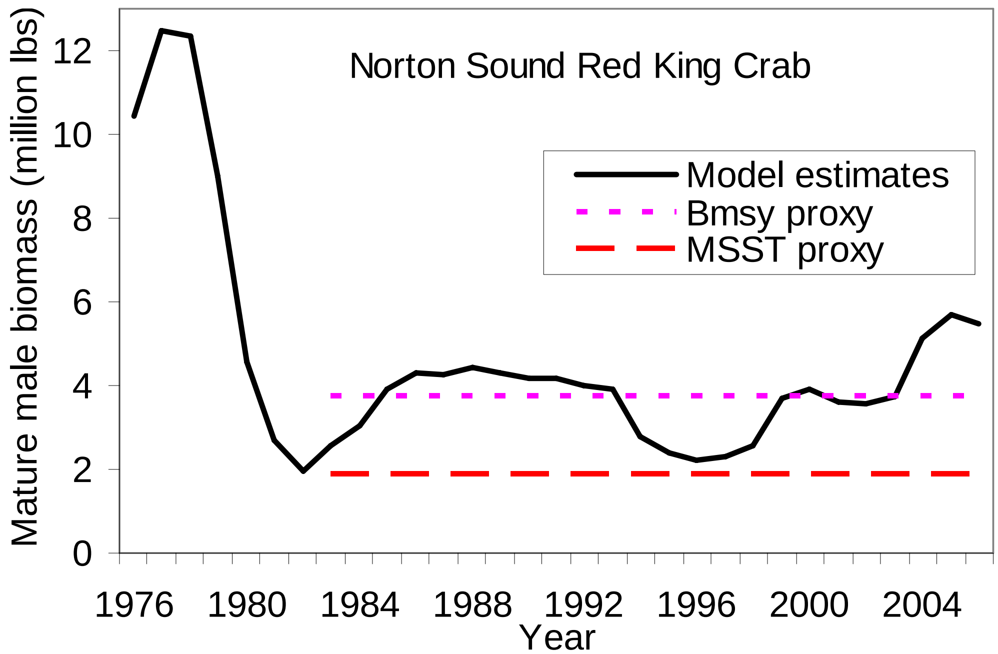

Figure 4-9 Norton Sound estimated legal male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

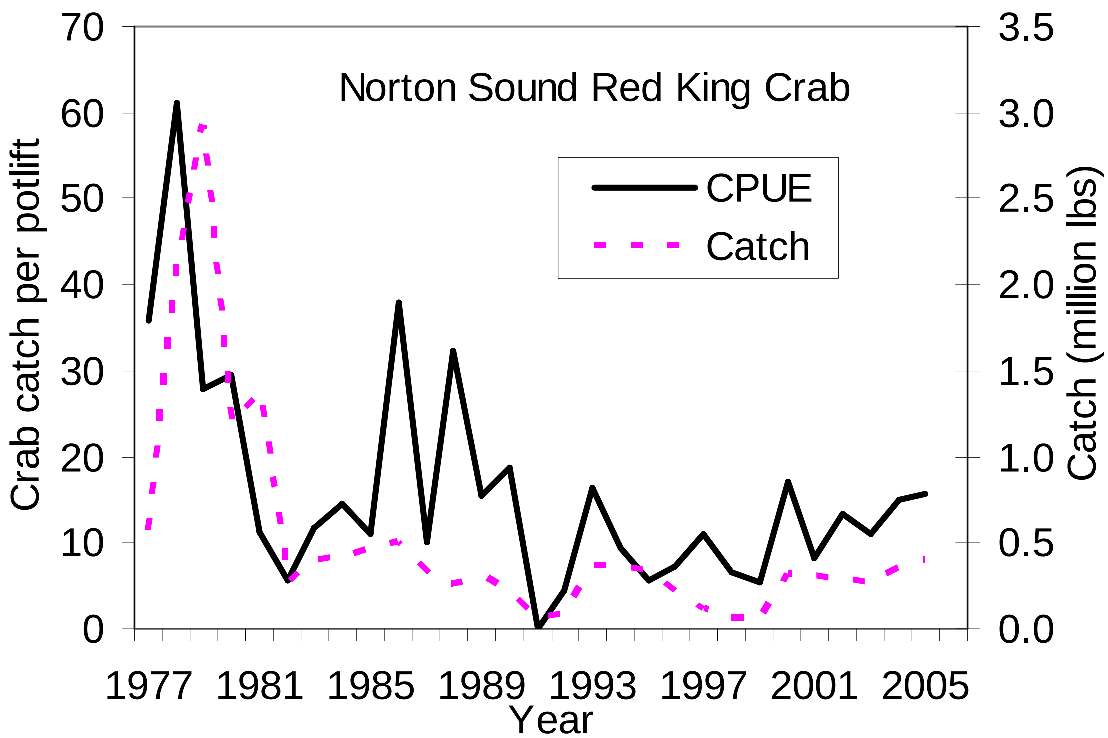

Figure 4-10 Catch and catch per pot lift for Norton Sound red king crab.

The Dutch Harbor red king crab stock has been extremely depressed during the last two decades, and the fishery has been closed since 1983. A trawl survey has been conducted on Dutch Harbor red king crab for most years. No models have been developed for Dutch Harbor red king crab. The new overfishing definitions would not have any impact on this stock in the near future because no fishery is predicted.

Adak red king crab is preliminarily placed in Tier 5 for purposes of this analysis. No stock assessment model has been developed for this stock. The Adak red king crab stock is depressed. This stock has only been opened to fish in the very small Petrel Banks area for four years during the last 10 years. The historic average yield has been high, with the highest annual catch of 21 million pounds in 1964. However, the average yield from 1985 to 1994 is only 947,900 pounds (430 t). The OFL could be set as 947,900 pounds (430 t), if average catch is chosen as the means to establish an OFL for this stock (Figure 4-11). This stock could be promoted to Tier 4 if routine surveys are conducted.

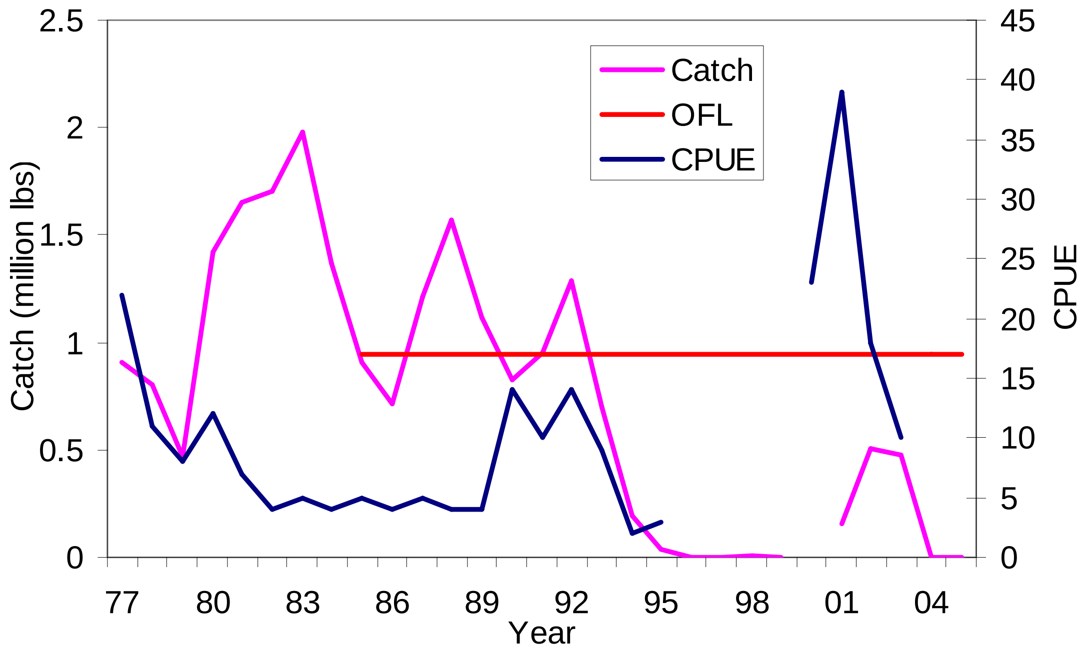

Figure 4-11 Adak red king crab historic catch compared to the suggested OFL under Alternatives 2 and 3.

5 Snow crab (*Chionoecetes opilio*)

One stock of snow crab is managed under this FMP. This Chapter reviews the stock status, 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.

5.1 Snow crab stock status

This stock is annually surveyed by NMFS. The survey TMB estimate for this stock in 2006 was 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 in 1999. The estimated TMB in 2006 remains below the rebuilt level (it is 59% of the "rebuilt" level of 921.6 million pounds (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 5-1). Since 1999, however, 2006 represents the first year that estimated TMB has been above MSST for 2 years in a row.

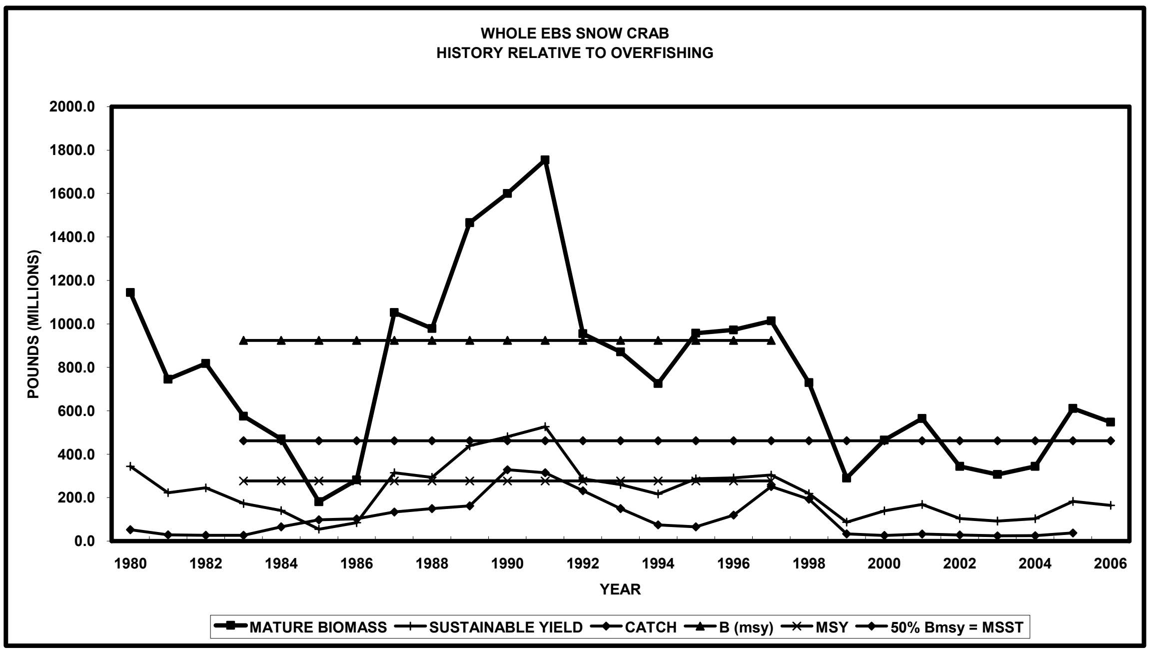

Figure 5-1 Snow crab stock status relative to overfishing.

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).

5.2 Effects on Snow Crab

5.2.1 Comparison of status determination criteria

Under Alternative 1, the snow crab stock was declared overfished in 1999 and has been under a rebuilding plan since this time period. The Alternative 1 status determination criteria for snow crab establish a B_{MSY} value of 921.6 million pounds (418,035 t) of TMB, 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. 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 consecutive years.

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,

$$OFL = SY = 0.3 * TMB,$$

where SY is the retained catch (total catch less discards) and TMB = males plus females.

The snow crab TAC for the 2006/2007 fishery was 36.6 million pounds (16,602 t), which is below the 2006 SY of 164.5 million pounds (74,617 t). 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 $F_{35\%}$.

In conjunction with the rebuilding plan, the harvest strategy for snow crab was modified in 2000 to allow for greater probability of rebuilding the depleted stock. 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 TMB.

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 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.

Under Alternative 2 and 3, B_{MSY} for snow crab is measured in MMB only, as discussed in Section 2.4.1. This long-term B_{MSY} estimate for the stock is 413.36 million pounds (187,500 t) of MMB. An MSST value for this stock would be estimated as ½ B_{MSY}. The 2006 mature male biomass estimate for 2006 is 210.98 million pounds (95,700 t). This is just above the MSST value for this stock.

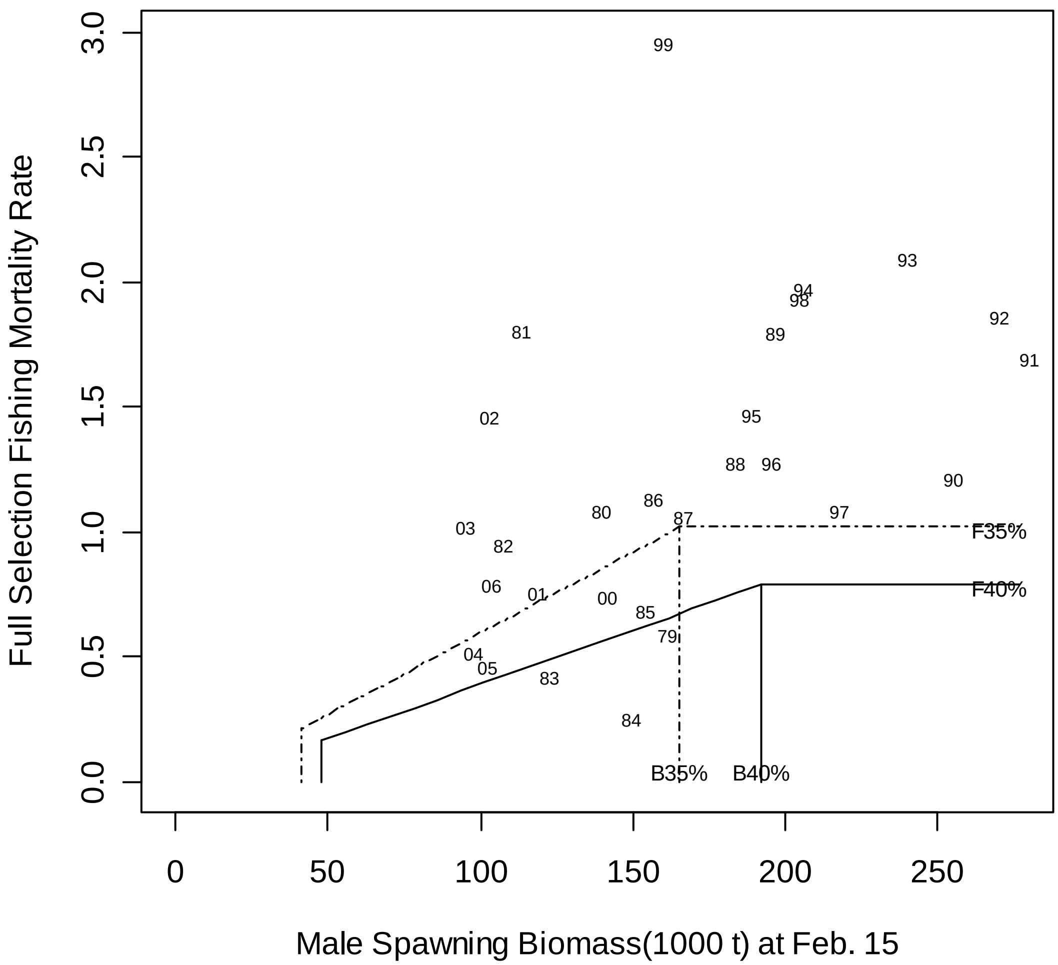

Figure 5-2 Full selection fishing mortality rate and male spawning biomass at February 15 estimated from the snow crab stock assessment model (Turnock and Rugolo 2006 Crab SAFE).

Under Alternatives 2 and 3, 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 and Table 2-2. Figure 5-2 shows the historical harvest rates and mature male biomass in conjunction with proposed $F_{35\%}$ and $F_{40\%}$ control rules under Alternatives 2 and 3. The recommended control rule for the snow crab stock is $F_{35\%}$ (see following section 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.

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}.

Bmsy under alternative 1 is estimated as the average of the survey total mature biomass (males and females) from 1983 to 1997. Mature male biomass at the time of mating is used in the control rules for alternatives 2 and 3. Mature male biomass per recruit at the time of mating is used with the average recruitment estimated from the stock assessment models to estimate B35% and a proxy for Bmsy. The 2006 total survey mature biomass was 59% of the Bmsy for alternative 1 (418,900 t). Under alternatives 2 and 3, the 2006 MMB was 58% of B35% (160,900 t). If mature male biomass at the time of the fishery estimated from the snow crab stock assessment model were used with the status quo control rule (0.3 * biomass), the OFL in terms of retained catch averaged about 62% of the status quo OFL (0.3*TMB) (Table 5-1). Mature male biomass at the time of the fishery is used for the control rule because the values of MMB at Feb 15 have the observed catch removed and would not represent the OFL for that year. While the retained catch was not restricted in any year with the status quo OFL, the OFL using mature male biomass at the time of the fishery was lower than the retained catch in 1990 to 1992 and 1997 to 1998. If mature male biomass were used historically to set the OFL, a different time series of catches and biomass values may have occurred.

Table 5-1 Snow crab total survey mature biomass (1000s tons) and mature male biomass at time of mating and at the beginning of the fishery estimated from the stock assessment model.

		From stock assessment				Observed
	Total survey mature biomass	MMB (Feb 15 year +1)	MMB at time of fishery	0.3*MMB at time of fishery	SY (0.3*TMB)	Retained Catch
1980	519.0	105.6	135.0	40.5	155.7	30.4
1981	338.0	97.0	109.4	32.8	101.4	13.3
1982	371.0	106.5	116.9	35.1	111.3	11.9
1983	261.0	128.1	138.9	41.7	78.3	12.2
1984	213.2	130.9	158.0	47.4	64.0	30.0
1985	82.3	132.7	172.4	51.7	24.7	44.5
1986	127.6	142.7	182.6	54.8	38.3	46.3
1987	477.0	159.0	211.4	63.4	143.1	61.5
1988	444.0	169.2	228.3	68.5	133.2	67.9
1989	665.0	221.2	282.6	84.8	199.5	73.6
1990	726.0	243.8	367.8	110.3	217.8	149.4
1991	796.0	235.4	357.6	107.3	238.8	143.3
1992	433.0	208.2	303.3	91.0	129.9	104.9
1993	395.0	177.4	236.8	71.0	118.5	68.1
1994	329.0	162.5	194.0	58.2	98.7	34.2
1995	434.0	168.2	195.2	58.6	130.2	29.9
1996	441.0	190.1	235.4	70.6	132.3	54.3
1997	460.0	178.0	271.9	81.6	138.0	114.6
1998	331.0	136.7	211.9	63.6	99.3	88.3
1999	131.6	120.6	133.9	40.2	39.5	15.1
2000	211.2	100.1	110.9	33.3	63.4	11.5
2001	256.0	85.9	100.3	30.1	76.8	14.9
2002	156.2	78.8	90.2	27.1	46.9	12.9
2003	139.4	80.9	90.1	27.0	41.8	10.8
2004	155.9	85.0	95.4	28.6	46.8	11.8
2005	277.0	86.2	101.7	30.5	83.1	16.8
2006	248.4	92.9	112.6	33.8	74.5	16.8

5.2.2 Sensitivity analysis of α and β

Various combinations of the α (0, 0.05, 0.1, 0.25) and β (0, 0.25) parameters of the control rule were used to evaluate short-term performance and rebuilding (Table 5-2 and Table 5-3). The F_{MSY} control rule was used for all simulation runs. The rebuilding time starting at 10% B_{MSY} was 26 years for α = 0.1 and β = 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 α = 0.25 (β = 0.25, however, not needed), rebuilding time was 25 years, fishery closures were lower than other scenarios with β = 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 α and β values considered when rebuilding from 50% B_{MSY} (Table 5-2). The scenario with α = 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 (α = 0.1 and β = 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 5-2). 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.

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

The impact of fishing at the status quo OFL control rule 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 status quo OFL control rule and the status quo harvest strategy. Table 5-4 through Table 5-9 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 Tier3 with $F_{35\%}$ control rule. The Alternative 1 scenarios include the status quo harvest strategy and fishing at the status quo OFL control rule. 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 (2001) 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.

5.2.3.1 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 (Table 5-10 and Table 5-11). Long-term (100 years) simulation results estimated F_{MSY} at 1.0 and B_{MSY} (MMB at mating time) at 391.98 million pounds (177,800 t) (Table 5-5) using a Beverton and Holt S-R curve with steepness 0.68 and $R_{MAX} = R_0 = 2.0$ 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 t) were estimated using ½ mean estimated recruitment from the stock assessment model (0.63 billion) and MMB 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 status quo OFL control rule results in mean MMB 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 MMB, 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).

5.2.3.2 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 (Tables 5-6 and 5-7).

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 status quo OFL control rule, which did not rebuild the stock (Table 5-7). 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 (α=0.1 and β=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} (MMB at mating time) at 413.36 million pounds (187,500 t) (Table 5-7) 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 MMB 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 5-3 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 MMB 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 5-9). The 2007 fishery catch was fixed for all scenarios at 37.04 million pounds (16,800 t). Fishing at the status quo OFL control rule, catch is almost 3 times the $F_{35\%}$ 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 MMB for 100 year simulations using the status quo OFL control rule was 16% of B_{MSY} (Table 5-7). 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 5-9 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 5-2 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 5-3 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 5-4 25% discard mortality. Short-term rebuilding simulations for snow crab, 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 5-5 25% discard mortality. Long-term simulations for snow crab, 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 constant 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 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 5-6 50% discard mortality. Short-term rebuilding simulations for snow crab, 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 5-7 50% discard mortality. Long-term simulations for snow crab, 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 5-8 Short-term rebuilding simulations for snow crab, 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 rate, Beverton-Holt h=0.68, and Female 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 5-9 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, $F_{35\%}$, $F_{40\%}$, 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	$F_{35\%}$ CR retained catch	$F_{35\%}$ CR MMB	$F_{40\%}$ CR retained catch	$F_{40\%}$ 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

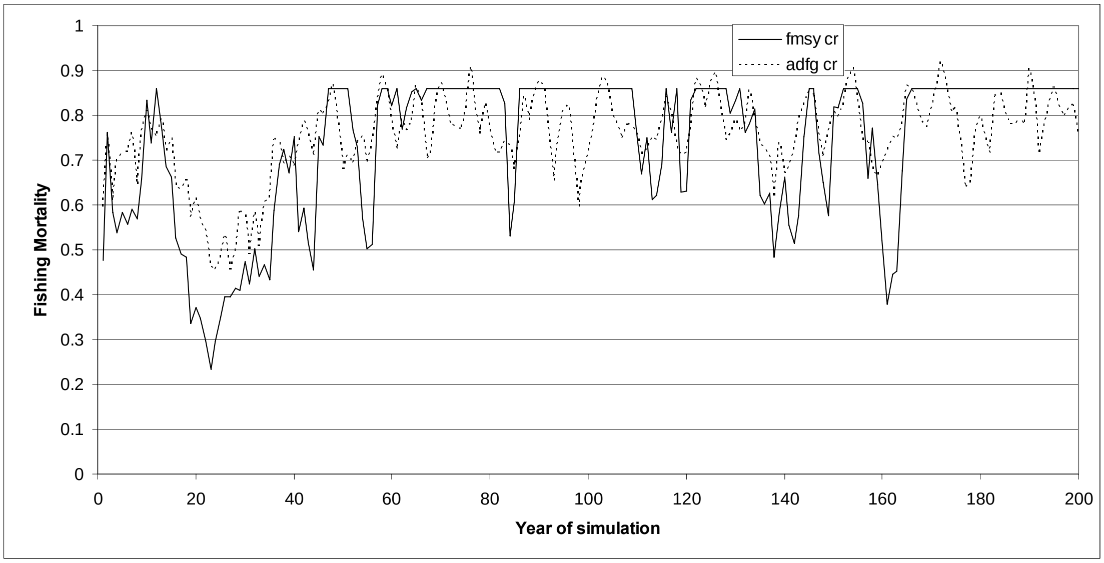

Figure 5-3 Comparison of snow crab fishing mortality estimated each year using the status quo harvest strategy CR and the F_{MSY} CR for one simulation run of 200 years, using the 50% discard mortality model

5.2.3.3 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% handling 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 (11th to 30th years) were similar to long-term averages, at 5.5% lower for 60% handling mortality than 25% handling mortality (Table 5-10 and Table 5-11).

Table 5-10 Long-term (100-yr) simulation for snow crab 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 5-11 Short-term (30 years) simulation for snow crab 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 5-4 shows the range of S-R models used to determined $F_{x\%}$ for different handling mortality values (0.25, 0.4, 0.5, 0.6), using Clark's method for a steepness (h) parameter range of 0.53–0.84. The $F_{x\%}$ value was $F_{35\%}$ for all handling mortality levels.

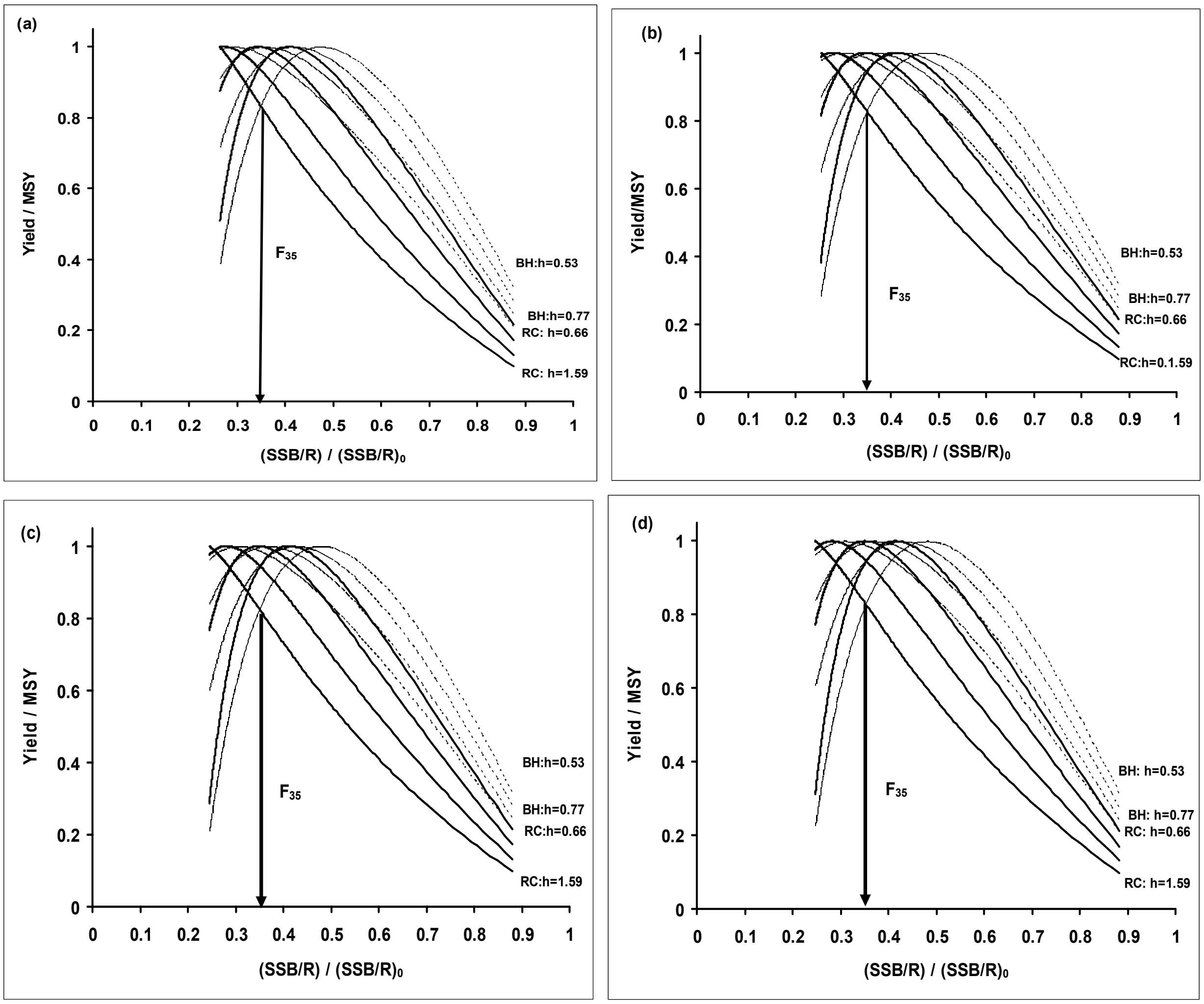

Figure 5-4 Locations of spawning potential ratio ($F_{x\%}$) by equilibrium yield method for different handling mortality rates: (a) 0.25, (b) 0.4, (c) 0.5, and (d) 0.6 for snow crab. Steepness (h) ranged from 0.53 to 0.84. Solid lines: Ricker S-R model (RC), dotted lines: Beverton-Holt S-R model (BH).

6 Tanner crab (*Chionoecetes bairdi*)

Three stocks of *C. bairdi* Tanner crab are managed under this FMP, the Eastern Bering Sea Tanner crab stock, the Eastern Aleutian Islands Tanner crab stock, and the Western Aleutian Islands Tanner crab stock. This Chapter 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.

6.1 Tanner crab stock status

Eastern 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 2006 TMB estimate for this stock 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 6-1). 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 consecutive years. 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.

