Alaskan Crab Overfishing Definitions Review

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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.

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Zheng, J., 2004. *Bristol Bay red king crab stock assessment in 2004.* ADF&G, Juneau.

Zheng, J., 2006. *Issues dividing the Crab Work Group.* ADF&G, Juneau.

Zheng, J. & Kruse, G.H., 2006. Recruitment variation of eastern Bering Sea crabs: Climate-forcing or top-down effects? *Progress in Oceanography*, **68**, 184-204.

Further documentation available to the reviewers, including presentations given to the crab overfishing workshop is given at:

http://www.afsc.noaa.gov/refm/stocks/CrabWs.htm