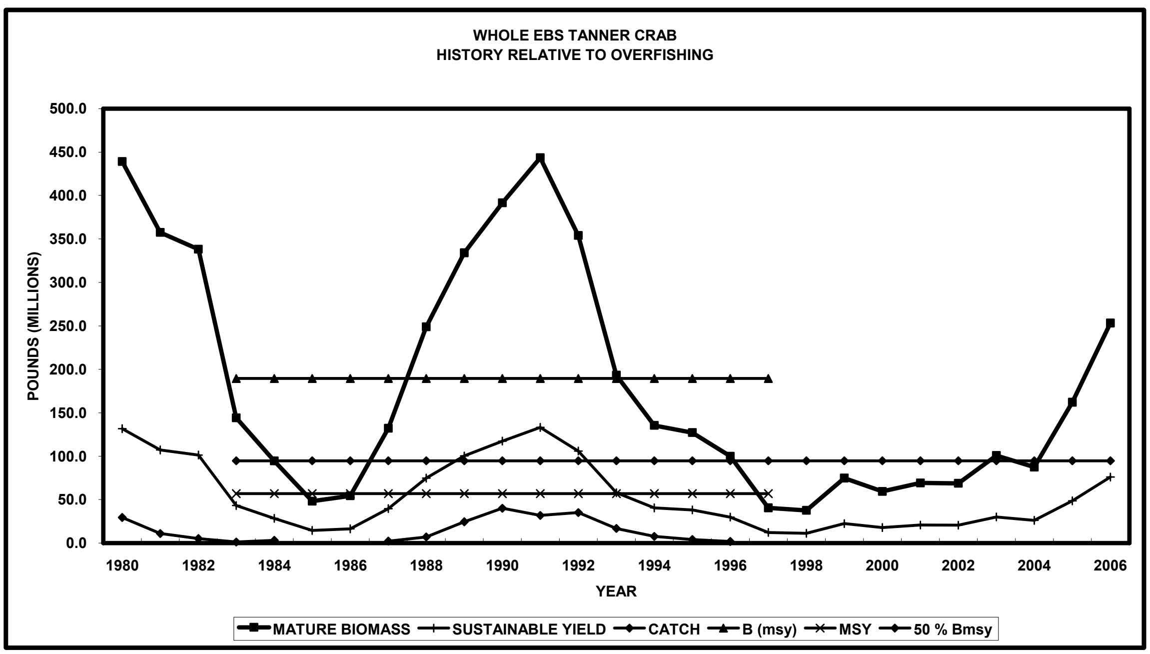

Figure 6-1 EBS Tanner crab stock status relative to overfishing

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).

EBS Tanner crab is managed east and west of 166º W longitude, with a separate TAC for each area. The calculated 2005/06 TAC for the area east was below the minimum TAC and the east fishery was not opened. In the west area, the 2005/06 TAC was 1.62 million pounds (735 t). For the 2006/07 fishery, ADF&G calculated the TAC of 1.875 million pounds (850 t) for the east, using a 10% harvest rate applied to the molting mature male abundance. West of 166° W long., the TAC of 1.094million pounds (496 t) was calculated using a 25% harvest rate applied to the exploitable legal male abundance estimate.

In the area west of 166° W long., ADF&G statistical area 695700 which lies between 169° W long. and 170° W long. and 57° N lat. and 57° 30’ N lat. was closed to commercial fishing for Tanner crab to protect the Pribilof blue king crab stock. The majority of blue king crabs captured during the 2005 and 2006 survey were found in this area. The exploitable legal male Tanner crabs that were estimated to be in this statistical area were not used in setting the 2005/05 or 2006/07 TACs.

Eastern Aleutian Islands Tanner crab

Abundance for this stock is not annually estimated by NMFS. ADF&G conducted pot surveys in the Eastern Aleutians District in 1975, 1976, 1977, 1979, 1980, 1981, 1984, 1985, 1986, and 1987 (Donaldson and Hicks 1980a, 1980b; Colgate and Hicks 1981; ADF&G 1985, 1986, 1987). Those surveys primarily targeted red king crab, but also captured Tanner crabs (Colgate and Hicks, 1981). The pot surveys provided general information on relative abundance and distribution of Tanner crabs, but no estimates of Tanner crab abundance have been made from the pot survey results. The pot surveys during 1975-1987 do not provide a consistent time series in terms of area of coverage. For example, whereas 20-40% of the stations surveyed during the pot surveys of 1975-1981 were offshore ocean stations, stations sampled during the 1985 and subsequent pot surveys were almost exclusively within the state waters of bays and inlets. Trawl surveys in the Eastern Aleutians District, which have provided data for computing abundance estimates for Tanner crab within the areas surveyed, were performed by ADF&G in 1990, 1991, 1994, 1995, 1999, 2000, and 2003-2005 (Urban 1992, 1993, 1996a, 1996b; Worton 2000, 2001; Spalinger 2004, 2005, 2006). Most recently, a trawl survey in the Eastern Aleutians District was performed in 2006, but the results have not been published at this time. The trawl survey sampling has mainly concentrated on the Bering Sea side of Unalaska Island and Akutan Bay, where the majority of commercial catch has occurred since the 1970s (ADF&G 1979). Like the pot surveys, the area covered by ADF&G's Eastern Aleutian District trawl survey has varied over time, with the area surveyed generally contracting over the years; for example, 45 stations were sampled by the 1990 survey, whereas 21-24 stations were sampled by the 2004-2006 surveys. Also like the pot surveys of the mid-1980's, the trawl survey has been performed almost exclusively within the state waters of bays and inlets; only four of the 46 stations that have been sampled by the trawl survey during 1990-2006 involve tows outside of state waters and 96% of the tows were within state waters during the most recent three trawl surveys. Since the trawl survey began, the majority of the Tanner crab stock has been found in the vicinity of Akutan Island, Beaver Inlet, Unalaska Bay and Makushin/Skan Bay, whereas the trawl survey estimates of abundance in the Usof, Akun, Pumicestone, and Inanudak Bays and the area off Cape Idak have been low. In 2003, to better assess abundance in some historically important areas for Tanner crabs, ADF&G conducted a pot survey within the state waters of Unalaska Bay, Beaver Inlet, and the Akutan/Akun Islands areas through the cooperative efforts of commercial fishermen participating under a commissioner's permit (Bon and Bowers 2006).

The Eastern Aleutian District Tanner crab commercial fishery began in the 1970s and is a small fishery compared to the EBS Tanner fishery. Harvests peaked at 2.5-million pounds (1,134 t) in the 1977/1978 season (Bush et al. 2005) and, even during the only three seasons in which the harvests exceeded 1-million pounds (454 t) (the 1976/1977 through 1978/1979 seasons), the fishery was characterized as being "limited to smaller local fishing vessels fishing in local bays" (ADF&G 1980). The fishery has continued to be concentrated in nearshore waters, bays, and inlets; 93% of the total harvest during 1985-2006 occurred within statistical areas representing state waters (ADF&G Venus fish ticket system, 3 March 2007). Following the 1976/1977-1979/1980 seasons, during which the average annual harvest was 1.6-million pounds, harvests decreased in the 1980s, averaging 370-thousand pounds (168 t) for the 1980-1989 seasons. Harvests continued to decline in the 1990s, averaging 106-thousand pounds (48 t) during the 1990-1994 seasons, and the fishery was closed for the 1995 through 2002 seasons. During 2003, the State only allowed commercial fishing for vessels participating in a pot survey under the provisions of a commissioner's permit (see above), during which 15-thousand pounds (6.8 t) were retained for sale. For the 2004-2007 seasons, the State opened the fishery with GHLs of 34-thousand to 135-thousand pounds (15.4 t – 61.2 t). Since 2004, the State has restricted commercial fishing to Unalaska, Makushin/Skan, or Akutan Bays, depending on season, with separate GHLs established for separate bays if more than one bay is opened during a season.

The Eastern Aleutian District Tanner crab stock also supports a subsistence fishery (Bush et al. 2005). Based on a survey of Unalaska residents, total subsistence harvest of Tanner crab by that community in 1994 was 11-thousand crabs. From returns of subsistence permits issued in Dutch Harbor during 2000-2004, the annual subsistence harvest of Tanner crabs during those years is estimated to have increased from 1.2-thousand crabs in 2000 to 6.9-thousand in 2004, with an annual average over that period of 4.1-thousand crabs.

Abundance estimates of Eastern Aleutian District Tanner crabs from the ADF&G trawl survey are not directly comparable year-to-year due to the general contraction since 1990 in the area surveyed and, consequently, the area for which abundance estimates were made. However, using a minimum 114-mm CW as a proxy for identifying mature males, there has been an apparent increase in the abundance of mature-sized males from the early 1990s to the more recent survey years. Abundance of mature-sized males estimated from the 1990-1995 surveys averaged 0.37-million crabs, whereas abundance of mature-sized males estimated from the 1999-2005 surveys averaged 1.22-million crabs (Spalinger 2006). Abundance of mature-sized male Tanner crabs for the area surveyed by the 2005 trawl survey (i.e., Akutan, Unalaska/Kalekta, Makushin, and Pumicestone Bays) was 1.12-million crabs, of which 478-thousand were legal males (Spalinger 2006). Those results were comparable to the 2004 trawl survey (1.17-million mature-sized males and 542-thousand legal males), which was limited to the same bays as the 2005 survey (Spalinger 2005). Stations in Makushin/Skan Bay accounted for 80% of the legal male estimate from the 2005 survey. On the basis of those results, Makushin/Skan Bay was opened to commercial fishing for the 2006 season with a GHL of 87-thousand pounds (39.5 t), representing 10% of the estimated abundance of legal males in that bay.

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 (363 t) during the 1981/82 season to less than 8,000 pounds (3.6 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).

6.2 Biological Parameters

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

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 C provides the input base parameter values. Terminal molt at maturity was assumed for both sexes in all simulations.

6.2.1 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, terminal molt for male Tanner crab is accepted for this analysis. However, this analysis also attempts 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 NMFS EBS trawl survey since 1990. These data can be used to estimate male maturity probability. Table 6-1 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. It is difficult to explain where the legal males come from during the 1970s, late 1980s and early 1990s for EBS 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 conducted two analyses, called option 1 and option 2. Option 1 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. Estimated F_{MSY} from option 1 is still very high, and these probabilities may still be difficult to explain where legal males come from.

For option 2, 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 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 6-2. 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 6-1 Proportions of immature males within newshell Tanner crab from 1990 to 1997

Year/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, crabs 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 6-1, 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 crabs were abundant in the survey data (Table 6-3). 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 6-2 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 6-3 Proportions of old-shell male crab for eastern Bering Sea Tanner crab from the NMFS EBS trawl survey

Year/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

6.2.2 Steepness parameter estimate

The Beverton-Holt and Ricker S-R models were fitted to the Tanner crab stock in Bristol Bay with MMB 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 6-3 depicts the stock-recruitment scatter plot and the S-R fits,which suggested that the Ricker curve was more appropriate to this data set than the Beverton-Holt curve. The statistical fit also confirmed the choice (see Chapter 3). The steepness parameter value for the Ricker curve was 1.6. This value was used for performance statistics calculations by stochastic simulations. Appendix C provides the base input parameter values of EBS Tanner crab for model simulations.

6.2.3 BMSY and proxy BMSY estimate

The simulated population with a maximum number of 104 million recruits produced a B_{MSY} of 63.25 million pounds (28,690 t) of MMB and $B_{35\%}$ of 73.58 million pounds (33,377 t) of MMB (proxy B_{MSY}) for the Ricker S-R curve with the estimated steepness parameter value of 1.6. These B_{MSY} and proxy B_{MSY} values were used in the Tier 2-4 formulas for stochastic simulations.

6.2.4 Fx% estimate

The $F_{x\%}$ estimate for a handling mortality rate of 0.2 is shown in Figure 6-4. (The $F_{x\%}$ value was $F_{34\%}$. We selected a conservative $F_{35\%}$ for detailed stochastic simulations. The corresponding F was 0.0.80, the legal male harvest rate (at the time of the fishery) was 36%, and the mature male harvest rate (at the time of survey, June 15) was 16%.

6.3 Effects on EBS Tanner Crab

6.3.1 Comparison of status determination criteria

Under Alternative 1, the EBS Tanner crab stock was declared overfished in 1998 and has been under a rebuilding plan since then. The Alternative 1 status determination criteria for EBS Tanner crab establish a B_{MSY} value of 189.6 million pounds (86,002 t) of TMB with an MSST value of 94.8 million pounds (43,001 t) of TMB. The 2006 TMB from the survey area-swept estimate was 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 consecutive years. 2006 represents the first time the TMB was above the B_{MSY} for this stock since NMFS declared the stock overfished in 1998.

In conjunction with the rebuilding plan, the harvest strategy was modified to allow for greater probability of rebuilding the depleted stock. The State of Alaska harvest strategy for the EBS 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 OFL control rule for Tanner crab is the following:

Sustainable yield = 0.3* TMB (male + female).

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 (1,361 t), which is below the 2006 SY of 75.99 million pounds (34,469 t).

Under the Alternative 2 and 3 status determination criteria, B_{MSY} for Tanner crab is measured in MMB, as discussed in Section 2.4.1. The long-term B_{MSY} estimate for the stock would be 63.25 million pounds (28,690 t) of MMB. For comparison, the 2006 MMB for the stock is 62.76 million pounds (28,470 t). This stock would be just below its B_{MSY}, unlike under Alternative 1. This stock would still be above MSST as under Alternative 1; thus the stock would not be overfished; however it would remain under the rebuilding plan.

Given that new biological parameters for this stock would be re-estimated under Alternatives 2 and 3, 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}.

Under Alternatives 2 and 3, 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 Tiers described in Section 2.2.1 and Table 2-3 and Table 2-4. 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 following section for simulation and results). Figure 6-2 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.

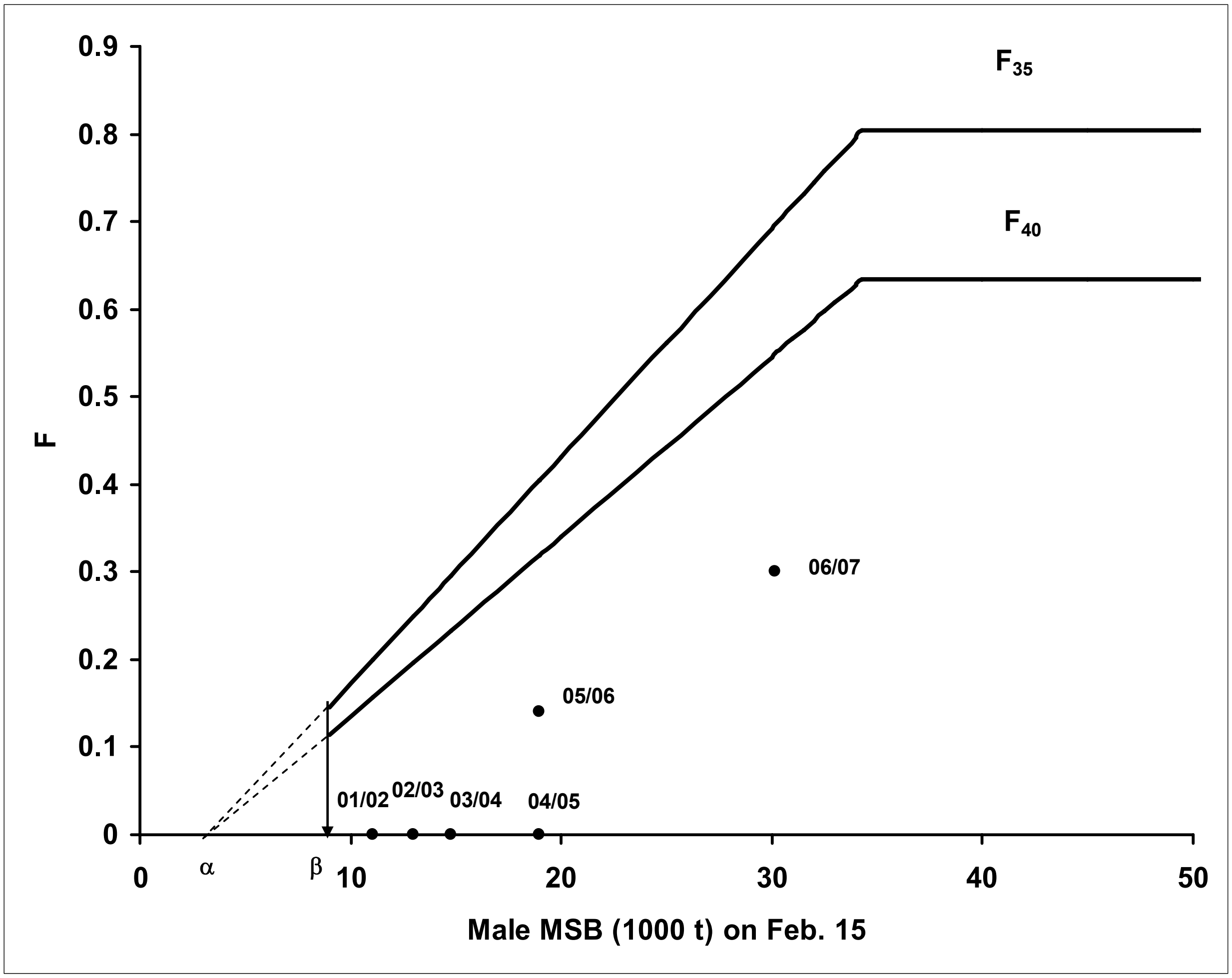

Figure 6-2 Relationship between legal male F and male mature biomass (MMB) on February 15 for Eastern Bering Sea Tanner crab. $F_{35\%}$ and $F_{40\%}$ control rules are included. The filled circles are F values for respective fishing seasons, 2001/2002 – 2005/2006.

The change in currency from the total mature biomass (TMB) to mature male biomass (MMB) unit affected 'overfishing' and 'overfished' definitions for the ESB Tanner crab during 1983-2006 (Table 6-4). There should be caution when comparing TMB and MMB results because the TMB was estimated for the whole ESB area while MMB was estimated only for the Bristol Bay portion because of the limitation on current assessment. Because of relatively high abundance of Tanner crabs in the Pribilof Islands area during recent years, the percentage of $B_{35\%}$ and estimate of proposed F_{OFL} will be higher for the whole ESB area than those reported in Table XX2 during recent years. Under current FMP, the historical harvest has not exceeded OFL (overfishing level); whereas under the proposed plan, overfishing occurred during 1983-1985 and 1988 due to change in currency and in biological reference points. TMB as a percentage of B_{MSY} was low during 1983 – 1987 and 1995 onwards until 2005. This pattern was reflected in the MMB although it referred to part of the stock. The Bristol Bay part of the MMB exceeded B_{MSY} during 1990-1994, which was reflected in the TMB trend for the whole ESB area as well.

Since the fishery was started in 2005, as the result of low TACs, the F values on legal males at the time of the fishery were most likely to be much lower than the F_{OFL}. Overall the differences in overfishing definitions for the ESB Tanner crab are due to the change in currency and subsequent estimation of biological reference points. However, assessment model for the whole ESB area is needed to make a firm conclusion.

Table 6-4 Comparison of total mature biomass (TMB) and mature male biomass used for current and proposed 'overfishing' and 'overfished' definitions for Tanner crab. The TMB estimates are for the whole ESB area while the MMB estimates are only for the Bristol Bay area. The biomasses are expressed in millions of pounds.

Year	TMB	$\%B_{MSY}$	Current OFL = SY	TAC	Feb 15 MMB	$\%B_{35\%}$	Proposed F_{OFL}
1983	144.18	76	43.25	5.27	22.64	31	0.19
1984	94.58	50	28.37	1.21	21.99	30	0.18
1985	48.28	25	14.48	3.15	16.15	22	0.11
1986	54.37	29	16.31	Closed	13.90	19	0.08
1987	132.06	70	39.62	Closed	14.13	19	0.08
1988	248.90	131	74.67	2.21	21.11	29	0.17
1989	334.00	176	100.20	7.01	47.70	65	0.49
1990	391.54	207	117.46	44.59	85.37	116	0.80
1991	443.57	234	133.07	51.84	83.20	113	0.80
1992	354.06	187	106.22	35.13	91.00	124	0.80
1993	193.12	102	57.94	16.89	95.02	129	0.80
1994	135.36	71	40.61	7.77	85.01	116	0.80
1995	127.21	67	38.16	4.23	61.49	84	0.66
1996	99.87	53	29.96	1.81	38.63	52	0.38
1997	40.59	21	12.18	Closed	24.12	33	0.20
1998	37.59	20	11.28	Closed	17.79	24	0.13
1999	74.74	39	22.42	Closed	15.36	21	0.10
2000	59.39	31	17.82	Closed	18.21	25	0.13
2001	69.22	37	20.77	Closed	25.85	35	0.22
2002	68.78	36	20.64	Closed	25.22	34	0.22
2003	100.75	53	30.23	Closed	20.52	28	0.16
2004	87.48	46	26.24	Closed	17.89	24	0.13
2005	162.04	85	48.61	1.62	19.18	26	0.14
2006	253.31	134	75.99	2.97	20.69	28	0.16

6.3.2 Evaluation of Alternatives with short-term and long-term performance statistics

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 status quo OFL. For Alternatives 2 and 3, an evaluation was made of Tier 2 to 4. For analytical purposes, additional scenarios considered included a flat FMSY (i.e., constant FMSY), flat $F_{35\%}$, F = M, and F = 0.

The status quo harvest strategy was simulated following the criteria in 5 AAC 35.508. Fishing at the Alternative 1 OFL control rule for Tanner crab was simulated using the following formula:
Sustainable yield = 0.3* total survey mature biomass (male + female).

Table 6-5 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}, Tier 3 with $F_{35\%}$ and $F_{40\%}$, Tier 4 with three times M, the status quo harvest strategy, fishing at the status quo OFL control rule, 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.

The impact of fishing under the status quo OFL control rule 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 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.

Tier 2 with F_{MSY} 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 in between Tier 3 with $F_{35\%}$ and with $F_{40\%}$ performance . Thus, for Tanner crab with a male M of 0.23, a γ value up to 3 is feasible. The status quo harvest strategy was satisfactory, with performance somewhat lower than Tier 3 with $F_{40\%}$. However, the simulation procedure for application of the status quo harvest strategy was an approximation to the actual procedure being followed by the State. The status quo OFL control rule performed worst of all, with very low mean number of recruits, higher overfished percent, and much lower 30th year relative MMB. The stock did not rebuild during this time period under the status quo OFL control rule. Flat F_{MSY} and Flat $F_{35\%}$ performed worse than the sliding scale counterparts.

Table 6-5 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 6-6 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 6-7 provides the same performance statistics for the long-term (100 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 performance of the status quo OFL control rule was again the worst at this initial biomass level.

The F = 0 scenarios provide the non-fishery yields, which are mainly trawl bycatch yields. The results indicated that nearly 3,155 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 EBS, 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 status quo harvest strategy, status quo OFL control rule, $F_{40\%}$, and $F_{35\%}$ harvest control rules for 2007 to 2012 were made for EBS Tanner crab (Table 6-9). The 2006 catch was set according the status quo harvest strategy for all scenarios. Recruitment was projected by an estimated S-R curve. Projected catch and MMB for the status quo 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 $F_{35\%}$. Fishing at the current OFL control rule results in much higher fishing mortality, higher catch, and lower mature male biomass on February 15 than those by the status quo 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.

Table 6-5 Short-term rebuilding simulations under various control rules for EBS 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 and harvest implementation error. 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)	Status quo Harvest CR	Status quo OFL CR	Flat F_{MSY}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	89.1	91.0	91.6	92.4	92.3	91.4	94.6	55.1	80.6	84.6	90.5	84.6
Mean total yield (t)	13159	12168	12422	11276	11484	11887	10754	13229	12535	12078	7445	2893
Mean retained yield (t)	8261	7589	7797	6958	7114	7389	5785	66894	7592	7372	3908	0
Mean mature male biomass (t)	27089	30645	30950	34514	33886	31594	33486	10728	21410	24577	45011	57433
Mean mature female biomass (t)	34887	36063	36242	37049	36928	36316	39363	21632	31581	33242	37980	37510
Mean F	0.73	0.58	0.58	0.46	0.48	0.55	0.67	3.02	0.99	0.80	0.20	0
Rebuilding time (y)[a]	10	8	8	7	7	8	6	NR	16	13	6	5
Years B<B_{msy} (%)[b]	67.6	58.4	57.0	48.8	50.1	56.0	52.8	97.9	81.1	73.3	32.4	23.1
Years overfished (%)[c]	13.2	9.2	8.4	6.2	6.5	8.5	9.6	80.3	32.7	23.7	3.9	3.0
Years fishery closed (%)[d]	0.2	0.2	0.1	0	0.1	0.1	0.1	NA	2.6	1.2	0	0
30th year biomass ratio (%)[e]	104	121	121	137	134	125	132	29	82	98	186	233
First 10-yr mean retained yield (t)	6159	5402	5431	4647	4784	5200	5054	8293	6649	6109	2454	0
CV first 10-yr mean retained yield	0.70	0.78	0.76	0.75	0.76	0.70	0.46	0.46	0.51	0.52	0.70	0
Next 20-yr mean retained yield (t)	9312	8683	8980	8114	8278	8483	6150	6195	8064	8004	4635	0
CV next 20-yr mean retained yield	0.38	0.36	0.37	0.35	0.35	0.35	0.30	0.49	0.40	0.38	0.30	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 6-6 Short-term rebuilding simulations under various control rules for EBS 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 and harvest implementation error. 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)	Status quo Harvest CR	Status quo OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	93.0	94.5	94.8	95.2	95.2	94.7	97.7	66.7	88.9	91.7	92.2	84.8
Mean total yield (t)	15549	14253	14517	13100	13354	13896	12230	17929	15496	14663	8509	3199
Mean retained yield (t)	9711	8867	9080	8078	8262	8621	6454	9650	9487	9030	4500	0
Mean mature male biomass (t)	30366	34344	34432	38439	37731	35410	36943	14676	27104	3.539	50519	64253
Mean mature female biomass (t)	40050	41255	41344	42140	42025	41505	44976	28321	38518	39929	42803	41652
Mean F	0.82	0.65	0.65	0.51	0.54	0.61	0.73	3.02	0.99	0.80	0.22	0
Rebuilding time (y)[a]	2	1	1	1	1	1	1	NR	2	2	0	0
Years B<B_{msy} (%)[b]	57.7	46.7	45.9	36.7	38.2	44.2	42.5	93.9	66.3	57.0	18.9	9.8
Years overfished (%)[c]	6.4	3.7	3.3	1.9	2.1	3.2	3.5	57.7	15.1	9.3	0.6	0.5
Years fishery closed (%)[d]	0	0	0	0	0	0	0	NA	0.7	0.2	0	0
30th year biomass ratio (%)[e]	105	121	112	137	134	125	133	33.5	99	102	185	231
First 10-yr mean retained yield (t)	9823	8633	8742	7539	7750	8320	6592	13682	10206	9291	4000	0
CV first 10-yr mean retained yield	0.51	0.52	0.55	0.56	0.56	0.52	0.43	0.38	0.46	0.47	0.54	0
Next 20-yr mean retained yield (t)	9655	8984	9249	8347	8518	8772	6384	7634	9127	8899	4750	0
CV next 20-yr mean retained yield	0.37	0.35	0.36	0.34	0.35	0.35	0.29	0.45	0.37	0.35	0.29	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 6-7 Long-term rebuilding simulations under various control rules for EBS 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 and harvest implementation error. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, 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)	Status quo Harvest CR	Status quo OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	91.2	93.1	93.6	94.2	94.1	93.4	92.8	40.9	82.7	87.6	91.3	83.8
Mean total yield (t)	14427	13460	13766	12556	12780	13171	11324	9276	13308	13176	8237	3063
Mean retained yield (t)	9075	8436	8677	7809	7974	8233	6011	4812	8112	8109	4413	0
Mean mature male biomass (t)	29010	33234	33399	37605	36863	34362	34982	7466	23003	27259	50177	64030
Mean mature female biomass (t)	37248	38735	38892	39804	39677	39036	41313	15197	33203	35781	40233	38424
Mean F	0.78	0.62	0.62	0.50	0.52	0.59	0.72	3.02	0.99	0.80	0.22	0
Rebuilding time (y)[a]	9	8	8	7	7	8	7	NR	15	12	6	5
Years B<B_{msy} (%)[b]	62.1	50.8	49.9	40.4	41.9	48.1	48.2	98.9	76.5	66.3	21.7	12.5
Years overfished (%)[c]	9.6	5.8	5.2	3.4	3.6	5.1	7.2	89.6	28.5	17.8	1.6	1.2
Years fishery closed (%)[d]	0.1	0	0	0	0	0	0	NA	2.6	0.9	0	0
100th year biomass ratio (%)[e]	104	120	120	136	133	124	137	17	99	100	183	235

[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 6-8 Long-term rebuilding simulations under various control rules for EBS 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 and harvest implementation error. B = total mature male biomass, B_{MSY} = total MSY mature male biomass, 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)	Status quo Harvest CR	Status quo OFL CR	Flat F_{msy}	Flat F_{35}	F=M CR	F=0
Mean recruit no. (millions)	92.3	94.1	94.5	95.0	95.0	94.4	93.6	46.1	85.4	89.8	91.7	83.8
Mean total yield (t)	15135	14074	14384	13093	13330	13762	11747	11117	14275	13988	8551	3155
Mean retained yield (t)	9504	8812	9056	8138	8311	8595	6194	5861	8728	8629	4588	0
Mean mature male biomass (t)	29980	34321	34423	38756	37991	35483	35823	9008	24867	29137	51790	66086
Mean mature female biomass (t)	38773	40262	40390	41296	41172	40560	42952	17917	35484	37886	41649	39669
Mean F	0.80	0.64	0.65	0.51	0.53	0.60	0.73	3.02	0.99	0.80	0.22	0
Rebuilding time (y)[a]	2	1	1	1	1	1	1	NR	2	2	0	0
Years $B<B_{msy}$ (%)[b]	59.1	47.5	46.6	36.8	38.4	44.7	45.3	97.6	71.7	61.1	17.6	8.4
Years overfished (%)[c]	7.7	4.2	3.8	2.2	2.4	3.6	5.8	81.9	22.7	13.4	0.7	0.5
Years fishery closed (%)[d]	0	0	0	0	0	0	0	NA	1.9	0.6	0	0
100th year biomass ratio (%)[e]	104	120	120	136	133	124	137	17	99	100	183	235

[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

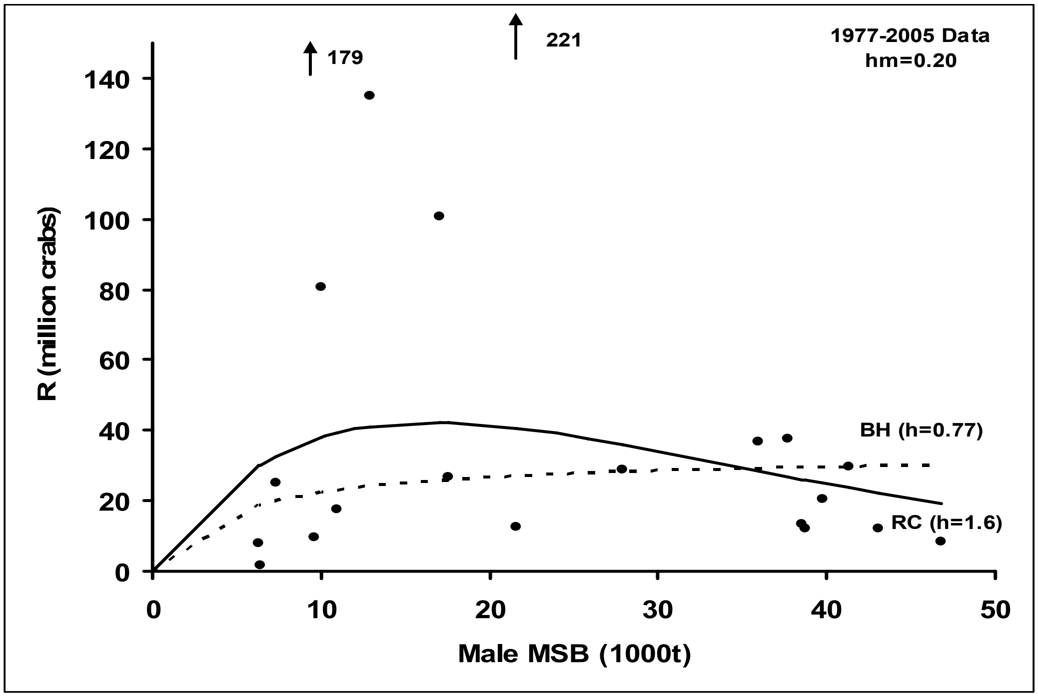

Figure 6-3 Stock-recruitment fit for the eastern Bering Sea Tanner crab 1977-2005 data assessed at male M=0.23 and female M=0.29 and handling mortality, hm=0.2. The steepness parameter (h) values are given in parentheses. BH=Beverton and Holt curve, RC=Ricker curve.

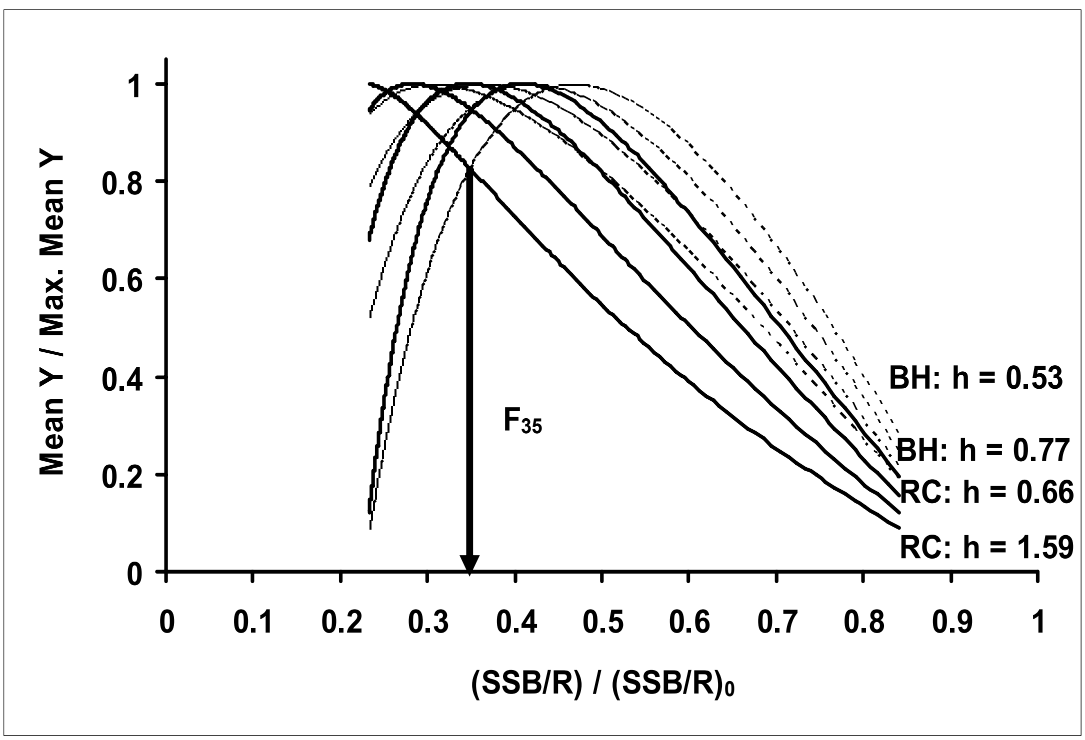

Figure 6-4 Approximate location of spawning potential ratio ($F_{x\%}$) by equilibrium yield method for a handling mortality rate of 0.2 for Tanner crab. Solid lines = Ricker S-R model (RC), dotted lines = Beverton-Holt S-R model (BH).

Table 6-9 Short-term projections using the status quo harvest strategy, status quo 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 status quo harvest strategy for all scenarios. Recruitment was projected by an estimated S-R curve. Catch and biomass are in 1000 t.

	Retained Catch	F	Feb. 15 Mature Male Bio.
Status quo Harvest Strategy			
2006	1.347	0.303	28.470
2007	6.718	0.762	30.490
2008	8.881	0.766	34.049
2009	9.742	0.616	36.656
2010	8.348	0.712	34.758
2011	7.374	0.741	32.673
2012	7.580	0.747	31.885
$F_{40\%}$			
2006	1.347	0.303	28.470
2007	5.550	0.591	31.507
2008	8.041	0.630	35.990
2009	10.440	0.630	38.090
2010	7.794	0.630	36.390
2011	6.810	0.630	34.626
2012	7.041	0.630	34.138
$F_{35\%}$			
2006	1.347	0.303	28.470
2007	6.499	0.728	30.682
2008	9.237	0.800	33.972
2009	11.728	0.800	34.874
2010	8.290	0.785	32.796
2011	6.976	0.744	31.290
2012	7.287	0.738	31.040
Status quo OFL control rule			
2006	1.347	0.303	28.470
2007	13.259	2.679	24.408
2008	12.698	2.912	23.529
2009	14.244	2.292	22.810
2010	11.002	2.999	20.966
2011	10.381	3.299	20.088
2012	11.214	3.599	19.886

6.4 Effects on Aleutian Islands Tanner crabs

B_{MSY} proxy estimates are available for the EAI Tanner crab stocks (Figure 6-5, Table 3-5). Under the Alternative 2 and 3 Tier system this stocks would be under Tier 4. For this analysis, average mature biomass (>114 mm CW) from 1990 to 2006 was used as a proxy for EAI Tanner crab. No survey data are available for this stock during the other years. The current stock status is above its B_{MSY} proxy. Historical comparison of stock status shows that the stock was below the MSST proxy in 1990, 1994 and 1995.

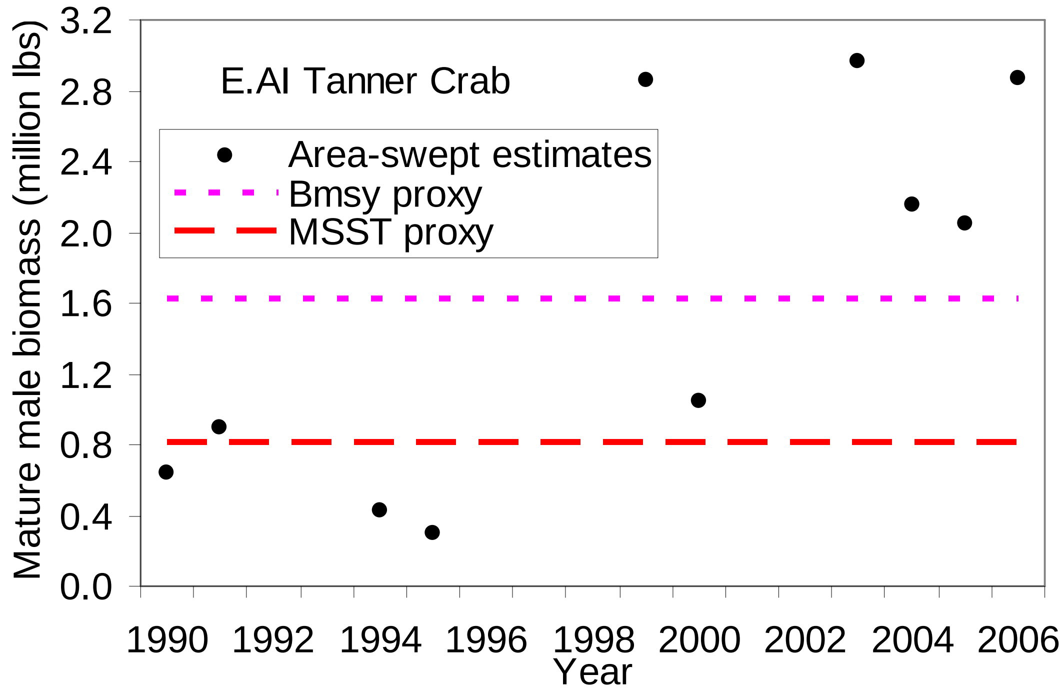

Figure 6-5 EAI Tanner crab estimated mature male biomass compared to the B_{MSY} proxy and MSST proxy proposed in Tier 4 under Alternatives 2 and 3.

No other survey data from which abundance can be directly estimated are available. Historical comparison of stock status shows that the stock was below the MSST proxy in all years prior to 1999 for which trawl survey data is available. In examining Figure 6-5, it should be noted that the area surveyed by the ADF&G trawl survey (and the area for which abundance estimates are made) has contracted during 1990-2005. It should also be noted that areas sampled by the ADF&G trawl survey have been almost exclusively inside of state waters, consistent with the historic distribution of the fishery.

Under Alternative 2, Western Aleutian Islands Tanner crab is suggested for management as a Tier 5 stock. Based on fishing effort data, the appropriate period for catch average may be 1985 to 1992. The average yield during that period is 76,700 pounds. If the OFL was established for this stock based upon the use of average yield over this time period, the OFL would be 76,700 pounds. If the GHL were set at 75% of the OFL, this would be 57,525 pounds.

Under Alternative 3, Western Aleutian Islands Tanner crab is suggested for management as a Tier 6 stock due to lack of available information. For Western Aleutian Islands Tanner crab, bycatch data is available from the directed red king crab fishery. No catch has occurred since 1997. Under Tier 6, a default OFL would be set at zero.

Under Option A, the Aleutian Islands Tanner crab stocks would be removed from the FMP and exclusively managed by the State. The Aleutian Islands Tanner crab fisheries are essentially state-waters fisheries because 93 percent of landings from 1985 to 2006 were in state-waters statistical areas. The effects of removing these stocks from the FMP on the stocks themselves would be negligible because this action would not change their management. The state also provides all of the management functions for these fisheries. ADF&G is proposing a regulatory harvest strategy for the Eastern Aleutian District Tanner crab fishery to the Alaska Board of Fisheries for consideration at their March 2008 meeting.

ADF&G is also proposing a regulation establishing the Akutan, Unalaska/Kaletka Bay, Makushin/Skan Bay, and General Sections within the Eastern Aleutian District as a companion to the harvest strategy proposal. The harvest strategy to be proposed for regulation is that which has been used to manage the fishery since 2004. Under that harvest strategy, GHLs for individual surveyed bays have been established on the basis of preseason estimates of the "mature male abundance" (MMA = abundance of males >114-mm CW), "molting mature male abundance" (MMMA = 100% of newshell and 15% of oldshell males >114-mm CW) for the bay. The proposed harvest strategy would establish a threshold for opening the commercial fishery in a section, defined as 50% of the average MMA in the section for the period 1990-2000. When the current estimate of MMA in the section is below the MMA threshold level, the bay is closed to commercial fishing. When the current estimate of MMA in the section is above the MMA threshold level but below the average MMA for the period 1990-2000, the section is open to commercial fishing with a GHL computed using a 10% harvest rate on the MMMA in the section and a maximum 30% harvest rate on legal-sized males. When the current estimate of MMA in the section exceeds the average MMA for the period 1990-2000, the section is open to commercial fishing with a GHL computed using a 20% harvest rate on the MMMA in the section and a maximum 30% harvest rate on legal-sized males. Under the proposed harvest strategy, a minimum computed GHL of 35,000 is necessary to open a section to commercial fishing to assure manageability of the fishery under pot limits currently in regulation for the Eastern Aleutians District (maximum of 300 pots for the entire fleet with no more than 50 pots per vessel; 5 AAC 35.525 (c) (5)).

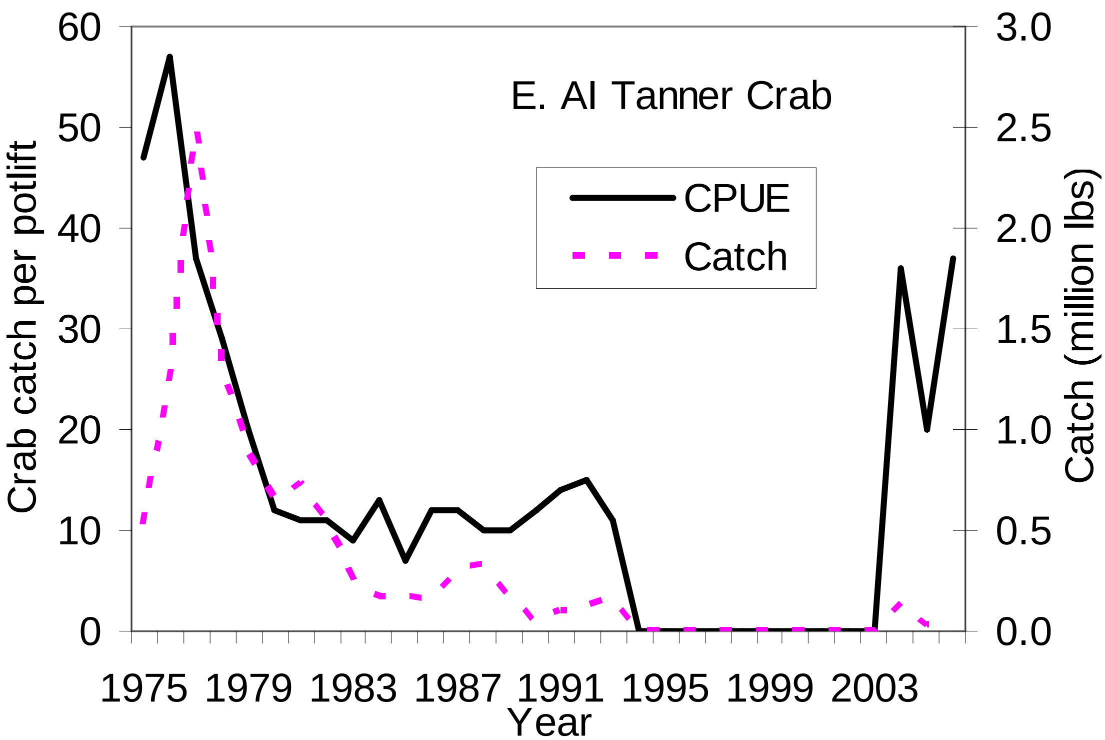

Figure 6-6 Catch and catch per pot lift for eastern Aleutian Islands Tanner crab.

7 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 Saint Matthew blue king crab and Pribilof Islands blue king crab stocks are under rebuilding plans following overfished determinations in 1999 and 2002, respectively. This Chapter 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.

7.1 Blue king crab stock status

This section examines relevant and recent biological information necessary to understand the status of the blue king crab stocks and the overfishing definitions.

Pribilof Islands 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 TMB for 2006 is 1.6-million pounds, the same as in 2005 and at the second lowest on record (Figure 7-1). 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).

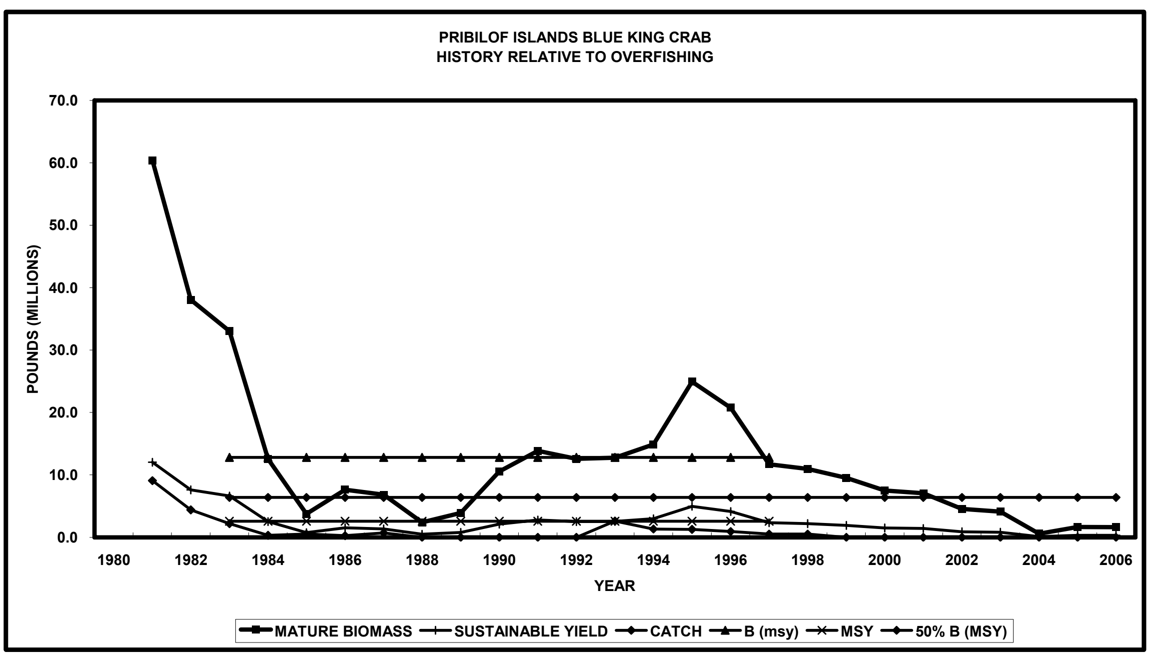

Figure 7-1 Pribilof Islands blue king crab stock status relative to overfishing.

This fishery has been closed since 1999. Because estimated TMB in 2005 was less than the B_{MSY} of 13.2 million pounds (5,987 t), this fishery was closed for the 2006/2007 season under the status quo harvest strategy. Also, the 2006 TMB was less than B_{MSY} and the fishery will remain closed for the 2007/2008 season under the State harvest strategy.

Saint Matthew blue king crab

This stock is annually surveyed by NMFS. 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 7-2).

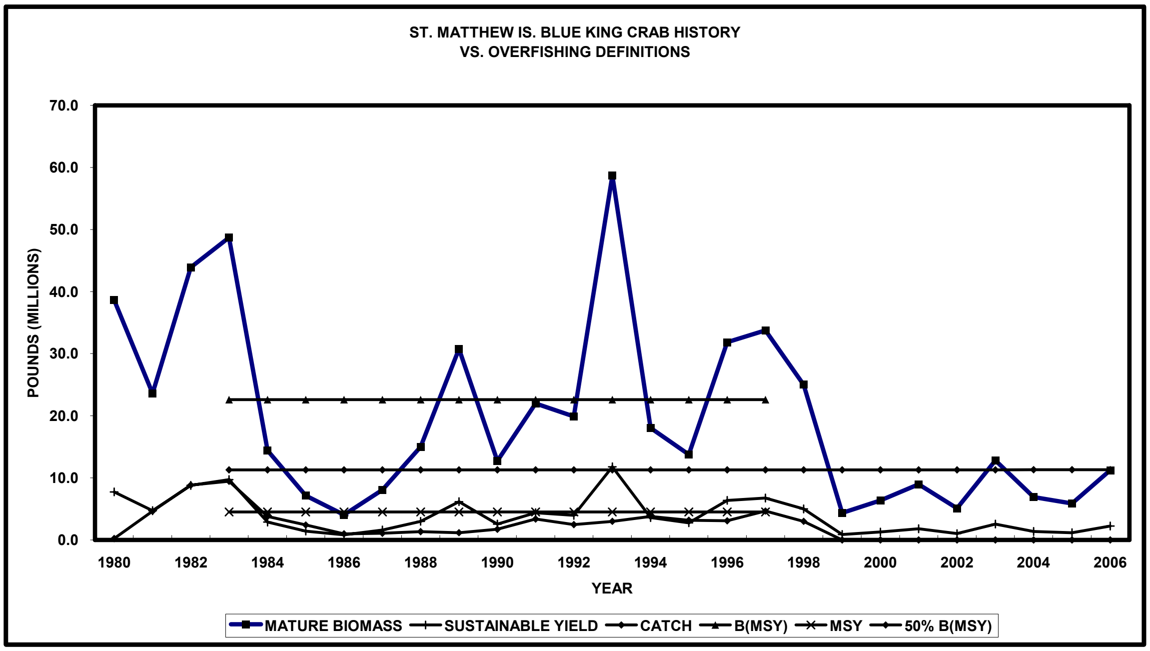

Figure 7-2 St. Matthew blue king crab stock status relative to overfishing.

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, NMFS 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; NMFS 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.

TMB 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 TMB. 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 have only been reported in 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). In 1984, 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).

7.2 Effects on Blue King Crab

Under Alternative 1, both the Saint 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, prompting NMFS to declare that the stocks were overfished. The Pribilof District blue king crab fishery has been closed since 1999, and other crab management measures and bycatch closure zones have 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 (Saint Matthew) and NPFMC 2003 (Pribilof Islands) for more information on the rebuilding plans and subsequent analysis of these stocks. Both stocks will not be fully rebuilt until biomass is above B_{MSY} for two consecutive years.

The Alternative 1 status determination criteria for Pribilof 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). The 2006 estimated TMB from the survey area-swept estimate is 1.6 million pounds (726 t), well below the MSST for this stock (Figure 7-1). The Pribilof stocks remains overfished with no indication of stock recovery.

For Saint Matthew blue king crab under Alternative 1, a B_{MSY} of 22 million pounds (9,979 t) was established with an MSST of 11 million pounds (4,990 t). The 2006 estimated TMB for this stock, as measured by the survey area-swept method, is 11.2 million pounds (5,080 t), just slightly above the MSST for this stock (Figure 7-2). With a survey estimate just above MSST, the Saint Matthew stock is no longer considered overfished.

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 status quo 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 status quo 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.

MMB for blue king crabs is defined for management purposes as the biomass of males ≥105-mm CL. When MMB is below the 2.9 million pounds (1,315 t) threshold of the status quo 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). When the MMB is >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 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.

Under the new Tier system in Alternatives 2 and 3, both of these stocks would be managed as Tier 4 stocks. As such, proxy B_{MSY} values may be estimated. Figure 7-3 provides estimated mature male biomass and B_{MSY} proxy and MSST proxy (½ B_{MSY}) for the Pribilof District blue king crab stock. Estimated mature male biomass, B_{MSY} proxy and MSST proxy (½ B_{MSY}) for the St. Matthew blue king crab stock are shown in Figure 7-5. 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 7-4, Figure 7-6).

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 because the fisheries are closed for the foreseeable future.

Given that both stocks are under rebuilding plans and new biological parameters for these stocks are proposed under Alternatives 2 and 3, 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}.

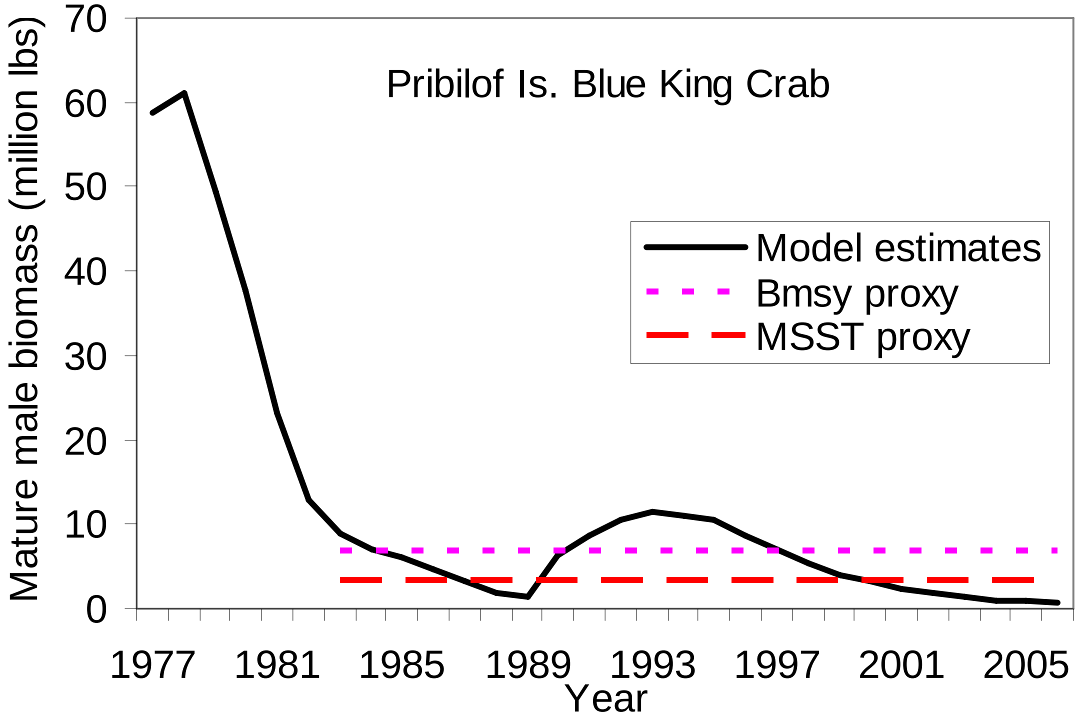

Figure 7-3 Pribilof Islands blue king crab estimated mature male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

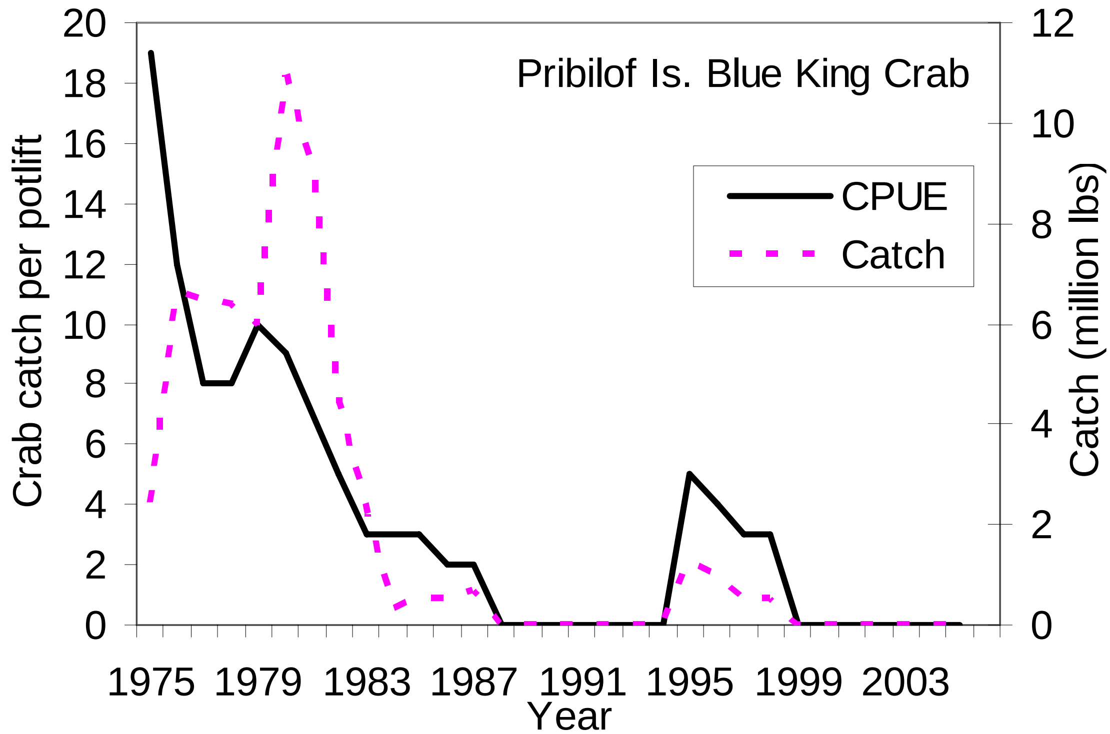

Figure 7-4 Catch and catch per pot lift for Pribilof District blue king crab.

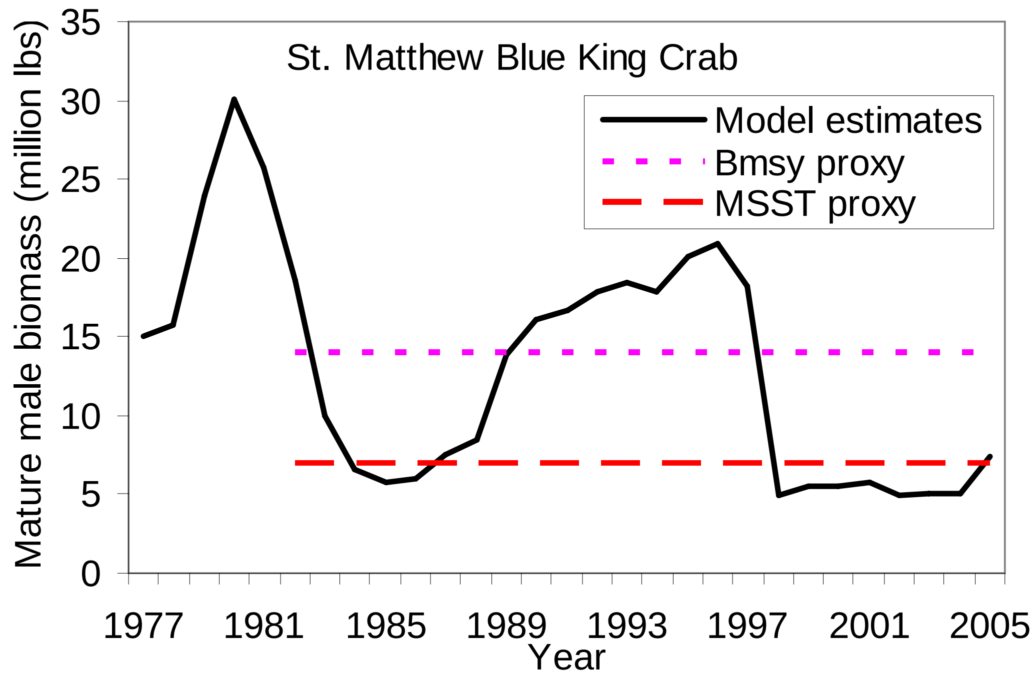

Figure 7-5 Saint Matthew blue king crab estimated mature male biomass compared to the B_{MSY} proxy and MSST proxy proposed under Alternatives 2 and 3.

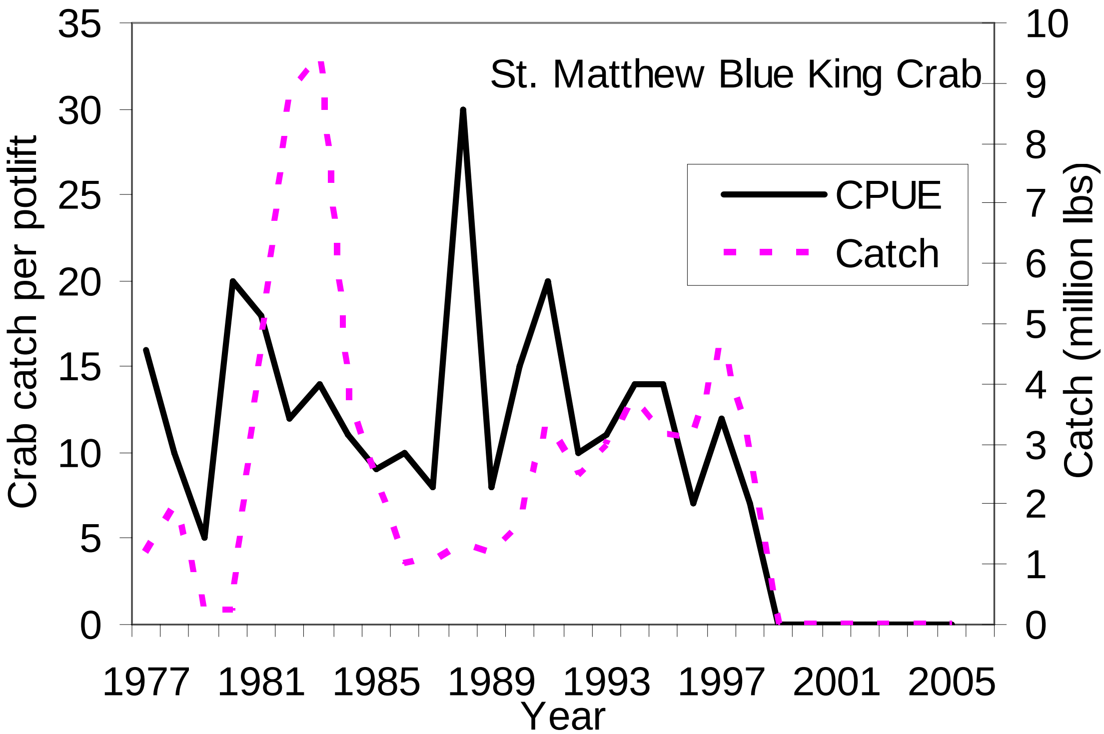

Figure 7-6 Catch and catch per pot-lift for Saint Matthew Island blue king crab.

The change in currency from the current TMB to the proposed MMB affects the overfished definitions slightly for both Pribilof Islands and Saint Matthew Island blue king crab stocks (Figures 7-7 and 7-8). During 1983-2006, under the current definitions, the overfished years were 1985, 1988, 1989, and 2002-2006 for Pribilof Islands blue king crab and 1985-1987 and 1999-2006 for Saint Matthew Island blue king crab. During the same period, the stocks were overfished in 1988-1989 and 2000-2006 for Pribilof Islands blue king crab and 1985-1987 and 1999-2005 for Saint Matthew Island blue king crab under the proposed definitions. The difference may mainly be due to survey measurement errors of TMB, which was directly based on area-swept estimates. The MMB used in the proposed definitions was derived from a catch-survey model. There may be a big difference between the current overfishing rates (F_{OFL}) and the proposed rate due to a change in the biological reference point for these two blue king crab stocks. The current F_{OFL} is applied to both mature male and female crabs whereas the proposed F_{OFL} is for legal males only, and the default M for the proposed biological points is 0.18 vs 0.2 used in the current definitions. For legal males, the Alternative 2 and 3 F_{OFL} should be more conservative than the Alternative 1 overfishing rate. Overall, for these two blue king crab stocks, the difference in F_{OFL} between the current and proposed definitions may mainly be due to a change in the biological reference point.

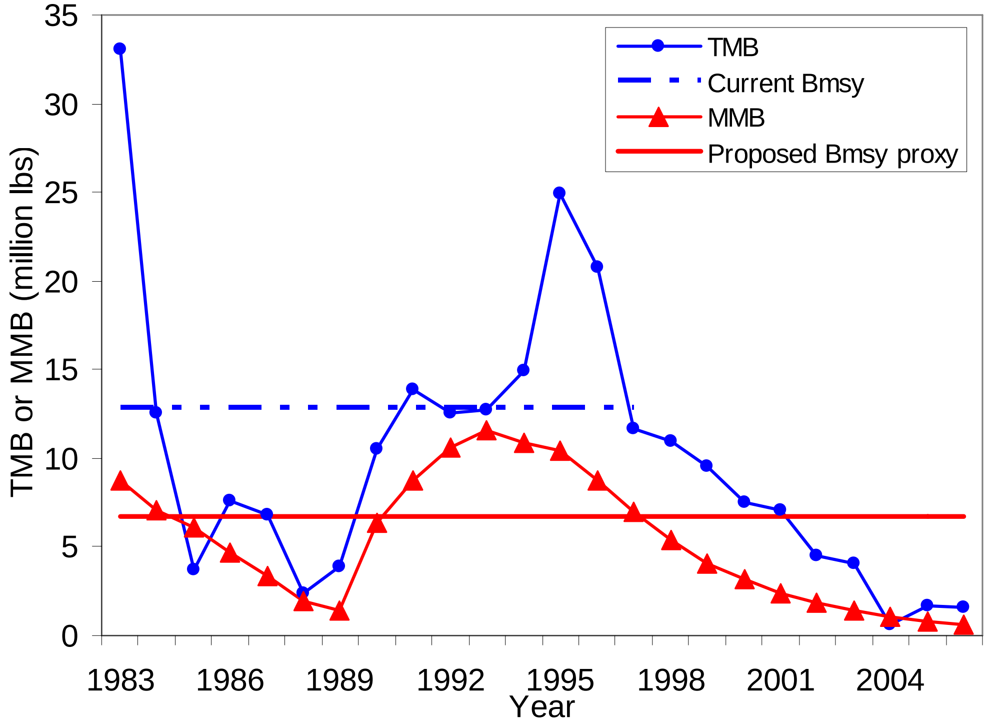

Figure 7-7 **Comparison of total mature biomass and mature male biomass used for the current and proposed overfishing/overfished definitions for Pribilof Islands blue king crab.**

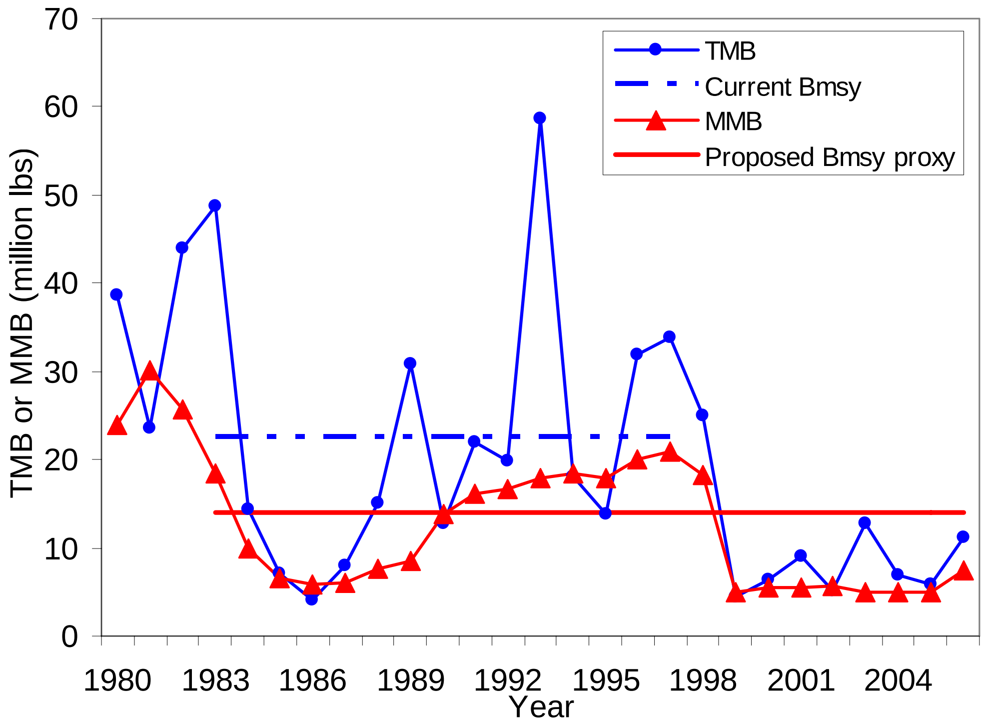

Figure 7-8 **Comparison of total mature biomass and mature male biomass used for the current and proposed overfishing/overfished definitions for St. Matthew Island blue king crab.**

The Saint Lawrence blue king crab stock does not have a current estimate of B_{MSY}. Under Alternatives 3, this stock would be managed under Tier 6 and OFL would be set at zero for this stock due to lack of information. There is currently no fishery for this stock. Under Option a, the Saint Lawrence blue king crab stock would be removed from the FMP and this stock and any potential future fishery would be exclusively managed by the State. The effects of removing this stock from the FMP would be negligible because this action would not change its management.

8 Golden king crab

There are three stocks of golden king crab managed under this FMP, the Aleutian Islands golden king crab stock, the Pribilof Islands golden king crab stock, and the Northern District golden king crab stock. This Chapter reviews the stock status, 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.

8.1 Golden king crab stock status

This section examines relevant and recent biological information necessary to understand the status of the golden king crab stocks and the overfishing definitions.

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 ADF&G 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 with the changes in exploitable biomass, 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).

8.2 Effects on 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 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).

Under Alternative 3, St. Matthew golden king crab is recommended for placement in Tier 6, whereby OFL would be set to a default value of zero, unless the SSC establishes an alternative value based on the best scientific information.

Aleutian Islands Golden King Crab

The Aleutian Islands golden king crab fishery has been conducted since 1981. The State has set the TAC at 5.7 million pounds (2,586 t) for about the past 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. Considering the catches after 1999 were strictly based on the TAC of 5.7 million pounds, the average catch of 8.261 million pounds (3,747 t) from 1985 to 1999 is used to establish an OFL for this stock (Figure 8-1). This would not constrain the current TAC and would provide a small room for future increases in TAC if the stock abundance continues to increase. The CPUE for this stock increased sharply during recent years.

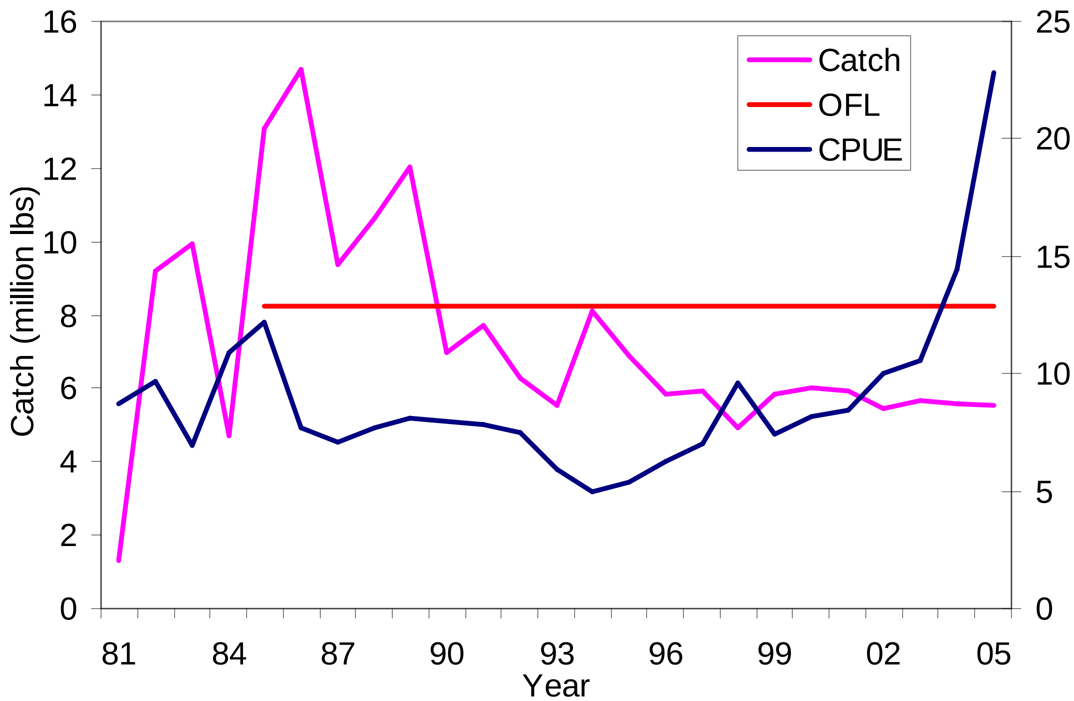

Figure 8-1 Aleutian Islands golden king crab historic catch compared to proposed OFL under Alternatives 2 and 3.

No golden king crab stocks would be in Tier 4 currently, however, 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 in 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 may need to be evaluated once the stock assessment model is available and the stock is moved up to Tier 4.

Pribilof Islands 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 (68 t), 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 1999. The catches after 1999 were primarily based on the TAC, and the catches after 2002 were confidential. The average yield during 1993- 1999 is 174,200 pounds (79 t). If the OFL was established for this stock based upon the use of average yield over this time period, the OFL would be 174,200 pounds (79 t, see Figure 8-2). If a TAC is set at 75% of the OFL, this would be 130,700 pounds (59 t, see Figure 8-2). This would be a reduced TAC from status quo; however, the current GHL of 150,000 pounds (68 t) has not been fully harvested in recent years.

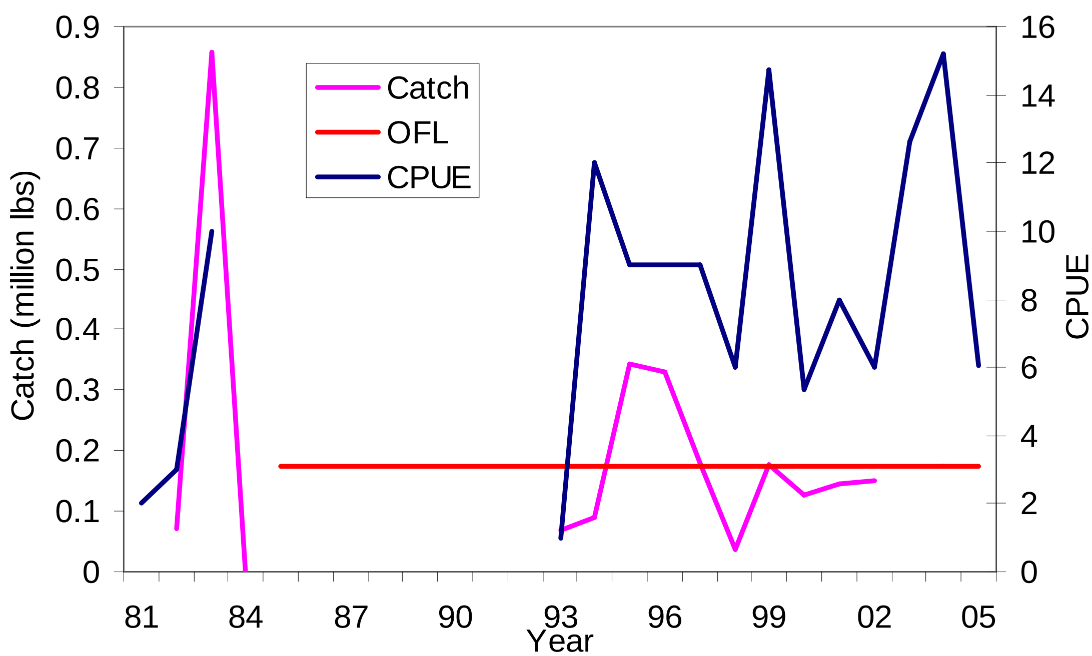

Figure 8-2 Pribilof Islands golden king crab historic catch compared to proposed OFL under Alternatives 2 and 3.

Saint Matthew Golden King Crab

There has been limited fishing effort on the St. Matthew golden king crab stock in the last 10 years. Under Alternative 2, this stock would be in Tier 5. Based on fishing effort data, the appropriate period for catch average may be 1987 to 2003, using the following seven years: 1987-1989, 1992, 1994, 2001, and 2003. The average yield during 1987- 2003 is 86,400 pounds. If the OFL was established for this stock based upon the use of average yield over this time period, the OFL would be 86,400 pounds. If the GHL were set at 75% of the OFL, this would be 64,800 pounds. This OFL may not be accurate because mean catch for St. Matthew Island golden king crab may be too low (the maximum annual catch is more than 4.7 times of the average).

Under Alternative 3, this stock would be placed in Tier 6, whereby OFL would be set at zero, unless the SSC establishes an alternative value based on the best scientific information. Under Option A, this stock would be removed from the FMP and managed exclusively by the State. The effects of removing this stock from the FMP on the stock itself would be negligible because this action would not change their 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 Chapter reviews the stock status, 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 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 grooved 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. Retention of scarlet king crabs captured incidentally during fisheries that target other deepwater crab species 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 ADF&G 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). No stock assessment surveys are performed on any of the three stocks and population levels are unknown. Fishery data from the mid 1990s is the primary source of information regarding abundance and stock status.

Prior to 1988, grooved Tanner crabs were landed only occasionally in the BSAI as incidental catch in the Aleutian Islands golden king crab fishery. A special permit fishery for deep water Tanner crabs (including grooved Tanner crabs) was established in 1988 and in that year two vessels obtained permits to fish for EBS grooved Tanner crabs. No commercial landings of grooved Tanner crabs were reported from the BSAI from 1989 through 1991, however, in 1992 only two vessels landed grooved Tanner crabs as incidental catch in the golden king crab fishery. In 1993, seven vessels directed effort on grooved Tanner crabs and reported landings from the EBS and EAI. Exploratory fishery participation, effort, harvest, and value in the BSAI grooved Tanner crab fisheries increased steadily from 1993 through 1995, when 15 vessels landed 2-million pounds.

Catch per unit of effort from the EAI stock declined from 15 legal crabs per pot lift in 1993 to two in 1996 and catches decreased from over 850,000 pounds (386 t) in 1995 to 106,000 pounds (48 t) in 1996. In addition, fishing effort was concentrated in three statistical areas immediately to the south of Unalaska Island. 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).

Participation, effort, and landings declined in 1996 to the extent that the EBS and EAI 1996 harvests were roughly 10% of the 1995 levels. During 1997-1999 there were no landings of BSAI grooved Tanner crabs and since 2000 fishery effort and catch has been sporadic and low relative to 1993-1995.

ADF&G manages the grooved Tanner crab fisheries as a special-permit fishery under provisions of **5 AAC 35.511** that allow for exploration and development of the fishery without the benefit of a stock assessment survey. Grooved Tanner crab may be harvested only under the conditions of a permit issued by ADF&G. Under **5 AAC 35.511**, conditions may be placed on the permits by ADF&G to: restrict the depths fished; establish season dates; establish areas of operation by statistical areas or district; establish minimum size for retained crabs; require presence of an onboard observer; require logbook reporting of operations; and specify the type, size, and configuration of the pots fished. Given low catch and effort during 1988-1992 no restrictions other than area or district registration were placed on the permits until 1993, when a minimum size limit of 5 inches (127 mm) carapace width (including spines) was established in issued permits. Beginning in 1994, requirements to carry observers were put on the permits. Since 1997 specifications for escape mechanisms for the pots were also placed on the permits. Also, since 1997, ADF&G has managed both the EBS and EAI stocks to assure that the harvests do not exceed 200,000 pounds (91 t). Although exploratory fishing for WAI grooved Tanner crab was allowed under a maximum harvest level of 100,000 pounds (45 t) from 1997 through 1999, the WAI stock has been closed to commercial fishing since 2000.

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 ADF&G'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, ADF&G 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.

9.2 Effects on Other Crab Stocks

Information is insufficient to define B_{MSY} for these crab stocks and only limited information is available for these stocks from historic fisheries. Crabs stocks landed as incidental catch during fisheries targeting other species of crabs include: 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 historic fisheries that targeted AI golden king crab. For Eastern Bering Sea scarlet king crab and Bering Sea triangle Tanner crab, bycatch data are available from the historic directed Eastern Bering Sea grooved Tanner crab fishery. Information is insufficient to define B_{MSY} for these crab stocks. Limited information is available for these stocks with no directed fisheries.

Four of the stocks have been harvested only sporadically in exploratory fisheries: Eastern Aleutian Islands triangle Tanner crab, Eastern Aleutian Islands grooved Tanner crab, Western Aleutian Islands grooved Tanner crab, and Eastern Bering Sea grooved Tanner crab. Landings of Eastern Aleutian Islands triangle Tanner crab and Eastern Aleutian Islands grooved Tanner crabs have occurred during only one year (2001) out of the last 10 years. For Western Aleutian Islands grooved Tanner crab, there has been no fishing effort during the last 10 years. Consequently, of the scarlet king crab, triangle Tanner crab, and grooved Tanner crabs stocks covered by this FMP, only the Eastern Bering Sea grooved Tanner crab stock may have a catch history sufficient for use to define overfishing levels.

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 Alternative 2, all stocks in this section are recommended for Tier 5 consideration for purposes of this analysis, including stocks with very limited catch history. Tier 5 OFLs would be calculated based upon average catch in years with fishing efforts 10 percent or higher of the mean fishing efforts. Only using data with fishing efforts 10 percent or higher of the average efforts filters out years that do not represent normal fishing effort. (Table 9-1)

The problems with establishing an OFL based on catch history for these stocks include: (1) catch data come from exploratory and incidental fisheries for most stocks, (2) there are only 2 to 4 years of catch data for several stocks, and (3) mean catch for some species may be either too high (grooved Tanner crab) or too low (Aleutian Islands scarlet king crab). The mean catch for Eastern Aleutian Islands grooved Tanner crab used to set the OFL of 504,800 pounds may be too high (only 4 years of data and the CPUE declined during these 4 years). In contrast, the State established a GHL range of 50,000 (23 t) to 200,000 (91 t) pounds for grooved Tanner crab in the Eastern Aleutian District. For Eastern Bering Sea grooved Tanner crab, there has been sporadic fishing effort during the last 10 years and limited information is available for this stock. The mean catch for Eastern Bering Sea grooved Tanner crab used to set the OFL of 351,900 pounds may be too high when compared to the State's harvest limit of 200,000 (91 t) pounds. Additionally, Aleutian Islands scarlet king crab OFL of 13,400 may be too low (the maximum annual catch of 63,000 is more than 4.7 times of the average).

Table 9-1 Estimated OFLs (in pounds) for other crab stocks in Tier 5 under Alternative 2. OFLs based on mean catches from appropriate period during 1985-2005. Only used data with fishing efforts 10% or higher of the average efforts.

Stock	OFL	GHL= 75% of OFL	Years used	Number of years
EBS grooved Tanner crab	351,900	263,925	93-96, 01, 03, 04	7
Aleutian Islands scarlet king crab	13,400	10,050	92, 94-04	12
EBS scarlet king crab	14,800	11,100	95, 96, 01, 03-05	6
Bering Sea triangle Tanner crab	37,700	28,275	95, 96, 01, 04	4
Eastern Aleutian Islands triangle Tanner crab	295,300	221,475	95, 96	2
Eastern Aleutian Islands grooved Tanner crab	504,800	378,600	93-96	4
Western Aleutian Islands grooved Tanner crab	74,600	55,950	94-96	3

Under the Tier system in Alternatives 3, all stocks in this section are recommended for Tier 6 consideration for purposes of this analysis. For Tier 6 stocks, a default OFL would be set at zero for the directed fishery, unless the SSC establishes an alternative value based on the best available scientific information. No additional status determination criteria are currently estimated for these stocks nor proposed under the revised definitions.

Option A would remove all of the crab stocks in this Chapter from the FMP. These stocks would continue to be managed by the State, as detailed in section 9.1. The effects of removing these stocks from the FMP on the stocks themselves would be negligible because this action would not change their management.

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**

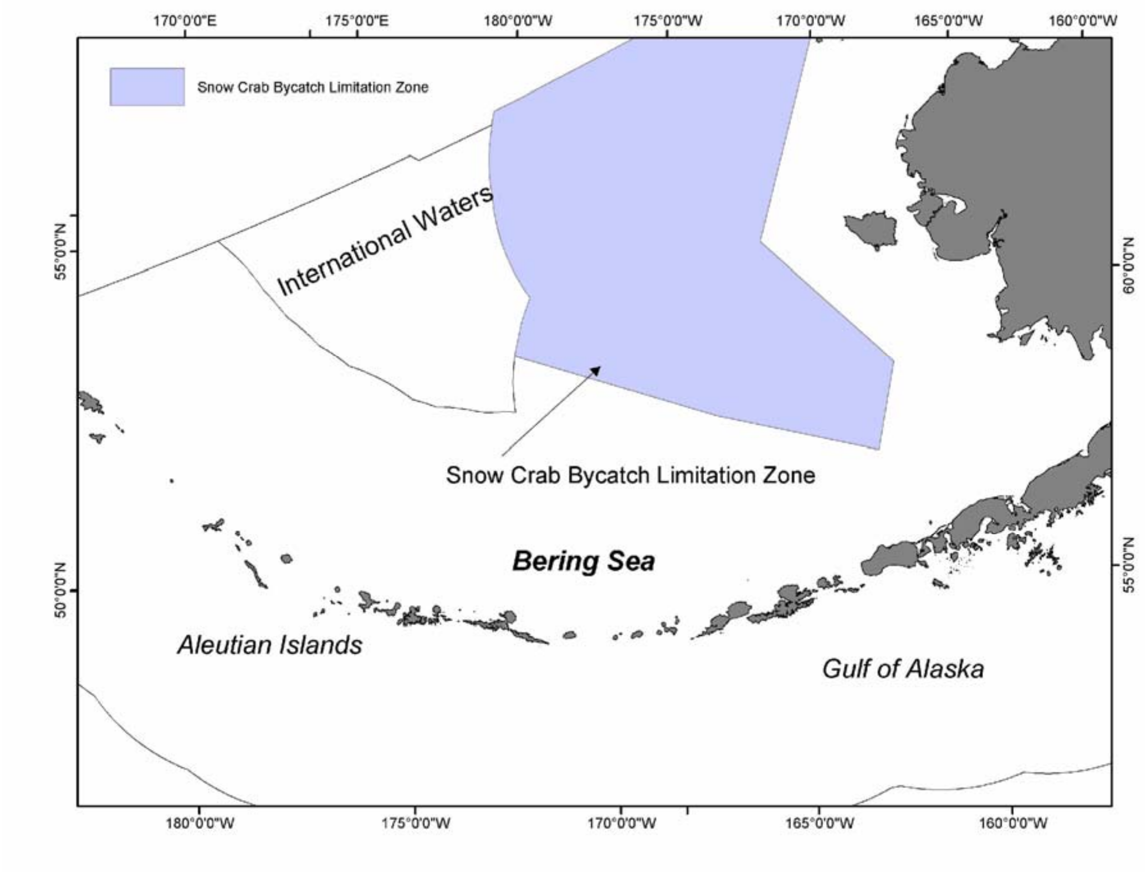

Figure 10-1 ***C. opilio*** **Bycatch Limitation Zone (COBLZ)**

Under Amendment 80 to the BSAI Groundfish FMP, the current bycatch limits as established by Amendment 40 (and modified by Amendment 57) for snow crab would 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 would 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.

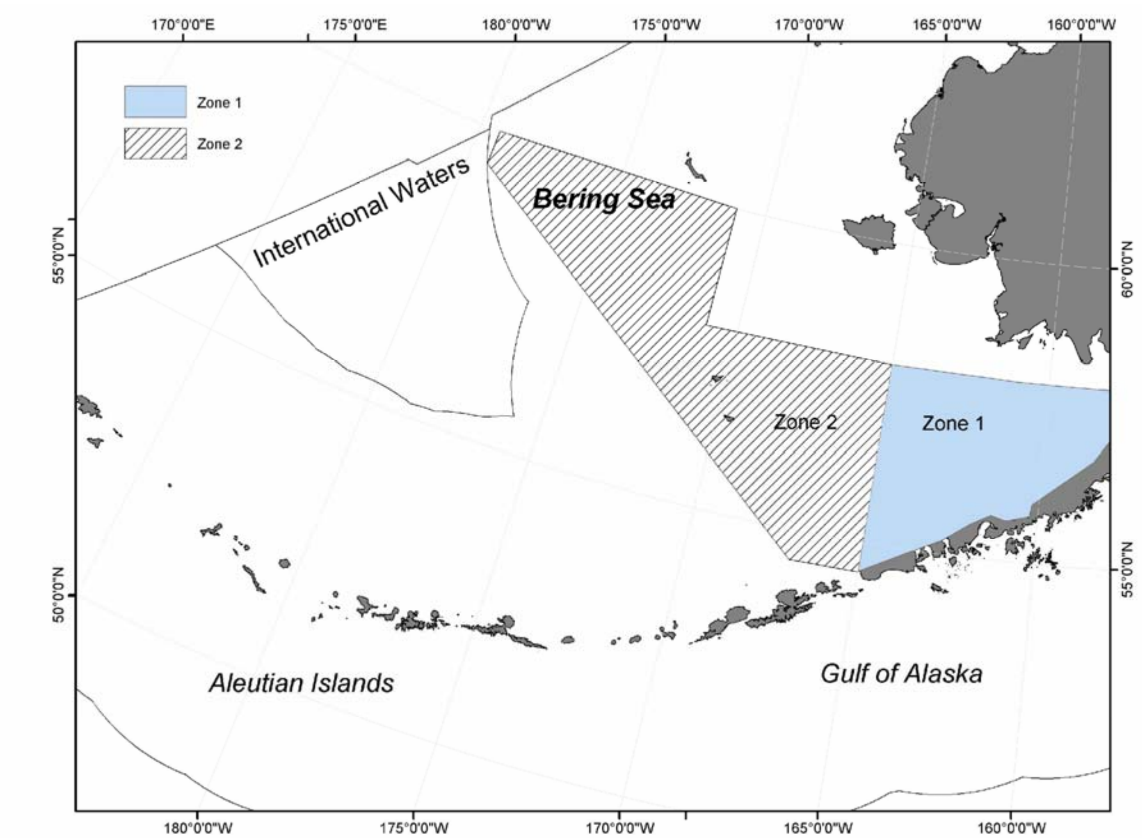

Figure 10-2 Zones 1 and 2 for red king crab and Tanner crab

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

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

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 crabs and 260,000 Tanner crabs. 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). However areas are closed in some regions due to in-season monitoring of bycatch rates, particularly in the Bering Sea region. A rate of 1 crab/1lb scallop meats has been used by ADF&G since 1993 as a conservative measure to protect crab stocks. Regions are closed by ADF&G for exceeding this rate.

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.

For the scallop fishery, the practice of using a rate-based approach to manage the fishery in-season could lead to a potential constraint on the scallop fishery if crab stocks increase. This is particularly important in the Bering Sea scallop registration area, where the fleet has been moved off grounds for exceeding this rate while remaining well below CBLs for the region. Additional information is available in the 2007 Scallop Stock Assessment and Fishery Evaluation (SAFE) report (NPFMC 2007).

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 a Biological Opinion, are conducted for Federal actions that may have an adverse affect on the listed species. Through the Biological Opinion, 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 consultation process 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 of the alternatives on the social and economic environment. The economic and social impacts differ in fundamental ways from other resource components examined in this EA. Effects on the social and economic environment 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.

This section provides the social and economic analysis of the three alternatives: (1) Status Quo/No Action, (2) new tier system with five tiers and a framework for assigning each crab stock into a tier and for setting the OFLs, and (3) new tier system with six tiers and a framework for assigning each crab stock into a tier and for setting the OFLs. The proposed action also includes two sets of options. Options 1 and 2 establish different annual processes for tier and OFL setting and review. Option 1 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. Option 2 would establish a process whereby the Council and SSC would review the models and tier system framework, tier levels, and model parameterization in June. Option A would remove specific stocks from the FMP for which there is no directed fishery, a limited exploratory fishery, or the majority of catch occurs in State waters. Under Option B, the current 22 crab stocks would remain in the FMP and, as required by the Magnuson-Stevens Act, OFLs would need to be established for all FMP stocks.

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 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.

As a result, the economic and social analysis of the alternatives under consideration 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 fishing 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.

12.1 Existing Crab Management[3]

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 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

[3] A large part of the crab management background section originates from Barnard and Pengilly, 2006

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.

The Program contains several provisions intended to protect the interests of communities that depend on the fisheries. Many of the measures, including the underlying dual share structure, are intended by the Council to provide community protections absent in a more traditional harvester only IFQ program. Allocation of processing shares for 90 percent of the TAC is intended to support communities' historic participation by tying quota to community based processing. This community link is intended to provide stability to not only the processing sector but also to support industries in the communities[4].

To maintain the historic regional distribution of landings in the crab fisheries, the Council chose to regionalize harvest and processing shares. QS, Class A IFQ (which requires delivery to a processor holding unused IPQs) and processor shares are regionally designated under the Program based on the location of the activity that gave rise to the allocation. Crab harvested with regionally designated IFQ are required to be delivered to a processor in the designated region. Likewise, a processor with regionally designated shares are required to accept delivery of and process crab in the designated region. Communities in the Pribilof Islands are the prime beneficiaries of the regionalization of the program. Table 12-1 provides PQS by region and community.

Table 12-1 Crab rationalization PQS by region and community

Fishery	Region	Community of Right of First Refusal	Number of PQS holders	Percent of PQS pool
Bristol Bay red king crab	North	St. Paul	2	2.6
	South	Akutan	1	19.9
		False Pass	1	3.7
		King Cove	1	12.8
		Kodiak	3	3.8
		None	3	2.7
		Port Moller	3	3.5
		Unalaska	11	51.1
		Total		97.4

[4] This paragraph and the following three paragraphs originate from Fina (2004).

Fishery	Region	Community of Right of First Refusal	Number of PQS holders	Percent of PQS pool
Bering Sea *C. opilio*	North	None	3	1.0
		St. George	2	9.7
		St. Paul	6	36.3
		Total		47.0
	South	Akutan	1	9.7
		King Cove	1	6.3
		Kodiak	4	0.1
		None	4	1.8
		Unalaska	12	35.0
		Total		53.0
E. Aleutian Islands Golden King crab	South	Akutan	1	1.0
		None	1	0.9
		Unalaska	7	98.1
Pribilof Island red and blue king crab	North	None	1	0.3
		St. Paul	5	67.3
		Total		67.5
	South	Akutan	1	1.2
		King Cove	1	3.8
		Kodiak	4	2.9
		Unalaska	5	24.6
		Total		32.5
St. Matthews blue king crab	North	None	5	64.6
		St. Paul	4	13.8
		Total	9	78.3
	South	Akutan	1	2.7
		King Cove	1	1.3
		Kodiak	1	0.0
		Unalaska	6	17.6
		Total		21.7
W. Aleutian Islands golden king crab	Undesignated	NA	9	50.0
	West	NA	10	50.0
W. Aleutian Islands red king crab	South	NA	10	100.0

The Program includes several measures to protect revenues and employment in fishery dependent coastal communities with a history of participation in these fisheries. These measures take the form of geographic landing and/or transfer restrictions on IFQ, PQS, and IPQ. There are nine Eligible Crab Communities: Adak, Akutan, Unalaska/Dutch Harbor, False Pass, King Cove, Kodiak, Port Moller, Saint George, and Saint Paul. Of these, all but Adak have the “right of First Refusal” on proposed sales of PQS. All nine are protected by “Cooling-off,” a temporary prohibition against use of IPQ outside of the community or borough boundary in which the IPQ was derived. Three crab fisheries are exempt from the cooling off provision: Tanner crab, Western Aleutian Islands red king crab, and Western Aleutian Islands golden king crab. The two-year “cooling off period” will expire July 1, 2007.

Exceptions to the right of first refusal allow a company to consolidate operations among several commonly owned plants to achieve intra-company efficiencies and to lease shares temporarily outside of a community. To exercise a right of first refusal, a community group is required to meet all of the terms and conditions of the underlying transaction. There is the potential for companies to use the exceptions to the right and the performance requirements to prevent the community from exercising their right of first refusal.

Under the Program, 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.

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 12-2 provides season open dates for BSAI crab fisheries.

Table 12-2 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. Crab rationalization, which was implemented in August 2005, has reduced the number of vessels participating in the BSAI crab fisheries and has slowed the pace of the BSAI crab fisheries. Table 12-3 depicts the changes 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. In contrast, 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 12-3 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 presents processor participation by BSAI crab and other groundfish species. For each species, the number of processors participating and wholesale value are presented in Table 12-4 and Table 12-5. Crab processor data for Dutch Harbor and Kodiak are provided in the community profiles presented in Sections 12.6.2 and 12.6.5. Processor data for Akutan, King Cove, St. Paul, and Adak are not reported to prevent release of confidential information.

Table 12-4. The number of unique crab processors aggregated across Dutch Harbor, Akutan, King Cove, Kodiak, St. Paul, and Adak communities from 2000 to 2005

	Year					
Species	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Crab, Bairdi	-	8	6	6	7	13
Crab, Golden King	8	7	5	7	6	6
Crab, Opilio	14	14	17	15	17	14
Crab, Red King	12	13	15	18	16	11
Grand Total	**34**	**42**	**43**	**46**	**46**	**44**

Data Source: ADFG Commercial Operator Annual Report Summary

Table 12-5. Value (in dollars) of crab processed aggregated across Dutch Harbor, Akutan, King Cove, Kodiak, St. Paul, and Adak processors by species from 2000 to 2005

	Year					
Species	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Crab, Bairdi		$2,022,845	$1,089,537	$1,820,021	$2,884,915	$6,040,383
Crab, Golden King	$26,139,816	$27,002,265	$21,059,192	$27,603,224	$21,138,595	$12,392,228
Crab, Opilio	$70,920,022	$42,957,017	$69,431,163	$70,922,518	$69,891,523	$58,943,785
Crab, Red King	$38,795,745	$49,434,366	$71,023,874	$87,238,762	$80,698,679	$91,612,958
Total	**$135,855,583**	**$121,416,493**	**$162,603,766**	**$187,584,525**	**$174,613,712**	**$168,989,354**

Data

Source: ADFG Commercial Operator Annual Report Summary

12.4 Estimated Ex-vessel Prices

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

Table 12-6 provides annual harvest, ex-vessel 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 ex-vessel 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 ex-vessel 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 ex-vessel prices ranged from nearly $1.50 a pound to a little over $2 a pound between 2001 and 2005. During the 2005/2006 season, ex-vessel 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 ex-vessel 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 ex-vessel price and value of the fishery declined. In the WAI, the ex-vessel 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 ex-vessel 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 ex-vessel price for that season was $1.28. The remaining BSAI crab fisheries were closed to fishing.

Table 12-6 Ex-vessel price, total value and total landed pounds by crab fishery from 2001 to 2006

Fishery	Season	Total Landed Pounds	Total Value[a]	Ex-vessel 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 study examined 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 developed a model to study the effects supply and demand on the Alaska snow and king crab markets. The study showed 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 Existing Community Conditions

In this section, six Alaska communities with direct links to the BSAI crab fishery are summarized. These communities are Unalaska, Akutan, King Cove, St. Paul, Adak, and Kodiak. These communities vary in their geographic relation to the fishery; their historical relationship to the fishery; and the nature of their contemporary engagement with the fishery through local harvesting, processing, and support sector activity or ownership. Each of these factors influences the direction and magnitude of potential social impacts associated with the proposed action. The information used in these community profiles are based on the crab fishery prior to rationalizing the crab fisheries. Current detailed community profiles since crab rationalization have not been generated at this time. This lack of current detailed community conditions hampers the description of the existing community conditions. Where available, community information was updated with more recent data.

12.6.1 Community Variability

BSAI crab communities are spread over a wide geographic range. St. Paul is located on the Pribilof Islands while Unalaska, Akutan, and Adak are located on the Aleutian Chain on the Bering Sea. King Cove and Kodiak, on the Alaska Peninsula and Kodiak Island, respectively, are located on the Gulf of Alaska.

These communities have very different histories with respect to the Bering Sea and Aleutian Islands crab fisheries. Early in the development of these fisheries, Kodiak was the center of crab processing. Somewhat later, Unalaska/Dutch Harbor emerged as the center of both processing and fishery support activity, a position it has held since the crab boom years of the late 1970s. King Cove, a community with a substantial fisheries based economy for the better part of century, has emerged as a multispecies dependent community wherein crab plays a major role. The community of Akutan, located on Akutan Island east of Unalaska/Dutch Harbor in the Aleutians, is also a major Bering Sea crab port. Akutan has one of the largest commercial shore plants in the region, but has very limited direct harvest participation and support service sector involvement. St. Paul has quite a different historical relationship to local commercial natural resources utilization than either Unalaska or King Cove. St. Paul was founded upon and for decades was sustained by a commercial harvest of marine mammals rather than fishery resources. Further, St. Paul faces fishery development challenges not seen in other crab ports. Despite being adjacent to waters where a great deal of crab harvest activity takes place, St. Paul has seen little onshore commercial fisheries related development, due to a lack of adequate harbor facilities and infrastructure as well as logistical challenges inherent in a location that is relatively remote from major transportation routes and the environmental constraints of more extreme weather and ice conditions resulting from its northerly location.

Adak has yet a different historical relationship to the fishery. Like St. Paul, historically Adak did not have a commercial fisheries based economy. While some commercial fishing related activity has taken place over the years, Adak was first and foremost a military community until very recently. This has meant that the recently emerged civilian community is essentially attempting to build a fisheries based local economy from scratch. Kodiak, which early in the development of the Bering Sea crab fishery was at its economic center, has becomes less of a factor in this respect in more recent due to this development of crab harvesting, processing, and fishery support capacity elsewhere. These varying historical relationships with the fisheries have served to shape the contemporary involvement with the BSAI crab fisheries and will influence the way that social impacts result from this action will affect the different communities.

Changes in the TAC of the BSAI crab as a result of revising crab overfishing definitions could have both direct and indirect economic impacts for any or all of the communities noted above. Although the magnitude of these impacts can not be quantified, it is safe to say that the impacts of this action would not be uniform in distribution. Regional and community protection measures from rationalization, proximity to fishing grounds, differing natures of resident and nonresident fleets that make local and non-local deliveries, locally owned or locally sited processing plant capacity and capability differences, availability and variety of support facilities offered, and intermediate and final markets served would effect the distribution across the major BSAI crab fishing ports.

The following community information presented, unless otherwise noted, is excerpted from EDAW (2005).

12.6.2 Unalaska

As noted above, the king crab fishery during the late 1970s played a significant role in its development as a town dependent upon fishing and seafood processing. Although more diversified now, crab harvesting and processing still play a significant economic role in the community. Unalaska has ranked as the number one U.S. port in volume of landings since 1992 and ranked first in value of landings from 1988 to 1999. In 2000, Unalaska dropped to second in value of landings. In 2003, the volume of fish landed was 908 million pounds at value of 156.9 million.

From an employment perspective, commercial fishing and seafood processing are a very large component of the employment base in Unalaska. The four largest employers in the community are UniSea, Inc., Westward Seafoods, Inc, Alyeska Seafood, Inc. and Royal Aleutian Seafoods, Inc.

Looking at gross revenue estimates for Unalaska permit holders, it would appear that local permit holders are heavily dependent upon king and Tanner crab. The gross revenue for Dutch Harbor permit holders for 2002 was $328 thousand for Tanner crab and $736 thousand for king crab (EDAW, 2005). In relation to the total gross revenue, tanner crab was 9.83% and king crab was 22.04% for 2002. These figures would suggest that the local fleet is highly dependent on tanner and king crab revenue, but interviews in the community suggest that very few vessels owned by individuals considered to be local residents are currently engaged in these fisheries. This suggests some caution should be used in interpreting these data, as it is possible that even a few high producing permits held by individuals from outside the community, but who listed an Unalaska/Dutch Harbor address on their permit, could skew the date. This is more likely to occur in Unalaska than in other regional ports, given the large number of vessels from elsewhere that work out of the community.

The vast majority of fish landed in Unalaska both in terms of volume and value are landed by vessels from outside of the community. Unalaska is at once both an industrial-scale fishing community and a small boat fleet town. It is home to a greater concentration of processing and catcher vessel activity than any other Alaskan community, but its residential fleet is much smaller than the fleets of some other fishing communities with much smaller populations within the same region (e.g., King Cove and Sand Point).

There is at present little direct participation in the BSAI crab fisheries by vessels owned or crewed by local residents. Local vessels also do not participate in the locally important pollock fishery, but they do participate in the local cod, halibut, and crab fisheries on a small scale. Commercial fishing for small boat owners in Unalaska is generally one part of a (variable) multiple income source strategy of "piecing together a living."

According to information gained from interviews conducted for the NPFMC crab rationalization project in December 2001, local small boat participation in BSAI crab fisheries has dropped to near zero due to closures restricting access to crab in waters near the community, with Tanner having been closed since 1994 and king crab since the early 1980s. When open, the Tanner fishery was effectively a Unalaska Bay fishery for the small boats, but there was some competition from larger vessels that would drop pots on the local grounds on the way out to more distant fishing areas and retrieve them on their return to port. Local small vessel owners interviewed ranged in their estimate of the number of locally owned small vessels still participating in any BSAI crab fishery as between one and three vessels. At least some local small vessels do participate indirectly in the crab fisheries by selling bait to the larger vessel crab fleet. Reportedly, however, this business has been made much more difficult with the very short crab seasons. A lengthening of seasons through rationalization should assist this local market for small vessels owners, through longer turnarounds as well as more port calls during an extended season. This would make investment in such enterprises less speculative as well.

A very recent (2004) change for the local fleet has been the reopening of the Eastern Aleutian District local C. *bairdi* Tanner crab fishery after a decade of closure. The season opened on January 15, with a guideline harvest level of 47,219 pounds in Unalaska Bay and 87,891 pounds in Makushin Bay. The Unalaska Bay portion of the fishery closed on January 19, and the Makusin Bay portion closed on February 3. The 2004 harvest level was a small fraction of the average levels seen in the 1970 and 1980s (the peak of almost 2.5 million pounds occurred in 1977), but this does represent a positive development for local fishermen. Four of the 7 vessels over 60 feet and 20 of the 21 vessels under 60 feet with interim use Dutch Harbor Tanner crab are listed as locally owned, but a gear limit of 300 pots, so while additional vessels may be attracted to the fishery, there likely will be a relatively low number of vessel owners who will find it attractive to share this pot limit (Northern Economics 2004). Locally provided harvest figures (that included both local and outside vessels) indicate that in 2004 a total of 128,000 pounds were harvested at $3.25 per pound for a harvest value of $415,000, while in 2005 a total of 35,000 pounds were harvested at $2.50 per pound for a harvest value of $85,000. The sharp drop-off in 2005 was attributed to the Makushin Bay closure brought about by the oil spill from the December 2004 wreck of the freighter M/V Selendang Ayu.

Ownership patterns of the larger catcher vessels have been changing in recent years, and this is making the local versus outside fleet dynamic somewhat more complex. This is more obvious within the groundfish fishery (and the pollock fishery specifically) than it is within the crab fishery. Within the pollock fishery, one of the trends in recent years has been the dramatic increase in ownership and/or control (through third-party entities with some type of business relationship to the processors) of pollock harvest vessels by the shoreplants in Unalaska. Prior to this pattern of acquisition, it was accurate to say that no permanent residents of Unalaska were involved in the pollock fishery as vessel owners, nor were any vessels homeported out of Unalaska in the sense of being the community of residence for the skipper and crew. This change in ownership patter, while it may have shifted where vessels are homeported or, perhaps more importantly from an economic perspective, spend more of the year, it is still the case that very few, if any, permanent residents of the community work on pollock harvesting vessels.

There are also indications that there are fundamental changes in relations between vessel crew and owners with the conversion of one or more vessel crew compensation structures from a share to a wage basis on vessels controlled by processing entities. How closely this is tied to pollock rationalization itself, and how this experience may in turn be generalized to crab rationalization conditions is unclear; however, this type of shift is perhaps consistent with an assigned quota system where vessel revenues are generally predictable.

Table 12-7 summarizes Commercial Operators Annual Report (COAR) processing data by year for the period 2000 through 2005 by species for pounds purchased for processors in the community along with the ex-vessel and wholesale value associated with those purchases. This information may be used to gauge community processing sector relative engagement in and dependency on particular fisheries. As shown, pollock accounts for nearly 70 percent of the total wholesale value processed in Dutch Harbor in 2005. The second largest contributor to total wholesale value processed in Dutch Harbor is crab at nearly 20 percent. Of the crab species, red king crab provided the largest contribution at $51 million in the 2005 followed by snow crab at $33 million.

Table 12-7 Processing summary for Unalaska/Dutch Harbor, 2000-2005

	2000	2001	2002	2003	2004	2005
Species	**Number of Processors**					
Cod, Pacific	11	7	7	7	6	7
Crab, Bairdi				1	2	3
Crab, Golden King	5	3	3	3	3	5
Crab, Opilio	5	7	8	8	8	6
Crab, Red King	3	5	9	9	7	4
Halibut, Sablefish, and Other Groundfish	9	10	10	10	10	8
Pollock, walleye	4	5	4	4	4	4
Salmon and Herring	1	2	2	2	3	1
Total	**38**	**39**	**43**	**44**	**43**	**38**
	Pounds Purchased					
Cod, Pacific	57,457,806	45,428,613	53,620,560	55,791,013	66,000,750	61,998,817
Crab, Bairdi	-	-	-	*	*	*
Crab, Golden King	4,907,953	*	*	*	*	3,272,765
Crab, Opilio	10,828,377	9,908,446	13,068,040	12,428,315	10,799,182	12,227,462
Crab, Red King	*	3,376,258	4,103,656	7,012,706	6,200,986	7,907,256
Halibut, Sablefish, and Other Groundfish	15,542,080	9,258,909	10,384,614	8,736,311	8,338,294	8,644,335
Pollock, walleye	614,006,201	767,967,412	818,424,456	825,449,453	811,212,331	812,404,032
Salmon and Herring	*	*	*	*	*	*
Total	**705,039,659**	**841,705,961**	**905,798,555**	**913,220,510**	**906,306,639**	**907,030,323**
	Ex-vessel Value					
Cod, Pacific	$17,192,672	$11,014,115	$11,155,935	$15,664,700	$15,341,475	$16,168,938
Crab, Bairdi	-	-	-	*	*	*
Crab, Golden King	$16,597,605	*	*	*	*	$9,106,107
Crab, Opilio	$19,996,719	$15,247,811	$18,036,649	$23,041,113	$22,356,119	$22,176,159
Crab, Red King	*	$16,602,295	$25,675,396	$36,111,810	$29,286,339	$35,889,896
Halibut, Sablefish, and Other Groundfish	$20,082,125	$13,866,890	$17,751,673	$19,216,461	$18,234,625	$18,014,568
Pollock, walleye	$75,734,720	$85,111,759	$96,406,260	$91,058,625	$88,519,966	$102,221,682
Salmon and Herring	*	*	*	*	*	*
Total	**$160,714,732**	**$156,181,349**	**$180,315,293**	**$196,946,917**	**$183,273,020**	**$203,867,090**
	Wholesale Value					
Cod, Pacific	$36,894,677	$26,755,214	$39,818,572	$41,426,284	$37,350,851	$44,032,802
Crab, Bairdi	-	-	-	*	*	*
Crab, Golden King	$21,279,999	*	*	*	*	$11,452,928
Crab, Opilio	$31,395,515	$24,570,523	$30,516,665	$38,560,268	$35,055,004	$33,221,295
Crab, Red King	*	$29,229,264	$40,034,688	$52,340,470	$46,717,154	$51,799,927
Halibut, Sablefish, and Other Groundfish	$26,147,381	$19,333,823	$20,587,667	$22,602,613	$21,935,668	$20,466,546
Pollock, walleye	$219,889,562	$237,721,421	$253,253,485	$268,674,713	$273,768,020	$340,242,214
Salmon and Herring	*	*	*	*	*	*
Total	**$355,926,180**	**$361,548,654**	**$399,070,990**	**$442,297,638**	**$430,261,461**	**$501,586,252**

Source: ADFG Commercial Operator Annual Report Summary
* Indicates the data are confidential and cannot be released

Unalaska is unique among Alaska coastal communities in the degree to which it provides support services for the Bering Sea fisheries. As described in detail in the Inshore/Offshore-1 community profile, Unalaska serves as an important support port for several different sectors of subsectors of the pollock fishery, including harvesters (including a wide range of vessel classes), inshore processors (including shoreside and floating processors), and offshore processors (including processor/motherships and catcher/processors). This same pattern holds true for the crab fishery and the other major fisheries of the area.

Support services include a wide range of companies, including such diverse services as accounting and bookkeeping, banking, construction and engineering, diesel sales and services, electrical and electronics services, freight forwarding, hydraulic services, logistical support, marine pilots/tugs, maritime agencies, gear replacement and repair, vessel repair, stevedoring, vehicle rentals, warehousing, and welding, among others. There is no other community in the region with this type of development and capacity to support the various fishery sectors in the Bering Sea.

12.6.3 King Cove

For a number of decades, King Cove was primarily involved in the commercial salmon fisheries of the area, but with the decline of the salmon fishery, processing in the community has diversified into other species, including both Gulf of Alaska and Bering Sea fisheries, and both Bering Sea crab and groundfish have come to be important components of local processing operations. The shore processor in King Cove is now Peter Pan Seafoods, and the plant processes salmon, crab, and halibut, along with pollock, Pacific cod, and other groundfish.

In terms of employment, a relatively recent study concluded that more than 80 percent of King Cove's workforce is employed full time in the commercial fishery (USACE 1997). Fishing employment was followed by local government (borough and local) and then by private businesses. These results need to be interpreted in context, however, as this report ranked seafood processing after each of these other employers in terms of local employment, meaning that the vast majority of the workforce at the shoreplant was either not counted as community residents under the study methodology or the study was conducted during an off-season time when most workers were not present in the community. Also, commercial fisherman are self-employed, are difficult to enumerate, and thus are often not well represented in employment discussions. Thus, the 80 percent employment "dependency" of the local economy on the commercial fishing sector is probably underestimated.

The King Cove economy in general is cyclical, due largely to its strong relationship to fishing and fish processing. In recent years, because of a number of factors, including but not limited to low salmon prices, the community has experienced severe local effects from a number of fisheries related downturns as well as non-fisheries related events. Given that many of the factors cited for these effects are regional and cumulative in nature (low fish prices, Steller sea lion protection measures, competition from farmed fish, Area M restrictions, low Bering Sea Guideline Harvest Levels (GHLs), and other management and resource concerns), it is possible that King Cove has grown in size because of population movement from smaller regional communities in even worse economic shape. This dynamic is likely to continue but is not, however, likely to strengthen the local economy.

The total number of vessels and the number of vessels fishing have steadily declined during the 1995 to 2002 period. The number of vessels fishing in 2002 is approximately half of the number of vessels that were fishing in 1995. In 2002, there were a total of 80 vessels owned by King Cove residents. Of those 80 vessels, 69 were less than 59 feet length overall with the remaining vessels ranging from 60-124 feet length overall.

In addition to vessel ownership information, data on permit holders for King Cove provide a perspective on local harvester engagement in various fisheries. Salmon permits dominate all other permits, with relatively few individuals holding only one type of permit other than salmon. In 2002, there were 24 salmon permits, 7 groundfish permits, 4 halibut and sablefish permits, and 3 crab/all other species permits. Looking at estimates of the percentage of non-confidential gross revenues for King Cove permit holders by species group by year provides one type of fundamental measure of "dependency" of community harvesters on particular fisheries. Seine caught salmon, pot caught groundfish, and trawl caught groundfish have consistently comprised more than 10 percent of total estimated grow revenue from 1995 to 2002, with seine salmon going over 30 percent some years and pot groundfish going over 20 percent some years. During that same period, either tanner or king crab has accounted for over 10 percent of total estimated gross earnings and for each of these years the estimated gross revenue for Tanner and king crag combined has exceeded 20 percent of the total estimated gross revenue for local permit holders.

King Cove, as already noted, has a sizable residential fleet. Local vessels deliver primarily to the King Cove Peter Pan Seafoods shoreplant, but outside vessels deliver to this plant as well. Outside vessels also provide income and employment opportunities for King Cove residents, both in terms of support service opportunities (as discussed in a subsequent section) and in terms of direct fishery participation employment, as noted below. Peter Pan representatives report that they have designed their local processing operations around serving the smaller range of the catcher vessel fleet, and the fishery around the Pribilof Islands (Schwarzmiller and Sterling, personal communication, 2002).

The local residential fleet in King Cove as a whole is primarily focused on salmon, with a secondary focus on cod. With respect to crab, beyond the one locally owned relatively large vessel that fishes Bering Sea crab with a local crew (skipper plus four crew for a total of five persons on board), three other local boats (58-footers) did qualify for the Pribilof fisheries, but reportedly not one is active at present. Conditions are extremely difficult for these relatively small vessels, and one of these vessels was lost in the mid-1990s, with the loss of one life. Many more small vessels reportedly have fished the local Tanner crab fishery during the years that it was open. Additionally, before seasons were changed from the fall to the winter, a time of year much less favorable for fishing by small vessels, several local boats in the 58-foot class were also reported to have fished in the Bering Sea crab fisheries but have not done so since the change a number of years ago.

There is also significant local direct participation in the Bering Sea crab fisheries on non-locally owned vessels. One outside owner keeps four Bering Sea crab vessels in King Cove most of the time, and two of these vessels are skippered by King Cove residents and have crews comprised 100 percent of King Cove residents (i.e., four crew in addition to the skipper), while the other two have outside skippers but local crew members. In addition to these four vessels, local fishermen estimate that about a half-dozen to a dozen other King Cove residents have crewed aboard outside crab boats in any given season in recent years (but apparently no King Cove residents crew on other outside vessels for other fisheries). These vessels and their crew opportunities become known to King Cove residents in a variety of ways. Most vessels spend at least some time in the community before and after crab seasons, an estimated 40 to 50 outside vessels store crab pots in the community and others become known to locals when they act as tenders during other fisheries. Individuals who crew on these outside boats include, among others, owners of King Cove local fleet vessels. Thus, while only one locally owned vessel fishes crab in the Bering Sea, crabbing in the Bering Sea nonetheless represents a significant source of income and employment for commercial fishermen in King Cove.

With one exception, BSAI crab boats that deliver to the local plant are from outside the community, typically from Kodiak or the Pacific Northwest. Some of these Pacific Northwest crab boats are moored in King Cove or other Alaskan ports. Some of these crab boats will participate in other fisheries (fishing for cod and halibut, tendering for salmon and herring), although most fish only crab for Peter Pan and tender in other fisheries as their primary revenue sources. Some will fish crab for Peter Pan and then go fish for brown crab. Peter Pan representatives estimate that about 30 crab boats have delivered to them in the past few years, but earlier years saw more crabbers delivering to the community. Because of low quotas, most, if not all, BSAI crab fisheries have recently been “one trip” fisheries, with only time enough for each crab boat to fill up once, but crab rationalization will likely change fishing and delivery dynamics in a number of different ways. The Peter Pan crab fleet is composed mostly of independent catcher vessels, with a mixture of sizes and with owners from a variety of communities. Local (King Cove and Sand Point) crab boats tend to cluster at the lower end of the size range of this fleet; whereas, Kodiak and

Pacific Northwest crab boats are larger. With one exception, no local boats participate in the Dutch Harbor crab fisheries but rather concentrate on more local (Gulf of Alaska) and Pribilof area crab fisheries. The King Cove plant does take deliveries from vessels fishing in the North Region rationalization area, but, according to plant management, for vessels to make that long of a run the processor needs to give incentives to do so. It only makes economic sense to offer these types of incentives to the larger vessels.

Harvest value and volume figures for crab vessels specifically owned by residents of King Cove cannot be discussed because the vessels are too few in number to meet confidentiality requirements. Those from Sand Point are similarly too few to discuss by community, but combining data from the two communities resolves this problem, and the two fleets do share many characteristics. For the period 1991 through 2000 (the most recent and longest time series information available), the number of vessels fishing from these two communities averaged seven vessels for Bristol Bay red king crab, five vessels for opilio crab, six vessels for tanner crab, nine vessels for Pribilof red or blue king crab, and less than one vessel for Dutch Harbor brown crab. Much of this crab would probably have been delivered to the Peter Pan processing plant in King Cove, although for some of the more distant fisheries, deliveries would be made to other plants (shore or floating) that may or may not be operated by Peter Pan. For the 1991 through 2000 period, 30 different vessels owned by residents of the two communities participated in the BSAI crab fisheries, and most (17, with 2 unknown) were 58 feet or less in length. These are multi-fishery/salmon boats and are limited in the BSAI crab fisheries by weather and sea conditions. Still, for these vessels BSAI crab contributed 68 percent of the value of their catch, with opilio as the most significant single fishery. For the combined fleet of those communities as a whole, BSAI crab contributes only 18 percent of the total value of the harvest. Larger vessels are clearly preferable for BSAI fisheries, however, of the seven vessels from these communities active in the fisheries in 2000, only five were over 58 feet in length. Many of the smaller vessels have dropped out of the BSAI fisheries, and most if not all more recent entrants are over 58 feet in length.

As noted, only one shore processor has been active in King Cove during the 1995 to 2002 period. The plant was built around the local salmon fisheries, and like the common name in the community suggests, the plant was and still is a "cannery." In recent years, however, canned salmon has declined in importance as a product for a variety of reasons including, according to plant staff, changes in markets, such as consolidation of grocery chains resulting in less buyers, and changes in economics that have resulted in a decline in margin on the product. Despite this decline, however, the King Cove plant still produces a substantial volume of canned product. In addition to canned salmon, the facility produces a variety of fresh and frozen salmon products. The King Cove plant also processes a good amount of crab and has developed groundfish processing capability, with Pacific cod and pollock as the predominant species. Substantial amounts of cod are supplied from both the Gulf of Alaska and the BSAI regions. Pollock products have been expanded in the past few years to include block as well as surimi, mince, and shatter pack fillets. The Peter Pan plant also processes halibut on a regular basis, and herring and other species less often.

Detailed production figures cannot be disclosed because of confidentiality restrictions. In general, it can be stated that King Cove is somewhat unique among the four key regional groundfish ports of Unalaska, Akutan, King Cove, and Sand Point as it is relatively more dependent upon Pacific cod than pollock, among the various groundfish species landed. The relative dependence of the plants on different species has varied over time and with stock fluctuations. For instance, 1993 was clearly a very good year for salmon, while 1996 and 1997 were both poor salmon years. While changes from 1999 to 2000 cannot be definitively stated to be other than statistical fluctuations, it is interesting to note that for King Cove the poundage processed and percentage of total plant dollars for crab decreased, while groundfish increased somewhat. Crab stocks (and quotas) have been declining. Gulf of Alaska pollock is obtained from the local small boat fleet as well as from a small number of outside boats, but BSAI pollock is obtained exclusively from larger-capacity non-resident boats.

Crab deliveries and processing were much reduced in recent years, due primarily to a reduction in quotas related to reduced stocks. AFA vessel sideboard caps on BSAI crab have also limited the amount of crab that can be processed by the King Cove plant. This has required that the processor charter an uncapped floater (otherwise employed during crabbing in the Pribilofs) to process additional crab while moored near King Cove. Otherwise, production in King Cove would be essentially limited to the amount processed in the past (as adjusted for other allocations). Peter Pan representatives report that this in fact represents a production level lower than in the past and would require that they limit the number of boats from which they buy crab. To service these boats and maintain market share, Peter Pan has thus taken the step of chartering the Steller Sea (owned by an affiliated entity) as a crab processor. Given the present low crab stocks and associated low GHLs, Peter Pan representatives report that they could physically process all the crab they currently harvest in the King Cove shoreplant, but that this would not be equitable to the Pribilofs (and may not be possible under the AFA crab caps). Certainly the use of the Steller Sea in the Pribilofs helps maintain/increase Peter Pan's market share in the crab fisheries in that area.

12.6.4 Akutan

Akutan is incorporated as a Second Class City, and, like King Cove, is part of an organized borough (the Aleutians East Borough [AEB]). Unlike Unalaska and King Cove, Akutan is a Community Development Quota (CDQ) community. It also the site of one of the largest of the shoreplants in the region, but it is also the site of a village that is geographically, demographically, socially, and historically distinct from the shoreplant. This "duality" of structure has had marked consequences for the relationship of Akutan to the Bering Sea
commercial fisheries.

The community of Akutan participates in commercial fisheries a number of different ways: through locally owned small vessel harvesting, participation in the CDQ program, having a major seafood processing plant located in the community, having floating processors operate locally, and providing limited support services to the fishery in the community. Overall, the private sector economy of the community, exclusive of the local processor, is very limited.

The vast majority of catch landed in Akutan comes off of vessels from outside of the community.
While there is a "local" non-CDQ commercial fishery, it is of a small scale, pursued out of open
skiffs.

Local Akutan residents do participate in other commercial fisheries as crew members. According to field interviews, in 2004 there were three local residents working on the Prowler factory longline boats fishing for IFQ black cod, two were deckhands on the Trident trawl fleet, and about six individuals worked as crew fishing for king or opilio crab.

The Akutan delivery fleet for the single processor, including "outside" vessels, was characterized by processing company management as comprising the following components:

- About 20 "large" boats have capacities of 500,000 to 1,000,000 pounds, mainly fishing pollock, and primarily with Seattle-area ownership (although they spend most of their time in and around Akutan).
- About 20 "smaller" boats have capacities of 150,000 to 300,000 pounds, mainly fishing pollock and cod, and primarily with Kodiak and Newport ownership.

- The crab boat fleet has little overlap with the groundfish fleet (and much less than was the case in the past). A few of the biggest crab boats also fish groundfish, but Trident's fishermen generally seem to specialize in one or the other. Crab boats are a mixture of Kodiak and Seattlearea boats, and the increased specialization in crab or groundfish may be due to the American Fisheries Act, sideboards, and relative stock sizes. This degree of specialization was the only change in the nature of Trident's delivery fleet in recent years that was described by Trident representatives.
- There is a truly local "skiff" fleet.

As a CDQ community, the community of Akutan has access to the BSAI commercial fishery resources independently of direct participation in the fishery. Akutan, like the other CDQ communities, has benefited from the increase under AFA from 7.5 percent to 10 percent of each BSAI groundfish TAC (except for the fixed gear sablefish TACs, of which CDQ communities receive 20 percent for the eastern Bering Sea and the Aleutian Islands areas). Also, like other CDQ communities, Akutan has access to the 10 percent CDQ allocation of relevant BSAI crab species. APICDA, including the community of Akutan, has participated in the crab fishery via acquiring partial (25 percent) ownership interest in two crab harvest vessels, the Golden Dawn and the Farwest Leader. In general, APICDA has substantial investments in both harvesting and processing sectors of the BSAI fishery. The most recent executive summary of APICDA's community development plan (APICDA 2002) describes the scope of these investments, as well as the community development goals they serve. In Akutan, the primary thrust is to develop a partnership with Trident to custom process the harvest of local fishermen. As described by a Trident representative, this is still a relatively small operation for Trident but quite important for a number of local fishermen. APICDA encourages local hire for all of its joint ventures and partnerships, but information on how many locals are actually so employed, and more specifically how many are from Akutan, is not available.

Trident Seafoods operates the major shore processing facility in the community of Akutan. Trident first opened a shoreplant in the community in the summer of 1982, but the original structure was destroyed by fire in the summer of 1983. The plant was rebuilt later that year, and major expansions occurred in the 1990s. Like the large processing plants in Unalaska, the Trident Akutan plant is an AFA-qualified plant with its own pollock co-op. Also like the large Unalaska plants, it is a multi-species processing facility, and it accounts for a significant amount of regional crab processing as well as groundfish processing. Specific figures are confidential. Company representatives report that BSAI crab can comprise a significant percent of the total value of processing at the plant, although the present depressed status of most crab stocks has reduced this percentage in recent years. As a high-value species, however, crab is quite important to the overall operation of the plant (although pollock is still the prime mover in terms of labor requirements and overall economic operations).

In addition to its shore facility, Trident has operated the floating processor Arctic Enterprise in Akutan Bay since its purchase several years ago. Previously operated in Beaver Inlet on Unalaska Island, this is currently (2004) the only floater that operates in Akutan Bay on an ongoing basis, or has for several years. While multiple floaters used to be common, according to city officials this changed due to environmental constraints (as well as changing fishery economics). Around 1990, the U.S. Environmental Protection Agency (EPA) declared the inner portion of Akutan Bay an "impaired water body" with the result that floaters could not operate in that area. According to city officials, the bay has subsequently moved up on EPA's water quality scale as restrictions placed on Trident have improved conditions, but the inner bay remains on the impaired list, and floaters have not returned in number. The Arctic Enterprise operates outside of this inner bay area, but still within Akutan Bay itself. According to city officials, other mobile processing capacity for crab has been brought in by Trident in recent years to help with finishing up during crab seasons.

Akutan differs sharply from nearby Unalaska in terms of opportunity to provide a support base for the commercial fishery. Akutan does not have a boat harbor, other than a small skiff moorage facility, or an airport in the community, with air service limited to either float planes or amphibious aircraft servicing the community out of Unalaska. There is also very little privately held land available for development in or around the community (outside of lands held by the local Akutan Corporation).

12.6.5 Kodiak

Despite the relative diversification of Kodiak's economy, direct fishery related employment is still a very large component of total local employment. Excluding the USCG, 4 of the top 10 employers in Kodiak in 2003 were fish processors. It should be further noted that while Kodiak's economy is apparently far more diversified than those of the other fishing communities profiled in this document (Unalaska, Akutan, and King Cove), much of the non-direct economic activity in Kodiak relies to a greater or lesser degree on fishing activity as a base. The education, service and retail, and government sectors, including the USCG, are all very important for Kodiak. In this regard, interviews with some support providers who in the past have been primarily direct fisheries-oriented indicate that more recently customers from other sectors, including USCG, tourism, government, and education, have become significant in terms of the sale of outboard motors, boats, and similar marine-oriented items than in the past. As one such provider remarked, one-third of the USCG base turns over every year, which equates to a constant stream of new customers for him. Realtors have also noted that large homes are less likely to be purchased by fishermen and more likely to be purchased by "Coasties" (USCG personnel) or other Kodiak residents than in the past. Again, however, with the exception of the tourism industry, a large reason the other sectors are as well developed as they are is related back to servicing, supplying, or otherwise directly or indirectly supporting the fishing industry. As previously noted, this includes the local USCG presence, with their primary local focus on fisheries activities.

Clearly, the value of landings in Kodiak are dominated by halibut, salmon, and Pacific cod, which together accounted for 68 percent of the total value of all species landed during 2003. These three species (or species groups) accounted for between 20 and 27 percent of total value each, while no other species accounted for more than about 10 percent of the total. Sablefish, pollock, and Bristol Bay red king crab, the next three most important species after halibut, salmon, and Pacific cod, accounted for 10 percent, 8 percent, and 6 percent of the overall total, respectively. No other species accounts for more than about 2 percent of the total. Salmon, pollock, and Pacific cod accounted for greatest volume of fish landed, with these three high volume species (or species complex) comprising over three-quarters of all landings by weight.

Kodiak residents own a very large number of vessels compared to other major fishing communities in the southwestern part of the state, such as Unalaska, Akutan, or King Cove. However, the total number of vessels has decreased in recent years from over 700 to less than 600, with less than 300 vessels actively fishing in 2002.

The Kodiak fleet is primarily composed of multi-gear and multi-species boats. Vessels in this fleet usually have a handshake agreement with a shore processor for the delivery of fish. The vessel is said to "work for" the shoreplant and sometimes the plant operators refer to "their boats" meaning those with which working relationships exist. These vessels deliver to that plant on a regular basis. The size and composition of processor fleets vary, depending on the plant's capacity and product mix, as noted in the processor discussion below. Most of the boats that deliver to Kodiak processors are multi-purpose vessels that can change fisheries to meet the current market and fishing circumstances. For example, some vessels will switch between crab, halibut, and cod or crab, halibut, and pollock. One vessel owner interviewed reported that he fished for in excess of 20 species with three different types of gear. The size of a processor's fleet depends on what season it is and what they are targeting at the time. It is not uncommon, however, for a plant to have a fleet of 8 to 16 boats fishing groundfish and crab. Among plants that run pollock, there is a bimodal distribution of trawl fishing power. The larger plants typically have 8 to 10 trawlers working with them; whereas, the smaller plants typically have 4 or fewer trawlers in their pollock fleet. Most plants also have 6 to 10 fixed gear vessels in their fleet. Most of the fixed gear boats are pot boats fishing for Pacific cod and/or tanner crab. There is a small fleet that fishes for dungeness crab as well.

In addition to vessel ownership information, data on permit holders for Kodiak provide a perspective on local harvester engagement in various fisheries. Nearly half of all permit holders have permits for two or more of the major fisheries, another indication of the diversity of Kodiak's harvest sector. Estimated landings and revenues varied considerably through the time period shown, with total estimated gross revenues varying between $64 million and $111 million between 1995 and 2002. More recent years have generally lower revenues than previous years, with a decline of about 40 percent between 1999 and 2002.

As Kodiak is known for its numerous and diverse harvest fleet, so it is known for its relatively numerous and diverse processing operations. For most years Pacific cod, pollock, pink salmon, and sockeye salmon are typically the species with a greater than 10 percent of total value contribution. Pollock was most often the leading species, followed by Pacific cod and pink salmon.

Kodiak's shoreplants have played a significant role in the history of the community, influencing its economic and demographic patterns over the years. The contemporary processing plants maintain a considerable amount of diversity in the size, volume, and species processed. It is this diversification that best characterizes Kodiak's ability to weather the ebbs and flows of an industry dependent upon changes in the viability of the resource being harvested, the market itself, and past/future regulatory shifts. Locally based processors vary in product output and specialization, ranging from large quantity canning of salmon, processed at several different locations within Kodiak, to fresh and fresh-frozen products, as well as niche markets servicing the sports-fishing industry.

Table 12-8 summarizes Commercial Operators Annual Report (COAR) processing data by year for the period 2000 through 2005 by species for pounds purchased for processors in the community along with the ex-vessel and wholesale value associated with those purchases. This information may be used to gauge community processing sector relative engagement in and dependency on particular crab fisheries. As shown, salmon and herring account for 42 percent of the total wholesale value during 2005. Halibut, sablefish, and other groundfish contributed 22 percent of the total wholesale value, while Tanner crab contributed less than 5 percent of the total wholesale value.

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Table 12-8 Processing summary for Kodiak, 2000-2005

Species	2000	2001	2002	2003	2004	2005
	Number of Processors					
Cod, Pacific (gray)	8	9	8	10	9	9
Crab, Bairdi	-	5	5	5	5	6
Crab, Golden King	1	1	1	1	1	-
Crab, Opilio	2	2	3	1	2	1
Crab, Red King	5	5	4	4	3	3
Halibut, Sablefish, and Other Groundfish	11	12	11	12	13	14
Pollock, walleye	5	4	6	7	5	8
Salmon and Herring	12	13	10	13	15	16
Total	**44**	**51**	**48**	**53**	**53**	**57**
	Pounds Purchased					
Cod, Pacific (gray)	31,519,141	28,379,657	86,619,105	42,370,985	52,660,721	53,584,873
Crab, Bairdi	-	268,019	266,609	507,337	508,330	1,770,035
Crab, Golden King	*	*	*	*	*	-
Crab, Opilio	*	*	*	*	*	*
Crab, Red King	275,176	738,218	771,264	824,603	*	*
Halibut, Sablefish, and Other Groundfish	24,679,163	26,331,218	28,262,083	24,315,491	27,460,885	34,969,964
Pollock, walleye	55,533,862	53,949,109	32,991,917	44,634,584	56,827,314	99,243,809
Salmon and Herring	61,771,741	99,011,913	94,714,040	84,029,762	117,331,042	131,255,688
Total	**174,372,165**	**209,049,127**	**244,296,166**	**196,756,858**	**255,880,607**	**321,723,467**
	Ex-vessel value					
Cod, Pacific (gray)	$11,382,752	$8,262,789	$26,216,227	$13,516,150	$14,912,342	$16,793,138
Crab, Bairdi	-	$616,443	$586,124	$1,255,864	$1,246,151	$3,065,256
Crab, Golden King	*	*	*	*	*	-
Crab, Opilio	*	*	*	*	*	*
Crab, Red King	$1,373,176	$3,721,510	$5,031,912	$4,421,954	*	*
Halibut, Sablefish, and Other Groundfish	$31,154,509	$36,060,563	$31,103,602	$39,231,268	$34,423,105	$37,000,503
Pollock, walleye	$8,398,926	$7,495,671	$3,770,330	$4,159,263	$6,230,264	$13,798,461
Salmon and Herring	$23,104,107	$24,011,951	$15,003,504	$20,053,441	$25,524,100	$29,218,735
Total	**$76,579,804**	**$80,766,641**	**$82,732,088**	**$82,795,913**	**$87,051,755**	**$103,717,480**
	First Wholesale Value					
Cod, Pacific (gray)	$33,416,687	$30,077,297	$30,733,963	$27,960,142	$37,673,044	$34,578,915
Crab, Bairdi	-	$1,604,992	$1,089,537	$1,763,075	$2,376,366	$4,590,225
Crab, Golden King	*	*	*	*	*	-
Crab, Opilio	*	*	*	*	*	*
Crab, Red King	$4,622,485	$4,360,596	$5,522,146	$5,022,925	*	*
Halibut, Sablefish, and Other Groundfish	$38,759,670	$33,641,718	$34,332,331	$41,647,909	$44,636,580	$50,048,701
Pollock, walleye	$33,277,884	$31,246,185	$17,841,809	$17,561,818	$25,257,581	$38,923,478
Salmon and Herring	$64,626,776	$62,248,712	$40,469,486	$66,889,456	$77,442,018	$96,424,568
Total	**$177,617,969**	**$164,021,143**	**$131,518,164**	**$161,073,478**	**$192,942,411**	**$228,939,336**

Source: ADFG Commercial Operator Annual Report Summary
* Indicates the data are confidential and cannot be released

As noted in the subsequent individual operation discussions, employment varies considerably during any given year as plants will add a shift, hire additional employees, and maximize processing and freezing capabilities during various seasons and season overlaps. These adaptations are required since various species need separate processing lines, machinery, and crews. At other times, especially during the later months of the year, the plants have little, if anything, to process and will reduce employment to a level sufficient to cover maintenance and off-season needs while minimizing overhead costs. All of these factors should lead to caution when looking at "annual average" employment figures. Further, it should be understood that the available data only cover a few years and do not portray important longer-term trends that would require data from the years before 1999 and after 2002 to illustrate. For example, as detailed in subsequent discussions, a number of the plants included in this table were no longer in business at the time of fieldwork in late 2004; others have changed hands in the interim. In general, declines in a number of fisheries have taken their toll on Kodiak over the years. Despite these limitations, the data do allow a look at the relative scale of different processing entities in the community.

While the presence of local processing has been a constant in the community, individual operations have substantially different histories and have undergone a variety of changes in recent years. For example, among the large plants processing groundfish and salmon in the community, the facility now operating as Trident Seafood Group centers around a converted World War II “Liberty Ship” that was reportedly brought to the community by previous owners (Alaska Packers) in the wake of the devastating 1964 earthquake to become the first plant up and running after that disaster. (This facility apparently later operated under the names All Alaskan and Tyson Seafoods before being acquired by its present owner.) Ocean Beauty, on the other hand, operates in a facility originally built in 1911, which was the oldest and largest seafood production facility in Kodiak when it was purchased in the 1960s. In 1967, B&B Fisheries opened its doors, which became Western Alaska Fisheries in the early 1970s, and is still in existence today. Ownership type also varies widely. For example, International Seafoods is a wholly owned subsidiary of True World Group, Inc., which is in turn owned by the Unification Church. In contrast, Alaska Fresh Seafood, a smaller plant, has been in operation for 26 years and is owned, in part, by Kodiak and other Alaska fishermen.

The community of Kodiak is distinguished from most other Alaskan fishing ports by the number and range of support service businesses that cater in whole or in part to the commercial fishing industry. Support services include a wide range of companies, including such diverse services as grocery and hardware stores, welding and hydraulics, marine electronics, satellite phone providers, fishmeal and biodrying processors, marine fueling facilities, marine hardware, marine electrical, fishing gear supply, maritime shipping, air cargo transport, passenger airline services, accounting and bookkeeping, banking, engineering, freight forwarding, tug and barge operators, ship repair facilities, stevedoring, and vehicle rentals.

While Kodiak has consistently been a center for support service provision for the commercial fishing industry, the level and nature of service provision have not been consistent, with changes in the fishery driving changes in the support sector. While systematic data on how individual support services have been affected by changes in the local fishing economy are not available, there are a number of qualitative indicators of these impacts. Interviews with primary fisheries support businesses, such as the electrical services and hydraulics shops, indicated that fishermen were deferring regular maintenance and canceling upgrades that had been scheduled in the past. In the light of changes in halibut fishery regulations, for example, a lack of urgency has stretched repairs throughout the year, while some upgrades have moved altogether to Oregon or Washington ports. Several businesses noted changes to their previously robust schedule due to changes in halibut fishing, Steller sea lion Resource Protection Areas (RPAs), and the decline in salmon fishing.

12.6.6 St. Paul

The federally controlled fur seal industry dominated the economy of the Pribilofs until the mid-1980s. The presence of large seal populations still contributes to the local economy, as the rookeries and more than 210 species of nesting sea birds attract almost 700 tourists annually, and the community is working to further develop eco-tourism.

There is also a reindeer herd on the island, from a previous commercial venture. Residents utilize halibut, fur seals (1,645 may be taken each year), reindeer, marine invertebrates, plants and berries for subsistence. Locally obtained subsistence resources are shared and exchanged with relatives and friends living in other communities, sometimes in return for resources obtained elsewhere, such as salmon.

More recently, harbor development in the support of commercial fishing has been quite important, in conjunction with the development of those fisheries. St. Paul, as a CDQ community, has a viable opportunity to partner with the fishing industry in these ventures. Summary information on local CDQ group-related employment is only available for 1994-1997, and ranged from 89 to 15 people employed, with average earnings ranging from $9,807 to $14,880 (CBSFA website 2001). Due to the recent drastic reduction in opilio crab stocks (and quotas), St. Paul has also recently shared in the receipt of Opilio Crab Disaster Funds, as has the Aleut Community of St. Paul (the local IRA organization) and the CBSFA. The raw fish tax is the largest single local source of funds for the City of St. Paul. Opilio crab is by far the most important species for St. Paul processors and thus the City of St. Paul.

The local fishing fleet focuses primarily on halibut in the local area (4C), although there is interest in expansion into other areas. As discussed in the Inshore/Offshore-1 community profiles (IAI 1991), Tanadgusix Corporation (typically referred to as "TDX"), the local ANCSA village corporation, has fostered the growth of this fleet, beginning in 1981, by providing loans for boats and, in the early years, operating a facility to buy and process the halibut. The CDQ program, which was implemented in 1992 as part of the groundfish management changes of Inshore/Offshore-1, allocated a percentage of the pollock quota to CDQ communities to aid in economic development through involvement in Bering Sea commercial fisheries. St. Paul is the only community that is the sole member of its own CDQ group (the CBSFA). The CDQ program expanded in 1998 to a number of other species, including crab, in addition to pollock.

According to ownership data, all crab deliveries to processors in the Pribilof Islands are made by non-local boats from other Alaskan communities and the Pacific Northwest. These data indicate there is little or no local crab fleet in St. Paul. There has, however, been recent local investment in crab harvesters through the local CDQ group, so there is a local stake in harvest issues, even if this is not apparent in the majority ownership data. Furthermore, local residents now commonly serve as crew members on vessels that the CBSFA has an ownership stake in, so that in most years one or two St. Paul residents earn crew shares in Bering Sea crab fisheries. The level of harvesting and processing of crab in the Pribilofs and more specifically around St. Paul has depended on the resource population levels and quotas. Some years there have been large local harvest, and some years low ones. Floating processors and catcher processors processed most of this crab though the 1980s, and continue to process much of it, but shoreplant operations on St. Paul since 1992 have become more significant for crab. The relative production of shoreplant and floating processors in and near St. Paul since 1992 can not be discussed in any more detail because of data confidentiality restrictions. Information for the area designated as the "northern region" for the purposes of crab rationalization alternatives and options analysis involving a regionalization component (i.e., all areas on the Bering Sea north of 56^{o} 20' North Latitude) is discussed in the following section. Although community specific data cannot be parsed out for this region, it is clearly understood through common knowledge that most of the processing within the northern region takes place in St. Paul.

Contemporary local processing can trace continuity to a TDX pilot project that harvest and process local halibut beginning in 1981. One source suggested that they were using the "Anderson plant" which had been built in the 1970s (Joe Plesha, personal communication, January, 2002). Small volumes of halibut were processed in 1981-1983, and increased significantly in 1984. TDX sold the operation to the local IRA Council in 1984, which operated it until 1988. After 1988, the facilities were upgraded and leased to an outside operator, Pribilof Island Processors (PIP), which reportedly processed halibut, cod, and crab – although total amounts may have been relatively small. PIP went out of business in 1991 and its assets, including the St. Paul operations, were acquired by Unipac. Unipac continued to operate the existing facilities, but also built a large crab plant. Unipac processed a significant amount of crab in 1992-1994. In 1994, Trident Seafoods purchased the Unipac assets and has operated the crab plant since then. More recently TDX and the Aleut Community of St. Paul have jointly operated as another local buyer for halibut, doing business as PASCO, and attribute the increased local price for halibut to this increased competition. The first year they processed the halibut with their own crew, using facilities leased from

Trident. In 2001, according to local sources, a different custom processing arrangement instituted by Trident had the effect of resulting in less profit for PASCO. As a result, PASCO is seeking to start a small independent processing facility to gain control over a larger portion of their total operation.

A number of floating processors have also operated in the area, and have established consistent relationships with various regional communities. Icicle and Norquest are the two major floaters who are currently processing crab in the Pribilofs. Another operator, UniSea, processed crab in the Pribilofs during the mid- and late-1990s, but has sold their platform (the UniSea[22]) and did not process crab in the Pribilofs in 2000 or 2001. Icicle processes inside the St. Paul harbor, while Norquest processes outside of the harbor itself, as well as in other in other locations in the Pribilofs. Other processors may also have used floaters to process crab in and around St. Paul and St. George as well.

Snow crab is by far the most important of crab species for the north region, accounting for 74 to 100 percent of the relevant BSAI crab processed in that region annually in the period 1991-2000. In terms of the opilio fishery as a whole, processing in the northern region was most significant since 1993, and especially since 1994. For the period 1991-2000, northern region processing accounted for about 31 percent of the total processing value of the fishery. For the period 1995-1999, the comparative percentage is about 43 percent. The sharp decline in the GHL from 1999 to 2000 resulted not only in a corresponding drop in the harvest, but also in a sharp decline in the percentage of the total opilio crab fishery processed in the northern region, from 49 percent in 1999 to 18 percent in 2000. That is, the reduced stock size resulted in a different distribution of where crab was processed, not a proportional decline in all areas.

Qualitative interview information suggest that the shift of processing away from St. Paul during dropping stock conditions in 1999-2000 may be related to the "slow" nature of the fishing, and a crab fishery that was less of a race for crab than in the past. Data from interviews with harvesters would suggest that shorter seasons (and/or lower harvest levels), among other factors, result in a higher proportion of crab being taken further from the grounds (away from St. Paul) for processing because "last loads" that often go elsewhere account for a higher proportion of the total harvest than would otherwise be the case. The distribution of marketable crab also seems to have affected delivery patterns. Finally, most (if not all) CDQ crab is processed in the northern region, and this would appear to function as a foundation or "critical mass" to attract other (non-CDQ) crab landings to northern region processors, which can counter some of the incentives for crab processing to occur elsewhere. With a lower "critical mass", this pull for other processing activity may not have been as strong as otherwise would have been the case.

Most processors that operate in the Pribilofs also process crab in other locations (with shoreplants and/or floating facilities). Those processors that operate only floaters in the Pribilofs could operate those same facilities anywhere that logic and economic incentives dictate, while the single northern region shoreplant (in St. Paul) is fixed in location.

12.6.7 Adak

The following community information on Adak, unless otherwise noted, is copied from Social Impact Assessment BSAI Crab Rationalization Overview and Community Profiles prepared for the North Pacific Fishery Management Council by EDAW, Inc. on May 2002.

The Aleut Corporation is currently developing Adak as a commercial center, and this development focuses heavily on the potential for commercial fishing, and support of commercial fishing activities, in the Western Aleutians area of the Bering Sea and the North Pacific Ocean.

[22] The UniSea barge, long a fixture in Dutch Harbor and later St. Paul, was sold for scrap, leaving the fishery entirely.

As a new civilian community, Adak does not have an established residential fishing fleet. According to community sources, however, a small boat fleet is beginning to materialize, with four or five small vessels (under 60 feet) participating in local fisheries in 2001, although none were LLP vessels. It is locally anticipated that area small boat set-asides that the community successfully lobbied for with the Board of Fish in combination with relatively poor returns in the Area M salmon fisheries will make Adak relatively attractive to small vessel owners from the Alaska Peninsula/Eastern Aleutians area. According to the Aleut Enterprise Corporation, there have been specific efforts directed at recruiting fishermen to make the transition to the area, and between 8 and 12 small vessels are expected to fish locally in the Spring of 2002. The community is also attempting to attract more vessels to the area with small boat harbor improvements. Currently underway, this project would result in approximately 4 acres of a 30-foot depth that would be out of all seas, although sheltering from all winds is not possible in this location.

Most deliveries to the local plant are made by larger boats from outside of the area. While landings data are confidential, according to a senior local government official, brown king crab, while still an important fishery, ranks behind cod, halibut, and black cod in terms of local importance.

There is a single processing plant in the community, and it has seen a number of ownership transitions in recent years. The current operation can trace it lineage to a time several years ago when the plant operated as Adak Seafoods. Later, the plant was operated by Norquest. Following Norquest, it was operated by a "transitional entity" known as Adak Fisheries Development Corporation. At present (early 2002), the plant is owned by an entity doing business as Adak Fisheries, which is comprised of one of the two original partners in Adak Seafoods along with a new business partner, Icicle Seafoods. This last transition is new enough that Icicle has not yet been involved in operating the plant.

The relationship between the plant and the community are somewhat different than that seen for other communities profiled, as Icicle has entered into a long term relationship with the Aleut Corporation, which, in turn, directly and through subsidiaries owns, manages, and/or operates much of the community infrastructure and property. This relationship gives Icicle exclusive abilities with respect to some local processing, and in return requires that Icicle support attempts to build a local fishery by agreeing to essentially handle landings for all local fisheries as well as to pay prices pegged to regional norms established in Dutch Harbor. In the past, this plant ran crab but, reportedly due to AFA crab caps, Icicle is not planning to do so. Previously the plant also ran cod, halibut, and sablefish, and plans are to continue these processing these species when Icicle begins operating the plant.

Growth of existing operations is likely, as according to local officials, Icicle is in the process of expanding into one of the "three sheds that have 15 acres under tin" and are planning on augmenting freezing capacity with the Discovery Star. Also according to local officials, it is thought that the local operation has a goal of increasing by a factor of two or greater the local production at the plant.

The community has also seen at least some crab and cod activity related to other seafood firms. Although neither company has a physical presence in the community, additional processing activity has taken place in recent years on behalf of both Westward and Trident Seafoods.

Adak is in the process of developing support service capabilities for the fishing fleet. According to the Aleut Enterprise Corporation, the transition to a civilian community took place in phases as the Aleut Corporation and it subsidiaries took over support service infrastructure, starting with fueling and then moving into housing followed by port facilities.

Adak has become the main marine refueling station the adjacent portion of the North Pacific. The island's underground tank farm has a storage capacity of approximately 22 million gallons of marine diesel, bunker grade fuel, gasoline and jet fuel. Fuel sales are run through the Aleut Enterprise Corporation.

Constructed to accommodate U.S. Naval ships, the port facilities on Adak consisting of three deep water docks, and fueling facilities, can support a wide variety of vessels. Research ships, station work vessels, cruise ships, factory trawlers, and fishing boats use the port facilities at Sweeper Cover and Kuluk Bay. At-sea processors have used the port for transfer of product as well as a supply stop, and this has generated opportunities for shippers.

12.6.8 Recent Community Studies

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 Alternative 1: Status quo

Alternative 1 would maintain the existing status determination criteria established in Amendment 7 to the FMP. Amendment 7 provided fixed values in the FMP for the minimum stock size threshold (MSST), MSY, OY, and maximum fishing mortality threshold for the BSAI king and Tanner crab stocks, as shown in Table 2-1. Determination of whether a crab stock is overfished or approaching an overfished status is done by comparing the annual survey or model abundance estimate to the MSST for each surveyed stock under alternative 1. 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. A BSAI crab stock is considered rebuilt when the stock exceeds the B_{MSY} for two consecutive years.

Overall, in the short-term, Alternative 1 would likely result in similar harvest amounts for most of the crab stocks. General risks associated with continuing to use the status determination criteria specified under this alternative are discussed in Section 2.6.2. Simulations for Bristol Bay red king crab, EBS Tanner crab and snow crab indicate that longer term impacts include lower retained yields and higher rebuilding times for these stocks under this alternative. Reduced yields and longer rebuilding times could result in negative economic impacts on harvests, processors, support businesses, and communities. The effects will likely be disproportional in nature, affecting those participants and communities with a high degree of dependency on the crab fisheries more severely than participants and communities who are more diversified across different fisheries. Communities like St. Paul and King Cove, which are highly dependent on crab fisheries could be significantly impacted by lower yields and longer rebuilding times compared to more diversified communities like Dutch Harbor and Kodiak.

12.8 Alternative 2: Tier system with five tiers

Alternative 2 would amend the FMP to include the Tier system with five tiers and a framework for assigning each crab stock into a tier and for setting the OFLs. Timing considerations for OFL determination would be as described in Option 1 or Option 2. Additionally, the Council may choose to remove specific crab stocks from the FMP, as described in Option A.

The proposed Tier system has analogs to the Council's current groundfish Tier system. In Tiers 1 through 3, reliable estimates of B, Bmsy, and Fmsy, or their respective proxy values are available.

12.8.1 Methodology for impact determination

The economic impacts of the proposed OFL control rules depend upon the extent to which those control rules constrain the existing harvest strategies used in establishing TACs. Longer–term scenarios to evaluate the flexibility of the control rules under various stock rebuilding scenarios were described inSection 4.3. These scenarios show indications of longer-term yields and progress towards rebuilding but are not intended to provide a simulation of long-term stock status, merely to show that the control rules are equally responsive and effective at stock rebuilding regardless of whether a stock is declining or increasing in biomass at the time of application. As described previously (Section 3.2) these scenarios were run to ensure that the control rule formulation is appropriate for crab stocks.

Short-term scenarios were evaluated in order to estimate the immediate impacts of management under proposed control rules. This analysis utilizes the yield results comparing short-term simulations of fishing under proposed OFL control rules with fishing at the current State harvest strategy (as an estimate of future TAC-setting). These simulations begin at the current biomass estimate for all three stocks. 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 beginning at the current stock biomass for Bristol Bay red king crab, Tanner crab and snow 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 retained yield under the status quo harvest strategy in conjunction with the maximum retained catch permitted under 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.

In each of the species noted below, the short-term simulation projections suggest that TACs under Alternative 2 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 Alternative 2 would be lower than those under Alternative 1, so TACs would have to be set lower to remain below the lower OFLs (and prevent overfishing).

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 might need to be incorporated into the setting of the TAC. 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.

12.8.2 Bristol Bay Red King Crab

Table 12-9 provides 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 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 the $F_{35\%}$ or $F_{40\%}$ control rule would be projected to constrain harvests compared to the status quo harvest strategy in 2008. In 2007 and 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. Figure 12-1 demonstrates simulation results for Bristol Bay red king crab from 2007 to 2012.

Table 12-9 Projected retained catch for Bristol Bay red king crab using existing harvest strategies and $F_{40\%}$ and $F_{35\%}$ harvest control rules from 2007 to 2012. Shading represents projected constrained harvests.

Year	Bristol Bay Red King Crab Projected Retained Catch (million of pounds)		
	State Harvest CR	$F_{40\%}$	$F_{35\%}$
2007	18.38	15.93	19.20
2008	23.60	18.65	21.60
2009	24.80	23.69	26.89
2010	23.45	26.18	29.09
2011	22.19	25.37	27.53
2012	21.22	23.58	25.08

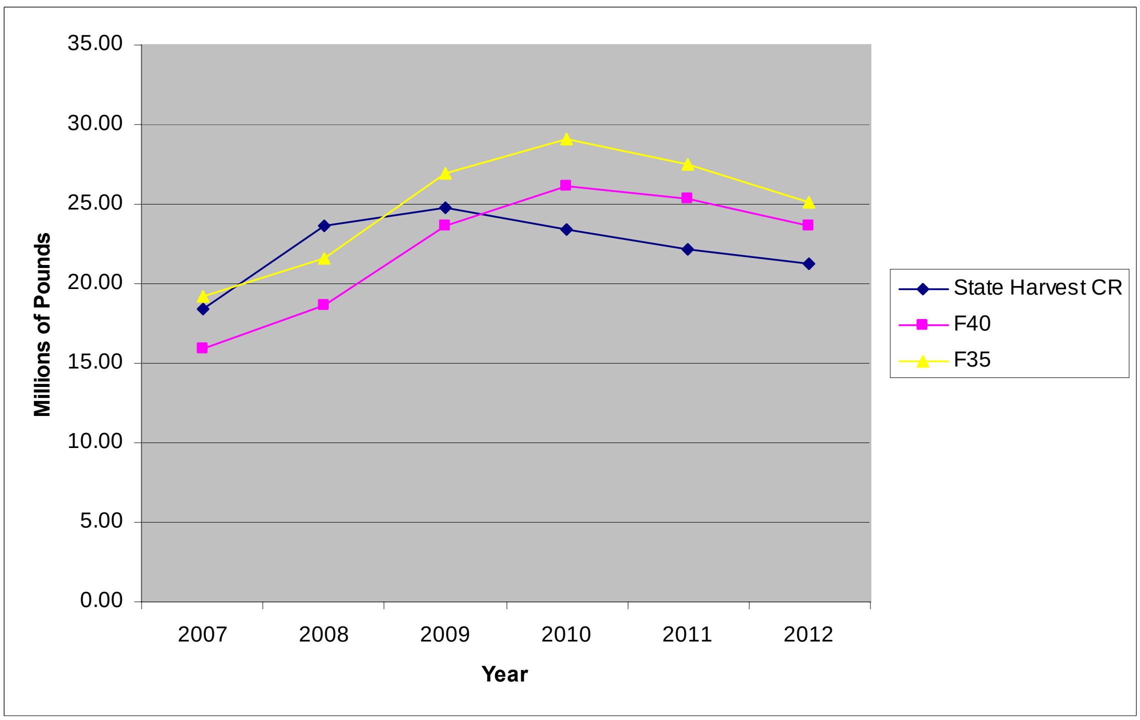

Figure 12-1 Projected retained catch for Bristol Bay red king crab under F40, $F_{35\%}$, and existing harvest control rules from 2007 to 2012

In general, a decline in Bristol Bay red king crab TAC in 2008 so as not exceed $F_{35\%}$ and $F_{40\%}$ harvest control rules could reduce gross revenues to harvesters and processors in the fishery and could contribute to fleet consolidation. Specifics on the magnitude of the social and economic impacts cannot be determined in this analysis, since it is not known where the TAC will be set by the State relatively to the $F_{35\%}$ and $F_{40\%}$ harvest control rules. In general, the larger the buffer between the OFL and the TAC, the greater the impact to harvesters, processors, and communities. However, it is likely 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 yield increases in later years as a result of lower yields in earlier years, gross revenues to harvesters and processors could increase. Communities also would likely benefit when yield increases. As noted above, specifics on the effects of TAC increases to harvesters, processors, and communities are limited to a quality discussion given that the exact level of the TAC is not known.

Any change in the Bristol Bay red king crab TAC resulting from the proposed action will impact the communities which process this species, specifically Dutch Harbor with 51.1 percent of the Bristol Bay red king crab PQS pool, Akutan with 19.9 percent, and King Cove with 12.8 percent. Communities with small shares of the PQS could also be impacted by changes in the Bristol Bay red king crab TAC, and, in some cases, could be impacted to a higher degree compared to communities like Dutch Harbor or Akutan. The degree to which the community is impacted by the TAC changes is dependent upon the contribution the fishery provides to the local economy. For communities like Kodiak and Dutch Harbor, the red king crab fishery plays a smaller role in the local economy since these communities are diversified across different fisheries. However, for communities like King Cove and St. Paul, which are less diversified, the Bristol Bay red king crab fishery plays a more prominent role in the local economy, so these communities would be affected to a higher degree by changes in the Bristol Bay red king crab TACs.

12.8.3 Snow Crab

Table 12-10 provides a comparison of 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 snow crab fishery. Similar to the Bristol Bay red king crab, 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 snow crab, the $F_{35\%}$ 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. Figure 12-2 demonstrates these simulation results for snow crab from 2007 to 2012.

Table 12-10 Projected retained catch for snow crab using existing harvest strategies and $F_{40\%}$ and $F_{35\%}$ harvest control rules from 2007 to 2012. Shading represents projected constrained harvests.

	EBS Snow Crab Projected Retained Catch (millions of pounds)		
Year	**State Harvest CR**	**$F_{40\%}$**	**$F_{35\%}$**
2007	36.96	36.96	36.96
2008	61.38	46.42	61.82
2009	82.28	85.14	100.32
2010	78.32	70.40	77.22
2011	58.74	52.80	56.54
2012	71.28	62.04	68.20

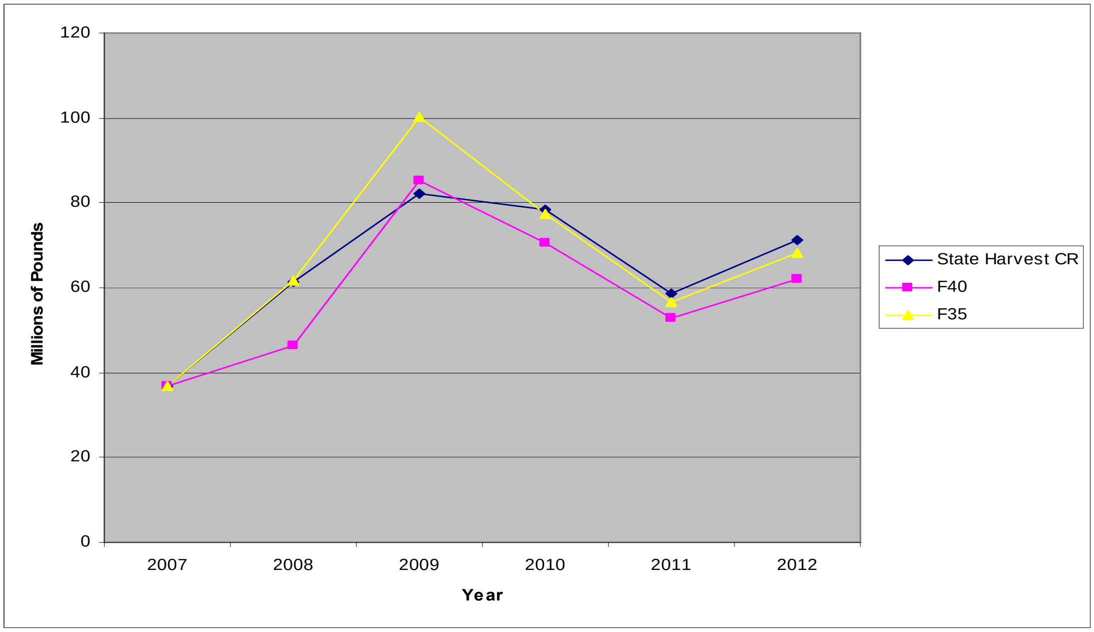

Figure 12-2 Projected retained catch for snow crab under F40, $F_{35\%}$, and existing harvest control rules from 2007 to 2012

In general, any decline in snow crab TAC is likely to contribute to reduced gross revenues to harvesters, processors, and other businesses that rely on the snow crab fishery. In addition, any prolonged reduction in the snow crab TAC could also contribute to fleet consolidation. Reductions in TAC could also negatively impact communities through reduced spending in that community by harvesters, processors, residents that work in the snow crab industry, and residents and businesses that indirectly rely on the snow crab industry. In circumstances where the snow crab TAC increase in later years because of a lower TAC in earlier years, gross revenues to harvesters and processors could increase. Communities would also likely benefit from increased TACs.

Any decline in snow crab TAC resulting from the proposed action will likely impact several communities. The impacts will likely vary across communities depending on the degree of importance the snow crab fishery plays is in the local economy. Communities with a high degree of dependency on the snow crab fishery will likely be impacted at a higher degree then communities with low dependency on the fishery. Table 12-1 presents the percent of PQS for snow crab by community, which provides a current depiction of snow crab deliveries by port. For communities like St. Paul, St. George, and King Cove, the snow crab fishery is crucial to the local economy. Any changes in the snow crab OFL that result in a change in the snow crab TAC will likely impact these community to a much higher degree than Dutch Harbor or Kodiak which are more diversified across many different fisheries.

12.8.4 Tanner Crab

Table 12-11 provides 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 Tanner crab fishery. 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 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 and 2008 using $F_{35\%}$.[5] Figure 12-3 demonstrates the simulation results for Tanner crab from 2007 to 2012.

Table 12-11 Projected retained catch for Tanner crab using existing harvest strategies and $F_{40\%}$ and $F_{35\%}$ harvest control rules from 2007 to 2012. Shading represents projected constrain harvests.

Year	Tanner Crab Projected Retained Catch (million of pounds)		
	State Harvest CR	$F_{40\%}$	$F_{35\%}$
2007	14.81	12.23	14.33
2008	19.57	17.72	20.36
2009	21.47	23.01	25.85
2010	18.40	17.17	18.27
2011	16.24	15.01	15.38
2012	16.71	15.52	16.07

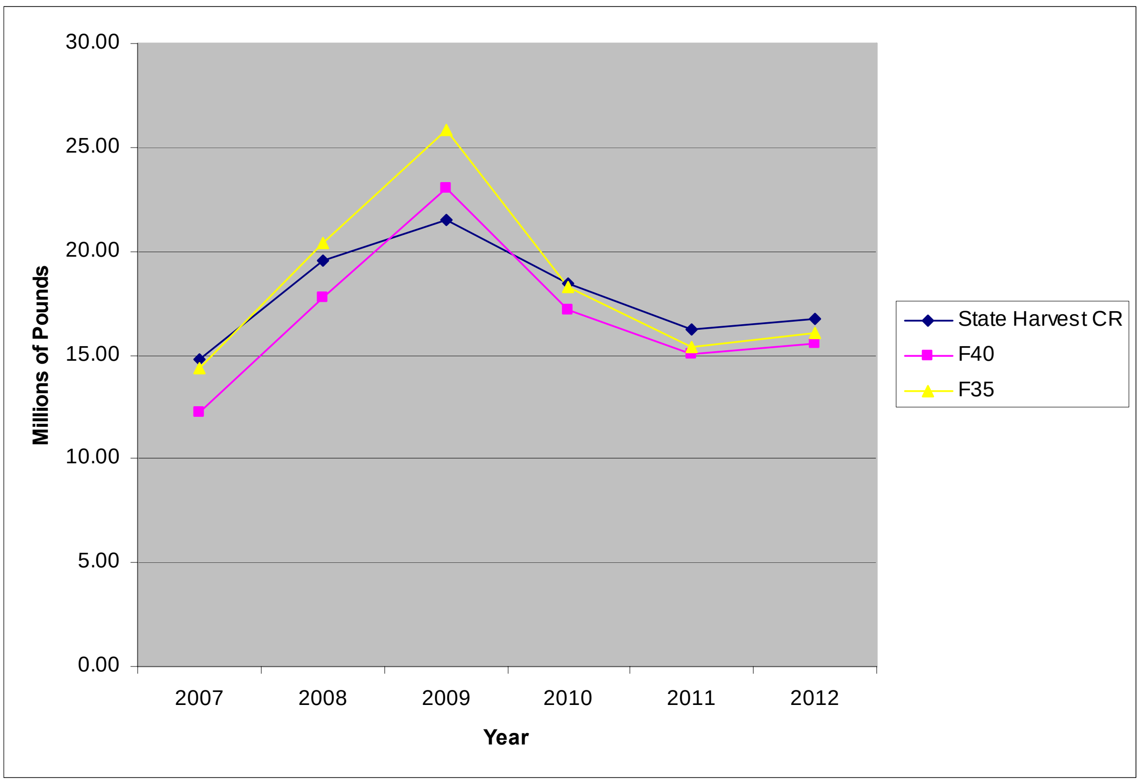

Figure 12-3 Projected retained catch for Tanner crab under $F_{40\%}$, $F_{35\%}$, and existing harvest control rules from 2007 to 2012

As noted above under the snow crab and Bristol Bay red king crab discussion, any decline in Tanner crab TAC is likely to contribute to reduced gross revenues to harvesters, processors, and other businesses that rely on the Tanner crab fishery. One potential side effect of a reduction in revenue for Tanner crab is that

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

the fleet could experience some consolidation. Factors influencing the level of consolidation would be the magnitude of the decline in gross revenue and the number of years the industry experienced declining gross revenue. In addition, reductions in yield could also negatively impact those communities that directly rely on the Tanner crab fishery. In circumstances where the Tanner crab yield increases in later years because of a lower yield in earlier years, gross revenues to Tanner crab harvesters, processors, and other businesses could increase. Communities would also likely benefit from increased yields through increased spending by harvesters, processors, and businesses supporting the Tanner crab fishery.

Any decline in Tanner crab TAC resulting from the proposed action will likely impact several communities. The impacts will likely vary across communities depending on the degree of importance the Tanner crab fishery plays is in the local economy. Communities with a high degree of dependency on the Tanner crab fishery will likely be impacted to a higher degree then communities with low dependency on the fishery. Unlike snow crab and Bristol Bay red king crab, the Bering Sea Tanner crab fishery did not include regional designations. The Bering Sea Tanner crab fishery is primarily concurrent with the regionalized Bristol Bay red king crab and Bering Sea snow crab fisheries, which made the regional designation of Tanner crab landings unnecessary. To provide a picture of current delivery patterns, Table 12-12 provides Bering Sea Tanner crab landings by port for the 2005/2006 fishing season. As noted in the table, approximately 38 percent of the Bering Sea Tanner crab was landed in Dutch Harbor, followed by St. Paul at 24 percent. Landings in Akutan, King Cove, and Kodiak were not reported since data are confidential. Any changes in the Tanner crab OFL that result in a change in the Tanner crab TAC will likely impact St. Paul, Akutan, and King Cove to a higher degree than Dutch Harbor or Kodiak, which is more diversified across several fisheries.

Table 12-12 Deliveries by port for Bristol Bay Tanner crab for 2005/2006 fishing season.

Port	Rank	Vessel landings[a]	Total harvest[b]	Percent allocations[c]
Dutch Harbor	1	28	370,826	46.9
Akutan	2	7	**	**
St. Paul	3	21	122,628	28.9
At Sea[d]	4	13	48,261	6.1
King Cove	5	4	**	**
Kodiak	6	1	**	**
Total		74	791,025	100

Source: Bering Sea and Aleutian Islands Crab Rationalization Program Report Fishing Year 2005/2006
** Indicates data are confidential

[a] A vessel landing is an offload
[b]Percent harvest is the total landed pounds, excluding overages; percents may not total 100% due to rounding
[c]Harvest is raw crab pounds
[d]"at-sea" mean landings by catcher processors and stationary floating processors

12.8.5 Other King Crab Stocks

Norton Sound red king crab

The Norton Sound red king crab stock is preliminarily placed in Tier 4. This stock is currently open to fishing. Under Alternative 2, 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 Alternative 2. The Norton Sound red king crab fishery, which is excluded from the Crab Rationalization Program, is operated under a vessel registration intended to protect the interests of local, small-vessel participants. Although there is no indication the fishery will be constrained under Alternative 2, if there is a change in the TAC as a result of this proposed action, the impacts will likely be limited exclusively to the participants and communities that participate in this fishery in and around the Norton Sound area.

Dutch Harbor red king crab

The Dutch Harbor red king crab fishery has been extremely depressed during the last two decades, and the fishery has been closed since 1983. The stock is preliminarily placed into Tier 4 for purposes of this analysis. The new overfishing definitions will likely not have any impact on this stock in the near future because no fishery is predicted; therefore the proposed action is estimated to have no economic and social impact for this stock.

Adak red king crab

Adak red king crab is preliminarily placed in Tier 5 under this alternative. The stock has only been opened to fish in the Petrel Bank area for 4 years during the last 10 years. The historic average yield has been high, with the highest annual catch of 21 million pounds in 1964. However, the average yield from 1985 to 1994 is only 947,900 pounds (430 t). The OFL could be set as 947,900 pounds (430 t), if average catch for this time period is chosen as the means to establish an OFL for this stock. This stock could be promoted to Tier 4 if routine surveys are conducted.

Overall, it is unlikely the fishery would be constrained if Alternative 2 were selected. If CPUE increase in the future, TACs could be constraining by the proposed redefining of the OFL. In those cases, depending on the size of the buffer between the OFL and TAC, there is the potential for a decline in the gross revenue for harvesters and processors in this fishery from lower TACs.

Pribilof Island red king crab

Under the Alternative 2 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 4-6 and Table 3-5 provides estimated MMB and B_{MSY} proxy and MSST proxy (½ B_{MSY}) for the Pribilof Island red king crab stock. Average abundance from 1988 to 2006 was used for a proxy for this stock because model estimates of biomass were not available before 1988.

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 Alternative 2 (Figure 4-6) show the stock below the B_{MSY} and declining. Should Alternative 2 be adopted, it is unlikely that this stock will open to directed fishing. Based on past catch history, the fishery was important to the St. Paul economy and its closed status has likely negatively impacted the St. Paul economy to some degree. Since it is likely this fishery will remain closed to directed fishing under this alternative, the St. Paul economy must continue to function without the revenue this fishery could bring to the local economy.

Saint Matthew blue king crab and Pribilof Islands blue king crab

Saint Matthew blue king crab and Pribilof Islands blue king crab stocks are both suggested for Tier 4 management under this alternative. Both stocks remain under rebuilding plans and are closed to fishing. Under this alternative, estimated F_{OFL} rates (as listed in Table 3-5) are F = 0.36. As both stocks are currently closed to fishing (F=0), there is no constraint imposed by the calculated OFLs for these stocks. However, if either stock were to open in the future, the harvest rate would need to be below the calculated F_{OFL} rate for this fishery. This could impose a harvest constraint on the current harvest strategy for these stocks.

Revised estimates of stock status under Alternative 2 remain similar to estimates under Alternative 1. Should Alternative 2 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. Table 12-1 provides the percent of PQS for Saint Matthew and Pribilof Island blue king crab by community, which provides a current depiction of deliveries by port. As noted in the table, the St. Matthew and Pribilof Island blue king crab fishery, when open, are crucial to St. Paul economy. Any changes in the blue king crab OFL that result in a change in the TAC will likely impact St. Paul.

Aleutian Island golden king crab

The golden king crab stock is recommended for management under Tier 5. Under Tier 5, no estimates of status determination criteria are made and management uses a fishing mortality estimated based on average catch. 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.

Considering the catches after 1999 were strictly based on the TAC of 5.7 million pounds, the average catch of 8.261 million pounds (3,747 t) from 1985 to 1999 is used here (Tier 5) to establish an OFL for this stock (Figure 8-1). This would not constrain the current TAC and would provide a small room for future increases in TAC if the stock abundance continues to increase. The CPUE for this stock has increased sharply during recent years. This stock could be moved to Tier 4 once the model under development (Siddeek et al., 2005) is used for annual stock assessment. Golden king crab may be able to sustain higher harvest rates than red and blue king crabs (see section 8.2 for additional information on harvest rate adjustments relative to movement to Tier 4 status).

Table 12-1 provides the percent of PQS for Eastern and Western Islands golden king crab by community, which provides a current depiction of deliveries by port. For Eastern Aleutian Islands golden king crab, Dutch Harbor has 98 percent of the PQS. Any changes in the OFL for this species that results in a change in the TAC will likely impact Dutch Harbor. In the Western Aleutian Islands golden king crab fishery, 50 percent of the PQS is designated as west shares to be delivered west of 174º W, regardless of historic landing locations in the fishery. The remaining 50 percent of the PQS has neither regional designation nor regional delivery requirements. Communities most impacted by changes in the TAC for these stocks will be Adak and Dutch Harbor.

Pribilof Island golden king crab

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 golden king crab is excluded from Crab Rationalization Program.

Under Alternative 2, 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 1999. The catches after 1999 were primarily based on the TAC, and the catches after 2002 were confidential. The average yield during 1993- 1999 is 174,200 pounds (79 t). If the OFL was established for this stock based upon the use of average yield over this time period, the OFL would be 174,200 pounds (79 t, see Figure 8-2). If a TAC is set at 75% of the OFL, this would be 130,700 pounds (59 t, see Figure 8-2). This would be a reduced

TAC from status quo; however, the current GHL of 150,000 pounds (68 t) has not been fully harvested in recent years.

To avoid overfishing, TACs must be established below 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. Depending on the size of the buffer, there could be some potential for a decline in the gross revenue for harvesters and processors in this fishery from lower TACs.

12.8.6 Other crab stocks

Eastern Aleutian Islands Tanner crab

The Eastern Aluetian Islands Tanner crab stock is suggested for management under Tier 4. Stock status for Eastern Aleutian Islands Tanner crab 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 (Figure 6-5). This fishery is primarily a state-water fishery given that 93 percent of the landings from 1985-2006 were in state-waters statistical areas. The 2004 harvest of Eastern Aleutian Islands Tanner crab was 34,022 pounds with a value of $0.88 million. Although there is no indication the fishery will be constrained under Alternative 2, if there is a change in the TAC as a result of this proposed action, the impacts will be limited exclusively to the participants and communities that participate in this fishery. In addition, given that the fishery is primarily a State water fishery, this stock is one of the eleven species that would be removed from the Federal FMP if the Council were to select Option A under this alternative. The State would have sole management authority for this species, as they do for hair crab (the hair crab fishery, which occurs in the EEZ, was removed from the FMP). Currently, the FMP defers the management of these fisheries to the State. Therefore, the State already manages these stocks and collects all of the biological information. Based on this information, the economic and social effects of removing this species from the Federal FMP would be minimal.

Western Aleutian Islands Tanner crab is suggested for management under Tier 5. Here the appropriate period for average catch may be 1985 to 1992. The average yield during this period is 76,700 pounds. If the OFL were established based upon this time period, then the OFL would be 76,700 pounds. If a GHL were established at 75% of this amount, the GHL would be 57,525 pounds. This stock is also considered for removal from the Federal FMP under Option A.

The remaining stocks are all placed in Tier 5 for purposes of analysis under this alternative. However, catch information for these stocks is very limited. Tier 5 OFLs would be calculated based upon average catch in years with fishing efforts 10 percent or higher of the mean fishing efforts. Only using data with fishing efforts 10 percent or higher of the average efforts filters out years that do not represent normal fishing effort. (Table 12-13)

The problems with establishing an OFL based on catch history for these stocks include: (1) catch data come from exploratory and incidental fisheries for most stocks, (2) there are only 2 to 4 years of catch data for several stocks, and (3) mean catch for some species may be either too high (grooved Tanner crab) or too low (Aleutian Islands scarlet king crab). The mean catch for Eastern Aleutian Islands grooved Tanner crab used to set the OFL of 504,800 pounds may be too high (only 4 years of data and the CPUE declined during these 4 years). In contrast, the State established a GHL range of 50,000 (23 t) to 200,000 (91 t) pounds for grooved Tanner crab in the Eastern Aleutian District. For Eastern Bering Sea grooved Tanner crab, there has been sporadic fishing effort during the last 10 years and limited information is available for this stock. The mean catch for Eastern Bering Sea grooved Tanner crab used to set the OFL of 351,900 pounds may be too high when compared to the State's harvest limit of 200,000 (91 t) pounds. Additionally, Aleutian Islands scarlet king crab OFL of 13,400 may be too low (the maximum annual catch of 63,000 is more than 4.7 times of the average).

Table 12-13 Estimated OFLs (in pounds) for other crab stocks in Tier 5 under Alternative 2. OFLs based on mean catches from appropriate period during 1985-2005. Only used data with fishing efforts 10% or higher of the average efforts.

Stock	OFL	GHL= 75% of OFL	Years used	Number of years
EBS grooved Tanner crab	351,900	263,925	93-96, 01, 03, 04	7
Aleutian Islands scarlet king crab	13,400	10,050	92, 94-04	12
EBS scarlet king crab	14,800	11,100	95, 96, 01, 03-05	6
Bering Sea triangle Tanner crab	37,700	28,275	95, 96, 01, 04	4
Eastern Aleutian Islands triangle Tanner crab	295,300	221,475	95, 96	2
Eastern Aleutian Islands grooved Tanner crab	504,800	378,600	93-96	4
Western Aleutian Islands grooved Tanner crab	74,600	55,950	94-96	3

In addition, the stocks listed below are under consideration for removal from the Federal FMP. These stocks have no directed fishery or are limited to an exploratory fishery. As noted above, Option A would remove specific stocks from the Federal FMP for which there is no directed fishery, a limited exploratory fishery, or the majority of catch occurs in State waters. Many of the stock have not had a directed fishery. Some stocks have had sporadic historical fisheries that were predominantly prosecuted in State waters. Any future exploratory fishery would be operated by commissioner's permit, which means the State determines if and when these fisheries occur, who may participate, observer requirements, and how much is harvested. Based on this information, the economic and social effects would be minimal.

- Eastern Aleutian Islands Tanner crab
- Western Aleutian Islands Tanner crab
- Western Aleutian Islands grooved Tanner crab
- Eastern Aleutian Islands grooved Tanner crab
- Eastern Aleutian Islands triangle Tanner crab
- Eastern Bering Sea grooved Tanner crab
- Bering Sea triangle Tanner crab
- Aleutian Islands scarlet king crab
- Eastern Bering Sea scarlet king crab
- Saint Matthew golden king crab
- Saint Lawrence Islands blue king crab

12.8.6.1 Options 1 and 2

Option 1 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. Option 2 would establish a process whereby the Council and SSC would review the models and tier system framework, tier levels, and model parameterization in June. However, the OFL determination would occur in the fall and involve the incorporation of new survey data into model formation of the OFL. The primary economic and social effects of Option 1 relative to Option 2 appear to be the seasonal preparation time for harvesters and processors. Option 1 could potentially allow more time for harvesters and processors to adjust their capabilities to better fit annual changes in OFL. Under Option 1, the time between when the OFL is set by the Council and when the first crab season would start is roughly three months. Under Option 2, the time period between when the OFL is set (fall) and the start of the first crab season, could be very limited.

12.8.6.2 Alternative 2 Summary

Overall, Alternative 2 will specify a tier system and a framework for annually assigning each crab stock to a tier and for setting the OFLs. From an economic and social effects perspective, there appears little difference between Alternatives 2 and 3. However, there appears to be potential for some economic and social effects to occur in comparing Alternative 1 with Alternative 2. The effect of this action depends to a great degree on where the State sets crab stock TACs in relation to the revised OFLs under this action. Under the current status determination criteria, the MSY control rule for these fisheries has not been constraining. However, the proposed OFLs for Alternative 2 would be lower than those under Alternative 1, so TACs would likely have to be set lower to adjust for the lower OFLs.

If State sets TACs near the revised OFL proposed for Alternative 2, the economic and social effects are estimated to be limited and short in duration. However, 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 may need to be incorporated into the setting of the TAC. However, if the State incorporates a significant buffer resulting in much lower TACs for many of the crab stocks in relation to current TACs under Alternative 1, there could be significant short-term negative economic and social effects to harvesters, processors, support businesses, and communities. In general, a lower TAC in any of the crab species under consideration for this action is likely to contribute to lower gross revenues for locals that rely on these species. This could include local fisherman that harvest these species. Other residents impacted by lower TACs might be residents that work in crab processing facilities or residents that directly support the crab industry by providing fleet services. In addition, the local government might see lower tax revenue collected with a lower TAC. This in turn could impact the local economy through less spending by the government on community projects. To a lesser degree, local residents that do not work directly in the crab fishing industry or do not support the crab fleet directly, could also be impacted from changes in the crab TAC. With a lower TAC, spending in the community by local residents and non-residents working in the crab fishery would likely decline, thereby negatively impacting community residents that are not directly linked to the crab industry.

These effects will likely be disproportional in nature, affecting those that have a high dependency on the crab fisheries more severely than those who are more diversified across several different fisheries. Communities like St. Paul and King Cove, which are highly dependent on the many of the crab fisheries could be significantly impacted by a decline in TACs , whereas communities like Dutch Harbor, Akutan, and Kodiak, which are more diversified across several fisheries, would be impacted less.

Finally, while short-term retained yields could decline for many of the crab stocks, the proposed OFLs are estimated to produce higher retained yields and lower mean rebuilding time in the future. Given that the proposed OFL control rules could result in higher retained yields and lower rebuilding times for these stocks, this likely will contribute to increased gross revenues to harvesters, processors, crab support businesses, and communities in the future and could contribute to some fleet expansion in the long-term. Similarly, as the TAC increases, local residents and businesses directly supporting the crab industry and local residents and businesses that are not directly supporting the crab industry will likely benefit from increased earnings and gross revenues.

12.9 Alternative 3: Tier system with six tiers

Alternative 3 would amend the FMP to include the tier system with six tiers and a framework for assigning each crab stock into a tier and for setting the OFLs. The timing of OFL determination under this alternative would be as described in Option 1 or Option 2.

The Tier system in Alternative 3 is the same as Alternative 2 for the first four tiers, however, Tier 5 is modified and Tier 6 is added. Tier 5 stocks have no reliable estimates of biomass, 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 the OFLs in terms of catch instead of fishing mortality. Tier 6 is for stocks where information necessary to establish an overfishing limit is currently unavailable. The default OLF for Tier 6 stocks would be set at zero for the directed commercial fishery. No directed fishing would be allowed for stocks with an OFL equal to zero.

12.9.1 Bristol Bay Red King Crab, Snow Crab, and Tanner Crab

Similar to Alternative 2, 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. Alternative 3 utilizes the same of short-term simulations of fishing at proposed OFL control rules on current biomass estimates for Bristol Bay red king crab, snow crab, and Tanner crab as Alternative 2. Given that Alternative 3 simulation results are the same as Alternative 2 with regard to these three stocks, please refer to that section for details of economic and social effects of Alternative 3.

12.9.1.1 Other Crab Stocks

Norton Sound red king crab

The Norton Sound red king crab stock is currently open to fishing. Under Alternative 3, the model estimate of mature male biomass for the Norton Sounds red king crab stock (Figure 4-9) is well above the B_{MSY} proxy for this stock, thus there is no indication that the fishery will be constrained by Alternative 3. The Norton Sound red king crab fishery, which is excluded from the Crab Rationalization Program, is operated under a vessel registration intended to protect the interests of local, small-vessel participants. Although there is no indication the fishery will be constrained under Alternative 3, if there is a change in the TAC as a result of this proposed action, the impacts will likely be limited exclusively to the participants and communities that participate in this fishery in and around the Norton Sound area.

Dutch Harbor red king crab

The Dutch Harbor red king crab fishery has been extremely depressed during the last two decades, and the fishery has been closed since 1983. The stock is preliminarily placed into Tier 4 for purposes of this analysis. The new overfishing definitions will likely not have any impact on this stock in the near future because no fishery is predicted; therefore the proposed action is estimated to have no economic and social impact for this stock.

Adak red king crab

Adak red king crab is preliminarily placed in Tier 5 under this alternative. The stock has only been opened to fish in the Petrel Bank area for 4 years during the last 10 years. The historic average yield has been high, with the highest annual catch of 21 million pounds in 1964. However, the average yield from 1985 to 1994 is only 947,900 pounds (430 t). The OFL could be set as 947,900 pounds (430 t), if average catch for this time period is chosen as the means to establish an OFL for this stock. This stock could be promoted to Tier 4 if routine surveys are conducted.

Overall, it is unlikely the fishery would be constrained if Alternative 3 were selected. If CPUE increase in the future, TACs could be constraining by the proposed redefining of the OFL. In those cases, depending on the size of the buffer between the OFL and TAC, there is the potential for a decline in the gross revenue for harvesters and processors in this fishery from lower TACs.

Pribilof Island red king crab

Under the Alternative 3 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 4-6 and Table 3-5provides estimated MMB and B_{MSY} proxy and MSST proxy (½ B_{MSY}) for the Pribilof Island red king crab stock. Average abundance from 1988 to 2006 was used for a proxy for this stock because model estimates of biomass were not available before 1988.

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 Alternative 3 (Figure 4-6) show the stock below the B_{MSY} and declining. Should Alternative 3 be adopted, it is unlikely that this stock will open to directed fishing. Based on past catch history, the fishery was important to the St. Paul economy and its closed status has likely negatively impacted the St. Paul economy to some degree. Since it is likely this fishery will remain closed to directed fishing under this alternative, the St. Paul economy must continue to function without the revenue this fishery could bring to the local economy.

Saint Matthew blue king crab and Pribilof Islands blue king crab

Saint Matthew blue king crab and Pribilof Islands blue king crab stocks are both suggested for Tier 4 management under this alternative. Both stocks remain under rebuilding plans and are closed to fishing. Under this alternative, estimated F_{OFL} rates (as listed in Table 3-5) are F = 0.36. As both stocks are currently closed to fishing (F=0), there is no constraint imposed by the calculated OFLs for these stocks. However, if either stock were to open in the future, the harvest rate would need to be below the calculated F_{OFL} rate for this fishery. This could impose a harvest constraint on the current harvest strategy for these stocks.

Revised estimates of stock status under Alternative 3 remain similar to estimates under Alternative 1. Should Alternative 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. Table 12-1 provides the percent of PQS for Saint Matthew and Pribilof Island blue king crab by community, which provides a current depiction of deliveries by port. As noted in the table, the St. Matthew and Pribilof Island blue king crab fishery, when open, are crucial to St. Paul economy. Any changes in the blue king crab OFL that result in a change in the TAC will likely impact St. Paul.

Aleutian Island golden king crab

The golden king crab stock is recommended for management under Tier 5. Under Tier 5, no estimates of status determination criteria are made and management uses a fishing mortality estimated based on average catch. 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.

Considering the catches after 1999 were strictly based on the TAC of 5.7 million pounds, the average catch of 8.261 million pounds (3,747 t) from 1985 to 1999 is used here (Tier 5) to establish an OFL for this stock (Figure 8-1). This would not constrain the current TAC and would provide a small room for future increases in TAC if the stock abundance continues to increase. The CPUE for this stock has increased sharply during recent years. This stock could be moved to Tier 4 once the model under development (Siddeek et al., 2005) is used for annual stock assessment. Golden king crab may be able to sustain higher harvest rates than red and blue king crabs (see section 8.2 for additional information on harvest rate adjustments relative to movement to Tier 4 status).

Table 12-1 provides the percent of PQS for Eastern and Western Islands golden king crab by community, which provides a current depiction of deliveries by port. For Eastern Aleutian Islands golden king crab, Dutch Harbor has 98 percent of the PQS. Any changes in the OFL for this species that results in a change in the TAC will likely impact Dutch Harbor. In the Western Aleutian Islands golden king crab fishery, 50 percent of the PQS is designated as west shares to be delivered west of 174º W, regardless of historic landing locations in the fishery. The remaining 50 percent of the PQS has neither regional designation nor regional delivery requirements. Communities most impacted by changes in the TAC for these stocks will be Adak and Dutch Harbor.

Pribilof Island golden king crab

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 golden king crab is excluded from Crab Rationalization Program.

Under Alternative 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 1999. The catches after 1999 were primarily based on the TAC, and the catches after 2002 were confidential. The average yield during 1993- 1999 is 174,200 pounds (79 t). If the OFL was established for this stock based upon the use of average yield over this time period, the OFL would be 174,200 pounds (79 t, see Figure 8-2). If a TAC is set at 75% of the OFL, this would be 130,700 pounds (59 t, see Figure 8-2). This would be a reduced TAC from status quo; however, the current GHL of 150,000 pounds (68 t) has not been fully harvested in recent years.

To avoid overfishing, TACs must be established below 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. Depending on the size of the buffer, there could be some potential for a decline in the gross revenue for harvesters and processors in this fishery from lower TACs.

Eastern Aleutian Islands Tanner crab

The Eastern Aluetian Islands Tanner crab stock is suggested for management under Tier 4. Stock status for Eastern Aleutian Islands Tanner crab 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 (Figure 6-5). This fishery is primarily a state-water fishery given that 93 percent of the landings from 1985-2006 were in state-waters statistical areas. The 2004 harvest of Eastern Aleutian Islands Tanner crab was 34,022 pounds with a value of $0.88 million. Although there is no indication the fishery will be constrained under Alternative 3, if there is a change in the TAC as a result of this proposed action, the impacts will be limited exclusively to the participants and communities that participate in this fishery. In addition, given that the fishery is primarily a State water fishery, this stock is one of the eleven species that would be removed from the Federal FMP if the Council were to select Option A under this alternative. The State would have sole management authority for this species, as they do for hair crab (the hair crab fishery, which occurs in the EEZ, was removed from the FMP). Currently, the FMP defers the management of these fisheries to the State. Therefore, the State already manages these stocks and collects all of the biological information. Based on this information, the economic and social effects of removing this species from the Federal FMP would be minimal.

12.9.2 Other crab stocks

These remaining stocks lack sufficient information to determine an OFL and no reliable catch history exists for these stocks. For these stocks, only exploratory fishing or incidental catch has occurred in the recent past. Incidental catch would be allowed as long as it remains within the historical norm. Based on that information, these stocks would be placed in Tier 6 status. The default OFL would be set at zero for the directed commercial fishery. No directed fishing would be allowed for stocks with an OFL equal to zero. A directed commercial fishery means any fishing activity that result in the retention of an amount of a species on board a vessel. However, if ADF&G intends to open a directed fishery for a specific stock, then the SSC may recommend an OFL for that Tier 6 stock based on the best available scientific information through the OFL setting process and prior to the ADF&G GHL setting process.

Stocks are monitored for trends in fishing effort, CPUE, mean size landed crab, and ratio of landed new shell to oldshell crab. Under Alternative 3, stocks would be evaluated annually for upgrading to Tier 5 for OFL determination.

The stocks which would be managed under Tier 6 with OFL = 0 for the directed fishery are as follows:

- Western Aleutian Islands grooved Tanner crab
- Eastern Aleutian Islands grooved Tanner crab
- Eastern Aleutian Islands triangle Tanner crab
- Western Aleutian Islands Tanner crab
- Eastern Bering Sea grooved Tanner crab
- Bering Sea triangle Tanner crab
- Aleutian Islands scarlet king crab
- Eastern Bering Sea scarlet king crab
- Saint Matthew golden king crab
- Saint Lawrence Islands blue king crab

12.9.2.1 Options 1 and 2

Option 1 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. Option 2 would establish a process whereby the Council and SSC would review the models and tier system framework, tier levels, and model parameterization in June. However, the OFL determination would occur in the fall and involve the incorporation of new survey data into model formation of the OFL. The primary economic and social effects of Option 1 relative to Option 2 appear to be the seasonal preparation time for harvesters and processors. The industry has indicated that Option 1 would potentially allow more time for harvesters and processors to adjust their capabilities to better fit annual changes in OFL. Under Option 1, the time between when the OFL is set by the Council and when the first crab season would start is roughly three months. Under Option 2, the period between when the OFL is set (fall) and when the first crab opener could be very limited.

12.9.2.2 Alternative 3 Summary

Overall, Alternative 3 will specify a tier system and a framework for annually assigning each crab stock to a tier and for setting the OFLs. From an economic and social effects perspective, there appears little difference between Alternatives 2 and 3. However, there appears to be potential for some economic and social effects to occur in comparing Alternative 1 with Alternative 3. The effect of this action depends to a great degree on where the State sets crab stock TACs in relation to the revised OFLs under this action. Under the current status determination criteria, the MSY control rule for these fisheries has not been constraining. However, the proposed OFLs for Alternative 3 would be lower than those under Alternative 1, so TACs would likely have to be set lower to adjust for the lower OFLs.

If the State sets TACs near Alternative 3 OFL , the economic and social effects are estimated to be limited and short in duration. However, 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 may need to be incorporated into the setting of the TAC. However, if the State incorporates a buffer resulting in significantly lower TACs for many of the crab stocks relative to current TACs under Alternative 1, there could be significant short-term negative economic and social effects to harvesters, processors, support businesses, and communities. These effects will likely be disproportional in nature, affecting those that have a high dependency on the crab fisheries more severely than those who are more diversified across several fisheries. Communities like St. Paul and King Cove, which are highly dependent on the many of the crab fisheries could be significantly impacted by a decline in TACs , whereas communities like Dutch Harbor, Akutan, and Kodiak, which are more diversified across several fisheries, would be impacted less.

Finally, in the short-run, retained yields could decline for many of the crab stocks, the proposed OFLs are estimated to produce higher retained yields and lower mean rebuilding time in the long-run. Given that the proposed OFL control rules could result in higher retained yields and lower rebuilding times for these stocks, this likely will contribute to increased gross revenues to harvesters, processors, crab support businesses, and communities in the future and could contribute to some fleet expansion in the long-term.

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 crab fishing under 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 two reasonably foreseeable future actions may have a continuing, additive and meaningful relationship to the direct and indirect effects of the alternatives.

13.1 Amendment 80 to the BSAI Groundfish FMP

In June 2006, the Council approved Amendment 80, a bycatch reduction program in the BSAI for the Head and Gut (H&G) trawl CP sector which targets 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, approved Amendment 80 to provide economic incentives for members of the sector to join a cooperative.

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), should allow this sector to be better able to utilize its PSC in relation to its target fisheries. Crab PSC is typically not a constraining factor for the H&G fleet; 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).

Among the most significant elements of Amendment 80 for purposes of crab by catch was the selection of specific crab PSC limits for the H&G fleet and the other BSAI trawl fishery participants. The Council selected percentages of the total trawl PSC limit for crab to be allocated to the H&G sector 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%

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.

13.1.1 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 degree.

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 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 under Amendment 80.

		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

13.2 Bristol Bay Drilling

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 been discovered in the area. Within the basin, the marine environment is home to pollock, Pacific cod, flatfish, and crab species, as well as many of the salmon species. The basin 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.

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Appendix A. Simulation Models

A.1 Notations used in the equations

a, b = parameters in the auxiliary models,
c_t = retained catch of legal-sized male in year t,
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_{MSY} = instantaneous fishing mortality that will produce MSY at the MSY-producing biomass,
F_T = instantaneous bycatch fishing mortality by the trawl fishery, a fixed value of 0.01 was used,
F_t = instantaneous fishing mortality in year t,
$F_{x\%}$ = instantaneous fishing mortality that results in x% equilibrium spawning potential ratio,
h = steepness parameter of a stock-recruitment curve,
hm = proportion of discarded males and females that died due to capture and release to sea,
$HM^s_{i,t}$ = instantaneous handling mortality of sex *s*, length-class i, and year t,
$immat\,N^s_{i,k,t}$ = new-shell immature abundance of sex *s*, length-class i, age k, and year t,
$immat\,O^s_{i,k,t}$ = old-shell immature abundance of sex *s*, length-class i, age k, and year t,
$immolt^s_i$ = immature crab molt probability of sex *s* and length-class i,
k = age in years,
L_c = minimum legal size,
M = instantaneous natural mortality,
mat^s_i = maturity probability of sex *s* and length-class i,
$matN^s_{i,k,t}$ = new-shell mature abundance of sex *s*, length-class i, age k, and year t,
$matO^s_{i,k,t}$ = old-shell mature abundance of sex *s*, length-class i, age k, and year t,
B_t = mature male biomass corresponding to a fishing mortality F in year t,
B_0 = mature male biomass corresponding to a fishing mortality F = 0,
B = a general term used for mature male biomass,
B_{MSY} = mature male biomass at the MSY producing level,
$mmolt^s_i$ = mature crab molt probability of sex *s* and length-class i,
MSY = maximum sustainable yield,
$N^s_{i,k,t}$ = new-shell stock abundance in number of sex *s*, length-class i, age k, and year t,
$O^s_{i,k,t}$ = old-shell stock abundance of sex *s*, length-class i, age k, and year t,
R = a general term used for total number of recruits,
R_0 = number of recruits at F = 0,
$R_{0,t}$ = number of recruits at age 0, and year t,
R_{max} = maximum number of recruits,
s'_i = trawl bycatch selectivity for length-class i,
s_i = pot fishery retained/discard selectivity for length-class i,
S = a general term used for spawning biomass,
W^s_i = mean weight of crabs of sex *s* in a length-class i,
y_t = retained yield of legal-sized male in year t,
$Z^s_{i,t}$ = instantaneous total mortality of sex *s*, length-class i, and year t,
σ_e = standard deviation of the interannual variability of recruitment error,
ρ = temporal correlation parameter,

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

$\kappa, \eta, \gamma, \theta$ = parameters in the stock-recruitment models.

A.2 Model equations for Bristol Bay red king and EBS Tanner crabs

An age-sex-length-based model was used in all simulations.

The following assumptions were made to simplify the derivation in the analyses:

a) M is constant;

b) Timing of events: molting and mating of primiparous females (first time spawners) on 15 February, molting of males on 1 April; and molting and mating of multiparous females (previously spawned spawners) on 1 May;

c) Initial recruits to simulation models have a 1:1 sex ratio.

d) All female red king crabs were assumed to molt annually.

The population dynamics model:

The abundance of different stages and shell conditions of crabs of sex *s* (in number) and age k (last age is plus group) growing from smaller size classes i into a larger size class j at the start of year t+1 is,

when $k = 0$, $immatN^{s}_{j,0,t+1} = (R_{0,t} / 2) \times P^{s*}_{j}$ (B.1)

($R_{0,t}$ is first set to R_{max} to build the age structure; thereafter, it is set to an $R_{0,t}$ value generated by the S-R model.)

when $1 \le k <$ maximum age,

$$matN^{s}_{j,k,t+1} = \sum_{i=1}^{j} \left[\begin{array}{l} (matN^{s}_{i,k-1,t} + matO^{s}_{i,k-1,t}) \ mmolt^{s}_{i} \ P^{s}_{i,j} + \\ (immatN^{s}_{i,k-1,t} + immatO^{s}_{i,k-1,t}) \ immolt^{s}_{i} \ mat^{s}_{j} \ P^{s}_{i,j} \end{array} \right] e^{-Z^{s}_{i,t}}$$

(B.2)

where $Z^{s}_{i,t} = M + F_T s'_i + (F_t s_i + HM^{s}_{i,t})\,\delta$ for males and $Z^{s}_{i,t} = M + F_T s'_i + HM^{s}_{i,t}\,\delta$ for females. F_t is determined by the MSY or target control rule.

$$matO^{s}_{j,k,t+1} = \sum_{i=1}^{j} [(matN^{s}_{i,k-1,t} + matO^{s}_{i,k-1,t})(1 - mmolt^{s}_{i})] e^{-Z^{s}_{i,t}} \quad \text{(B.3)}$$

$$immatN^{s}_{j,k,t+1} = \sum_{i=1}^{j} [(immatN^{s}_{i,k-1,t} + immatO^{s}_{i,k-1,t})\ immolt^{s}_{i}(1 - mat^{s}_{j})P^{s}_{i,j}] e^{-Z^{s}_{i,t}}$$

(B.4)

$$immatO^{s}_{j,k,t+1} = \sum_{i=1}^{j} [(immatN^{s}_{i,k-1,t} + immatO^{s}_{i,k-1,t})(1 - immolt^{s}_{i})] e^{-Z^{s}_{i,t}}$$

(B.5)

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 = mature male biomass/R_{male} (B.6)

Stochastic S-R models and steepness parameter

$$R_{0,t} = \frac{B_t}{\kappa + \eta B_t} e^{\varepsilon_t - \sigma^2_{\varepsilon}/2} \quad \text{(Beverton-Holt, 1957)} \quad \text{(B.7)}$$

$$R_{0,t} = \gamma B_t e^{-\theta B_t} e^{\varepsilon_t - \sigma^2_{\varepsilon}/2} \quad \text{(Ricker, 1954)} \quad \text{(B.8)}$$

where,

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

(ρ is the autocorrelation)

Note: For $F_{x\%}$ estimation by the equilibrium method, the recruitment random errors were set to zero.

Deterministic forms of the two stock-recruitment models (B.7 and B.8) was re-parameterized in terms of steepness parameter, h, assumed maximum recruitment (R_{max}), and virgin spawning biomass-per-recruit (B_0/R_0) as:

$$\kappa = \frac{(1-h)}{4\,h} \times (B_0 / R_0) \qquad \text{(Beverton-Holt)}$$

$$\eta = \frac{1}{R_{max}} \qquad \text{(Beverton-Holt)}$$

$$\gamma = \frac{(5h)^{5/4}}{B_0 / R_0} \qquad \text{(Ricker)}$$

$$\theta = \frac{\gamma\, e^{-1}}{R_{max}} \qquad \text{(Ricker)}$$

Where h is defined as:

$$h\, R_0 = f(0.2\, B_0) \qquad \text{(B.9)}$$

and f() is a stock-recruitment function.

Note: We used independent estimates of R_{max} based on observed recruitment data to calculate η and θ for stochastic simulations.

Retained catch:

$$c_t = \sum_{j=L_c,k} (N^s_{j,k,t} + O^s_{j,k,t})\left(\frac{F_t s_j}{Z^s_{j,t}}\right) e^{-(M + F_T s'_j)\, et} (1 - e^{-Z^s_{j,t}\delta}) \qquad \text{(B.10)}$$

$$y_t = \sum_{j=L_c,k} (N^s_{j,k,t} + O^s_{j,k,t})\left(\frac{F_t s_j}{(Z^s_{j,t})}\right) e^{-(M + F_T s'_j)\, et} (1 - e^{-Z^s_{j,t}\delta})\, W^s_j \qquad \text{(B.11)}$$

Total catch:

Discard catch was computed using the same equations (B.10 and B.11) 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.

Auxiliary Models:

1.The instantaneous handling mortality for sex *s* and size j, $HM^s_{j,t}$, is defined as a function of F_t with discard selectivity s_j, ignoring M and trawl and other bycatch mortality as follows:

$$1 - e^{-HM^s_{j,t}\,\delta} = hm\,(1 - e^{-F_t\,s_j\,\delta}) \qquad \text{(B.12)}$$

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).

A.3 Model equations for Bering Sea snow crab

Model equations were the same as for red king and Tanner crab except that fishery selectivity curves for discard and retained catch were estimated from the stock assessment model for each assumed mortality of discarded catch. Retained catch and discarded catch were estimated as in equations B.10 and B.11 above with the appropriate fishery selectivities. The complete set of parameter values from the stock assessment model with the assumed mortality of discarded crab was used in the simulation projections using the same discard mortality.

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. Base parameters of snow crab for simulations.

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

Parameter	Male	Female
Size range (mm CW)	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

Appendix E. Crab Workshop Report

Appendix E

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

Contents

List of Attachments

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:

Red King Crab (Kodiak observations)

- 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.

Tanner Crab (mostly Kodiak observations)

- 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

List of Participants

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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 F. CIE Review

Center for Independent Experts (CIE)

Reviews of the Crab Stock Overfishing Definition

Reports by:

Michael C. Bell

Dr. Nick Caputi
Department of Fisheries (Western Australia)

Patrick Cordue
Fisheries Consultant, New Zealand

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 ½B_{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.

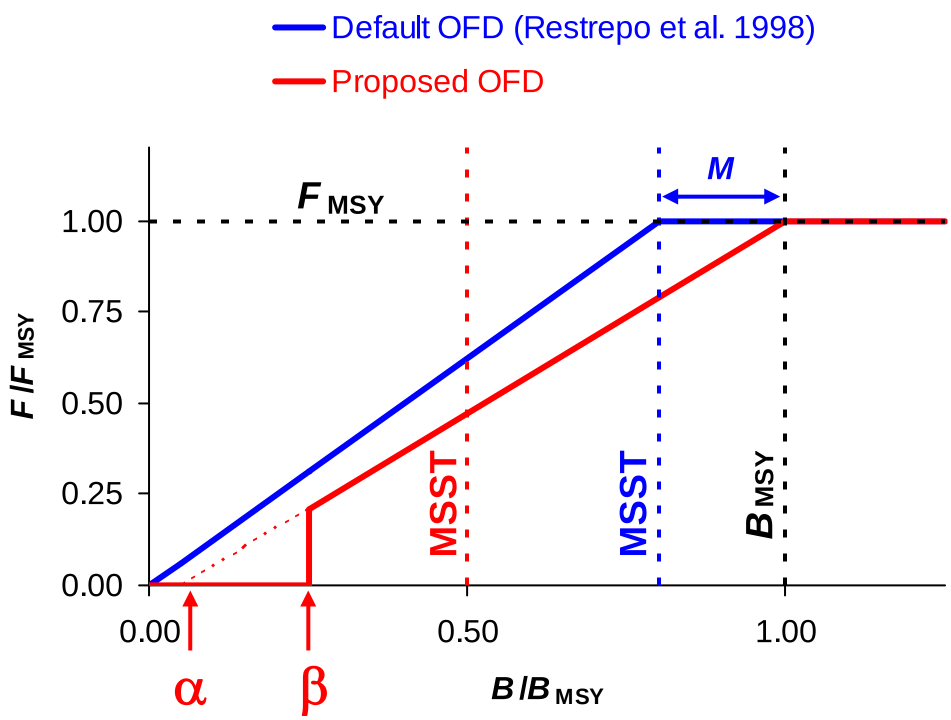

FIGURE 1. Proposed MSY control rule (red lines and captions) shown in relation to the default MSY control rule (blue lines and captions) put forward in technical guidance by Restrepo *et al.* (1998).

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.

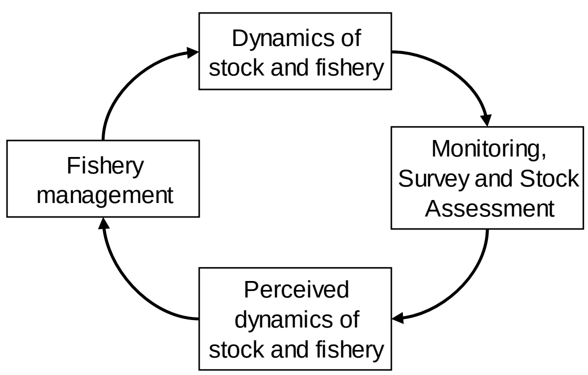

FIGURE 2. Processes involved in simulating fishery management.

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.

Acknowledgements

I would like to thank Anne Hollowed, Jim Ianelli, Lou Rugolo, Diana Stram, Shareef Siddeek, Jack Turnock and Jie Zheng for effective, interesting and good humoured presentations and discussions during the review meeting. Aric Bickel and Manoj Shivlani, University of Miami CIE, steered me and my fellow reviewers through the complications and pitfalls of attending the review and subsequent meetings. I would also like to thank my fellow reviewers, Nick Caputi and Patrick Cordue, for stimulating discussions during the review meeting and for providing notes for my presentations at the CPT and SSC meetings.

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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.

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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.

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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.

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

REPORT ON

BERING SEA & ALEUTIAN ISLANDS

CRAB STOCK OVERFISHING DEFINITIONS

24-27 APRIL, 2006

SEATTLE, WASHINGTON

Prepared by

Patrick Cordue
Fisheries Consultant
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
    - o default values for parameters are not yet determined
    - o sensible definition of biomass in the stock recruit relationship is not determined/specified
    - o 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 $C = \{ c_i \mid i\ \varepsilon\ n \}$ 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., $s(C, \text{male}) = \{ c_i \mid s(c_i) = \text{male} \}$. Let TFEP = $\Gamma(C)$. 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, 2nd 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, 2nd 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